GMT Observatory Architecture Document

GMT Requirements Document

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Revision Log

Revision	Date	Affected Sections	Change Request #	Comments	Change Author
A	04/10/2018	All	GMT-CR-03259	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	03/07/2019	All	GMT-CR-03768	Major content changes in all sections. Changes on sections: 2.1.2 Facilities 2.1.3 Enclosure 2.1.5 Mount 2.1.6 Telescope Metrology System 3.2.3.3 Auxiliary Spaces 3.2.4.3 Telescope Pier 5.1 Environmental	G. Angeli/ B. Walls / J. Souza / A. Santana
D	04/07/2020	All	GMT-CR-04236	Wavefront Control • NGAO Transfer function • ASMS Transfer function • ASMS Stroke Environmental Conditions ORD/OAD changes and flowdown based on standard year statitstics Field Distortion Stability Configuration times and Target Acquisition Budgets (OAD 5.3.5.3) Logistics -> Move ORD and OAD into new template for export in DOORS. Underlying	G. Angeli/ B. Walls / J. Souza / A. Santana / B. Sitarski, A. Bouchez / B. Goodrich / A. Souza

				changes with small cosmetic effects on export. Implement CR-3635 -> telescope mass limit. Seismic Related (ID Req 36688, 70772). update SEF PBS (Section 3.2.1, 3.2.3 and 3.2.4)	
E	05/18/2020	5.1.5.2.0 5.1.5.3.0 5.1.5.4.0	GMT-CR-04415 & GMT-CR-04416	- OAD GMT Standard Handling New Section in OAD with 6 Applicable Standards Requirements. (Section 7) - Range of Motion allocations revised (Section 4.1.2.2) - Fig 3-13 M2 Top End Exploded updated (Section 3) - Clearly specify M1S scope - Updated OAD to attend the consistency of PBS and WBS (Section 2.1) - New Offset Time Requirements: REQ-L3-OAD-92316 through REQ-L3-OAD-92321 - Table and Budget Target Acquisition updated - Added the ISS in PBS and updated the PBS to OCS (Section 2.1.4 and 2.1.7) - REQ-L3-OAD-36844 changed from "operational" to "operating" and REQ-L3-OAD-3650 from "observing mode" to "instrument's configuration." - New Requirement Remote Access to User Interface-	B. Walls/ A. Bouchez/ R. Goodrich/ B. Sitarski/ A. Santana / J. Souza

				Seismic Requirements Update - Added ID 92170 - Added ID 92173 - Added id 92567, 92172, 92171	
F	10/13/2020	5.4.7.2 5.7.2.2 5.7.6.3 5.7.6.4 3.3.4 5.7.6.4 4.1.4 2.1.27 5.9 5.1.5 3.1.2 4.1.4	GMT-CR-04476	1. - Update for consistency with PBS: Table 5-19 [ID 37443]: Transportation of Components between Buildings most of those transports does not exist anymore after descope of M2 Lab - REQ-L3-OAD-37626: Diesel Fuel - complete rephrase - REQ-L3-OAD-61204: Lightning Protection -REQ-L3-OAD-37673: Lightning Protection Design merge and rephrase. - REQ-L3-OAD-37201: Equipment Service Life change to “All subsystems shall deliver " -REQ-L3-OAD-38397: De-Ionized (DI) Water - REQ-L3-OAD-38400: De-Ionized (DI) Water Storage change to Optics Services 2. OAD Missing Requirement: ASM Offload Control Loop in NGAO Mode 3. Update NSIQ budget for consistency with Mount and AGWS Requirements	A. Bouchez/ R. Goodrich/ B. Sitarski/ A. Souza / M. Cox

				4. Update for consistency with ISS Requirement 5. Seismic Inputs: REQ-L3-OAD-34610 GMT Telescope Mass Limit 6. Section 5.3.5.3 Science Target Acquisition Efficiency: Clarify REQ-L3-OAD-38191 - Time Reference and additional changes 7. Update all IQ budgets for consistency with Mount and ASMS requirements. Added LTAO IQ budgets to the OAD along with a short description. 8. Added Supplied by for the M1 Cell in Table 5-19, ID 37443. Rephrased REQ-L3-OAD-37673.	
G	10/04/2021	2.1.2.8 3.2.2.3 3.2.5 3.3 4 4.1 4.8 4.14 5.4.7 5.7 5.8	GMT-CR-05051	Added section names in references to Algorithms documents. Corrected a typo in REQ-L3-OAD-106987 Clarified definition of the surface gradient in notes to REQ-L3-OAD-34932 and REQ-L3-OAD-35427. Removed C-ADC from TMS AOM functional requirement REQ-L3-OAD-106985. Removed Figure 5.2 Conceptual	A. Souza / B. Sitarski / B. Goodrich / A. Santana / O. Mclrwin / A. Bouchez / M. Cox

				Backup System via Automatic Transfer Switch to Essential Loads and via Dynamic-UPS to Critical Loads since it is not up to date. Removed the REQ-L3-OAD-37623 Backup Power Manual Switchover. The Utilities Requirements IDs 37586, 37590, 37602, 37605, 37614, 37620, 37636, 37640, 37653, 37656 and 37669 were updated.	

For detailed revision history in DOORs, click here.

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1 Introduction

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 for Science 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.

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 Architecture Document defines the entire technical scope of the GMT construction project through the key and driving requirements for all the deliverable subsystems and their interconnections. However, it does not specify all the deliverables, as those are captured in the lower level Design Requirements Documents.

This Section 1 includes information (metadata) about the document itself. Section 2 identifies the decomposition of the system into subsystems and their interfaces. Section 3 explains how these subsystems integrate to manifest in the various Observatory Configurations. The allocation of key performance metrics to the subsystems is captured in Section 4. The complex interactions of the subsystems in science and maintenance operations are defined in Section 5. The last Section addresses environmental, health and safety considerations.

1.3 Purpose

The Observatory Architecture Document is the highest-level engineering design for the GMT Observatory. It captures the technical baseline for the subsequent detailed design, construction, and commissioning of the observatory subsystems. The OAD characterizes the observatory through its building blocks (subsystems), as well as the allocation of its functionality and performance to these building blocks by defining the key and driving requirements for the subsystems.

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

Last but not least, the OAD, as the high-level design of the GMTO Project, is instrumental for establishing project cost and schedule. Together with the cost and schedule, as well as the other Foundation Documents, the OAD is under formal project change control.

1.4 Definitions

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.)

1.5 Acronyms

Table 1-2: Acronyms

Acronym	Definition
ADC	Atmospheric Dispersion Compensator
AGWS	Acquisition, Guiding, and Wavefront Control System
AIT	Assembly, Integration, and Testing
AO	Adaptive Optics
AORTS	Adaptive Optics Real-Time System
AOS	Adaptive Optics System
AP	Auxiliary Port
API	Application Programming Interface
ASM	Adaptive Secondary Mirror
ASMS	Adaptive Secondary Mirror System
ATCF	Ambient Tracking Coolant Fluid

ATS	Automatic Transfer Switch
AWG	American Wire Gauge
BOD	Basis of Design
C-ADC	(Wide-Field) Corrector-Atmospheric Dispersion Compensator
CE	Conformité Européenne
CFD	Computational Fluid Dynamics
CFHT	Canada-France-Hawaii Telescope
CISPR	Comité International Spécial des Perturbations Radioélectriques (Special International Committee on Radio Interference)
CMMS	Computerized Maintenance Management System
DG	Direct Gregorian
DGNF	Direct Gregorian Narrow-Field
DGWF	Direct Gregorian Wide Field
DI	Deionized (water)
DIMM	Differential Image Motion Monitor
DIQ	Diffraction-limited Image Quality
DOF/DoF	Degree(s) of Freedom
DOORS	Dynamic Object-Oriented Requirements System
DRD	Design Requirements Document
EE	Encircled Energy
ELT	Extremely Large Telescope
EMC	Electromagnetic Compliance
EMF	Environmental Monitoring Facility
EMI	Electromagnetic Interference
ERS	Enclosure Rotation System
ESD	Electrostatic Discharge
FCC	Federal Communications Commission
FG	Folded Gregorian
FITS	Flexible Image Transport System
FMECA	Failure Modes, Effects, and Criticality Analysis
FOV	Field of View
FP	Folded Port
FSM	Fast-steering Secondary Mirror
FSMS	Fast-steering Secondary Mirror System
FTCF	Fixed-Temperature Cooling Fluid
G-CLEF	GMT-Consortium Large Earth Finder
G2CF	GIR 2nd Stage Tracking Chilled Fluid
GIR	Gregorian Instrument Rotator
GIS	Gravity-Invariant Instrument Station
GLAO	Ground Layer Adaptive Optics
GMACS	GMT Areal Camera and Spectrograph
GMT	Giant Magellan Telescope
GMTIFS	GMT Integral Field Spectrograph
GMTNIRS	GMT Near Infrared Spectrograph
GMTO	GMTO Corporation
HBS	Hydrostatic Bearing System

HVAC	Heating, Vacuum, and Air Conditioning
ICD	Interface Control Document
ICS	Instrument Calibration System
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFS	Integral Field Spectroscopy or Integral Field Spectrograph or Integral Field Spectrometer
IP	Instrument Platform
IPL	Instrument Platform Lift
IQ	Image Quality
ISO	International Standards Organization
ISS	Interlock and Safety System
IT	Information Technology
KASI	Korean Astronomy and Space Science Institute
LBT	Large Binocular Telescope
LCO	Las Campanas Observatory
LEC	Laser Electronics Cabinet
LGS	Laser Guide Star
LLN	Low-Latency Network
LPA	Laser Projection Assembly
LSST	Large Synoptic Survey Telescope
LTAO	Laser Tomography Adaptive Optics
LTWS	Laser Tomography Adaptive Optics Wavefront Sensor Subsystem
M2P	M2 Positioner
MANIFEST	MANy Instrument FibEr SysTem
MASS	Multi-Aperture Scintillation Sensor
MBE	Model-Based Engineering
MCL	M2 Calibration Laboratory
MIL	M1 Integration Laboratory
MOS	Multi-Object Spectroscopy
NCE	Noise Control Engineering (company name)
NEC	National Electric Code (NFPA 70)
NFPA	(US) National Fire Protection Agency
NGAO	Natural Guide Star Adaptive Optics
NGS	Natural Guide Star
NGWS	Natural Guide Star Adaptive Optics Wavefront Sensor Subsystem
NIRMOS	Near-Infrared Multi-Object Spectrograph
NSEC	Non-Standard Electronics Cabinet
NSIQ	Natural Seeing Image Quality
OAD	Observatory Architecture Document
OCD	Operations Concept Document
OCS	Observatory Control System
OIWFS	On-Instrument Wavefront Sensor
OPM	Observing Performance Mode
ORD	Observatory Requirements Document
OSHA	Occupational Safety and Health Administration

OSS	Optical Support Structure
P-V	Peak-to-Valley
PBS	Product Breakdown Structure
PI	Principal Investigator
PLC	Programmable Logic Controller
PLP	Pier Lift Platform
PRV	Precision Radial Velocity
PSI	Pounds per Square Inch
PSSN	Normalized Point Source Sensitivity
PTP	Precision Time Protocol
QOS/QoS	Quality of Service
RAM	Reliability, Availability, and Maintainability
RAMS	Reliability, Availability, Maintainability, and Safety
RBM	Rigid Body Motion
RF	Radio Frequency
RFCML	Richard F. Caris Mirror Lab
RMS	Root-Mean Square
RTF	Rejection Transfer Function
SE	Systems Engineering or Software Engineering
SEC	Standard Electronics Cabinet
SEF	Site, Enclosure, and Facilities
SLR	System-Level Requirements
SPS	Segment Piston Sensor
SRD	Science Requirements Document
SS1	Site Support Building 1
SS2	Site Support Building 2
SSB	Summit Support Building
SSSHA	Site-Specific Seismic Hazard Analysis
SUB	Summit Utility Building
SUT	Summit Utility Tunnel
SWC	Software and Controls
TAC	Time Allocation Committee
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Reviewed
TCS	Telescope Control System
TFOV	Technical Field of View
TMS	Telescope Metrology Subsystem
UHF	Ultra-High Frequency
UPS	Uninterruptible Power Supply
UV	Ultraviolet
VC	Vibration Criterion (used, for example, as “VC-D” for Vibration Criterion D)
VHF	Very High Frequency
VIP	Very Important Person
VWS	Visible Wavefront Sensor

WCCS	Wavefront Control Calibration System
WEB	Water Equipment Building
WFC	Wide Field Corrector
WFCS	Wavefront Control System
WFCT	Wavefront Control Testbed
WFS	Wavefront Sensor

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 subsequent sections. 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
GMT-DOC-03205	GMT Concept of Operations	https://bit.ly/3eqUjqz
GMT-REF-00019	GMT Electrical Power Systems	https://bit.ly/3s3ZljS
GMT-REF-00144	GMT Environmental Conditions document	https://bit.ly/3gyN1nF
GMT-REF-00229	GMT Reference for Regulations, Codes, and Standards	https://bit.ly/3esDxYk
GMT-REF-00366	GMT Telescope Utilities Allocation Budget	https://bit.ly/352pTbm
GMT-REF-00805	GMT Telescope Utility One-Line Diagram	https://bit.ly/2SQYi9k
GMT-REF-03725	GMT Spaces and Equipment Registry	https://bit.ly/3l6WZwb
GMT-REQ-03213	GMT Science Requirements Document (SRD)	https://bit.ly/2I9fX7b
GMT-REQ-03214	GMT Observatory Requirements Document (ORD)	https://bit.ly/2JylZ1o
N/A	Standard for the Installation of Lightning Protection Systems NFPA 780	N/A
N/A	National Electric Code, (NEC) NFPA 70	N/A
N/A	Norma Tecnica De Seguridad Y Calidad de Servicio 01/2016	N/A
N/A	Norma Chilena	N/A
GMT-REF-00029	GMT Software and Controls Standards	https://bit.ly/3oYdpt4

GMT-REQ-04495	GMT Utilities Architecture Document	https://bit.ly/3dBsMUA

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	Link
GMT-DOC-00128	GMT Site Master Plan	https://bit.ly/3jYCbpc
	NFPA-110	
GMT-REF-00517	AOS Set Up Time Efficiency Performance Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-5948
GMT-REF-00518	AOS IQ Error Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-5945
GMT-REF-00519	AOS Flexure Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-10244
GMT-CAD-100708	Telescope Swept Volume	https://bit.ly/2WxaMVz
GMT-CAD-175159	Telescope Electronics Cabinet Envelope Layout	https://bit.ly/38hrXgb
GMT-DOC-00010	GMT Optical Design	GMT-DOC-00010
GMT-DOC-00127	Site-Specific Seismic Hazard Analysis (SSSHA) report	https://docushare.gmto.org/docushare/dsweb/Services/Document-20940
GMT-DOC-00145	Natural Seeing and GLAO Image Quality Budgets	https://docushare.gmto.org/docushare/dsweb/Services/Document-4592
GMT-DOC-01168	Mass Properties Control Plan	GMT-DOC-01168
GMT-DOC-01221	GMT Reliability, Availability, Maintainability, and Safety (RAMS) Plan	GMT-DOC-01221
GMT-DOC-01244	GMT Fine Alignment and Phasing Plan	GMT-DOC-01244
GMT-DOC-01337	GMT Standard Electronics Cabinet Design Concept	TBD
GMT-DOC-00128	GMT Site Master Plan	https://bit.ly/3jYCbpc
GMT-DOC-01369	Wavefront Control Architecture	https://docushare.gmto.org/docushare/dsweb/Services/Document-50036
GMT-DOC-01444	Operational Concepts for In Situ Snow Cleaning	https://docushare.gmto.org/docushare/dsweb/Services/Document-57742
GMT-DOC-01479	Optical Turbulence Profiling at the GMT Site	https://docushare.gmto.org/docushare/dsweb/Services/Document-45199
GMT-DOC-01483	M1 Mirror Cell Coordinate System & Datum Definition	https://docushare.gmto.org/docushare/dsweb/Services/Document-45244
GMT-DOC-01515	Phasing System Algorithms and Performance	https://docushare.gmto.org/docushare/dsweb/Services/Document-50045
GMT-DOC-01582	GMT Science Archive	https://docushare.gmto.org/docushare/d

		sweb/Services/Document-48284
GMT-DOC-01584	GMT Metrics	https://docushare.gmto.org/docushare/dsweb/Services/Document-47810
GMT-DOC-01871	GMT SRD to ORD Analysis	TBD
GMT-DOC-01901	GMT Telescope Motions in Science Operations	https://docushare.gmto.org/docushare/dsweb/Services/Document-47785
GMT-DOC-03091	M1 Model	https://docushare.gmto.org/docushare/dsweb/Services/Document-56203
GMT-DOC-03137	GMT Technical Note Stray Light Considerations	https://docushare.gmto.org/docushare/dsweb/Services/Document-57168
GMT-DOC-03140	GMT Self-Induced Vibration Testing and Analysis	https://docushare.gmto.org/docushare/dsweb/Services/Document-57434
GMT-REQ-00090	GMT Facilities & Site Infrastructure/Utilities Requirements	https://docushare.gmto.org/docushare/dsweb/Services/Document-49550
GMT-ICD-01455	SEC-to-Observatory Interface Control Document	https://docushare.gmto.org/docushare/dsweb/Services/Document-45358
GMT-OCDD-01776	Observatory Operations Concept Document (OpsCon)	https://docushare.gmto.org/docushare/dsweb/Services/Document-57507
GMT-REF-00144	GMT Environmental Conditions document	GMT-REF-00144
GMT-REF-00189	GMT Coordinate Systems and Vertical Datum	https://docushare.gmto.org/docushare/dsweb/Services/Document-11101
GMT-REF-00191	GMT Electronics Standards	https://docushare.gmto.org/docushare/dsweb/Services/Document-10312
GMT-REF-00364	GMT Throughput Performance Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-6244
GMT-REF-00805	GMT Telescope Utility One-Line Diagram	https://docushare.gmto.org/docushare/dsweb/Services/Document-57368
GMT-REF-03054	GMT M1, M2, and M3 Motion Budget	TBD
GMT-REF-03242	Pupil Stability Budget	N/A
GMT-REQ-01280	GMT Standard Electronics Cabinet Requirements Document	TBD
GMT-REQ-01454	Standard Electronics Cabinet User Design Requirements Document	TBD
GMT-REF-00420	GMT Maintenance Time Allocation Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-45378
GMT-TEL-DOC-00703	GMT Mount Design	https://docushare.gmto.org/docushare/dsweb/Services/Document-17676
MIL-STD-810E	Environmental Engineering Considerations and Laboratory Tests	TBD
MIL-STD-810G	Environmental Engineering Considerations and Laboratory Tests	TBD
SAO-DOC-00201	Acquisition Guiding and Wavefront Sensing System Preliminary Design Report	https://docushare.gmto.org/docushare/dsweb/Services/Document-46118
Racine et al. 1991		http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1991PASP..103.1020R&data_type=PDF_HIGH&whol

		e_paper=YES&type=PRINTER&filetype=.pdf
Boccas et al. 2004		https://www.spiedigitallibrary.org/conference-proceedings-of-spie/5494/1/Coating-the-8-m-Gemini-telescopes-with-protected-silver/10.1117/12.548809.full?SSO=1
Neichel et al. 2014		https://arxiv.org/abs/1409.0719
GMT-REF-00023	GMT Product Tree - GMT Product Breakdown Structure (PBS)	https://docushare.gmto.org/docushare/dsweb/ServicesLib/Document-2393/View

1.8 Definition of Requirement Terms

Throughout the document, requirements statements are shown in numbered paragraphs to enable their unambiguous referencing. 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.

For example, if the requirements call for a "8-meter long, retractable, blue ladder", the length is tested, retractability is demonstrated, and the color is inspected for verification.

2 System Decomposition

2.1 Product Breakdown Structure

The functions of the Observatory have been allocated to various subsystems as described below. These subsystems describe Level 4 of the Product Breakdown Structure (PBS).

REQ-L3-OAD-61139: Observatory Service Life

The Observatory service life shall be at least 50 years except for instruments and the adaptive optics subsystems.

Rationale: REQ-L2-ORD-25044 requires a 50-year lifetime for the Observatory. Instruments will have a minimum 10-year lifetime (ConOps) but are not expected to have a 50-year lifetime. Technology for the adaptic optics wavefront sensors is very likely to evolve rapidly over the next 50 years, and the Observatory will benefit from a technology refresh of those items. The adaptive optics subsystems consist of the ASMS, AGWS, NGWS, LTWS, LGS, WCCS, and AOTC.
Notes: Service Life- The span of time after commissioning during which functional and performance requirements are to be met. Service life takes into account: real-world operating and environmental conditions, upgrades of field replaceable items, and maintenance practices. Functional and performance requirements do not have to be met during maintenance, upgrades, or during certain environmental conditions as specified in the ORD and OAD.

REQ-L3-OAD-85024: Adaptive Optics Subsystem Service Life

The Observatory adaptive optics subsystems service life shall be at least 20 years.

Rationale: Technology for the adaptive optics wavefront sensors, computers, and deformable mirrors is likely to evolve rapidly over the next 50 years and the observatory will benefit from a technology refresh of those items. This requirement allows for maximum scientific return on the investment to support long-term scientific programs.
Notes: The adaptive optics subsystems consist of the ASMS, AGWS, NGWS, LTWS, LGSS, WCCS, and AOTC.

REQ-L3-OAD-70761: Spaces and Equipment Registry

GMT subsystems shall provide the spaces and equipment listed in GMT-REF-03725.

Rationale: A central repository of spaces and major equipment provides consistent nomenclature and allows association of spaces and equipment to Observatory processes, hence to requirements.
Notes: The Spaces and Equipment Registry (GMT-REF-03725) lists spaces and heavy equipment that will be available for operations and maintenance of the Observatory. The Registry lists the owners (in terms of the organizational breakdown structure of the Project) of each space and piece of equipment, also describes their function. The Registry also links equipment to the space or spaces in which they will be used, and further links the list of operational behaviors and AIT tasks to the spaces and equipment that they will require.
Requirements for specific Spaces are listed mostly in sections 3.1.3 (Focal Stations), 3.2 (Physical Layout), and 5.4.1 (Equipment Maintenance). Not all equipment is called out in separate requirements in the OAD.

2.1.1 Site Infrastructure

Site infrastructure includes improvements which connect the observatory buildings but are not a part of the buildings themselves, including roads, walkways, stairs, parking areas, overhead and underground utility distribution systems, commercial power transmission to the site, electrical power distribution and emergency back-up systems, water wells, tanks, pumping systems, domestic and fire water distribution systems, waste water plumbing and treatment systems, and distribution of data, safety, and communication networks.
The Site Infrastructure fulfills the following functions:

- **Provide electrical power transmission and distribution systems** (commercial, generator, and UPS power) for the GMT site
- **Provide communications infrastructure** (optical fiber) distribution systems for the GMT site
- **Provide potable water and waste water treatment** for all facilities at the GMT site (summit and support sites)
- **Provide safe pedestrian and vehicle access** to all facilities at the GMT site (roads, parking, guardrails, signage, drainage, walkways)

2.1.2 Facilities

The GMT Facilities will support the final assembly, integration, operation, and maintenance of the observatory, including the telescope and its instruments, as well as personnel functions such as dining, lodging, transportation, staff health and safety, etc. This includes facilities both on the mountain and at the Base Facility in La Serena. The facilities must provide most of their functionality continuously, 24 hours per day, 365 days per year, to support personnel health and safety (including both working and non-working periods).
In terms of physical architecture, the Facilities consist of conventional civil, horizontal, and vertical construction (buildings). In the current project Product Breakdown Structure (PBS), the Facilities also include shared/common material handling equipment, including forklifts, bridge cranes, and portable cranes. Basic furniture enabling the core functionalities of the Facility buildings is also in the scope of this subsystem; examples are tables, chairs, work desks, beds, kitchen equipment, and bathroom facilities. Facilities will also provide an IT room in buildings that require network connection, to hold system and subsystem computer equipment.
Exception: Furniture and equipment specific to any subsystem is the responsibility of that subsystem; examples are clean rooms, computer racks, assembly and vibration-isolated tables.
The Facilities fulfills the following functions:

- **Provide safety functions, features, and systems** to enable safe operations and maintenance of the facilities and equipment.
- **Provide areas and/or spaces for the final assembly, integration, and maintenance of subsystems**, including temporary and/or permanent spaces for assembly, integration, and testing of the primary and secondary mirror systems.
- **Provide spaces for the final assembly, integration, test, and maintenance of instruments**, including temporary and/or permanent spaces for these functions.
- **Provide material handling functions**, such as hoisting and lifting, of telescope components and instruments inside the technical Facility building(s).
- **Provide spaces for service, repair, maintenance, and cleaning functions** for the telescope optics, including stripping, cleaning, and re-coating of the telescope primary mirrors
- **Provide storage areas for material handling equipment** (e.g. forklifts) and storage of spare parts for maintenance and repair of key observatory subsystems.
- **Provide low-level software and controls** for operation of automated or computer-controlled Facilities subsystems (e.g. health, safety, and functional monitoring of the domestic water system).
- **Provide accommodations and services** for observatory staff and visitors (lodging, meals, transportation).

2.1.3 Enclosure

Following conventional optical observatory practice, the GMT Enclosure is a structural system which fully envelopes the telescope, and exists to protect, control, and modulate the environment around the telescope (the observing chamber), and to support the final integration, operation, and maintenance of the telescope and its instruments. Unlike the telescope and its instruments, the Enclosure must provide most of its functionality continuously; under scientific operating conditions (primarily at night), under maintenance operating conditions (primarily during the day), and under non-operational conditions (primarily during extreme weather and seismic events). Given that the Enclosure must protect the telescope from inclement weather but must not inhibit the telescope's field of view during scientific operation, it follows that the Enclosure must provide an open/close function. Similarly, given the need to avoid obstructing the optical path of the telescope as it moves around on the sky, the Enclosure must rotate synchronously with the telescope about a common vertical (azimuth) axis.

In terms of physical architecture, the Enclosure structures consist of civil and vertical construction components, including fixed lower portions which extend below and above grade and whose foundations rest on summit bedrock, and an upper portion, which rotates about a vertical axis coincident with the telescope azimuth axis. It also includes the attached buildings, Utility Tunnel and Summit Utility Building.

The Enclosure fulfills the following primary and key functions:

- **Provide environmental protection** for subsystems inside the enclosure, including protection from precipitation, wind, dust, stray light, and seismic events (shutter, wind screen, vent baffles, pier seismic isolation systems)
- **Provide environmental control** inside the enclosure during observations (wind vents and wind-screen) and during daytime (forced ventilation and air conditioning)
- **Provide material handling infrastructure** for large subsystems from one part of the Enclosure to another, or to grade, including M1 cells, the Mount Top End with installed M2, and instruments (bridge crane, pier lift platform, access hatches).
- **Provide personnel work areas** for instrument assembly, integration, test, and maintenance (low- and high-bay lab areas in lower enclosure)

- **Provide space** for observatory control system computers and IT equipment (server room and IT room)
- **Provide personnel work areas** for day and nighttime operations (control room, meeting room, kitchen, office space, bathrooms, labs, loading dock), including basic furniture enabling the core functionalities of these work areas
- **Provide personnel and equipment access** to all service points on the telescope and enclosure (elevators, catwalks, stairways, lifts, etc.)
- **Provide safety functions, features, and systems** to enable safe operations and maintenance of the telescope, instruments, and enclosure subsystems.
- **Provide and route utilities** to, and including, the manifolds and interface panels in the Mount Utility Interface Access Corridor and any off-telescope area in the enclosure where subsystems are maintained. (Power, Glycol-Based Coolants, Refrigerants, Compressed Air, Vacuum, Cryogenic Cooling, and Fiber. The source of production may be unique for each location.
  - **Note:** Routing these utilities beyond the manifolds and interface panels in the Mount Utility Interface Access Corridor to the manifolds and interface panels at subsystem points of use on the mount assembly is not Enclosure responsibility.
- **Provide and route in-situ wash services** including domestic water, de-ionized water, and effluent drain to a location convenient to the azimuth disk (TBC).
- **Physically support the Mount** (Mount pier, pier seismic isolation system, and pier foundation)

2.1.4 Observatory Control System (OCS)

The Observatory Control System (OCS) coordinates all the GMT controlled subsystems and supports the GMT observing process, from the preparation of observing proposals and science programs, the scheduling and execution of accepted observations, and the archival and export of scientific data to the astronomical community.
To efficiently operate the GMT observatory the OCS fulfills the following functions:

1. **Proposal submission**: this capability allows astronomers to create and edit observing proposals (aka Phase 1), including all the target observability calculators, astronomical data modelling tools, or instrument specific calculators necessary to prepare and verify the proposals before the final validation and submission.
2. **Proposal review**: this capability allows the Time Allocation Committees (TAC) to review, merge, sort and rank the received proposals. It incorporates the computation of statistics and observatory metrics and simulates the scheduling of observing programs for the proposal cycle semester. Accepted proposals pass on to the next phase.
3. **Observation Definition**: this capability (aka Phase 2) enables observers to convert accepted proposals to observing programs for runtime scheduling and execution. For each science program a set of observing blocks is created. Each observing block includes the detailed configuration of the instrument and the telescope required for nighttime observing execution.
4. **Observation Scheduling**: this software capability allows observers and observatory staff to manage the runtime observing schedule, which includes long-term, mid-term and nightly schedules. It also allows the observatory staff to monitor all short- or long-term programs, to schedule Targets of Opportunity, to make real-time changes in the schedule, or to schedule fixed windows for classical observing programs or engineering operations.
5. **Observation Execution:** this software capability includes all the operations required to sequentially execute pre-scheduled observation blocks at the telescope during the night and convert the collected photons to actual data. The OCS enables the operation of all GMT controlled subsystems. Each subsystem (environment monitoring facility, enclosure, mount, primary and secondary mirrors, acquisition and guiding system, science instruments, etc.)

includes a Device Control System (DCS), which is responsible for controlling and monitoring the actuators and sensors. To ensure a safe and efficient operation of the telescope the Software and Controls Standards (GMT-REF-00029) define key requirements and the reference architecture that govern all DCS. The GMT Control System incorporates these device control systems and the OCS into an overall control system.

6. **Telescope Control and Operation:** this software capability includes the Telescope Control System (TCS) which is responsible to coordinate the real-time control loops of all the controlled subsystems. Two main capabilities are provided:
   a. Pointing, tracking and guiding functions coordinate the controlled subsystems to point the telescope and move AGWS probes to the corresponding targets, so as to guide and maintain a nominal optical configuration to achieve optimal image quality. These functions relate sky coordinates with mechanical and detector coordinates and vice vers
   b. Wavefront control provides the high-level optical control of the telescope and implements active and adaptive optics control loops.
7. **Laser Clearance**: this capability ensures the safety of the laser operations at the observatory. This includes safety regulations that prevent propagation of the laser beacons onto flying aircrafts, satellites, the International Space Station, or other non-disclosed objects, and also observatory protocols that prevent laser light from interfering with observations of nearby telescopes. The software provides monitoring and real-time detection of aircrafts or space objects, and coordination with other observatories.
8. **Data Management:** this crucial capability provides functionalities for data archiving, data processing, and quality control. The data archiving system contains the science and engineering archives; and manages, stores, and distributes all data products related to the operations of the observatory. The data processing system includes the telescope and science instrument pipelines required for an efficient operation. Finally, the quality control system provides capabilities to enforce the correctness of the observing process. Data visualization and the ability to export raw and processed data to the astronomical community are two important features of this subsystems.
9. **System Configuration**: this capability allows the OCS and observatory staff to systematically manage, organize, and control the changes in system settings, databases, software source code, documents and other artifacts during the observation process.
10. **System Monitoring:** this functionality monitors all the engineering, science, and environment state variables required to operate the observatory and creates the telemetry databases.
11. **System Supervision**: this functionality monitors the system health, the resources and provides the capability to start and stop any controlled subsystem.
12. **Operation User Interfaces**: this functionality provides users the capability to obtain different views of the system, and notification of important events, warnings and alarms. In general, it also allows users to interact with the system to perform operations and maintenance functions.
13. **Interlock and Safety Monitoring**: this functionality provides the monitoring of safety functions implemented by the Interlock and Safety System (ISS). The ISS is the GMT subsystem responsible for the functional safety of observatory subsystems as a whole.
14. **Scientific Support:** this functionality includes all the support and help tools required by the astronomical community at any point working with the GMT data, software, and staff (proposal submission, observing block preparation, data exportation, etc.). It includes on-line documentation, forums, and real-time communications with telescope staff.

The Observatory Control System does not include the safety-rated hardware, software and ISS Safety Network components responsible for the local Interlock and Safety System in each subsystem. By design, the ISS software, hardware and communications infrastructure is completely independent from the observatory control system infrastructure.

2.1.5 Mount

The Mount Subsystem is the structural, mechanical, hydraulic, and electronic system that is required to support, align, point, and track. This subsystem is comprised of the following assemblies: Optical Support Structure, Azimuth Structure, Azimuth Track, the Hydrostatic Bearings System, the Mount Drives, restrictors and locking pins, M1 conical baffle, and the Azimuth and Elevation cable wraps.
The Mount fulfills the following functions:

- **Physically support the optical elements of the telescope,** including the M1 System, M2 System, C-ADC, and M3.
- **Physically support other subsystems and components** attached to the Mount, including Instruments, TMS, AGWS, and LGS.
- **Position the optical axis of the telescope** in azimuth and elevation.
- **Provide rotational control of the instruments** around the optical axis to orient the sky as seen by the instrument appropriately (GIR).
- **Maintain position on a moving target**, to allow for finite integration times on astronomical targets as they move across the sky. This will be done open loop, by tracking, and in closed loop using guiding on an astronomical source.
- **Provide safety features** to prevent personnel or component injury during operations.
- **Protect optical components** while installed on the Mount.
- **Provide personnel and equipment access** to subsystems that are attached to the Mount.
- **Route Utilities** providing plumbing, cabling, cable trays and conduits from the Enclosure provided manifolds and interface panels in the Mount Utility Interface Access Corridor to the points of use and payload utility panels on the mount assembly. G2CF production, control, and routing to the points of use is also the responsibility of the mount.
  - **Note**: Utilities routed from the summit utility building to the manifolds and interface panels in the Mount Utility Interface Access Corridor is the responsibility of SEF.
  - **Exception**: Local subsystem secondary loops are the responsibility of the subsystem. Mount is responsible for providing HBS equipment and services from the SUB to points of use on the mount.
- **Provide stray light suppression to the focal plane** via an M1 conical baffle.

2.1.6 Telescope Metrology Subsystem

The Telescope Metrology Subsystem (TMS) is a distributed system which measures the position of the telescope main optics (M1, M2, M3, C-ADC) to enable rapid initial alignment of the telescope, and maintenance of the alignment during observing.
The TMS fulfills the following functions:

- **A large capture range absolute metrology system** which enables initial alignment of components of the Mount, M1, M2, M3, C-ADC, and instrument during integration and after segment exchanges. The system is also tracking the position of the pier relative to the foundation of the pier to detect displacements due to seismic activation and/or drift of Seismic Isolation System.
- **A precision absolute metrology system** which measures the rigid body positions of M1, M2, and M3 with respect to the GIR and provides control signals to the OCS to move the segments to within the capture range of the AGWS. This subsystem enables rapid optical alignment at the start of the night and maintains alignment during telescope slews. The function is fulfilled by a

multi-line laser metrology system simultaneously measuring baselines between M1, M2, M3, and the GIR.

- **A prime focus engineering camera and wavefront sensor** which enables measurement of the shape of M1 by observing a bright guide star on-axis, prior to the installation of M2, as well as integration and testing of the M2 on-telescope and alignment of M1 and M2 segments to a common axis (GIR rotator axis).
- **Edge sensors between M1 segments and between M2 segments** which measure high temporal frequency segment phase piston errors of M1 and M2 due to wind buffeting and structural vibrations. This function is fulfilled by relative distance measuring interferometers integrated with the multi-line absolute metrology system. Edge sensors also play some part in seeing-limited alignment.

The edge-sensor function is only required in the LTAO correction mode; all other functions are required for telescope commissioning.

2.1.7 Wavefront Control Calibration Subsystem

The Wavefront Control Calibration Subsystem (WCCS) provides the prime focus optics necessary to calibrate the GMT wavefront control function. It includes 4 independent units that fulfill different calibration functions:

- **The Prime Focus Source:** Projects an on-axis light source from the prime focus to the Gregorian focus. It is used to align M2 and calibrate the AGWS.
- **The Prime Focus Retro-Reflector:** Enables an on-axis source projected from the Gregorian focus to reflect twice off M2 and return to the Gregorian focus. It is used to measure the M2 surface shape using an interferometer located at the FP focus, and to calibrate and verify the performance of the NGAO wavefront control mode using a broadband on-axis point source projected from an NGWS at the FP focus.
- **The Laser Tomography Adaptive Optics Calibration Source:** Simultaneously projects a broadband on-axis source and six off-axis sources emulating 589 nm lasers from the prime focus to the Gregorian focus. It is used to calibrate and verify the performance of the LTAO wavefront control mode, including the LTWS and Instrument OIWFS.
- **An M2 interferometer**: Measures the M2 alignment and surface figure. Used in conjunction with the Prime Focus Retro-Reflector.

2.1.8 Wide Field Phasing Testbed

The Wide Field Phasing Testbed (WFPT) is an optical testbed designed to verify active optics and phasing sensors and control algorithms in the laboratory. It will feed a prototype AGWS probe.
The WFPT fulfills the following functions:

- **Active optics and phasing sensor verification:** Verify sensitivity and accuracy of the AGWS wavefront sensors.
- **Active optics and phasing algorithm validation:** Validate planned active optics and phasing algorithms.

2.1.9 Acquisition, Guiding, and Wavefront Sensing Subsystem

The Acquisition, Guiding, and Wavefront Sensing Subsystem (AGWS) is the primary telescope guider and wavefront sensor, providing all optical feedback necessary to implement the Natural Seeing and GLAO correction modes. It also provides several critical wavefront sensing functions in the diffraction-limited correction modes, including sensing field-dependent wavefront errors and slow segment phase piston (phasing) errors. These functions are fulfilled by a set of wavefront sensor probes which patrol the periphery of the Direct Gregorian field of view, below M3 and ahead of the Direct Gregorian focal surface.

The AGWS fulfills the following functions:

- **Acquisition:** Enable initial field acquisition after a slew, and evaluate system image quality.
- **Fast Segment Tip-Tilt:** Measure segment and global tip-tilt errors caused by tracking errors and vibrations.
- **Active Optics Wavefront Sensing:** Provide optical feedback to control slow (<0.1 Hz) thermal and gravity errors in the Mount tracking, M1 and M2 segment alignment, and M1 optical figure.
- **Ground-Layer Adaptive Optics Wavefront Sensing:** Fast (≥80 Hz) sensing of ground-layer optical turbulence (GLAO mode only).
- **Segment Pistons Sensing**: Slow (~0.03 Hz) sensing of segment phase piston and phase piston gradients across the field of view (Diffraction-limited modes only).

2.1.10 Laser Guide Star Subsystem

The Laser Guide Star Subsystem (LGS) projects six 589 nm wavelength lasers to the sodium layer at ~90 km altitude in the Earth's mesosphere to produce an asterism of artificial guide stars surrounding the science field for high-order atmospheric wavefront sensing.

The LGS fulfills the following functions:

- **Create an asterism of artificial guide stars** in the sodium layer of Earth's atmosphere, using a laser tuned to sodium wavelengths.
- **Measure the location of the artificial guide stars on the sky**, to enable the alignment of the artificial guide stars to the reference optical axis.

2.1.11 Laser Tomography Adaptive Optics Wavefront Sensor Subsystem

The Laser Tomography Adaptive Optics Wavefront Sensor Subsystem (LTWS) fulfills the high-order wavefront sensing function in the LTAO correction mode. It is replicated for each client instrument, and uses visible light reflected by that instrument's dichroic cryostat window. It operates in conjunction with the instrument's On-Instrument Wavefront Sensor (OIWFS), which senses the atmospheric phase errors to which the LTWS is blind.

The LTWS fulfills the following function:

- **Measure atmospheric wavefront error** in spatial modes higher than global tip-tilt at high bandwidth, using an asterism of artificial guide stars.

2.1.12 Natural Guide Star Adaptive Optics Wavefront Sensor Subsystem

The Natural Guide Star Adaptive Optics Wavefront Sensor Subsystem (NGWS) is the primary visible-light wavefront sensor which enables the NGAO wavefront control mode. It is replicated for each client instrument, and uses light reflected by that instrument's dichroic cryostat window.

The NGWS fulfills the following function:

- **Measure atmospheric wavefront error** at high bandwidth, using a single natural guide star.

2.1.13 Environmental Monitoring Facility

The Environmental Monitoring Facility (EMF) measures and provides real-time access to environmental conditions, including weather (temperature, wind, humidity, pressure, precipitation, dust levels, and clouds), atmospheric conditions (integrated seeing, optical turbulence profile, and extinction), and seismic activity. It will include external sources of data, such as satellite weather maps and seismic early-warning networks. EMF data will be curated by the Observatory Control System's engineering data archive.
The EMF fulfills the following functions:

- **Provide real-time measurements of site environmental conditions**, to assist in making tactical decisions about science observing and maintenance tasks, and to allow rapid response of observatory safety systems to changes in those conditions (precipitation, seismic activity).
- **Provide real-time measurements of environmental conditions within the Enclosure.**
- **Provide current regional environmental conditions**, to assist in making longer-term (time scale of hours to days) decisions on observing and maintenance strategy.

2.1.14 M1 System

The M1 System (M1) consists of the borosilicate glass M1 segments, support and positioning system, associated utilities, electronics, and control systems, and handling and testing equipment. The M1 System does not include the M1 cell weldments, which instead form integral elements of the Mount and to which most of the M1 components interface.
The GMT is designed to use large and stiff mirror segments based on mature techniques developed at the Richard F. Caris Mirror Lab (RFCML), which is located on the campus of the University of Arizona. The techniques used to cast, generate, polish and test the M1 Segment Mirrors are similar to those used for the MMT, Magellan Telescopes, LBT, and LSST. This architectural decision is intended to reduce risk by reusing architectures that have proven successful.
The M1 System consists of the following major elements:

- M1 Segment Mirrors: 1 center segment and 7 off-axis segments, including 1 spare
- M1 Segment Static Supports: Passively supports the M1 Segment Mirrors
- M1 Segment Active Supports: Actively supports, positions, and bends the M1 Segment Mirrors
- M1 Segment Thermal Control: Maintains segment mirrors near ambient temperature
- M1 Segment Instrumentation: Includes thermometry, accelerometers, and pressure sensors
- M1 Segment Controller: Control hardware and software for the above subsystems
- M1 Segment Utilities: Utilities distribution within the M1 cells
- M1 Segment Service and Test: Includes the M1 Test Cell, M1 Segment Mirror Simulator, Actuator Calibration System, and Hardpoint Test Stand

The M1 System fulfills the following functions:

- **Reflect the light of astronomical sources to the prime focus,** following the GMT optical design.
- **Safely support the M1 segment mirrors** in operational, maintenance, and survival (e.g. seismic) conditions.
- **Independently position the M1 segment mirrors** to compensate for gravity and thermal flexure in the Mount.
- **Adjust the M1 segment mirror shapes** to compensate for gravity and thermal flexure in the M1 cells and M1 segment mirrors.
- **Control the temperature of the M1 segment mirrors** to maintain a uniform and near-ambient temperature distribution.

2.1.15 Adaptive Secondary Mirror Subsystem

The Adaptive Secondary Mirror Subsystem (ASMS), one of two secondary mirror (M2) subsystems, consists of seven circular segments, a positioning system, associated electronics and control systems including software, handling and testing equipment, and a baffle. The ASMS relays light from the prime focus to the Gregorian focus, while correcting atmospheric wavefront error with high precision and bandwidth in the adaptive optics wavefront control modes. Control signals are provided by the OCS, derived from measurements made by the TMS, wavefront sensors, and edge sensors. The ASMS segments have interfaces to metrology fiducials of the TMS.

The ASMS forms a functional handling unit with the Mount's Top End (the interface when changing M2 systems is between the Top End and the Upper Truss of the Mount). The seven ASM segments are supported and positioned by an M2 Positioner which attaches to the Top End.

The ASMS fulfills the following functions:

- **Relay light from the prime focus to the Gregorian focus** following the GMT optical design.
- **Independently position the ASM segments** to compensate for gravity and thermal flexure in the Mount.
- **Provide adaptive optics wavefront correction** in AO wavefront control modes, while under continuous and high-bandwidth optical feedback control
- **Provide fast tip-tilt segment actuation** in the Natural Seeing wavefront control mode, using only low-order and low-bandwidth optical feedback of surface shape.
- **Provide stray light suppression** via a secondary mirror baffle.
- **Enable optical testing of the ASMS** by providing a test stand that supports the Top End + ASMS in a horizon-pointing orientation.

2.1.16 Fast Steering Mirror Subsystem

The Fast Steering Mirror Subsystem (FSMS) is the backup M2 system used for commissioning and during ASMS maintenance. It consists of seven circular segments, a positioning system, associated electronics and control systems including local control software, handling and testing equipment, and a baffle. The FSMS relays light from the prime focus to the Gregorian focus, while correcting telescope pointing errors and segment tip-tilt errors. Control signals are provided by the OCS, derived from measurements made by the TMS and AGWS. The FSMS segments have interfaces to metrology fiducials of the TMS.

The FSMS does not include the Top End of the Mount, but forms a functional handling unit with it. The seven FSM segments are supported and positioned by an M2 Positioner similar to that of the ASMS.

The FSMS fulfills the following functions:

- **Relay light from the prime focus to the Gregorian focus** following the GMT optical design.
- **Independently position the FSMS segments** to compensate for gravity and thermal flexure in the Mount.
- **Provide fast tip-tilt actuation of the segments** to compensate Mount tracking errors and wind-induced vibrations.
- **Provide stray light suppression** via a secondary mirror baffle.

2.1.17 M3 Subsystem

When deployed, the M3 Subsystem (M3) intercepts the central 3 arcminute diameter portion of the telescope beam and directs it to a Folded Port (FP), Instrument Platform (IP) Port, or Auxiliary Port (AP) instrument. The M3 is located ahead of the AGWS and must transmit the periphery of the Direct

Gregorian field to the AGWS while deployed.
The M3 fulfills the following functions:

- **Deploy and retract to/from the Reference Optical Axis** to direct the central region of the telescope beam to one of several instruments at the Instrument Platform Level.
- **Rotate around the Reference Optical Axis** while deployed to select which of the instruments on the IP Level receives the optical beam.
- **Correct for pupil motion** measured by these instruments by tip/tilt/piston adjustment.

2.1.18 Corrector-ADC Subsystem

The Corrector and Atmospheric Dispersion Compensator Subsystem (C-ADC) is an optical subsystem which can be inserted in the beam ahead of the Direct Gregorian focus. The C-ADC will correct the native telescope field aberration and simultaneously mitigate the effects of the atmospheric refraction when observing off-zenith targets in the visible spectral bands. Both functions are achieved with sufficient accuracy to not significantly degrade the seeing-limited image quality across a 20 arcmin diameter field of view. The C-ADC is deployed into the beam by mechanisms provided by the Mount.
The C-ADC fulfills the following functions:

- **Correct field aberrations** across the maximum field of view provided by the GMT optical design, in concert with the wide-field instrument's field lens. (The instrument's field lens is an integral part of the wide-field correction.)
- **Compensate optically for differential atmospheric refraction** in the wavelength range 350–1300 nm.

2.1.19 Optics Servicing

The Optics Servicing Subsystem enables the maintenance of the optical surfaces of M1, M2, M3, and the C-ADC. This includes CO_2 cleaning and wet washing of coated optics, and recoating (including stripping off the old coating, washing the substrate, and applying a fresh reflective coating) of optical surfaces as appropriate. The Optics Servicing Subsystem also includes an Optical Subsystems Laboratory for assembly, testing, and maintenance of M2, M3, and the C-ADC.
The functions of optics servicing include:

- **Monitoring and measuring telescope throughput,** to assure that optical performance requirements are being met.
- **Keeping large optics clean**, including M1, M2, M3, and C-ADC. It will do this using regular CO_2 cleaning as well as occasional in-situ wet washing of M1 segments.
- **Recoating large optics**, refreshing reflectivity or throughput. This will be done off-telescope, and includes stripping off old coatings, washing, and recoating.
- **Enable inspection and monitoring of coatings and optical components** to identify incipient problems such as cracks.
- **Enable the assembly, testing, and maintenance of M2, M3, and the C-ADC off of the telescope** by providing the support equipment to outfit an Optical Subsystems Laboratory. This does not include the building itself, which is part of the Facilities.

2.1.20 Commissioning Camera

The Commissioning Camera (ComCam) is a medium-field visible imager designed primarily to evaluate the performance of the GLAO wavefront control mode. It may also have limited scientific capabilities as a narrow-band imager in both the Natural Seeing and GLAO modes.

ComCam fulfills the following functions:

- **GLAO performance evaluation**, by simultaneously imaging a 6.0 arcmin diameter field of view, in wide and narrow-band filters at 360–950 nm wavelength.
- **Scientific imaging** using discrete and tunable narrow-band filters.

2.1.21 GMTO-Consortium Large Earth Finder (G-CLEF)

The GMT-Consortium Large Earth Finder (G-CLEF) is a general purpose, visible–light, high spectral resolution (echelle) spectrograph, that also provides precision radial velocity (PRV) capabilities for exoplanet detection and characterization. The G-CLEF spectrograph is vacuum-enclosed and located on the Gravity-Invariant Instrument Station (GIS) on azimuth structure, in order to optimize wavelength stability. The spectrograph is fed by an optical fiber from a Front-End unit located on the Instrument Platform (IP). G-CLEF will initially operate in the Natural Seeing and GLAO modes, with a potential for a future upgrade to the NGAO mode.
G-CLEF fulfills the following functions:

- **Deliver science enabled by the following Observatory Performance Modes (OPM)**
  - Small Field Visible Natural Seeing (OPM 1).
  - Small Field Visible GLAO (OPM 2).
  - Small Field Visible Natural Seeing PRV (OPM 3).
  - Small Field Visible GLAO PRV (OPM 4).
- **Provide an interface to MANIFEST fibers,** enabling a Multi-Object Spectroscopy (MOS) mode over the full GMT's corrected 20 arcmin diameter field of view.
- **Provide light sources** and optics necessary to calibrate the spectrograph.
- **Measure the relative flexure** between the G-CLEF entrance focal plane and the AGWS and provide those measurements to the OCS.

G-CLEF functions and requirements are representative of and relevant to future generation instruments of the same type.

2.1.22 GMT Multi-object Astronomical and Cosmological Spectrograph (GMACS)

The GMT Multi-object Astronomical and Cosmological Spectrograph (GMACS) is general purpose, visible-light, medium spectral resolution multi-object spectrograph, with a relatively wide field of view (for an extremely large telescope). GMACS will be used in Natural Seeing and GLAO wavefront control modes. It will be located at the Direct Gregorian port.
GMACS fulfills the following functions:

- **Deliver science enabled by the following Observatory Performance Modes (OPM)**
  - Medium Field Visible Natural Seeing (OPM 10).
  - Medium Field Visible GLAO (OPM 11).
  - Wide Field Visible Natural Seeing (OPM 14, with MANIFEST).
  - Wide Field Visible GLAO (OPM 15, with MANIFEST).
- **Reconfigurability** for different target fields.
- **Provide an interface to MANIFEST fibers,** increasing the accessible field of view to the full GMT's corrected 20 arcmin diameter field of view.
- **Measure the relative flexure** between the GMACS entrance focal plane and the AGWS and provide those measurements to the OCS.

GMACS functions and requirements are representative of and relevant to future generation instruments of the same type.

2.1.23 GMT Integral Field Spectrograph (GMTIFS)

The GMT Integral Field Spectrograph (GMTIFS) is a general purpose, near-infrared, diffraction–limited, single-object integral field spectrograph (IFS) with moderate spectral resolution, plus a simultaneous narrow-field imaging camera. GMTIFS will operate with all wavefront control modes of the GMT (GLAO, NGAO, and LTAO) with an emphasis on achieving high sky coverage via LTAO observations. It also directs light to and physically supports the NGWS and LTWS wavefront sensors and includes an On-Instrument Wavefront Sensor (OIWS) to provide feedback on wavefront errors not sensed by the external wavefront sensors (AGWS, NGWS, and LTWS). GMTIFS will be located at the Folded Port.
GMTIFS fulfills the following functions:

- **Deliver science enabled by the following Observatory Performance Modes (OPM)**
  - Small Field Infrared LTAO (OPMs 7 and 8).
  - Small Field Infrared NGAO (OPM 9).
- **Provide light sources** and optics necessary to calibrate the spectrograph and imager channels.
- **Reflect natural and laser guide star light** to the NGWS and LTWS, located at the front of the instrument.
- **Measure the atmospheric and telescope wavefront and alignment errors** to which the NGWS and LTWS are insensitive, using an On-Instrument Wavefront Sensor (OIWS), and provide those measurements to the wavefront control system.
- **Provide capabilities for wavefront control diagnostics and calibration** including a pupil imager, phase diversity optics, and non-redundant pupil masks in the imager channel.

GMTIFS functions and requirements are representative of and relevant to future generation instruments of the same type.

2.1.24 GMT Near Infrared Spectrograph (GMTNIRS)

The GMT Near Infrared Spectrograph (GMTNIRS) is a general purpose, infrared, diffraction-limited, single-object, high spectral-resolution spectrograph, optimized for sensitivity and for large spectral grasp. GMTNIRS will operate with all AO modes of the GMT (GLAO, NGAO, and LTAO). It also directs light to and physically supports the NGWS and LTWS wavefront sensors and includes an On-Instrument Wavefront Sensor (OIWS) to provide feedback on wavefront errors not sensed by the external wavefront sensors (AGWS, NGWS, and LTWS). GMTNIRS will be located at the Folded Port.
GMTNIRS fulfills the following functions:

- **Deliver science enabled by the following Observatory Performance Modes (OPM)**
  - Small Field Infrared LTAO (OPMs 7 and 8).
  - Small Field Infrared NGAO (OPM 9).
- **Provide light sources** and optics necessary to calibrate the spectrograph.
- **Reflect natural and laser guide star light** to the NGWS and LTWS, located at the front of the instrument.
- **Measure the atmospheric and telescope wavefront and alignment errors** to which the NGWS and LTWS are insensitive, using an On-Instrument Wavefront Sensor (OIWS), and provide those measurements to the wavefront control system.

GMTNIRS functions and requirements are representative of and relevant to future generation instruments of the same type.

2.1.25 Many Instrument Fiber System (MANIFEST)

The Many Instrument Fiber System (MANIFEST) is a facility fiber utility to feed other instruments, for

which it enables access to the GMT's full 20 arcmin diameter field of view. Initially MANIFEST fibers will feed the GMACS and G-CLEF instruments, but can also feed potential future instruments.
MANIFEST is located at the Direct Gregorian focus and makes use of the Direct Gregorian Wide Field optical layout, which includes the Corrector-ADC subsystem. MANIFEST will be used in the Natural Seeing and GLAO wavefront control modes.
MANIFEST fulfills the following functions:

- **Direct the light of multiple targets** across the GMT's full 20 arcmin diameter field of regard to the GMACS and G-CLEF spectrographs.
- **Reconfigurability** for different target fields and different client instrument.
- **Measure the relative flexure** between the MANIFEST entrance focal plane and the AGWS and provide those measurements to the OCS.

2.1.26 Instrument Calibration Subsystem (ICS)

The Instrument Calibration Subsystem (ICS) provides a deployable subsystem to project continuum and spectral light sources with beam characteristics that match the light coming from the sky and celestial sources. The ICS will enable general purpose flat-field and wavelength calibration of science instruments in the spectral passband 320–2500 nm and over the full 20 arcmin diameter GMT field of view. The ICS will be operable during both daytime and nighttime, at any telescope elevation, and with minimal impact on the efficiency of science and technical observations.
The ICS fulfills the following functions:

- **Project continuous-spectra sources** to the instrument focal planes while reproducing the pupil illumination from astronomical targets, to enable flat-fielding of images and spectra.
- **Project emission-line sources** to the instrument focal planes while reproducing the telescope pupil illumination from astronomical targets, to enable absolute wavelength calibration of spectra.

2.1.27 Global Interlock and Safety System (Global ISS)

The Interlock and Safety System (ISS) implements the functional safety of the Observatory as determined by the Observatory Hazard Analysis. The ISS is divided in two parts: (a) the Global Interlock and Safety System that implement the system level functional safety that involves more than one subsystem, and (b) the Local Interlock and Safety Subsystems that implement the local functional safety functions if required by the specific hazard analysis of the corresponding Controlled Subsystem.
The ISS will monitor and control safety functions relating to the following:

- Any system/subsystem that presents a serious hazard to personnel or other equipment,
- Any hazard where the failure of system safeguard could lead to a serious or catastrophic accident,
- Any hazard where safeguards in different systems must interact with each other.

The Global ISS is responsible for system level safety-related control functions, whereas each controlled subsystem will include a Local ISS responsible for safety-related control functions within the controlled the subsystem. Both Global and Local ISS use a safety-certified network that is provided by the Global ISS, which is completely independent from the Observatory Control System (OCS) network. The ISS safety network is distributed throughout the telescope and enclosure building, including across the rotating parts of the mount and enclosure. The global ISS controller will also interface with the OCS to provide status information.

2.1.28 Instruments Support Equipment

The Instruments Support Equipment provides specialized but not instrument-specific equipment required

by Scientific Instruments.
Instruments Support Equipment fulfills functions including:

- Direct Gregorian (DG) Instrument Mounting Frame (IMF) Handling Cart: designed for transporting one DG instrument mounted in its IMF within the enclosure.
- DG – IMF Transfer Fixture: permanently connected to the top of the Pier Lift Platform (PLP), used to secure the DG–IMF onto the PLP and to compensate for misalignments with the GIR central opening during DG instrument installation.
- Clean room tents: portable and modular, to provide a clean environment for servicing and maintenance of scientific instruments in the instrument spaces within the enclosure.
- Folded Port (FP) Instrument Handling Cart designed to transport FP instrument, and likely to be used by AP instrument and IP instrument.

Baseline concepts for the DG–IMF Handling Cart and Transfer Fixture are described in GMT-DOC-00860, “DG Instrument Mounting Procedure - Mechanical Design Description” (2014) and in GMT-DOC-01296, “Gregorian Instrument Rotator Design Update” (2016). Alternative COTS options may be identified.

2.1.29 High Contrast AO Testbed (HCAT)

The High Contrast AO Testbed (HCAT) is a laboratory testbed intended to verify phasing control and performance in the NGAO wavefront control mode. It consists of a simple telescope simulator feeding the MagAO-X instrument. It will also host a prototype of the GMT Natural Guide Star Wavefront Sensor (NGWS)

2.1.30 AO Test Camera (AOTC)

The Adaptive Optics Test Camera (AOTC) is a diffraction-limited near-infrared engineering camera used to verify AO performance in the laboratory and on the telescopes. It fulfills the following functions:

- **Adaptive Optics image quality verification:** Evaluate the diffraction-limited image quality after AO correction.
- **On-Instrument Wavefront Sensor validation:** The AOTC includes an On-Instrument Wavefront Sensor identical to that of GMTNIRS, validating that design.

3 Observatory Configurations

The performance of the GMT is specified in terms of 15 Observatory Performance Modes (OPM), sets of requirements which must be met simultaneously to enable a specific SRD Observing Case. Each OPM specifies a distinct field of view, wavelength range, and balance between image quality and sky coverage. Two additional OPM enable the Precision Radial Velocity (PRV) observing case.
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 Diffraction-Limited 50% Sky Coverage
8. Small Field Infrared Diffraction-Limited 80% Sky Coverage
9. Small field Infrared Natural Guide Star Corrected

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

These OPM map to configurations of the observatory as illustrated in Figure 3-1. Driving requirements on system elements which enable these performance modes are included in this section.

Observatory Performance Mode					Telescope Systems											Instr. Ports					First-Gen. Instr.				
Field of View	Wavelen	IQ	Other	ID	ASMS	FSMS	M3	NGWS	LTWS	LGS	TMS	WCCS	ICS	C-ADC	MANIFEST	DG	GIS	FP	AP	IP	ComCam	G-CLEF	GMACS	GMTIFS	GMTNIRS
Small Field	Visible	NS		1		F	F				F		F					F	F	F					
		GL		2	F		F				F		F					F	F	F					
		NS	PRV	3		F					F						F					E			
		GL	PRV	4	F						F						F					E			
	Infrared	NS		5		F	F				F		P					F							
		GL		6	F		F				F		P					F							
		DL 50%		7	F		F		F	F	F	F	P					F						E	E
		DL 80%		8	F		F		F	F	F	F	P					F						E	E
		HC		9	F		F	F			F	F	P					F	F						
Medium Field	Visible	NS		10		F					F		F			F					E		E		
		GL		11	F						F		F			F					E		E		
	Infrared	NS		12		F					F		P			F									
		GL		13	F						F		P			F									
Wide Field	Visible	NS		14		F					F		F	F	F	F						E	E		
		GL		15	F						F		F	F	F	F						E	E		

Legend:
F = Full compliance to OPM required
P = Partial compliance to OPM required
E = Enabled by OPM

Figure 3-1: Summary of Observatory Configurations by Observatory Performance Mode

3.1 Optical Design

3.1.1 Optical Design

The GMT has an aplanatic Gregorian optical prescription with an f/0.71 primary focal ratio and f/8.16 final focal ratio (see Figure 3-2). The fast primary mirror enables a compact telescope and enclosure, while the aplanatic prescription eliminates off-axis coma and provides the widest possible uncorrected field of view. The primary mirror (M1) is composed of seven 8365 mm diameter clear aperture circular segments with a focal length of 36,000 mm. The secondary mirror (M2) is identically segmented and formed of 1050 mm diameter clear aperture circular segments. The 207,589 mm focal length of the two-mirror telescope produces an image scale of 0.994 arcsec/mm at the Gregorian focal plane. The curved Gregorian focal surface is located 5830 mm below the primary mirror vertex.

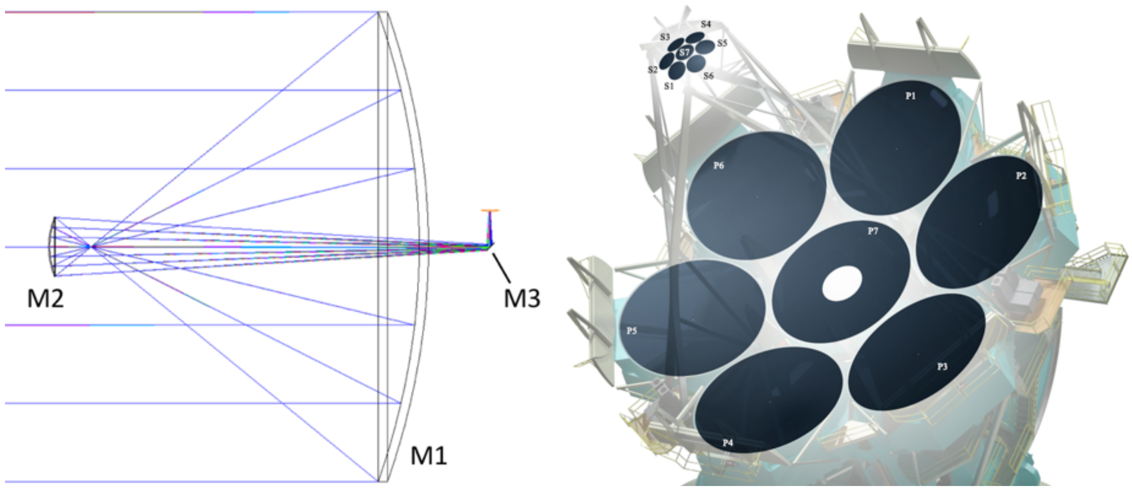

Figure 3-2: (Left) GMT optical design. (Right) M1 and M2 segmentation.

The aplanatic Gregorian design was chosen over a Cassegrain for the following reasons:

1. M2 is optically conjugated to a position 165 meters above M1, enabling ground-layer adaptive optics correction over a large field of view.
2. The Gregorian design provides a prime focus at which calibration sources can be inserted, allowing an adaptive secondary mirror based AO system to be calibrated in daytime.
3. The curvature of the telescope focal plane is in a favorable direction for the design of wide-field collimators for multi-object spectrographs.
4. The concave M2 is easier to fabricate than the equivalent convex M2.
5. The 2935 mm diameter telescope exit pupil is located 2320 mm below M2, and potentially accessible as a location for a flat field screen for instrument calibration.

The greatest disadvantage of the Gregorian design is its greater length, due to M2 being located above the prime focus. This Gregorian length penalty, approximately 4 m for the GMT, is minimized by the fast M1 focal ratio. For the adopted back focal distance and f/8.16 final focal ratio, the Gregorian M2 is 0.5 m larger in diameter than equivalent Cassegrain M2.

The GMT M2 segments are critically sized with respect to the M1 segments, a compromise between throughput and the risk of collision between segments. Vignetting due to beam walk into the gaps between M2 segments increases linearly from zero on-axis to 7% at the edge of the useable 20′ diameter field of view.

REQ-L3-OAD-33835: Optical Design

The GMT shall be an aplanatic Gregorian telescope with segmented primary and secondary mirrors as specified in GMT-DOC-00010.

Rationale: This optical design provides manufacturable M1 and M2 segments, a location for calibration sources at the prime focus, a compact image scale, and an advantageous curvature of the focal plane.
Notes: GMT-DOC-00010 specifies the optical prescriptions of M1 and M2 (ASM and FSM).

3.1.2 Optical Layouts

The basic Gregorian optical design is supplemented by two additional optical layouts which enable wide field observations and rapid narrow-field instrument changes (Figure 3-3).

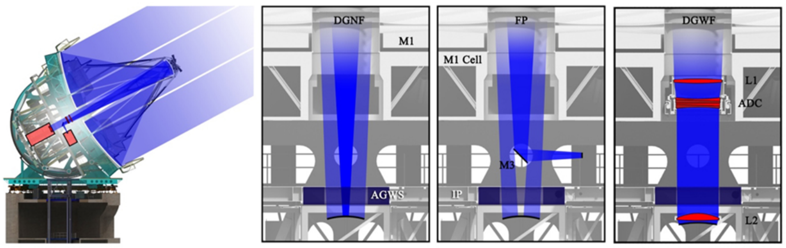

Figure 3-3: The GMT Optical Layouts

A Corrector and Atmospheric Dispersion Compensator (C-ADC) increases the corrected field of view of the telescope and provides atmospheric dispersion correction. These two functions are combined in one optical system to maximize the throughput. Two surfaces of the ADC prisms are powered, acting as one element of the corrector. The C-ADC provides correction over a 20′ diameter field of view from 350 nm to 1.0 μm wavelength (Figure 3-4) into each instrument which uses the C-ADC. The additional optical elements increase the back focal distance (defined from the M1 vertex) to 6.01 m.

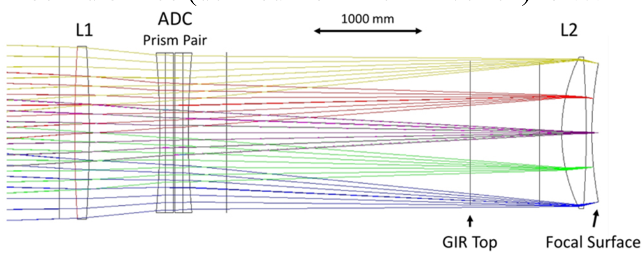

Figure 3-4: Corrector-Atmospheric Dispersion Compensator Optical Design

The first group of elements (L1 + ADC) must be deployable to enable observations outside of the C-ADC design wavelength, and to improve the throughput and emissivity for narrow-field instruments. An infrared wide-field corrector and/or ADC has not yet been designed but could be implemented in the future if it maintains a similar optical layout to the C-ADC. A storage volume for the first lens group of a second corrector has been reserved opposite that of the C-ADC.

A Folded Gregorian focal station is implemented by inserting a flat tertiary mirror (M3) at 45° incidence angle 1930 mm from focus. This additional optical layout enables a larger number of instruments to be permanently mounted on the telescope, and its small size enables rapid switching between narrow-field instruments.

The location and size of M3 are a trade between the volume available for these instruments, their scientific and technical fields of view, and the sky coverage for active optics and phasing control since only light not intercepted by M3 is available to the AGWS. All FP/AP/IP instruments currently envisioned have a scientific field of view <30 arcsec. However, a technical field of view ≥ 2 arcmin is required to pass the natural and laser guide stars required to implement the NGAO and LTAO wavefront control modes.

The selected compromise is a 3.0 arcmin field of view reflected at a right angle 1930 mm ahead of focus. This provides sufficient volume for the envisioned FP instruments and wavefront sensors, a field of view at the instruments which enables high sky coverage LTAO correction, and a patrol field at the AGWS sufficient to ensure ≥99% sky coverage [2]. The specified M3 volume leaves 52% of the Direct Gregorian field unvignetted (82% of the annular field of view outside of 5.9 arcmin radius).

Optical Layouts

The GMT shall provide the optical layouts listed in Table 3-1.

Table 3-1: GMT Optical Layouts

Requirement ID	Optical Layout	FOV	Wavelength Range	ADC
REQ-L3-OAD-33858	Direct Gregorian Narrow Field (DGNF)	≥ 10′	≤0.320 to ≥25 µm	No
REQ-L3-OAD-33863	Direct Gregorian Wide Field (DGWF)	≥ 20′	≤0.350 to ≥1.3 µm	Yes
REQ-L3-OAD-33868	Folded Gregorian (FG)	≥ 3′	≤0.45 to ≥25 µm	No

Notes: GMT-DOC-00010 specifies the optical prescriptions of M3 and C-ADC.
Rationale: Three optical layouts are required to meet the Optical Performance Modes specified in the ORD. Wavelength ranges are consistent with those required for science, but increased in the case of the Folded Port to enable natural and laser guide star wavefront sensors at the FP focus.

REQ-L3-OAD-33875: Corrector-ADC Function

The GMT shall have a Corrector and Atmospheric Dispersion Compensator that provides wide-field aberration correction over a 20 arcmin diameter field of view and atmospheric dispersion compensation over the wavelength range 0.350 to 1.3 µm at the Direct Gregorian focus.

Rationale: The functions of a field corrector and an atmospheric dispersion compensator are combined in a single optical system to optimize throughput for wide-field visible wavelength instruments.
Notes: The prescription of the C-ADC is specified in GMT-DOC-00010. Only the L1 and ADC optics and their rotation mechanism are included in the C-ADC system. The deployment mechanism is included in the Mount, and L2 must be included in each DGWF Instrument and the MANIFEST fiber feed.

REQ-L3-OAD-33879: Corrector-ADC Insertion/Removal

The GMT Mount shall provide a deployment mechanism for inserting and removing the C-ADC first lens group (L1 and ADC) into the Direct Gregorian beam.

Rationale: Required to support multiple optical layouts: DGNF, DGWF, and FP.
Notes: The C-ADC insertion mechanism and storage location are provided by the Mount.

REQ-L3-OAD-33883: Second Wide-Field Corrector or ADC Insertion/Removal

The GMT Mount shall provide a deployment mechanism for inserting and removing a second wide-field corrector and/or atmospheric dispersion compensator into the Direct Gregorian beam.

Rationale: The limited wavelength range of the C-ADC may require a separate infrared wide-field corrector for future wide-field infrared instruments.
Notes: No design for a second corrector yet exists, but it is assumed to require the same mass and volume allocations as the C-ADC. The insertion mechanism and storage location are provided by the Mount.

REQ-L3-OAD-33887: Corrector-ADC Field Lens Location

Any Instrument operating in the Direct Gregorian Wide Field optical layout shall provide a C-ADC field lens (L2).

Rationale: Required to support multiple optical layouts: DGNF, DGWF, and FP.
Notes: The prescription of the C-ADC field lens is specified in GMT-DOC-00010.

REQ-L3-OAD-33891: Tertiary Mirror (M3)

The GMT shall have a flat tertiary mirror (M3) to direct an optical beam perpendicular to the Reference Optical Axis to instruments located at Folded Port, Auxiliary Port, or Instrument Platform Port.

Rationale: The M3 mirror enables a larger number of instruments to be permanently mounted on the telescope, and rapid switching between narrow-field instruments.
Notes: The prescription of M3 is specified in GMT-DOC-00010.

REQ-L3-OAD-33895: M3 Reflected Field of View

The M3 shall reflect an unvignetted field of view of at least 3.0 arcmin diameter.

Rationale: M3 must transmit an unvignetted scientific field of view of ≥30 arcsec diameter, a technical field of view for LTAO natural guide star selection of 3.0 arcmin diameter, and the 60 arcsec diameter LTAO laser guide star asterism at a limiting range of 82.5 km. The LTAO mode natural guide star patrol field is the driving requirement.
Notes: The required LTAO natural guide star patrol range is derived in ANU-AO-DOC-00023.

REQ-L3-OAD-33899: M3 Transmitted Field of View

The M3 shall vignette no more than 48% of the 20 arcmin diameter Direct Gregorian field when deployed.

Rationale: Consistent with ≥ 99% sky coverage for the Natural Seeing OPMs, and ≥ 80% sky coverage for OPM 7 (High Angular Resolution Spectroscopy).
Notes: The current requirement is derived from the M3 conceptual design and demonstrated to be consistent with the sky coverage requirements in SAO-DOC-00201 and GMT-DOC-01515. However, the shape of the M3 shadow matters, so this requirement should be re-evaluated if the design of M3 changes significantly.

REQ-L3-OAD-33903: M3 Insertion/Removal

The M3 shall provide a deployment mechanism for inserting and removing M3 onto the Reference Optical Axis.

Rationale: M3 must be removed from the Direct Gregorian optical path to enable the DGNF and DGWF optical layouts.
Incomplete Telescope Segmentation
The GMT shall operate with reduced performance in the incomplete optical layouts listed in Table 3-2.

Table 3-2: Incomplete Optical Layouts

Requirement	Situation	Description	WFC Modes
REQ-L3-OAD-33915	First Light	1 on-axis and ≥1 off-axis M1-FSM segment pair	NS
REQ-L3-OAD-33919	Early AO	1 on-axis + ≥2 off-axis M1-ASM segment pairs	NS, GLAO, NGAO[a]
REQ-L3-OAD-33923	M1S7 recoating	M1 on-axis segment missing	NS, GLAO

Notes: [a] Reduced image quality.
The performance of some systems will be degraded when operating in this mode. These modes may also be necessary when M2 segments have been removed for servicing.
Rationale: Incomplete optical layouts enable early science operations during the AIV phase, and continued scientific productivity during some maintenance periods when fewer than seven segments are available.

3.1.3 Focal Stations

The GMT provides instrument focal locations with various fields of view, volumes, and gravitational orientations, enabling a diverse set of instruments to be available at all times. The instrument focal station locations are illustrated in Figure 3-5.

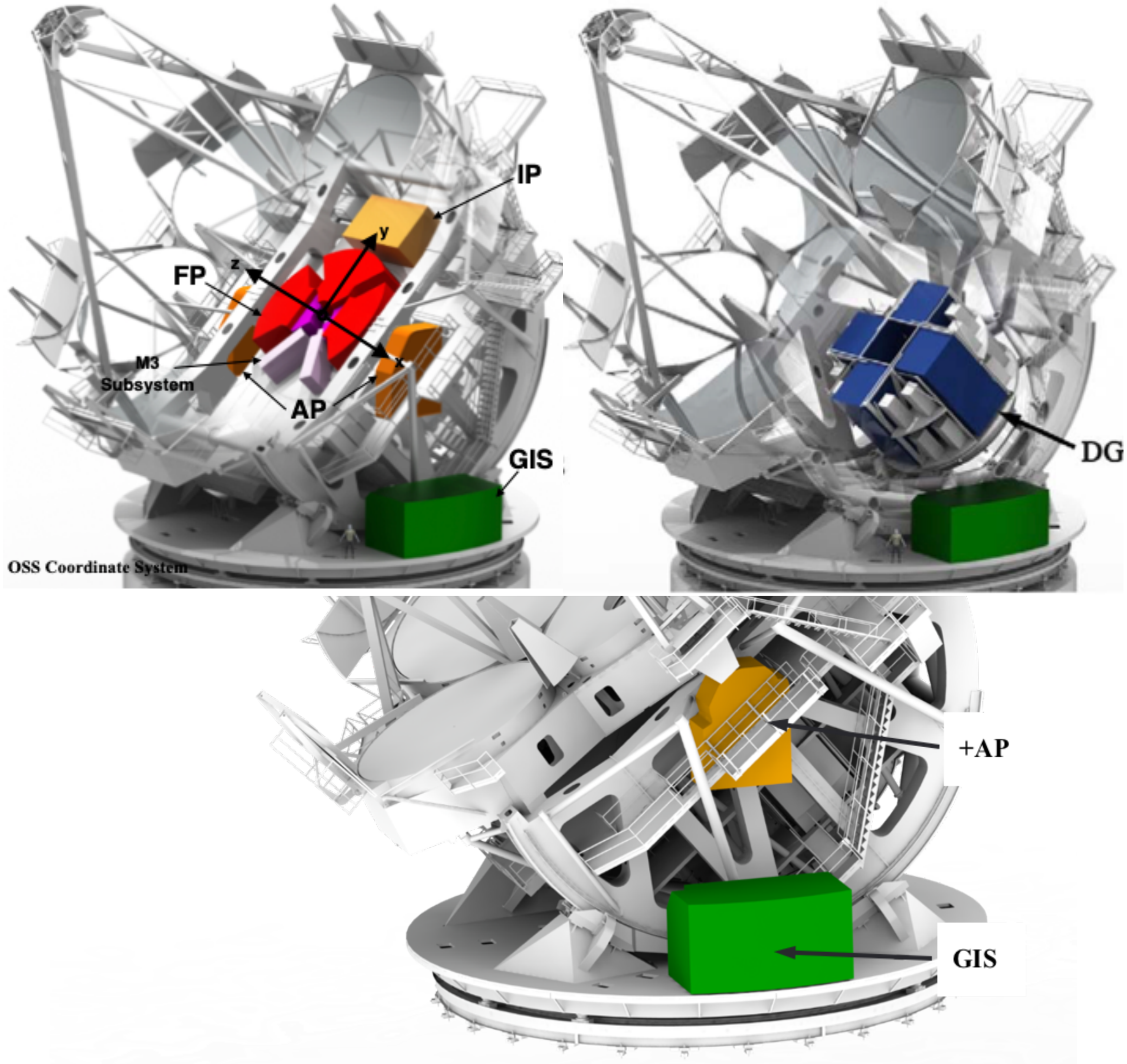

Figure 3-5: Instrument Focal Stations. The Second AP is shown is the first figure, but it is not shown in the detail figure since it would be on the other side invisible in this last figure.

The GMT optical design places both the Direct and Folded Gregorian foci below the M1 assembly, within the OSS. Since the OSS motion axes are altitude and azimuth, it is necessary to de-rotate the image of the sky at the instrument foci. This is accomplished using a single large Gregorian Instrument Rotator (GIR) on which most instruments are mounted.
Two standardized instrument interfaces (or Ports) are provided on the GIR: Direct Gregorian (DG) and Folded Port (FP). Three Direct Gregorian instruments, two large and one small with similar interfaces, can be stored on the GIR and deployed linearly onto the Reference Optical Axis. Three Folded Port

instruments, also identical in volume and interfaces, can be mounted on the top surface of the GIR. Instruments mounted on the GIR are subjected to a gravity vector varying in two dimensions.

A location for a large instrument requiring a stable gravity vector is provided on one side of the Azimuth disk, referred to as the Gravity Invariant Station (GIS). It is possible to direct light to this instrument either through a long optical relay passing through the elevation axis (and the Auxiliary Port instrument volume), or via optical fibers for the DG or FP focus. The volumes currently allocated to the GIS are based on the design of the GCLEF instrument, which uses an independent tertiary mirror and relay on the GIR, and a fiber injection unit on the fixed Instrument Platform. The GIR must be maintained at a fixed angle to use the GIS, leading to a rotating field at the GIS fiber injection unit.

A location for an additional large instrument is provided on the +Y side of the fixed Instrument Platform, called the IP Port. Instruments at the IP Port must provide an optical relay on the GIR from the Folded Gregorian focus to the instrument. Exclusive volume for this relay has not been allocated, and this relay would take the place of an FP instrument. The GIR must be maintained at a fixed angle to use the IP, leading to a rotating field at the instrument. The IP port is subjected to a gravity vector varying in only one dimension.

While the GMT does not have Nasmyth platforms, the Auxiliary Ports provide a similar gravity-invariant capability for narrow-field instruments. A mounting interface, utilities, and a volume are provided for two instruments on the elevation axis on the outboard side of both C-Rings. Instruments at the AP must provide an optical relay on the GIR from the Folded Gregorian focus to the instrument. Exclusive volume for this relay has not been allocated, and this relay would take the place of an FP instrument.

The flowdown from the ORD Observatory Performance Modes to instrument ports is illustrated in Figure 3-6. The DG port must support all Medium Field and Wide Field OPMs (10–15), while the other ports must support various combinations of Small Field OPMs (1–9). Note that this does not rule out hosting instruments at ports for which the relevant OPM is not specified.

Observatory Performance Mode					Instrument Ports				
Field of View	λ	IQ	Other	ID	DG	GIS	FP	AP	IP
Small Field	Visible	NS		1			F	F	F
		GL		2			F	F	F
		NS	PRV	3		F			
		GL	PRV	4		F			
	Infrared	NS		5			F		
		GL		6			F		
		DL 50%		7			F		
		DL 80%		8			F		
		HC		9			F	F	
Medium Field	Visible	NS		10	F				
		GL		11	F				
	Infrared	NS		12	F				
		GL		13	F				
Wide Field	Visible	NS		14	F				
		GL		15	F				

F = Full compliance required

Figure 3-6: Flowdown from Observatory Performance Modes to Focal Stations

Focal Stations

The GMT shall provide the instrument stations, number of simultaneously supported instruments, field of view, gravity variation, and the field de-rotation listed in Table 3-3.

Table 3-3: Instrument Focal Stations

Requirement ID	Focal Station	# Instr.	Min. FOV	Gravity	De-rotation
REQ-L3-OAD-33953	Direct Gregorian (DG)	1[a]	20′ [b]	2D	Mount
REQ-L3-OAD-33959	Folded Port (FP)	3	3′	2D	Mount
REQ-L3-OAD-33965	Gravity Invariant (GIS)	1	N/A[c]	Invariant	Instrument
REQ-L3-OAD-33971	Auxiliary Port (AP)	2	3′	Invariant	Instrument
REQ-L3-OAD-33977	Instrument Platform (IP)	1	3′	1D	Instrument

Notes:
[a] The DG focal station is in the DG Deployed Instrument Bay.
[b] The DG port in the DGWF optical layout will be partially vignetted by the AGWS.
[c] The GIS field of view is dependent on the instrument design.
Narrow-field instruments that require the highest stability (e.g., precision radial velocity spectrographs, extreme AO systems) will mount at the Gravity Invariant Station or Auxiliary Ports. Wide-field instruments will mount at the Direct Gregorian port. Other focal stations enable narrow-field instruments of various sizes to be simultaneously accommodated on the GMT.
Rationale: These five focal stations enable a diverse set of up to 10 instruments to be simultaneously mounted on the OSS and available every night.

REQ-L3-OAD-33986: Gregorian Instrument Rotator (GIR)

The Mount shall provide a common instrument rotator on the OSS to deliver a non-rotating field of view to DG and FP Science Instruments mounted on the rotator.

Rationale: The DG and FP instruments are located on a common Gregorian Instrument Rotator (GIR) to enable a larger number of instruments to be mounted on the telescope at one time. This architecture leads to excellent dynamic performance, excellent optical performance, smaller instruments and low cost at the expense of decreased access.

REQ-L3-OAD-39037: GIR Static Position

The Mount GIR shall have a static position mode with rotation angle accuracy of less than ±36.5 micro radians RMS.

Rationale: A static position mode is required to support AP, IP, and GIS focal stations, which require an optical relay which crosses from the GIR to the Instrument Platform. The value is based on analysis for the GCLEF instrument, which requires an alignment of the GIR-IP interface of less than ±150 µrad P-V, including both GIR rotation error and flexure. Approximately half of this has been allocated to GIR rotation error.

REQ-L3-OAD-69511: DG Instrument Bays

The Mount shall provide three instrument bays on the GIR, each adjacent to the DG Deployed Instrument Bay and each of which can hold one DG instrument.

Rationale: To minimize handling of DG instruments, and for operational efficiency, at least three DG instruments will be available (installed) in the GIR at any given time.

REQ-L3-OAD-33989: DG Instrument Deployment

The Mount shall provide mechanisms for moving installed DG Instruments between their stowed positions and the DG focal station.

Rationale: Deployment of DG instruments from a storage locations 2.9 m off-axis to the Reference Optical Axis is required by the architectural design of the focal stations. An automated deployment mechanism minimizes instrument handling to limit both the staffing requirements and the risk of damage to instruments.

REQ-L3-OAD-33992: FP Instrument Selection

The M3 shall provide a mechanism to rotate M3 about the Reference Optical Axis (ROA) and direct the Folded Gregorian beam to the Folded Port, Auxiliary Port, and Instrument Platform focal stations.

Rationale: Instrument selection by rotating M3 around the ROA enables rapid switching between up to 7 narrow-field instruments mounted on the OSS.

REQ-L3-OAD-33995: GIS Instrument Optical Feed

Instruments using the GIS focal station shall provide an optical or fiber relay from the Direct Gregorian or Folded Gregorian beams to the GIS instrument volume.

Rationale: The GIS instrument volume must be fed by either a long optical relay or fiber. This relay can either begin at from the Reference Optical Axis or the Folded Gregorian focus.
Notes: A volume is reserved on the GIR and on the IP for the G-CLEF optical and fiber relays. If a deployable pick-off mirror on the ROA is used, then it must follow the same DG shadowing requirements as M3.

REQ-L3-OAD-33999: AP Instrument Optical Feed

Instruments using AP focal station shall provide an optical relay from the Folded Gregorian focus to the AP instrument volume.

Rationale: An optical relay approximately 5 m in length is required to transfer the focal plane to the AP instrument volume.
Notes: No volume has been reserved for the AP optical relay where it traverses the FP instrument volumes.

REQ-L3-OAD-34003: IP Instrument Optical Feed

Instruments using the IP focal station shall provide an optical or fiber relay from the Direct Gregorian or Folded Gregorian beams to the IP instrument volume.

Rationale: The IP instrument volume must be fed by either a ~5-m optical relay or fiber. This relay can either begin at from the Reference Optical Axis or the Folded Gregorian focus.
Notes: If a deployable pick-off mirror on the ROA is used, then it must follow the same DG shadowing requirements as M3.

REQ-L3-OAD-34007: AP Instrument Gravity Invariance

The Mount shall provide a rotation mechanism to maintain Auxiliary Port instruments in a gravity-invariant orientation.

Rationale: Necessary to maintain gravity invariance as the OSS rotates around the elevation axis.

REQ-L3-OAD-34010: GIS Instrument Field De-Rotation

Instruments using the GIS focal station shall provide their own field de-rotation mechanism, if necessary.

Rationale: The rotation mechanism may be needed to counteract field rotation.

REQ-L3-OAD-34013: Auxiliary Port Instrument Field De-Rotation

Instruments using the AP focal station shall provide their own field de-rotation mechanism, if necessary.

Rationale: The rotation mechanism may be needed to counteract field rotation.

REQ-L3-OAD-34016: IP Instrument Field De-Rotation

Instruments using the IP focal station shall provide their own field de-rotation mechanism, if necessary.

Rationale: The rotation mechanism may be needed to counteract field rotation.

3.2 Physical Layout

3.2.1 Site Infrastructure

The GMT Site Master Plan (M3-PN110107) describes the general arrangement of the GMT site (Figure 3-7), its division into summit and support sites, and the roads the connect the internal sites with the LCO road (the primary access road to the LCO and GMT sites). The summit site includes the leveled platform on Las Campanas peak (2415 m above sea level). The technical support site (Support Site 1, SS1) is located roughly 300 m South-West of the summit (2426 m above sea level). The personnel support site (Support Site 2, SS2) is located roughly 300 m South of Support Site 1 (2385 m above sea level).

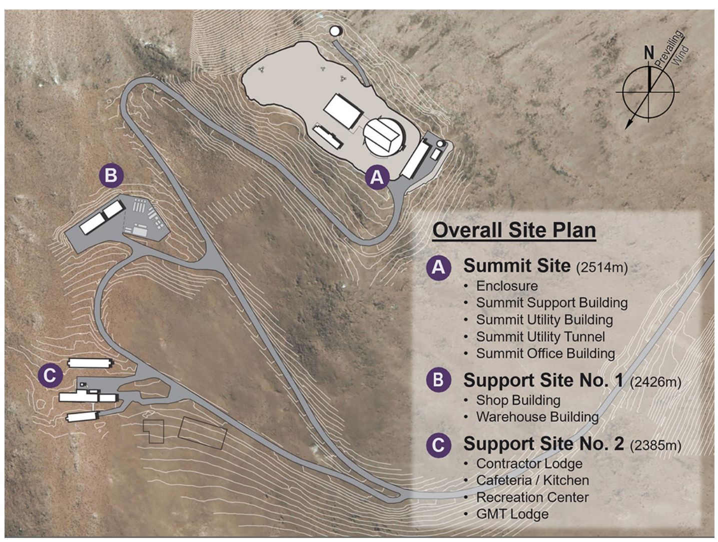

Figure 3-7: GMT Site Building Layout

3.2.1.1 Personnel and Vehicle Access

REQ-L3-OAD-34024: Vehicle Access

The GMT site infrastructure shall include roads which connect to the LCO access road, and to connect all facility locations on the site.

Rationale: Required for construction and operation of the observatory and support facilities.

3.2.1.2 Water System

REQ-L3-OAD-69477: Water Plant

The site infrastructure shall provide space for a water plant to store, treat, and distribute water to other buildings.

Rationale: To provide water.

REQ-L3-OAD-69479: Water Plant Electrical Yard

The site infrastructure shall provide space for outdoor equipment related to the water plant.

Rationale: Some equipment will not need to be stored in a building.

3.2.1.3 Waste Water Treatment

REQ-L3-OAD-38390: Domestic Waste Water Treatment Systems

The site infrastructure shall provide domestic waste water treatment systems to service all site facilities buildings.

Rationale: No municipal waste water treatment plants are accessible from the GMT site. The site infrastructure must include waste water treatment locally. Multiple buildings may share a single waste water treatment plant.

3.2.1.4 Power Distribution

REQ-L3-OAD-37587: Commercial Electrical Power - Connection

The site infrastructure shall include an electrical power connection to the Chilean commercial electrical grid.

Rationale: Commercial electric power will be the most cost-effective option to power the observatory.

REQ-L3-OAD-37608: Site Electric Power Distribution

The site infrastructure shall include an electrical power distribution system to supply commercial and backup power to the facilities at the summit, SS1, and SS2.

Rationale: Required for operation of the facilities. See Figure [figure-66365] for conceptual illustration.

REQ-L3-OAD-37599: Site Electric Power Distribution - Substations

The site infrastructure shall include electrical power substations and associated switchgear at the summit and support sites.

Rationale: Required for operation of the facilities.

3.2.1.5 Communications Infrastructure

REQ-L3-OAD-38434: Cabling Infrastructure

The GMT shall provide a cabling infrastructure to support general services.

Rationale: Providing these services will reduce the complication and risk of installing cables after operations are underway.
Notes: General services include, but are not limited to, communication networks, fibers, electrical distribution, and isolated grounds.

3.2.1.6 Cooling System Infrastructure

REQ-L3-OAD-37918: Coolants

Enclosure shall provide (a) cooling system(s) to provide coolant for instrumentation and telescope systems.

Rationale: Heated air migrating in front of the telescope will degrade imaging performance.
Notes: This may require multiple cooling systems to service different applications, such as fixed temperature and variable temperature systems.

3.2.2 Facilities

The GMT facilities buildings provide space and functionality to support the final assembly, integration, test, operation, and maintenance of the observatory. The Site Master Plan defines the facilities buildings and their locations on the site (Figure 3-7). The Base Facility will have a separate architectural description.
The summit site facilities include the leveled platform on Las Campanas peak (2514 m above sea level), the summit support building (SSB), the Support Site 1 (SS1), the Support Site 2 (SS2) and the mobile equipment.
The technical support site (support site 1, SS1) is located downhill and South-West of the summit site (2426 m above sea level), on a level graded area with building sites for the warehouse building (with M1 integration bays), the shop building, and the Support Site 1 yard.
The personnel support site (support site 2, SS2) is located downhill and almost due South of SS2 (2385 m above sea level), on multiple levels graded areas with building sites for the GMT lodge, the construction worker's lodge, the main kitchen and dining room, the recreational building, and additional small storage facilities (including storage containers).

REQ-L3-OAD-34045: Common Auxiliary Spaces

The Enclosure and Facilities shall provide space within buildings for common uses such as office space, bathrooms, and storage space.

Rationale: Each building should be relatively self-sufficient for day-to-day operations for effiency.

REQ-L3-OAD-69481: Residence

The Facilities shall provide space for housing staff and visitors at Support Site 2.

Rationale: Staff will require dining, sleeping, and recreational facilities close to the telescope.

3.2.2.1 Summit Support Building

REQ-L3-OAD-34049: Summit Support Building

The facilities shall provide a summit support building (SSB) to house the M1 washing and reflective coating systems, and the Optical Subsystems Lab for secondary mirrors integration and testing.

Rationale: The primary mirror (M1) assemblies are fragile and challenging to transport safely. The M1 coating systems will generate heat, noise, and vibration that would jeopardize performance of the telescope where it located in the enclosure. Hence a separate building on the summit, near the enclosure, is needed for the M1 cleaning and coating systems.

REQ-L3-OAD-34062: Summit Support Building - Storage Bay

The SSB shall provide a storage bay for the seventh off-axis M1 assembly.

Rationale: When cleaning and recoating the center M1 assembly an additional storage location is needed for the seventh off-axis M1 assembly.

REQ-L3-OAD-34071: Summit Support Building - Mezzanine

The SSB shall provide a mezzanine for storage of M1 assembly accessories.

Rationale: During cleaning and recoating, the mirror covers, and other components must be removed from the M1 assembly. The mezzanine provides the storage area for these items.

REQ-L3-OAD-34080: Summit Support Building - Washing/Stripping Bay

The SSB shall provide a washing bay for cleaning and stripping of M1 mirrors.

Rationale: M1 optical surfaces must be stripped of old coatings and cleaned prior to recoating.

REQ-L3-OAD-34052: Summit Support Building - Staging Bay

The SSB shall provide a staging bay for removal and replacement of M1 accessories.

Rationale: Components of the M1 assemblies, including the mirror covers, must be removed prior to cleaning and coating of the M1 optics. These items are removed and reinstalled in the staging bay.

REQ-L3-OAD-34089: Summit Support Building - Coating Bay

The SSB shall provide a coating bay for the M1 coating chamber.

Rationale: A coating chamber is needed for periodically replacing the reflective coatings on the M1 assemblies.

REQ-L3-OAD-34104: Summit Support Building - Electrical Room

The SSB shall provide an electrical / UPS room.

Rationale: For electrical power conditioning and UPS systems needed to support the coating chamber systems and other building functions.

REQ-L3-OAD-34110: Summit Support Building - Equipment Room

The SSB shall provide an equipment room.

Rationale: For equipment, utilities, and related services to support the M1 cleaning, stripping, and recoating processes.

REQ-L3-OAD-34113: Summit Support Building - Magnetron Target Room

The SSB shall provide a magnetron target room.

Rationale: The coating chamber conceptual design calls for the use of multiple ~4 m long magnetron targets. The magnetron targets are service items for the coating chamber.

REQ-L3-OAD-34122: Summit Support Building - Integration Area

The SSB shall provide space for the Optical Subsystems Lab

Rationale: To provide spaces for assembly, integration, test, calibration, and maintenance of the M2 systems and related subsystems.

REQ-L3-OAD-34141: Summit Support Building - Bridge Crane

The SSB shall include a bridge crane.

Rationale: To support M1 washing, stripping and recoating activities as well as installation, assembly, integration, testing, and calibration of the M2 assemblies and related subsystems.

3.2.2.2 Support Site 1

The primary function of the facilities is to support the assembly, integration, test, and operation of the observatory. During the construction and early operations phases, the warehouse building will provide an M1 Integration Lab (MIL) with four large bays for integration of the M1 mirror cells, support systems, and optics. Following completion of observatory construction, the MIL will be transitioned to warehouse space and partially reconfigured to provide electronics and detector laboratories.

REQ-L3-OAD-34118: SS1 - Warehouse Building

The facilities shall provide a warehouse building to house the M1 Integration, provide spaces for construction and operations.

Rationale: To provide off-summit spaces for final integration of M1 assemblies and AIT and maintenance of the adaptive secondary mirrors and related subsystems.

REQ-L3-OAD-34157: SS1 - Warehouse Vestibule

The warehouse shall provide an entry vestibule.

Rationale: To provide an entry for large items into the warehouse, without exposing the MCL or MIL to direct exposure to the outdoor environment (wind, dust, debris, etc.).

REQ-L3-OAD-34198: SS1- Shop Building

The Facilities shall provide space for a shop building at SS1.

Rationale: To provide for machine shop and auto shop functions at the Observatory.

REQ-L3-OAD-34204: SS1 Yard

The Facilities shall provide space for Storage of mobile equipment and electrical equipment.

Rationale: Space must be allocated for equipment that will be stored outside of the Observatory buildings.

3.2.2.3 Base Facility

REQ-L3-OAD-110049: Base Facility work spaces

The GMTO Base Facility shall have climate-controlled work spaces.

Rationale: Comfortable work environments are necessary for staff morale and productivity

Notes: It is not necessary to climate control spaces like shipping and receiving in which staff will spend minimal time.

REQ-L3-OAD-110050: Base Facility office space

The GMT Base Facility shall provide office spaces for staff members and visitors.

Rationale: The Operations Plan Description (GMT-DOC-03838) lists staff members who normally work from the sea-level facility, including some that work primarily from the mountain but will also work at the Base Facility a significant amount of time.
Notes: It is not necessary for every person to have their own private office.

REQ-L3-OAD-110051: Base Facility remote operations room

The GMT Base Facility shall provide a remote operations room.

Rationale: A dedicated room designed for efficient and effective communication with the Observatory and with the mountain control room (and other remote observing sites) will be valuable for scientists, engineers and visitors participating in night-time operations. It is also useful for videoconferencing with the daycrew. During significant commissioning events (e.g. a new instrument), or public events, a remote observing room provides easy communications with mountain operations.
Notes: Note that we will initially require that the Telescope Operator role be done only from the mountain, although this could change in the future. The Observer role, however, can be done remotely.

REQ-L3-OAD-110052: Base Facility shipping and receiving

The GMT Base Facility shall provide an enclosed space for shipping and receiving, and for temporary storage of equipment transiting to and from the mountain.

Rationale: As equipment transits to and from the mountain, a space is needed to temporarily store equipment of modest size, and to handle shipping and receiving procedures efficiently.
Notes: It is not necessary to temporarily store large pieces of equipment at the Base Facility. If needed, a larger warehouse space in the local area can be rented short term.

REQ-L3-OAD-110053: Base Facility parking

The GMT Base Facility shall provide enough parking for staff and visitors.

Rationale: Staff and visitors must have easy access to the Base Facility from their vehicles, including those using bicycles and motorbikes. This number includes the number of staff and visitors expected to have space at the Base Facility plus the number expected to park during their turnos on the mountain. Note that enough space for the overlap of the turnos is required.

REQ-L3-OAD-110054: Base Facility backup power

The GMT Base Facility shall provide power to critical services through a commercial power outage.

Rationale: A commercial power outage should not affect the ability to contribute to science operations from the Base Facility. Critical systems include all computer systems (including administrative computers) as well as lights and the HVAC system.

REQ-L3-OAD-110055: Base Facility theater

The GMT Base Facility shall provide a large theater with reconfigurable space and seating for 50 people.

Rationale: A large, reconfigurable room has many uses, from public lectures to all-staff meetings.

REQ-L3-OAD-110056: Base Facility conference room

The GMT Base Facility shall provide three conference rooms with enough space and seating for 15 people each.

Rationale: Simultaneous meetings must be supported.

REQ-L3-OAD-110057: Base Facility A/V equipment

Each GMT Base Facility conference room, and theater, shall be equipped with audio-visual presentation and videoconferencing equipment.

Rationale: These large gathering rooms will be used for presentations and video conferencing with external partners, collaborators, vendors, etc.

REQ-L3-OAD-110058: Base Facility kitchen/dining facilities

The GMT Base Facility shall provide kitchen/dining facilities to support staff and visitors.

Rationale: Many staff will eat lunch within the Base Facility, requiring refrigeration and light cooking facilities, such as microwaves.

REQ-L3-OAD-110059: Base Facility lab space

The GMT Base Facility shall provide a small lab space.

Rationale: A lab space to perform small optical experiments, or work on electronics, will enable work that could be disruptive to or disrupted by other work on the mountain.

REQ-L3-OAD-110060: Base Facility showers

The GMT Base Facility shall provide shower and changing facilities for staff and visitors.

Rationale: To promote healthy activities, staff and visitors should be able to change clothing and freshen up before returning to work.

3.2.2.4 Mobile Equipment

Facilities include shared/common material handling equipment, including forklifts, portable cranes and scissor lifts.

3.2.3 Enclosure

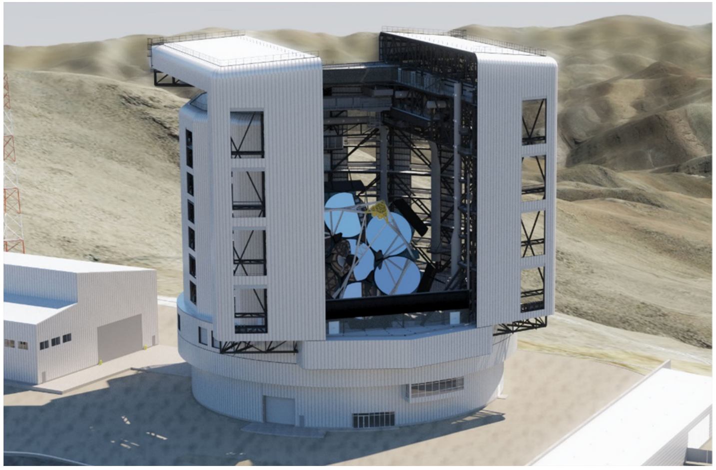

Figure 3-8: An Example of Enclosure Design

REQ-L3-OAD-34207: Telescope Enclosure

The observatory shall provide an enclosure for the telescope.

Rationale: The telescope, including its optics and instruments, must be protected from direct sunlight during the day, and from dust, rain, snow, and related weather hazards at any time. The project element which supports and protects the telescope is called the enclosure.

REQ-L3-OAD-34210: Enclosure Observing Chamber

The enclosure shall provide an observing chamber for the telescope.

Rationale: The primary function of the enclosure is to continuously control the environment around the telescope. The protected volume around the telescope is called the observing chamber.

3.2.3.1 Upper Enclosure

Control of scattered light is discussed in Section 4.8. This includes the Moon shades and vent shades. Handling equipment is discussed in Section 5.4.7.1.

REQ-L3-OAD-34215: Upper Enclosure

The enclosure shall provide an upper portion, which provides the side and upper boundaries of the observing chamber.

Rationale: A portion of the enclosure is elevated several meters above ground level to locate the observing chamber above the local atmospheric "ground layer." The elevated portion of the enclosure is called the upper enclosure.

REQ-L3-OAD-34218: Enclosure Observing Chamber Floor

The enclosure shall provide a fixed (non-rotating) working floor at the bottom of the observing chamber.

Rationale: A primary function of the enclosure is to support telescope construction and access for maintenance of the telescope throughout the lifetime of the observatory. The enclosure floor level at the bottom of the observing chamber, and at the top of the lower enclosure, is called the observing floor.

REQ-L3-OAD-34221: Observing Chamber Floor Level

The enclosure observing chamber floor level shall be coincident with the top surface of the telescope azimuth disk.

Rationale: A primary function of the enclosure is to provide personnel access to the telescope. The primary means of this access, for personnel and equipment, is at a level crossing between the observing floor and the top of the telescope azimuth disk.

REQ-L3-OAD-34224: Enclosure Observing Chamber Floor Hatch

The enclosure shall provide a mechanized hatch in the observing floor to enable access to the grade level in the lower enclosure.

Rationale: A primary function of the enclosure is to support telescope servicing, including removal and replacement of primary mirror assemblies for recoating. The opening in the observing floor which provides access to the grade level is called the floor hatch.

REQ-L3-OAD-34230: Enclosure Viewing Aperture

The enclosure shall provide an unobstructed view of the night sky for any combination of operational telescope azimuth and elevation angles.

Rationale: While the primary function of the enclosure is to protect the telescope observing chamber, it must do so without restricting the telescope's operational range of azimuth and elevation angles. The enclosure feature through which the telescope views the sky is called the viewing aperture.
Notes: During a power outage, in the 40 seconds it takes to recover onto generator power, the telescope will move at most about 1 meter. If the Enclosure rotation is not on UPS, the shutter width should be oversized by at least 2 meters.

REQ-L3-OAD-34234: Enclosure Rotation System

The enclosure shall provide a means for continuously aligning the viewing aperture with the telescope azimuth angle.

Rationale: Since the telescope can point to any azimuth angle, the enclosure must be able to continuously position the viewing aperture at any azimuth angle, such that the telescope field of view is not obstructed. The subsystem that enables rotation of the viewing aperture is called the enclosure rotation system (ERS).

REQ-L3-OAD-34237: Enclosure Rotation System - Ventilation System

The enclosure shall provide a means for protecting the observing chamber from heat released by the enclosure rotation system.

Rationale: The power systems required for the ERS will not be perfectly efficient, and hence will release heat that could potentially disturb the temperature environment in the observing chamber. The component which will remove waste heat from the volume containing the ERS is called the ERS ventilation system.

REQ-L3-OAD-34240: Enclosure Flushing

The enclosure shall provide a means for wind-driven flushing of air in the observing chamber.

Rationale: While the primary function of the enclosure is to protect the environment around the telescope observing chamber, it must do so while minimizing nighttime temperature differences between the observing chamber and ambient external air.

REQ-L3-OAD-34243: Enclosure Shutters

The enclosure shall provide an open/close function for the viewing aperture, whereby the enclosure, when open, will provide an unobstructed view of the sky for any telescope operational orientation.

Rationale: When the enclosure viewing aperture is "closed," the observing chamber is protected from the external environment. The open/close function for the viewing aperture is provided by components called the shutters.

REQ-L3-OAD-34246: Enclosure Wind-screen

The enclosure shall provide a means for modulating wind-flow through the viewing aperture, while simultaneously allowing an unobstructed view of the sky for any telescope operational elevation angle.

Rationale: Airflow through the open enclosure shutters must be modulated to balance flushing of the observing chamber with wind-driven vibration of the telescope (wind-shake). The wind modulating function is provided by a subsystem called the wind-screen.

REQ-L3-OAD-34249: Enclosure Wind Vents

The enclosure shall provide a means for modulating the wind-driven flushing of air through the observing chamber.

Rationale: While the primary function of the enclosure is to protect the telescope observing chamber, it must do so while simultaneously minimizing air temperature differences inside and outside the observing chamber. In general, the enclosure viewing aperture will not be aligned with the wind direction. So additional openings in the enclosure are required to allow flushing of the observing chamber regardless of telescope azimuth angle and wind direction. The components which enable modulation of flushing are called wind vents.

REQ-L3-OAD-34252: Enclosure Material Handling Systems

The enclosure shall provide means for lifting and positioning telescope components, including optics and instruments inside the observing chamber, during the observatory final assembly, integration, testing, and operational phases.

Rationale: A key function of the enclosure is to support construction and operation of the telescope, optics, and instruments, for the lifetime of the observatory. This function will include installation and removal of telescope components, with lifting and positioning components from grade level to various locations inside the enclosure and the observing chamber. In general, this function will be provided by one or more cranes and hoists inside the enclosure.

REQ-L3-OAD-34255: Enclosure Bridge Crane

The enclosure shall provide a bridge crane, located above the highest point on the telescope, to enable construction and maintenance of the telescope and its subsystems.

Rationale: A key function of the enclosure is to support construction and operation of the telescope, its optics, and instruments. The enclosure bridge crane will be the primary component of the enclosure material handling systems.

REQ-L3-OAD-34264: Upper Enclosure Elevator

The upper enclosure shall provide a personnel-rated freight elevator.

Rationale: The upper enclosure will require personnel access to all its subsystems, as well as the roof of the enclosure. The roof of the enclosure is ~50 m (~165 feet, 16 floors) above the observing floor level. An elevator is necessary to provide safe and efficient personnel access (with tools and handling carts) to all service levels in the upper enclosure.

3.2.3.2 Lower Enclosure

REQ-L3-OAD-34268: Lower Enclosure

The enclosure shall provide a lower portion, which structurally supports the upper enclosure, and defines the bottom of the observing chamber.

Rationale: The enclosure includes a lower portion which includes the telescope and enclosure foundations, as well as a variety of personnel, utility, and related service areas. The portion of the enclosure between its foundations and the bottom of the observing chamber is called the lower enclosure.

REQ-L3-OAD-34274: Control Level Floor

The lower enclosure shall provide an elevated personnel floor level above the grade level and below the observing floor.

Rationale: The upper floor level in the lower enclosure is intended to support daytime and nighttime operation of the observatory. The upper floor level in the lower enclosure is called the control level.

REQ-L3-OAD-69459: Lower Enclosure Interstitial Space

The lower enclosure shall provide an interstitial space directly below the Observing Floor to house HVAC and potentially other equipment.

Rationale: Beneath the Observing Floor is a space-efficient, readily accessible volume for equipment such as the HVAC system.

REQ-L3-OAD-34277: Lower Enclosure Elevator

The lower enclosure shall provide a personnel-rated freight elevator.

Rationale: An elevator is necessary to provide safe and efficient personnel access (with tools and handling carts) to all floor levels in the lower enclosure. The elevator will have stops at the grade level, control level, and observing floor level. The height between grade and the observing floor is ~11.8 m (~40 ft.).

REQ-L3-OAD-34280: Grade Level - High Bay Lab

The lower enclosure grade level shall provide a "high bay" lab space.

Rationale: A primary function of the enclosure is to provide working areas to support assembly, integration, test, and operation of the observatory, including subsystems for the telescope, optics, and instruments. The “high bay” lab is intended to support those functions for components with heights up to ~8 m (~25 ft.)

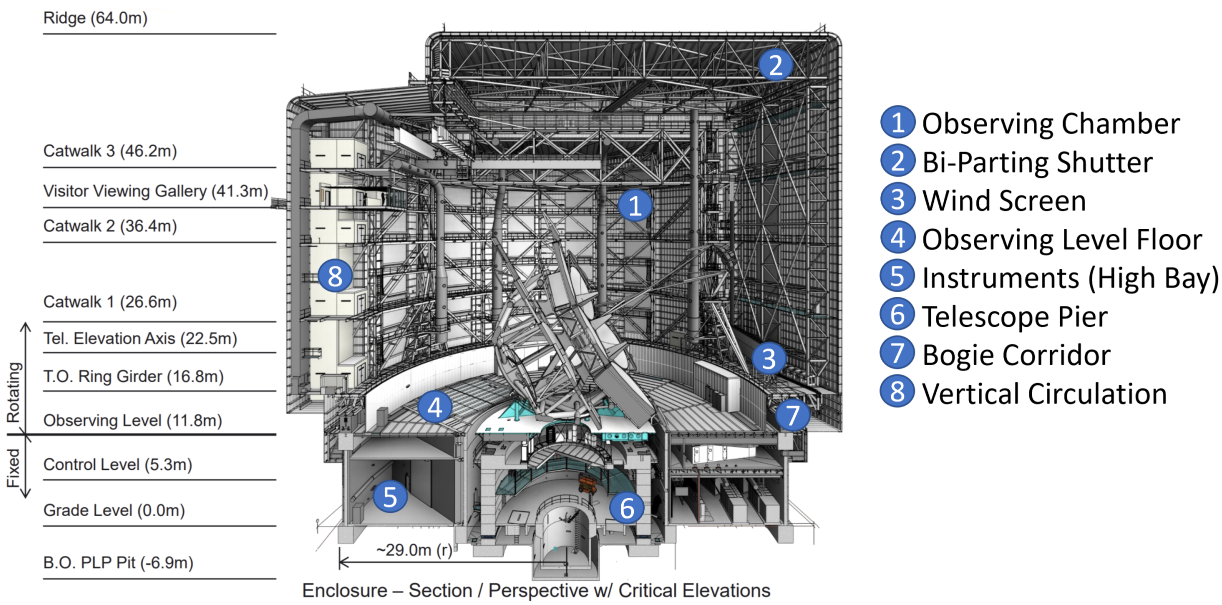

Figure 3-9: Components and Heights of the Enclosure

REQ-L3-OAD-34290: Grade Level - Low Bay Lab

The lower enclosure grade level shall provide a “low bay” lab space.

Rationale: A primary function of the enclosure is to provide working areas to support assembly, integration, test, and operation of the observatory, including subsystems for the telescope, optics, and instruments. The “low bay” lab is intended to support those functions for components with heights up to ~3.5 m (~12 ft.)

REQ-L3-OAD-69449: Grade Level - Low Bay Lab - Clean Room

The Science Instruments shall provide a clean room in the Low Bay Lab.

Rationale: A clean room will be needed for servicing certain parts of instruments, such as optics.

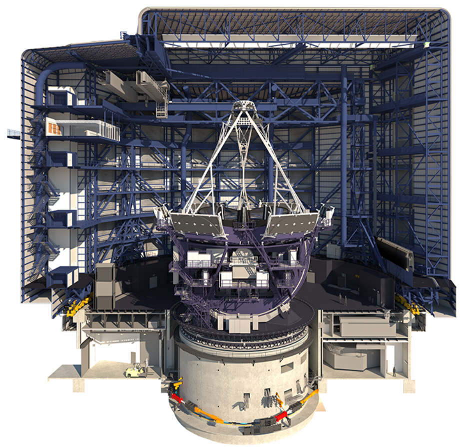

Figure 3-10: Cross Section of the Enclosure

REQ-L3-OAD-69451: Grade Level - M1 Transfer Bay

The lower enclosure grade level shall provide a bay below the Observing Floor Hatch large enough to fit an M1 cell.

Rationale: Recoating procedure will require moving a cell from its position on the telescope to a transporter at grade level, via the Observing Floor Hatch.

REQ-L3-OAD-34300: Grade Level - Shipping and Receiving Bay

The lower enclosure grade level shall provide a shipping and receiving bay.

Rationale: The lower enclosure will be a focal point for the arrival and departure of telescope, optics, and instrument subsystems throughout the lifetime of the observatory. Experience at existing observatories indicates the necessity of having a dedicated space for shipping and receiving functions.

REQ-L3-OAD-34309: Grade Level - Storage Bay

The lower enclosure grade level shall provide space for a storage bay.

Rationale: A primary function of the enclosure is to provide working areas to support safe and efficient operation of the observatory. The storage bay is intended to provide safe local storage of large moveable components of the observatory.

REQ-L3-OAD-69447: Grade Level - Utility Shaft

The lower enclosure shall provide space for a utility shaft.

Rationale: Access to utilities will be needed for maintenance.

REQ-L3-OAD-69455: Grade Level - Utility Distribution Bay

The lower enclosure shall provide space for utility distribution equipment.

Rationale: Utilities will come into the Enclosure and require distribution to various spaces within the building.

REQ-L3-OAD-34318: Control Level - Control Room

The lower enclosure control level shall include a science operations control room.

Rationale: To support science users throughout the lifecycle of the observatory, including final assembly, integration, test, commissioning, and operations.

REQ-L3-OAD-34321: Control Level - Control Room Area

The lower enclosure science operations control room.

Rationale: The observatory lifecycle will include multiple campaigns associated with the installation and commissioning of new instruments and adaptive optics systems. These campaigns may include 25-30 engineers and scientists working simultaneously on the telescope, control software, AO systems, laser guide-star systems, and instruments.

REQ-L3-OAD-34324: Control Level - Operations Room

The lower enclosure control level shall include an operations room.

Rationale: To support daytime users throughout the lifecycle of the observatory, including final assembly, integration, test, commissioning, and operations.

REQ-L3-OAD-34327: Control Level - Operations Room Area

The lower enclosure operations room.

Rationale: The normal daytime operations staff who repair and maintain the telescope, enclosure, optics, instruments, etc. will need a meeting area for planning daily operations activities.

REQ-L3-OAD-69457: Control Level - Computer Room

The lower enclosure control level shall include a room dedicated to computer and network equipment.

Rationale: Computer equipment should be located close to operations staff to allow troubleshooting. Low latency computers, such as used for adaptive optics, need to be close to the mechanisms they control to provide proper control bandwidth.

3.2.3.3 Telescope Pier

REQ-L3-OAD-34331: Telescope Pier

The enclosure shall provide the telescope pier.

Rationale: The telescope pier is the structure that connects the moving portions of the telescope to site bedrock. The telescope pier and the lower enclosure foundations are co-located, and both constructed from concrete. A logical construction sequence dictates that pier and lower enclosure construction essentially inseparable, and hence are both components of the lower enclosure.

REQ-L3-OAD-34334: Telescope Pier Foundation

The enclosure shall provide the concrete foundation for connecting the telescope pier to site bedrock.

Rationale: The telescope pier is included in the enclosure scope due to similarity of construction methods and its location within the enclosure foundations.

REQ-L3-OAD-34343: Telescope Pier - Pier Ventilation System

The enclosure shall provide a means for forced-air ventilation of the volume surrounding the telescope pier.

Rationale: The telescope pier (and local telescope subsystems) have the potential to release heat into the observing chamber, thus disturbing its temperature environment. The subsystem that protects the observing chamber from pier volume heat release is called the pier ventilation system.

REQ-L3-OAD-34346: Telescope Pier - Pier Lift

The enclosure shall provide the means for transferring Direct Gregorian (DG) instruments from grade level in the lower enclosure, to the Gregorian Instrument Rotator (GIR).

Rationale: The telescope design requires insertion of DG instruments into the GIR via a vertical lift from grade to the bottom of the GIR. The pier subsystem that provides this function is called the pier lift platform (PLP).

REQ-L3-OAD-69461: Telescope Pier - Pier Pit

The enclosure shall provide space beneath the Pier Lift to allow access to the Pier Lift for maintenance.

Rationale: Access must be allowed to maintain the lift.

REQ-L3-OAD-69463: Telescope Pier - Pier Chamber

The enclosure shall provide space within the pier to allow transfer of instruments and other large equipment onto the pier lift at grade.

Rationale: Movement of instruments and other equipment from the lower enclosure labs, or from outside the enclosure, to the Observing Floor may use the Pier Lift, and space must be available to accommodate their movement.

REQ-L3-OAD-69465: Telescope Pier - Inner Azimuth Track Access Corridor

The enclosure shall provide space within the pier to allow access to the inner part of the azimuth track.

Rationale: Required to maintain the azimuth track.

REQ-L3-OAD-69467: Telescope Pier - Outer Azimuth Track Access Corridor

The enclosure shall provide space within the pier to allow access to the outer part of the azimuth track.

Rationale: Required to maintain the azimuth track.

REQ-L3-OAD-69469: Telescope Pier - Mount Utility Interface Access Corridor

The enclosure shall provide space within the pier to allow access to the Mount utility interfaces.

Rationale: Required to maintain the Mount utilities at the utility interface.

REQ-L3-OAD-37193: Summit Utility Building

The Enclosure shall provide a utility building at the summit site to house electrical and mechanical equipment needed for operation of the Enclosure, Mount, and Instruments.

Rationale: The enclosed areas are required to manage the heat and vibrations generated by telescope support equipment and minimize any detrimental effects on the seeing performance of the telescope.
Notes: The telescope support equipment may include, but is not limited to, air compressors, chillers, pumps, ventilation fans, and electrical distribution gear.

REQ-L3-OAD-69473: Summit Utility Building Utility Yard

The Enclosure shall provide space next to the summit utility building for an electrical and equipment yard.

Rationale: Outdoor space for electrical equipment that does not need to be housed in a building.

REQ-L3-OAD-69475: Summit Utility Tunnel

The Enclosure shall provide a covered tunnel to run utilities between the Summit Utility Building and the Enclosure.

Rationale: To provide a protected path for utilities between the building.

3.2.3.4 Utilities

REQ-L3-OAD-37942: Liquid Nitrogen (LN2)

Enclosure shall provide Liquid Nitrogen (LN2) at 77 K ± 0.5 K TBC to support instruments and coating operations.

Rationale: Some instruments and the coating facility require LN2 for operation.

REQ-L3-OAD-38215: Clean, Dry Compressed Air

Enclosure shall provide a source of clean, dry compressed air to support the operation of the telescope and general services for each subsystem.

Rationale: Clean, dry compressed air is necessary for the operation of critical systems, such as the primary mirror supports. Clean, dry compressed air is filtered to ISO quality class 1.3.1 or better. See Utility Budget GMT-DOC-00366 for further details.

REQ-L3-OAD-38238: CO_2

Enclosure shall provide a reserve of 2700 kg of liquid CO_2 to service mirror cleaning

Rationale: 2700 kg of liquid CO_2 estimates the needs for one month of mirror cleaning. See Operational Concepts for In Situ Snow Cleaning GMT-DOC-01444 for more details.

3.2.4 Telescope

3.2.4.1 Telescope Dimensions

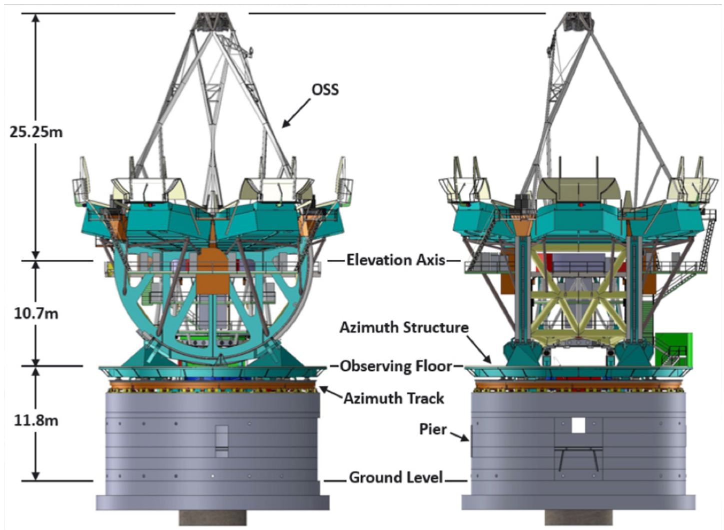

Figure 3-11: Telescope Dimensions

REQ-L3-OAD-34352: Telescope Coordinate System Definition

The telescope coordinate systems and vertical datum shall be as defined in GMT-REF-00189.

Rationale: Coordinate system identification, definition, assignment to subsystems, and transformational relationships are a key component of hardware and software interfaces. Providing a single reference document ensures consistency of the following coordinate systems: Optical Support Structure (OSS), Azimuth Structure, Telescope Pier/Enclosure Base, Enclosure, Gregorian Instrument Rotator, Instrument Ports, Primary Mirror, Secondary Mirror, and Tertiary Mirror.

REQ-L3-OAD-34356: Telescope Elevation Axis Location

The GMT Mount shall have an elevation axis nominally 22.500 m above Grade Level.

Rationale: The elevation axis of the telescope must be high enough so that the mirrors remain adequately off the Enclosure floor at the highest zenith angles.

REQ-L3-OAD-34358: Telescope Azimuth Floor Location

The GMT Mount shall have an Azimuth Floor (including insulation) nominally 10.700 m below the elevation axis.

Rationale: The azimuth floor must be far enough away from the elevation axis so that the mirrors are adequately far away from the azimuth floor at high elevation angles.

REQ-L3-OAD-34360: Telescope Azimuth Track Location

The GMT Mount shall have an Azimuth Track nominally 12.285 m below the elevation axis.

REQ-L3-OAD-34362: Telescope Gregorian Instrument Rotator Location

The top of the GIR of the GMT Mount shall be nominally 1.000 m below the elevation axis.

Rationale: Follows from the Gregorian optical design of the telescope and the architectural choice to have two suites of instruments in the rotator (GIR) – Direct Gregorian and Folded Gregorian located above the GIR top plate.

REQ-L3-OAD-69484: Telescope Instrument Platform

The Mount shall provide an Instrument Platform to allow access to instruments and other equipment.

Rationale: The instrument platform is required to access science instrument and other equipment located on the GIR top plate.

REQ-L3-OAD-34364: Telescope Instrument Platform Location

The top of the IP of the GMT Mount shall be nominally 1.000 m below the elevation axis.

Rationale: Follows from the Gregorian optical design of the telescope and the architectural choice to have two suites of instruments in the rotator (GIR) – Direct Gregorian and Folded Gregorian located above the GIR top plate.

REQ-L3-OAD-34366: Telescope Azimuth Track Diameter

The GMT Mount shall have an Azimuth Track with a nominal diameter of 19.000 m.

Rationale: Design constraint to enable interface development between mount and enclosure.

REQ-L3-OAD-34368: Telescope GIR Diameter

The GIR shall have a nominal diameter of 9.380 m.

Rationale: The number and types of DG instruments required of satisfy the GMT Science Cases, and the field of view of the telescope, implies a minimum GIR size. A minimum GIR size, once access considerations are added, is desired for ease of design that maintains its static and dynamic structural integrity.

3.2.4.2 Mount Payload Support

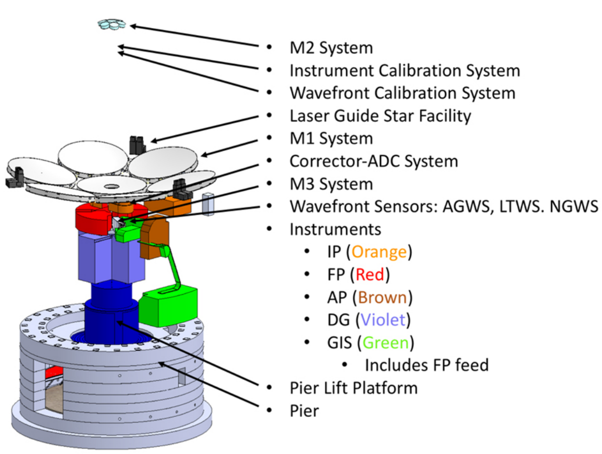

Figure 3-12: Mount Payloads (Mount Hidden, EMF and TMS Payloads not shown).

Mount Subsystems Payloads
The GMT Mount shall support and point the payloads listed in Table 3-4.

Table 3-4: Mount Payloads

Requirement ID	Mount Subsystem	Payload	Number	Notes
REQ-L3-OAD-34380	OSS	M1 System	1	
REQ-L3-OAD-34384	OSS	M2 System	1	2 payloads, one installed at a time
REQ-L3-OAD-34389	GIR	M3 System	1	
REQ-L3-OAD-34393	OSS	C-ADC System	2	
REQ-L3-OAD-34397	GIR	DG Instrument	3	All installed, one active at a time
REQ-L3-OAD-34402	GIR	FP Instrument	3	
REQ-L3-OAD-34406	OSS	AP Instrument	2	
REQ-L3-OAD-34410	OSS, GIR, Az. Structure	GIS Instrument	1	
REQ-L3-OAD-34414	GIR	AGWS	1	
REQ-L3-OAD-34418	OSS	LGS	1	
REQ-L3-OAD-34422	OSS	WCCS	1	2 payloads, one installed at a time
REQ-L3-OAD-34427	OSS	ICS	1	
REQ-L3-OAD-34431	OSS	TMS	1	

Notes: All payloads must be supported simultaneously, with the following exceptions:

- The M2 System consists of two independent subsystems (FSMS and ASMS), one of which must be supported at a time
- Three DG instruments must be supported, but only one in the active position on the Reference Optical Axis.
- The WCCS consists of two independent subsystems (Prime Focus Retro-Reflector and LTAO Calibration Source), one of which must be supported at a time.

Rationale: The subsystems identified here must be co-pointed to the astronomical target to enable scientific observations.

REQ-L3-OAD-34438: Telescope Utilities

The GMT Mount shall distribute utilities to each of the payloads.

Rationale: This requirement defines the responsibility of the Mount distribution of utilities. Mount Utility distribution begins at the interface with the Enclosure (called the Mount Utility Interface Access Corridor) and ends at the interface with Mount Payloads.

3.2.4.2.1 Top End and M2 System

The GMT will have two independent secondary mirror (M2) assemblies: the Adaptive Secondary Mirror (ASM) and Fast-steering Secondary Mirror (FSM). Both consist of seven 1.05 meter segments conjugated to the primary mirror segments as described above. The segments mount below the telescope top end frame on actuators (M2 positioner) that provide 6 degrees of motion control for segment alignment in the telescope.

The M2 System Top End is a removable structural member of the telescope truss system that fastens to the Upper Truss of the telescope.

3.2.4.2.1.1 Adaptive Secondary Mirror Subsystem (ASMS)

The Adaptive Secondary Mirror Subsystem is the adaptive secondary optical element in the GMT adaptive optics (AO) system, providing AO correction to every AO capable instrument on the telescope. The mirror consists of seven 1.05m segments in their cells attached to the top frame with positioners that provide six degree of motion for alignment in the telescope optical system. Each ASM segment has 672 voice coil actuators, lightweight Zerodur reference body, 2mm Zerodur shell which acts as the optical surface of the mirror, and cold plate which serves 2 functions, cooling plant for the ASM segment and mounting location of the reference body, voice coils and optical shells. With the AO system, it will be possible to achieve diffraction limited performance. This will provide about 30X higher resolution. It will also support the natural seeing observing by passively maintaining a static figure (with or without tip-tilt stabilization).

3.2.4.2.1.2 Fast-Steering Mirror Subsystem (FSMS)

The Fast-steering Secondary Mirror Subsystem (FSMS) is the commissioning secondary mirror for the GMT and the backup when the ASM is off the telescope for service. The mirror consists of seven 1.05 meter segments in their cells attached to the M2 positioner that provides six degree of motion for alignment in the telescope optical system. The purpose of the FSMS is to position the secondary mirrors in such a way that light from the primary mirrors of the telescope is brought to a focus at the telescope focal plane and to provide seeing limited optical performance using a fast-steering mechanism in each Fast-steering Mirror Segment (FSM). Each FSM segment contains a tip-tilt capability for fine co-alignment of the telescope subapertures and to attenuate telescope wind shake and mount control jitter, thus optimizing the seeing limited performance of the telescope.

REQ-L3-OAD-34450: ASMS and FSMS Interchangeability

The ASMS and the FSMS shall be interchangeable with the natural disconnect at the Top End-to-Truss interface.

Rationale: An interchangeable secondary mirror system allows us to minimize the telescope downtime (non-observation time) while one system (FSMS or ASMS) is being serviced.

Figure 3-13: M2 Top End Exploded View

The ASMS and FSMS both include an M2 Positioner assembly that provides positioning control of both the 7-segment array and differential positioning of the individual segments.

REQ-L3-OAD-34461: M2 Positioner - Coarse Positioning

The M2 Positioner shall compensate the large, common motion of the M2 segments.

Rationale: Large motion corrections of the ASMS and FSMS 7-segment arrays are required to compensate for gravitational and thermal flexure of the Mount.

REQ-L3-OAD-34464: M2 Positioner - Fine Positioning

The M2 Positioner shall compensate for the smaller, differential motions of the M2 segments.

Rationale: Small differential motions of the 7 ASMS and FSMS segments are required to compensate for flexure of the Top End and of the segments themselves.

3.2.4.2.2 M1 System

The Primary Mirror (M1) System must support the orientation, weight, and desired temperature of each of the seven borosilicate glass mirror segments. The components of the M1 System are shown in Figure 3-14.

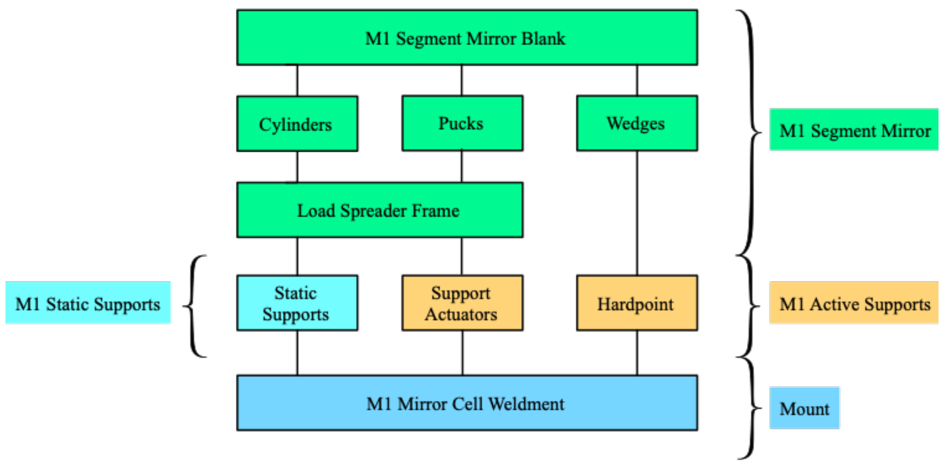

Figure 3-14: M1 Segment Overview

3.2.4.2.2.1 Weldment

Each M1 system segment has a weldment that is the responsibility of the mount. The weldment is removable from the telescope to enable mirror recoating. The support and positioning systems as well as the thermal system, are part of the M1 System, and reside inside the weldment.
The weldment is comprised of a bottom plate and a top plate in a 8.6-meter hexagonal shape for the off axis segment and in an 8.6-meter diameter circular shape for the center segment. The weldment has a height of 3.2 m. The off axis segment mirror cell is show in Figure 3-15. Figure 3-16 shows the actuators attached to the top plate.

REQ-L3-OAD-34472: M1 Interchangeability

The off axis mirror cells shall be interchangeable.

Rationale: Considering the length of time needed for recoating each off axis segment and the periodicity of the recoating, all the off axis cells and the spare cell should be able to be placed at any off axis location in the CCF.

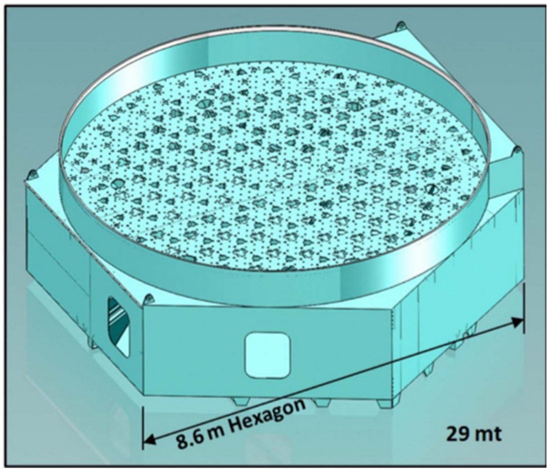

Figure 3-15: Weldment of the Off-Axis Cell

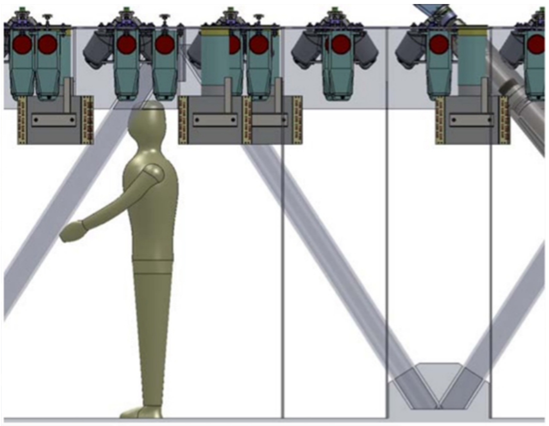

Figure 3-16: View of the Actuators Attached to the Top Plate

REQ-L3-OAD-34477: M1 Off-Axis Cell Mass

Off axis M1 Cell mass shall be no greater than 60,000 kg.

Rationale: The mass value includes the weldment and all M1 System components of the cell.

REQ-L3-OAD-34480: M1 On-Axis Cell Mass

On axis M1 Cell mass should be no greater than 60,000 kg.

Rationale: The mass value includes the weldment and all M1 System components of the cell.

3.2.4.2.2.2 Static supports

Static supports (shown in Figure 3-17) are passive spring isolators that carry the weight of the mirrors when the M1 System is not operational. The weight of the mirror is distributed among hundreds of static

supports to keep the stresses in the mirror below the stress limits (100 psi long term and 150 psi for less than 5 minutes). Static Supports interface with the top plate of the mirror cell weldment, and the mirror load spreaders. They also limit the forces on the segments and their motions to safe values during handling and seismic events with the cell.
Several design considerations for the static support system include:

a) Preventing "print through" of cell deflections during handling and assembly operations.
b) No forces may be applied to the mirror by the static supports during operation.
c) Mirror displacements must be limited to acceptable levels by the static supports always.

REQ-L3-OAD-34489: M1 System Static Supports

Each segment shall have static supports to carry the weight of the mirrors when active supports are not engaged.

Rationale: A method of supporting the mirror within the stress safety limits must be in place when the cell support system is shut down. See Figure 3-18 as an example distribution of on-axis and off-axis static supports.

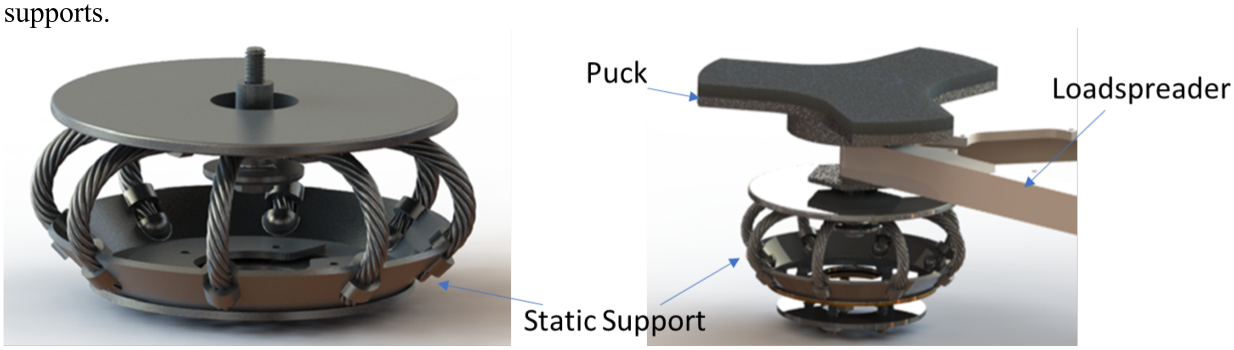

Figure 3-17: Static Support

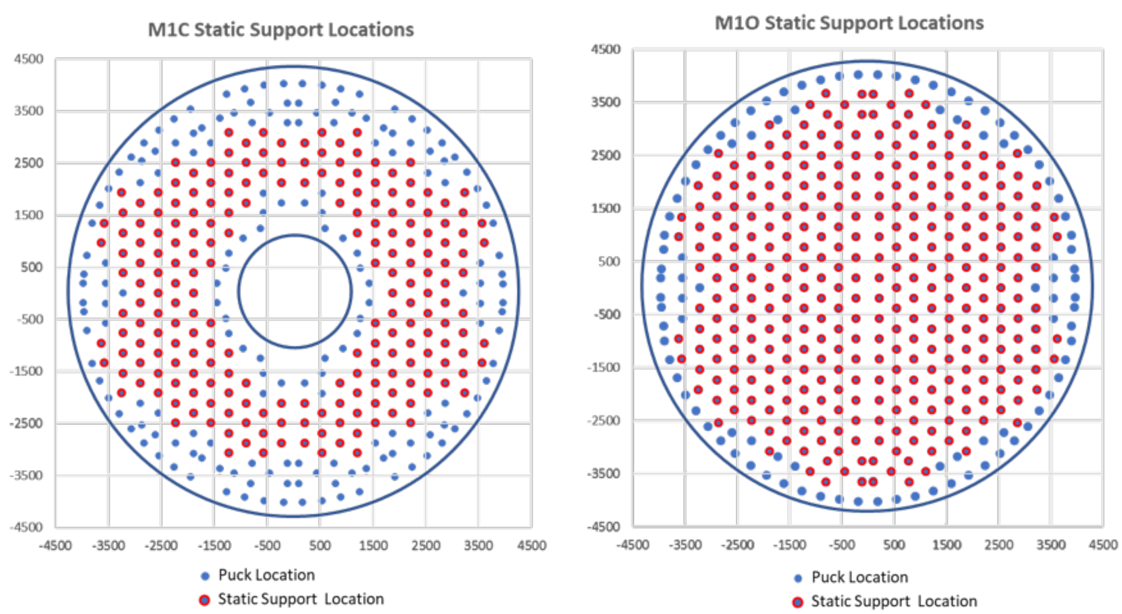

Figure 3-18: Example Distribution of Static Supports (in red) on M1O and M1C Cell

3.2.4.2.2.3 Support Actuators

Support actuators are pneumatic force actuators attached at the back of the mirrors. They apply a controlled force to the mirror back surface to support its weight against gravity as well as bend it to correct for surface figure errors as commanded by the Active Optics (AcO) loop. The actuators come in two forms: single-axis and triple-axis actuators. Single-axis actuators can apply force only in the direction normal to the mirror back surface. Triple-axis actuators can apply force in all 3 directions, that is normal to the back surface and in plane to the back surface. Figure 3-19 shows examples of Single-Axis and Triple Axis Actuators. Actuators are mounted on the top plate of the mirror cell and attach to load-spreaders that are permanently bonded to the back surface of the mirror.

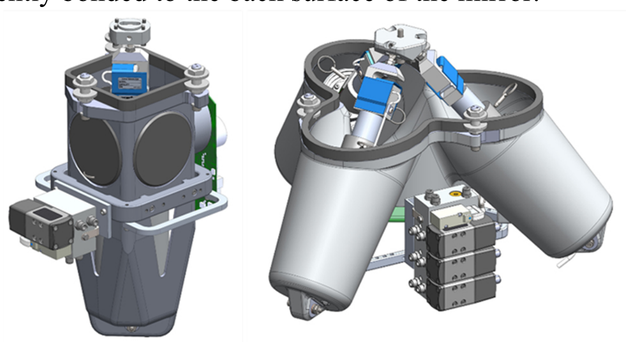

Figure 3-19: Example of Single-Axis and Triple Axis Actuators

Support Actuators
The M1 Cells shall contain a quantity of support actuators listed in Table 3-5.

Table 3-5: Actuator and Cylinder Count

Requirement ID	Cell	Single-Axis Actuators	Triple-Axis Actuators	Airs Cylinders
REQ-L3-OAD-34508	Off-Axis Cell	80	90	350
REQ-L3-OAD-34513	On-Axis Cell	90	72	306

Rationale: Requirement established to meet image quality constraints associated with bending modes.

3.2.4.2.2.4 Hardpoints

The M1 hardpoints are part of a 6-DoF rigid body positioning system that is used for controlling M1 optical alignment between mirror segments. They are mounted to stiff points in the bottom of the cell weldment and are attached to interface plates (wedges) that are bonded to the back surface of the mirrors (see Figure 3-20).
There are six hardpoints to every mirror cell (M1O and M1C) to define the mirror in six degrees of freedom (hexapod design). The mirror can be positioned by varying the length of the hardpoints. The support forces applied by the active supports are controlled such that the forces experienced by the hardpoint are near zero. The lateral forces and moments at the mirror connection points are minimized by the design of the hardpoint. Ideally, during normal operations, there is no force on the mirror at the

hardpoint attachment locations. Since, the hardpoints are the only solid attachment between the mirror and the mirror cell, the possibility of unacceptable high forces at the hardpoint attachment points is possible during a seismic event or active support system malfunction. A breakaway mechanism is designed in series with the hardpoint to limit the axial forces being applied to the mirror.

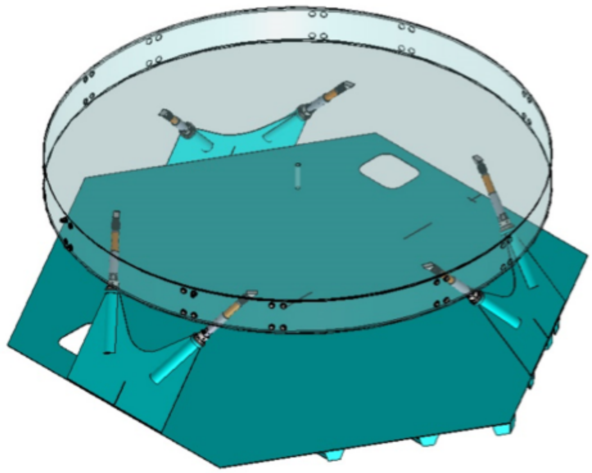

Figure 3-20: Hardpoint Assemblies in M1O Cell

The hardpoint position is controlled by the actuator assembly. The position of the hardpoint is sensed by the encoder assembly. The force on the hardpoint is measured by a loadcell mounted on the upper flexure. When excessive force is detected, the breakaway mechanism is activated which brings down the mirror onto the static support. The moment decoupling mechanism decouples the hardpoint from external moments and transmitting them to the mirror.

REQ-L3-OAD-34523: Hardpoint Quantity per Cell

Each M1 cell shall contain 6 hardpoints.

Rationale: Hardpoints constrain rigid body position of the glass in 6 DoF.

REQ-L3-OAD-34526: Hardpoint Stiffness

Each hardpoint shall have stiffness of at least 120 N/micron.

Rationale: Hardpoints must be resilient to high frequency wind loads and vibrations.

REQ-L3-OAD-66715: M1 Segment First Modal Frequency

The M1 Segment Mirror first modal frequency, when supported by the M1 Hardpoints, shall be greater than or equal to 10Hz.

Rationale: While the weight of the M1 Segment Mirror is nominally supported by the Support Actuator of the M1 Active Support system, the modal frequency of an M1 Segment Mirror is governed by the mass and stiffness of the Segment Mirror and the stiffness of the load path through the Hardpoint to "ground". Experience has shown that the M1 Segment Mirror modal frequency must be at least 5-10 times the closed-loop frequency of the M1 Active Support system, which is 1-2Hz in order to provide sufficient wind rejection to control segment tracking error and Hardpoint print-through in the presence of a wind disturbance.

3.2.4.2.2.5 M1 Thermal Control System

In order to maintain sufficient image quality, GMT requires actively controlling the thermal state of the mirror glass in each cell and minimizing disparity between it and ambient conditions. Achieving and maintaining thermal equilibrium, within a prescribed tolerance range, requires an integrated thermal monitoring and regulation system which references ambient conditions against the mirror thermal state.

The M1 Thermal Control System is designed to actively cool and heat the primary mirror segments when they are integrated with the telescope. The Thermal Control System reads the temperature of the ambient environment inside of the enclosure and then actively controls the temperature of the primary mirrors, through forced convection, to reduce the thermal gradient between the mirrors and its surrounding environment. It is a "semi-closed" loop system as air flow from the outside of the cell can mix with the circulating air inside of them.

The mechanical assembly for the M1thermal control is comprised of Fan Assemblies, Heat Exchangers, Nozzles, and Coolant plumbing for the M1 mirror segments. See Figure 3-21 for illustrations of the heat exchanger assembly and Figure 3-22 for concept illustration of coolant circulation loop.

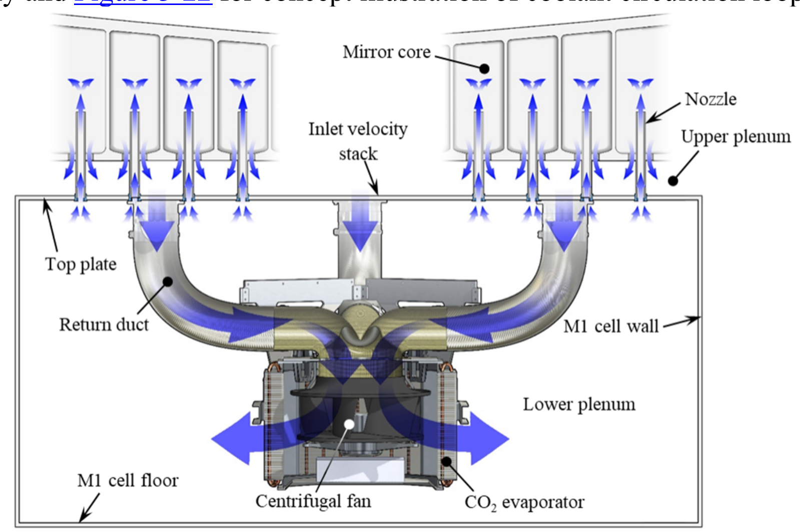

Figure 3-21: Conceptual M1 System Fan and Heat Exchanger Assembly for Thermal Control

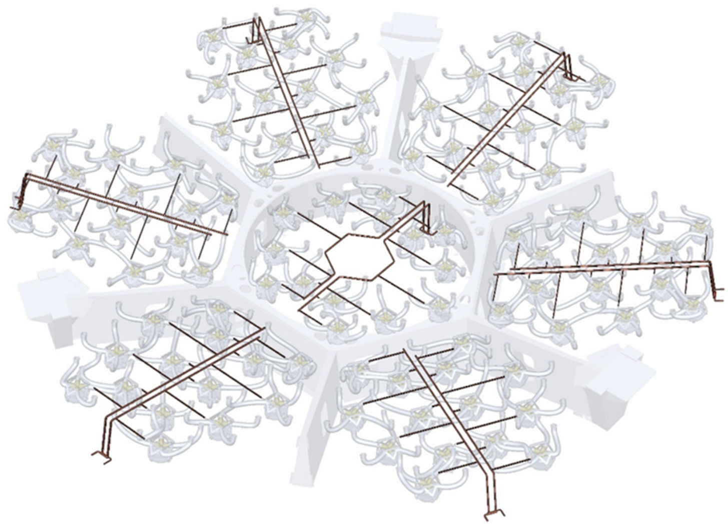

Figure 3-22: Distribution of AHUs and CO2 Supply and Return Line in the Seven M1 Mirror Cells

REQ-L3-OAD-34535: M1 Cell Quantity of Fan Assembly Units

Each M1 Cell shall have no greater than 50 Fan Assembly Units to control thermal load.

Rationale: The coolant and heat exchanger circuit drive the temperature of the mirror to the desired temperature.

3.2.4.3 Telescope Ranges

REQ-L3-OAD-34545: Azimuth Operational Range

The GMT mount shall have a minimum azimuth operational range of motion of no less than ±260 degrees, with respect to 120° true azimuth.

Rationale: This is the minimum range of motion required to track a single object from horizon to horizon. A larger range may be necessary to minimize the number of "unwrap" moves during the night and meet operational efficiency goals (see analysis in GMT-SE-DOC-00248).
Notes: This is measured with respect to 120° true azimuth. See GMT-DOC-00248 for analysis. This is the permitted range for science observing. Pointing and tracking specifications are valid in this range.

REQ-L3-OAD-34549: Elevation Operational Range

The GMT mount shall have an elevation operational range of motion of no less than 30.0–89.5 degrees.

Rationale: Direct flowdown from the operational range specified in the ORD.
Notes: This is measured from elevation = 0 (horizon pointing) to elevation = 90 (zenith). This is the permitted range for science observing. Pointing and tracking specifications are valid in this range. This does not include maintenance needs for Balancing.

REQ-L3-OAD-34553: Elevation Access to Zenith

The GMT Mount shall have stationary access to 90.0 degrees elevation.

Rationale: This is needed for calibrations, instrument changes, and service operations.

Notes: This is the elevation stow position of the telescope.

REQ-L3-OAD-34557: GIR Observing Range

The GMT Mount shall have a minimum GIR range of motion of no less than ±270 degrees [Goal: ±290 degrees] for observing.

Rationale: The requirement is the minimum range of motion required for an instrument with 180 deg symmetry to track a single object from minimum elevation in the East to minimum elevation in the West from any position on the GIR. The goal is the same for instruments without symmetry. A larger range may be necessary to minimize the number of "unwrap" moves during the night and meet operational efficiency goals (see analysis in GMT-SE-DOC-00248).
Notes: This is the permitted range for science observing. Pointing and tracking specifications are valid in this range. Observing efficiency is improved by increasing the range of motion.

3.2.5 Mass Allocation and Limits

The Mass Properties Control Plan (MPCP), GMT-DOC-01168, defines terminology and establishes uniform processes, procedures, and methods for the management, control, monitoring, determination, verification, and documentation of mass properties during the design and development phases of GMT. The Telescope Mass and Moment Budget, GMT-REF-00365, is the implemented GMT resource budget following the Mass Properties Control Plan.

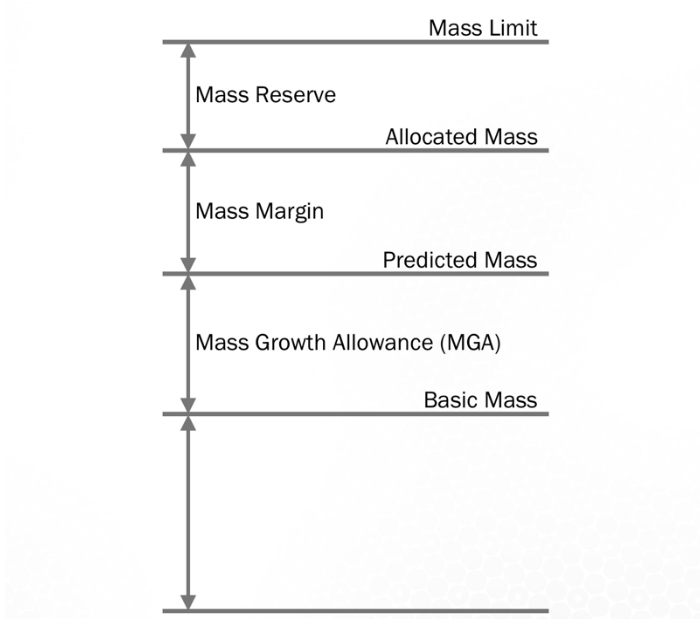

Figure 3-23: GMT Definitions of Mass Properties

The Mass Allocations and Mass Limits for the GMT Observatory are as follows. Note, mass reserve is held for unforeseen mass impacts between the Mass Allocations and Mass Limits below.

3.2.5.1 Mass Allocations

REQ-L3-OAD-34567: GMT Mount Mass Allocation

The Mount mass shall not exceed 1,892,000 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34570: GMT TMS Mass Allocation

The Telescope Metrology Subsystem mass shall not exceed 120 kg (TBR).

Rationale: The design plans for 3 laser trackers, meaning each is allocated 40 kg (mass limit of 42 kg). The mass allocation is based on a FARO Vantage laser tracker weighing 13.4 kg plus generous mass growth allowance and margin for yet to be designed components such as an interface adapter base plate for the laser tracker. The mass of collimators and retroflectors were deemed negligible at this point.

REQ-L3-OAD-34573: GMT AGWS Mass Allocation

The Acquisition, Guiding, and Wavefront Sensing Subsystem mass shall not exceed 3,270 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34576: GMT LGSS Mass Allocation

The Laser Guide Star Subsystem mass shall not exceed 9,200 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34579: GMT M1S Mass Allocation

The M1 System mass shall not exceed 170,611 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34582: GMT ASMS Mass Allocation

The Adaptive Secondary Mirror Subsystem mass shall not exceed 4,875 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34585: GMT FSMS Mass Allocation

The Fast Steering Mirror Subsystem mass shall not exceed 3,342 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34588: GMT M3 Mass Allocation

The M3 Subsystem mass shall not exceed 1,500 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34591: GMT C-ADC Mass Allocation

The C-ADC Subsystem mass shall not exceed 4,000 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34594: GMT FP Mass Allocation

The Folded Port Instruments mass shall not exceed 6,450 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure. Note that One of FP ports is assigned a lower allocation FP-C = 4050 kg

REQ-L3-OAD-34597: GMT DG Mass Allocation

The Direct Gregorian Instruments mass shall not exceed 11,250 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure. Includes IMF. One of DG ports is assigned a lower allocation of 8750 kg.

REQ-L3-OAD-34600: GMT GIS Mass Allocation

The Gravity Invariant Instruments mass shall not exceed 20,550 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure. Accounts for 5 instruments parts: GIS Pick-off, GIS Fixed IP, GIS Fiber Boom and Upper Link, GIS Thermal Enclosure and GIS Vacuum Vessel

REQ-L3-OAD-34603: GMT IP Mass Allocation

The IP Instruments mass shall not exceed 7,000 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

REQ-L3-OAD-34606: GMT AP Mass Allocation

The Auxiliary Port Instruments mass shall not exceed 3,000 kg.

Rationale: Mass allocation indicates the mass value that systems are designing to without regard to capabilities of the systems support structure.

3.2.5.2 Mass Limits

REQ-L3-OAD-34610: GMT Telescope Mass Limit

The GMT Telescope Pier shall support a Telescope mass of no less than 2,312,520 kg.

Rationale: The Telescope Mass limit is defined considering Mount mass limit and Payloads mass limits with a reserve for upgrades during the life of the observatory. Latest mass specifications and status are in GMT Mass Budget (GMT-REF-00365).
Notes: The Telescope mass of this requirement is the mass limit of the telescope.
Mass Limits
The GMT Mount shall support the masses listed in Table 3-6.

Table 3-6: Mount Supported Mass Limits (kg)

M1 System		
REQ-L3-OAD-34618	M1-Sn Segment (n = 1 thru 6)	17,010
REQ-L3-OAD-34621	M1-Sn Segment Support System (excluding Hardpoints)	8,060
REQ-L3-OAD-34624	M1-S7 Segment	15,750
REQ-L3-OAD-34627	M1-S7 Segment Support System (excluding Hardpoints)	7,372
REQ-L3-OAD-34630	Hardpoint	133
Corrector-ADC System		
REQ-L3-OAD-34634	C-ADC (Deployed)	4,269
M2 Systems		
REQ-L3-OAD-34638	M2 FSMS	3,510
REQ-L3-OAD-34641	M2 ASMS	5,118
M3 System		
REQ-L3-OAD-34645	M3 (Deployed)	1,575
Acquisition, Guiding, and Wavefront Sensing System		
REQ-L3-OAD-34649	AGWS Probe A	858
REQ-L3-OAD-34652	AGWS Probe B	858
REQ-L3-OAD-34655	AGWS Probe C	858
REQ-L3-OAD-34658	AGWS Probe D	858
Laser Guide Star System		
REQ-L3-OAD-34662	LPA pair 1	3,150
REQ-L3-OAD-34665	LPA pair 2	3,150
REQ-L3-OAD-34668	LPA pair 3	3,150
REQ-L3-OAD-34671	Laser Guidestar Acquisition Subsystem	210
Facility Calibration System		
REQ-L3-OAD-34675	Instrument Calibration Subsystem (Deployed)	42
REQ-L3-OAD-34678	Wavefront Control Calibration Subsystem (Deployed)	42
REQ-L3-OAD-103445	Telescope Metrology System (TMS)	126 (TBR)
Folded Port Instruments		
REQ-L3-OAD-34682	FP Port B Instrument	6,773
REQ-L3-OAD-34685	FP Port C Instrument	4,253
REQ-L3-OAD-34688	FP Port D Instrument	6,773
Direct Gregorian Instruments		
[1]REQ-L3-OAD-34692	DG Port A (Stowed)	11,813
[1]REQ-L3-OAD-34695	DG Port B (Stowed)	9,188
[1]REQ-L3-OAD-34701	DG Port D (Stowed)	9,188
Auxiliary Port Instruments		
REQ-L3-OAD-34705	AP Instruments "+X" (Gravity Invariant)	3,150
REQ-L3-OAD-34708	AP Instruments "-X" (Gravity	3,150

	Invariant)	
IP Instrument		
REQ-L3-OAD-34712	IP Instrument	7,350
Gravity Invariant Station Instrument		
REQ-L3-OAD-34716	GIS G-CLEF Pick-Off (Stowed)	998
REQ-L3-OAD-34719	GIS G-CLEF IP	998
REQ-L3-OAD-103446	GIS G-CLEF Fiber Boom and Upper Link	263
REQ-L3-OAD-34722	GIS G-CLEF Thermal Enclosure, Fiber Lower Link & Base	11,130
REQ-L3-OAD-34725	GIS G-CLEF Vacuum Vessel	8,190
Electronics Cabinets		
REQ-L3-OAD-34729	SEC	389
REQ-L3-OAD-34732	LEC	630

Rationale: Subsystems mass limit, mass allocation, margin, and reserve are tracked and maintained in the GMT Mass Budget (GMT-REF-00365).
[1]Includes IMF.

3.3 Wavefront Control Architecture

3.3.1 Wavefront Control Modes

The GMT incorporates both active optics (AcO, active control of telescope optics to compensate for slow alignment and figure errors) and adaptive optics (AO, correcting for high-frequency atmospheric and telescope phase errors). Many of the wavefront sensors and compensators for these two functions are shared in the GMT design. We therefore include both functions under the broader term Wavefront Control (WFC).
The first-generation Performance Modes (OPM) specified in the Observatory Requirements Document (ORD) define the minimum acceptable performance for combinations of observing wavelength, sky coverage, and image quality. To enable these 15 OPMs, the GMT shall provide the 4 wavefront control modes specified in Table 3-7 Each wavefront control mode requires simultaneously meeting sensing, actuation, and algorithmic requirements specified in the following sections.
Wavefront Control Modes
The GMT shall provide the wavefront control modes specified in Table 3-7.

Table 3-7: Wavefront Control Modes

Requirement ID	Wavefront Control Mode	Definition	Meets OPM
REQ-L3-OAD-34746	Natural Seeing	Image quality limited by the site atmosphere.	1, 3, 5, 10, 12, 14
REQ-L3-OAD-34750	Ground Layer Adaptive Optics	Improved image quality by correcting for low-altitude atmospheric turbulence.	2, 4, 6, 11, 13, 15
REQ-L3-OAD-34754	Natural Guide Star Adaptive Optics	Diffraction-limited, high contrast image quality using an on-axis natural guide star for wavefront sensing.	9
REQ-L3-OAD-34758	Laser Tomography Adaptive Optics	Diffraction-limited image quality with wide sky coverage using laser guide	7, 8

		stars and one natural guide star for wavefront sensing.	

Rationale: These four wavefront control modes are necessary to meet the image quality requirements specified in the 15 ORD Observatory Performance Modes.

3.3.2 Natural Seeing

3.3.2.1 Introduction

The Natural Seeing (NS) wavefront control mode seeks to reduce wavefront errors caused by observatory subsystems to a negligible level, delivering spatially uniform image quality limited only by the atmosphere above the site. Only displacements of the M1 and M2 segments in all 6 rigid body degrees of freedom, and low-order figure errors of the M1 segments, are actively controlled. This includes wind-induced segment vibrations and telescope tracking errors up to 10 Hz. No attempt is made to correct atmospheric wavefront error.

In the absence of feedback, all controlled optical degrees of freedom (Mount axes, M1 and M2 segment positions, M1 segment bending modes, M3 position) will follow model-based trajectory commands provided by the Observatory Control System (OCS) based on temperature distribution, elevation, and other environmental and configuration-based parameters. Wavefront sensors detect high-frequency disturbances and low-frequency trajectory errors, which are applied by the OCS as offsets to the model-based trajectories.

After a slew to a new target, measurements by the Telescope Metrology System (TMS) are first used to adjust the main optics to within the field of view of the Acquisition, Guiding, and Wavefront Sensing Subsystem (AGWS). One probe of the AGWS is initially configured to fulfill an acquisition imaging function that enables segment stacking (co-alignment of the 7 segment pairs) and any required mount pointing corrections.

The AGWS is then reconfigured to provide fast segment tip-tilt measurements and slower time-averaged wavefront measurements simultaneously at multiple locations in the periphery of the Direct Gregorian focal surface. The multiple wavefront measurements are necessary to differentiate between wavefront errors generated at M1 and M2, eliminating the degenerate modes of M2 that are common in current-generation telescopes with a single active optics wavefront sensor. The OCS converts the AGWS wavefront measurements to Mount, M1 Subsystem (M1S) and the Fast Steering Mirror Subsystem (FSM) or Adaptive Secondary Mirror Subsystem (ASMS) commands. The active science instrument participates in the wavefront control, using an On-Instrument Wavefront Sensor (OIWFS) to measure slow image motion and focus errors that may occur due to mechanical flexure between the instrument and the AGWS.

The NS wavefront control mode will be supported by both the FSMS and ASMS secondary mirrors. However, the ASMS segment surface figure requirement in the absence of feedback is less stringent than that of the FSMS, leading to slightly reduced image quality. However, the universal availability of the improved image quality GLAO wavefront control mode with the ASMS justifies this relaxed requirement.

The GMT segments will not be phased in the NS mode, as segment phase piston error results in negligible image quality degradation in the visible and near-infrared (<5 µm wavelength). This architectural choice results in a more readily achievable radius of curvature tolerance of the FSMS segments, and simpler FSMS actuation design as no piston of off-axis segments is required when controlling global image motion. Potential future wide-field mid-infrared instruments could instead use a phased GLAO observing mode.

In summary, the NS wavefront control mode shall control the optical degrees of freedom listed in Table 3-8 using model-based trajectories supplemented by measurements provided by the sensors listed in Table

3-9. A control block diagram in provided in Figure 3-24.

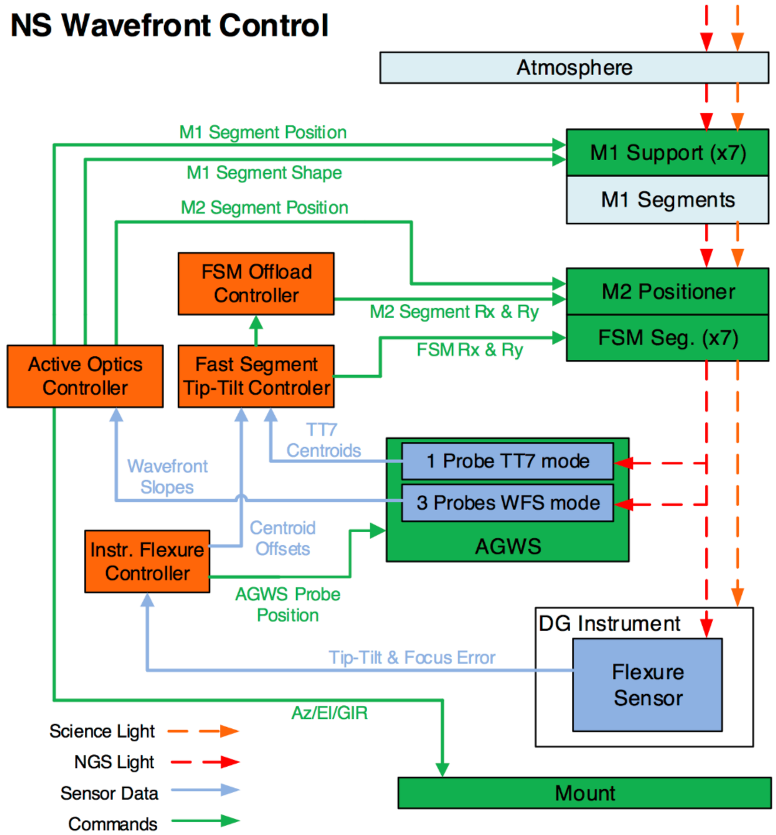

Figure 3-24: Natural Seeing Wavefront Control Block Diagram

Natural Seeing Controlled Optical Degrees of Freedom
The GMT in the Natural Seeing wavefront control mode shall control the optical degrees of freedom specified in Table 3-8.

Table 3-8: Natural Seeing Controlled Degrees of Freedom

Requirement ID	Subsystem	Degree of Freedom	# DOF
REQ-L3-OAD-34798	Mount	Azimuth, Elevation, and GIR Rotation	3
REQ-L3-OAD-34802	M1S	M1 segment rigid body position	7 × 6
REQ-L3-OAD-34806	M1S	M1 segment shape	7 × ≥ 27 bending modes
REQ-L3-OAD-34810	FSMS/ASMS	M2 segment rigid body position	7 × 6

Rationale: Active control of these degrees of freedom is required to compensate for gravity and thermal deflections and distortions, and achieve the image quality specified in OPM 1, 3, 5, 10, 12, and 14.
Notes: No wavefront sensor feedback to the M3S degrees of freedom is planned in the baseline Natural Seeing mode. Such control is not precluded, but pupil position sensing would have to be provided by the instrument.
Natural Seeing Wavefront Sensing and Metrology
The GMT in the Natural Seeing wavefront control mode shall utilize the wavefront and metrology sensors

specified in Table 3-9.

Table 3-9: Natural Seeing Wavefront Sensing and Metrology

Requirement ID	Subsystem	Measurement	Rate
REQ-L3-OAD-35127	TMS	M1 and M2 segment rigid body position with respect to OSS coordinates	≥ 0.067 Hz
REQ-L3-OAD-106982	AGWS	Acquisition imaging of ≥ 1 off-axis guide star	N/A
REQ-L3-OAD-35131	AGWS	Wavefront error at ≥3 locations in DG focal plane with at least 24×24 sampling of the pupil.	≥ 0.03 Hz
REQ-L3-OAD-35135	AGWS	Segment tip-tilt error at ≥1 field location	≥ 200 Hz
REQ-L3-OAD-35139	Instrument	Image motion and global focus error	≥ 0.03 Hz

Rationale: Active sensing of these degrees of freedom is required to measure gravity and thermal deflections and distortions, and correct wind-induced vibrations, to achieve the image quality specified in OPM 1, 3, 5, 10, 12, and 14.
Notes: Instruments that do not provide an OIWFS measuring image motion and focus error may only achieve the specified image quality over limited exposure times due to differential flexure between the AGWS and instrument.

3.3.2.2 Natural Seeing Control Algorithms

REQ-L3-OAD-34820: Active Optics Trajectories

The GMT shall control all optical degrees of freedom based on a model of the telescope gravity and thermal flexure, with offsets provided by the wavefront control loops when these are operating.

Rationale: Flexure rates for GMT will be up to 1.6 µm/s (M2 y-translation with respect to OSS), while wavefront sensor feedback for many degrees of freedom will only be available every 30 s. Since misalignment tolerances are on the order of 1 µm, continuous trajectories are necessary to maintain acceptable image quality between wavefront sensor measurements.
Notes: This requirement applies in all wavefront control modes.

REQ-L3-OAD-106469: TMS Optical Alignment

At the start of each night and after each slew, the GMT shall correct the positions of the main optics (M1, M2, M3) using measurements of their positions in the OSS coordinate system made by the TMS.

Rationale: Enables rapid target acquisition by ensuring that optics are within the capture range of the AGWS wavefront sensors.
Notes: Stray light generated by the TMS may interfere with some scientific observations. It is therefore expected to be used only during acquisition, with the science instrument is shuttered.
The TMS Coarse Optical Alignment step may become unnecessary in many observing conditions once open-loop pointing models are refined.
This requirement applies in all wavefront control modes.

REQ-L3-OAD-106470: Field Acquisition and Segment Stacking

After each slew, the GMT shall correct initial Mount pointing and segment co-alignment errors using images of one or more off-axis guide stars recorded by the AGWS as specified in GMT-REQ-04426 Section 6.1 (Acquisition).

Rationale: Images of one or more bright off-axis guide stars enable the telescope pointing direction to be unambiguously verified and both Mount and segment pointing error corrected.
Notes: A series of 7 or more short-exposure images will be acquired with known tip-tilt offsets on 6 of the FSM segments. These images are then used to derive average pointing error and the differential pointin error on each M1/M2 segment pair.
The Field Acquisition and Segment Stacking step may become unnecessary in many observing conditions once open-loop pointing models are refined.
This requirement applies in all wavefront control modes.

REQ-L3-OAD-34770: Natural Seeing Active Optics Control Loop

The NS Active Optics Control Loop, specified in GMT-REQ-04426 Section 6.3 (Active Optics Control), shall use the wavefront error measured by the AGWS at ≥3 locations in the Direct Gregorian focal surface to correct gravity and thermal flexure of the Mount and main optics.

Rationale: Wavefront measurements at 3 locations in the focal plane are necessary to unambiguously differentiate between aberrations generated at M1 and at M2, and ensure image quality in the presence of gravitational and thermal deflections.
Notes: Wavefront sensor reference slopes are determined using an on-board calibration source in each WFS, modified to account for the static aberrations inherent in the GMT optical design at the current AGWS probe position and GIR angle. The Active Optics reconstructor is calculated using a synthetic calibration approach based on knowledge of the guide star positions. A calibration matrix is computed by perturbing each controlled degree of freedom in a ray trace model of the telescope, and recording the predicted WFS slopes at the guide star locations. All M1 and M2 rigid body degrees of freedom except axial rotation of the on-axis segments are included, along with 27 bending modes of each M1 segment and angular errors of the telescope Mount axes. The reconstructor matrix is obtained by computing the pseudo-inverse of the calibration matrix using singular value decomposition, with additional regularization terms to control poorly-sensed modes and avoid range-of-motion limits. The uncontrolled modes are:
1. Rotation of M1 and M2 segments around the Reference Optical Axis. These motions have no optical effect.
2. Differential segment phase piston. The AGWS Shack-Hartmann sensors are blind to segment phase piston, and this mode does not contribute measurable image quality degradation in the NS mode. Penalizing this mode in the wavefront reconstruction maintains the piston errors to the ~15 µm RMS wavefront error provided by initial alignment with TMS.
3. Global image scale. These cannot be controlled due to excessive uncertainty in the AGWS probe position in the focal plane. There are 3 such modes; a radially symmetric scale change and two asymmetric distortion modes. They will be controlled only by M1 thermal control system limiting thermal gradients in the M1 segments. Differential image scale between segments is controlled.
The wavefront sensor reference slopes and reconstructor are updated at up to 1 Hz as the AGWS probe positions and GIR angle change.

REQ-L3-OAD-34778: Natural Seeing Fast Segment Tip-Tilt Control Loop

The NS Fast Segment Tip-Tilt Control Loop, specified in GMT-REQ-04426 Section 6.2 (Fast Segment Tip-Tilt Control), shall use the segment tip-tilt error measured by the AGWS at ≥1 location in the Direct

Gregorian focal surface to correct Mount tracking errors and wind-induced vibrations in the Mount and main optics.

Rationale: A fast control loop compensating wind-induced disturbances to the Mount, M1, and M2 is necessary to meet image quality requirements. These disturbances include both image motion (global tip-tilt error) and differential motion of the images formed by the 7 M1-M2 pairs (segment tip-tilt error), typically at <10 Hz frequency.
Notes: The Fast Segment Tip-Tilt control loop corrects both image motion produced by Mount pointing errors and structural flexure, and differential segment tip-tilt errors cause by vibrations of M1 and M2 segments. The initial correction for both is applied to the FSMS fast tip-tilt actuators or ASMS face sheet. However, the Active Optics control loop will detect any long-lived global tilt of M2 with respect to the reference optical axis due to the field-dependent astigmatism that it produces, and will command a Mount pointing offset to correct it.
In the reference architecture and image quality budget allocations, segment tip-tilt error is assumed to be measured by one off-axis AGWS probe.

REQ-L3-OAD-34785: Natural Seeing FSM Offload Control Loop

The NS FSM Offload Control Loop, specified in GMT-REQ-04426 Section 6.4 (M2 Offload Strategy), shall offload FSMS or ASMS fast R_X and R_Y rotational degrees of freedom to the FSMS or ASMS Positioner.

Rationale: The FSMS and ASMS in Natural Seeing mode provide high bandwidth Segment RX and RY control with a limited range of motion, while the segment positioners provide lower bandwidth control of all 6 rigid body degrees of freedom with a wide range of motion. Regular offloads from the high-bandwidth to low-bandwidth actuators maximize the available tip-tilt stroke.

REQ-L3-OAD-34781: Natural Seeing and GLAO Instrument Flexure Control Loop

The NS and GLAO Instrument Flexure Control Loop, specified in GMT-REQ-04426 Section 6.5 (Instrument Flexure Control), shall use image motion and focus error measured by the active science instrument On-Instrument Wavefront Sensor to compensate for flexure between the instrument and the AGWS.

Rationale: Differential structural flexure between the active science instrument focal plane and AGWS leads to slow image motion and focus errors, which would exceed image quality budget allocations if uncorrected.
Notes: This requirement applies in both the NS and GLAO wavefront control modes.
The pointing and focus error measured by the On-Instrument Wavefront Sensor will be used to offset the position and focus stages of all AGWS probes.
The Natural Seeing image quality budget assumes that image motion and focus error will be measured by one OIWFS at the edge of the scientific field of view. An average of measurements at several locations would reduce some error terms.
Instruments that do not provide an OIWFS measuring image motion and focus error may only achieve the specified Natural Seeing image quality over integrations periods up to 60 s.

3.3.2.3 Natural Seeing Controlled Degrees of Freedom

The Mount must point to and track astronomical objects while rejecting external torque disturbances that arise primarily from wind forces on the Mount and its payloads. The majority of the disturbance is at low frequencies (<10 Hz) and the resulting pointing errors will be corrected by the Fast Segment Tip-Tilt control loop. The maximum high-frequency residual pointing error is specified through an allocation in

the Natural Seeing image quality budget (REQ-L3-OAD-38686).
Low-frequency Mount pointing errors are corrected initially by the FSMS or ASMS, and subsequently converted to offsets to the Mount axis trajectories by the Active Optics control loop. The following requirements specify the transfer function response of the Mount axes for these trajectory corrections (typically provided every 30 s), as well as for pointing offsets during target acquisition (provided at up to 1 Hz).
These requirements apply in all wavefront control modes.

3.3.2.3.1 Mount System

The key architectural wavefront control requirements of the Mount, M1S and FSMS are provided here. Many are derived from allocations in the Natural Seeing Image Quality budget, but some flow from the capture ranges of sensors or the amplitude of expected disturbances. Note that this is not a complete set of requirements on these subsystems derived from the NSIQ budget allocations.

REQ-L3-OAD-34824: Mount Azimuth Transfer Function

The Mount shall provide Azimuth actuation with a transfer function response to commands within the limits specified in Figure 3-25. The frequency bandwidth (–3 dB) shall be larger than 2.4 Hz. The command response shall be below +6 dB below 2.4 Hz. The resonant peaks shall be less than –6 dB above 1.0 Hz. Stability phase margin shall be at least 45 degrees and the stability gain margin shall be at least 10 dB.

Rationale: Limits are based on the expected performance of the Mount reference design, and used in the GMT integrated model.
Notes: The illustrated example response is the 2016 Mount reference design.

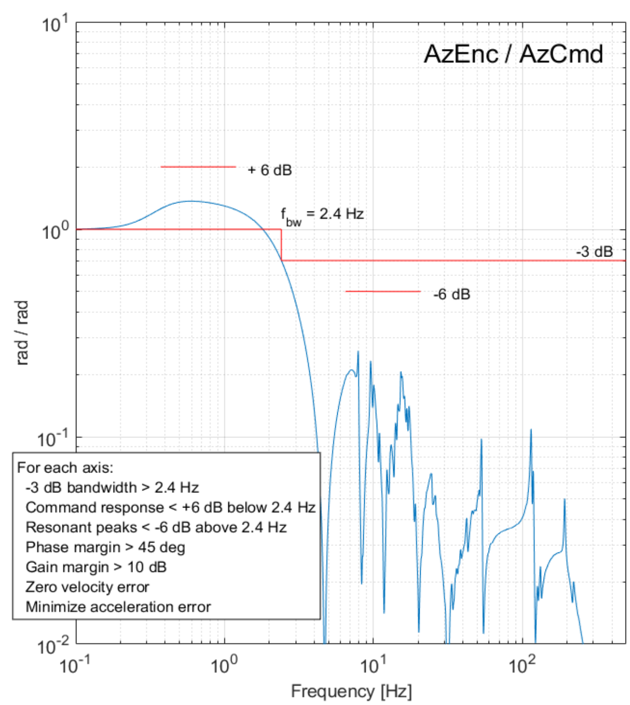

Figure 3-25: Mount Azimuth Axis Trajectory Correction Transfer Function Limits

REQ-L3-OAD-34829: Mount Elevation Transfer Function

The Mount shall provide Elevation actuation with a transfer function response to commands within the limits specified in Figure 3-26. The frequency bandwidth (-3 dB) shall be larger than 2.4 Hz. The command response shall be below +6 dB below 2.7 Hz. The resonant peaks shall be less that -6 dB above 2.7 Hz. The stability phase margin should be at least 45 degrees and the stability gain margin should be at least 10 dB.

Rationale: Limits are based on the expected performance of the Mount reference design, and used in the GMT integrated model.
Notes: The illustrated example response is the 2016 Mount reference design.

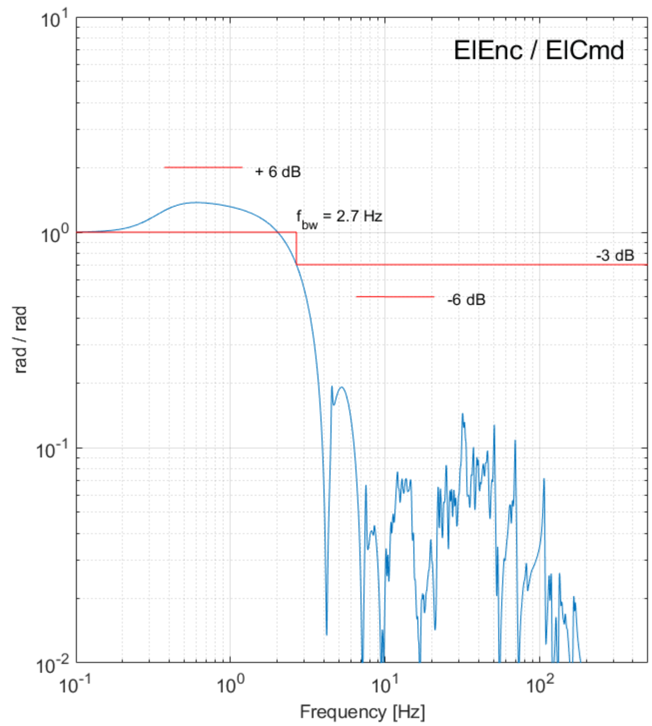

Figure 3-26: Mount Elevation Axis Trajectory Correction Transfer Function Limits

3.3.2.3.2 M1

The six rigid body degrees of freedom of each M1 segment must be controlled at low bandwidth to maintain the segments on the parent optical surface defined by the GIR rotation axis and reference focal plane location. This requires a segment positioning system with ≤0.5 µm of precision and ±~5 millimeters of useable stroke to compensate gravity and thermal flexure of the Mount and M1 Cell installation tolerances (ref. M1 Active Optics Range of Motion Budget). In addition to returning the M1 segments to their intended position on the parent optical surface, adjustments in the rigid body DOF will be used to minimize the forces required to correct figure errors caused by to gravitational or thermal flexure of the segments. This strategy of continuously updating the M1 segment rigid body DOF during operation differs from the control strategy used at the Large Binocular Telescope and the Magellan telescopes due to the need to co-align the 7 GMT segments.
The M1 figure actuators have broad influence functions due to the stiffness of the segments, and the force

which can be applied to any one actuator is limited by the allowable glass stress. The mirror shape is therefore controlled using the orthogonal basis set defined by the force-induced flexible modes (bending modes) of the segment. Control of 27 bending modes per segment is required to achieve the image quality requirements specified in the ORD.

The absolute accuracy requirements on the M1 segment positioning and figure control systems are driven by acquisition efficiency considerations. Although the baseline acquisition strategy uses closed-loop feedback from the TMS to align the main optics after slews, we nevertheless require that the M1 segment positioning system meet the same accuracy requirements as the TMS. This will enable rapid alignment without use of the TMS if accurate open-loop models of gravitational and thermal can eventually be developed. The requirements ensure that the images formed by the seven M1-M2 segment pairs will fall within the AGWS acquisition field of view. Similarly, the absolute accuracy requirement for M1 surface figure control matches the capture range of the AGWS wavefront sensors.

The finite precision of the M1 segment positioning system leads to small quasi-static alignment errors after each Active Optics control loop correction. Only the T_X, T_Y, T_Z, and R_Z degrees of freedom contribute significantly, since the Fast Segment Tip-Tilt control loop can compensate for M1 segment tip-tilt errors. Stringent precision requirements on the M1 segment R_X and R_Y degrees of freedom are however specified in the diffraction-limited NGAO and LTAO observing modes, to limit field-dependent segment phase piston error.

Similarly, the finite precision of the M1 support actuators limits the image quality that can be achieved by the Active Optics control loop. Requirements on the non-repeating errors at all spatial frequencies are given below.

These requirements apply in all wavefront control modes.

M1 Segment Position Accuracy

The M1 System shall provide actuation of segment position with the accuracy specified in Table 3-10.

Table 3-10: M1 Segment Position Accuracy Requirements

Requirement ID	DOF	1σ Accuracy
REQ-L3-OAD-34842	T_X	≤ 75 μm
REQ-L3-OAD-34845	T_Y	≤ 75 μm
REQ-L3-OAD-34848	T_Z	≤ 4.3 μm
REQ-L3-OAD-34851	R_X	≤ 1.8 μrad
REQ-L3-OAD-34854	R_Y	≤ 1.8 μrad
REQ-L3-OAD-34857	R_Z	≤ 190 μrad

Rationale: Given perfect knowledge of the Mount and M1 flexure, these requirements enable ≥ 99.9% probability of capture by the Fast Segment Tip-Tilt and Active Optics control loops with the capture ranges specified in Table 3-15.

Notes: These requirements specify the RMS position error of the M1 segment optical surface with respect to the Mount-M1S mechanical interface, anywhere within a segment's range of motion after calibration, in the M1 Front Surface coordinate system.

M1 Segment Position Repeatability

The M1 System shall provide actuation of segment position with the repeatbility specified in Table 3-11.

Table 3-11: M1 Segment Position Repeatability Requirements

Requirement ID	DOF	1σ Precision
REQ-L3-OAD-34870	T_X	≤ 0.5 μm
REQ-L3-OAD-34873	T_Y	≤ 0.5 μm
REQ-L3-OAD-34876	T_Z	≤ 0.5 μm
REQ-L3-OAD-34885	R_Z	≤ 0.2 μrad

Rationale: Position errors due to M1 segment position repeatability have been allocated PSSN(0.5 μm) ≤ 0.9995 in the NSIQ budget (REQ-L3-OAD-38648). This has been flowed down via Monte Carlo

simulations to the T_X, T_Y, T_Z, and R_Z repeatability errors listed here.
Notes:
These requirements specify the repeatability of small offsets of the M1 segments anywhere within a segment's range of motion, in the M1 Front Surface coordinate system.
The M1 segment position R_X and R_Y repeatability are driven by NGAO/LTAO mode requirements REQ-L3-OAD-34879 and REQ-L3-OAD-34882.

REQ-L3-OAD-34927: M1 Segment Position Transfer Function

The M1 System shall provide segment position actuation with a transfer function response to commands within the limits specified in Figure 3-27. For axis the frequency bandwidth (–3 dB) shall be larger than 1.0 Hz. The command response shall be below +6 dB below 1.0 Hz. The resonant peaks shall be less that –6 dB above 1.0 Hz.

Rationale: Limits are based on the expected performance of the M1S reference design, and used in the GMT integrated model.
Notes: Offsets to the M1 segment position trajectory will typically be provided every 30 s to average over the atmospheric optical turbulence. During target acquisition, they may be provided at up to 1 Hz.
The illustrated example responses are the 7 M1 segments on the 2016 Mount reference design.

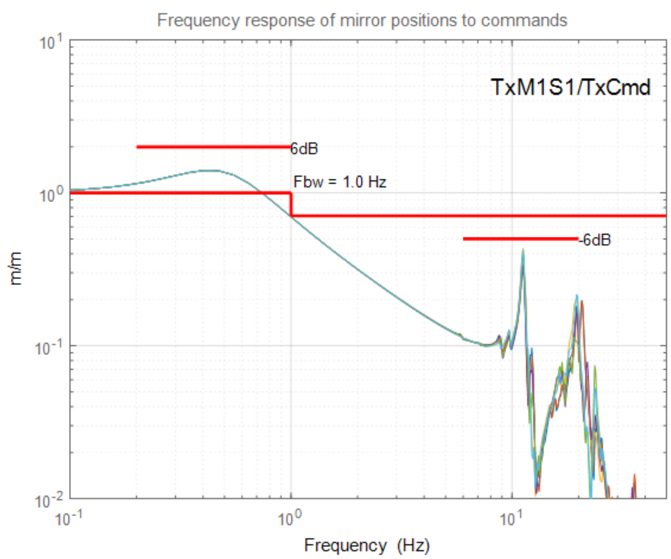

Figure 3-27: M1 Segment Position Transfer Function Limits

REQ-L3-OAD-34932: M1 Segment Shape Accuracy

The M1 System shall provide actuation of M1 segment shape with an accuracy resulting in a average surface gradient over any 0.53 × 0.53 m region of the segment no greater than 1.45 µrad (TBC).

Rationale: Equivalent to the allocation of 0.6 arcsec wavefront slope in the AGWS 48x48 WFS dynamic range budget.
Notes: This requirement specifies the maximum local surface slope error (relative to the optical prescription) of each M1 segment optical surface after calibration for gravity and thermal effects.

REQ-L3-OAD-34936: M1 Segment Shape Repeatability

The M1 System shall provide actuation of M1 segment shape with a repeatability of ≤ 22.5 nm RMS surface when controlling 27 bending modes per segment.

Rationale: The largest contributor to non-repeating shape actuation error is expected to be M1 support actuator force errors. These produce low-order surface figure errors, and analysis in GMT-DOC-03091 demonstrates that the image quality budget allocation of PSSN(0.5 µm) ≤ 0.9995 is equivalent to a surface figure error of 22.5 nm RMS.
Notes: This requirement specifies the maximum error on bending modes commanded by the active optics control loop.

REQ-L3-OAD-34940: M1 Segment Shape Transfer Function

The M1 System shall provide segment shape actuation with a transfer function response to commands within the limits specified in Figure 3-28. The frequency bandwidth (–3 dB) shall be larger than 1.0 Hz. The command response shall be below +6 dB below 1.0 Hz. The resonant peaks shall be less than –6 dB above 1.0 Hz.

Rationale: Limits are based on the expected performance of the M1S reference design, and used in the GMT integrated model.
Notes: Offsets to the M1 segment shape trajectory will typically be provided every 30 s to average over the atmospheric optical turbulence. During target acquisition, they may be provided at up to 1 Hz. The illustrated example responses are the 7 M1 segments on the 2016 Mount reference design.

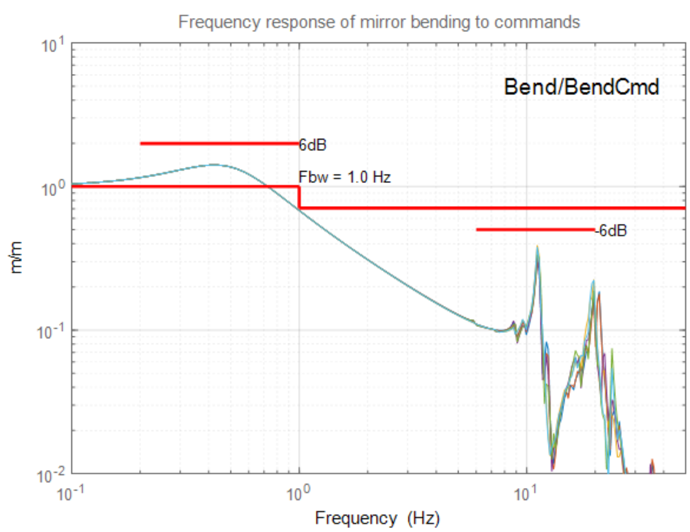

Figure 3-28: M1 Segment Shape Transfer Function Limits

3.3.2.3.3 M2

Both the FSMS and ASMS must support the Natural Seeing wavefront control mode, with identical functionality and minor differences in performance. Both subsystems provide similar large-stroke segment positioning systems, and a second actuation stage for fast segment tip-tilt control. When operating in the Natural Seeing mode, the ASMS will maintain the higher-order degrees of freedom of each face sheet fixed and act as a rigid mirror. However, no requirement is placed on the ASMS surface figure in this mode because matching the figure specifications of a stiff mirror would add significant cost and complexity with little benefit – with the ASMS installed, the GLAO mode is always available with better image quality.

As with M1, the six rigid body degrees of freedom of each FSMS or ASMS segment must be controlled at low bandwidth to maintain the segments on the parent optical surface defined by the GIR rotation axis and reference focal plane location. This requires a segment positioning system with ≤1.0 µm of precision and ±~11 millimeters of useable stroke to compensate gravity and thermal flexure of the Mount and M2, and manufacturing and installation tolerances (ref. M2 Active Optics Range of Motion Budget).

The absolute accuracy requirements on the M2 segment positioning system are driven by acquisition efficiency considerations. Although the baseline acquisition strategy uses closed-loop feedback from the TMS to align the main optics after slews, we nevertheless require that the M2 segment positioning system meet the same accuracy requirements as the TMS. This will enable rapid alignment without use of the TMS if accurate open-loop models of gravitational and thermal can eventually be developed. The requirements ensure that the images formed by the seven M1-M2 segment pairs will fall within the AGWS acquisition field of view.

The finite precision of the M2 segment positioning system leads to small quasi-static alignment errors in the T_X, T_Y, T_Z, and R_Z degrees of freedom after each Active Optics control loop correction. The high-bandwidth R_X and R_Y actuation stage corrects any positioning system errors in these degrees of freedom, but has its own stringent repeatability requirements derived from an allocation in the image quality budget.

The tip-tilt bandwidth requirement on the FSMS is a compromise between image quality in high-wind conditions and fabrication risk. The required -20 dB rejection at 1.0 Hz enables compensation of tracking and wind disturbances.

While the FSMS high-bandwidth tip-tilt actuation stage may also be capable of segment piston actuation, this mode cannot be driven at high frequency due to the momentum of the thick mirror substrate. The intention is therefore to actuate only segment tip-tilt when correcting global tip-tilt, leaving the segment phase piston error that this generates on the off-axis segments uncorrected. For consistency, the ASMS face sheet will similarly only be actuated in segment tip and tilt in the NS mode.

M2 Segment Position Accuracy

The FSMS and ASMS shall provide actuation of segment position with the accuracy specified in Table 3-12.

Table 3-12: M2 Segment Position Accuracy Requirements

Requirement ID	DOF	1σ Accuracy
REQ-L3-OAD-34953	T_X	≤ 75 µm
REQ-L3-OAD-34956	T_Y	≤ 75 µm
REQ-L3-OAD-34959	T_Z	≤ 4.3 µm
REQ-L3-OAD-34962	R_X	≤ 15 µrad
REQ-L3-OAD-34965	R_Y	≤ 15 µrad
REQ-L3-OAD-34968	R_Z	≤ 1600 µrad

Rationale: Given perfect knowledge of the Mount and M2 flexure, these requirements enable ≥ 99.9% probability of convergence of the AGWS segment stacking process, the Fast Segment Tip-Tilt control loop, and the Active Optics control loop with the capture ranges specified in Table 3-15.

Notes:

These requirements specify the RMS position error of the M2 segment optical surface with respect to the Mount-FSMS or Mount-ASMS mechanical interface, anywhere within a segment's range of motion after calibration, in the M2 Front Surface coordinate system.

These requirements apply in all wavefront control modes, for both the FSMS and ASMS.

M2 Segment Position Repeatability

The FSMS and ASMS in the Natural Seeing wavefront control mode shall provide actuation of segment position with the repeatability specified in Table 3-13.

Table 3-13: M2 Segment Position Repeatability Requirements

Requirement ID	DOF	1σ Precision
REQ-L3-OAD-34981	T_X	≤ 1.0 μm
REQ-L3-OAD-34984	T_Y	≤ 1.0 μm
REQ-L3-OAD-34987	T_Z	≤ 1.0 μm
REQ-L3-OAD-34990	R_X	≤ 0.1 μrad
REQ-L3-OAD-34993	R_Y	≤ 0.1 μrad
REQ-L3-OAD-34996	R_Z	≤ 0.5 μrad

Rationale:
T_X, T_Y, T_Z, and R_Z: These requirements apply to the segment positioning system. Errors in these degrees of freedom will be injected at every Active Optics control loop and FSMS/ASMS Offload control loop update. These errors have been allocated PSSN(0.5 μm) ≤ 0.9975 in the NSIQ budget. This has been flowed down via Monte Carlo simulations to the requirements listed here.
R_X and R_Y: These requirements apply to the fast tip-tilt actuation stage only. Segment tip-tilt repeatability errors have been allocated PSSN(0.5 μm) ≤ 0.9995 in the NSIQ budget. This has been flowed down via Monte Carlo simulations to ≤0.1 μrad RMS in each axis.
Notes: These requirements specify the repeatability of small offsets of the M2 segments anywhere within a segment's range of motion, in the M2 Front Surface coordinate system.

REQ-L3-OAD-35039: M2 Segment TX, TY, TZ, and RZ Transfer Function

The FSMS and ASMS shall provide actuation of the T_X, T_Y, T_Z, and R_Z degrees of freedom with a transfer function response to commands within the limits specified in Figure 3-29.

Rationale: Limits are based on the expected performance of the ASMS positioner reference design, and used in the GMT integrated model.
Notes: 107589

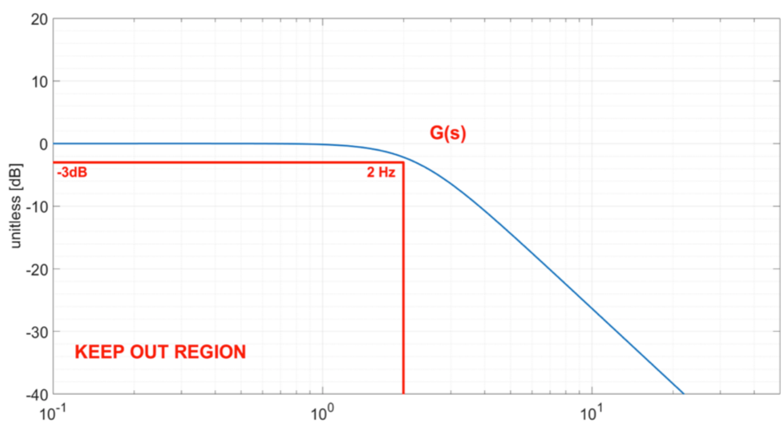

Figure 3-29: M2 segment Tx, Ty, Tz, and Rz Transfer Function Limits

Notes:
Offsets to the M2 segment position trajectory in the NS mode will typically be provided every 30 s to average over the atmospheric optical turbulence. In other modes and during target acquisition, they may be provided at up to 1 Hz.
This requirement applies in all wavefront control modes, for both the FSMS and ASMS.
The illustrated example response is:

$$G(s) = \frac{\omega_1^2}{s^2 + 2\zeta_1\omega_1 s + \omega_1^2} \text{ where } \omega_1 = 2\pi f_1$$

with f_1 = 2.2 Hz, ζ_1 = 0.7.

REQ-L3-OAD-35044: M2 Natural Seeing Segment RX and RY Transfer Function

The FSMS shall provide actuation of the segment R_X and R_Y degrees of freedom with a transfer function response outside the keep-out region specified in Figure 3-30.

Rationale: The limits defining the transfer function are derived from the KASI FSM prototype measured performance with resonances suppressed. They are consistent with the segment tip-tilt rejection transfer function specified in REQ-L3-OAD-35337.
Notes: 35049

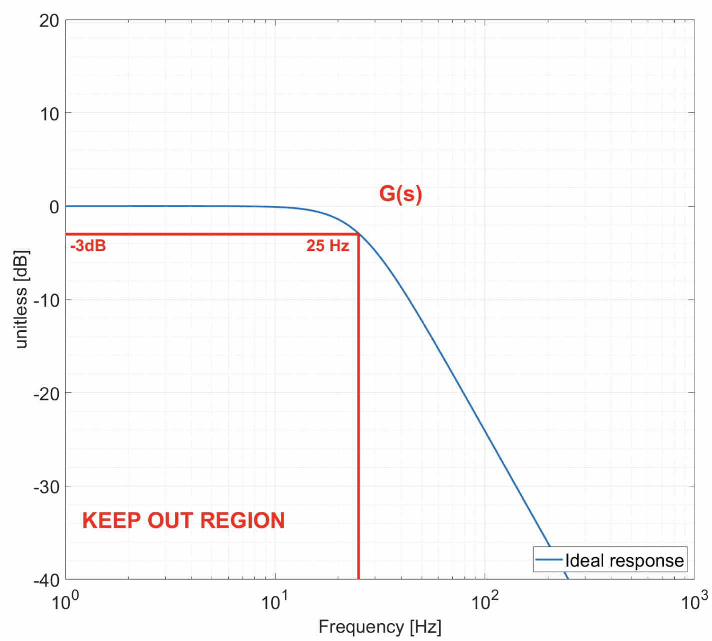

Figure 3-30: M2 FSMS Segment Rx and Ry Transfer Function Limits

Notes:
The illustrated example response is:

$$G(s) = \frac{\omega_1^2}{s^2 + 2\zeta_1\omega_1 s + \omega_1^2} \text{ where } \omega_1 = 2\pi f_1$$

with f_1 = 25 Hz, ζ_1 = 0.7.

3.3.2.3.4 M3

The facility tertiary mirror (M3) directs the central 3.0 arcmin diameter field to instruments mounted at the Folded Port (FP), Instrument Platform (IP), or Auxiliary Port (AP). While the NS wavefront control mode can be used at these focal stations, the specifications of the M3 derive from the diffraction-limited observing modes.

3.3.2.4 Natural Seeing Wavefront Sensing and Metrology

3.3.2.4.1 TMS

The Telescope Metrology Subsystem (TMS) provides the measurements used by the OCS to align the telescope main optics to within the capture range of optical wavefront sensors. The TMS includes two absolute metrology systems with overlapping capabilities. The Large Capture Range Absolute Metrology System consists of a network of laser trackers located on the Mount that enable alignment of instruments, wavefront sensors, and the main optics (M1, M2, M3, C-ADC) following initial assembly and maintenance operations. Its accuracy must be sufficient to locate the optics to well within the capture range of the Precision Absolute Metrology System. The Precision Absolute Metrology System consists of a fixed laser metrology truss which can simultaneously measure the positions of all M1 and M2 segments with respect to the GIR. It enables rapid realignment at the start of the night and after slews. Its accuracy is sufficient to locate the optics within the capture range of the AGWS (Figure 3-31).
The acquisition time budgets for all wavefront control modes assume that a single measurement of the Precision Absolute Metrology System will be made after every slew to a new target. However, the absolute accuracy of the M1 and M2 segment positioning systems has been specified such that this will not be necessary if accurate gravity and thermal flexure models of the Mount can eventually be developed. The Precision Absolute Metrology System will greatly assist in the development of these models.
All TMS requirements apply in all wavefront control modes.

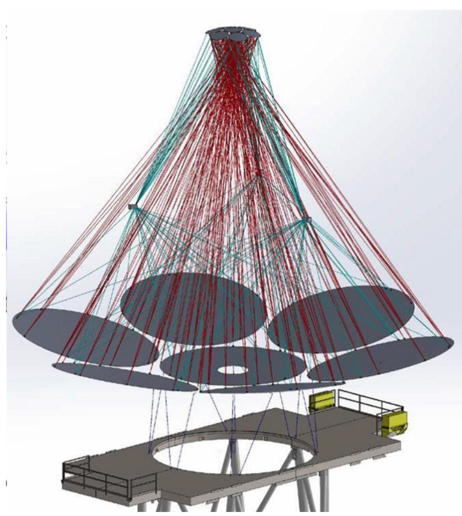

Figure 3-31: The TMS laser metrology lines of sight (Large Capture Range Absolute Metrology System in blue, Precision Absolute Metrology System in red)

TMS Capture Range

REQ-L3-OAD-106984: TMS Large Capture Range

The TMS Large Capture Range Absolute Metrology System shall measure the locations of M1, M2, M3, and the C-ADC in the OSS coordinate system with a capture range greater than the sum of the manufacturing tolerances, assembly and installation tolerances, and maximum expected flexure, and an inaccuracy less than the capture range of the TMS Precision Absolute Metrology System.

Rationale: The TMS Large Capture Range Absolute Metrology System provides the measurements used to initially align the main optics to within the capture range of the TMS Precision Absolute Metrology system.
Notes: The TMS Large Capture Range Absolute Metrology System will also be used for other metrology tasks, including calibration of the Mount pointing model and the alignment of instruments, wavefront sensors, and other Mount payloads. Lines of sight must be preserved for all of these functions.

REQ-L3-OAD-106985: TMS Precision Capture Range

The TMS Precision Absolute Metrology System shall measure the locations of M1, M2, and M3 in the OSS coordinate system, with a capture range greater than the maximum expected flexure of the combined Mount and main optics.

Rationale: The TMS Precision Absolute Metrology System provides the measurements used after every slew to rapidly align the main optics to within the capture range of the AGWS.
TMS Accuracy
The TMS shall measure the locations of the main optics with the accuracy specified in Table 3-14.

Table 3-14: TMS Accuracy Requirements

Requirement	DOF	1σ Accuracy (surface)
REQ-L3-OAD-35212	M1 T_X & T_Y	≤ 75 μm
REQ-L3-OAD-35215	M1 T_Z	≤ 4.3 μm
REQ-L3-OAD-35218	M1 R_X & R_Y	≤ 1.8 μrad
REQ-L3-OAD-35221	M1 R_Z	≤ 190 μrad
REQ-L3-OAD-35224	M2 T_X & T_Y	≤ 75 μm
REQ-L3-OAD-35227	M2 T_Z	≤ 4.3 μm
REQ-L3-OAD-35230	M2 R_X & R_Y	≤ 15 μrad
REQ-L3-OAD-35233	M2 R_Z	≤ 1600 μrad
REQ-L3-OAD-35236	M3 T_X & T_Y	≤ 500 μm
REQ-L3-OAD-35239	M3 T_Z	≤ 25 μm
REQ-L3-OAD-35242	M3 R_X & R_Y	≤ 80 μrad
REQ-L3-OAD-35245	M3 R_Z	≤ 2000 μrad

Rationale:
M1 and M2: Consistent with ≥ 99.9% probability of convergence of the AGWS segment stacking process, the Fast Segment Tip-Tilt control loop, and the Active Optics control loop with the capture ranges specified in Table 3-15.
M3: R_X, R_Y, and T_Z consistent with ± 1.0 arcsec allocation in guided pointing budget and OIWFS capture range for FP instruments specified in Table 3-17. T_X, T_Y, and R_Z are flowed down from a polishing margin tolerance of ± 1 mm.
Notes: These requirements are specified in the M1-S, M2-S, and M3 coordinate systems, which are the OSS coordinate system translated and rotated to the vertex of each segment.

3.3.2.4.2 AGWS

The Acquisition, Guiding, and Wavefront Sensing Subsystem (AGWS) is the central wavefront sensing system of the telescope and is active in all wavefront control modes. It enables target acquisition, active optics wavefront sensing, and telescope guiding in all wavefront control modes and optical configurations. It also enables GLAO wavefront sensing in the GLAO mode and low-bandwidth segment phasing in the NGAO and LTAO modes.
The AGWS is located ~0.5 m ahead of the Direct Gregorian focal surface, between the active DG

instrument and the upper surface of the GIR. The M3 mirror can be deployed directly above the AGWS volume, shadowing a portion of its patrol field but still enabling the same wavefront sensors to be used in the FP optical configuration.

The AGWS consists of four identical and independent probes that patrol the 20 arcmin diameter DG field (Figure 3-32). Each probe includes a configurable visible channel for acquisition, guiding, and low-order wavefront sensing, and an infrared channel to measure segment phase piston errors. In the NS observing mode, 3 wavefront sensors and 1 fast segment tip-tilt sensor are required to meet image quality requirements. The fraction of the sky observable by the GMT with the specified image quality is dependent on the patrol area and sensitivity of these sensors.

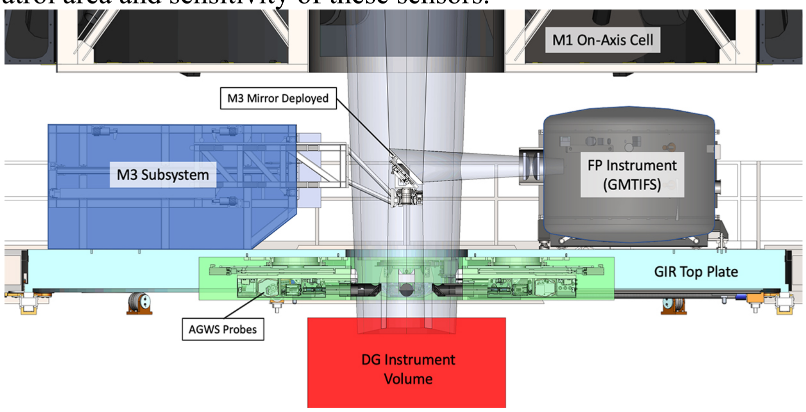

Figure 3-32: AGWS location.

REQ-L3-OAD-106987: AGWS Natural Seeing Sky Coverage

The AGWS shall meet its Natural Seeing measurement accuracy requirements with a sky coverage of no less than 99% in all observatory optical configurations, with the following constraints:

- DGNF: Requirement must be met while not vignetting the 10 arcmin diameter science field.
- DGWF: Requirement must be met while vignetting ≤15% of the 20 arcmin diameter science field.
- FP: Requirement must be met using only guide stars in the 52% of the DG focal surface not vignetted by M3.

Rationale: Direct flowdown from ORD sky coverage requirements, combined with constraints imposed by the optical configurations. Maximum DGWF vignetting of 15% is derived from the conceptual design of the AGWS.

Notes: Sky coverage is defined as the fraction of the sky observable from the site above 30 elevation over which the requirements are met.

All configurations must be met with the GIR either tracking apparent sky rotation or fixed.

The 52% available patrol field is the FP optical layout is consistent with REQ-L3-OAD-33899.

AGWS Capture Range

The AGWS shall measure the system wavefront with the capture ranges specified in Table 3-15.

Table 3-15: AGWS Natural Seeing Mode Capture Range Requirements

Requirements	Measurement	Min. Capture Range
REQ-L3-OAD-106988	Acquisition Imaging	± 15 arcsec
REQ-L3-OAD-35270	Segment Tip-Tilt	± 1.6 arcsec
REQ-L3-OAD-35273	Active Optics WFS	± 1.6 arcsec

Rationale: Consistent with ≥ 99.9% probability of convergence of the AGWS segment stacking process, the Fast Segment Tip-Tilt control loop, and the Active Optics control loop with the Mount pointing error

specified in REQ-L3-OAD-36268.
Notes: This requirement applies in all wavefront control modes.
AGWS Natural Seeing Measurement Accuracy
The AGWS in the Natural Seeing wavefront control mode shall measure the system wavefront with the accuracy specified in Table 3-16.

Table 3-16: AGWS Natural Seeing Accuracy Requirements

Requirements	Measurement	1σ Accuracy
REQ-L3-OAD-35285	Segment Tip-Tilt	≤ 28.3 mas
REQ-L3-OAD-35288	Active Optics WFS	≤ 42 mas

Rationale:
Segment Tip-Tilt: Consistent with PSSN(0.5 µm) ≤ 0.9883 allocation to AGWS segment tip-tilt measurement.
Active Optics WFS: Consistent with PSSN(0.5 µm) ≤ 0.9990 allocation to AGWS Measurement Shape Error and PSSN(0.5 µm) ≤ 0.9990 allocation to AGWS Measurement Alignment Error.
Notes: These requirements specify the maximum closed-loop measurement error of wavefront slope (the RSS of both axes) across the relevant pupil area, including errors due to probe motion. They do not include static calibration errors, which are budgeted separately. The Active Optics WFS requirement assumes 24×24 subapertures across the pupil.

3.3.2.4.3 OIWFS

The observatory architecture assumes that every instrument will include an On-Instrument Wavefront Sensor (OIWFS) to measure wavefront errors that cannot be sensed by the telescope wavefront sensors. However, the requirements on each OIWFS will vary depending on the specific needs of its science case. The requirements in this section specify a generic OIWFS consistent with the ORD Natural Seeing image quality requirements. Sky coverage is not specified, as this will be derived from each instrument's science case.
In the NS and GLAO wavefront control modes, the OIWFS is only required to sense image motion and focus errors between the AGWS sensors and the instrument focal surface caused by gravitational and thermal flexure. The image quality allocation for plane tip-tilt and rotation, and pupil motion requirements, will be met passively by flexure requirements on the Mount, AGWS, and instruments. Some specialized instruments may choose to forego an OIWFS altogether, limiting the maximum integration time over which the ORD image quality requirements are met to ≤ 120 s.
OIWFS Capture Range
Instruments operating in the NS and GLAO wavefront control modes shall include an OIWFS with the capture ranges specified in Table 3-17.

Table 3-17: OIWFS Natural Seeing Capture Range Requirements

Requirements	Focal Station	Measurement	Min. Capture Range
REQ-L3-OAD-35303	DG	Image Motion	± 0.5 arcsec
REQ-L3-OAD-35307	FP, AP, IP	Image Motion	± 2.5 arcsec
REQ-L3-OAD-35311	All	Focus	± 5.0 mm

Rationale:
Image Motion: Guide pointing budget totals of 0.2 arcsec RMS at DG and 1.0 arcsec RMS at FP were flowed down as P-V = 2×2.5σ.
Focus: Matches ± 5.0 mm total axial position error allowed by the NSIQ budget allocations.
Notes:
The minimum capture range is specified with respect to the Mount-Instrument interface. It does not include any allocation for flexure within the instrument.

The focus error capture range is specified in terms of axial displacement of the focus.
OIWFS Measurement Accuracy
Instruments operating in the NS and GLAO wavefront control modes shall include an OIWFS with the measurement accuracy specified inTable 3-18.

Table 3-18: Instrument OIWFS Accuracy Requirements

Requirements	Measurement	1σ Accuracy
REQ-L3-OAD-35326	Image Motion	≤ 10 mas
REQ-L3-OAD-35329	Focus	≤ 100 nm

Rationale: The combination of both errors has been allocated PSSN(0.5 µm) ≤ 0.9992.
Notes: These requirements specify the maximum closed-loop measurement error (the RSS of both axes in the case of image motion). The focus measurement accuracy is specified in term of RMS wavefront error.

3.3.2.5 Natural Seeing Disturbance Rejection

The rejection of optical disturbances is a function of the wavefront sensor frame rate, latency in the control loop, the transfer function of the corrector, and the control algorithm used.
The bandwidth of the Fast Segment Tip-Tilt control loop is primarily limited by technological constraints: the maximum frame rate of available wavefront sensor cameras, and the transfer function of an FSM with acceptable cost and manufacturing risk. The wind disturbances that this control loop must compensate are primarily in the 0.1-5.0 Hz range. The rejection in this band has been optimized by including a mid-frequency lead filter in the controller to counteract phase lag of the FSM and a low-frequency lag filter to improve disturbance rejection below 1 Hz (see GMT-DOC-04426). The resulting control system has -20 dB rejection at 1 Hz, and a 0 dB crossing at 7.4 Hz.
In contrast, the bandwidth of the Active Optics control loop is limited by the need to average down large atmospheric phase errors to resolve the much smaller quasi-static aberrations of the telescope. Other contributors, such as computational latency and the transfer function of actuators, are negligible. The baseline approach is to use 30 s AGWS WFS integrations. However, this integration time could be reduced to better balance errors when compensating unusually large thermal disturbances.
Natural Seeing Fast Segment Tip-Tilt Latency Budget
The AGWS and OCS in the Natural Seeing wavefront control mode shall have Fast Segment Tip-Tilt control loop latencies as specified in Table 3-19.

Table 3-19: Natural Seeing Segment Tip-Tilt Latency Budget

Requirement	Source	Latency [ms]	Comment
REQ-L3-OAD-70738	AGWS Segment Tip-Tilt Readout	≤ 5.00	At 200 Hz frame rate
REQ-L3-OAD-70740	AGWS Segment Tip-Tilt Slope Processing	≤ 0.50	From last pixel received to last slope transmitted
REQ-L3-OAD-70741	OCS Segment Tip-Tilt Computation	≤ 0.50	Includes data transmission from AGWS and to FSMS
	Total Latency	≤ 6.00	

Rationale: It meets latency error allocations in the NS image quality error budget.

REQ-L3-OAD-35337: Natural Seeing Tip-Tilt Rejection Transfer Function

The Natural Seeing rejection transfer function for global and segment wavefront tip-tilt disturbances shall remain outside of the keep-out region specified in Figure 3-33.

Rationale: The specified rejection transfer function limits ensure the maximum realistic suppression of wind disturbances at 1 Hz while limiting amplification of telescope disturbances in the 10-20 Hz range. They are consistent with the error budget allocation of PSSN(0.5 µm) ≤ 0.9958 to residual wind disturbance of the Mount, M1, and M2 subsystems.
Notes: 35342

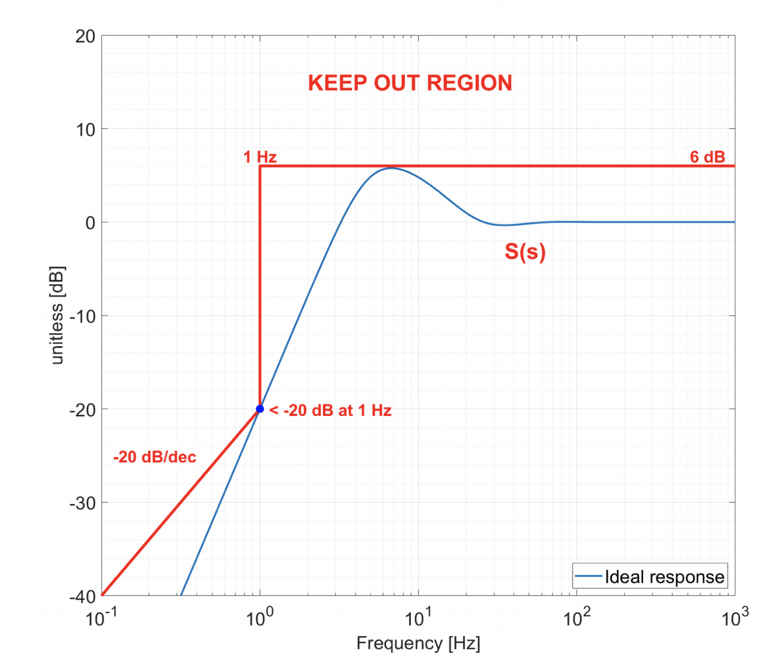

Figure 3-33: Natural Seeing Tip-Tilt Rejection Transfer Function Limits

Notes:
The example RTF is included to demonstrate consistency of the RTF limits with all other OAD requirements in this wavefront control mode. It is also used for system-level performance simulations. The following formalism applies to all other RTF requirements herein.
The wavefront control architecture illustrated in Figure 3-34.

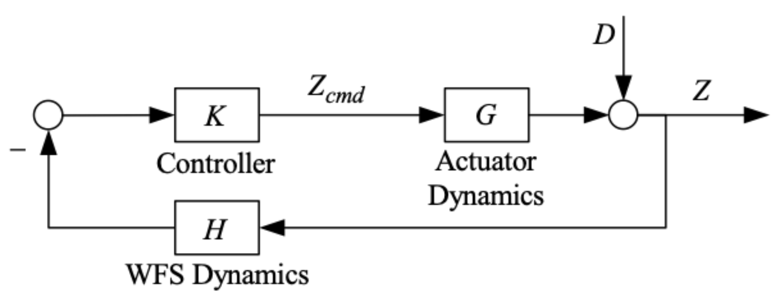

Figure 3-34: Wavefront Control Block Diagram

The wavefront is decomposed into spatial modes, which can be either Zernike or Karhunen-Loève modes. The signals for one spatial mode are defined below:

Z_{cmd} = actuator command
D = wavefront disturbance
Z = wavefront response

Actuator: The system $G(s)$ is the actuator, which in general is a complicated optical-mechanical system mounted on the telescope with local sensors, actuators, and controllers. There will also be software that converts modal commands into local actuator commands. The system is designed so that the $G(s)$ satisfies –3 dB bandwidth and AO robustness requirements.

A simplified version of $G(s)$ is a second order Butterworth filter with a break frequency equal to or greater than the –3 dB bandwidth requirement:

$$G(s) = \frac{\omega_{bw}^2}{s^2 + 2\zeta\omega_{bw}s + \omega_{bw}^2} \tag{1}$$

where:

$\omega_{bw} = 2\pi f_{bw}$ = break frequency [rad/sec]
f_{bw} = break frequency [Hz]
ζ = damping ratio [unitless]

The damping ratio for a Butterworth filter is $\zeta = 1/\sqrt{2} = 0.7071$. The gain at the break frequency is also $1/(2\zeta) = 0.7071$, which is –3 dB, and so the break frequency of a second order Butterworth filter equals the –3 dB bandwidth.

Wavefront sensor: The Wave Front Sensor (WFS) dynamics is approximated as one-frame integration and latency:

$$H(s) = \frac{1 - e^{-sT_i}}{sT_i} e^{-s\tau_\ell} \quad (2)$$

where:

T = integration time [sec]

τ_ℓ = latency [sec]

The latency has three parts: readout, slope processing, and computation and transmission.

The wavefront sensor also includes software that converts the optical measurements to modal responses, plus gain compensation as needed.

Controller: The first and second order AO controllers are:

$$K(s) = \frac{\omega_c}{s} \quad (3)$$

$$K(s) = \frac{\omega_c}{s} \times \frac{s + \omega_2}{s} \quad (4)$$

where:

$\omega_c = 2\pi f_c$ = unit magnitude crossover frequency [rad/sec]

$\omega_2 = 2\pi f_2$ = lag frequency [rad/sec]

f_c = unit magnitude crossover frequency [Hz]

f_2 = lag frequency [Hz]

$g_i = \omega_c T = 2\pi f_c T$ = digital gain [unitless]

The first order AO controller is included for reference. The second order AO controller is used in the OAD Rejection Transfer Function requirements.

Loop transfer function (LTF): The LTF is the gain around the feedback loop:

$$L = GKH$$

The controller gain ω_c is called the “unit magnitude crossover frequency” because it is the frequency at which the LTF has unit magnitude.

Rejection transfer function (RTF): The AO controller is defined to reject the wavefront disturbance, where:

$$\frac{Z}{D} = S = \frac{1}{1+L} \tag{5}$$

The letter “*S*” is used because the RTF is also called the sensitivity function. RTF parameters include:

$$S_{max} = \text{maximum value of } |S| \text{ over frequency [dB]}$$
$$f_{wc} = \text{wind-corner frequency [Hz], the frequency where } |S| = -20 \text{ dB}$$
$$f_{bws} = \text{lowest frequency where } |S| = 0 \text{ dB}$$

The Smax and fwc metrics are requirements. The fbws metric is reported but not used as a requirement.

The parameters used for the ideal NS RTF are:

- Requirements: T_i=5.0 ms, τ_l=6.0 ms, f_{bw}=25 Hz, f_{wc}=1.0 Hz, S_{max}=6 dB
- Controller: ζ=0.7, f_c=4.38 ms, f_2=2.29 ms, g_i=0.138

3.3.3 Ground Layer Adaptive Optics

3.3.3.1 Introduction

The GLAO wavefront control mode corrects low-altitude optical turbulence to improve image quality over that delivered by a passive telescope. It is available at all focal stations whenever the ASMS is installed and requires no additional wavefront sensing by the instruments over that needed in the NS mode.

The GMT GLAO architecture uses off-axis natural guide stars, sensed by the four AGWS wavefront sensors read out at high frame rates, to tomographically reconstruct the optical turbulence volume. A trade between the use of LGS and NGS concluded that the performance benefit of LGS GLAO was outweighed by the cost and operational efficiency benefits of an NGS GLAO architecture (see GMT-RVW-00407). In both cases, the GLAO-corrected field of view can be traded off against the delivered image quality: A smaller corrected field of view allows turbulence at greater altitude be corrected, resulting in improved average image quality. The selected tomographic NGS GLAO architecture can be optimized for any scientific field of view from 0' to 20' diameter, or at any number of discrete locations in the field.

The GLAO controller uses the wavefront slopes measured by four AGWS WFS to control the ASM face sheet figure at ≥100 Hz. The approach relies on the covariance tomography algorithm, and pseudo open-loop control to directly estimate the DM actuator commands that best compensate for a given set of synchronous wavefront sensor measurements (ref. GMT-REQ-04569). The reconstructor is optimized for the location and magnitude of the four guide stars, as well as the regions of the field of view over which correction is required. The most recent ASM command is read back and subtracted from the WFS slopes to estimate the open-loop wavefront error, which is used as the basis for the tomographic reconstruction.

Global and segment tip-tilt errors are corrected by the main tomographic GLAO control loop.
The Active Optics control loop in the GLAO mode uses the same ≥100 Hz pseudo open-loop AGWS WFS measurements as the GLAO control loop, but averaged over 30 s to remove the high-altitude optical turbulence. The field-dependent wavefront errors that remain are the results of M1 or Mount errors, erroneously corrected at the M2 conjugate, and are used to update the trajectories of these subsystems. As in the NS mode, the instrument provides pointing and focus measurements every 30 s, allowing flexure between the AGWS and instrument to be corrected.
The baseline approach leaves segment phasing errors uncorrected, as these have negligible impact on image quality for GLAO observations at <5 µm wavelength. This approach could be reconsidered if desired as the AGWS and ASMS have the sensing and correction capabilities required to phase the telescope to <100 nm RMS.
The acquisition strategy in the GLAO mode is identical to the NS mode.
In summary, the GLAO wavefront control mode shall control the optical degrees of freedom listed in Table 3-20 using model-based trajectories supplemented by measurements provided by the sensors listed in Table 3-21. A control block diagram is provided in Figure 3-35.

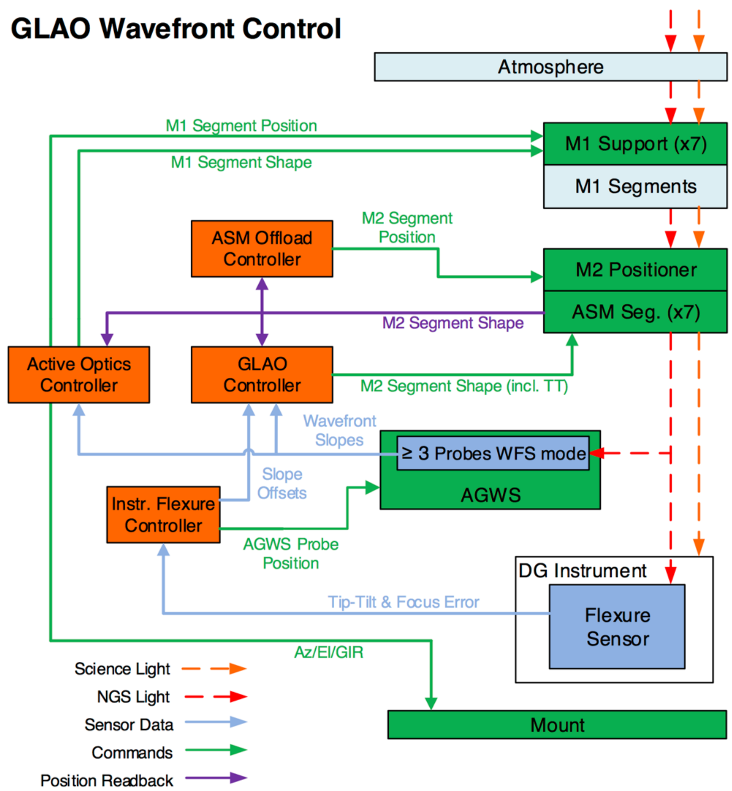

Figure 3-35: GLAO Wavefront Control Block Diagram

GLAO Controlled Degrees of Freedom
The GMT in the GLAO wavefront control mode shall actively control the optical degrees of freedom specified in Table 3-20.

Table 3-20: Natural Seeing Controlled Degrees of Freedom

Requirement ID	Subsystem	Degree of Freedom	# DOF
REQ-L3-OAD-34798	Mount	Azimuth, Elevation, and GIR Rotation	3

REQ-L3-OAD-34802	M1S	M1 segment rigid body position	7 × 6
REQ-L3-OAD-34806	M1S	M1 segment shape	7 × ≥ 27 bending modes
REQ-L3-OAD-34810	FSMS/ASMS	M2 segment rigid body position	7 × 6
REQ-L3-OAD-107002	ASMS	M2 segment shape	7 × ≥150 K-L modes

Rationale: Active control of these degrees of freedom is required to compensate for gravity and thermal deflections and distortions, and ground-layer optical turbulence, to achieve the image quality specified in OPM 2, 4, 6, 11, 13, and 15.

Notes: No wavefront sensor feedback to the M3S degrees of freedom is planned in the baseline GLAO mode. Such control is not precluded, but pupil position sensing would have to be provided by the instrument OIWFS.

GLAO Wavefront Sensing and Metrology

The GMT in the GLAO wavefront control mode shall utilize the wavefront sensors specified in Table 3-21.

Table 3-21: GLAO Wavefront Sensing and Metrology

Requirement ID	Subsystem	Measurement	Rate
REQ-L3-OAD-35127	TMS	M1 and M2 segment rigid body position with respect to OSS coordinates	≥ 0.067 Hz
REQ-L3-OAD-106982	AGWS	Acquisition imaging of ≥ 1 off-axis guide star	N/A
REQ-L3-OAD-35387	AGWS	Wavefront error at ≥4 locations in DG focal plane with at least 48×48 sampling of the pupil.	≥ 100 Hz
REQ-L3-OAD-35139	Instrument	Image motion and global focus error	≥ 0.03 Hz

Rationale:

Active sensing of these degrees of freedom is required to measure gravity and thermal deflections and distortions, and correct wind-induced vibrations, to achieve the image quality specified for OPM 2, 4, 6, 11, 13, and 15.

While 3 NGS wavefront sensors can be used for GLAO control, 4 are required to achieve the image quality requirements. Available low-noise cameras require a trade between pupil sampling and frame rate. The optimal wavefront sensor configuration for the cameras available in 2016 was found to be 48×48 pupil sampling at ~100 Hz. For more detail, see FWN 89 and GMT-DOC-01533.

Notes: Instruments that do not provide an OIWFS measuring image motion and focus error may only achieve the specified image quality over limited exposure times due to differential flexure between the AGWS and instrument.

3.3.3.2 GLAO Control Algorithms

The GLAO wavefront control mode algorithms are defined in applicable document GMT-REQ-04569 GLAO Wavefront Control Mode Algorithms. The acquisition steps and Instrument Flexure control loop are identical to the NS mode, and those requirements from Section 3.3.2.2 apply.

REQ-L3-OAD-35360: Active Optics Control Loop in GLAO Mode

The Active Optics Control Loop in the GLAO control mode, specified in GMT-REQ-04569 Section 3.4.4 (Active Optics Loop), shall use time-averaged GLAO wavefront sensors measurements at 3-4 locations in the Direct Gregorian focal plane to correct Mount tracking errors and M1 segment position and shape errors.

Rationale: The GLAO control loop will rapidly correct Mount and M1 errors at M2, leading to field-dependent errors. These can be differentiated from atmospheric errors by their quasi-static nature.
Notes: Two methods have been proposed for implementing the Active Optics loop in GLAO mode. The baseline is to use the Natural Seeing reconstructor and pseudo-open loop control. In this case, the ASM actuator positions are subtracted from the measured AGWS slopes prior to time-averaging those slopes. The pseudo-open loop slope is then multiplied by the standard NS reconstructor to derive Mount and M1 offset commands (see FWN98). The alternative is to build a synthetic reconstructor that includes ideal on-axis NGAO correction, and multiply it by the raw AGWS WFS slopes. This method is simpler but has not yet been thoroughly investigated.

REQ-L3-OAD-35356: GLAO Control Loop

The GLAO Control Loop, specified in GMT-REQ-04569 Section 3.4.3 (Atmospheric Tomography Loop), shall use tomographic reconstruction of the residual wavefront measured at 3-4 locations in the Direct Gregorian focal plane to correct low-altitude optical turbulence and telescope disturbances.

Rationale: Tomographic reconstruction enables the image quality to be optimized over any desired field of view, regardless of the location of the natural guide stars.
Notes: The covariance tomography technique is used, with pseudo-open loop control. The ASM actuator positions must be read back and subtracted from the measured slopes to enable the GLAO estimator to operate on "pseudo-open loop" slopes. For more detail, refer to GMT-DOC-01533.

REQ-L3-OAD-35364: ASM Offload Control Loop

The ASM Offload control loop, specified in GMT-REQ-04569 Section 3.4.5 (Offloading Loops), shall offload low-order face sheet shape offsets to the M2 Positioner to preserve face sheet stroke.

Rationale: The M2 Positioner degrees of freedom are degenerate with respect to segment piston, tip, tilt, focus, and astigmatism produced by the ASM face sheets. The ASM provides high bandwidth control of these modes with a limited stroke, while the M2 Positioner provides lower bandwidth with a wide range of motion. An offload from the ASM to M2 Positioner maximizes the available ASM face sheet stroke.
Notes: The ASM offload control loop will be implemented by the ASMS. The offloads will be an offset to the model-based M2 Positioner trajectory.

3.3.3.3 GLAO Controlled Degrees of Freedom

The GLAO wavefront control mode actuation requirements on the Mount, M1, and M3 are identical to those of the NS mode. Requirements on the ASMS segment positioning function are also largely identical. Of the requirements in Section 3.3.2.3 the following *do not* apply in the GLAO mode:

- REQ-L3-OAD-34990: M2 Segment Position Repeatability - Rx
- REQ-L3-OAD-34993: M2 Segment Position Repeatability - Ry
- REQ-L3-OAD-35044: M2 Natural Seeing Segment RX and RY Transfer Function

These requirements are replaced ASMS figure control requirements, which include control of the segment RX and RY (tip and tilt) degrees of freedom.
The requirements on ASMS figure control are driven by the performance in the NGAO and LTAO

wavefront control modes. We do not consider it worthwhile to specify the less stringent requirements on a "GLAO-only" ASMS, with one exception: The following requirement specifies the minimum number of Karhunen-Loève modes that must be controlled in the GLAO mode.

REQ-L3-OAD-35370: ASM GLAO Controlled Degrees of Freedom

The ASM in the GLAO wavefront control mode shall have at least 150 controlled modes per segment.

Rationale: GLAO image quality budget flowdown used 150 controlled Karhunen-Loève modes per segment.
Notes: The driving requirements on the ASM flowed down from the NGAO wavefront control mode (OPM 9).

3.3.3.4 GLAO Wavefront Sensing and Metrology

REQ-L3-OAD-107009: AGWS GLAO Sky Coverage

The AGWS shall meet its GLAO measurement accuracy requirements with a sky coverage of no less than 99% in all observatory optical configurations, with the following constraints:

- DGNF: Requirement must be met while not vignetting the 10 arcmin diameter science field.
- DGWF: Requirement must be met while vignetting ≤15% of the 20 arcmin diameter science field.
- FP: Requirement must be met using only guide stars in the 52% of the DG focal surface not vignetted by M3.

Rationale: Direct flowdown from ORD sky coverage requirements, combined with constraints imposed by the optical configurations. Maximum DGWF vignetting of 15% is derived from the conceptual design of the AGWS.
Notes: Sky coverage is defined as the fraction of the sky observable from the site above 30 degrees elevation over which the requirements are met.
All configurations must be met with the GIR either tracking apparent sky rotation or fixed.
The 52% available patrol field is the FP optical layout is consistent with REQ-L3-OAD-33899.

REQ-L3-OAD-107010: AGWS GLAO WFS Measurement Accuracy

The AGWS in the GLAO wavefront control mode shall measure the system wavefront with an accuracy of ≤80 mas RMS in each subaperture.

Rationale: Consistent with PSSN (1.65 µm) ≥ 1.0338 allocation to GLAO atmospheric correction. See analysis in FWN114.
Notes: This requirement specifies the maximum closed-loop measurement error of wavefront slope (the RSS of both axes) over square ≤0.53 m subapertures at ≥100 Hz (REQ-L3-OAD-35387), at 99% sky coverage. It does not include errors due to probe motion or static calibration errors, which are budgeted separately.

3.3.3.5 GLAO Disturbance Rejection

The rejection of optical disturbances is a function of the wavefront sensor frame rate, latency in the control loop, the transfer function of the corrector, and the control algorithm used.
The bandwidth of the GLAO control loop is overwhelmingly limited by the framerate of available wavefront sensor cameras. The AGWS wavefront sensors must be highly linear to operate in pseudo open-loop and in the presence of off-axis telescope design aberrations. For this reason, a minimum 100

Hz frame rate was established early on as an achievable requirement, but technological advances now enable readout at up to 120 Hz for candidate sensors.
Using an integral controller with a low-frequency lag filter, the resulting control system meets the same rejection disturbance requirement of -20 dB at 1 Hz for all controlled modes as Natural Seeing mode does for just segment tip-tilt.
GLAO Latency Budget
The AGWS and OCS in the GLAO wavefront control mode shall have latencies as specified in Table 3-22.

Table 3-22: GLAO Latency Budget

Requirement	Source	Latency [ms]	Comment
REQ-L3-OAD-70747	AGWS GLAO Readout	10.0	At 100 Hz frame rate
REQ-L3-OAD-70748	AGWS GLAO Slope Processing	1.00	From last pixel received to last slope transmitted
REQ-L3-OAD-70749	OCS GLAO Computation	1.00	Includes data transmission from AGWS and to ASMS
	Total Latency	12.00	

Rationale: It meets latency error allocations in the GLAO image quality error budget.

REQ-L3-OAD-35398: GLAO Rejection Transfer Function

The GLAO wavefront control mode rejection transfer function for all controlled modes shall not exceed that in Figure 3-36.

Rationale: The specified rejection transfer function limits ensure the maximum realistic suppression of wind and ground-layer disturbances at 1-5 Hz while limiting amplification of telescope resonances in the 10-20 Hz range. They are consistent with the error budget allocation of PSSN (0.5 µm) ≤ 0.9958 to residual wind disturbance, and ≤ 1.060 to atmospheric correction.
Notes: 35403

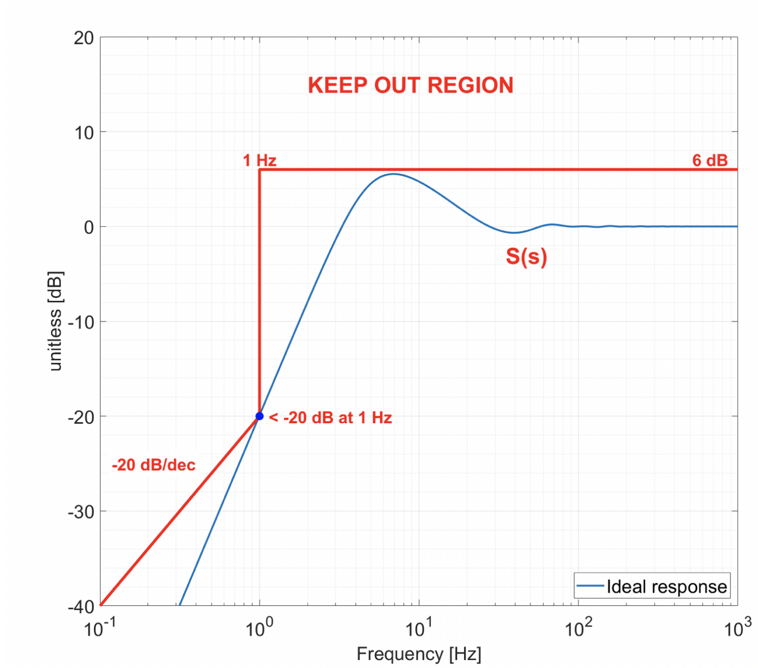

Figure 3-36: GLAO Rejection Transfer Function Limits

Notes:

See REQ-L3-OAD-35337 for a discussion of the transfer function limits and the ideal response. The parameters used for the ideal GLAO RTF are:

- Requirements: T_i=10 ms, τ_l=12 ms, f_{bw}=800 Hz, f_{wc}=1.0 Hz, S_{max}=6 dB
- Controller: ζ=0.7, f_c=4.45 ms, f_2=2.25 ms, g_i=0.280

3.3.4 Natural Guide Star Adaptive Optics

3.3.4.1 Introduction

The NGAO wavefront control mode uses the measured wavefront of a single on-axis natural guide star, corrected in closed-loop by the Adaptive Secondary Mirror Subsystem (ASMS), to deliver diffraction-limited images with high contrast over a field of view limited by atmospheric anisoplanatism. This mode is used for general-purpose high spatial resolution imaging and spectroscopy, high-contrast science programs (i.e. exoplanets and debris disks), and to improve the wavelength stability of high-resolution single-object spectrographs.

The Natural Guide Star Wavefront Sensor Subsystem (NGWS) is the primary wavefront sensor in the NGAO mode. It must sense all wavefront error caused by the atmosphere and telescope, including image motion and segment phase piston error. The need to sense segment phase piston at high bandwidth drove the selection of a pyramid wavefront sensor, which also provides high sensitivity and low aliasing. The NGWS is replicated for each instrument, and fed by light reflected off of a dichroic instrument window. This "direct feed" wavefront sensor architecture minimizes the number of optical surfaces in the path to both the wavefront sensor and instrument (Figure 3-37). Instruments using the NGAO wavefront control mode may be located at any focal station, but the requirements flowdown has so far been performed only for the Folded Port station, where the GMTIFS and GMTNIRS instruments will be located.

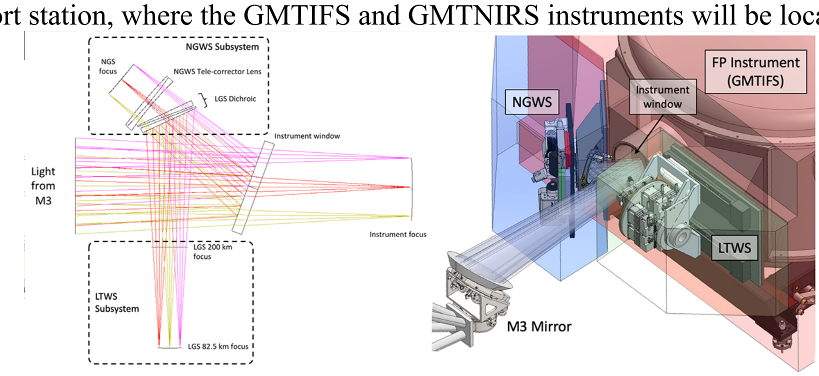

Figure 3-37: Direct Feed NGAO and LTAO Wavefront Sensing Architecture, Ray Trace (Left) and Volume Allocations for an FP Instrument Deployment (Right)

The stringent performance requirements of ORD OPM 9 flow down to an NGWS pupil sampling of at least 90´90 and ≥ 3500 modes controlled on the ASMS at ≥1 kHz. The segmented ASMS architecture enables this to be achieved while maintaining a similar number of actuators per segment to existing adaptive secondary mirrors. The NGAO control loop uses a modal control approach based on Karhunen-Loève modes defined by the covariance of atmospheric phase error in the ASM actuator's command space, enabling performance to be optimized for both bright and faint guide stars.

As in the other wavefront control modes, the AGWS fulfills the target acquisition and segment stacking functions and brings the telescope to an initial seeing-limited state. It is also required to sense segment phase piston errors with a large capture range to enable initial coarse phasing of the seven M1-M2 segment pairs. Once the high-bandwidth NGAO control loop is closed between the NGWS and ASMS, the AGWS continues to operate in a supporting role, measuring residual aberrations off-axis to enable low-bandwidth correction of M1 segment position and figure errors and Mount pointing errors.

An On-Instrument Wavefront Sensor (OIWFS) within the instrument measures low-order aberrations in the non-common light path between the NGWS and instrument focal plane. Image motion and focus errors are used to update the position of the NGWS with respect to the instrument, while pupil position errors are used to correct tip and tilt of M3. Any higher-order aberrations measured by the OIWFS, such as those caused by deformation of the instrument window due to ambient pressure changes, will be used to update the calibration vector (setpoint) of the NGWS.

Phasing the GMT segment pairs at high bandwidth and with high precision is a critical aspect of the NGAO wavefront control mode. The phasing strategy for the NGAO and LTAO modes is illustrated in Figure 3-38. Initial alignment using the TMS laser truss (Step 1) is followed by phasing capture and control over a wide field at low bandwidth by the AGWS DFS sensors (Step 2). The AGWS is allocated a segment phase piston measurement error of ≤ 50 nm RMS across the full GMT field of view, using guide stars that provide a sky coverage ≥ 90%. When combined with other error sources, this enables the telescope to be phased to ≤ 100 nm RMS. From this point the control strategy depends on the diffraction-limited observing mode.

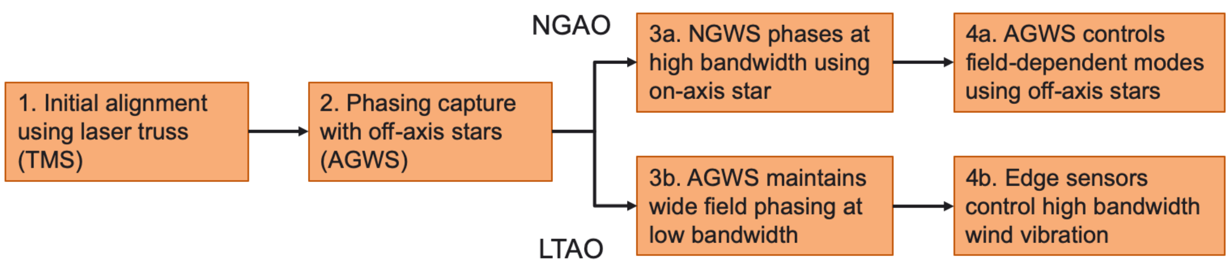

Figure 3-38: GMT Segment Phasing Steps in the NGAO and LTAO Modes

In the NGAO wavefront control mode, the NGAO control loop then takes over high-bandwidth phasing control (Step 3a). The residual segment phase piston allocation in the NGAO mode is ≤ 45 nm RMS when using R<10 stars in median conditions. This requires the NGWS to measure segment phase piston at 500-1000 Hz frame rate with a measurement error of ≤ 30 nm RMS. The AGWS continues to control field-dependent wavefront errors at low bandwidth (Step 4a), including field-dependent segment phase piston error caused by small M1 segment tilts corrected by the ASMS.

In summary, the NGAO wavefront control mode shall control the optical degrees of freedom listed in Table 3-23 using model-based trajectories supplemented by measurements provided by the sensors listed in Table 3-24. A control block diagram is provided in Figure 3-39.

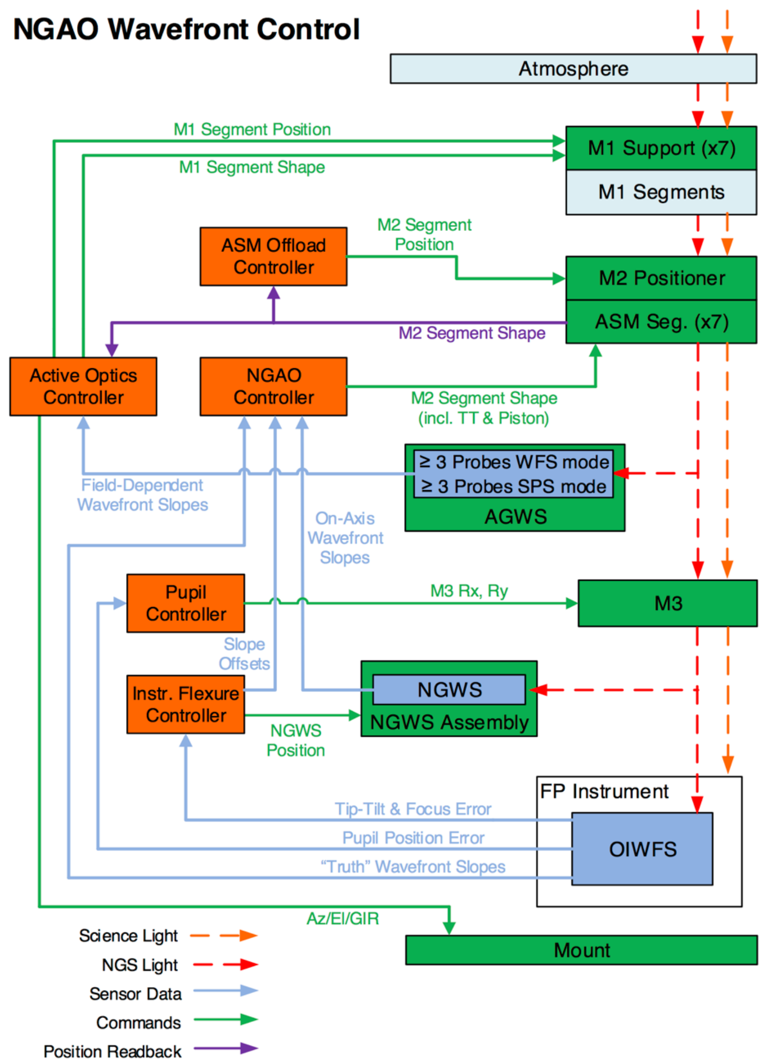

Figure 3-39: NGAO Wavefront Control Block Diagram

NGAO Controlled Degrees of Freedom
The GMT in the NGAO wavefront control mode shall actively control the optical degrees of freedom specified in Table 3-23.

Table 3-23: Natural Seeing Controlled Degrees of Freedom

Requirement ID	System	Degree of Freedom	# DOF
REQ-L3-OAD-34798	Mount	Azimuth, Elevation, and GIR Rotation	3
REQ-L3-OAD-34802	M1S	M1 segment rigid body position	7 × 6
REQ-L3-OAD-34806	M1S	M1 segment shape	7 × ≥ 27 bending modes
REQ-L3-OAD-34810	FSMS/ASMS	M2 segment rigid body position	7 × 6
REQ-L3-OAD-107023	ASMS	M2 segment shape	7 × ≥500 K-L modes

REQ-L3-OAD-34814	M3	M3 piston, tip, and tilt	3

Rationale: Active control of these degrees of freedom is required to compensate for gravity and thermal deflections and distortions, and atmospheric optical turbulence, to achieve the image quality specified in OPM 9.

Notes:

NGAO Wavefront Sensing and Metrology

The GMT in the NGAO wavefront control mode shall utilize the wavefront sensors specified in Table 3-24.

Table 3-24: NGAO Wavefront Sensing and Metrology

Requirement ID	Subsystem	Measurement	Rate
REQ-L3-OAD-35127	TMS	M1 and M2 segment rigid body position with respect to OSS coordinates	$\geq$ 0.067 Hz
REQ-L3-OAD-106982	AGWS	Acquisition imaging of $\geq$ 1 off-axis guide star	N/A
REQ-L3-OAD-35131	AGWS	Wavefront error at $\geq$3 locations in DG focal plane with at least 24×24 sampling of the pupil.	$\geq$ 0.03 Hz
REQ-L3-OAD-35483	AGWS	Segment phase piston error at $\geq$3 locations in DG focal plane	$\geq$ 0.03 Hz
REQ-L3-OAD-107035	NGWS	Acquisition imaging of the on-axis guide star	N/A
REQ-L3-OAD-35487	NGWS	On-axis wavefront error with at least 90×90 sampling of the pupil	$\geq$ 1000 Hz
REQ-L3-OAD-35491	Instrument	Image motion and global focus error	$\geq$ 0.10 Hz
REQ-L3-OAD-35495	Instrument	Low-order (~16×16) wavefront error	$\geq$ 0.10 Hz
REQ-L3-OAD-35499	Instrument	Pupil position (chief ray angle) error	$\geq$ 0.10 Hz

Rationale:

AGWS: The AGWS WFS is used for initial acquisition, stacking, alignment, and figure correction of the telescope, and to maintain negligible field-dependent aberrations during NGAO operation. The AGWS SPS are necessary to initially phase the telescope and maintain the field-dependent segment piston error within allocation during NGAO operation.

NGWS: A fast on-axis wavefront sensor with at least 90×90 pupil sampling is necessary to meet the atmospheric fitting error WFE allocation. An acquisition channel is required to detect any initial flexure between the AGWS and NGWS and enable evaluation of AO performance.

Instrument: The instrument OIWFS must measure flexure between the instrument focal plane and NGWS to maintain WFE allocations. It must also measure low-order errors due to changing non-common path aberrations to the NGWS. The feedback on pupil alignment is required by the pupil motion allocation.

Notes:

3.3.4.2 NGAO Control Algorithms

The NGAO wavefront control mode algorithms are defined in applicable document GMT-REQ-04174 NGAO Wavefront Control Mode Algorithms. The acquisition steps are identical to the NS mode, and those requirements from Section 3.3.2.2 apply.

REQ-L3-OAD-35410: NGAO Control Loop

The NGAO Control Loop, specified in GMT-REQ-04174 Section 4 (NGAO Control Loop Algorithms), shall reconstruct on-axis wavefront error from measurements made by the NGWS and apply corrections for these errors to the ASMS face sheet.

Rationale: High spatial and temporal frequency wavefront control is required to achieve ≤ 150 nm RMS wavefront error (ORD-25705). A budget allocation for segment phase piston error of ≤ 45 nm RMS requires this mode to be measured by the NGWS, rather than using metrology or off-axis guide stars.
Notes: A pyramid wavefront sensor design for the NGWS enables continuous wavefront errors and segment phasing errors to be measured simultaneously.

The spatial scales are limited by the ASM cut-off spatial frequency, which is equal to 1/(2r_s) where r_s is the average inter-actuator distance (r_s = 0.286 m)

REQ-L3-OAD-97014: Active Optics Control Loop in NGAO Mode

The Active Optics control loop in the NGAO control mode, specified in GMT-REQ-04174 Section 5 (Active Optics Control Algorithms), shall reconstruct field-dependent segment aberrations and field-dependent segment phase piston from measurements made by the AGWS and apply corrections for these errors to the Mount and M1S segment positions and shapes.

Rationale: The Active Optics control loop corrects Mount pointing errors and M1 segment position and shape errors to maintain field-dependent aberrations within acceptable limits.

REQ-L3-OAD-35414: Dynamic Calibration Control Loop in NGAO Mode

The Dynamic Calibration control Loop in the NGAO control mode, specified in GMT-REQ-04174 Section 6 (Dynamic Calibration Control Algorithms), shall reconstruct tip-tilt, focus, and low-order wavefront error from measurements made by the OIWFS and apply corrections for these errors to the NGWS reference slopes.

Rationale: The Dynamic Calibration control loop corrects low-order aberrations induced by flexure and changing non-common path aberrations between the NGWS and Instrument, to deliver diffraction-limited image quality to the science instrument.
Notes: The image position and focus feedback from the OIWFS are critical to achieve the image quality requirements of OPM 9.
Most of the NCPA in the science path are introduced by the instrument window.

REQ-L3-OAD-35418: Instrument Pupil Control Loop

The Instrument Pupil control loop, specified in GMT-REQ-04174 Section 7 (Instrument Pupil Control Algorithms), shall reconstruct pupil position from the subaperture intensities measured by the instrument OIWFS and apply corrections for this error to the R_X and R_Y degrees of freedom of M3.

Rationale: The Instrument Pupil control loop corrects flexure of the Mount and M3, to maintain the chief ray aligned to the instrument and wavefront sensor optical axes.
Notes: A tip-tilt error of M3 will result in pupil (chief ray) misalignment at the instrument and a pointing error. The pupil misalignment will be detected as a displacement of the illuminated subapertures in the OIWFS Truth sensor. When corrected by a tip or tilt of M3, this will result in a pointing change, which the NGWS or OIWFS (in NGAO and LTAO modes, respectively) will detect and correct with the ASMS.

REQ-L3-OAD-35364: ASM Offload Control Loop

The ASM Offload control loop, specified in GMT-REQ-04569 Section 3.4.5 (Offloading Loops), shall offload low-order face sheet shape offsets to the M2 Positioner to preserve face sheet stroke.

Rationale: The M2 Positioner degrees of freedom are degenerate with respect to segment piston, tip, tilt, focus, and astigmatism produced by the ASM face sheets. The ASM provides high bandwidth control of these modes with a limited stroke, while the M2 Positioner provides lower bandwidth with a wide range of motion. An offload from the ASM to M2 Positioner maximizes the available ASM face sheet stroke.
Notes: The ASM offload control loop will be implemented by the ASMS. The offloads will be an offset to the model-based M2 Positioner trajectory.

3.3.4.3 NGAO Controlled Degrees of Freedom

The NGAO wavefront control mode drives most of the performance requirements on the ASMS. It also imposes requirements on M1 segment tip-tilt precision, and M3 accuracy and precision.

3.3.4.3.1 M1

M1 Segment Rx and Ry Repeatability
The M1 System shall provide actuation of segment position with the repeatability specified in Table 3-25.

Table 3-25: M1 Segment Rx and Ry Repeatability Requirements

Requirement ID	DOF	1σ Precision
REQ-L3-OAD-34879	R_X	≤ 0.5 µrad
REQ-L3-OAD-34882	R_Y	≤ 0.5 µrad

Rationale: R_X and R_Y errors at M1, corrected at M2, will lead to field-dependent segment phase piston error (see GMT-DOC-01369). This does not significantly degrade image quality in the NS and GLAO modes, but it could do so in the NGAO and LTAO modes. The most stringent considered case is that imposed by a potential future Multi-Conjugate Adaptive Optics with a 90″ diameter field of view. Maintaining field-dependent segment phase piston error 45″ off-axis below 30 nm RMS would require M1 R_X and R_Y precision errors of ≤ 0.5 µrad.
Notes: These requirements specify the repeatability of small offsets of the M1 segments anywhere within a segment's range of motion, in the M1 Front Surface coordinate system.

3.3.4.3.2 ASMS

REQ-L3-OAD-35423: ASMS NGAO Controlled Degrees of Freedom

The ASMS in the NGAO wavefront control mode shall have at least 500 controlled modes per segment.

Rationale: The NGAO image quality budget allocation of 69.1 nm RMS requires at least 50. modes per segment to be controlled (ref. GMT-DOC-04695).
Notes: The central ASM segment will have the first five actuators rings obscured by the GMT central occultation. Those ~75 actuators will have to be commanded as slaves.

REQ-L3-OAD-35427: ASMS Segment Shape Accuracy

The ASMS shall provide control of segment shape with an accuracy resulting in a average surface gradient over any 6.6 × 6.6 cm region of the segment no greater than 11.7 µrad (TBC).

Rationale: Equivalent to the allocation of 0.6 arcsec wavefront slope in the AGWS 48x48 WFS dynamic range budget.
Notes: This requirement specifies the maximum local surface slope error (relative to the optical prescription) of each ASMS segment optical surface after calibration for gravity and thermal effects.

REQ-L3-OAD-35431: ASMS Segment Shape Precision

The ASM shall provide control of segment shape with a precision of ≤ 5 nm RMS surface.

Rationale: Allocation in NGAO WFE budget.
ASMS Stroke
The ASMS shall provide a range of actuation no less than that specified in Table 3-26.

Table 3-26: ASMS Stroke Requirements

Requirement ID	DOF	Min. Stroke [surface]
REQ-L3-OAD-35446	Segment tip and tilt	36 µrad P-V
REQ-L3-OAD-35449	Segment piston	40 µm P-V
REQ-L3-OAD-35452	Higher-order modes	10 µm P-V

Rationale:
Flowed down from expected disturbances via the M2 Dynamic Stroke Budget GMT-REF-03402.
Segment Tip and Tilt: The total dynamic segment tip-tilt budget when pointed directly into 17 m/s wind, including 20% margin, is 4.5 µrad RMS surface (ref. GMT-REF-03402 v8). Defining P-V as 2 × 4 × results in a requirement of ≥ 36 µrad P-V surface.
Segment Piston: The total dynamic segment piston budget when pointed directly into 17 m/s wind, including 20% margin, is 5.0 µm RMS surface (ref. GMT-REF-03402 v8). Defining P-V as 2 × 4 × sigma results in a requirement of ≥ 40 µm P-V surface.
Higher-Order Modes: The dominant term in the piston- and tip-tilt-subtracted wavefront error is the atmopsheric turbulence. Assuming r0 = 7 cm (~98th percentile) and L0 = 50 m, the required total stroke, including 60% margin, is 1.3 µm RMS surface. Defining P-V as 2 × 4 × sigma results in a requirement of ≥ 10 µm P-V surface.
Notes: The segment tip-tilt and piston requirements must be met simultaneously. High order errors may be combined by root-sum-square with these.

REQ-L3-OAD-35459: ASM Segment Shape Transfer Function

The ASMS shall provide actuation of segment shape in all controlled modes with a transfer function response to commands outside the keep-out regions specified in Figure 3-40.

Rationale: The limits defining the transfer function keep-out regions are derived from the VLT DSM measured performance, and are consistent with system segment tip-tilt RTF specified in REQ-L3-OAD-35570 as well as key AO-loop robustness requirements. The ideal response has no resonant modes.
Notes: 113011

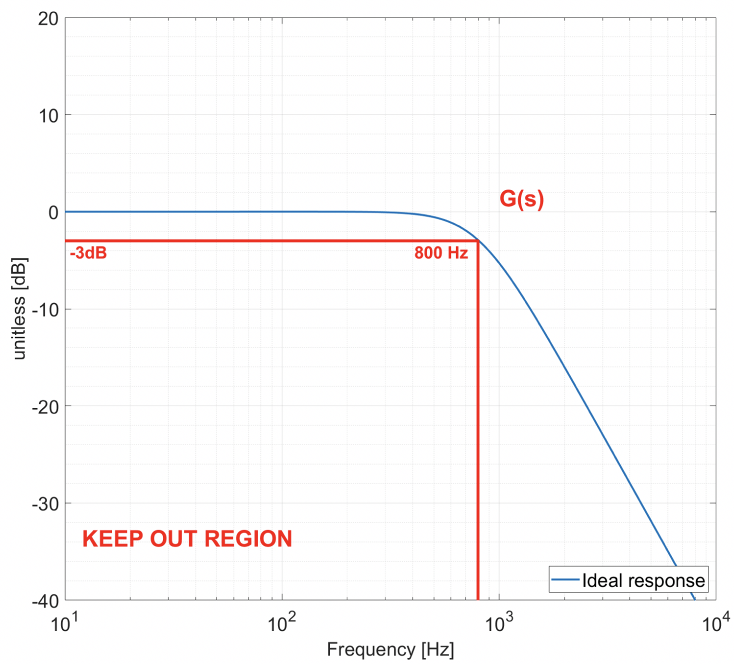

Figure 3-40: ASMS Transfer Function Limits

Notes:
The illustrated example response is:

$$G(s) = \frac{\omega_1^2}{s^2 + 2\zeta_1\omega_1 s + \omega_1^2} \text{ where } \omega_1 = 2\pi f_1$$

with f_1 = 800 Hz, ζ_1 = 0.7.

3.3.4.3.3 M3

The facility tertiary mirror (M3) directs the central 3.0 arcmin diameter field to instruments mounted at the Folded Port, Instrument Platform, or Auxiliary Port. It is only deployed when these instruments are in use, and retracted when using Direct Gregorian or Gravity Invariant Station instruments. The M3 is located ahead of the AGWS, which is specified to meet all of its functional and performance requirements when limited to guide stars in the Direct Gregorian focal surface unvignetted by M3.
The M3 provides 3 actively controlled degrees of freedom: tip (R_X), tilt (R_Y), and piston (T_Z). These degrees of freedom will be commanded to follow a continuous trajectory based on an open-loop model of gravity and thermal deflections. The trajectory will be adjusted every 30 s, based on feedback from the OIWFS of the active instrument. The other three degrees of freedom will be controlled by mechanical tolerances.
M3 Rigid Body Position Accuracy
The M3 System shall provide actuation of the M3 tip, tilt, and piston with the accuracy specified in Table 3-27.

Table 3-27: M3 Rigid Body Position Accuracy Requirements

Requirement ID	DOF	1σ Accuracy
REQ-L3-OAD-107038	T_X & T_Y	≤ 200 µm
REQ-L3-OAD-35065	T_Z	≤ 25 µm

REQ-L3-OAD-35059	R_X & R_Y	≤ 120 µrad
REQ-L3-OAD-35062	R_Z	≤ 500 µrad

Rationale: These requirements ensure that the light of the NGAO guide star will fall on the M3 clear aperture and within the OIWFS capture range. R_X, R_Y, and T_Z are derived from a 0.5 mm RMS image motion allocation in guided pointing budget. T_X, T_Y, and R_Z are flowed down from a polishing margin tolerance of ± 1 mm.
Notes: These requirements specify the RMS position error of the M3 optical surface with respect to the Mount-M3S mechanical interface, anywhere within its range of motion after calibration, in the M3 coordinate system.
M3 Rigid Body Position Repeatability
The M3 Subsystem shall provide actuation of the M3 tip, tilt, and piston with the repeatability specified in Table 3-28.

Table 3-28: M3 Rigid Body Position Precision Requirements

Requirement ID	DOF	1σ Accuracy
REQ-L3-OAD-35077	R_X & R_Y	≤ 12 µrad (TBC)
REQ-L3-OAD-35083	T_Z	≤ 2 µm (TBC)

Rationale: R_X and R_Y repeatability requirement are derived from a preliminary M3 pupil motion budget allocation of 0.03% peak error. The image motion and focus error resulting from Tz repeatability errors will be sensed and corrected by the NGAO and LTAO control loops, and the requirement is therefore made consistent with the displacement at 2/3 radius resulting from the Rx/Ry specification.
Notes: These requirements specify the repeatability of small offsets of the M3 anywhere within its range of motion, in the M3 coordinate system.

3.3.4.4 NGAO Wavefront Sensing and Metrology

The NGAO wavefront control mode sensing requirements on the TMS are identical to those in the NS mode. All AGWS requirements in Section 3.3.2.4.2 apply as well, with only the following exception:

- REQ-L3-OAD-106987 (AGWS Natural Seeing Sky Coverage)

The AGWS has additional requirements related to bringing the seven GMT M1-M2 segment pairs into phase to within the capture range of the NGWS, and a lower minimum sky coverage applies to these requirements.
Requirements on the NGWS and OIWFS are unique to the NGAO wavefront control mode.

3.3.4.4.1 AGWS

REQ-L3-OAD-107050: AGWS NGAO Sky Coverage

The AGWS shall meet its NGAO measurement accuracy requirements with a sky coverage of no less than 90% in the FP optical configuration.

Rationale: Direct flowdown from ORD sky coverage requirements, combined with constraints imposed by the optical configurations.
Notes: Sky coverage is defined as the fraction of the sky observable from the site above 30 degrees elevation over which the requirements are met.
The requirement must be met with the GIR either tracking apparent sky rotation or fixed.
No less than 52% of the total DG focal surface is available to the AGWS in the FP optical configuration (REQ-L3-OAD-33899.)

REQ-L3-OAD-35520: AGWS SPS Capture Range

The AGWS SPS sensor shall have a capture range no less than ± 30 µm.

Rationale: Consistent with ≥ 99.9% probability of capture after TMS alignment.
AGWS SPS Accuracy
The AGWS in the NGAO wavefront control mode shall measure on-axis and field-dependent segment phase piston with the accuracy specified in Table 3-29.

Table 3-29: AGWS NGAO Mode Accuracy Requirements

Requirements	DOF	Function	1σ Accuracy
REQ-L3-OAD-35531	On-axis segment phase piston	SPS	≤ 50 nm
REQ-L3-OAD-35535	Field-dependent segment phase piston	SPS	≤ 10 nm/arcmin

Rationale:
On-axis SPP Accuracy: This requirement is consistent with a total on-axis telescope segment phase piston error of ≤ 100 nm RMS in the LTAO mode, including ASMS actuation errors, wind, and vibrations. This ensures ≥99.9% probability of a successful segment phase piston control hand-off to the NGWS in the NGAO mode.
Field-dependent SPP Accuracy: Constrains field-dependent phasing error to a negligible level. Also consistent with the WFE budget of any potential future MCAO instrumentation.

3.3.4.4.2 NGWS

REQ-L3-OAD-35507: NGWS Direct Feed Architecture

The NGWS shall be replicated for each instrument operating in the NGAO wavefront control mode, and fed by reflection off the instrument cryostat window.

Rationale: The direct feed architecture and ASM wavefront correction enables diffraction-limited AO instruments to operate with only 3 warm reflections (M1, M2, and M3.)
Notes: The Direct Feed layout is illustrated in Figure 3-37.

REQ-L3-OAD-107051: NGWS Wavelength Range

The NGWS shall meet its performance requirements using only 450-920 nm wavelength light.

Rationale: The NGWS is fed by light reflected off a dichroic coating on the instrument window, which transmits all infrared light into the science instrument.
Notes: While the full 450-920 nm band is available to the NGWS, in the LTAO wavefront control mode the 588.0-590.6 nm light must be reflected to the LTWS by the LGS Dichroic included in the NGWS (REQ-L3-OAD-XXXXX).

REQ-L3-OAD-107052: NGWS Patrol Field

The NGWS shall meet its performance requirements using guide stars up to 60 arcsec off-axis.

Rationale: Based on site survey data, the median zenith anisoplanatic angle at 1.65 µm wavelength is 8 arcsec. The LTAO mode will provide significantly higher image quality for science targets whose nearest natural guide star is located beyond this.
Notes: This requirement implies some form of patrol mechanism to displace and/or tilt the NGWS optical axis with respect to the beam reflected from the instrument window.

REQ-L3-OAD-35512: NGWS Segment Phase Sensitivity Across Segment Gaps

The NGWS shall be sensitive to both continuous wavefront errors and phase differences across the GMT segment gaps.

Rationale: The high Strehl specified in OPM 9 requires control of both continuous and discontinuous atmospheric and telescope-caused phase errors, with a total residual error of ≤ 61 nm RMS. The coherent light of an on-axis guide star enables this to be achieved with a single sensor.
Notes: While a pyramid wavefront sensor can sense phase errors across gaps in the pupil, it is susceptible to phase wrapping when the wavefront error across the gaps exceeds one half of the sensing wavelength. The capture range requirement REQ-L3-OAD-35556 therefore implies the need for a secondary sensing channel to increase the capture range.
NGWS Capture Range
The NGWS shall have the capture ranges specified in Table 3-30.

Table 3-30: NGWS Capture Range Requirements

Requirements	Measurement	Min. Capture Range	Rationale
REQ-L3-OAD-35548	Image Motion	± 3.0 arcsec	Provides 99.9% probability of acquiring a guide star with 1.0 arcsec RMS differential pointing error between AGWS and FP.
REQ-L3-OAD-35552	Focus	± 1.6 mm	Accommodates a ±0.5 mm tolerance in the FP Instrument to NGWS mechanical interface, ±0.1 mm tolerance in the instrument window axial position, and an additional ±1.0 mm reserve.
REQ-L3-OAD-35556	Segment phase piston	± 2 µm	Accommodates extreme case of AGWS phasing error with faint guide stars.
REQ-L3-OAD-35560	Wavefront error excluding TTF	± 500 nm RMS (TBC)	On-axis active optics Instrument cryostat window aberrations plus expected active optics residual.
REQ-L3-OAD-35564	Chief ray angle	± TBD µrad	Sum of maximum flexure allotted to AGWS, Mount, M3, and Instrument in the Pupil Motion Budget.

Notes: The NGWS capture range must accommodate non-common path alignment and wavefront errors between then NGWS and AGWS, including those generated by the Mount, M3, and the Instrument supporting the NGWS.

REQ-L3-OAD-35516: NGWS Measurement Accuracy

The NGWS shall measure the wavefront error of an R = 10 guide star with a measurement error of ≤ 60 nm RMS wavefront at ≥1000 Hz.

Rationale: The NGAO wavefront error budget allocate ≤ 60 nm RMS to measurement error, and ≤ 28.3 nm RMS to temporal error. This requires a minimum of 1000 Hz frame rate (see ARC-AO-DOC-00011).

Notes: This requirement includes measurement of all modes, including segment and global tip-tilt and segment phase piston.
It includes all sources of measurement error inherent to the sensor, such as measurement noise, charge diffusion, aliasing, and pupil alignment error under the control of the NGWS. It does not include temporal errors due to the 1.0 ms nominal integration time or other latencies.

3.3.4.4.3 Instrument and OIWFS

Instrument Window
FP Instruments operating in the NGAO or LTAO wavefront control modes shall direct the light of natural and laser guide stars to the NGWS and LTWS using a dichroic instrument window specified in Table 3-31.

Table 3-31: Instrument Window Requirements

Requirement ID	Instrument Window Parameter	Value
REQ-L3-OAD-107057	Front surface distance from focus	500 ± 0.1 mm
REQ-L3-OAD-107058	Incidence angle	20.0 ± 0.05 deg
REQ-L3-OAD-107059	Reflected clear aperture	≥ 209.4 mm
REQ-L3-OAD-107062	Average reflectivity, 450.0 < λ < 560.0 nm	≥ 80%
REQ-L3-OAD-107063	Average reflectivity, 588.0 < λ < 590.6 nm	≥ 95%
REQ-L3-OAD-107064	Average reflectivity, 600.0 < λ < 920.0 nm	≥ 92%
REQ-L3-OAD-107065	Reflected wavefront error over any 150 mm diameter LGS footprint	≤ 100 nm RMS tip/tilt/piston removed

Rationale: The requirements specified here reflect the selected sensor layout and architectural design. This optical interface between subsystems is also defined in GMT-CAD-101372. The reflected wavefront requirement is derived from the expected wavefront error of the GMTIFS window under average atmospheric pressure (90 nm RMS at the worst-case field angle, ref. GMTIFS-FOS1-SDN-0001), with an additional allocation for polishing errors.
Notes: Atmospheric pressure will distort the instrument window with respect to its original polished figure. The reflected wavefront error specification above includes pressure distortion. Some compensation for the average aberrations in the reflected wavefront may be implemented within the NGWS and LTWS. Residual field-dependent and time-variable aberration will be initially transferred to the ASMS by the NGAO or LTAO control loop, and subsequently corrected by the Dynamic Calibration control loop.
OIWFS NGAO Capture Range
Instruments operating in the NGAO mode shall include an OIWFS with the capture ranges specified in Table 3-32.

Table 3-32: OIWFS NGAO Capture Range Requirements

Requirement ID	Measurement	Value
REQ-L3-OAD-107069	Image Motion	± 1.0 arcsec (TBC)
REQ-L3-OAD-107070	Focus	± 200 nm (TBC)
REQ-L3-OAD-107071	Low-order wavefront sensing ≥16×16 across pupil	± 1.0 arcsec wavefront slope (TBC)
REQ-L3-OAD-107072	Chief ray angle	± 6 mrad (TBC)

Rationale:
Initial target acquisition will be performed by the NGWS. The OIWFS capture range is therefore derived from the maximum expected flexure between the instrument and NGWS.

- **Image Motion:** Initial estimate, TBC.
- **Focus:** Initial estimate, TBC.
- **Low-order modes:** Initial estimate, TBC.
- **Chief ray angle:** Initial estimate, TBC.

Notes:
OIWFS NGAO Measurement Accuracy
Instruments operating in the NGAO mode shall include an OIWFS with the measurement accuracy specified in Table 3-33.

Table 3-33: OIWFS NGAO Measurement Accuracy Requirements

Requirement ID	Measurement	1σ Accuracy
REQ-L3-OAD-107078	Image Motion	≤ 0.10 mas at 0.1 Hz
REQ-L3-OAD-107079	Focus	≤ 5 nm at 0.1 Hz
REQ-L3-OAD-107080	Low-order wavefront sensing ≥16×16 across pupil	≤ 20 nm at 0.1 Hz
REQ-L3-OAD-107081	Chief ray angle	≤ 120 µrad at 0.1 Hz

Rationale: Allocations in NGAO WFE budget.
Notes: These requirements specify the maximum closed-loop measurement error (the RSS of both axes in the case of image motion). The focus measurement accuracy is specified in term of RMS wavefront error.

3.3.4.5 NGAO Disturbance Rejection

The rejection of optical disturbances is a function of the wavefront sensor frame rate, latency in the control loop, the transfer function of the corrector, and the control algorithm.
NGAO Latency Budget
The NGWS and OCS in the NGAO wavefront control mode shall have latency as specified in Table 3-34.

Table 3-34: NGAO Latency Budget

Requirement	Source	Latency [µs]	Comment
REQ-L3-OAD-70755	NGWS Readout	500	At 1.0 kHz frame rate
REQ-L3-OAD-70756	NGWS Slope Processing	100	From last pixel received to last slope transmitted
REQ-L3-OAD-70757	OCS NGAO Computation	200	Includes data transmission from NGWS and to ASMS
	Total Latency	800	

Rationale: Analysis in NGWS Preliminary Design Report (GMT-DOC-04969) found that a 2.0 ms delay in median atmospheric conditions results in 29.1 nm RMS WFE. This result has been scaled to flow down allowable latencies for each contributor from the NGAO WFE budget allocations.

REQ-L3-OAD-35570: NGAO Rejection Transfer Function

The NGAO wavefront control mode rejection transfer function for all controlled modes shall not exceed that in Figure 3-41.

Rationale: The specified rejection transfer function envelope is consistent with atmospheric and wind residual error allocated in the NGAO WFE budget, and limits the overshoot of the RTF that could otherwise excite resonances of the ASM reference body at 100-200 Hz.
Notes: 35575

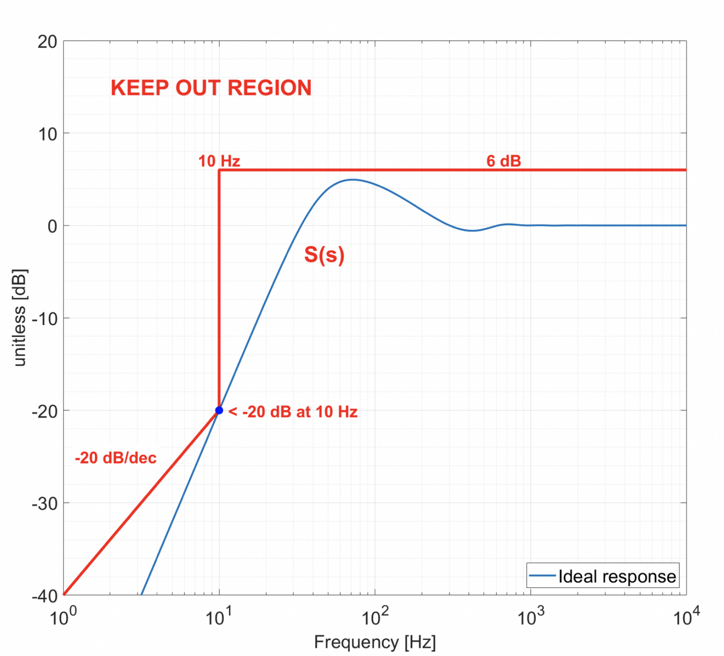

Figure 3-41: NGAO Rejection Transfer Function Limits

Notes:
These transfer function limits apply strictly only to the segment tip, tilt, and piston modes, for which wind is the dominant disturbance and the excitation of reference body mechanical resonances is a concern. The transfer function for higher-order modes should be optimized based on the relevant disturbances and mechanical constraints.
See REQ-L3-OAD-35337 for a discussion of the transfer function limits and the ideal response. The parameters used for the ideal NGAO RTF are:

- Requirements: T_i=1.0 ms, τ_l=0.8 ms, f_{bw}=800 Hz, f_{wc}=10 Hz, S_{max}=6 dB
- Controller: ζ=0.7, f_c=44.62 ms, f_2=22.40 ms, g_i=0.280

3.3.5 Laser Tomography Adaptive Optics

3.3.5.1 Introduction

The LTAO wavefront control mode uses an asterism of laser guide stars to tomographically reconstruct the high-order components of the atmospheric wavefront error in the direction of an on-axis science target, which are corrected by the Adaptive Secondary Mirror. This control mode provides a nearly diffraction-limited PSF in the near-infrared over a field of view limited by atmospheric anisoplanatism, with high sky coverage. This mode is used for general-purpose high spatial resolution imaging and spectroscopy, particularly of faint and/or extended objects.
Wavefront sensing in the LTAO mode is provided by the Laser Tomography Wavefront Sensor Subsystem (LTWS) and the On-Instrument Wavefront Sensor (OIWFS). These are supplemented by the AGWS (low-bandwidth segment phasing control) and M1 and M2 edge sensors (high-bandwidth segment

phasing control). Instruments using the LTAO wavefront control mode may be located at any focal station, but the requirements flowdown has so far been performed only for the Folded Port station, where the GMTIFS and GMTNIRS instruments will be located.

The LTWS is replicated for each instrument and fed by light reflected off the instrument dichroic window (see Figure 3-37). It measures high-order wavefront errors with a pupil sampling of at least 60x60 at ≥500 Hz, but is unable to measure global tip, tilt, and focus due to the co-mounting of the lasers on the telescope and unknown range to the sodium layer in which the guide stars are generated. It is also unable to measure segment piston errors due to the incoherence of the laser guide star light.

An On-Instrument Wavefront Sensor (OIWFS) within the instrument measures the aberrations that cannot be sensed by the LTWS using the light of a faint off-axis natural guide star. These include global tip-tilt at ≥500 Hz (lower for very faint guide stars), focus at ≥10 Hz, and slowly-varying low-order aberrations caused by non-linear response of the LTWS and non-common aberrations to the LTWS.

Phasing the GMT segment pairs at high bandwidth and with high precision is a critical aspect of the LTAO wavefront control mode. As in the NGAO mode, initial alignment using the TMS laser truss (Figure 3-38, Step 1) is followed by phasing capture and control over a wide field at low bandwidth by the AGWS DFS sensors (Step 2). The AGWS is allocated a segment phase piston measurement error of ≤ 50 nm RMS across the full GMT field of view, using guide stars that provide a sky coverage ≥ 90%. When combined with other error sources, this enables the telescope to be phased to ≤ 100 nm RMS at low bandwidth (update every 30s).

The high-bandwidth component of telescope segment phasing control is provided by the M1 and M2 edge sensors. The M1 edge sensors are a component of the TMS, while the M2 edge sensors are a component of the ASMS. Both are required to measure segment piston errors with a sampling rate of ≥500 Hz, and their measurements are fed-forward to the ASMS. Any long-term drift of the edge sensors is corrected by the outer AGWS phasing feedback loop.

As in the other wavefront control modes, the AGWS fulfills the target acquisition and segment stacking functions and brings the telescope to an initial seeing-limited state. Once the high-bandwidth LTAO control loops are closed between the LTWS and OIWFS and the ASMS, the AGWS continues to operate in a supporting role, measuring residual aberrations off-axis to enable low-bandwidth correction of M1 segment position and figure errors and Mount pointing errors. It also maintains segment phasing at low bandwidth, as described above.

In summary, the LTAO wavefront control mode shall control the optical degrees of freedom listed in Table 3-35 using model-based trajectories supplemented by measurements provided by the sensors listed in Table 3-36. A control block diagram is provided in Figure 3-42.

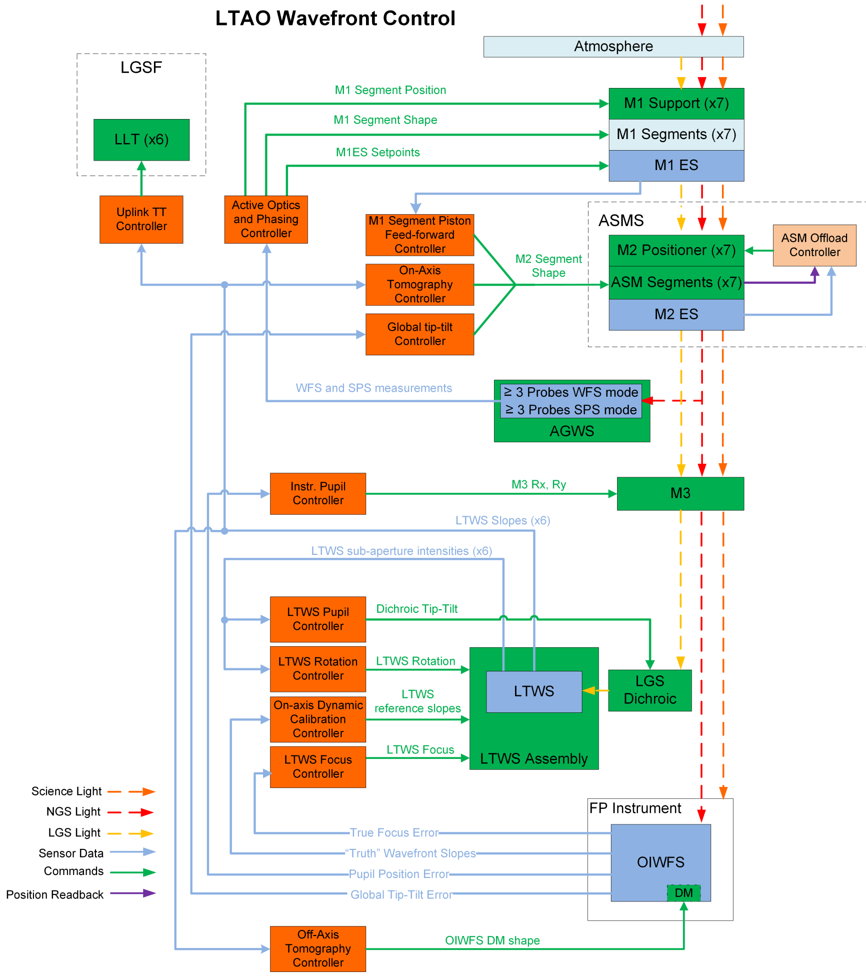

Figure 3-42: LTAO Wavefront Control Block Diagram

LTAO Controlled Degrees of Freedom

The GMT in the LTAO wavefront control mode shall actively control the optical degrees of freedom specified in Table 3-35.

Table 3-35: LTAO Controlled Degrees of Freedom

Requirement ID	System	Degree of Freedom	# DOF
REQ-L3-OAD-34798	Mount	Azimuth, Elevation, and GIR Rotation	3
REQ-L3-OAD-34802	M1S	M1 segment rigid body position	7 × 6
REQ-L3-OAD-34806	M1S	M1 segment shape	7 × ≥ 27 bending modes
REQ-L3-OAD-34810	FSMS/ASMS	M2 segment rigid body position	7 × 6
REQ-L3-OAD-107023	ASMS	M2 segment shape	7 × ≥ 500 actuators
REQ-L3-OAD-34814	M3	M3 piston, tip, and tilt	3

Rationale: Active control of these degrees of freedom is required to compensate for gravity and thermal deflections and distortions, and atmospheric optical turbulence, to achieve the image quality specified in OPM 7 and 8.

Notes:
LTAO Wavefront Sensing and Metrology
The GMT in the LTAO wavefront control mode shall utilize the wavefront sensors specified in Table 3-36.

Table 3-36: NGAO Wavefront Sensing and Metrology

Requirement ID	Subsystem	Measurement	Rate
REQ-L3-OAD-35127	TMS	M1 and M2 segment rigid body position with respect to OSS coordinates	≥ 0.067 Hz
REQ-L3-OAD-106982	AGWS	Acquisition imaging of ≥ 1 off-axis guide star	N/A
REQ-L3-OAD-35131	AGWS	Wavefront error at ≥3 locations in DG focal plane with at least 24×24 sampling of the pupil.	≥ 0.03 Hz
REQ-L3-OAD-35483	AGWS	Segment phase piston error at ≥3 locations in DG focal plane	≥ 0.03 Hz
REQ-L3-OAD-110122	LTWS	Wavefront of 6 off-axis LGS with at least 60×60 sampling of the pupil	≥ 500 Hz
REQ-L3-OAD-110123	Instrument	Image motion	≥ 500 Hz
REQ-L3-OAD-110871	Instrument	Image motion	≥ 10 Hz
REQ-L3-OAD-35495	Instrument	Low-order (~16×16) wavefront error	≥ 0.10 Hz
REQ-L3-OAD-35499	Instrument	Pupil position (chief ray angle) error	≥ 0.10 Hz

Rationale:
AGWS: The AGWS WFS is used for initial acquisition, stacking, alignment, and figure correction of the telescope, and to maintain negligible field-dependent aberrations during LTAO operation. The AGWS SPS are necessary to initially phase the telescope and maintain phasing at low bandwidth.
LTWS: A fast wavefront sensor with at least 60×60 pupil sampling is necessary to meet the atmospheric fitting error WFE allocation.
Instrument: The instrument OIWFS must measure the aberrations to which the LTWS is insensitive: tip-tilt, focus, and low-order LGS aberrations. It must also measure low-order errors due to changing non-common path aberrations to the LTWS. The feedback on pupil alignment is required by the pupil motion allocation.
Notes:

3.3.5.2 LTAO Control Algorithms

The LTAO wavefront control mode algorithms are defined in applicable document GMT-REQ-04467 LTAO Wavefront Control Mode Algorithms. The acquisition steps are identical to the NS mode, and those requirements from Section 3.3.2.2 apply.

REQ-L3-OAD-110878: On-Axis Tomography Control Loop

The On-Axis Tomography control loop shall tomographically reconstruct the on-axis wavefront error from wavefront measurements made by the LTWS, and apply corrections for this error to the ASMS face sheets.

Rationale: The On-Axis Tomography control loop corrects atmospheric and telescope phase error to deliver diffraction-limited image quality for the science instrument. Tomographic reconstruction of multiple laser guide stars is required to minimize the error caused by the finite altitude of the LGS (the cone effect).

REQ-L3-OAD-110879: Off-Axis Tomography Control Loop

The Off-Axis Tomography control loop shall tomographically reconstruct the off-axis wavefront error from wavefront measurements made by the LTWS, and apply corrections for this error to the OIWFS deformable mirror.

Rationale: The Off-Axis Tomography control loop corrects the high-order anisoplanatism between the science target and an off-axis NGS used for low-order wavefront sensing to enable the use of faint NGS.
Notes: This control loop is only required for instruments using off-axis NGS corrected by an open-loop DM, such as GMTIFS.

REQ-L3-OAD-110880: Uplink Tip-Tilt Control Loop

The Uplink Tip-Tilt control loop shall reconstruct the global tip-tilt error of each LGS from wavefront measurements made by the LTWS, and apply corrections for this error using the LGSS fast steering mirrors.

Rationale: The Uplink Tip-Tilt control loop maintains the LGS centered on the LTWS Shack-Hartmann wavefront sensor field stops, compensating for flexure in the Mount and LGSS, and atmospheric tip-tilt.

REQ-L3-OAD-110881: NGS Tip-Tilt Control Loop

The NGS Tip-Tilt control loop shall receive the NGS global tip-tilt error measured by the OIWFS and apply corrections for this error to the ASMS face sheets.

Rationale: The NGS Tip-Tilt control loop corrects the global tip-tilt error that cannot be measured with the LGS, to deliver diffraction-limited image quality to the science instrument.

REQ-L3-OAD-110882: LTWS Focus Control Loop

The NGS Focus control Loop shall receive the NGS global focus error measured by the OIWFS and apply corrections for this error to the LTWS focus stage.

Rationale: The NGS Focus control loop corrects the global focus error that cannot be measured with the LGS, to deliver diffraction-limited image quality to the science instrument.

REQ-L3-OAD-110884: On-Axis Dynamic Calibration Control Loop in LTAO Mode

The On-Axis Dynamic Calibration control loop in the LTAO control mode shall reconstruct the low-order wavefront error from measurements made by the OIWFS, and apply corrections for this error to the LTWS reference slopes.

Rationale: The On-Axis Dynamic Calibration control loop corrects low-order aberrations induced by LGS sodium layer density variations and changing non-common path aberrations between the LTWS and Instrument, to deliver diffraction-limited image quality to the science instrument.

REQ-L3-OAD-110885: Off-Axis Dynamic Calibration Control Loop in LTAO Mode

The Off-Axis Dynamic Calibration control loop in the LTAO control mode shall reconstruct the low-order wavefront error from measurements made by the OIWFS downstream of its deformable mirror, and apply corrections for this error to the OIWFS deformable mirror commands.

Rationale: The Off-Axis Dynamic Calibration control loop corrects low-order aberrations in the open-loop OIWFS DM figure, to optimize the sensitivity of the OIWFS and achieve the required sky coverage.
Notes: This control loop is only required for instruments using off-axis NGS corrected by an open-loop DM, such as GMTIFS.

REQ-L3-OAD-110886: LTWS Rotation Control Loop

The LTWS Rotation control loop shall reconstruct pupil rotation error from the subaperture intensities measured by the LTWS, and apply corrections for this error to the LTWS rotation stage.

Rationale: The LTWS Rotation control loop corrects rotation errors of the LTWS rotation stage, to maintain the LGS asterism in its expected geometry.

REQ-L3-OAD-110887: LTWS Pupil Control Loop

The LTWS Pupil control loop shall reconstruct pupil position error from the subaperture intensities measured by the LTWS, and apply corrections for this error to the LGS Dichroic tip and tilt.

Rationale: The LTWS Pupil control loop corrects flexure between the instrument and LTWS optical axes, to maintain the expected LTWS subaperture to ASMS actuator registration.
Notes: The LTWS Pupil control loop is effectively a second-stage control of the chief ray angle, after the Instrument Pupil control loop aligns the chief ray to the OIWFS optical axis.

REQ-L3-OAD-110888: M1 Segment Piston Feed-Forward Control Loop

The M1 Segment Piston feed-forward loop shall receive the M1 differential piston error measured by the TMS M1 Edge Sensors, and apply corrections for this error to the ASMS face sheets.

Rationale: The M1 Segment Piston feed-forward control loop corrects flexure and segment vibrations at temporal frequencies greater than those corrected by the Active Optics and Phasing control loop, to deliver diffraction-limited image quality for the science instrument.

REQ-L3-OAD-110889: M2 Segment Piston Feed-Forward Control Loop

The M2 Segment Piston feed-forward loop shall receive the M2 differential piston error measured by the ASMS M2 Edge Sensors, and apply corrections for this error to the ASMS face sheets.

Rationale: The M2 Segment Piston feed-forward control loop corrects flexure and segment vibrations at temporal frequencies greater than those corrected by the Active Optics and Phasing control loop, to deliver diffraction-limited image quality for the science instrument.
Notes: The M2 Segment Piston feed-forward loop is implemented within the ASMS.

REQ-L3-OAD-111929: Active Optics and Phasing Control Loop in LTAO Mode

The Active Optics and Phasing control loop in the LTAO control mode shall reconstruct field-dependent segment aberrations and both on-axis and field-dependent segment phase piston from measurements made by the AGWS, and apply corrections for these errors to the Mount, M1S segment positions and shapes, and TMS M1 Edge Sensor setpoints.

Rationale: The Active Optics and Phasing control loop corrects Mount pointing errors and M1 segment position and shape errors to maintain field-dependent aberrations within acceptable limits. It also provides low-bandwidth control of on-axis segment phase piston by correcting the setpoints of the M1 Edge Sensors.

REQ-L3-OAD-35364: ASM Offload Control Loop

The ASM Offload control loop, specified in GMT-REQ-04569 Section 3.4.5 (Offloading Loops), shall offload low-order face sheet shape offsets to the M2 Positioner to preserve face sheet stroke.

Rationale: The M2 Positioner degrees of freedom are degenerate with respect to segment piston, tip, tilt, focus, and astigmatism produced by the ASM face sheets. The ASM provides high bandwidth control of these modes with a limited stroke, while the M2 Positioner provides lower bandwidth with a wide range of motion. An offload from the ASM to M2 Positioner maximizes the available ASM face sheet stroke.
Notes: The ASM offload control loop will be implemented by the ASMS. The offloads will be an offset to the model-based M2 Positioner trajectory.

REQ-L3-OAD-35418: Instrument Pupil Control Loop

The Instrument Pupil control loop, specified in GMT-REQ-04174 Section 7 (Instrument Pupil Control Algorithms), shall reconstruct pupil position from the subaperture intensities measured by the instrument OIWFS and apply corrections for this error to the R_X and R_Y degrees of freedom of M3.

Rationale: The Instrument Pupil control loop corrects flexure of the Mount and M3, to maintain the chief ray aligned to the instrument and wavefront sensor optical axes.
Notes: A tip-tilt error of M3 will result in pupil (chief ray) misalignment at the instrument and a pointing error. The pupil misalignment will be detected as a displacement of the illuminated subapertures in the OIWFS Truth sensor. When corrected by a tip or tilt of M3, this will result in a pointing change, which the NGWS or OIWFS (in NGAO and LTAO modes, respectively) will detect and correct with the ASMS.

3.3.5.3 LTAO Controlled Degrees of Freedom

The LTAO wavefront control mode imposes few additional requirements on optics actuation beyond those of the NGAO mode. The sole exceptions are requirements on actuation of the the LGS Dichroic, used to control pupil position (chief ray angle) on the LTWS.

3.3.5.3.1 LGS Dichroic

The LGS Dichroic is a component of the NGWS that directs light of the LGS to the LTWS when operating in the LTAO wavefront control mode. This function could be fulfilled by a dichroic optic as in the PDR design or by a mirror than can be translated out of the beam when operating in NGAO wavefront control mode.

REQ-L3-OAD-112752: LGS Dichroic Tip-Tilt Function

The NGWS shall actuate the LGS Dichroic in tip and tilt.

Rationale: Required to compensate for LTWS focus stage angular errors (pitch and yaw). Also used for initial alignment and flexure compensation.

REQ-L3-OAD-112753: LGS Dichroic Tip-Tilt Accuracy

The NGWS LGS Dichroic tip-tilt actuation shall have an absolute accuracy of $\leq$ 1.0 mrad RMS with respect to the Instrument-NGWS mechanical interface, anywhere within its range of motion after calibration.

Rationale: This corresponds to a pupil alignment error of one LTWS subaperture, easily detectable and corrected.

REQ-L3-OAD-112754: LGS Dichroic Tip-Tilt Repeatability

The NGWS LGS Dichroic tip-tilt actuation shall have a repeatability of ≤ 10 μrad RMS for small offsets.

Rationale: This corresponds to a pupil alignment error of 1% of an LTWS subaperture, a negligible term in the pupil alignment budget.

REQ-L3-OAD-112755: LGS Dichroic Tip-Tilt Range

The NGWS LGS Dichroic tip-tilt actuation shall have a range of at least ± 6.0 mrad (TBC).

Rationale: This corresponds to 10 times the largest LTWS focus stage tilt errors considered in GMT-DOC-01508. The additional range can be used to compensate initial alignment errors and flexure.
LGS Dichroic Optical Requirements
The NGWS shall direct the light of laser guide stars to the LTWS using a dichroic or mirror specified in Table 3-37.

Table 3-37: LGS Dichroic Optical Requirements

Requirement ID	Parameter	Value
REQ-L3-OAD-112169	Front surface distance from instrument window	320.0 ± 0.1 mm
REQ-L3-OAD-112170	Incidence angle	25.0 ± 0.05 deg
REQ-L3-OAD-112171	Reflected clear aperture	≥ 175.2 mm
REQ-L3-OAD-112172	Average reflectivity, 588.0 < λ < 590.6 nm	≥ 98%
REQ-L3-OAD-112175	Reflected wavefront error over any 110 mm diameter LGS footprint	≤ 1.0 μm P-V ≤ 20 nm RMS with tip, tilt, and focus removed

Rationale: These requirements reflect the selected sensor layout and architectural design. The optical interface between subsystems is defined in GMT-CAD-101372. The reflected wavefront error requirement is derived from the LTAO WFE budget allocation.
Notes: If this optic were implemented as a fixed dichroic rather than an actuated mirror, then transmitted throughput and wavefront error requirements would be derived from the NGWS performance allocations.

3.3.5.4 LTAO Wavefront Sensing and Metrology

The LTAO wavefront control mode sensing requirements on the TMS and AGWS are identical to those in the NGAO mode.
Requirements on the LGSS, LTWS, Instrument OIWFS, and TMS that are unique to the LTAO wavefront control mode are specified in this section.

3.3.5.4.1 LGSS

The Laser Guide Star Subsystem (LGSS) projects lasers to the mesospheric sodium layer to create an asterism of laser guide stars (LGS). It also provides a Laser Acquisition System to identify initial laser pointing errors to enable the LGS to be steered to the correct location in the telescope focal plane. The system-level performance requirements on the LGSS are specified in this section.

REQ-L3-OAD-112151: LGSS function

The LGSS shall generate sodium laser guide stars at 589 nm wavelength.

Rationale: Architectural choice that enables high sky coverage with an acceptably low tomography error.

REQ-L3-OAD-112152: LGS Asterism

The LGSS shall project a 6 laser guide stars in a circular asterism centered on the telescope optical axis, with a radius adjustable between 25.0 and 35.0 arcsec.

Rationale: Six LGS are sufficient to provide a tomography error of <100 nm RMS, while also matching the GMT pupil's six-fold symmetry. The optimal radius for on-axis tomography is 25 arcsec at zenith and 20 arcsec at za=45. However, a wider asterism improves the off-axis tomographic reconstruction, and this correction will reduce the dominant error budget term when using faint off-axis NGS. A range of 25-35 arcsec radius is sufficient to optimize the system performance for all first-generation instrument science cases.
Notes: It is expected that each instrument will use an LTWS designed to a fixed LGS asterism (eg. 25.0 arcsec for the GMTNIRS LTWS and 30.0 arcsec for the GMTIFS LTWS).

REQ-L3-OAD-112153: LGS Photon Return Flux

The LGSS shall generate laser guide stars with an annual-median return flux at the GMT primary mirror of no less than 400 ph/cm^2/s (TBC).

Rationale: Analysis in GMT-DOC-05025 derives an expected return flux of 407 ph/cm2/s at 15 degrees zenith angle for seasonal minimum sodium density. This has been conservatively adopted as the annual median value.
Notes: This requirement specifies the median return flux over a representative ensemble of GMT observations (over zenith angle and season).

REQ-L3-OAD-112154: LGS Spot Size

The LGSS shall generate LGS with a FWHM no greater than 1.0 arcsec along the axis perpendicular to spot elongation, when imaged through a 42x42 cm square aperture.

Rationale: The PDR LGS spot size budget predicts a detected FWHM of 0.89 arcsec, dominated by detector charge diffusion. We therefore adopt a conservative requirement of 1.0 arcsec, and use this value in performance simulations.
Notes: Includes all sources of spot broadening, including atmospheric phase error, subaperture diffraction, and charge diffusion on the LTWS detector.

REQ-L3-OAD-112155: LGS Pointing Range

The LGSS shall point the laser guide stars over an angular range of no less than ± 2.6 arcmin with respect to the normal to the Mount-LGSS mechanical interface.

Rationale: The maximum LGS pointing range required to compensate for asterism adjustment (25-35 arcec) and all expected sources of misalignment (eg. installation tolerances, Mount and LGSS gravity flexure) is 5.2 arcmin P-V.
Notes: The LGSS must meet all performance requirements over this pointing range.

REQ-L3-OAD-112305: LGS Blind Pointing Accuracy

The GMT shall point the laser guide stars with a blind pointing accuracy of ≤ 4.6 arcsec peak error.

Rationale: Correspondnds to half of the LTWS 9.2 arcsec square field stop, enabling the LGS to be acquired by the LTWS without the need for LAS feedback during routine operation.
Notes: This requirement applies after calibration of open-loop pointing and flexure models.

REQ-L3-OAD-112306: Laser Acquisition System Function

The LGSS Laser Acquisition System shall measure the position of the LGS with respect to the telescope optical axis.

Rationale: Required for initial alignment of the LGS asterism, and developing LGSS pointing and flexure models.
Notes: The current LAS concept is a small off-axis telescope located on the Mount that images the LGS and computes an astrometric solution for them based on observed background field stars.

REQ-L3-OAD-112307: Laser Acquisition System Accuracy

The LGSS Laser Acquisition System shall measure the position of the LGS with respect to the telescope optical axis with an accuracy of ≤ 0.5 arcsec RMS.

Rationale: Sufficient to accurately center the LGS in the 9.2 arcsec square LTWS field stops.

REQ-L3-OAD-112880: Laser Acquisition System Capture Range

The LGSS Laser Acquisition System shall have a capture range ≥ 6.0 arcmin diameter centered on the telescope optical axis.

Rationale: The maximum LGS pointing range required to compensate for asterism adjustment (25-35 arcec) and all expected sources of misalignment (eg. installation tolerances, Mount and LGSS gravity flexure) is 5.2 arcmin P-V. A field of view of 6.0 arcmin, once properly boresighted with the GMT, should be sufficient to command all correctable motions of the LGS.

3.3.5.4.2 LTWS

The Laser Tomography Wavefront Sensor Subsystem (LTWS) measures the high-order components of the atmospheric and telescope phase error.

REQ-L3-OAD-112156: LTWS Direct Feed Architecture

The LTWS shall be replicated for each instrument operating in the LTAO wavefront control mode, and fed by reflection off the instrument cryostat window and the NGWS LTAO Dichroic.

Rationale: The direct feed architecture and ASM wavefront correction enables diffraction-limited AO instruments to operate with only 3 warm reflections (M1, M2, and M3.)
Notes: The Direct Feed layout is illustrated in Figure 3-37.

REQ-L3-OAD-112157: LTWS Wavelength Range

The LTWS shall operate using the 589 nm wavelength light of the sodium laser guide stars.

Rationale: Consistent with the use of sodium laser guide stars.

REQ-L3-OAD-112158: LTWS Sensor Configuration

The LTWS shall have 6 wavefront sensors equally spaced on a circle centered on the telescope optical axis, configurable to radii of 25 to 35 arcsec.

Rationale: The optimal asterism radius for instruments using only on-axis NGS is 25 arcsec, while that for instruments using off-axis NGS is 30-35 arcsec (see GMT-DOC-05025). The design of the LTWS must be consistent with both of these configurations.
Notes: The intent of this requirement is that the LTWS be configurable based on the instrument science case. It does not require the LTWS to be adjustable during operation.

REQ-L3-OAD-112159: LTWS Sensor Type

The LTWS wavefront sensors shall be of a Shack-Hartmann type with a pupil sampling of at least 60x60 subapertures.

Rationale: Shack-Hartmann wavefront sensors provide the required combination of large field of view and linearity. The pupil sampling of 60x60 minimizes the sum of atmospheric fitting error and measurement error assuming seasonal sodium minimum conditions.

REQ-L3-OAD-112160: LTWS Pixel Sampling

The LTWS shall have a pixel sampling of ≤ 0.8 arcsec/pixel.

Rationale: Maintains acceptable centroiding error assuming delivered laser spot could be somewhat smaller than specified by OAD-112154. See analysis in GMT-DOC-05025.
Notes: PDR reference design has 0.71 arcsec pixels.

REQ-L3-OAD-112161: LTWS Field of View

The LTWS shall have a field of view of ≥ 9.2 arcsec.

Rationale: Maintains acceptable LGS truncation errors. See analysis in GMT-DOC-05025.
Notes: PDR reference design has an 9.2 arcsec FOV.

REQ-L3-OAD-112162: LTWS Differential Registration Error

The LTWS wavefront sensors shall have a relative pupil registration error of ≤ 4.2 cm (TBC) in the entrance pupil.

Rationale: This corresponds to ≤10% of a subaperture, often used as a rule of thumb for AO misregistration errors. Analysis is required to evaluate the impact of relative pupil registration errors on tomography error.
Notes: This requirement specifies the maximum allowable mis-registration between matched subapertures of the 6 LTWS wavefront sensors, due to flexure, magnification, distortion, etc. Global registration errors between the LTWS to the ASMS are not included.

REQ-L3-OAD-112163: LTWS Frame Rate

The LTWS shall have a maximum frame rate no less than 500 Hz.

Rationale: Required to meet the 30 nm RMS WFE latency allocation.

REQ-L3-OAD-112164: LTWS Measurement Error

The LTWS shall have ≤ TBD mas RMS slope error averaged over the pupil, at 500 Hz frame rate with the LGS return flux specified in REQ-L3-OAD-112153.

Rationale: Derived from a 69.4 nm RMS WFE allocation to LTWS measurement and aliasing errors.

REQ-L3-OAD-112165: LTWS Asterism Rotation

The LTWS shall track the rotating LTAO asterism.

Rationale: The GIR will usually track the apparent sky rotation, causing the LTAO asterism to appear to rotate at the instrument.

REQ-L3-OAD-112166: LTWS Focus Range

The LTWS shall refocus to track the LGS range from 83.5 km to 190 km.

Rationale: The mesospheric sodium layer has a density-weighted mean altitude of 91.79 km with a standard deviation of 1.15 km (Moussaoui et al., A&A 511, A31, 2010). We adopt as limits the 5-sigma values of 86.0 to 97.5 km altitude. At the GMT site altitude of 2550 m, this corresponds to focus range limits of 83.5 km (at zenith) to 190 km (at zenith angle 60 degrees).

3.3.5.4.3 Instrument and OIWFS

Instruments operating in the LTAO wavefront control mode must provide an NGS OIWFS that senses the aberrations that cannot be measured from the LGS. Since the LGS can be pointed anywhere, the patrol field and sensitivity of the OIWFS determine the locations on the sky for which a given threshold of image quality can be achieved.

A common approach to deriving performance requirements on an LGS-based AO system is to specify the minimum fractional sky coverage over which the threshold image quality must be achieved. This is equivalent to the fraction of known science targets that can be observed if the spatial distribution of those science targets is uncorrelated with that of the NGS. The ORD requirements on Strehl and encircled energy diameter achievable at 50% and 80% sky coverage (OPM 7 and OPM 8) are derived from GMTIFS extragalactic science cases, and flow down to requirements on the GMTIFS OIWFS.

In contrast, the GMTNIRS instrument will exclusively observe infrared-bright targets for which the LTAO NGS can be the science target itself. Fractional sky coverage is therefore an irrelevant metric, replaced by the fraction of the potential GMTNIRS science targets that can be observed. The requirements for on-axis guide stars have been derived assuming that at least 90% of the potential GMTNIRS targets must be observable with the image quality meeting the OPM 7 (50% sky coverage) requirements.

OIWFS LTAO Capture Range

Instruments operating in the NGAO mode shall include an OIWFS with the capture ranges specified in Table 3-38.

Table 3-38: OIWFS LTAO Capture Range Requirements

Requirement ID	Measurement	Value
REQ-L3-OAD-113462	Image Motion	± 2.5 arcsec
REQ-L3-OAD-113463	Focus	± 5 µm (TBC)
REQ-L3-OAD-113464	Low-order wavefront sensing ≥16×16 across pupil	± 1.0 arcsec wavefront slope (TBC)
REQ-L3-OAD-113465	Chief ray angle	± 6 mrad (TBC)

Rationale:

Image motion: Initial target acquisition will be performed by the AGWS. The OIWFS capture range is therefore specified as ±2.5 times the standard deviation of the FP guided pointing budget total (1.0 arcsec).

Focus and Low-order aberrations: The LTAO Tomography control loop will be closed prior to OIWFS operation, and the focus and low-order mode capture ranges are therefore derived from the maximum expected error in the sodium layer range estimate and the low-order wavefront error due to sodium layer density variations.

Chief ray angle: Derived from the maximum expected error at FP in open loop, due primarily to M3 flexure.
Notes:
OIWFS LTAO 50% Sky Coverage Measurement Accuracy
Instruments operating in the LTAO mode using off-axis NGS shall have an OIWFS with the measurement accuracy as specified in Table 3-39, when using a K=17.0 guide star at 45 arcsec off-axis (TBC).

Table 3-39: OIWFS LTAO 50% Sky Coverage Measurement Accuracy Requirements

Requirement ID	Measurement	1σ Accuracy
REQ-L3-OAD-112190	Image Motion	≤ 2.1 mas at 500 Hz (TBC)
REQ-L3-OAD-112191	Focus	≤ 35 nm at 10 Hz (TBC)
REQ-L3-OAD-112192	Low-order wavefront sensing ≥16×16 across pupil	≤ 45 nm at 0.1 Hz (TBC)
REQ-L3-OAD-112193	Chief ray angle	≤ 120 µrad at 0.1 Hz (TBC)

Rationale: Allocations in the LTAO 50% Sky Coverage WFE budget, for measurement error and aliasing. Does not include latency error or anisoplanatism.
Notes: These requirements specify the maximum closed-loop measurement error (the RSS of both axes in the case of image motion).
OIWFS LTAO 80% Sky Coverage Measurement Accuracy
Instruments operating in the LTAO mode using off-axis NGS shall have an OIWFS with the measurement accuracy as specified in Table 3-40, when using a K=18.0 guide star at 60 arcsec off-axis (TBC).

Table 3-40: OIWFS LTAO 80% Sky Coverage Measurement Accuracy Requirements

Requirement ID	Measurement	1σ Accuracy
REQ-L3-OAD-112885	Image Motion	≤ 5.0 mas at 500 Hz (TBC)
REQ-L3-OAD-112886	Focus	≤ 50 nm at 10 Hz (TBC)
REQ-L3-OAD-112887	Low-order wavefront sensing ≥16×16 across pupil	≤ 60 nm at 0.1 Hz (TBC)
REQ-L3-OAD-112888	Chief ray angle	≤ 120 µrad at 0.1 Hz (TBC)

Rationale: Allocations in the LTAO 80% Sky Coverage WFE budget, for measurement error and aliasing. Does not include latency error or anisoplanatism.
Notes: These requirements specify the maximum closed-loop measurement error (the RSS of both axes in the case of image motion).
OIWFS LTAO On-Axis NGS Measurement Accuracy
Instruments operating in the LTAO mode using on-axis NGS shall have an OIWFS with the measurement accuracy as specified in Table 3-41, when using a J=15.4, H=14.5, and K=13.8 on-axis guide star.

Table 3-41: OIWFS LTAO On-Axis NGS Measurement Accuracy Requirements

Requirement ID	Measurement	1σ Accuracy
REQ-L3-OAD-112905	Image Motion	≤ 2.1 mas at 500 Hz (TBC)
REQ-L3-OAD-112906	Focus	≤ 35 nm at 10 Hz (TBC)
REQ-L3-OAD-112907	Low-order wavefront sensing ≥16×16 across pupil	≤ 45 nm at 0.1 Hz (TBC)
REQ-L3-OAD-112908	Chief ray angle	≤ 120 µrad at 0.1 Hz (TBC)

Rationale: Allocations in the LTAO 50% Sky Coverage WFE budget (OPM 7) are adopted for the on-axis NGS threshold performance. The limiting NGS magnitudes are derived from the sample GMTNIRS target lists analyzed in FWN114. They represent the 90th percentile magnitudes of the TW Hya targets (J and H) and exoplanet targets (K).
Notes: These requirements specify the maximum closed-loop measurement error (the RSS of both axes in

the case of image motion).
OIWFS Deformable Mirror
Instruments operating in the LTAO mode using off-axis NGS shall have a deformable mirror in the OIWFS as specified in Table 3-42.

Table 3-42: OIWFS Deformable Mirror Requirements

Requirement ID	Parameter	Value
REQ-L3-OAD-112894	Number of actuators across pupil	≥ 20×20 (TBC)
REQ-L3-OAD-112895	Surface stroke	≥ 2.0 µm (TBC)
REQ-L3-OAD-112896	Update rate	≥ 500 Hz (TBC)
REQ-L3-OAD-112897	Surface figure error	≤ 50 nm RMS (TBC)

Rationale: The number of actuators, stroke and update rate were derived in the LTAO Preliminary Design (GMT-DOC-05025). The surface figure error is an initial allocation.
Notes: The surface figure error specifies the total figure error due to the best-flat, ringing, creep, and similar effects.

REQ-L3-OAD-112756: OIWFS Patrol Field

The Instrument OIWFS shall be capable of observing any NGS from 15.0 to 60.0 arcsec (TBC) from the instrument optical axis.

Rationale: Required to achieve 80% sky coverage.
Notes: Applicable only to instruments using off-axis NGS.

3.3.5.4.4 Edge Sensors

Edge sensors between M1 and M2 segments supplement the low-bandwidth segment phase piston measurements made by the AGWS to enable phasing of the GMT in the LTAO mode. The edge sensor measurements are fed forward to the ASMS, and their setpoints corrected every 30s based on the off-axis natural guide star measurements made by the AGWS.
The M1 Edge Sensor measurement accuracy is specified explicitly in this section because the control is performed by the OCS. However, at M2 the control is performed internal to the ASMS and therefore only the final phasing error is specified.

REQ-L3-OAD-112760: ASMS Segment Piston Error

The ASMS shall maintain the segments in their commanded positions with a differential segment phase piston error ≤ 31 nm RMS surface.

Rationale: Corresponds to a 62 nm RMS WFE allocation in the LTAO image quality budget.
Notes: The requirement applies over any 120s period (the nominal AGWS outer loop bandwidth), median over regular operating conditions.
M1 Edge Sensor Measurement Accuracy
The TMS shall measure differential motion of the M1 segments with the accuracy specified in Table 3-43.

Table 3-43: M1 Edge Sensor Measurement Accuracy Requirements

Requirement ID	**DOF**	**1σ Accuracy**
REQ-L3-OAD-112764	Differential T_Z	≤ 25 nm RMS surface at ≥ 500 Hz
REQ-L3-OAD-112765	Differential R_X & R_Y	≤ TBD nrad RMS surface at ≥

		500 Hz

Rationale:
T_Z: Corresponds to 50 nm RMS WFE allocation in LTAO WFE budget. This does not include bandwidth error or any errors due to M1 low-order shape uncertainty or vibrations.
R_X and R_Y: TBD.
Notes: These requirements apply over any 120s period (the nominal AGWS outer loop bandwidth), median over regular operating conditions.

3.3.5.4.5 Accelerometer Metrology System

The Mount Accelerometer Metrology System provides a backup sensing system for control of global and segment vibrations outside the sensing bandwidth of the optical wavefront sensors. The system will also initially be used to verify Mount and subsystem vibration requirements.

REQ-L3-OAD-113445: Mount Accelerometer Metrology System

The Mount accelerometer metrology system shall measure Mount, M1 segment, and M2 segment rigid body degrees of freedom acceleration in the 0.1 to 160 Hz frequency range.

Rationale: The accelerometer metrology system provides a backup set of sensors for feed-forward control of segment vibrations.
Notes: Accelerometers on the M1 and M2 optics will be provided by those subsystems. The Mount provides only accelerometers on the Mount structure and the capability of recording all signals.

3.3.5.5 LTAO Disturbance Rejection

The rejection of optical disturbances is a function of the wavefront sensor frame rate, latency in the control loop, the transfer function of the corrector, and the control algorithm. Only latency budgets for the tomography control loops and the tip-tilt control loops are specified, as these dominate the image quality performance.
LTAO Tomography Latency Budget
The LTWS and OCS in the LTAO wavefront control mode shall have latency as specified in Table 3-44.

Table 3-44: LTAO Tomography Latency Budget

Requirement	Source	Latency [µs]	Comment
REQ-L3-OAD-112922	LTWS Readout	100	At 500 Hz frame rate
REQ-L3-OAD-112923	LTWS Slope Processing	100	From last pixel received to last slope transmitted
REQ-L3-OAD-112924	OCS Tomography Computation	200	Includes data transmission from LTWS and to ASMS
	Total Latency	400	

Rationale: Flowed down from latency allocations in LTAO WFE budget. See GMT-REF-03416.
Notes: The low LTWS readout latency is dependent on detector technology. The 100 µs specified here assumes a rolling shutter readout with 2 kHz ASMS updates.
LTAO Tip-Tilt Latency Budget
The Instrument and OCS in the LTAO wavefront control mode shall have latency as specified in Table 3-45.

Table 3-45: LTAO Tip-Tilt Latency Budget

Requirement	Source	Latency [µs]	Comment
REQ-L3-OAD-112931	OIWFS Readout	286	At 500 Hz frame rate
REQ-L3-OAD-112932	OIWFS Slope Processing	100	From last pixel received to last slope transmitted
REQ-L3-OAD-112933	OCS Tip-Tilt Computation	100	Includes data transmission from Instrument and to ASMS
	Total Latency	486	

Rationale: Flowed down from latency allocations in LTAO WFE budget. See GMT-REF-03416.
Notes:

REQ-L3-OAD-112937: LTAO Rejection Transfer Function

The LTAO wavefront control mode rejection transfer function for all controlled modes except segment piston shall not exceed that in Figure 3-43.

Rationale: The specified rejection transfer function envelope is consistent with atmospheric and wind residual error allocated in the LTAO WFE budget, and limits the overshoot of the RTF that could otherwise excite resonances of the ASM reference body at 100-200 Hz.
Notes: 113254

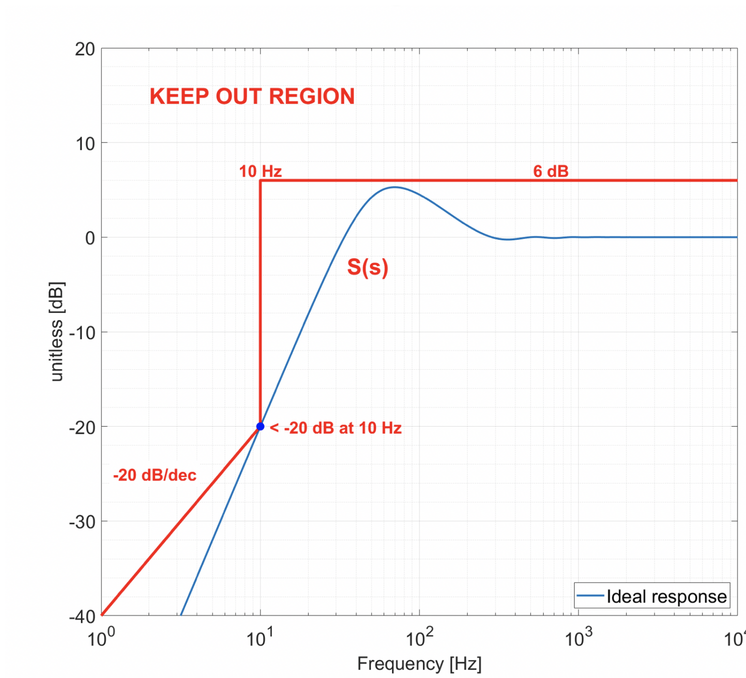

Figure 3-43: LTAO Rejection Transfer Function Limits

Notes:
These transfer function limits apply strictly only to the segment tip and tilt, for which wind is the dominant disturbance and the excitation of reference body mechanical resonances is a concern. The transfer function for higher-order modes should be optimized based on the relevant disturbances and mechanical constraints.

See REQ-L3-OAD-35337 for a discussion of the transfer function limits and the ideal response. The parameters used for the ideal LTAO RTF are:

- Requirements: T_i=2.0 ms, τ_l=0.4 ms, f_{bw}=800 Hz, f_{wc}=10 Hz, S_{max}=6 dB
- Controller: ζ=0.7, f_c=45.68 ms, f_2=21.79 ms, g_i=0.574

3.3.6 Wavefront Control Calibration

Regular calibration of the wavefront control functions of the Observatory will be necessary. Many of these calibrations require the optical response of one subsystem on another to be measured, for example measuring the influence functions of modal commands to the ASMS on the NGWS and LTWS sensors, or optimizing the correction of instrument aberrations with a static offset to the ASMS. Other calibrations are internal to subsystems.
The Gregorian optical design of the GMT enables calibration sources inserted at the prime focus to illuminate M2 and wavefront sensors located near on-axis at the Gregorian focus. This Wavefront Control Calibration System (WCCS) provides many of the system-level calibration functions required by the NGAO and LTAO modes, and will be used for some calibrations of the NS and GLAO modes. The AGWS and NGWS must also include calibration sources. Calibrations requiring measuring the response of the Mount and M1 must be performed on-sky using star light. Figure 3-44 illustrates the Mount Prime Focus Assembly (deployment arm) and WCCS optical payload.

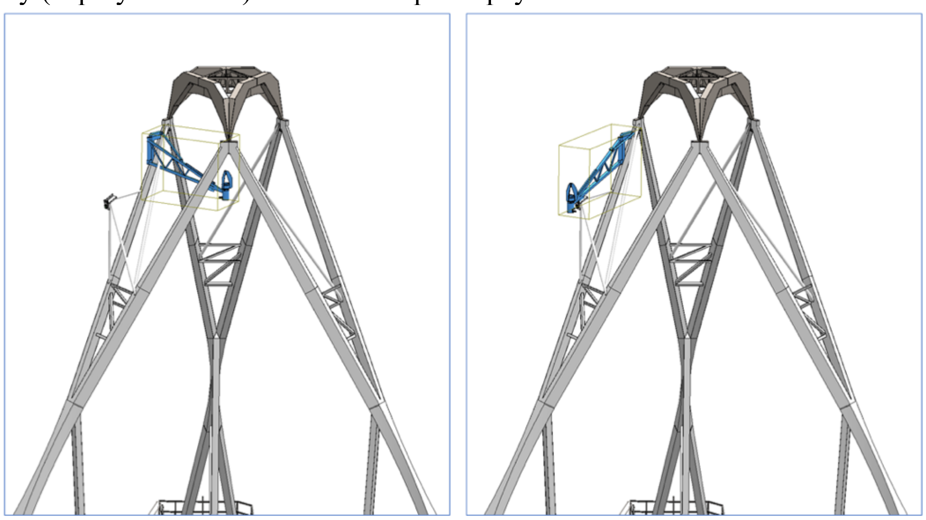

Figure 3-44: Mount Prime Focus Assembly and WCCS Payload, Deployed (Left) and Stowed (Right)

3.3.6.1 Wavefront Control Calibration System

REQ-L3-OAD-113447: WCCS Broadband Source

The WCCS shall project a diffraction-limited broadband on-axis light source from the prime focus to M2.

Rationale: Required to align M2 to the optical axis and calibrate M2 segment rigid body actuation using an AGWS probe on-axis for feedback.

REQ-L3-OAD-113448: WCCS Retro-Reflector

The WCCS shall retro-reflect light projected from the Gregorian focus off M2, while preserving the pupil position.

Rationale: Required to measure the M2 surface shape using an interferometer located at the FP focus, and to calibrate and verify the performance of the NGAO observing mode using a broadband on-axis point source projected from an NGWS at the FP focus.

REQ-L3-OAD-113449: WCCS LTAO Source

The WCCS shall project broadband and monochromatic off-axis sources from the prime focus to M2 that mimic the light of natural and sodium laser guide stars.

Rationale: Required to calibrate and verify the performance of the LTAO observing mode, including the LTWS and Instrument OIWFS.

REQ-L3-OAD-113450: WCCS M2 Interferometer

The WCCS shall measure the surface figure of M2 using a metrology interferometer located at the Gregorian focus.

Rationale: Required to verify M2 surface figure on the telescope and measure ASMS actuator influence functions. Used in conjunction with the Prime Focus Retro-Reflector.

REQ-L3-OAD-35589: WCCS Retracted Position

The Mount shall retract the WCCS Deployment Mechanism to a position that is out of the optical beam of the telescope.

Rationale: When retracted, the prime focus source and deployment mechanism should not cause additional shadowing of the telescope beam.

REQ-L3-OAD-35592: WCCS Self-Vignetting

When deployed, the WCCS and Mount Deployment Mechanism shall vignette the projected calibration source beams by less than 5%.

Rationale: The AOS and instrumentation sources require even illumination of the pupil. Vignetting of the beam by the WCCS our Mount deployment mechanism will cause loss of illumination at those points in the pupil.

WCCS Deployment Accuracy

The Mount prime focus deployment mechanism shall position the WCCS relative to the prime focus location in OSS coordinates with the tolerances specified in Table 3-46.

Table 3-46: WCCS Deployment Accuracy

Degree of freedom	Requirement #	Value
Maximum position error in OSS Tx and Ty	REQ-L3-OAD-35605	≤ 6.73 mm
Maximum position error in OSS Tz	REQ-L3-OAD-35609	≤ 3.35 mm
Maximum position error in OSS Rx and Ry	REQ-L3-OAD-35613	≤ 492 mrad
Maximum vibration at >10 Hz	REQ-L3-OAD-35617	≤ 2.0 µm RMS

Rationale: Position tolerances were derived from the expected flexure of the M2 support truss. They will be used to establish the required stroke of the WCCS-provided positioning system. The vibration tolerance was derived from the LTAO Source Module design (ref. GMT-DOC-05035).

Notes: These requirements represent the peak error and are to be maintained over all zenith angles.

WCCS Source Positioning Accuracy

The WCCS shall position the WCCS optical modules relative to the prime focus location in OSS coordinates with the tolerances specified in Table 3-47.

Table 3-47: WCCS Source Positioning Accuracy

Degree of freedom	Requirement #	Value
Maximum position error in OSS Tx and Ty	REQ-L3-OAD-113430	≤ 70 µm
Maximum position error in OSS Tz	REQ-L3-OAD-113431	≤ 20 µm
Maximum position error in OSS Rx and Ry	REQ-L3-OAD-113432	≤ 1.0 mrad

Rationale: Driven by the alignment accuracy required for the Broadband Source Module, which is derived from the capture range of the AGWS Shack-Hartmann wavefront sensors.Combined in quadrature, these requirements result in an image motion of 0.56 mm and FWHM of 303 µm. An equal level of error is allocated for M2 segment position errors.
Notes: These requirements represent the peak error and are to be maintained over all zenith angles. Feedback from the Telescope Metrology System may be used to maintain this accuracy.

REQ-L3-OAD-35622: WCCS Off-Telescope

The Wavefront Control Calibration System shall be capable of being used in the AO Integration Facility for integrated functional and performance testing of the NGAO and LTAO observing modes.

Rationale: While the primary function of the WCCS is to calibrate the wavefront control subsystems on the telescope, initial use will take place on the AO Integration Facility, a test configuration in an optical laboratory. In this configuration, the Mount Prime Focus Assembly is not available to support the sources at the prime focus location, and this function must be provided by the WCCS.
Notes: The integrated functional testing will include the ASMS and Mount Top End mounted on a horizon-pointing test stand, the WCCS sources at the prime focus, and the NGWS, LTWS, and an FP Instrument located at the DG focus. The ASMS test stand will be provide by the ASMS. The WCCS must include a support structure to locate it at the prime focus, 2.2 m from the M2 vertex. See illustration in Figure 3-45.

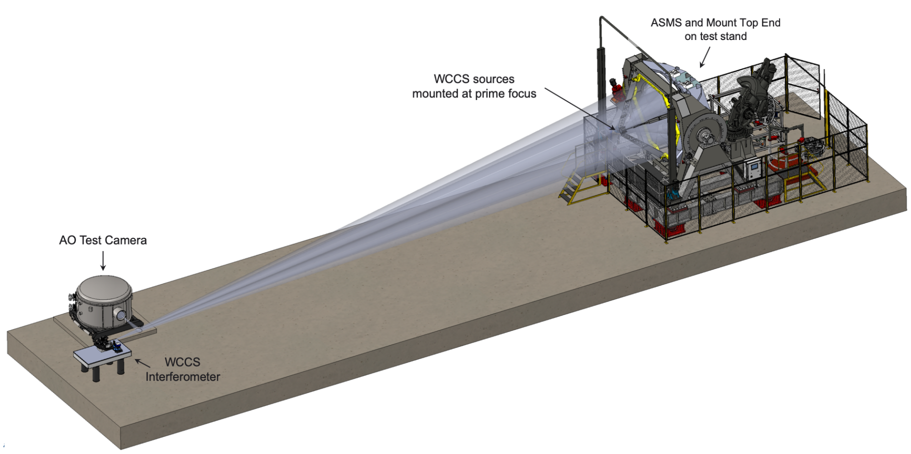

Figure 3-45: WCCS Use in an Optical Laboratory

3.3.6.2 Natural Guide Star Wavefront Sensor

REQ-L3-OAD-109704: NGWS Internal Calibration

The NGWS shall include an internal calibration source to calibrate its response to a flat wavefront.

Rationale: A internal calibration source is required to enable NGWS optical alignment, evaluate sensor performance, and calibrate internal wavefront errors.

REQ-L3-OAD-109705: NGWS System Calibration

The NGWS shall project a calibration light source upstream along the NGWS optical axis to enable testing and calibration of the NGAO wavefront control mode.

Rationale: A calibration source that projects a broadband source upstream to a retroreflector at the GMT prime focus while transmitting the return beam into the NGWS is required to enable calibration and performance evaluation of many aspects of the NGAO wavefront control mode.
Notes: This calibration source will be used with the WCCS Retro-Reflector Module deployed at the GMT prime focus.

REQ-L3-OAD-110003: NGWS Performance Characterization

The NGWS shall record diffraction-limited images of the guide star for engineering tests of the NGAO control loop performance.

Rationale: A diffraction-limited visible acquisition camera in the NGWS enables "rapid response" system-level performance characterization in the lab and on the telescope with low non-common path wavefront error.

3.4 Instrumentation

3.4.1 General

In this section we describe requirements that apply to all GMT instruments.

REQ-L3-OAD-35628: Instrument Service Life

The Observatory Instruments shall have a service life of at least 10 years [goal: not less than 15 years].

Rationale: Required for maximum scientific return on the investment in an instrument, and to support long-term scientific programs.

REQ-L3-OAD-35631: Instrument-Specific Data Reduction Pipelines

Each Instrument shall provide appropriate data reduction routines to extract scientific data from the raw data.

Rationale: The Instrument teams are best suited to optimal reduction of data produced by their instrument. See GMT-DOC-01582.
Notes: The raw data (level 0) will be reduced to remove instrument and telescope signatures (level 1) and then processed to obtain calibrated data (level 2). Further data processing routines can be applied to create higher level data.

3.4.2 Instrument–Specific

3.4.2.1 Commissioning Camera

REQ-L3-OAD-35637: Commissioning Camera Location

The Commissioning Camera (ComCam) shall be located at the Direct Gregorian (DG) focal station.

Rationale: Access to medium field of view for GLAO evaluation performance.
Notes: Implies requirements (on mass, volume, flexure sensor) and interfaces, defined elsewhere.

REQ-L3-OAD-35641: Commissioning Camera GLAO Performance Evaluation

The Commissioning Camera (ComCam) shall enable evaluation of the GLAO wavefront control mode.

Rationale: Need of GLAO performance evaluation.

REQ-L3-OAD-35644: Commissioning Camera Field of View

The Commissioning Camera (ComCam) shall have a field of view of minimum diameter 6.0 arcmin.

Rationale: Need of GLAO performance evaluation.

REQ-L3-OAD-35647: Commissioning Camera Wavelength Coverage

The Commissioning Camera (ComCam) shall have a wavelength coverage 360 – 950 nm.

Rationale: Need of GLAO performance evaluation.

REQ-L3-OAD-35650: Commissioning Camera Science Filters

The Commissioning Camera (ComCam) shall provide discrete and tunable narrow-band filters within its wavelength coverage.

Rationale: Enable scientific imaging.

3.4.2.2 GMTO-Consortium Large Earth Finder (G-CLEF)

REQ-L3-OAD-35654: G-CLEF Instrument Performance Modes

G-CLEF shall deliver science enabled by the following Observatory Performance Modes (OPM):

- Small Field Visible Natural Seeing (OPM 1)
- Small Field Visible GLAO (OPM 2)
- Small Field Visible Natural Seeing PRV (OPM 3)
- Small Field Visible GLAO PRV (OPM 4)
- Wide Field Visible Natural Seeing (OPM 14, with MANIFEST)
- Wide Field Visible GLAO (OPM 15, with MANIFEST)

Rationale: Flows from the GMT Science Requirements (GMT-REQ-03213).

REQ-L3-OAD-35658: G-CLEF Instrument Location

G-CLEF shall be located at the Gravity Invariant Station (GIS).

Rationale: Gravity invariance required for PRV measurements.
Notes: Implies requirements (on mass, volume, flexure sensor) and interfaces, defined elsewhere.

REQ-L3-OAD-35662: G-CLEF Optical Front End

G-CLEF light shall be picked-off on the Reference Optical Axis ahead of the DG focus and arrive at the GIS Spectrograph via optical fibers from a Front End unit located at the Instrument Platform (IP) focal station.

Rationale: The front-end includes the flexure sensor.

REQ-L3-OAD-35665: G-CLEF Instrument Calibration

G-CLEF shall provide an internal unit for instrument calibration (flat-field and wavelength).

Rationale: The small field of view of G-CLEF fibers allows an internal calibration environment that is better controlled and allows more efficient daytime calibration.
Notes: INST-GCLEF-10335.

3.4.2.3 GMT Multi-object Astronomical and Cosmological Spectrograph (GMACS)

REQ-L3-OAD-35670: GMACS Instrument Performance Modes

GMACS shall deliver science enabled by the following Observatory Performance Modes (OPM):

- Medium Field Visible Natural Seeing (OPM 10)
- Medium Field Visible GLAO (OPM 11)
- Wide Field Visible Natural Seeing (OPM 14, with MANIFEST)
- Wide Field Visible GLAO (OPM 15, with MANIFEST)

Rationale: Flows from the GMT Science Requirements (GMT-REQ-03213).

REQ-L3-OAD-35674: GMACS Instrument Location

GMACS shall be located at the Direct Gregorian (DG) focal station.

Rationale: Access to the medium and wide fields of view.
Notes: Implies requirements (on mass, volume, flexure sensor) and interfaces, defined elsewhere.

3.4.2.4 GMT Integral Field Spectrometer (GMTIFS)

REQ-L3-OAD-35679: GMTIFS Instrument Performance Modes

GMTIFS shall deliver science enabled by the following Observatory Performance Modes (OPM):

- Small Field Infrared LTAO (OPMs 7 and 8)
- Small Field Infrared NGAO (OPM 9)

Rationale: Flows from the GMT Science Requirements (GMT-REQ-03213).

REQ-L3-OAD-35683: GMTIFS Instrument Location

GMTIFS shall be located at a Folded Port (FP) focal station.

Rationale: The OPMs are supported at FP focal stations.
Notes: Implies requirements (on mass, volume, on-instrument wavefront sensor) and interfaces, defined elsewhere.

REQ-L3-OAD-35687: GMTIFS Instrument Calibration

GMTIFS shall provide an internal unit for instrument calibration (flat-field and wavelength).

Rationale: The small field of view of GMTIFS allows an internal calibration environment that is better controlled and allows more efficient daytime calibration.

REQ-L3-OAD-35690: GMTIFS Wavefront Control Diagnostics

GMTIFS shall provide capabilities for wavefront control diagnostics and calibration, including a pupil imager, phase diversity optics, and non-redundant pupil masks in the imager channel.

Rationale: Necessary to remove non-common-path wavefront errors.

3.4.2.5 GMT Near Infrared Spectrograph (GMTNIRS)

REQ-L3-OAD-35694: GMTNIRS Instrument Performance Modes

GMTNIRS shall deliver science enabled by the following Observatory Performance Modes (OPM):

- Small Field Infrared LTAO (OPMs 7 and 8)
- Small Field Infrared NGAO (OPM 9)

Rationale: Flows from the GMT Science Requirements (GMT-REQ-03213).

REQ-L3-OAD-35698: GMTNIRS Instrument Location

GMTNIRS shall be located at a Folded Port (FP) focal station.

Rationale: The OPMs are supported at FP focal stations.
Notes: Implies requirements (on mass, volume, on-instrument wavefront sensor) and interfaces, defined elsewhere.

REQ-L3-OAD-35702: GMTNIRS Instrument Calibration

GMTNIRS shall provide an internal unit for instrument calibration (flat-field and wavelength).

Rationale: The small field of view of GMTNIRS allows an internal calibration environment that is better controlled and allows more efficient daytime calibration.

3.4.3 Many Instrument Fiber System (MANIFEST)

REQ-L3-OAD-35706: MANIFEST Multi-object Capability

MANIFEST shall direct the light of multiple targets across the GMT's full 20 arcmin diameter field of regard to science instruments.

Rationale: Enable the wide field of view for science instruments.
Notes: Initially will feed GMACS and G-CLEF.

REQ-L3-OAD-35710: MANIFEST Reconfigurability

MANIFEST shall be reconfigurable such that it can interface to different target fields and different client instruments.

Rationale: MANIFEST will be used with multiple planned and future instruments.

REQ-L3-OAD-35713: MANIFEST Location

MANIFEST shall be located at the Direct Gregorian (DG) focal station.

Rationale: MANIFEST requires access to the widest field of view. It is part of the DGWF optical layout.
Notes: Implies requirements (on mass, volume, on-instrument wavefront sensor) and interfaces, defined elsewhere.

4 Observing Performance

4.1 Image Quality

Image quality in the Natural Seeing and GLAO wavefront control modes is specified in terms of the Normalized Point Source Sensitivity (PSSN), as explained in ORD Section 3.3.1.3.
Diffraction-limited image quality is specified in terms of the square root of the variance (RMS) of the wavefront error within the illuminated region of the pupil. Due to its more benign effect on some types of observations such as faint object spectroscopy, image motion (global wavefront tip-tilt) is budgeted independently of other errors. For the GMT pupil, 1 mas RMS image motion (average of both axes in quadrature) corresponds to 42.1 nm RMS wavefront error.

The reference optical turbulence profile C_n^2 adopted for image quality specifications is defined in 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 quality dependence on environmental and operational variables are characterized by its statistical parameters. In particular, the image quality requirements are specified for the median through the Standard Year, as specified in ORD Section 3.3.1.3.

4.1.1 Thermal Seeing

Thermal Seeing is one of two dominant image quality errors in the Natural Seeing mode, and is a significant source of error in the GLAO mode. It is the result of optical path length differences in the air through which the Telescope observes caused by temperature differences between observatory elements and the ambient air, and mixing of thermally inhomogeneous ambient air by the Enclosure and Mount. While we make the distinction between Dome Seeing (the contributions of all observatory elements except the surfaces of the main optics) and Mirror Seeing (the optical turbulence generated at the surfaces of the main optics) to enable the flow-down of requirements, in practice these will not be independently verifiable.

Heat Dissipation in the Enclosure

The maximum temperature differential between system elements and the ambient temperature, from evening to morning 12° twilight, shall be no greater than that listed in Table 4-1.

Table 4-1: Telescope Surface Temperature Requirements

Requirement	System Element	Max. Temp. Differential	Notes
REQ-L3-OAD-35733	Enclosure interior surfaces	1.0 K (TBC)	
REQ-L3-OAD-35736	Mount (below M1)	1.0 K (TBC)	
REQ-L3-OAD-35739	Mount (above M1)	0.5 K (TBC)	
REQ-L3-OAD-35742	M1 System	0.5 K (TBC)	
REQ-L3-OAD-35745	M2 FSMS	0.5 K (TBC)	
REQ-L3-OAD-35748	M2 ASMS	0.5 K (TBC)	

Notes: All requirements include the effect of residual daytime heating of the Enclosure, but allow for 45 minutes of passive ventilation during evening twilight. The requirements are to be met over the Regular

Operating Conditions.
Rationale: Computational fluid dynamics (CFD) simulations with these temperature differentials are consistent with the image quality allocation of PSSN(0.5µm) ≥ 0.9416 [Ref. CFD document].

REQ-L3-OAD-35753: Enclosure Passive Ventilation

The GMT Enclosure shall provide ventilation openings over ≥ 30% of its vertical area to enable wind-driven temperature equilibration within the telescope chamber.

Rationale: Analysis by R. Racine of existing observatory image quality suggests that ≥ 30% vent openings are necessary to minimize dome seeing.
Notes: The vertical area of the enclosure does not include the shutter doors, which will be open during observing.

REQ-L3-OAD-35757: Enclosure Vent Adjustability

The GMT Enclosure vents shall enable adjustment of the wind speed at M1 with a resolution ≤ 0.5 m/s.

Rationale: The IQ allocation for M1 Mirror Seeing requires the wind speed at M1 to be ≥ 1.0 m/s, while minimizing wind buffeting of the Mount, M2, and M1. An adjustability of ≤ 0.5 m/s is therefore required.

REQ-L3-OAD-35760: Enclosure Exterior Emissivity

The GMT Enclosure exterior surface shall have an average emissivity no greater than 0.4.

Rationale: Computational fluid dynamics (CFD) simulations with $\varepsilon = 0.4$ exterior enclosure surfaces in radiative equilibrium are consistent with the image quality allocation of PSSN(0.5 µm) ≥ 0.9416 [Ref. CFD document].

REQ-L3-OAD-93827: Enclosure Exterior Absorptivity

The GMT Enclosure exterior surface shall have an average absorptivity no greater than 0.2.

Rationale: Computational fluid dynamics (CFD) simulations with $\alpha = 0.2$ absorptivity for exterior enclosure surfaces in radiative equilibrium are consistent with the image quality allocation of PSSN(0.5 µm) ≥ 0.9416 [Ref. CFD document].

REQ-L3-OAD-35763: Elevation Axis Height Above Grade

The Mount Elevation axis shall be located no less than 20 m above the finished grade.

Rationale: The nighttime ground-layer optical turbulence strength at the GMT site has a scale height of ~5 m. Image quality requirements require the Telescope optics to be located well above this turbulent boundary layer.

REQ-L3-OAD-35766: M1 Surface Temperature

The M1 optical surface shall be maintained within ±0.2 K of the ambient air temperature.

Rationale: The IQ allocation for M1 Mirror Seeing requires the temperature differential to be no more than ±0.2 K.

REQ-L3-OAD-35769: M2 Surface Temperature

The M2 optical surface shall be maintained within ±0.2 K of the ambient air temperature.

Rationale: The IQ allocation for M2 Mirror Seeing requires the temperature differential to be no more than ±0.2 K.

4.1.2 Wind Buffeting

This section is under construction.
It will include wind speed reduction at M1 & M2 from CFD.

4.1.3 Vibration Budget

The NGAO budget (GMT-REF-00518) allocation for vibration is 1 mas for all sources not associated with wind; NGAO is the limiting wavefront control mode for vibration. Wavefront errors induced by wind disturbances, mount tracking jitter, and internal instrument vibrations are allocated separately in the image quality budget and are outside the scope of this budget. The rationales are broken down based on the electrical load schedule as a basis, assuming that the vibration force output of a subsystem will be somewhat proportional to its electrical power input (with cryocoolers and fluid distribution being notable exceptions). A system-level 30% is retained for additional allocation to the subsystems. Allocations for the individual subsystems and their rationale are described in GMT-REF-03245.
Vibration Induced Wavefront Error – [Subsystem] shall induce on-axis wavefront error at the telescope focal plane due to vibration forces and moments at the subsystem interfaces no greater than the allocation value shown in Table 4-2 during NGAO observing operations.
The parent requirement in the AO Image Quality Budget gives an allocation of 31.6nm (~1 mas pupil Tip/Tilt) RMS wavefront error (WFE) for the NGAO observing mode. From this parent value, the subsystems are allocated the following values.
As a largely top-down driven budget, most allocations are TBC, pending analysis to confirm their feasibility and acceptance as a requirement by their respective subsystems.

Table 4-2: Source Vibration (non wind) Budget

Requirement	Subsystem	WFE Allocation [nm RMS]	Note
REQ-L3-OAD-35788	Site Infrastructure	3.8	TBC
REQ-L3-OAD-35794	Facilities	4.2	TBC
REQ-L3-OAD-35800	Enclosure	8.4	TBC
REQ-L3-OAD-35806	Observatory Control System	1.2	TBC
REQ-L3-OAD-35812	Mount	N/A	Self-induced tracking jitter is specified elsewhere
REQ-L3-OAD-35816	Telescope Metrology Subsystem	2.1	TBC
REQ-L3-OAD-112961	Wavefront Control Calibration Subsystem	1.2	TBC
REQ-L3-OAD-112962	Wide Field Phasing Testbed	N/A	Assumed not a significant source of vibration
REQ-L3-OAD-112963	Acquisition, Guiding and Wavefront Sensing Subsystem	1.8	TBC

REQ-L3-OAD-112964	Laser Guide Star Subsystem	4.2	TBC
REQ-L3-OAD-112965	Laser Tomography Adaptive Optics Wavefront Sensor Subsystem	2.0	TBC
REQ-L3-OAD-112966	Natural Guide Star Adaptive Optics Wavefront Sensor Subsystem	2.0	TBC
REQ-L3-OAD-112967	Environmental Monitoring Facility	0.4	TBC
REQ-L3-OAD-112968	M1 System	24.1	Combined legacy M1 allocations per GMT-DOC-03140
REQ-L3-OAD-112969	Adaptive Secondary Mirror Subsystem / Fast Steering Mirror Subsystem	3.4	TBC; Only one subsystem installed at a time; Same requirement value applies to both; Excludes reaction forces to correct windshake.
REQ-L3-OAD-112970	M3 Subsystem	1.9	TBC
REQ-L3-OAD-112971	Corrector-ADC Subsystem	1.3	TBC
REQ-L3-OAD-112972	Optics Servicing	2.1	TBC
REQ-L3-OAD-112973	DG Instruments	3.0	TBC; Each of 3 total
REQ-L3-OAD-112974	FP Instruments	3.0	TBC; Each of 3 total
REQ-L3-OAD-112975	AP Instruments	3.0	TBC; Each of 2 total
REQ-L3-OAD-112976	IP Instrument	3.0	TBC; 1 total
REQ-L3-OAD-112977	GIS Instrument	3.0	TBC; 1 total
REQ-L3-OAD-112978	Instrument Calibration Subsystem	N/A	Assumed not a significant source of vibration
REQ-L3-OAD-112979	Global Interlock and Safety System	N/A	Assumed not a significant source of vibration
REQ-L3-OAD-112980	Instruments Support Equipment	N/A	Assumed not a significant source of vibration
REQ-L3-OAD-112981	High Contrast AO Testbed	N/A	Assumed not a significant source of vibration
REQ-L3-OAD-112982	Utility Distribution (On Telescope)	6.4	TBC
	Total	**29.5**	**Considers instrument quantity**
Requirement	**Requirement**	**31.6**	**NGAO vibration allocation per GMT-REF-00518**
Margin	**Margin**	**11.3**	

Rationale: low-down from the NGAO image quality error budget allocation of 31.6 nm RMS WFE on-axis at the telescope focal plane due to vibration sources. Each allocation is based on the electrical load schedule as a basis, assuming that the vibration force output of a subsystem will be somewhat proportional to its electrical power input.

REQ-L3-OAD-35822: Vibration-Induced Wavefront Error from an SEC

An individual standard electronics cabinet (SEC), exclusive of payloads, shall induce on-axis wavefront error at the telescope focal plane due to vibration forces and moments at the Mount interfaces no greater than 0.5nm RMS during NGAO observing operations.

Rationale: The standard electronics cabinets (SEC) are included as parts of various subsystems on the telescope. As such, the vibration they produce will count against the GMT-REF-03245 Vibration Budget allocation for their parent subsystems. Although the vibration produced by the cabinets is the responsibility of parent subsystems, the design of the cabinets is a system responsibility. This vibration requirement for the bare cabinet with its thermal conditioning equipment is needed to guide the design.

4.1.4 Image Quality Allocations

The ORD specifies 15 Observing Performance Modes. The image quality specifications in these have been so far been flowed down to system element contribution in 5 image quality budgets:

1. Direct Gregorian Narrow Field Natural Seeing (on-axis)
2. Direct Gregorian Narrow Field GLAO (10′ diameter field of view)
3. Folded Port NGAO with an R=10 guide star (on-axis)
4. Folded Port LTAO with 50% sky coverage (on-axis)
5. Folded Port LTAO with 80% sky coverage (on-axis)

While these budgets do not yet cover all the configurations required by the ORD, they do provide the driving requirements on nearly all system elements (the C-ADC excluded).

Natural Seeing DGNF On-Axis Image Quality Allocations

The GMT operating in the DGNF optical layout and Natural Seeing wavefront control mode shall maintain image quality allocations no less than those specified in Table 4-3, on-axis.

Table 4-3: DGNF Natural Seeing On-Axis Image Quality Budget

Requirement	Error Term	PSSN		Description
		0.5 µm	1.65 µm	
	Thermal	0.9394	0.9258	
REQ-L3-OAD-38604	Dome Seeing	0.9405	0.9287	Optical turbulence from Enclosure, Mount, etc.
REQ-L3-OAD-38609	Mirror Seeing	0.9988	0.9969	Optical turbulence at M1 and M2
	Optical Design	1.0000	0.9989	
REQ-L3-OAD-38617	Design Aberrations	1.0000	1.0000	Telescope design aberrations on-axis
REQ-L3-OAD-38622	Segment Phasing	1.0000	0.9989	Error due to uncontrolled segment phase piston
	Segment Shape	0.9157	0.9468	
REQ-L3-OAD-38630	M1 Segment Shape	0.9295	0.9669	M1 segment shape errors after active optics
REQ-L3-OAD-38635	M2 Segment Shape	0.9883	0.9852	M2 segment shape errors
REQ-L3-OAD-38640	AGWS Shape Meas.	0.9967	0.9939	Shape errors due to AGWS measurement and

	Segment Alignment	0.9905	0.9794	
REQ-L3-OAD-38648	M1 Segment Position	0.9995	0.9976	M1 segment positioner repeatability
REQ-L3-OAD-38653	M2 Segment Position	0.9975	0.9932	M2 segment positioner repeatability
REQ-L3-OAD-38658	Instrument Position	0.9995	0.9992	Instrument displacement with respect to reference
REQ-L3-OAD-38663	AGWS Alignment Meas.	0.9968	0.9931	Alignment errors due to AGWS measurement and estimation
REQ-L3-OAD-38668	SWC DAR	0.9980	0.9972	Error in differential atmospheric refraction
REQ-L3-OAD-38673	Instrument Sensor	0.9992	0.9989	Instrument flexure sensor tip-tilt and focus error
	Tracking and Vibration	0.9759	0.9570	
REQ-L3-OAD-38681	Dynamic Control	0.9855	0.9762	Image motion and blur caused by control loops
REQ-L3-OAD-38686	Wind Residual	0.9958	0.9914	Wind image motion and blur after tip-tilt
REQ-L3-OAD-38691	Vibration Residual	0.9944	0.9888	Vibration image motion and blur after tip-tilt
	Turbulence Correction	1.0030	1.0090	
REQ-L3-OAD-38699	Segment Tip-Tilt	1.0030	1.0090	IQ improvement due to global & segment tip-tilt
	Total	**0.8340**	**0.8280**	
	Requirement	**0.8258**	**0.7888**	ORD-25264 / ORD-25476
	Margin	4.70%	18.58%	Ratio of (1-PSSN)

Notes: These allocations represent the median performance over the standard year, but analysis to date has been against median environmental conditions. They are the basis for the key subsystem requirements specified in Section 3.

Rationale: These allocations meet the image quality requirements ORD-25264 and ORD-25476 with a margin of 4.70% and 18.58%, respectively, while being consistent with the expected distribution of errors between subsystems.

GLAO DGNF 10′ FOV Image Quality Allocations

The GMT operating in the DGNF optical layout and GLAO wavefront control mode shall maintain image quality allocations no less than those specified in Table 4-4, averaged over a 10 arcmin field of view.

Table 4-4: DGNF GLAO 10′ Field of View Image Quality Budget

Requirement	**Error Term**	**PSSN**		**Description**
		0.5 µm	**1.65 µm**	
	Thermal	0.9666	0.9692	
REQ-L3-OAD-38718	Dome Seeing	0.9681	0.9740	Optical turbulence from Enclosure, Mount, etc.
REQ-L3-OAD-38723	Mirror Seeing	0.9985	0.9951	Optical turbulence at M1 and M2
	Optical Design	0.9960	0.9940	

REQ-L3-OAD-38731	Design Aberrations	1.0000	1.0000	Telescope design aberrations on-axis
REQ-L3-OAD-38736	Segment Phasing	0.9960	0.9940	Error due to uncontrolled segment phase piston
	Segment Shape	0.9217	0.9496	
REQ-L3-OAD-38744	M1 Segment Shape	0.9247	0.9559	M1 segment shape errors after active optics
REQ-L3-OAD-38749	M2 Segment Shape	0.9990	0.9980	M2 segment shape errors
REQ-L3-OAD-38754	AGWS Shape Meas.	0.9977	0.9954	Shape errors due to AGWS meas. and estim.
	Segment Alignment	0.9925	0.9834	
REQ-L3-OAD-38762	M1 Segment Position	1.0000	1.0000	M1 segment positioner repeatability
REQ-L3-OAD-38767	M2 Segment Position	1.0000	1.0000	M2 segment positioner repeatability
REQ-L3-OAD-38772	Instrument Position	0.9994	0.9987	Instrument displacement with respect to reference
REQ-L3-OAD-38777	AGWS Alignment Meas.	0.9966	0.9907	Alignment errors due to AGWS measurement and estimation
REQ-L3-OAD-38782	SWC DAR	0.9975	0.9956	Error in differential atmospheric refraction
REQ-L3-OAD-38787	Instrument Sensor	0.9990	0.9983	Instrument flexure sensor tip-tilt and focus error
	Tracking and Vibration	0.9685	0.9360	
REQ-L3-OAD-38795	Dynamic Control	0.9805	0.9657	Image motion and blur caused by control loops
REQ-L3-OAD-38800	Wind Residual	0.9947	0.9865	Wind image motion and blur after tip-tilt correction
REQ-L3-OAD-38805	Vibration Residual	0.9930	0.9825	Vibration image motion and blur after tip-tilt
	GLAO Errors	0.8488	0.8457	
REQ-L3-OAD-38813	Guide Stars + Fitting	0.8528	0.8558	Error due to guidestar number, location, and WFS
REQ-L3-OAD-38818	AGWS Measurement	0.9987	0.9968	Physical optics, detector noise, photon noise, and background
REQ-L3-OAD-38823	AGWS Latency	0.9966	0.9914	Latency error dominated by ≥88 Hz readout rate
	Total	**0.7240**	**0.7122**	
	Requirement	**0.6839**	**0.5638**	ORD-25820 / ORD-25934
	Margin	12.68%	34.01%	Ratio of (1-PSSN)

Notes: These allocations represent the median performance over the standard year, but analysis to date has been against median environmental conditions. They are the basis for the key subsystem requirements specified in Section 3.

Rationale: These allocations meet the image quality requirement ORD-25820 and ORD-25934 with a margin of 15.5% and 36.9%, respectively, while being consistent with the expected distribution of errors between subsystems.

NGAO Wavefront Error Budget

The GMT in the NGAO wavefront control mode shall maintain wavefront error allocations no greater than those specified in Table 4-5 on-axis when using an R=10 guide star.

Table 4-5: NGAO Wavefront Error Budget

Requirement	Error Term	WFE (nm RMS)	Description
	Wavefront Control & Residual Atmosphere	**104.5**	
REQ-L3-OAD-38842	ASM Control	72.1	ASM fitting, latency, repeatability
REQ-L3-OAD-38847	High Bandwidth Wavefront Sensing	63.8	NGWS measurement, aliasing, latency
REQ-L3-OAD-38927	Truth Wavefront Sensing	20.8	OIWFS measurement
REQ-L3-OAD-38855	Wavefront Control	9.2	OCS latency, computational error
REQ-L3-OAD-38860	Uncorrected Atmospheric Errors	33.7	Anisoplanatism, chromatic errors, scintillation
	Telescope	**63.9**	
REQ-L3-OAD-38868	Optical Design	0.3	Optical design residuals
REQ-L3-OAD-38873	Telescope Tracking	31.7	Mount tracking, self-induced vibrations
REQ-L3-OAD-96801	M1 Figure and Alignment	30.7	M1 segment figure and alignment errors
REQ-L3-OAD-96802	M2 Figure and Alignment	40.0	M2 segment figure and alignment errors
REQ-L3-OAD-96803	M3 Figure and Alignment	23.1	M3 figure and alignment errors
	Disturbances	**65.5**	
REQ-L3-OAD-38881	Wind Forces	42.3	Wind-induced vibrations
REQ-L3-OAD-38886	Mechanical Vibration	31.6	Payload and pier mechanical vibrations
REQ-L3-OAD-38891	Aero-Thermal	35.6	Dome and mirror seeing
REQ-L3-OAD-38896	Gravity and Thermal Flexure	14.9	Instrument and wavefront sensor flexure
REQ-L3-OAD-38901	Atmospheric Refraction	3.0	Error in differential atmospheric refraction correction
	Calibration	**46.4**	
REQ-L3-OAD-38909	System/ASMS Calibration	22.9	Influence function and reconstructor calibration
REQ-L3-OAD-38914	NGWS Calibration	22.4	NGWS NCPA, alignment
REQ-L3-OAD-38919	Instrument Calibration	33.5	Instrument NCPA,

			OIWFS calibration
	Total	**146.4**	
	Requirement	**165.0**	Flowdown from ORD-25705
	Reserve	76.1	

Notes: These allocations represent the median on-axis wavefront error over the standard year, considering likely environmental conditions and observing scenarios. These requirements are the basis for the key subsystem requirements specified in Section 3.
Rationale: ORD-25705 specifies Strehl(H) ≥ 0.65 median performance. This corresponds to a wavefront error of 172 nm RMS following the Marechal approximation, rounded down to 165 nm RMS here. Allocations have been made based on analytic approximations for median site conditions.
LTAO Wavefront Error at 50% Sky Coverage
The GMT in the LTAO wavefront control mode shall have median wavefront error no greater than the allocations specified in Table 4-6 on-axis over 50% of the observable sky.

Table 4-6: LTAO 50% Sky Coverage Wavefront Error Budget

Requirement	Error Term	WFE (nm RMS)	Description
	Wavefront Control & Residual Atmosphere	**254.5**	
REQ-L3-OAD-96732	ASM Control	95.1	ASM fitting, latency, repeatability
REQ-L3-OAD-96733	Active Optics	50.0	AGWS segment piston measurement
REQ-L3-OAD-96734	High Bandwidth Wavefront Sensing	82.1	LTWS measurement, fitting, aliasing, latency
REQ-L3-OAD-96735	Segment Edge Sensing	84.4	M1 Edge Sensor measurement error
REQ-L3-OAD-96736	Instrument Wavefront Sensing	157.8	OIWFS measurement error, including anisoplanatism
REQ-L3-OAD-96737	Wavefront Control	9.2	OCS latency, computational error
REQ-L3-OAD-96738	Tomography	115.0	On-axis tomographic error, atmospheric segment piston
REQ-L3-OAD-96739	Uncorrected Atmospheric Errors	33.7	Anisoplanatism, chromatic errors, scintillation
	Telescope	**60.7**	
REQ-L3-OAD-99066	Optical Design	0.3	Optical design residuals
REQ-L3-OAD-96740	Telescope Tracking	31.7	Mount tracking, self-induced vibrations
REQ-L3-OAD-96741	M1 Figure and Alignment	30.7	M1 segment figure and alignment errors
REQ-L3-OAD-	M2 Figure and	34.6	M2 segment figure and alignment errors

96742	Alignment		
REQ-L3-OAD-96743	M3 Figure and Alignment	23.1	M3 figure and alignment errors
	Disturbances	**88.8**	
REQ-L3-OAD-96745	Wind Forces	73.4	Wind-induced vibrations
REQ-L3-OAD-96746	Mechanical Vibration	31.6	Payload and pier mechanical vibrations
REQ-L3-OAD-96747	Aero-Thermal	35.6	Dome and mirror seeing
REQ-L3-OAD-96748	Gravity and Thermal Flexure	14.9	Instrument and wavefront sensor flexure
REQ-L3-OAD-96749	Atmospheric Refraction	3.0	Error in differential atmospheric refraction correction
	Calibration	**46.4**	
REQ-L3-OAD-96751	System/ASMS Calibration	22.9	Influence function and reconstructor calibration
REQ-L3-OAD-96752	LTWS Calibration	22.4	LTWS NCPA, alignment
REQ-L3-OAD-96753	Instrument Calibration	33.5	Instrument NCPA, OIWFS calibration
	Total	**280.1**	
	Requirement	**290.0**	Flow-down from ORD-25594
	Margin	75.1	

Notes: These allocations represent the median on-axis wavefront error over the standard year, considering likely environmental conditions and observing scenarios. These requirements are the basis for the key subsystem requirements specified in Section 3.
Rationale: ORD-25594 specifies Strehl(H) ≥ 0.30 median performance over ≥ 50% of the observable sky. This corresponds to a wavefront error of 290 nm RMS following the Marechal approximation. Allocations have been made based on analytic approximations and simulations for median site conditions.
LTAO Wavefront Error at 80% Sky Coverage
The GMT in the LTAO wavefront control mode shall have median wavefront error no greater than the allocations specified in Table 4-7 on-axis over 80% of the observable sky.

Table 4-7: LTAO 80% Sky Coverage Wavefront Error Budget

Requirement	Error Term	WFE (nm RMS)	Description
	Wavefront Control & Residual Atmosphere	**319.9**	
REQ-L3-OAD-96766	ASM Control	95.1	ASM fitting, latency, repeatability
REQ-L3-OAD-96767	Active Optics	50.0	AGWS segment piston measurement
REQ-L3-OAD-96768	High Bandwidth Wavefront Sensing	82.1	LTWS measurement, fitting, aliasing, latency
REQ-L3-OAD-96769	Segment Edge Sensing	84.4	M1 Edge Sensor measurement error
REQ-L3-OAD-96770	Instrument Wavefront Sensing	250.0 (TBC)	OIWFS measurement error, including anisoplanatism

REQ-L3-OAD-96771	Wavefront Control	9.2	OCS latency, computational error
REQ-L3-OAD-96772	Tomography	115.0	On-axis tomographic error, atmospheric segment piston
REQ-L3-OAD-96773	Uncorrected Atmospheric Errors	33.7	Anisoplanatism, chromatic errors, scintillation
	Telescope	**60.7**	
REQ-L3-OAD-96775	Optical Design	0.3	Optical design residuals
REQ-L3-OAD-96776	Telescope Tracking	31.7	Mount tracking, self-induced vibrations
REQ-L3-OAD-96777	M1 Figure and Alignment	30.7	M1 segment figure and alignment errors
REQ-L3-OAD-96778	M2 Figure and Alignment	34.6	M2 segment figure and alignment errors
REQ-L3-OAD-96779	M3 Figure and Alignment	23.1	M3 figure and alignment errors
	Disturbances	**88.8**	
REQ-L3-OAD-96781	Wind Forces	73.4	Wind-induced vibrations
REQ-L3-OAD-96782	Mechanical Vibration	31.6	Payload and pier mechanical vibrations
REQ-L3-OAD-96783	Aero-Thermal	35.6	Dome and mirror seeing
REQ-L3-OAD-96784	Gravity and Thermal Flexure	14.9	Instrument and wavefront sensor flexure
REQ-L3-OAD-96785	Atmospheric Refraction	3.0	Error in differential atmospheric refraction correction
	Calibration	**46.4**	
REQ-L3-OAD-96787	System/ASMS Calibration	22.9	Influence function and reconstructor calibration
REQ-L3-OAD-96788	LTWS Calibration	22.4	LTWS NCPA, alignment
REQ-L3-OAD-96789	Instrument Calibration	33.5	Instrument NCPA, OIWFS calibration
	Total	**340.7**	
	Requirement	**350.0**	Flow-down from ORD-25649
	Margin	80.2	

Rationale: ORD-25649 specifies EE50(H) ≤ 50 mas median performance over ≥ 80% of the observable sky. An analytic PSF model was used to flow this down to 350 nm RMS wavefront error making reasonable assumptions about the magnitude of low-order errors. Allocations have been made based on analytic approximations and simulations for median site conditions.
Notes: These allocations represent the median on-axis wavefront error over the standard year, considering likely environmental conditions and observing scenarios. These requirements are the basis for the key subsystem requirements specified in Section 3.

4.2 Range of Motion Allocations

This section is under construction.
The subsystems need to provide enough range of motion to be able to align the telescope with the precision established in Section 3.3. The range of motion of the subsystems is mostly impacted by three main factors: Manufacturing and installation tolerances, elastic deformation under changing gravity vector and by thermal deformations. The temperature range is defined by the extended temperature operational range, as define in REQ-L2-ORD-25010. The gravity deformations are induced by a changing elevation axis, defined in GMT-REQ-03214 Section 3.2.1.

4.2.1 Mount Gravity Deflections

Primary Mirrors
Mount interface to the primary mirror.
The limited stiffness of the mount and the changing gravity vector will displace the primary mirror from its nominal optical prescription position and rotations.
The mount shall limit the elastic and hysteric displacement of the Primary mirrors vertices due to changing zenith angles to the values of the Table 4-8.

Table 4-8: Mount Displacement of Primary Mirror Vertices

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-35860	Mount	Primary mirror vertex *dX* with respect to OSS coordinates	≤ 1.01 mm
REQ-L3-OAD-35864	Mount	Primary mirror vertex *dY* with respect to OSS coordinates	≤ 0.78 mm
REQ-L3-OAD-35868	Mount	Primary mirror vertex *dZ* with respect to OSS coordinates	≤ 1.91 mm
REQ-L3-OAD-35872	Mount	Primary mirror vertex dR_x with respect to OSS coordinates	≤ 395 µrad
REQ-L3-OAD-35876	Mount	Primary mirror vertex dR_y with respect to OSS coordinates	≤ 310 µrad
REQ-L3-OAD-35880	Mount	Primary mirror vertex dR_z with respect to OSS coordinates	≤ 77 µrad

Rationale: Flows-down from the "Gravity, Mount" terms located in the system-level motion budget (GMT-REF-03054).
Notes: These values represent limitations to the values of the mount in addition to the mirror structure itself.
Secondary Mirrors
The mount shall limit the elastic and hysteric displacement of the Secondary mirrors vertices due to changing zenith angles to the values of the Table 4-9.

Table 4-9: Mount Displacement of Secondary Mirror Vertices

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-35893	Mount	Secondary mirror vertex *dX* with respect to OSS coordinates	≤ 0.72 mm
REQ-L3-OAD-35897	Mount	Secondary mirror vertex *dY* with respect to OSS coordinates	≤ 7.18 mm
REQ-L3-OAD-35901	Mount	Secondary mirror vertex *dZ* with respect to OSS coordinates	≤ 0.84mm
REQ-L3-OAD-35905	Mount	Secondary mirror vertex dR_x	≤ 260 µrad

		with respect to OSS coordinates	
REQ-L3-OAD-35909	Mount	Secondary mirror vertex dR_y with respect to OSS coordinates	≤ 68 µrad
REQ-L3-OAD-35913	Mount	Secondary mirror vertex dR_z with respect to OSS coordinates	≤ 270 µrad

Rationale: Flows-down from the "gravity" terms located in the M2 tab of the system-level motion budget (GMT-REF-03054).

Tertiary Mirror

The mount shall limit the elastic and hysteric displacement of the Tertiary mirrors vertices due to changing zenith angle and GIR angles to the values of Table 4-10.

Table 4-10: Mount Displacement of Tertiary Mirror Vertices

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-35925	Mount	Tertiary mirror vertex *dX* with respect to OSS coordinates	≤ 0.6 mm
REQ-L3-OAD-35929	Mount	Tertiary mirror vertex dY with respect to OSS coordinates	≤ 0.6 mm
REQ-L3-OAD-35933	Mount	Tertiary mirror vertex *dZ* with respect to OSS coordinates	≤ 1.4 mm
REQ-L3-OAD-35937	Mount	Tertiary mirror vertex dR_x with respect to OSS coordinates	≤ 100 µrad
REQ-L3-OAD-35941	Mount	Tertiary mirror vertex dR_y with respect to OSS coordinates	≤ 100 µrad
REQ-L3-OAD-35945	Mount	Tertiary mirror vertex dR_z with respect to OSS coordinates	≤ 100 µrad

Rationale: M3 Motion Budget in TBD.

Direct Gregorian instruments

When Direct Gregorian instruments are deployed, the Mount shall limit their gravity deflections due to changing zenith angle and GIR angle to the values of Table 4-11.

Table 4-11: Mount Displacement of Direct Gregorian Instrument Deployed

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-35957	Mount	DG instrument window *dX* with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-35961	Mount	DG instrument window *dY* with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-35965	Mount	DG instrument window *dZ* with respect to OSS coordinates	≤ 0.25 mm
REQ-L3-OAD-35969	Mount	DG instrument window dR_x with respect to OSS coordinates	≤ 100 µrad
REQ-L3-OAD-35973	Mount	DG instrument window dR_y with	≤ 100 µrad

		respect to OSS coordinates	
REQ-L3-OAD-35977	Mount	DG instrument window dR_z with respect to OSS coordinates	≤ 100 µrad

Folded port instruments

The Mount shall limit gravity deflections of folded port instruments due to changing zenith angle and GIR angle to the values of Table 4-12.

Table 4-12: Mount Displacement of Folded Port Instrument

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-35989	Mount	FP instrument window dX with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-35993	Mount	FP instrument window dY with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-35997	Mount	FP instrument window dZ with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-36001	Mount	FP instrument window dR_x with respect to OSS coordinates	≤ 100 µrad
REQ-L3-OAD-36005	Mount	FP instrument window dR_y with respect to OSS coordinates	≤ 100 µrad
REQ-L3-OAD-36009	Mount	FP instrument window dR_z with respect to OSS coordinates	≤ 100 µrad

IP port instruments

The Mount shall limit gravity deflections of IP port instruments due to changing zenith angle and GIR angle to the values of Table 4-13.

Table 4-13: Mount Displacement of Folded Port Instrument

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-36021	Mount	IP instrument window dX with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-36025	Mount	IP instrument window dY with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-36029	Mount	IP instrument window dZ with respect to OSS coordinates	≤ 0.5 mm
REQ-L3-OAD-36033	Mount	IP instrument window dR_x with respect to OSS coordinates	≤ 100 µrad
REQ-L3-OAD-36037	Mount	IP instrument window dR_y with respect to OSS coordinates	≤ 100 µrad
REQ-L3-OAD-36041	Mount	IP instrument window dR_z with respect to OSS coordinates	≤ 100 µrad

4.2.2 Optics Manufacturing and Mounting Tolerances

Primary mirrors

The optical surface is an off-axis piece of a conic section of revolution whose surface height z as a function of distance r from the parent optical axis is

$$z = \frac{r^2}{R + \sqrt{R^2 - (k-1)r^2}}$$

undefined

with $R = 36$ m and $k = -0.998286$. The center of the off-axis segment is at a distance $r = 8.71$ m from the parent axis. There is no tolerance on conic constant; an error in k is considered a figure error.

The polished optical surface has a diameter of 8.405 m. The figure specification applies to a clear aperture with a diameter of 8.365 m centered on the optical surface.

The static errors of the position and rotation of the center of the off-axis parabola over the glass substrate, can be largely removed by static correction of the cell installation on the mount structure. The requirements presented in Table 4-14 will be lately suballocated to cell-to-mount motion, therefore only the residual motions will be allocated to the active optic motion budget.

The primary mirror center, obtained from a best-fit curve into the glass substrate shall deviate from the nominal position

Table 4-14: Manufacture Dimensional Tolerances for the Primary Mirror

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-36058	M1 Segment	Radial displacement form the parent vertex	≤ 2 mm
REQ-L3-OAD-36062	M1 Segment	Tip or tilt respect to the M1-B1 coordinate system	≤ 0.005 deg
REQ-L3-OAD-36066	M1 Segment	Axial displacement from the M1-B1 coordinate system	≤ 2 mm
REQ-L3-OAD-36070	M1 Segment	Deviation of Rz or clocking	≤ 50 arcsec
REQ-L3-OAD-36074	Mount	Deviation of Radius of curvature	≤ 1 mm

Rationale: It is derived from a distance of 8710 ± 2 mm of the radial position of the segment. Mechanical reference must be mapped to the optical surface for each mirror; these tolerances specify the uncertainty between the optical surface and mounting features. Values flow down from the System-Level Motion Budget (GMT-REF-03054).

Primary mirror metrology

The primary mirror metrology is based on the hardpoint internal length sensor, because of the hardpoint's high stiffness, the mirror-weldment-hardpoint structure has a relatively high resonant frequency of the system (10-20 Hz), allowing the mirror to be stiff against wind buffeting. An array of pneumatic actuators apply a force to the mirror supporting the mirror against gravity, lifting the weight of the mirror from the hard points, therefore the hardpoints see only dynamic wind load and the position of the mirror in the cell can be estimated with high with the measurement information provided by the hardpoints. The hardpoint attaches to the back plate of the mirror at glass wedges bonded to the back plate of the mirror.

REQ-L3-OAD-36080: Primary Mirror Interface Plate Locations

The primary mirror wedges interface plates shall be located in the back of the mirror coordinate system M1-B1 with accuracy of ±2 mm per axis X, Y and Z

Rationale: This tolerance needs to be built in the operational range of motion of the hardpoints.

Primary Mirror Cell

The primary mirror cell attaches to mount at the Cell Connector Frame (CCF) in six locations. Providing a semi kinematic attachment as shown in Figure 4-1. The primary mirror cell coordinate system is M1-A, as defined in GMT-DOC-01483. The M1-Tn (n represents the segment number) coordinate system, as defined in GMT-REF-00189, defines the ideal location of the top plate of the mirror cell. The fabrication tolerance of the mounting points will limit the accuracy on the final location of the M1-A respect to M1-T.

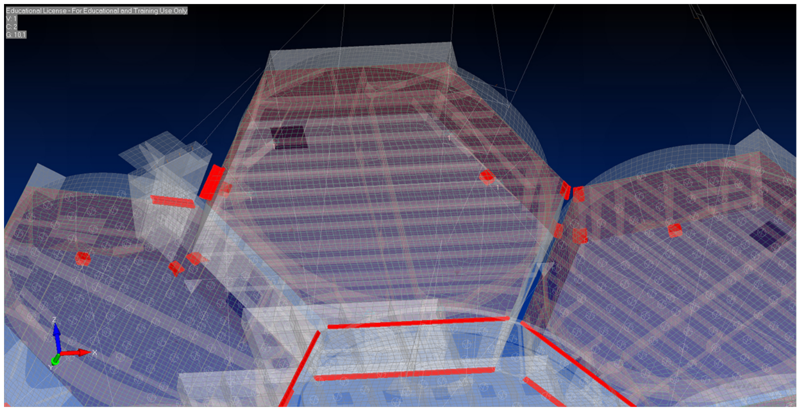

Figure 4-1: Mounting Surfaces of the M1 Cell into the CCF

M1 Cell Mounting Accuracy

The M1-A coordinate system shall deviate from the M1-T within limits specified in Table 4-15.

Table 4-15: Mounting Accuracy of M1 Cell into the Mount

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-36094	Mount	M1 Cell M1-A dX with respect to M1-T dX coordinate system	≤ 0.5 mm
REQ-L3-OAD-36098	Mount	M1 Cell M1-A dY with respect to M1-T dY coordinate system	≤ 0.5 mm
REQ-L3-OAD-36102	Mount	M1 Cell M1-A dZ with respect to M1-T dZ coordinate system	≤ 0.5 mm
REQ-L3-OAD-36106	Mount	M1 Cell M1-A dRx with respect to M1-T dRy coordinate system	≤ 125 µrad
REQ-L3-OAD-36110	Mount	M1 Cell M1-A dRy with respect to M1-T dRz coordinate system	≤ 125 µrad
REQ-L3-OAD-36114	Mount	M1 Cell M1-A dRz with respect to M1-T dRz coordinate system	≤ 125 µrad

Rationale: It is derived from lateral alignment tolerances allocated in the System-Level Motion Budget (GMT-REF-03054).

REQ-L3-OAD-36118: M1 Cell Position Adjusting Capability

The M1 cell shall be able to adjust it position respect to the mount in the Y and Z direction of M1-T coordinate system.

Rationale: This capability will allow to remove static errors of the mirror segments as defined in Table [ID-36136] and also to remove the mean motion due to gravity deformations.

REQ-L3-OAD-36121: M1 Cell Position Adjusting Range of Motion

The M1 cell shall have and adjustable range of motion of ±3.5 mm for Y and Z respect to the M1-T coordinate system.

Rationale: This range of motion allows to reduce the active optic range of motion without impacting performance. Alleviating design constraints for the Primary mirror support system.

REQ-L3-OAD-36124: M1 Cell Position Accuracy

The M1 cell shall be able to have adjustability of the Y and Z axis with an accuracy of 0.25 mm respect to the M1-T coordinate system.

Rationale: This accuracy will finally determine how much Active optics range of motion is allocated to the Primary mirror support system.

4.2.3 Thermal expansion

The mount structure has been modeled designed with steel. Due to the large coefficient of thermal expansion of the steel, and the broad range of temperatures of operation, M1, M2, M3 mirror positioning systems along with the ADC and AGWS have to be able to compensate for the departures from the nominal position. In order to allocate this range of motion a maximum coefficient of thermal expansion has to be imposed on the Mount structure.

REQ-L3-OAD-36129: Mount Coefficient of Thermal Expansion

The Mount shall have a maximum linear coefficient of thermal expansion of 12.2 ppm/K.

Rationale: Assumption made in the System-Level Motion budget that the structure that controls the relative positions of M1 and M2 is made of steel. If materials are used that results in a larger linear coefficient of thermal expansion, insufficient motion is available to compensate for thermally-induced deformation of the structure. Also driven by a trade betwen cost prohibitiveness, stiffness, and availability of materials.

4.2.4 Active Optics Range of motion

In order to position the mirror in the nominal optical prescription with origin in the OSS coordinate system, the optical elements require to have a range of motion that compensate for the displacements allocated in the sections 4.2.1, 4.2.2 and 4.2.3

M1 Segment Active Optic Range of Motion

The M1 segment positioning system shall have a range of motion as defined in the M1-S coordinate system of no less than Table 4-16.

Table 4-16: M1 Segment Active Optics Range of Motion

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-36141	M1S	M1 segment X translation	± 3.0 mm
REQ-L3-OAD-36145	M1S	M1 segment Y translation	± 4.75 mm
REQ-L3-OAD-36149	M1S	M1 segment Z translation	± 4.0 mm
REQ-L3-OAD-36153	M1S	M1 segment Rx rotation	± 650 µrad
REQ-L3-OAD-36157	M1S	M1 segment Ry rotation	± 575 µrad
REQ-L3-OAD-36161	M1S	M1 segment Rz rotation	± 575 µrad

Rationale: Allocations in the System-Level Motion Budget (GMT-REF-03054).

M2 Segment Active Optics Range of Motion

The M2 segment positioners shall have a range of motion as defined in the M2-S coordinate system of no less than Table 4-17.

Table 4-17: M2 Segment Active Optic Range of Motion

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-36173	ASMS, FSMS	M2 segment X translation	± 11.0 mm
REQ-L3-OAD-36177	ASMS, FSMS	M2 segment Y translation	±11.0 mm
REQ-L3-OAD-36181	ASMS, FSMS	M2 segment Z translation	± 12.0 mm
REQ-L3-OAD-36185	ASMS, FSMS	M2 segment Rx rotation	± 3000 µrad
REQ-L3-OAD-36189	ASMS, FSMS	M2 segment Ry rotation	± 3000 µrad
REQ-L3-OAD-36193	ASMS, FSMS	M2 segment Rz rotation	± 3000 µrad

Rationale: Allocations in the M2 Range of Motion Budget (GMT-REF-00422).
Notes: These ranges refer to the required motion of the optical surface with respect to the M2-Mount interface. They do not include any additional motion that may be required to compensate flexure within the ASMS or FSMS.

4.2.5 OAD Primary Mirror Seismic Range

During a seismic event the primary mirrors control system will turn off and rest the mirror on the static supports, both active supports and hardpoint apply minimal forces to the mirror. The mirror motions and stresses are constrained by the static supports' stiffness and damping properties. The seismic range of motion is the minimum range of motion that the M1 cell support system has to allow the mirror to move during a seismic event while only restrained by the static supports.

M1 Segment Seismic Range of Motion

The M1 segment shall be able to move with respect to the M1 weldment in a seismic event within the limits specified in Table 4-18.

Table 4-18: M1 Seismic Range of Motion

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-36208	Mount	M1 segment motion in X respect to the Cell respect to M1-A	≤ 17 mm
REQ-L3-OAD-36212	Mount	M1 segment motion in Y respect to the Cell respect to M1-A	≤ 17 mm
REQ-L3-OAD-36216	Mount	M1 segment motion in Z respect to the Cell respect to M1-A	≤ 12 mm
REQ-L3-OAD-36220	Mount	M1 segment motion in Rx respect to the Cell respect to M1-A	≤ 5 mrad
REQ-L3-OAD-36224	Mount	M1 segment motion in Ry respect to the Cell respect to M1-A	≤ 5 mrad*
REQ-L3-OAD-36228	Mount	M1 segment motion in Rz respect to the Cell respect to M1-A	≤ 0.75 mrad*

Rationale: Modeling and simulations of SLE estimated that this range of motion will have less than 0.5% of probability of damaging the mirror.

Notes: This number reflects the lateral Static Support Seismic Range motion budget. Refer to the GMT Active Optics Motion Budget (GMT-REF-03054).
The equivalent requirements on FP, AP, and IP instruments will be filled in eventually

Table 4-19: Instrument Position Error Requirements

Requirements	Element	Degree of Freedom	Req.
REQ-L3-OAD-36239	Mount	Instrument interface dZ_{DG} with respect to OSS coordinates	≤ 3.0 mm
REQ-L3-OAD-36243	Instrument	Instrument dZ_{DG} with respect to Mount interface	≤ 2.0 mm
REQ-L3-OAD-36247	Mount	Instrument interface F_{DG} with respect to OSS coordinates	≤ 0.993 mm
REQ-L3-OAD-36251	Instrument	Instrument F_{DG} with respect to Mount interface	≤ 0.2 mm
REQ-L3-OAD-36255	Mount	Instrument interface dRZ_{DG} with respect to OSS coordinates	≤ 0.6 mrad*
REQ-L3-OAD-36259	Instrument	Instrument dRZ_{DG} with respect to Mount interface	≤ 0.4 mrad*

Rationale: Needed to maintain off-axis optical quality after initial static alignment of the instrument and active optics corrections (OIWS and AGWS). Reference: GMT-DOC-04436.
Notes: The equivalent requirements on FP, AP, and IP instruments will be filled in eventually

4.3 Pointing, Offsetting, and Dithering

REQ-L3-OAD-36265: Initial Blind Pointing Accuracy

The GMT shall provide blind pointing to a position on the sky with an accuracy of 10 arcsec RMS [goal: 5 arcsec RMS] [TBR].

Rationale: This assumes a telescope pointing model and allows efficient location of one or more bright stars for initial calibration of the telescope pointing system at the start of each night.

REQ-L3-OAD-36268: Post-Calibration Blind Pointing Accuracy

After initial calibration, the GMT shall point to an absolute position in RA and Dec with an accuracy of 5 arcsec RMS.

Rationale: For efficient target acquisition, initial pointing to a science target must be accurate enough that the science target can be quickly identified.
Notes: This assumes that the pointing model has been calibrated by first pointing to one or more stars of known coordinates and the TMS not active.

REQ-L3-OAD-66732: Post-Calibration Blind Pointing with TMS Accuracy

After initial calibration, the GMT shall point to an absolute position in RA and Dec with an accuracy of 3 arcsec RMS, with the TMS active.

Rationale: For efficient target acquisition, initial pointing to a science target must be accurate enough that the science target can be quickly identified.
Notes: This assumes that the pointing model has been calibrated by first pointing to one or more stars of known coordinates.
Blind Pointing Budget
The GMT Blind Pointing budget is as follows.

Table 4-20: GMT Blind Pointing Budget Requirements

Item	Error Description	Error Source	Error (arcsec)	ReqID
Total Post Calibration Blind Pointing Error (includes Fitting Error)			4.17	
On-Axis Errors				
SWC				
	Positioning			
		Pointing Model Calibration Fitting Error	0.99	REQ-L3-OAD-36290
Mount				
	GIR			
		Mount Lower Structure/GIR Absolute Accuracy	2.50	REQ-L3-OAD-70871
		GIR Thermal Gradient Error	1.30	REQ-L3-OAD-70872
	Optical Support Structure			
		M1 and M2 Interface to Mount Structural Deflection, Non-Repeating	2.70	REQ-L3-OAD-70873
		OSS Thermal Gradient Error	0.65	REQ-L3-OAD-70874
Principle Optics				
	Optical Alignment			
		M1 Rigid Body Position Accuracy	0.57	REQ-L3-OAD-36304
		M2 Rigid Body Position Accuracy	0.62	REQ-L3-OAD-36297
External				
	Atmospheric Correction			
		ADC Residuals	TBD	REQ-L3-OAD-36349
		Humidity	0.00	REQ-L3-OAD-36352
		Pressure	0.10	REQ-L3-OAD-36355
		Temperature	0.03	REQ-L3-OAD-36358
Off Axis Errors				
Mount				
	GIR			
		AGWS Probe GIR	0.02	REQ-L3-OAD-

		Rotational Positioning Accuracy		70875
Principle Optics				
	Optical Alignment			
		Field Distortion and Image Scale	0.00	REQ-L3-OAD-70876
		Anisoplanatism	0.02	REQ-L3-OAD-70877
AGWS				
	Probe			
Mount		AGWS Probe GIR Local Deflection	0.20	REQ-L3-OAD-70878
AGWS		AGWS Probe Positioning Accuracy	0.14	REQ-L3-OAD-70879
		AGWS Probe Tracking Error	0.02	REQ-L3-OAD-70880

Rationale: For efficient target acquisition, initial pointing to a science target must be accurate enough that the science target can be quickly identified.

REQ-L3-OAD-36362: Guiding on a Different Wavelength

The GMT Observatory shall maintain the required pointing and image stability accuracies on the scientific target when the guide star measurements are performed at a different wavelength than the science observation.

Rationale: Guiding in visible wavelengths while observing in infrared is needed for several Observing Performance Modes.
Notes: This requirement is tied to PSF stability in the OPMs.

REQ-L3-OAD-36365: AGWS Non-Sidereal Guiding

The AGWS shall track guide stars at up to 6 arcsec/min relative to the sidereal rate with no more than 20 mas RMS of additional guiding error.

Rationale: This is needed to support the non-sidereal guiding requirement (ORD-25094). The allowable error of 20 mas is 10% of the best-condition infrared (1.65 µm) GLAO FWHM.
Notes: This requirement is exclusive of the Fixed GIR requirement below. Both do not have to be met simultaneously

REQ-L3-OAD-39040: AGWS Slit Scanning

The AGWS shall track guide stars at up to 1 arcsec/s relative to the sidereal rate with no more than 200 mas RMS of additional guiding error.

Rationale: Required to support the ORD scanning requirement (ORD-25098). The allowable error of 200 mas RMS is the best-case infrared (1.65 µm) GLAO FWHM.
Notes: This requirement is exclusive of the Fixed GIR requirement below. Both do not have to be met simultaneously.

REQ-L3-OAD-39043: AGWS Performance with Fixed GIR

The AGWS shall meet all of its performance requirements with the GIR fixed, over an apparent sky rotation angle of up to 60 degrees.

Rationale: Required to support the focal stations for which the GIR must be fixed (GIS, AP, and IP), as well as OPMs which may require the pupil to remain fixed on the instrument (Small Field Infrared High Contrast and certain spectroscopy modes). The rotation angle of 60 degrees corresponds to a ≥ 5 min integration at elevation 89.0 deg., or ≥10 min at elevation 88.0 deg.
Notes: This requirement must be met at all allowed elevation angles, but only for targets moving at the sidereal rate.

REQ-L3-OAD-113187: Direct Gregorian Port Guided Pointing

After calibration, the GMT shall provide guided pointing with an accuracy ≤ 0.2 arcseconds RMS at Direct Gregorian ports.

Rationale: Driven by the flexures between the subsystem controlling telescope guiding and the instrument or wavefront sensor being used. This flows-down to ~1 arcsecond field of view for DG instruments for 99% coverage.

REQ-L3-OAD-113001: Folded Port Guided Pointing

After calibration, the GMT shall provide guided pointing with an accuracy ≤ 1 arcsecond RMS at the Folded Port.

Rationale: Driven by the flexures between the subsystem controlling telescope guiding and the instrument or wavefront sensor being used. This flows-down to ~5 arcsecond field of view for FP instruments for 99% coverage.

Post-Calibration AGWS Guided Pointing Budget

The post-calibration AGWS guided pointing budget connected to REQ-L3-OAD-113187 and REQ-L3-OAD-113001 is shown in Table 4-21. The description and link to lower-level requirements can be found in GMT-REF-00477.

Table 4-21: Guided Pointing Budget

Requirement ID	ID	Subsystem	Error Term	DGNF (arcsec RMS)	DGWF (arcsec RMS)	FP (arcsec RMS)
	1	**Gravity and Thermal Flexure**				
REQ-L3-OAD-112985	1.1	Mount	AGWS to Instrument gravitational flexure	0.050	0.049	0.050
REQ-L3-OAD-112986	1.2	Mount	AGWS to Instrument thermal flexure	0.050	0.050	0.050
REQ-L3-OAD-112987	1.3	Mount	Mount-M3 interface motion	0.000	0.000	0.586
REQ-L3-OAD-112988	1.4	M3	M3 gravitational flexure	0.000	0.000	0.248
REQ-L3-OAD-112989	1.5	M3	M3 thermal flexure	0.000	0.000	0.124

	2	**Actuator Errors**				
REQ-L3-OAD-112991	2.1	AGWS	AGWS probe positioning accuracy	0.119	0.117	0.119
REQ-L3-OAD-112992	2.2	AGWS	AGWS probe tracking error	0.020	0.019	0.020
REQ-L3-OAD-112993	2.3	M3	M3 mirror position accuracy	0.000	0.000	0.497
REQ-L3-OAD-112994	2.4	M3	M3 mirror position repeatability	0.000	0.000	0.001
	3	**Telescope Guiding Errors**				
REQ-L3-OAD-112996	3.1	Mount	Mount Tracking Error	0.014	0.014	0.014
REQ-L3-OAD-112997	3.2	Mount	GIR rotation error	0.016	0.016	0.016
REQ-L3-OAD-112998	3.3	AGWS	AGWS Guiding Error	0.020	0.019	0.020
REQ-L3-OAD-112999	3.4	N/A	Tip-tilt anisoplanatism	0.015	0.015	0.015
REQ-L3-OAD-113000	3.5	SWC	Pointing model differential refraction	0.050	0.050	0.050
Post Calibration AGWS Guided Pointing Accuracy Requirement (arcsec RMS)				0.200	0.200	1.000
Error Allocated (arcsec RMS)				0.152	0.150	0.831
Reserve (RSS Difference in arcsec RMS)				0.130	0.133	0.556

Rationale: Driven by the flexures between the subsystem controlling telescope guiding and the instrument or wavefront sensor being used. Limits the field of view of the guide cameras.

REQ-L3-OAD-93828: Nodding and Dithering Accuracy

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

Rationale: Direct flow-down from REQ-L2-ORD-25062.
Notes: Direct flow-down is a placeholder; this will be updated with a budget to flow to L4.

4.4 Throughput

The reflectance of the mirrors directly influences the ability to meet the on-axis sensitivity requirement specified in the SRD. Here, throughput refers to the total throughput to the focal plane only and therefore does not take into account instrumental throughput.
Sensitivities in the SRD are computed assuming M1 and M2 are both coated with bare aluminum, and that M3 is coated with a 4-layer protected silver that has been utilized and tested on Gemini Observatory for the last decade (e.g., Boccas et al. 2004). This is consistent with the PDR throughput baseline specified in GMT-REF-00364. While there are potential problems with bare aluminum (aluminum can

oxidize over time and result in significant loss of reflectance in the UV; bare aluminum is soft and susceptible to scratches; other coatings perform better in the infrared), its fairly high reflectance across a broad bandpass makes it a viable option for M1 and M2. Coating M3 with the Gemini protected silver coating does imply that the FP configuration will not support UV instrumentation.

The DGWF layout also requires the use of a corrector and atmospheric dispersion compensator (C-ADC), which limits the wavelength range (0.35 µm < λ < 1.0 µm). The model for the C-ADC is discussed in the GMT Optical Design (GMT-DOC-00010) and in the PDR Baseline Throughput Budget (GMT-REF-00364). In short, the C-ADC uses standard and high blue transmission ("i-line") glasses to guarantee optimized throughput in the visible regime.

Reflectance curves for bare aluminum (data from Rocky Mountain Instrument Co., rmico.com/bare-aluminum) and the 4-layer protected Gemini Silver (Boccas et al. 2004) along with the throughput curve of the C-ADC are shown in Figure 4-2 through the UV and visible regime (left) and through the infrared (right).

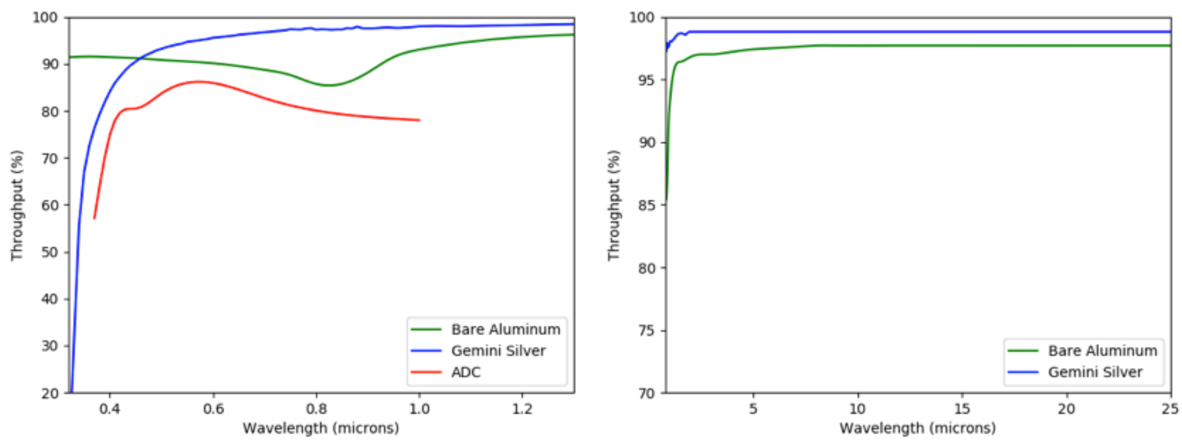

Figure 4-2: Throughputs of Bare Aluminum, 4-Layer Gemini Protected Silver, and the Transmission of the ADC (Bare Aluminum Data from RMI, Gemini Silver from Boccas et al. 2014, and C-ADC from GMT-REF-00364

The throughput as a function of configuration is plotted in Figure 4-3 below for the visible (left) and infrared (right). DGNF assumes reflections off of M1 and M2; DGWF assumes reflections off of M1 and M2 and transmission through M3; and FP assumes reflections off of M1, M2, and M3.

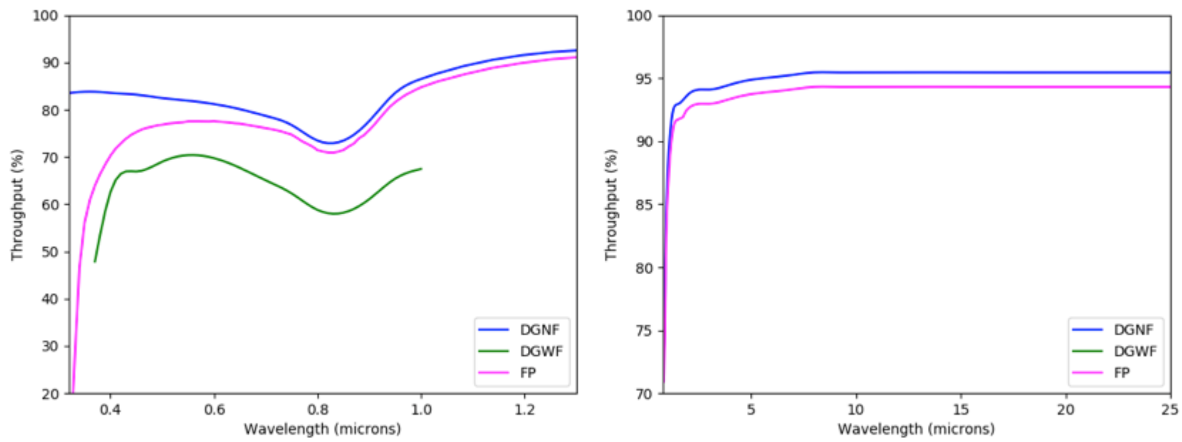

Figure 4-3: Throughput Through Each Telescope Configuration as a Function of Wavelength Assuming M1 and M2 are Coated with Bare Aluminum and M3 is Coated with Gemini Protected Silver

Appendix A contains a table with the average throughput over 50 nm windows; linear interpolation was performed when needed.

REQ-L3-OAD-36381: On-Axis Throughput

The GMT observatory shall be able to perform observations with the minimum average throughput in each 50 nm window for clean, freshly-polished mirrors as outlined in the table in Appendix B.

Rationale: Flows from the SRD requirements on on-axis sensitivity variation and absolute photometric accuracy.
Notes: High-reflectance mirrors are required to meet on-axis sensitivity requirements in each wavefront control mode. See GMT-DOC-01871 for more information.

4.5 Throughput Stability

REQ-L3-OAD-36386: Cleaning of Optics

The GMT observatory shall, at minimum, clean the optics with CO_2 once every two weeks, and the primary mirrors will be wet-washed every other year between re-coatings.

Rationale: Consistent CO_2 and wet washing is required to maintain high throughputs and low emissivities between recoatings. Dust and residue on the mirrors are particularly challenging for thermal infrared observations, as the overall telescope emissivity will increase and therefore negatively impact observing conditions.
Notes: GMT-DOC-01871 and GMT-REF-00364

REQ-L3-OAD-113186: Cleaning of M3

M3 shall be cleaned prior to folded port infrared observations (OPMs 5 – 9) to ensure that dust levels are minimized on the optics.

Rationale: Dust features can heavily impact infrared observations, particularly longward of 3 microns. To minimize any potential coherent features that may look like astronomical objects, M3 should be cleaned right before observations.

4.6 Throughput Spatial Variation and Vignetting

Vignetting causes field-dependent throughput loss and produces variable sensitivity over the field of view. The current optical design specifies that the secondary mirrors are matched 1:1 to the primary mirror segment. As a result, all off-axis field positions will be vignetted. The plot in Figure 4-4 shows the decrease in throughput as a function of field angle due to vignetting.

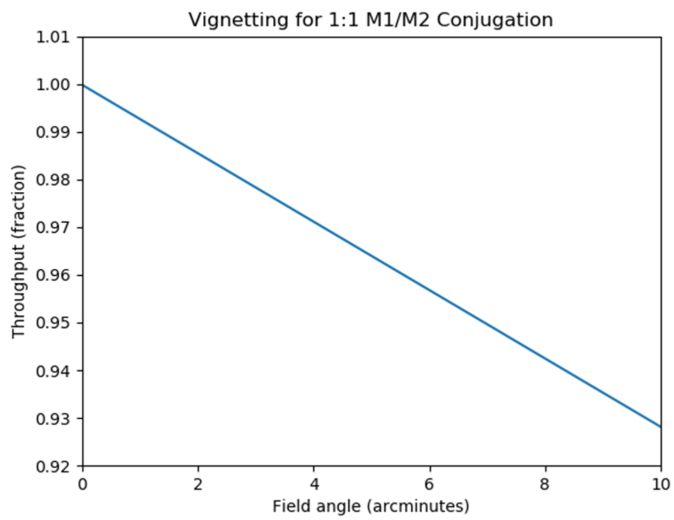

Figure 4-4: Vignetting as a Function of Field Angle

REQ-L3-OAD-63344: On-Axis Effective Collecting Area

The GMT shall have an effective collecting area of no less than 358 square meters, including all baffling.

Rationale: This effective area includes all M1 and M2 baffling in addition to the two M2 configurations. The effective area will directly influence the sensitivity of observations and therefore decreases in the effective areas must be carefully traded against other gains.

REQ-L3-OAD-36393: Maximum Vignetting, Small-field

The GMT shall be able to perform small field observations with vignetting < 1% at a field angle of 1.5 arcmin.

Rationale: Vignetting will contribute to photometric accuracy variation and affect off-axis sensitivities. To meet the off-axis sensitivity and photometric accuracy science requirements, vignetting must be minimized.
Notes: GMT-DOC-01871

REQ-L3-OAD-39046: Maximum Vignetting, Wide-field

The GMT shall be able to perform wide-field observations with vignetting < 7% at a field angle of 10 arcmin.

Rationale: Vignetting will contribute to photometric accuracy variation and affect off-axis sensitivities. To meet the off-axis sensitivity and photometric accuracy science requirements, vignetting must be minimized.
Notes: GMT-DOC-01871

4.7 Pupil Stability

As described in the SRD to ORD Analysis Document, science (SRD) requirements on sensitivity variation, and absolute and relative photometric accuracy flow into the throughput stability parameter that is part of each OPM definition, which in turn flows into a requirement on the stability (with respect to time) of the pupil location. The stability of the throughput is affected by the stability of the pupil due to signal loss due to vignetting (at visible and infrared wavelengths) and variable background (at thermal infrared wavelengths). The most stringent mode calls for 1% or better throughput stability, which translates to < 0.25% pupil shift. We note that optical axis tilts (pupil motion), also change the beam angle onto a dispersing element and thus the wavelength solution of a spectrograph; however, the motion at the focal plane of the instrument can be addressed through flexure compensation in the instruments and is not addressed here.

REQ-L3-OAD-36399: Pupil Stability

The GMT observatory shall be able to enable observations with a maximum pupil motion of less than 0.25% of the pupil diameter, in any OPM.

Rationale: Flows from the SRD requirements on sensitivity variation, and absolute and relative photometric accuracy, via the ORD requirement on throughput stability.
Notes: GMT-DOC-03229 (SRD to ORD Analysis).
Typically, the telescope's exit pupil is re-imaged in an instrument. The above requirement applies to any pupil location/diameter. Thus, we must decompose the pupil stability budget into a stability of the telescope's exit pupil as delivered by the active optics control system, and the stability of the instrument pupil under a changing telescope elevation (gravity vector). Moreover, the stability of the telescope's exit pupil must be analyzed separately for DG and FP focal stations. For DG instruments, pupil motion is not independently sensed or controlled and can only be mitigated by controlling instrument flexure. For FP instruments, the NGWS and LTWS have their own capability for pupil sensing and steering, thus the M3 can be used to correct the instrument pupil, using measurements from the OIWS. The decomposition used to analyze pupil stability performance and compliance with the above requirement is shown in Table 4-23. The chosen approach consists of determining the residual pupil motions after active control which is optimized for image quality. The analysis and development of a pupil stability performance budget (Table 4-22) is TBD and will be presented in GMT-REF-03242 when mature.

Table 4-22: Decomposition of Pupil Stability Analysis

Pupil Control Decomposition		DG Focal Station	FP Focal Station
Exit Pupil to Instrument Pupil	Exit Pupil to OSS	M1/M2 control • Gravity disturbance ○ Active Control (slow) • Thermal disturbance ○ Active Control (slow) • Wind on M2 ○ Dynamic control (fast)	M1/M2 control • Gravity disturbance ○ Active Control (slow) • Thermal disturbance ○ Active Control (slow) • Wind on M2 ○ Dynamic control (fast)
	Instrument Pupil to OSS	IMF Static Alignment IMF Gravity disturbance • FEM analysis of flexure ○ No control	Static Alignment Gravity disturbance • FEM analysis of flexure ○ M3/OIWS control for AO instruments (slow)
Exit Pupil to AGWS	AGWS Pupil to OSS	• AGWS mount to OSS I/F • AGWS internal flexure	• AGWS mount to OSS I/F • AGWS internal flexure

Table 4-23: Pupil Stability Performance Budget (TBD)

Requirement	Error Term	Pupil Shift (Max.) [% of Dpupil]	Pupil Shift (Integral) [% of Dpupil]	Description
DG Instrument				
REQ-L3-OAD-36413	M1/M2 Gravity	0.07		Exit Pupil to Instrument Pupil - Exit Pupil to OSS. (slow active control) TBC result of CEO simulation.
REQ-L3-OAD-36417	M1/M2 Thermal	TBD		Exit Pupil to Instrument Pupil - Exit Pupil to OSS. (slow active control)
REQ-L3-OAD-36421	M2 Wind Bufetting	TBD		Exit Pupil to Instrument Pupil - Exit Pupil to OSS. (dynamic control)
REQ-L3-OAD-36425	IMF Static Alignment	0.03		IMF to GIR axis. Allocation.
REQ-L3-OAD-36429	IMF Gravity	0.06		Exit Pupil to Instrument Pupil - Instrument Pupil to OSS. (no control) Allocation.
REQ-L3-OAD-36433	AGWS Static Alignment	0.03		Exit Pupil to AGWS - AGWS I/F to OSS. Allocation.
REQ-L3-OAD-36437	AGWS Gravity	0.06		Exit Pupil to AGWS - AGWS Internal Flexure. Allocation.
	Total			
	Requirement	**0.25**		REQ-L3-OAD-36399
	Margin			
FP AO Instrument				
REQ-L3-OAD-36447	M1/M2/M3 Gravity	TBD		Exit Pupil to Instrument Pupil - Exit Pupil to OSS.

				+ Flexure btw Instrument and NGWS or LTWS. (slow active control)
REQ-L3-OAD-36451	M1/M2/M3 Thermal	TBD		Exit Pupil to Instrument Pupil - Exit Pupil to OSS. + Flexure btw Instrument and NGWS or LTWS. (slow active control)
REQ-L3-OAD-36455	M2 wind buffeting	TBD		Exit Pupil to Instrument Pupil - Exit Pupil to OSS. (dynamic control)
REQ-L3-OAD-36459	Inst. Static Alignment	TBD		Instrument Static Alignment.
REQ-L3-OAD-36463	AGWS Static Alignment	TBD		Exit Pupil to AGWS - AGWS I/F to OSS.
REQ-L3-OAD-36467	AGWS Gravity	TBD		Exit Pupil to AGWS - AGWS Internal Flexure.
	Total			
	Requirement	**0.25**		REQ-L3-OAD-36399
	Margin			

Rationale: Flows from the SRD requirements on sensitivity variation, and absolute and relative photometric accuracy, via the ORD requirement on throughput stability.

4.8 Stray Light

Stray or scattered light refers to unwanted light arriving at the focal plane. Stray light will adversely affect the ability to meet sensitivity requirements and must therefore be mitigated.

REQ-L3-OAD-36478: Stray Light

GMTO shall design the telescope and enclosure to minimize stray light during night-time observing and daytime calibration sequences.

Rationale: This is driven by the desire to achieve maximum sensitivity. Scattered light adversely impacts both science data and instrumental calibrations.

4.8.1 Coatings

[Subsystem] shall have surface treatments consistent with the reflectivities given in Table 4-24

Table 4-24: Reflectivities of surfaces

Subsystem	Structure	Reflectivity Limit	Example Coating	Req. ID
ENC	Upper Enclosure Surfaces	≤ 50% Lambertian		[1]REQ-L3-OAD-36510
ENC	Observing Floor	≤ 50% (TBC, matte grey)	Smooth Concrete	[2]REQ-L3-OAD-36482
ENC	Items Mounted	≤ 50%		REQ-L3-OAD-

	on the Upper Enclosure	(TBC)		113016
MNT	Between primary and secondary mirrors	≤ 10% at 0.5 µm	Aeroglaze Z306	REQ-L3-OAD-113017
MNT	Aperture masks	≤ 10% at 0.5 µm	Aeroglaze Z306	REQ-L3-OAD-113018
MNT	Inner part of secondary support trusses, facing optical beam	≤ 10% at 0.5 µm (TBC)	Aeroglaze Z306	REQ-L3-OAD-113019
M2	Any surfaces with line-of-sight to primary	≤ 10% at 0.5 µm	Aeroglaze Z306	REQ-L3-OAD-113020
M2 Baffle	Surface w/ LOS to primary	≤ 10% at 0.5 µm	Aeroglaze Z306	REQ-L3-OAD-113021
M1 Baffle	Outer & inner surface (outer is facing M1 & M2; inner faces optical beam)	≤ 10% at 0.5 µm	Aeroglaze Z306	REQ-L3-OAD-113022

Rationale: Flows-down from OPM stray light requirements and required PST. The analysis is documented in GMT-REF-03244 with Jenny stray light model.

[1]Stray light can scatter off of dome surfaces and into the light path. To mitigate stray light, medium-reflectivity paint or medium-reflectivity surfaces are necessary to absorb scattered light.

[2]Scattered light will impact the detection limit for very faint sources and photometric accuracies. It will directly influence both on- and off-axis sensitivities, as stray light can vary substantially within the field of view. Above 1%, stray light will start to impact photometric accuracies.
Proper mitigation, such as good use of baffling and continuous stray light characterization of the observatory, is necessary to minimize the effect of stray light on observations. Careful considerations for baffling must be made, as warm baffles will emit in the infrared and increase the overall emissivity of the telescope.

4.8.2 Baffles

First-order baffles have been designed by GMTO to obscure direct lines of sight from the sky to the telescope focal plane (GMT-DOC-03137). These are large baffles, extending 2.4 m above M1 and can influence jitter due to wind turbulence and add some risk to the design of the telescope. Large baffles will also emit in the thermal infrared and add to the overall background noise of a detection.
There is also a double-bounce feature that bounces off both the primary and secondary mirrors, resulting in a focal plane image conjugate 1.8 km above the primary mirror. The optical path for the double-bounce feature is shown in Figure 5 in GMT-DOC-03137. Figure 7 in the same document shows a schematic for

the double-bounce light footprint on the primary mirror and highlights the need for proper baffling. Additional secondary scatter will deposit additional unwanted light onto the focal plane.

REQ-L3-OAD-36490: M1 Baffle

GMT shall have a primary mirror baffle to disrupt glancing incident reflections to the central hole with a height no greater than 6400 mm above the OSS origin (TBC) and an inner diameter no less than 1722 mm (TBC).

Rationale: Limits the direct-to-detector stray light arising from the critically-sized M2. GMT-DOC-03137 shows a conically-shaped baffle that sits 2.4 meters above the primary mirror vertex and is a compromise between the need to block the direct path and practical engineering practices.
Notes: GMT-DOC-03137

REQ-L3-OAD-36494: M2 Baffle

GMT shall have a secondary mirror baffle that circumscribes the secondary mirror segments with a diameter no larger than 3.6 meters as close to the exit pupil as the design will allow.

Rationale: Having the baffle as close to the exit pupil as possible will maximize the stray light mitigation from the direct path. The 3.6-m diameter was chosen as a compromise to circumscribe the secondary mirror segments and to minimize wind jitter and pupil obscurations.
Notes: GMT-DOC-03137

4.8.3 Enclosure

The enclosure provides opportunities for light to scatter. This can affect observations, particularly during the day when calibrations need to be performed. In order to mitigate the adverse effects of stray light, the enclosure needs to be light-tight and use low-reflectivity surfaces.

REQ-L3-OAD-36507: Light-tight Enclosure

The GMT shall limit total stray light levels to 1.3×10^{-3} W m^{-2} (TBC) at 0.5 µm in the observing chamber.

Rationale: Limits the amount of daytime stray light so that gradients or offsets in focal plane images will not impact flat-field calibrations. See GMT-REF-03244. Consistent with errors in the calibration field that is ≤ 0.1% of the calibration source's flux.

REQ-L3-OAD-113024: Fixed lights during science operations

No fixed lights shall be on during science operations (i.e., parking lot lights).

Rationale: Minimizes potential stray light effects from outside areas. When cars are driving, they should minimize having their lights on during nighttime observations as safety will allow.

REQ-L3-OAD-113025: Lights off

Each light source within the Observing Chamber shall have the ability to be switch to an "off" state so that it does not add excess stray light.

Rationale: Stray light from LED lights on computers, for example, can cause strange features, particularly if they are near the optical path. This can be controlled and should be minimized.
Notes: This could include covering it with a piece of tape, for example.

REQ-L3-OAD-113026: Light source afterglow

Light sources must be adequately guarded against afterglow leakage, visible or thermal, when they are turned off during science operations or calibrations.

Rationale: Afterglow can still cause stray light, and sometimes visible light fixtures can cause afterglow in the infrared. These should be avoided to minimize the impact on science observations.

4.8.4 Primary Mirror Stop

REQ-L3-OAD-36514: Primary Mirror Stop

The GMT shall have a baffling system where a circular annular ring is installed above the top surface of each primary mirror segment to mitigate against stray light from the rough round-off edges of the M1 segment mirror.

Rationale: This will prevent scattered light from entering the primary beam.
Notes: GMT-TEL-DOC-00703

4.9 Emissivity

Point source sensitivity requirements and measurements for the GMT are dependent on the emissivity of the system. The telescope and its peripherals (i.e., baffles, mirror coatings, pupil, etc.) will cause background noise and structure that can be comparable to the signal for faint targets. Without proper planning and design to mitigate the thermal background of the telescope, the thermal background noise can over-power any signal, especially at mid-infrared wavelengths.

REQ-L3-OAD-36527: Maximum Emissivity

The GMT contribution to on-axis emissivity shall not exceed the specifications below in Table 4-25 for DGNF (no C-ADC) and FP.

Rationale: Based on the optical design, mirror coating baselines, and science requirements.
Notes: GMT-DOC-01871

Table 4-25: Emissivity Budget (TBC)

Configuration	Direct Gregorian Focus with ASM		Folded Port Focus with ASM	
	2 µm	10 µm	2 µm	10 µm
Reflectivity of Mirrors	93.8%	95.5%	92.60%	94.30%
	Segmented cold stop			
Optical Coatings	6.20%	4.50%	7.40%	5.70%
Structure above M2 (TBC)	1.54%	1.54%	1.54%	1.54%
M2 hubs (TBC)	0.40%	0.40%	0.40%	0.40%
Diffraction	0.10%	0.20%	0.10%	0.20%
Total Segmented cold stop	8.24%	6.64%	9.44%	7.84%
	Non-segmented cold stop			
Additional M3 Emission	0%	0%	0.40%	0.40%
M2 Baffles (TBC)	2.40%	2.40%	2.40%	2.40%
Total Non-segmented	10.64%	9.04%	12.24%	10.64%

cold stop				
•Aluminum coatings on M1 & M2.				
•Instrument cold stop conjugated to M1 pupil.				
•Segmented cold stop rotates with pupil. •At FP, M3 is a filled aperture for a non-segmented stop.				

Additionally, for critical low-background applications, operating in the thermal infrared, internal rotating segmented cold stops conjugated to M1 need to be introduced to minimize emission from the telescope structure. All instruments operating in any wavelength regime will need to have some internal stops to mitigate light from outside the exit pupil reaching the detector (GMT-TEL-DOC-00703).
Additional work to formalize the emissivity is required, and it will have to evolve with the design of the GMT. For instance, the M1 and M2 baffles will affect the overall emissivity; as a final design has not been completed, the emissivity budget is TBC. When it has been more developed, it will be encompassed in GMT-REF-00364.

4.10 PSF Stability

The PSF stability describes the maximum change of the field-dependent point spread function over two hours. The change in the shape of the PSF equates to the change in the aperture photometry and directly affects the ability to perform relative photometry. It does not include field-dependent throughput variations.
PSF stability can be decomposed into the following items from Table 4-26.

Table 4-26: PSF Stability Items

Item	Description
Instrumental response/flat-fielding	Error on flat-field calibration. Derived from Poisson statistics of a high-throughput
Flat-field Illumination Uniformity	Flat-field illumination uniformity should not limit flat-field accuracy compared to photon statistics for moderately demanding science cases. Chose to limit uncertainties to 10% of instrument response.
Shape Variation	Considers PSF shape variation across the field in a non-crowding situation and the ability to PSF fit or aperture correct the total flux.
Stray Light	Uncertainty in stray light correction. This value should not limit demanding science cases.
Background structure	The background structure, particularly in the infrared, can add substantial field-dependent flux variations of the flux.

REQ-L3-OAD-36539: PSF Stability

The GMT Observatory shall be able to acquire images with a maximum change in the uncertainty in the flux in a 5 (TBC) x FWHM diameter aperture (excluding throughput variations) over a two-hour period as described in Table 4-27.

Rationale: Direct flow-down from Relative Photometric error of parent observing case.
Notes: For diffraction-limited OPMs, the field-dependent PSF shape predicted by telemetry will partially compensate for field-dependent atmospheric turbulence changes. For these cases, the requirements detailed in Table [ID 35073] puts a limit on the estimation error of field-dependent PSF photometric measurements.
PSF shape variation will be dependent on the following terms:

• Atmospheric effects/anisoplanatism

• Design optical aberrations
• Telescope shape errors (M1/M2 fabrication shape, print-through shape, dynamic shape, support shape, thermal shape, wind-induced shape), which lead to field-dependent optical aberrations
• Optical alignment errors (M1/M2 segment position error, instrument error, etc)

The PSF stability budget is largely TBC. In Table [ID 36547] below, the background structure is largely going to be dependent on the wavelength of observation; for OPM 9, additional variable background structure may be present from the data acquisition techniques and data reduction techniques.

Table 4-27: PSF Stability by OPM (TBC)

OPM	Instrumental Response	Flat-field Illumination calib. error	Shape Variation	Background structure	Stray Light Calibration	Allocation (%)	Requirement (%)
1	0.1%	0.01%	0.70%	0.2%	0.2%	0.8%	1%
2	0.1%	0.01%	0.70%	0.2%	0.2%	0.8%	1%
3	0.1%	0.01%	0.70%	0.2%	0.2%	0.8%	1%
4	0.1%	0.01%	0.70%	0.2%	0.2%	0.8%	1%
5	0.1%	0.01%	1.0%	0.7%	0.2%	1.25%	2%
6	0.1%	0.01%	1.0%	0.7%	0.2%	1.25%	2%
7	0.1%	0.01%	1.0%	0.7%	0.2%	1.25%	2%
8	0.1%	0.01%	1.0%	0.7%	0.2%	1.25%	2%
9	0.1%	0.01%	3.5%	1.0%	0.2%	3.6%	5%
10	0.1%	0.01%	0.7%	0.2%	0.2%	0.8%	1%
11	0.1%	0.01%	0.7%	0.2%	0.2%	0.8%	1%
12	0.1%	0.01%	1.0%	0.7%	0.2%	3.6%	2%
13	0.1%	0.01%	1.0%	0.7%	0.2%	3.6%	2%
14	0.1%	0.01%	0.7%	0.2%	0.2%	0.8%	1%
15	0.1%	0.01%	0.7%	0.2%	0.2%	0.8%	1%

4.11 Field Distortion Stability

REQ-L3-OAD-36549: Field Distortion Stability

The GMT observatory shall be able to maintain field distortion stability to the levels outlined in Table 4-28 over a 10-hour period.

Rationale: Direct flow-down from astrometric variatinon requirements in the science requriements document.
Field distortion is a direct flow-down from the Maximum Astrometric Variation requirement for each observing case. It is the peak-to-valley change in distortion at any location in the telescope focal plane in a 10-hour period. The requirements in the SRD for astrometric accuracy are derived considering that the image scale must have an RMS and absolute accuracy of 5% of the FWHM of the PSF for each OPM.
Field distortion can be broken down into the following effects:

- Thermal variation on each mirror/change in the effective focal length
- High-order geometric distortion
- Intra-pixel sensitivity changes

Note that this effect does not include contributions from residual differential atmospheric refraction across the field of view.
Intra-pixel sensitivity changes will be nearly negligible compared to the effects of the high-order

geometric distortion and thermal gradients on the mirrors. High-order distortion can be estimated from Gemini GeMS (Gemini Multi-Conjugate Adaptive Optics System) residual distortion (see GMT-DOC-01871 for detailed analysis; Neichel et al. 2014). Additional analysis is necessary to quantify how thermal gradients will affect field distortion variation over a 10-hour period. For spectroscopic measurements, errors in the image scale can cause loss of flux through the slit.

Table 4-28: Field Distortion Budget (TBD)

OPM	Thermal Gradients, TBC	Residual Geometric Distortion (mas), TBC	Total Estimated Error (mas)	Requirement (mas per OC FOV)	Field of View (arcsec)	Total Estimated Error (%)	Requirement (%)
1	0.01	3		13	180		0.007%
2	0.01	3		13	180		0.007%
3	N/A				180		N/A
4	N/A				180		N/A
5	0.01	3		10	180		0.006%
6	0.01	3		10	180		0.006%
7	0.002	< 1		1	30		0.001%
8	0.002	< 1		1	30		0.001%
9	0.002	< 1		1	30		0.001%
10	0.1	10		30	600		0.005%
11	0.1	10		30	600		0.005%
12	0.1	10		30	600		0.005%
13	0.1	10		30	600		0.005%
14	0.3	20		60	1200		0.005%
15	0.3	20		60	1200		0.005%

4.12 Spectral Stability

REQ-L3-OAD-36558: Spectral Stability

GMT shall enable spectral stability with a wavelength accuracy of ≤ 10% of the spectral resolution when the signal-to-noise ratio is ≥ 10.

Rationale: Direct flow-down from the spectral stability requirements in the science requirements document.

Spectral stability, or wavelength calibration stability, is going to depend on the spectral resolution of the instrument's configuration, pupil stability, and PSF stability. Each instrument will have its own spectral resolution defined by its own set of requirements; it must conform to this requirement. OPMs 3 and 4, the precise radial velocity modes, will require more accurate spectral calibrations; these capabilities must be provided by the instrument.

4.13 Calibration

Regular calibration of instruments will be necessary. Instruments need two basic types of calibration: wavelength calibration for spectroscopic instruments, and flat-field calibrations for all instruments. Since the instrument calibrations may be needed during the night, observational efficiency requires that they be deployed and retracted quickly, and at any elevation (including at zenith).

4.13.1 Instrument Calibration System

REQ-L3-OAD-36564: Instrument Calibration System

The GMT shall provide a deployable Instrument Calibration System (ICS).

Rationale: A facility-wide system for calibrating science data from the instruments will serve multiple uses. Wide-field instruments, in particular, will not be able to supply their own calibration systems to cover the entire field of view of the telescope.

REQ-L3-OAD-36567: ICS Elevation Range

The ICS Deployment Mechanism shall operate at any elevation angle within the observing range of the telescope (including zenith).

Rationale: Flow down from parent requirement.

REQ-L3-OAD-36570: ICS Retracted Position

The Mount shall retract the ICS to a position that is out of the optical beam of the telescope.

Rationale: When not in use the system should not cause additional shadowing of the telescope beam.

REQ-L3-OAD-36573: ICS Self-Vignetting

When deployed, the ICS Deployment Mechanisms shall vignette the projected calibration source beams by less than 5% [goal: 0%].

Rationale: The ICS requires even illumination of the pupil. Vignetting of the beam by the deployment mechanism will cause pupil vignetting.
Notes: This requirement only applies to the contribution of the deployment mechanism.

REQ-L3-OAD-36577: ICS Flat-Field Illumination

The GMT shall support the calibration of science instruments by providing a deployable system(s) to project continuum light sources with beam characteristics that match the light coming from the sky and celestial sources.

Rationale: Required to perform accurate relative photometric measurements within the field of view of a science instrument.
Notes: Instruments may be required to provide additional means of calibration when appropriate.

REQ-L3-OAD-36581: ICS Spectral Lines Illumination

The GMT shall support the calibration of science instruments by providing a deployable system(s) to project spectral light sources with beam characteristics that match the light coming from the sky and celestial sources.

Rationale: Enable absolute wavelength calibration of spectra.
Notes: Instruments may be required to provide additional means of calibration when appropriate.

REQ-L3-OAD-36585: ICS Wavelength Range

The ICS shall provide flat field and spectral calibration sources to cover the wavelength range of 320–2500 nm over the maximum Field of View of the telescope.

Rationale: Calibration required for visible and near IR instruments. All OPMs must be served at wavelengths below the point at which thermal background dominates.

REQ-L3-OAD-36588: ICS Field of View

The ICS shall provide calibration light over the maximum Field of View of the telescope.

Rationale: Supports all OPMs, including Wide Field OPMs.

REQ-L3-OAD-36591: ICS Deployment while Telescope in Motion

The ICS shall be deployable or retractable while the telescope is in motion.

Rationale: Being able to deploy the ICS while the telescope is slewing improves observing efficiency.

REQ-L3-OAD-36594: ICS Availability

The ICS shall be available for use in day and night time.

Rationale: Some calibrations can only be done when the telescope is in the same attitude as during the observations and thus are best done at night. Others can be carried out at the zenith and can be done during the day.

REQ-L3-OAD-36597: ICS Automated Calibration

The ICS shall enable the use of automated calibration sequences, including source selection and illumination control.

Rationale: Automated sequences of calibrations improve operational efficiency.

REQ-L3-OAD-36600: ICS Location

TBD.

Rationale: The ICS will produce uniform illumination at the telescope focal plane with beam characteristics that match the light coming from the sky and celestial source.
Notes: Candidate locations for the deployable ICS illumination source(s) are: the telescope's prime focus, the telescope's exit pupil, or located under

4.13.2 Internal Instrument Calibration

REQ-L3-OAD-36604: Instrument Internal Calibrations

Science instruments that require flat-field or spectral calibration performance beyond that provided by the GMT instrument calibration system shall provide their own calibration systems.

Rationale: The general calibration system provided as a part of the telescope facility may not meet the performance requirements of all instruments.
Notes: In general, since calibrating using external sources may also restrict other activities in the Enclosure and on the telescope, internal calibrations are encouraged in every instrument.

4.14 Effective Collecting Area

The effective collecting area budget flows-down from the total on-axis effective collecting area given by REQ-L2-ORD-106537. The purpose is to minimize obscurations and intrusions into the pupil of various hardware that would decrease the sensitivity of observations. It flows-down to tolerances on the M1 optical masks, the diameter of the M2 baffle, the size of figure flexures for the ASMS, drain cover holes, and specifies a continuous face sheet for the ASMS. The budget is shown below and the full description of each term is given in GMT-REF-04998. The value in the blue-shaded boxes is the total possible collecting area given a clear aperture of 8.365 m per M1 segment (with the outer segments at a 13.522° tilt), and all terms below subtract from that overall number.

Table 4-29: ECA

Requirement ID	Effective Collecting Area (DGNF)	Allocations	CBEs	Notes/Precedence
N/A	On-Axis Collecting Area, 6 x Off-Axis Segments	320.601	375.558	8.365 m clear aperture segments. Off-axis segments at 13.522° tilt. Since center segment's hole is obscured by M2 baffle, doesn't count against overall budget in this roll-up number.
N/A	On-Axis Collecting Area, On-Axis Segment	54.957		
REQ-L3-OAD-112950	Mount Trusses	5.54	5.463	Mount reference design trusses estimated via Delaunay triangles (see GMT-DOC-04667). The top end is included with the Mount Truss. CBE is Delaunay triangle estimate from R. Conan for the Mount reference design.
REQ-L3-OAD-112951	Additional Mount Obscurations	0.500	0.000	Vanes, prime focus deployment arms additional allocation, etc. Estimate from updated SL analysis performed Dec. 2019
REQ-L3-OAD-112952	M2 Baffle Contribution	10.850	10.850	Allocation & CBE represent a 3.6-m baffle that circumscribes range of motion of M2 segments. Area of the truss shadowed by the M2 baffles is counted under the M2 baffle. Includes baffling out the triangular-shaped areas between the baffle and the Mount. Allocation includes estimation of triangular-shaped areas from H. Chiquito.
REQ-L3-OAD-112953	Additional M2 Obscurations	0.200	0.200	Includes electronics cabinets, etc. Most things will be hidden behind the M2 baffle.
REQ-L3-OAD-112954	M1 Baffle Contribution	0.000	0.000	Already obscured by M2 segments
REQ-L3-OAD-112955	Baffles over drainage holes	0.046	0.046	100 mm baffle over 76.2 mm holes; 80 mm baffle

				over 50.8 mm hole.
REQ-L3-OAD-112956	Additional stray light mitigation strategies	0.800	0.723	Vane shadow is an estimate from updated stray light analysis performed December 2019.
REQ-L3-OAD-112957	M1 optical mask obscuration	1.268	1.268	Estimate using D. Ashby's Range of motion estimates + 2 mm manufacturing error (per email exchange documented in GMT-CR-04977 and on GMT-CAD-195434)
REQ-L3-OAD-112958	ASMS Center hole additional area	0.000	0.000	ASMS & FSMS are continuous
	FINAL EFFECTIVE COLLECTING AREA:	356.354	357.008	
	Margin (square meters):	0.354	1.008	REQ-L2-ORD-106537: 356 sq. meters

Rationale: The purpose is to minimize obscurations and intrusions into the pupil of various hardware that would decrease the sensitivity of observations. It flows down to tolerances on the M1 optical masks, the diameter of the M2 baffle, the size of figure flexures for the ASMS, drain cover holes and specifies a continuous face sheet for the ASMS.

5 Observatory Operations

5.1 Environment

REQ-L3-OAD-61209: 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.

Rationale: Condensation on optics degrades the coating and throughput. Condensation on electronics can cause short and other failures.
Notes: Condensing conditions are defined as a local ambient temperature less than 2 °C above the local dew point.

REQ-L3-OAD-61211: 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).

Rationale: Water on optics degrades the coating and throughput. Water on electronics can cause short and other failures. Water on other components can also cause failures or accelerate degradation of the components (e.g. oxidation of metals).

REQ-L3-OAD-61184: 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 5-1.

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. The temperature gradient refers to a linear slope gradient.
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). In regular operating conditions, 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. For more information on the derivation of the weather requirements and the methodology used to derive the joint probability, see GMT-REF-00144.

Table 5-1: Regular Operating Conditions Requirements

Night-time Environmental Condition	Value
External air temperature range	–3 °C to +19.5 °C
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)]
External air pressure	743 mbar to 758 mbar
External maximum wind speed (1-minute average @ M1 height)	up to 17.0 m/s

REQ-L3-OAD-61189: Extended Operating Conditions

The GMT Observatory shall meet all functional requirements under the Extended Operating Conditions specified in Table 5-2.

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. The temperature gradient refers to a linear temperature slope.
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.

Table 5-2: Extended Operating Conditions Requirements

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

REQ-L3-OAD-61194: Maintenance Conditions

The GMT Observatory shall enable all maintenance operations under the Maintenance Conditions specified in Table 5-3.

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.
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.

Table 5-3: Maintenance Conditions Requirements

Environmental Condition	Value
Ambient (external) air temperature range	–8 °C to +27.7 °C
Ambient (external) air pressure	740 mbar to 758 mbar

REQ-L3-OAD-61199: Survival Conditions

The GMT Observatory shall survive repeated exposure to the Survival Conditions specified in Table 5-4.

Rationale: 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/m³ (the latter being a conservative value for fresh snow deposited near 0 °C).

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). The temperature gradient corresponds to a linear slope.

Table 5-4: Survival Conditions Requirements

Environmental Condition	Value
External air temperature range	–8.5 °C to +27.7 °C
External air pressure	740 mbar to 758 mbar
External maximum wind speed (3s gust @M1 elevation)	Up to 55 m/s
External air temperature change over 30 minutes	–4.8 to +4.3 °C (extremes measured)
External rainfall rate	0.2 m/hour (maximum measured)
External snowfall	Column density up to 200 kg m^{-2}

REQ-L3-OAD-61206: 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.

5.1.1 OAD Environmental monitoring

REQ-L3-OAD-36611: Environmental Monitoring Facility

The GMT shall provide an Environmental Monitoring Facility for monitoring the seismic, particulate, weather and atmospheric conditions.

Rationale: This is required to ensure safe operating conditions and to monitor atmospheric conditions for science program optimization.
Notes: The facility will include, for example, a weather tower, MASS/DIMM tower, electronics, power, and communications.

REQ-L3-OAD-36615: Environmental Data Archive

The GMT shall archive Environmental Data into the Engineering Data Archive and make it available to Observatory users.

Rationale: This will allow trends to be identified and monitored for maintaining optimal performance of GMT, and allowing context for the interpretation of science data.

REQ-L3-OAD-36618: Environmental Alerts

The GMT shall provide a system to alert users of detrimental environmental conditions.

Rationale: Changing conditions may require users or subsystems to act to protect Observatory systems. For example, detection of precipitation while the enclosure shutter is open will cause operators to close the enclosure shutter.

The system should continuously provide graduated indicators and warnings as conditions approach predefined limits, and trigger alerts (audio and/or visual) as they exceed critical. The alert conditions include: dew point differential, precipitation, particulate, wind, and seismic.

Monitoring of External Summit Environmental Conditions

The GMT Environmental Monitoring Facility shall provide sensors and equipment to collect, display in real time, and store external environmental conditions at the summit, as shown in Table 5-5.

Table 5-5: External Environmental Conditions and Measurement Ranges

Requirement	External Parameter	Measurement Range	Documentation
REQ-L3-OAD-38962	Seismic Activity	Survival	
REQ-L3-OAD-38965	Temperature	Survival	
REQ-L3-OAD-38968	Barometric Pressure	Maintenance	
REQ-L3-OAD-38971	Humidity	0% to 100%	
REQ-L3-OAD-38974	Wind Speed	Survival	
REQ-L3-OAD-38977	Wind Direction	0° to 360°	
REQ-L3-OAD-38980	Precipitation	Survival	
REQ-L3-OAD-38983	Airborne Particles	Extended Operating	Dust & smoke
REQ-L3-OAD-38988	Integrated optical turbulence (R_0)	7 cm to 50 cm Estimate of sky brightness near a Full Moon, to the sky brightness of a dark site.	Ref: *GMT Site Testing at Las Campanas Observatory*
REQ-L3-OAD-38993	Turbulence profile with height (Cn2)	Height from ground to 100 km: Cn2 between 3×10^{-15} to 5×10^{-12} $m^{-2/3}$	Ref: *GMT Site Testing at Las Campanas Observatory*
REQ-L3-OAD-38998	Precipitable Water Vapor	0.5 to 10 mm	Ref: *GMT Site Testing at Las Campanas Observatory*
REQ-L3-OAD-39003	Sky Transparency	0.5 to 5 V mag	Five mags of extinction will not be possible across the entire sky; only where bright stars ($V < 1$) are located.
REQ-L3-OAD-39007	Sky brightness	16 to 22 V mag arcsec^2	
REQ-L3-OAD-39011	Lightning		

Notes: The above measurement ranges refer to the four sets of environmental conditions defined in the

ORD: Regular Operating, Extended Operating, Maintenance, and Survival.
Rationale: This is required to ensure safe operating weather conditions and to monitor atmospheric conditions for the safety of the facility, preservation of optical coatings and observational planning for efficient use of the facility.
Monitoring of Enclosure Environmental Conditions
The GMT shall provide sensors and equipment to collect, display in real time, and store environmental conditions within the Enclosure, as shown in Table 5-6.

Table 5-6: Enclosure Environmental Conditions

Requirement	Internal Environmental Parameter	Measurement Ranges
REQ-L3-OAD-39013	Temperature	Survival Conditions
REQ-L3-OAD-39016	Humidity	0% to 100%
REQ-L3-OAD-39019	Wind Speed	Survival Conditions
REQ-L3-OAD-39022	Wind Direction	0° to 360°
REQ-L3-OAD-39025	Airborne Particulates	Extended Operating Conditions
REQ-L3-OAD-39028	Local optical turbulence	Cn2 between 3×10^{-15} to 5×10^{-12} $m^{-2/3}$

Notes: The above measurement ranges refer to the four sets of environmental conditions defined in the ORD: Regular Operating, Extended Operating, Maintenance, and Survival.
Rationale: The Enclosure protects against some environmental conditions, and measurements within the Enclosure at appropriate points will indicate how well it is succeeding. Local optical turbulence measurements allow quantification of dome seeing, and will inform the Enclosure state (vent, wind screen, and moon shade configurations).

REQ-L3-OAD-36634: GMT Weather Forecasting

The GMTO shall utilize weather forecasts for short-, medium- and long-range scheduling.

Rationale: Regional weather forecasts help staff to anticipate weather changes.
Notes: Short-range forecasts are typically 0–3 days, medium-range forecasts are for seven days and long-range forecasts are for 14 days.

5.1.2 Controlling the Internal Enclosure Environment

Control of scattered light is discussed in Section 4.8. This includes the Moon shades and vent shades.

REQ-L3-OAD-36644: Seal Protection

The GMT Enclosure Building, when closed, shall seal against external environmental conditions that could damage or degrade performance of the telescope systems.

Rationale: This is required to protect the telescope and instrumentation from detrimental effects under all expected environmental conditions as specified in GMT-SE-REF-00144.
Notes: External environmental conditions that could be detrimental to the telescope include precipitation, warm daytime air, and dust.

REQ-L3-OAD-36648: Precipitation Protection

The GMT Enclosure shall protect against precipitation (rain and snow) when closed.

Rationale: Snow and water infiltration should be kept to a minimum to ensure the structural integrity of the enclosure and cleanliness of the telescope and other systems.

REQ-L3-OAD-36651: Wind Protection

The GMT enclosure shall be designed using best practices to minimize the effects of wind disturbance on the telescope structure and thermal effects that contribute to image blur in the science field.

Rationale: Wind-driven disturbances and thermal gradients are expected to be more important for ELTs than they are for smaller telescopes. Even the best of the current 8-m-class telescopes suffer from windshake and the design and operation of the enclosure plays a large part in mitigating the impact of the wind on the telescope.
Notes: Normally, this requires minimizing the exposed thermal mass within the enclosure, the use of thin cross-sections for structural elements, providing a high degree of wind-driven flushing of the structure throughout the night to promote rapid equilibration of the internal air with the ambient outside temperature, and using low-emissivity coatings around the shutters to prevent over-cooling of the air crossing in front of the telescope.

5.1.3 Environment Inside Support Buildings

REQ-L3-OAD-36656: Summit Support Building Environmental Control

The GMT Support Buildings shall be environmentally conditioned to provide a temperature range from 20–24 °C and a humidity range between 20% and 60% during recoating processes.

Rationale: This range of environmental conditions represents a comfortable working environment. Section III, Chapter 2, Subsection V of the OSHA technical Manual, “Recommendations for the Employer” recommends 68–76 °F (20–24.4 °C), humidity between 20% and 60%.
Notes: While not being used for recoating processes thermal control is not necessary.

REQ-L3-OAD-36660: Summit Support Building Storage Bay Thermal Control

The Summit Support Building shall supply an area that can be thermally controlled within the Extended Operating Conditions and in which an off-axis M1 cell with mirror cover can be stored.

Rationale: M1 cells may need to be acclimatized to the temperature within the Enclosure before being installed onto the telescope. Generally, the Enclosure is kept at night-time temperatures.

REQ-L3-OAD-36663: Lower Enclosure Instrument Bay Thermal Control

The Lower Enclosure Instrument Bays shall be thermally controlled to provide a range of temperatures including the Extended Operating Conditions.

Rationale: The Instrument Bays should be comfortable for long-term work on instruments, but should also have minimal impact on Upper Enclosure temperature when opened to the Upper Enclosure. It is assumed that the Upper Enclosure is normally kept at night-time temperature.
Notes: The Extended Operating Conditions include most of the temperature range recommended by OSHA "Recommendations for the Employer” (OSHA Technical Manual, Section III, Chapter 2, Subsection V, available at https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_2.html), for a comfortable working environment.

5.1.4 Environment Inside Living Spaces

REQ-L3-OAD-36677: Living Space Environment

The GMT living spaces and office spaces shall be maintained at a temperature range from 20–24 °C.

Rationale: Guidelines from the OSHA Technical Manual, Section 3, Chapter 2, V.A.3 (TED 01-00-015).
Notes: Living spaces include sleeping quarters, dining areas, recreational spaces. Office spaces include the control room, conference rooms, and offices. The humidity guidelines from the OSHA manual are not included as we will not centrally control humidity. Local humidity control could be provided by Operations when necessary.

REQ-L3-OAD-36680: Living Space Light Tightness

The GMT living spaces shall have the ability to block internal light sources from escaping into the external environment during the night.

Rationale: Local light sources need to be controlled to prevent scattered light from adversely affecting science operations.
Notes: Night-time hours are defined in the ConOps to be between 12° evening twilight and 12° morning twilight.

5.1.5 Seismic Hazard

The site-specific hazard is defined in the Site-Specific Seismic Hazard Analysis (SSSHA) report (GMT-DOC-00127_C).
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 40% 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 equipments are items that would be extremely expensive, time-consuming or otherwise burdensome to replace. Onerous-to-replace equipment consists of [principal optics, primary mount structure, Telescope Pier Assembly, Pier Footing, and enclosure foundations] TBC.

5.1.5.1 Seismic Fragility Requirements

REQ-L3-OAD-36688: Seismic Risk to M1 Principal Optics

The Observatory shall limit M1 principal optics probability of failure due to seismic events over the service life of the Observatory to less than or equal to [1%] TBC.

Rationale: M1 is onerous to replace. The Project Risk Board determines the acceptable probability of failure.
Notes: This requirement is intended to prescribe a fragility analysis for the principal optics and drives the design for the M1 supports, mount and enclosure supporting structure. This requirement applies to the mirror glass and directly bonded components only. Other components of the mirror support and cell assembly are addressed separately. This requirement includes the probability of failure due to seismic motion during servicing and handling operations. Failure of the M1 Segment Mirror is indicated by the significant degradation of functionality or performance due to gross crack propagation in the glass substrate or glass wedges, de-bonding of load spreader pucks, yielding of the load spreaders, or similar

levels of damage. While some of such damage may be repairable, repairs cannot be conducted without the removal of the M1 Segment Mirror from the associated M1 Cell.

REQ-L3-OAD-70772: Seismic Risk to M2 Principal Optics

The Observatory shall limit M2 principal optics probability of failure due to seismic events over the service life of the Observatory to less than or equal to [1%] TBC.

Rationale: M2 is onerous to replace and so the project, via the Risk Board, will determine the acceptable probability of failure.
Notes: This requirement is intended to prescribe a fragility analysis for the principal optics and drives the design of the supporting structures including the mount and enclosure. This requirement applies to the mirror glass and directly bonded components only. Other components of the mirror support and cell assembly are addressed separately. This requirement includes the probability of failure due to seismic motion during servicing and handling operations. Failure of the M2 Segment Mirror is indicated by the significant degradation of functionality or performance due to gross crack propagation in the glass substrate or glass wedges, de-bonding of load spreader pucks, yielding of the load spreaders, or similar levels of damage.

REQ-L3-OAD-36704: Seismic Isolation System Probability of Failure

The Observatory shall limit Enclosure Telescope Pier Seismic Isolation System probability of failure due to seismic events during the Observatory service life to less than or equal to [0.5%]TBC.

Rationale: The Seismic Isolation System is largely limited by stroke, only extreme long period accelerations signals will drive the base isolation to its limits. This requirement along with the seismic hazard analysis will provide a minimum stroke to maintain this low probability of failure. The stroke defines other interfaces between the Enclosure and the Telescope Pier.

5.1.5.2 Rigidity Level Earthquakes

Motions up to the RLE level will occur frequently. To avoid downtime, it must not be necessary to perform repair, realignment, recalibration, inspection or maintenance operations as a result of these events.

REQ-L3-OAD-36707: Observatory RLE Response of All Subsystems

The Observatory shall meet all functional and performance requirements without the need of repair, realignment, recalibration, inspection or maintenance, except for recentering, immediately following ground motion up to and including an RLE event defined in [GMT-DOC-03787]TBC.

Rationale: This requirement sets clear functional and performance objectives for recovering from an RLE seismic event.
Notes: This requirement is not intended to imply that subsystems must satisfy nominal performance requirements during an RLE.

REQ-L3-OAD-92170: Observatory Response, Telescope Pier Recentering

The Observatory shall meet all functional and performance requirements without the need to recenter immediately following seismic events with an average return period of 1 year or less.

Rationale: This requirement ensures the set of requirements used to design the SIS are achievable. The reduction in RP will allow the breakaway friction value to be reduced so that the dynamic friction used to develop mount accelerations at the base of the pier are achievable.

Notes: This requirement does imply that the seismic isolation system must not activate as a result of these motions.

REQ-L3-OAD-104849: Post-RLE pointing model

After an RLE, the GMT shall measure the telescope position relative to fiducials and derive and apply corrections to the pointing model in a time no more than TBD minutes.

Rationale: When an earthquake moves the pier, the new orientation of the telescope should be measured and from those measurements changes to the pointing model derived and applied. As described in the OpsCon, when a small seismic event (an RLE) occurs during Science Operations, the Observatory is considered to have gone into an Environmental Standby state. The TBD time scale represents the time to transition from the Environmental Standby state back to the Science Operations state.
Notes: A moderate to large seismic event will require significant inspection time. In that case the Observatory is considered to have gone to a Fault state, and no time limit is assumed to recover from a Fault state. The time taken to recover is not considered technical downtime.

5.1.5.3 Operational Level Earthquakes

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. The operational plan will be based on available resources that include operational staff, equipment, spares, procedures, and designated recovery funds.

REQ-L3-OAD-70792: OLE Response of All Subsystems

The Observatory shall be capable of resuming normal operations using available resources following motions up to and including the level defined for an OLE defined in GMT-DOC-03270 and GMT-DOC-03271.

Rationale: The Observatory must be designed to mitigate risk of a significant loss of observing time due to OLE earthquakes. This requirement specifies the expected performance after OLE seismic events.
Notes: As a goal, it should be possible to resume science operations within one month of an OLE event. The resumption of service time should be evaluated using the maintenance assumptions of GMT-DOC-01221 the GMT Reliability, Availability, Maintainability, and Safety (RAMS) Plan and include all necessary inspection, repair, realignment and recalibration, and testing operations.

REQ-L3-OAD-92173: Response of Observatory, Pier OLE Excursions

The Observatory shall be capable of resuming normal operations using available resources following Telescope Pier OLE excursions of up to 100 mm radially and 3 mm in the Pier +Z direction with respect to the fixed Telescope Pier Footing.

Rationale: This requirement is to ensure that there are clear peformance criteria for pier excursions due to OLE earthquakes. The report supplement: [“GIANT MAGELLAN TELESCOPE ISOLATOR HEATING ANALYSIS FOR OLE LONG PERIOD CMS GROUND MOTIONS”]TBC found that the largest OLE displacement out of the 7 long period earthquakes studied was 14.2 mm in lateral radial motion. The 100mm limit includes considerable margin and reserve. The vertical displacement is computed using the spherical shape of the seismic isolator, assuming a bearing radius of curvature of 2240 mm:) :2240 mm-2240mm2-100mm2 = 2.2 mm.
Notes: See GMT-REF-00189, GMT Coordinate System and Vertical Datum for definition of the Telescope/Pier Enclosure Base Coordinate System.

5.1.5.4 Survival Level Earthquakes

Ground motions between the OLE and SLE levels have approximately a 37% chance of occurrence over the 50 year life. The facility must be designed to mitigate the risk of catastrophic loss and should be recoverable from an SLE level event given sufficient resources.

REQ-L3-OAD-70794: SLE Response of All Subsystems

The Observatory shall protect personnel and onerous-to-replace equipment from ground motions up to and including the level defined for an SLE event in [GMT-DOC-03785 and GMT-DOC-03786]TBC.

Rationale: The Observatory must be designed to mitigate the risk of catastrophic loss and should be recoverable from an SLE level event given sufficient resources.
Notes: It is expected that the Failure Modes and Effects Analysis and Hazard Analysis will determine failure modes, e.g. falling objects or weather damage after an SLE, that may cause damage to onerous-to-replace items or harm to personnel, and the mitigations necessary for protection. Failures that do not place personnel or onerous-to-replace-equipment at risk are acceptable. Onerous-to-replace equipment are items that would be extremely expensive, time-consuming or otherwise burdensome to replace.

REQ-L3-OAD-92171: Telescope Pier Excursions

The Observatory shall not impede Telescope Pier Assembly excursions of up to 700 mm radially and 112 mm in the Pier +Z direction with respect to the fixed foundation.

Rationale: This requirement is to ensure that the Enclosure and Mount accommodates the range of prospective bearings such that the restraining ring is not contacted.
Notes: See GMT-REF-00189, GMT Coordinate System and Vertical Datum for definition of the Telescope/Pier Enclosure Base Coordinate System.

REQ-L3-OAD-92172: Response of Observatory, Pier SLE Excursions

The Observatory shall protect personnel and onerous-to-replace equipment from the SLE Telescope Pier Assembly Excursions of GMT-L3-OAD-92171.

Rationale: This requirement is to ensure that excursions due to SLE earthquakes will protect Observatory valuable assets.
Notes: This requirement defines the SLE excursions of the pier. It is expected that the Failure Modes and Effects Analysis and Hazard Analysis will determine failure modes, e.g. falling objects or weather damage after an SLE, that may cause damage to onerous-to-replace items or harm to personnel, and the mitigations necessary for protection. Failures that do not place personnel or onerous-to-replace-equipment at risk are acceptable. Onerous-to-replace equipment are items that would be extremely expensive, time-consuming or otherwise burdensome to replace.

REQ-L3-OAD-92567: Enclosure Telescope Pier Assembly Return to Center

The Enclosure shall recenter the Telescope Pier Assembly after a seismic event, up to an SLE level earthquake, in [less than or equal to one day shift of 8 hours]TBC.

Rationale: Science Operations need to return as soon as is reasonable after small earthquakes that activate the SIS. 1 day shift was deemed reasonable. After larger earthquakes it will bencessary to move the pier to a safe position in a reasonable amount of time

5.2 Subsystem Operations and Monitoring

REQ-L3-OAD-82925: Remote access to user interfaces

All standardized software user interfaces shall be accessible from remote workstations by users with the appropriate access credentials.

Rationale: Remote operations, troubleshooting, and monitoring will be necessary for efficient science and technical operation.
Notes: "Standardized" means that the interface complies with the software standards, GMT-SW-REF-00029. These are generally OCS-provided interfaces and instrument interfaces, but do not necessarily include vendor-supplied interfaces affixed to hardware.

REQ-L3-OAD-85101: OCS design system

The OCS shall include a design system for developing consistent graphical user interfaces.

Rationale: Consistent design system facilitates:
- Common look and feel across the system,
- Uniform way to access system functionalities,
- Logical framework for understanding and reasoning about the system,
- Management, design, and distribution of interface components,
- General user efficiency in observatory operations.

Notes: Wikipedia defines a design system as “a set of interconnected patterns and shared practices coherently organized to aid in digital product design and development of products such as apps or websites. It may contain, but is not limited to, pattern libraries and design language, style guides, coded components, brand language and documentation for use of these.”

REQ-L3-OAD-92315: OCS operations user interfaces

The OCS shall include graphical user interfaces for observatory operations.

Rationale: Graphical interfaces have been proven to be effective and efficient at communicating information about the system to the users.

REQ-L3-OAD-61106: Subsystem Operations Documentation

GMT subsystems shall provide documentation on the subsystem's operation.

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

REQ-L3-OAD-36746: Subsystem Engineering Data

GMT subsystems shall provide engineering data to the Engineering Archive, including subsystem telemetry data and associated metadata.

Rationale: Engineering data will help identify incipient failures, interpret scientific data, and troubleshoot problems.

REQ-L3-OAD-36749: Subsystem Health Monitoring

GMT subsystems shall provide continuous performance, status and system health monitoring for any parameter that affects subsystem performance.

Rationale: For monitoring the performance and status of the components.

REQ-L3-OAD-36752: Subsystem Health Alarms

GMT subsystems shall provide alarm levels for any critical parameters that affect function or performance.

Rationale: Alarms alert staff to incipient problems. Design of an overall alarm system will include definition of alarm levels and alarm communication process.

REQ-L3-OAD-61127: Fault Tracking System

The OCS shall provide software and a 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.

5.3 Science Operations

This section describes the tools needed to plan a new scientific program, submit it to the Time Allocation process, and specify clear observing parameters to achieve the program's scientific goals.

REQ-L3-OAD-36757: User Workspace

The OCS shall provide access-controlled, individual workspaces for individual scientific users.

Rationale: Controlled workspaces limit maintenance support from software engineers. Different users working in a common workspace would cause conflicts; individual workspaces avoid this problem.
Notes: From this individualized workspace a scientific user will be able to access telescope proposal preparation software, information on execution of their own accepted proposals, proprietary access to their data in the Science Data Archive, and a data reduction workspace in which they can run Observatory-supported data reduction tools.

5.3.1 Telescope Proposal Preparation

The GMT shall provide software tools to allow external scientists and GMTO staff to define an observing program that includes the functionalities shown in Table 5-7.

Table 5-7: Telescope Proposal Requirements

Function	Requirement	Documentation
Science proposal preparation	REQ-L3-OAD-36768	Science proposals will include information on: investigators, institutional time charges, observing and operational modes, observing condition requirement, targets, instruments, justification narratives (science, technical, special requirements, etc.), time request (exposure and overhead). This is the Phase 1 process.
Detailed Observing Sequence definition	REQ-L3-OAD-36771	Observing sequences will include instrument and telescope configurations, exposure times, dither patterns, and guide star locations and brightnesses. This is the Phase 2 process.
Instrument Observation Simulator	REQ-L3-OAD-36774	Supplied by each instrument development team, the observation simulator will contain, at a minimum, a signal-to-noise estimator for a given target, instrument

		configuration, sky background, exposure time, detector noise, etc. The simulator may also include instrument overheads, spectral simulation, etc.
Telescope Overhead Calculator	REQ-L3-OAD-36777	The Telescope Overhead Calculator will estimate overheads for slewing, target acquisition, and telescope reconfiguration.

Rationale: These steps are necessary to allow the Time Allocation Process to be well-informed and to allow scheduling to be efficient and effective.

5.3.2 Observing Programs Management

The GMT shall provide software tools to manage the process flow of Observing Programs from TAC evaluation to implementation, including the functionalities described in Table 5-8.

Table 5-8: Observing Programs Management Requirements

Function	Requirement	Documentation
Current scheduling success metrics	REQ-L3-OAD-36788	Scheduling success metrics will include those in section 10 of GMT-DOC-01584.
Access to and organization of science proposals, including supporting information.	REQ-L3-OAD-36791	Supporting information will include signal-to-noise estimates and observation sequence definition.
Comments from both technical and scientific reviewers	REQ-L3-OAD-36794	Free-form text from both technical reviewers and TAC members.
Grading and ranking of proposals	REQ-L3-OAD-36797	TAC members are expected to enter individual, preliminary grades, from which ranking will be done. The TAC will then provide a final overall grade and rank.
Merging of proposals from multiple TACs	REQ-L3-OAD-36800	Multiple TAC grades and ranks will be combined into an overall ranking of each proposal.
TAC final recommendations	REQ-L3-OAD-36803	The TAC will provide feedback to each proposer, as well as scheduling recommendations to the GMT telescope scheduler.
Astronomer/user feedback on Observatory performance	REQ-L3-OAD-36806	Collect information from astronomers and users about observatory performance and user experience in order to improve observatory operations.

Rationale: These steps are necessary to manage the workflow of proposing for observing time on the telescope.

5.3.3 Telescope Scheduling

The GMT shall provide software tools to support telescope proposal implementation and scheduling, including the functionalities described in Table 5-9.

Table 5-9: Telescope Scheduling Requirements

Function	Requirement	Documentation
Results of TAC rankings	REQ-L3-OAD-36816	This allows the scheduler to assign appropriate

and recommendations		nights to different operations modes and schedule time-critical observations.
Schedule showing programs and program scheduling constraints for different operating modes (PI vs. queue) and maintenance	REQ-L3-OAD-36819	Information supplied will include a calendar of available time, percent of night with dark-sky conditions, phase of Moon, availability of targets for each program, time-critical constraints, observing cadence constraints, observing condition constraints, and observatory maintenance constraints.
A tool to generate an observing queue	REQ-L3-OAD-36822	An algorithm will be developed that optimize over TAC-supplied priorities (e.g. proposal ranking, partner balance), scheduling success metrics, current observing conditions and constraints, observing efficiency, and calibration efficiency. This algorithm will form the basis of an observing queue, but can also be used in other operations modes.
Success metrics for scheduling process	REQ-L3-OAD-36825	Scheduling success metrics shall include those in section 10 of GMT-DOC-01584.

Rationale: These functions are necessary to properly schedule science observations on the telescope.

5.3.4 Observing Execution

Observing Program Execution

The GMT shall provide software tools to execute Observing Programs, including the functionalities described in Table 5-10.

Table 5-10: Observing Execution Requirements

Function	Requirement	Documentation
Modify observing block definition	REQ-L3-OAD-36836	The tool will allow users to manually modify observing block parameters, such as exposure time, target location, dither pattern, instrument configuration, telescope configuration, and AGWS configuration. This allows for targets of opportunity where some information will not be available until the opportunity presents itself and allows adjustment of observing sequences to match changing observing conditions.
Select and execute an observing sequence	REQ-L3-OAD-36839	The tool will present the observer with a time-ordered list, allowing users to consider parameters such as: current observing conditions, TAC-supplied priorities (e.g. proposal ranking, partner balance), scheduling success metrics, and constraints, observing efficiency, and calibration efficiency. The tool will pass to the telescope operator information relevant to pointing the telescope, setting up the AGWS, and identifying the field and the target.

Rationale: This is necessary to be able to properly command the Observatory to take scientific data.

REQ-L3-OAD-36841: Real-Time Data Quality Assessment

Each instrument shall provide "quick look" data reduction software to allow near real-time quality assessment of the instrument's scientific data.

Rationale: Allows the quality of science data to be assessed in real-time.

REQ-L3-OAD-36844: Operation and Wavefront Control Mode Support

The GMT software tools shall support the operating and wavefront control modes of the telescope.

Rationale: This is required to manage and execute the required modes.

REQ-L3-OAD-36847: Simultaneous Instrument Operation

The GMT Observatory Control System shall enable data collection with multiple instruments operating simultaneously.

Rationale: This is derived from the ConOps.
Notes: Some instrument configurations and wavefront control modes will benefit from the simultaneous operation of several instruments (e.g. MANIFEST with GMACS and NIRMOS)

REQ-L3-OAD-36851: Automated Instrument Switching

The GMT shall allow the automated switching, initiated and monitored by the instrument operator, of the active instrument set during the night.

Rationale: This is required for efficient instrument switching
Notes: Automated switching may involve inserting or removing the M3, inserting or removing the C-ADC, adjusting focus, switching control to a different active instrument, etc.

REQ-L3-OAD-36855: PI Instrument Operation

PI Instruments will be designed for operational support by the Instrument groups with minimal assistance from the GMT Observatory staff, as defined in the agreement with the PI Institution.

Rationale: This is a system level requirement.
Notes: Aside from routine operational support, such as filling dewars, GMT will not be responsible for servicing, maintaining, upgrading or otherwise supporting PI instruments, other than providing standard interfaces to the rest of the system.

REQ-L3-OAD-36859: Configuration Visualization

The GMT shall provide a tool to visualize the configuration and its status.

Rationale: This will provide a way to quickly determine whether the configuration and status of the telescope optics and the instruments are correct for the current observation.

5.3.5 Science Operation Efficiency

Part of observing is acquiring the science target, which includes slewing to the target position, identifying the field, setting up the instrument and telescope, centering the science target in the focal plane appropriately, and optimizing the image quality. Once target acquisition is complete, the first science exposure can be started.

5.3.5.1 Optics Deployment and Configuration Efficiency

REQ-L3-OAD-36865: DG Instrument Deployment Time

The GMT DG Instrument Deployment Mechanism shall insert or remove a DG instruments in a time not to exceed 30 minutes.

Rationale: Required for Telescope Efficiency.

Notes: This includes the time to insert or remove one DG instrument. It does not include the time to move a second DG instrument, the time to move the telescope to zenith, or the time for instrument power up, configuration and calibration.

Instrument reconfiguration time

GMT reconfiguration between instruments has the following significant steps:

A = moving DG instruments and rebalancing the GIR
B = rotating M3 on the optical axis (no rebalancing needed)
C = deploying or retracting M3 and rebalancing the GIR
D = deploying or retracting one or more optical relays and rebalancing the GIR

Rebalancing the GIR is done only with the telescope pointing at zenith; none of the requirements given below include time spent to move the telescope to zenith.

The following symmetric matrix of possible reconfigurations (Table 5-11) shows which steps are important for each reconfiguration.

Table 5-11: Steps involved in reconfiguring between instruments.

To/From	DG	FP	AP	IP	GIS
DG	A	C	B+C+D	B+C+D	B+C+D
FP	C	B	B+D	B+D	B+D
AP	B+C+D	B+D	B+D	D	D
IP	B+C+D	B+D	D	D	D
GIS	B+C+D	B+D	D	D	N/A

REQ-L3-OAD-36876: Reconfiguring between DG Instruments

The GMT shall reconfigure from one DG instrument to another DG instrument in no more than 4 hours [goal: 1 hour].

Rationale: The goal allows DG instruments to be changed at night with acceptable loss of science time. The requirement allows efficient daytime DG instrument changes.
Notes: This includes rebalancing the GIR after the reconfiguration (Step A).

REQ-L3-OAD-36880: M3 Rotation Time

The M3 Rotation Mechanism shall move between any two rotational positions within a 360 degree range, at any gravity orientation in a time not to exceed 2 minutes.

Rationale: In switching from one FP/AP/IP instrument to another, repositioning M3 should be efficient. This is coarse rotation between instrument ports; it does not include fine tip/tilt adjustments done while fine-tuning pupil alignment to the instrument.
Notes: This requirement applies when M3 is deployed (Step B).

REQ-L3-OAD-36884: Time to Deploy/Retract M3

The GMT shall deploy or retract M3 and rebalance the GIR in no more than 5 minutes [Goal: 3 min].

Rationale: To reduce observing overheads and respond rapidly to changing environmental conditions or new scientific opportunties, reconfiguring the telescope must be quick.
Notes: Step C.

REQ-L3-OAD-36887: Time to Deploy/Retract Optical Relays

The GMT shall deploy or retract optical relays located on the FP and rebalance the GIR in no more than 5 minutes [Goal: 3 min].

Rationale: To reduce observing overheads and respond rapidly to changing environmental conditions or new scientific opportunties, reconfiguring the telescope must be quick.
Notes: This includes the GIS optical feed, as well as relays for AP and IP instruments (Step D).

REQ-L3-OAD-36890: Mount DG Instrument Deployment Orientation

The Mount DG Instrument Deployment Mechanism shall be capable of deploying or stowing a DG Instrument when the telescope is zenith pointing.

Rationale: Repeatable optical alignment of DG instruments to the rest of the telescope may require deployment at a consistent orientation with respect to gravity.
Notes: Due in part to dynamic changes in balance during deployment, DG Instrument deployment may not be possible at zenith angles other than zero.

REQ-L3-OAD-36894: Time to Insert/Remove the ADC

The GMT shall deploy the Corrector-ADC into or out of the beam in a time not to exceed 5 minutes [Goal: 3 minutes] with the telescope parked at zenith position.

Rationale: This allows rapid switching between a narrow- or medium-field configuration and a wide-field configuration during the night.

REQ-L3-OAD-36897: Calibration System Deployment Time

The ICS and WCCS shall each be deployable and ready for operation within 2 minutes [goal: 1 min].

Rationale: This is required to allow calibrations to be obtained during the night with minimal observing overhead.
Notes: This includes the deployable systems for flat-field, spectral, and AO calibrations.

5.3.5.2 Observation Execution Efficiency

REQ-L3-OAD-36902: Situation Monitoring Capability

The OCS shall provide visualization to support assessment of runtime observing conditions.

Rationale: Visualization of the current conditions is necessary to efficiently guide observers to an effective observing stategy.
Notes: A number of parameters factor into runtime decision making. The visualization should integrate environmental sensor data with the TCS to provide a concise and intuitive picture of the observing situation in real time. Useful information to visualize include:
• Science targets, Moon, Sun: locations in the sky, airmass, trajectories as a function of time, currently scheduled observing windows
• Sky camera maps: cloud/transparency, and sky brightness
• Wind: speed & direction
• Observatory: Telescope pointing location, cable wrap, wind-screen vignetting angle, moon-screen vignetting angle

5.3.5.3 Science Target Acquisition Efficiency

Target acquisition as used in this document refers to the time between starting to repoint (slewing) the Mount to a new target until the science pointing and image quality performance has met its specifications and the instrument is ready to begin a science observation. The four wavefront control modes — Natural Seeing, GLAO, NGAO, and LTAO — use different image quality loops and are described separately.

System behaviors GMT-DOC-03343 through GMT-DOC-03346 describe target acquisition in the four wavefront control modes, including information such as predecessors to each step and criteria for starting each step. Times given below are the time it takes for each step to reach convergence so that subsequent dependent steps can begin. Active and adaptive optics loops generally remain closed during the entire science sequence on the science target. Note that steps in common to more than one wavefront control mode have the same requirement number in each of the tables.
Times with asterisks after them do not contribute to the net time to acquire, usually because they are done in parallel with other steps.
The GMT shall support the following times for steps involved in target acquisition in Natural Seeing mode (Table 5-12).

Table 5-12: Natural Seeing Target Acquisition

Requirement	Step	Maximum Time (sec)	Notes	Element
REQ-L3-OAD-61352	Slew telescope to target	120	This includes positioning the GIR. It is a maximum slew (180° in azimuth, 60° in elevation), to correspond to the science requirement of getting from any position on the sky to any other position on the sky. It does not include an occasional need to unwrap the telescope's azimuth cable wraps. At the end of this step the Post-Calibration Blind Pointing Budget without TMS will be met. In some cases a telescope reconfiguration may require going to zenith first; this extra motion is not included in this requirement.	MOUNT
REQ-L3-OAD-92368	Reconfigure AGWS	45*	One probe in SH24, one probe ACQ, two probes SH48. Move probes to expected guide star positions.	AGWS
REQ-L3-OAD-92369	Reconfigure Enclosure Vents	300*	The vents will automatically be adjusted according to a look-up table or algorithm taking into	Enclosure

			account the wind speed and direction relative to the telescope pointing (at the new target). Vent positioning is not critical to subsequent steps.	
REQ-L3-OAD-92373	Reconfigure wind screen	120*	The wind screen will be automatically pre-positioned just below the telescope optical beam at the position of the new target (to provide maximum wind protection).	Enclosure
REQ-L3-OAD-92370	Rotate Enclosure	120*	The Enclosure must follow (or lead) the telescope to the new target.	Enclosure
REQ-L3-OAD-92371	Reconfigure M3 (if necessary)	300	This includes deployment or retraction, as well as rotation to point the telescope beam to a different instrument, if requested.	M3
REQ-L3-OAD-92372	Reconfigure C-ADC (if necessary)	300	This includes deployment or retraction, as well as setting the dispersion compensation to the destination elevation of the Mount.	C-ADC
REQ-L3-OAD-70818	Reconfigure instrument (if necessary)	300*	Will be done in parallel with slewing the telescope, and can also overlap the acquisition and active optics steps below.	Instrument
REQ-L3-OAD-70820	Use TMS to correct segment alignment	15	Includes measurement, calculation, commanding segment moves, and waiting for the moves to settle. At the end of this step the Post-Calibration Blind Pointing Budget with	TMS

			TMS will be met.	
REQ-L3-OAD-70824	Make stack and center measurements	5	Time includes shift, measurements, and final positioning of segments.	AGWS
REQ-L3-OAD-70825	Center and stack acquisition star	5	Includes Mount pointing offset.	AGWS
REQ-L3-OAD-70826	Fast segment tip-tilt	1	Begin fast segment tip-tilt control with FSM. At the end of this step the Instrument Acquisition Pointing Budget will be met.	M2, OCS
REQ-L3-OAD-70827	Active Optics, high gain mode	10	A rapid-convergence algorithm that does not average over atmospheric seeing.	M1, M2, OCS
REQ-L3-OAD-70821	Active Optics, low gain mode	60	Includes AGWS position control.	M1, M2, OCS
REQ-L3-OAD-70822	Instrument Flexure Compensation	30*	Measure and correct instrument-to-AGWS flexure. At the end of this step the Natural Seeing Image Quality Budget will be met.	Instrument
REQ-L3-OAD-70823	Identify and center science target	120	Identification will be highly dependent on the exact science case and observing strategy. This will be instrument-specific. After centering, target acquisition is complete and the observing sequence is started.	OCS

Rationale: The timing of each step of target acquisition is important to meet the science requirement to set up a new target, and to reduce observing overheads.

The GMT shall support the following times for steps involved in target acquisition in GLAO mode (Table 5-13).

Table 5-13: GLAO Target Acquisition

Requirement	Step	Maximum Time (sec)	Notes	Element
REQ-L3-OAD-61352	Slew telescope to target	120	This includes positioning the GIR. It is a maximum slew (180° in azimuth, 60°	MOUNT

			in elevation), to correspond to the science requirement of getting from any position on the sky to any other position on the sky. It does not include an occasional need to unwrap the telescope's azimuth cable wraps. At the end of this step the Post-Calibration Blind Pointing Budget without TMS will be met. In some cases a telescope reconfiguration may require going to zenith first; this extra motion is not included in this requirement.	
REQ-L3-OAD-92368	Reconfigure AGWS	45*	One probe in SH24, one probe ACQ, two probes SH48. Move probes to expected guide star positions.	AGWS
REQ-L3-OAD-92369	Reconfigure Enclosure Vents	300*	The vents will automatically be adjusted according to a look-up table or algorithm taking into account the wind speed and direction relative to the telescope pointing (at the new target). Vent positioning is not critical to subsequent steps.	Enclosure
REQ-L3-OAD-92373	Reconfigure wind screen	120*	The wind screen will be automatically pre-positioned just below the telescope optical beam at the position of the new target (to provide maximum wind protection).	Enclosure
REQ-L3-	Rotate	120*	The Enclosure must	Enclosure

OAD-92370	Enclosure		follow (or lead) the telescope to the new target.	
REQ-L3-OAD-92371	Reconfigure M3 (if necessary)	300	This includes deployment or retraction, as well as rotation to point the telescope beam to a different instrument, if requested.	M3
REQ-L3-OAD-92372	Reconfigure C-ADC (if necessary)	300	This includes deployment or retraction, as well as setting the dispersion compensation to the destination elevation of the Mount.	C-ADC
REQ-L3-OAD-70818	Reconfigure instrument (if necessary)	300*	Will be done in parallel with slewing the telescope, and can also overlap the acquisition and active optics steps below.	Instrument
REQ-L3-OAD-70820	Use TMS to correct segment alignment	15	Includes measurement, calculation, commanding segment moves, and waiting for the moves to settle. At the end of this step the Post-Calibration Blind Pointing Budget with TMS will be met.	TMS
REQ-L3-OAD-70824	Make stack and center measurements	5	Time includes shift, measurements, and final positioning of segments.	AGWS
REQ-L3-OAD-70825	Center and stack acquisition star	5	Includes Mount pointing offset.	AGWS
REQ-L3-OAD-70834	Fast segment tip-tilt	1	Begin fast segment tip-tilt control with FSM. At the end of this step the Instrument Acquisition Pointing Budget will be met.	M2, OCS
REQ-L3-OAD-70835	Active Optics, high gain	10	A rapid-convergence algorithm that does not	M1, M2, OCS

	mode		average over atmospheric seeing.	
REQ-L3-OAD-70836	Atmospheric Tomography	10	Close atmospheric tomography, active optics, ASM offload, and AGWS position control loops.	M1, M2, OCS
REQ-L3-OAD-70837	Instrument Flexure Compensation	10	Measure and correct instrument to AGWS flexure. At the end of this step the Natural Seeing Image Quality Budget will be met.	Instrument
REQ-L3-OAD-70838	Identify and center science target	120	Identification will be highly dependent on the exact science case and observing strategy. This will be instrument-specific. After centering, target acquisition is complete and the observing sequence is started.	OCS

Rationale: The timing of each step of target acquisition is important to meet the science requirement to set up a new target, and to reduce observing overheads.

The GMT shall support the following times for steps involved in target acquisition in NGAO mode (Table 5-14).

Table 5-14: NGAO Target Acquisition

Requirement	Step	Maximum Time (sec)	Notes	Element
REQ-L3-OAD-61352	Slew telescope to target	120	This includes positioning the GIR. It is a maximum slew (180° in azimuth, 60° in elevation), to correspond to the science requirement of getting from any position on the sky to any other position on the sky. It does not include an occasional need to unwrap the telescope's azimuth cable wraps. At the end of this step the Post-Calibration Blind Pointing Budget	MOUNT

			without TMS will be met. In some cases a telescope reconfiguration may require going to zenith first; this extra motion is not included in this requirement.	
REQ-L3-OAD-92368	Reconfigure AGWS	45*	One probe in SH24, one probe ACQ, two probes SH48. Move probes to expected guide star positions.	AGWS
REQ-L3-OAD-92369	Reconfigure Enclosure Vents	300*	The vents will automatically be adjusted according to a look-up table or algorithm taking into account the wind speed and direction relative to the telescope pointing (at the new target). Vent positioning is not critical to subsequent steps.	Enclosure
REQ-L3-OAD-92373	Reconfigure wind screen	120*	The wind screen will be automatically pre-positioned just below the telescope optical beam at the position of the new target (to provide maximum wind protection).	Enclosure
REQ-L3-OAD-92370	Rotate Enclosure	120*	The Enclosure must follow (or lead) the telescope to the new target.	Enclosure
REQ-L3-OAD-92371	Reconfigure M3 (if necessary)	300	This includes deployment or retraction, as well as rotation to point the telescope beam to a different instrument, if requested.	M3
REQ-L3-OAD-92372	Reconfigure C-ADC (if necessary)	300	This includes deployment or retraction, as well as	C-ADC

			setting the dispersion compensation to the destination elevation of the Mount.	
REQ-L3-OAD-70818	Reconfigure instrument (if necessary)	300*	Will be done in parallel with slewing the telescope, and can also overlap the acquisition and active optics steps below.	Instrument
REQ-L3-OAD-70820	Use TMS to correct segment alignment	15	Includes measurement, calculation, commanding segment moves, and waiting for the moves to settle. At the end of this step the Post-Calibration Blind Pointing Budget with TMS will be met.	TMS
REQ-L3-OAD-70824	Make stack and center measurements	5	Time includes shift, measurements, and final positioning of segments.	AGWS
REQ-L3-OAD-70825	Center and stack acquisition star	5	Includes Mount pointing offset.	AGWS
REQ-L3-OAD-70844	Fast segment tip-tilt	1	Temporary field stabilization prior to AO control. At the end of this step the Instrument Acquisition Pointing Budget will be met.	M2, OCS
REQ-L3-OAD-70845	Active Optics, high gain mode	10	A rapid-convergence algorithm that does not average over atmospheric seeing.	M1, M2, OCS
REQ-L3-OAD-70846	Active Optics, low gain + coarse phasing	120	Includes coarse segment phasing and AGWS position control.	M1, M2, OCS
REQ-L3-OAD-70847	Center NGAO guide star	10*	Center guide star and telescope pupil in the NGWS.	NGWS, OCS
REQ-L3-OAD-70848	Close NGAO control loops	10*	Begin high-order AO and phasing control.	NGWS, OCS
REQ-L3-	Start dynamic	30	Measure and correct	NGWS,

OAD-70849	calibration loop		instrument-to-NGWS flexure and non-common path errors. At the end of this step the NGAO Image Quality Budget will be met.	OCS
REQ-L3-OAD-70850	Identify and center science target	120	Identification will be highly dependent on the exact science case and observing strategy. This will be instrument-specific. After centering, target acquisition is complete and the observing sequence is started.	OCS

Rationale: The timing of each step of target acquisition is important to meet the science requirement to set up a new target, and to reduce observing overheads.

The GMT shall support the following times for steps involved in target acquisition in LTAO mode (Table 5-15).

Table 5-15: LTAO Target Acquisition

Requirement	Step	Maximum Time (sec)	Notes	Element
REQ-L3-OAD-61352	Slew telescope to target	120	This includes positioning the GIR. It is a maximum slew (180° in azimuth, 60° in elevation), to correspond to the science requirement of getting from any position on the sky to any other position on the sky. It does not include an occasional need to unwrap the telescope's azimuth cable wraps. At the end of this step the Post-Calibration Blind Pointing Budget without TMS will be met. In some cases a telescope reconfiguration may require going to zenith first; this extra motion is not included in this	MOUNT

			requirement.	
REQ-L3-OAD-92368	Reconfigure AGWS	45*	One probe in SH24, one probe ACQ, two probes SH48. Move probes to expected guide star positions.	AGWS
REQ-L3-OAD-92369	Reconfigure Enclosure Vents	300*	The vents will automatically be adjusted according to a look-up table or algorithm taking into account the wind speed and direction relative to the telescope pointing (at the new target). Vent positioning is not critical to subsequent steps.	Enclosure
REQ-L3-OAD-92373	Reconfigure wind screen	120*	The wind screen will be automatically pre-positioned just below the telescope optical beam at the position of the new target (to provide maximum wind protection).	Enclosure
REQ-L3-OAD-92370	Rotate Enclosure	120*	The Enclosure must follow (or lead) the telescope to the new target.	Enclosure
REQ-L3-OAD-92371	Reconfigure M3 (if necessary)	300	This includes deployment or retraction, as well as rotation to point the telescope beam to a different instrument, if requested.	M3
REQ-L3-OAD-92372	Reconfigure C-ADC (if necessary)	300	This includes deployment or retraction, as well as setting the dispersion compensation to the destination elevation of the Mount.	C-ADC
REQ-L3-OAD-70818	Reconfigure instrument (if necessary)	300*	Will be done in parallel with slewing the telescope, and can also	Instrument

			overlap the acquisition and active optics steps below.	
REQ-L3-OAD-70820	Use TMS to correct segment alignment	15	Includes measurement, calculation, commanding segment moves, and waiting for the moves to settle. At the end of this step the Post-Calibration Blind Pointing Budget with TMS will be met.	TMS
REQ-L3-OAD-70856	LGS acquisition	60*	Independent of NGS acquisition. Identifies laser spots and corrects laser pointing.	LGS
REQ-L3-OAD-70824	Make stack and center measurements	5	Time includes shift, measurements, and final positioning of segments.	AGWS
REQ-L3-OAD-70825	Center and stack acquisition star	5	Includes Mount pointing offset.	AGWS
REQ-L3-OAD-70859	Fast segment tip-tilt	1	Temporary field stabilization prior to AO control.	M2, OCS
REQ-L3-OAD-70860	Active Optics + phasing, high gain mode	60	A rapid-convergence algorithm that does not average over atmospheric seeing.	M1, M2, OCS
REQ-L3-OAD-70861	Active Optics + phasing, low gain	120	Includes coarse segment phasing and AGWS position control.	M1, M2, OCS
REQ-L3-OAD-70862	Uplink tip/tilt	1	Center laser spots on LTWS.	LGS
REQ-L3-OAD-70863	LTAO WFS focus	5	Measure sodium layer distance and set LTWS focus stage.	LTAO
REQ-L3-OAD-70864	LTAO WFS pupil registration	5	Close LTWS pupil alignment control loop.	LTAO
REQ-L3-OAD-70865	On-axis and off-axis tomography	5	Begin high-order AO control.	M1, M2, OCS
REQ-L3-OAD-70866	Fast global tip/tilt	1	Transfer field stabilization to OIWFS	M1, M2, OCS

			tip-tilt sensor. At the end of this step the Instrument Acquisition Pointing Budget will be met.	
REQ-L3-OAD-70867	On-axis and off-axis dynamic calibration	30	Measure and correct instrument to NGWS flexure and non-common path errors. At the end of this step the LTAO Image Quality Budget will be met.	NGWS, LTAO
REQ-L3-OAD-70868	M1 and M2 piston feed-forward	1*	Correct piston wind buffeting if necessary. These loops will converge before the dynamic calibration loops converge.	M1, M2
REQ-L3-OAD-70869	Identify and center science target	120	Identification will be highly dependent on the exact science case and observing strategy. This will be instrument-specific. After centering, target acquisition is complete and the observing sequence is started.	OCS

Rationale: The timing of each step of target acquisition is important to meet the science requirement to set up a new target, and to reduce observing overheads.
Notes:
1. Maximum slew is defined as a 180° slew in Mount azimuth, a 60° slew in Mount elevation, and a 360° slew for the GIR.
2. In steps requiring finding and centering stars, an exceptional case occurs if the star is not found where expected, and the system may have to spend time hunting for the star, or selecting another star.

REQ-L3-OAD-80128: Mount and Enclosure Azimuth Slewing Velocity

The Mount and Enclosure shall have an operational, bidirectional angular slewing velocity in azimuth of up to and including 1.8 deg/sec.

Rationale: Operational efficiency over a range of slew distances, and coordination between Mount and Enclosure, requires selecting an acceleration, maximum velocity pair that will meet other requirements.
Notes: See the analysis in GMT-TEL-DOC-00569.

REQ-L3-OAD-80131: Mount and Enclosure Azimuth Slewing Acceleration

The Mount and Enclosure shall have an operational bidirectional angular slewing acceleration in azimuth of no less than 0.1 deg/sec/sec.

Rationale: Operational efficiency over a range of slew distances, and coordination between Mount and Enclosure, requires selecting an acceleration, maximum velocity pair that will meet other requirements.
Notes: See the analysis in GMT-TEL-DOC-00569.

REQ-L3-OAD-80134: Mount and Enclosure Maximum Azimuth Tracking Velocity

The Mount and Enclosure shall have an operational angular tracking ability, at full performance, of up to and including 0.45 deg/sec.

Rationale: The maximum rate expected by a nonsidereal target (OAD-36365) passing at the maximum operational elevation (OAD-35459) will move at a rate of 0.4223 deg/sec. Some margin has been added to derive 0.45 deg/sec.

REQ-L3-OAD-96536: Mount and Enclosure Elevation Slewing Velocity

The Mount and Enclosure Wind Screen shall have an operational, bidirectional angular slewing velocity in elevation of up to and including 1.0 deg/sec.

Rationale: To avoid the Enclosure Wind Screen from vignetting the telescope optical path after a slew, and to specify operational efficiency values, requires selecting an acceleration, maximum velocity pair that will meet other requirements.

REQ-L3-OAD-96537: Mount and Enclosure Elevation Slewing Acceleration

The Mount and Enclosure Wind Screen shall have an operational, bidirectional angular slewing acceleration in elevation of no less than 0.1 deg/sec/sec.

Rationale: To avoid the Enclosure Wind Screen from vignetting the telescope optical path after a slew, and to specify operational efficiency values, requires selecting an acceleration, maximum velocity pair that will meet other requirements.

REQ-L3-OAD-92316: Natural Seeing Offset Times — small offsets

The GMT shall offset distances of < 5 arcsec on sky in no more than 5 seconds of time in Natural Seeing wavefront control mode.

Rationale: To fulfill ORD requirements, and make observing efficient.
Notes: The time taken is from the start of the offset until all GMT subsystems and relevant optical feedback loops have settled at the new position.

REQ-L3-OAD-92317: Natural Seeing Offset Times — moderate offsets

The GMT shall offset distances of between 5 arcsec and 30 arcsec on sky in no more than 10 seconds of time in Natural Seeing wavefront control mode.

Rationale: To fulfill ORD requirements, and make observing efficient.
Notes: The time taken is from the start of the offset until all GMT subsystems and relevant optical feedback loops have settled at the new position.

REQ-L3-OAD-92318: Natural Seeing Offset Times — large offsets

The GMT shall offset distances of more than 30 arcsec but no more than 180 arcsec on sky in no more than 20 seconds of time in Natural Seeing wavefront control mode.

Rationale: To fulfill ORD requirements, and make observing efficient. This distance represents a case in which new AGWS stars may need to be used.

Notes: The time taken is from the start of the offset until all GMT subsystems and relevant optical feedback loops have settled at the new position.

REQ-L3-OAD-92319: Diffraction-Limited Offset Times — small offsets

The GMT shall offset distances of < 5 arcsec on sky in no more than 2.5 seconds of time in diffraction-limited wavefront control modes.

Rationale: To fulfill ORD requirements, and make observing efficient.
Notes: The time taken is from the start of the offset until all GMT subsystems and relevant optical feedback loops have settled at the new position.

REQ-L3-OAD-92320: Diffraction-Limited Offset Times — moderate offsets

The GMT shall offset distances of between 5 arcsec and 30 arcsec on sky in no more than 5 seconds of time in diffraction-limited wavefront control modes.

Rationale: To fulfill ORD requirements, and make observing efficient.
Notes: The time taken is from the start of the offset until all GMT subsystems and relevant optical feedback loops have settled at the new position.

REQ-L3-OAD-92321: Diffraction-Limited Offset Times — large offsets

The GMT shall offset distances of more than 30 arcsec but no more than 180 arcsec on sky in no more than 10 seconds of time in diffraction-limited wavefront control modes.

Rationale: To fulfill ORD requirements, and make observing efficient. This distance represents a case in which new AGWS stars may need to be used.
Notes: The time taken is from the start of the offset until all GMT subsystems and relevant optical feedback loops have settled at the new position.

REQ-L3-OAD-37045: Image Quality Degradation with Two Guide Stars

For Natural Seeing Modes, the GMT shall maintain the specified Natural Seeing Image Quality over at least a 2 minute (TBC) period with two guide stars.

Rationale: There will be situations in which a bright offset star does not have a full set of AGWS stars. Since image quality performance must only be met on science targets, it is permissible to set up on the offset star with a smaller number of AGWS stars. The time period includes centering of the offset star and offsetting to the science target. Two guide stars allow control of the Mount position and GIR rotation.

5.3.5.4 Observatory State Transition Efficiency

REQ-L3-OAD-37049: Subsystem Automated Startup/Shutdown

The OCS shall provide for each subsystem an automated startup and an automated shutdown procedure.

Rationale: This is required to maximize operational efficiency and reduce errors.

REQ-L3-OAD-37052: Subsystem Observing Start-Up Time

The GMT subsystems shall transition from a daytime maintenance state to a state ready for science operations in less than 20 minutes.

Rationale: This requirement ensures that initialization of the telescope will be completed efficiently. Flowdown from ORD.

Notes: This requirement includes only those preparations that can be done during daytime. These include end-of-day safety check, off-sky subsystem calibrations, bringing up pressure on the HBS, initializing the M1 support system, initializing instruments, uncovering relevant optics, and prepositioning subsystems such as the enclosure (in rotation), AGWS probes, M3, C-ADC, and/or relay optics for the first target of the night.

5.3.5.4.1 Observatory Subsystem On-Sky Initialization Time

The GMT subsystems shall perform the following on-sky initialization tasks in the designated times (flowdown from ORD requirement of 45 minutes for this entire transition).

Table 5-16: On-Sky Subsystem Initialization Times

Requirement	Task	Time (min)	Element
REQ-L3-OAD-37064	Open Enclosure shutter and vents	10	Enclosure
REQ-L3-OAD-37068	Focus and stack images	10	AGWS
REQ-L3-OAD-37072	Calibrate pointing model	10	OCS
REQ-L3-OAD-37076	LGS checkout - LGS focus, tip, tilt - beam optimization (spot size) - tune laser	15	LGS, OCS

Rationale: On-sky initialization tasks must all be completed before 12-degree twilight to maximize the amount of time available to science observing.

REQ-L3-OAD-37080: Observatory Shutdown Time

The GMT Observatory subsystems shall transition from their science operations state to their daytime maintenance state in a total time not to exceed 10 minutes. (TBR)

Rationale: The Observatory should be ready to support daytime tasks in a reasonable time frame.
Notes: This transition to daytime maintenance will typically include closing the Enclosure shutter and vents, pointing the Mount to zenith, stowing M1, bringing the Mount off oil pressure, stowing the Enclosure moon shade and wind screen, and closing relevant protective covers (e.g. for M1 and the GIR), powering down relevant subsystems, and prepositioning or stowing various subsystems such as the Mount and Enclosure in azimuth, optics such as the C-ADC, M3, and relay optics, prepositioning the GIR. Prepositioning of subsystems during this transition to positions requested for the start of daytime maintenance makes the maintenance more efficient. In general, some science calibrations are expected to occur early in the day, so instruments will often be left in a state ready to take calibrations.

REQ-L3-OAD-37084: Time to Transition Subsystems to Environmental Standby

The GMT Observatory subsystems shall transition from their science operations state to their environmental standby state in a total time not to exceed 3 minutes. (TBR)

Rationale: Rapidly changing environmental conditions (e.g. the onset of precipitation) may require rapid protection of the Observatory components. This is a flowdown from the ORD.
Notes: Protection from inclement environmental conditions is primarily provided by the Enclosure shutter and vents. Secondary protection may be provided by the Enclosure rotation, the wind screen, the M1 covers, and the telescope position.

REQ-L3-OAD-92314: Subsystem Transition Time — Environmental Standby to Science Operations

The GMT Observatory subsystems shall transition from their environmental standby state to their science operations state in no more than TBD minutes.

Rationale: Return to science operations after an environmental event should be efficient.
Notes: Note that this includes correcting the pointing model after an RLE (but does not include physically recentering the pier, which will be done during daytime hours so as not o lose science operations time). This time to transition is considered part of the weather event, not a part of technical downtime.

5.4 Technical Operations (Engineering Maintenance & Management)

The following table (GMT-SE-REF-00420) provides the maintenance resource allocations for each subsystem.
Each subsystem shall be designed to be maintainable with at most the tabulated staff resources:

Table 5-17: Staff maintenance hours allocated by subsystem.

Requirement	Subsystem	Hours per Year
REQ-L3-OAD-37096	Facilities	2390
REQ-L3-OAD-37099	Enclosure	842
REQ-L3-OAD-37102	Observatory Control System	1713
REQ-L3-OAD-37105	Mount	3097
REQ-L3-OAD-37108	Telescope Metrology Subsystem (TMS)	784
REQ-L3-OAD-37111	Wavefront Control Calibration Subsystem	784
REQ-L3-OAD-37114	Wavefront Control Testbed	784
REQ-L3-OAD-37117	AGWS	706
REQ-L3-OAD-37120	Laser Guide Star Subsystem	1394
REQ-L3-OAD-37123	LTWS (x2)	958
REQ-L3-OAD-37126	NGWS (x2)	1684
REQ-L3-OAD-37129	Environmental Monitoring Facility (EMF)	784
REQ-L3-OAD-37132	M1 Subsystem	929
REQ-L3-OAD-37135	ASM Subsystem	658
REQ-L3-OAD-37138	FSM Subsystem	377
REQ-L3-OAD-37141	M3 Subsystem	726
REQ-L3-OAD-37144	C-ADC	426
REQ-L3-OAD-37147	Optics Servicing	435
REQ-L3-OAD-37150	GMTIFS	1606
REQ-L3-OAD-37153	GMTNIRS	319
REQ-L3-OAD-37156	GMACS	639
REQ-L3-OAD-37159	Manifest	1384
REQ-L3-OAD-37162	Commissioning Camera	155
REQ-L3-OAD-37165	G-CLEF	1161
REQ-L3-OAD-37168	Instrument Calibration Subsystem (ICS)	697
	TOTAL	**25,433**

Rationale: Each subsystem must have an allotment of maintenance hours to constrain the overall staff resources needed to support the Observatory.

5.4.1 Equipment Maintenance

REQ-L3-OAD-37174: GMT Maintenance System

The GMT shall provide a maintenance system that includes procedures for maintaining GMT subsystems as described in GMT-DOC-01221.

Rationale: Maintenance of the Observatory is required to reach availability and cost targets.
Notes: GMT-DOC-01221 describes the different types of maintenance and lists information that must be provided to a maintenance system.

REQ-L3-OAD-37178: Maintenance Program

Each GMT subsystem shall develop a maintenance program for servicing that subsystem.

Rationale: Down time is minimized if components are routinely serviced to promote longevity and reliable operation.
Notes: This includes preventive, predictive, and condition-based maintenance.

REQ-L3-OAD-37182: Subsystem Maintenance Program

Each GMT subsystem shall provide procedures and documentation for subsystem maintenance in a form that can be ingested into and used by the GMT Maintenance System.

Rationale: Each subsystem will need to supply maintenance information, but all such information must be integrated holistically.

REQ-L3-OAD-37185: Instrument Assembly and Maintenance Space

The Facilities shall provide space at the observatory for off-telescope assembly and maintenance of two instruments, each space being four times the footprint of the instrument, and the height sufficient to allow movement and disassembly/assembly of the instrument.

Rationale: This is required for on-site assembly and maintenance of Science Instrumentation and AO.
Notes: Assembly/maintenance space will be kept moderately clean but instruments will need covers, crates, etc. to keep clean.

REQ-L3-OAD-70809: Instrument Assembly and Maintenance Clean Room Tents

Instrument Support Equipment shall provide modular and portable clean room tents for assembling and servicing Scientific Instruments.

Rationale: Required for assembling and servicing any scientific instrument which contains components (e.g. optics, detectors, mechanisms) that must be kept uncontaminated.

REQ-L3-OAD-37189: Instrumentation Storage

The Facilities shall provide dry storage space at the observatory for the temporary storage of instruments/AO and associated handling and support equipment.

Rationale: This is required for on-site storage of Science Instrumentation and AO.
Notes: Storage space will be kept moderately clean but instruments will need covers, crates, etc. to keep clean. The space will be dry but not temperature- or humidity-controlled.

REQ-L3-OAD-69485: FP Instrument Maintenance Station

The Mount shall provide space on the Instrument Platform for an FP Instrument Maintenance Station.

Rationale: This avoids unnecessarily removing an FP instrument from the telescope when only minor maintenance is required, but that maintenance requires the instrument to be pulled back from its operational position on the GIR.

Notes: Critical instrument utilities will be available at the Maintenance Station.

REQ-L3-OAD-69488: AP Lower Access Platforms

The Mount shall provide access platforms at either AP Instrument Station to allow instrument maintenance tasks.

Rationale: Allows safe personnel access to the instrument for maintenance.
Notes: The two platforms will be called the AP +X Lower Access Platform and the AP –X Lower Access Platform.

REQ-L3-OAD-69491: IP Outer Access Platforms

The shall provide outer access platforms on the Instrument Platform to facilitate maintenance performed on the Instrument Platform level.

Rationale: Allows safe maintenance access to FP and IP instruments, and other equipment on the Instrument Platform.
Notes: The two platforms will be called the IP +X Outer Access Platform and the IP –X Outer Access Platform.

REQ-L3-OAD-69494: OSS Mid-Level Platform

The Mount shall provide an access platform that does not rotate with the GIR and is located to allow personnel access to the midpoint, parallel to the telescope Z axis, of the GIR and DG instruments.

Rationale: To allow maintenance of DG instruments and electronics cabinets mounted at this level.
Notes: Electronic cabinets can be located on this platform, as long as they do not block access to the DG instruments. Maintenance access to those electronic cabinets will also be provided by the platform.

REQ-L3-OAD-69497: GIR Mid-Level Platform

The Mount shall provide an access platform on the rotating GIR and is located at the same level as the OSS Mid-Level Platform.

Rationale: To allow safe access to equipment at the mid-level that will rotate with the GIR.
Notes: Equipment that rotates with the GIR will include electronics cabinets serving the DG instruments and the DG instruments themselves. Access from the OSS Mid-Level Platform across to the GIR Mid-Level Platform will be allowed only when the GIR is locked out (cannot rotate).

REQ-L3-OAD-69500: OSS Lower Level Platform

The Mount shall provide an access platform that does not rotate with the GIR and is located to allow personnel access to the bottom, parallel to the telescope Z axis, of the GIR and DG instruments.

Rationale: To allow maintenance of DG instruments and electronics cabinets mounted at this level.
Notes: Electronic cabinets can be located on this platform, as long as they do not block access to the DG instruments. Maintenance access to those electronic cabinets will also be provided by the platform.

REQ-L3-OAD-69503: GIR Lower Level Platform

The Mount shall provide an access platform on the rotating GIR and is located at the same level as the OSS Lower Level Platform.

Rationale: To allow safe access to equipment at the mid-level that will rotate with the GIR.

Notes: Equipment that rotates with the GIR will include electronics cabinets serving the DG instruments and the DG instruments themselves. Access from the OSS Lower Level Platform across to the GIR Lower Level Platform will be allowed only when the GIR is locked out (cannot rotate).

REQ-L3-OAD-69506: Azimuth Disk

The Mount shall provide a platform at the same level as the Observing Floor that rotates with the telescope in azimuth and allows maintenance access to the lower components of the GIR and Mount.

Rationale: To allow safe access to equipment at the bottom of the telescope structure.
Notes: The Azimuth Disk will have a central hole through which the Pier Lift Platform can extend. When in its normal, stowed position, the Pier Lift Platform will provide the central part of the floor to prevent fall hazards.

REQ-L3-OAD-37197: Equipment Service Access and Control

The GMT shall make serviceable equipment accessible and include local controls as required for maintenance.

Rationale: Down time and maintenance time are minimized if components are easily accessible for service and/or repair. Local control of equipment allows troubleshooting to be done safely and efficiently.
Notes: Safe access could include doors, removable panels, passageways, platforms, ramps, etc. Examples of serviceable components include cable trays/wraps, motors, drives, gears, slip rings, electronics, etc.

REQ-L3-OAD-37201: Equipment Service Life

All Subsystems shall deliver equipment necessary to maintain all critical components and systems over their lifetime on the observatory.

Rationale: Having the proper equipment for maintenance is essential to minimize service time and promote longevity.

REQ-L3-OAD-37204: Instrument Installation Time

Each GMT Instrument shall be able to be physically installed on the Mount in less than 6 hours.

Rationale: This allows the Observatory to be returned to scientific operations the following night.
Notes: This does not include preparing the instrument for installation (pumping down the vacuum, cooling the instrument, pre-installing electronics cabinets, etc.), or rebalancing the telescope or optically aligning the instrument. It does not imply that the instrument itself will be ready for science operations that night.

REQ-L3-OAD-37208: Visitor Instrument Maintenance

Each Visitor Instrument will be designed for maintenance by the Visiting Instrument group with minimal assistance from the GMT Observatory staff, as defined in the agreement with the PI Institution.

Rationale: This is a system level requirement.
Notes: Aside from routine operational support, such as filling dewars, GMT will not be responsible for servicing, maintaining, upgrading or otherwise supporting visitor instruments, other than providing standard interfaces to the rest of the system.

REQ-L3-OAD-37212: Instrument Scheduled Nighttime Maintenance Time

Each GMT Instrument shall require no more than 10 hours [goal: 5 hours] of scheduled nighttime maintenance per year.

Rationale: This is derived from the Maintenance Time Budget.
Notes: This includes on-sky performance tests as well as post-maintenance functional and performance verification. It assumes that daytime testing has already been performed, leaving only tasks that require the instrument to see sky.

REQ-L3-OAD-37216: Troubleshooting and Diagnostics Capability

GMT shall provide the capability to record a failure of the system, perform troubleshooting on a specific failure and run extensive system diagnostics.

Rationale: This is needed to meet the requirements for the maintenance down-time.

REQ-L3-OAD-37219: Controlling Individual Degrees of Freedom

GMT shall provide the capability to control any single degree of freedom within any subsystem.

Rationale: This will support maintenance and troubleshooting processes, but also be available during regular operations for manual control.

5.4.2 Optics Maintenance

REQ-L3-OAD-37223: Coating System Upgradeable

The GMT Mirror Coating Facility shall be upgradable in the future for advanced multi-layer low-emissivity coatings.

Rationale: This is required to meet the science requirement to maximize the throughput.

REQ-L3-OAD-37226: Coating Maintenance

The GMT shall provide facilities and procedures for cleaning and/or recoating optical surfaces as required to meet throughput and emissivity specifications during science operations.

Rationale: This is required to meet the science requirements for optical coatings.
Notes: It is expected that the GMT optical coating facility will handle M1 segments, FSM segments, M3, and the large mirrors in the M2 test pit. ASM and smaller optics may be sent out for recoating.

REQ-L3-OAD-37230: In-Situ M1 Segment Cleaning - CO_2

The GMT Observatory shall deliver equipment and procedures for in-telescope CO_2 cleaning of the M1 reflective surfaces.

Rationale: Required to maintain the coating throughput performance. In-situ washing required to ensure efficiency requirements are met.

REQ-L3-OAD-37233: In-Situ M1 Segment Cleaning - Wet Wash

The GMT Observatory shall deliver equipment and procedures for in-telescope wet wash cleaning of the M1 reflective surfaces.

Rationale: Required to maintain the coating throughput performance. In-situ washing required to ensure efficiency requirements are met.

REQ-L3-OAD-37236: In-Situ M2 CO_2 Cleaning

The GMT Observatory shall provide equipment and establish procedures for in-telescope CO_2 cleaning of the M2 reflective surfaces.

Rationale: This is to promote high throughput, low emissivity, and low scattering while at the same time minimizing the frequency at which segments need to be removed from the telescope for re-coating.
Notes: This applies to the FSM. It is uncertain whether the ASM segments can be cleaned with CO_2.

REQ-L3-OAD-37240: In-Situ M3 CO_2 Cleaning

The GMT Observatory shall provide equipment and establish procedures for in-telescope CO_2 cleaning of the M3 reflective surface.

Rationale: Required to maintain the coating throughput performance.

REQ-L3-OAD-37243: In-Situ Corrector-ADC Cleaning

The GMT Observatory shall provide equipment and establish procedures for in-telescope cleaning of the exposed optical surfaces of the Corrector-ADC.

Rationale: Required to maintain the throughput performance.

5.4.3 Spares

Critical spares are needed for components that are essential for maintaining science operations and have a high failure potential or a long lead-time. The Critical Spares Document (GMT- DOC-00277, TBD) contains a risk analysis for the failure of critical components at the system and subsystem level in terms of impact and likelihood of failure and cost/benefit trade-offs. The information in this document is maintained by SE and provided by GMT groups/vendors.

REQ-L3-OAD-37248: Subsystem FMECA

Each GMT subsystem shall develop a Failure Modes Effects and Criticality Analysis (FMECA).

Rationale: Failure and criticality analyses are necessary to identify weak points in the design and mitigations that can be taken.
Notes: GMT-DOC-01221, GMT Reliability, Availability, and Maintainability (RAM) Plan, provides more details on the high-level RAM strategy.

REQ-L3-OAD-37252: Spares Policy

Each GMT subsystem shall assess the need to provide spares according to the "Spares Policy" described in GMT-DOC-01221.

Rationale: Following a spares policy helps effective and efficient maintenance.
Notes: GMT-DOC-01221 is the GMT Reliability, Availability, and Maintainability (RAM) Plan. The Spares Policy is described in Section 6.

5.4.4 Maintenance Operations Efficiency

REQ-L3-OAD-37257: M1 Washing Time

The M1 in-situ washing equipment shall be designed to allow the washing of one (1) M1 segment to be completed in no more than 4 hours during the day without the loss of a night.

Rationale: This allows the Observatory to be returned to science operations for the following night.

Notes: M1 washing is estimated to occur once between coatings. Coatings are estimated at every two years. Washing is therefore once every two years, per mirror. The cleaning of individual segments is staggered during the year.

REQ-L3-OAD-37261: M1 Off-Axis Segment Exchange Time

The GMT Observatory shall exchange an M1 off axis segment in less than 10 hours.

Rationale: This allows the Observatory to be returned to science operations for the following night.
Notes: This time includes the time required for alignment checks.

REQ-L3-OAD-37265: M1 CO_2 Cleaning Time

The in-situ M1 CO_2 cleaning equipment shall be designed to allow the cleaning of one (1) M1 segment to be completed in no more than 2 hours during the day without the loss of a night.

Rationale: This allows for frequent cleaning, essential in maintaining system throughput. It also allows for more than one segment per day, making efficient use of cleaning overhead (equipment setup and break down).
Notes: The two hour time does not include initial set up and positioning of equipment before the CO2 cleaning process starts. It does include repetitive steps that need to be done for each segment, such as replacing empty CO2 cylinders with full cylinders for each segment.

REQ-L3-OAD-37269: M2 CO_2 Cleaning Time

The in-situ M2 CO_2 cleaning equipment shall be designed to allow the cleaning of all seven (7) M2 segments to be completed in no more than 2 hours during the day without the loss of a night.

Rationale: This allows the Observatory to be returned to science operations for the following night.
Notes: The estimate M2 cleaning frequency is all segments once per month.

5.4.5 Availability

REQ-L3-OAD-37274: Operational Availability

The GMT shall be designed to operate 365 days/year under normal observing/maintenance conditions.

Rationale: The cost and value of the facility are such that it should be operated on as many days in a year as possible.
Notes: Not everything will run 24/7. Observing is not allowed during daytime.
Technical down time
The GMT systems shall be designed to achieve a maximum unplanned technical down time as shown in Table 5-18.

Table 5-18: Down Time Allocations by PBS

Requirement	PBS #	Name	Hours downtime/yr
REQ-L3-OAD-37286	1	Facilities	1
REQ-L3-OAD-37290	2	Enclosure	1
REQ-L3-OAD-37294	3	Observatory Control System	19
REQ-L3-OAD-37298	4	Mount	14
REQ-L3-OAD-37302	5	Telescope Metrology Subsystem (TMS)	1
REQ-L3-OAD-37306	6	Wavefront Control Calibration	0

		Subsystem	
REQ-L3-OAD-37310	7	Wavefront Control Testbed	0
REQ-L3-OAD-37314	8	AGWS	2
REQ-L3-OAD-37318	9	Laser Guide Star Subsystem	7
REQ-L3-OAD-37322	10	LTWS (x2)	3
REQ-L3-OAD-37326	11	NGWS (x2)	3
REQ-L3-OAD-37330	12	Environmental Monitoring Facility (EMF)	0
REQ-L3-OAD-37334	13	M1 Subsystem	3
REQ-L3-OAD-37338	14	ASM Subsystem	40
REQ-L3-OAD-37342	15	FSM Subsystem	2
REQ-L3-OAD-37346	16	M3 Subsystem	2
REQ-L3-OAD-37350	17	C-ADC	1
REQ-L3-OAD-37354	18	Optics Servicing	0
REQ-L3-OAD-37358	19	GMTIFS	11
REQ-L3-OAD-37362	20	GMTNIRS	2
REQ-L3-OAD-37366	21	GMACS	4
REQ-L3-OAD-37370	22	Manifest	10
REQ-L3-OAD-37374	23	Commissioning Camera	1
REQ-L3-OAD-37378	24	G-CLEF	8
REQ-L3-OAD-37382	25	Instrument Calibration Subsystem (ICS)	1
		TOTAL	**136**

Rationale: Each subsystem must have a constraint on their allowable technical downtime, to meet the overall Observatory downtime, and to guide design towards high-reliability solutions.
Notes: Technical downtime refers to time lost to science operations due to unforeseen technical problems. It refers only to loss of functionality, not degradation of performance, unless such degradation is sufficient to also cause effective loss of functionality. Subsystem functionality that is not needed during science operations (e.g. Enclosure air conditioning, which is off at night) do not contribute to technical downtime.

REQ-L3-OAD-37388: Instrument Availability

Instruments shall be kept in an environmentally controlled state at all times unless undergoing maintenance.

Rationale: To minimize deleterious effects of thermal cycling on instruments, particularly cryogenic instruments and detectors. To minimize times to switch between instruments.
Notes: Environmentally controlled means the instrument is at operating temperature (including detectors, optical benches) and pressure (for vacuum vessels) and under active control. Each instrument will have to define this state in more detail. Instruments must be ready to take science data during the night and calibration data during the day. Thermally cycling detectors, in particular, is something to minimize. Even maintenance should attempt to retain as much of the instrument at an operationally ready state as is practical.

REQ-L3-OAD-37392: Facility Instrument Major Maintenance Timescale

Facility Instruments shall be designed to be mounted on the telescope for a minimum of 2 years, requiring only in-situ maintenance, following policies established by GMTO.

Rationale: Derived from the OCD and SLR requirements detailing down time/scheduled maintenance and operational availability. These needs are balanced and allocated in the Maintenance Time Budget (GMT-SE-DOC-0420). Observational projects typically require several seasons to acquire data; removing an instrument changes its calibration and reduces the final data quality.
Notes: Facility Instruments are intended to be used for extended periods of time without removal. If an instrument is removed, a minor recommissioning plan and procedure will be required.

REQ-L3-OAD-37396: Instrument Recovery Time

Instruments shall recover in at most one hour from a loss of critical services (power, communication, cooling, vacuum) for a minimum of one hour.

Rationale: Moving an instrument may require loss of critical services, which will take the instrument away out of an operational state. The instrument must be returned to an operational state within an hour after restoring services.
Notes: Critical services may be different for different instruments. Power, cooling, communications, and vacuum are often critical services.

REQ-L3-OAD-61141: Loss of Critical Services

The Observatory shall provide power, cooling, and communications with no interruption in service longer than one hour for normal maintenance procedures.

Rationale: Related to REQ-L3-OAD-37396, loss of critical services for a long period of time can impact recovery of a subsystem to an operational state.

REQ-L3-OAD-104848: Planned Power Outages

The Observatory shall allow for a planned, continuous power outage of up to 8 hours occurring at least once per year.

Rationale: Regular maintenance on the Observatory's power system is necessary to keep the system in good condition and avoid unplanned downtime.
Notes: This maintenance will be done during the day, hence will not impact technical downtime for the subsystems. Subsystems may require temporary power sources if the 8-hour period would otherwise cause problems with the subsystem (e.g. instrument cooling).

5.4.6 Access

REQ-L3-OAD-37401: In-Situ Maintenance Access

The GMT shall provide safe access to subsystems and components that require in-situ maintenance.

Rationale: Some GMT subsystems may be serviced in situ, and access to those subsystems will be necessary.
Notes: Access requirements may at times be found in ICDs.

5.4.7 Handling

5.4.7.1 Handling within the Enclosure

REQ-L3-OAD-37407: Boom Lift

The Enclosure shall provide a Boom Lift in the Upper Enclosure with a capacity of at least 400 kg and a reach that allows access to the interface between the upper and lower trusses, and all points on all M1 segment surfaces.

Rationale: This facilitates maintenance that requires access to the upper truss connection points and to M1 segments for CO2 cleaning. The 400 kg represents two people and a modest amount of tools or CO2 tanks.
Notes: Access to different sides of the Mount structure may require moving the Mount in azimuth. The detachment points for the upper truss are the furthest reach needed. Other access points include the LGS components and the outer edges of the off-axis M1 cells.

REQ-L3-OAD-37411: IP Jib Crane

The Mount shall provide a Jib Crane for aiding in the installation/ removal and handling of equipment between the Enclosure Observing Floor and the Instrument Platform.

Rationale: Enables moving of smaller equipment and maintenance items between the observing floor and IP without having to use the Enclosure Gantry Crane.
Notes: An analysis of the maintenance requirements will be used to derive the detailed requirements for the IP Jib Crane.

REQ-L3-OAD-37415: FP GIR Equipment Hoist

The Mount shall provide a Hoist for aiding in the handling of components of the VWS.

Rationale: Enables maintenance on the VWS without having to remove/install the FP Instrument.
Notes: An analysis of the maintenance requirements will be used to derive the detailed requirements for the FP GIR Hoist.

REQ-L3-OAD-37419: M1 Warehouse Mirror Vacuum Lifting Fixture

The M1 System shall provide a vacuum lifting fixture to safely lift an uncoated M1 mirror into its cell.

Rationale: Enables assembly of the mirror into its weldment.
Notes: This will be modeled after the vacuum lifting fixtures used in the Richard F. Caris Mirror Lab during creation of the M1 segments. It requires an uncoated mirror surface. This should be needed only during M1 cell assembly at the start of the project, and should only be needed once per M1 segment.

REQ-L3-OAD-37427: Specialized Subsystem Handling Fixtures

Each subsystem shall provide any specialized equipment (e.g. fixtures, carts) needed to handle the subsystem or its components.

Rationale: Specialized handling fixtures are needed to ensure safe and efficient handling, servicing, and storage of subsystems and components.

REQ-L3-OAD-37430: Instrument Equipment Handling Safety

The Instrument shall provide fixtures and containers for safely handling and transporting equipment.

Rationale: Required for personnel and equipment safety.

REQ-L3-OAD-70811: Direct Gregorian (DG) – Instrument Mounting Frame (IMF) Handling Cart

Instrument Support Equipment shall provide a DG–IMF Handling Cart for safely transporting one DG instrument mounted in its IMF within the enclosure.

Rationale: Required for servicing and installation of any DG instrument.

Notes: Baseline concepts for the DG–IMF Handling Cart and Transfer Fixture are described in GMT-DOC-00860, "DG Instrument Mounting Procedure - Mechanical Design Description" (2014) and in GMT-DOC-01296, "Gregorian Instrument Rotator Design Update" (2016). Alternative COTS options may be identified.

REQ-L3-OAD-70814: Direct Gregorian (DG) – Instrument Mounting Frame (IMF) Transfer Fixture

Instrument Support Equipment shall provide a DG–IMF Transfer Fixture to be attached to the top of the Pier Lift Platform (PLP).

Rationale: Required to secure the DG–IMF onto the PLP and to align the IMF with the GIR central opening during DG instrument installation.
Notes: Baseline concepts for the DG–IMF Handling Cart and Transfer Fixture are described in GMT-DOC-00860, "DG Instrument Mounting Procedure - Mechanical Design Description" (2014) and in GMT-DOC-01296, "Gregorian Instrument Rotator Design Update" (2016). Alternative COTS options may be identified.

REQ-L3-OAD-109112: Folded Port (FP) – Instrument Handling Cart

Instrument Support Equipment shall provide a FP Handling Cart for safely transporting one FP instrument.

Rationale: Required for servicing and installation of FP instrument, AP instrument and IP instrument.
Notes: Baseline concepts will be based on the needs described in FP Instrument Installation Behavior (GMT-DOC-01382), AP Instrument Installation Behavior (GMT-DOC-01384),and IP Instrument Installation Behavior (GMT-DOC-01383).

5.4.7.2 Handling External to Observatory Buildings

REQ-L3-OAD-37434: Protection from External Environment During Transportation

Each GMT subsystem shall provide protection from the environment external to Observatory buildings during transportation of sensitive components from building to building.

Rationale: Without a building to protect sensitive components, a separate mechanism for protection must be supplied.
Notes: Sensitive components include optics and instruments. Subsystems are expected to specify requirements for specific components, including which environmental conditions are protected against.

REQ-L3-OAD-37438: External Unpacking Crane

The GMT shall provide an external crane with capacity to remove transportation crates for M1 mirrors, weldments, and covers.

Rationale: Uncrating components outside the M1 Assembly Building improves efficiency in assembling cells.
Means of transporting for moving the following subsystems between buildings:

Table 5-19: Transportation of Components between Buildings

Requirement	Subsystem	Buildings	Documentation
[1]REQ-L3-OAD-37448	M1 cell	Summit Support Building - Enclosure	Supplied by the Mount. This transportation mechanism can also be used inside the Summit Support Building.

[2]REQ-L3-OAD-37452	ASM	Summit Support Building – Enclosure	Supplied by the ASM.
[3]REQ-L3-OAD-37455	FSM	Summit Support Building – Enclosure	Supplied by the FSM
REQ-L3-OAD-37458	M3	Summit Support Building– Enclosure	Supplied by the M3
REQ-L3-OAD-37469	C-ADC	Summit Support Building– Enclosure	Supplied by the C-ADC. Maintenance location is in the SSB
REQ-L3-OAD-37465	Instruments	Summit Support Building– Enclosure	This is for transport to maintenance areas outside the Enclosure

Rationale: Critical components must be safely transported between their operational locations and their maintenance locations.
[1]Supplied by the Mount Subsystem. This transporter may also be used to transport ASM and FSM Subsystems with adaptations. This transportation mechanism can also be used inside the Summit Support Building.
[2]This may be the same transporter as the M1 Cell with adaptations provided by ASM Subsystem.
[3]This may be the same transporter as the M1 Cell with adaptations provided by FSM Subsystem.

5.5 Data Archives

The GMT Data Archive is a repository which manages, stores and distributes all data products related to the operations of the observatory, including, but not limited to, science, engineering, facility and environmental data.

REQ-L3-OAD-37483: Science Data Archive

The OCS shall provide a science data archive, including data storage, automated ingestion software, and an externally available archive interface.

Rationale: Re-use of the Observatory's primary data product has significant value, and accessing past data is useful for maintenance and troubleshooting.
Notes: GMT-DOC-01582, GMTO Science Archive, describes the Science Archive in more detail.

REQ-L3-OAD-37487: Engineering Data Archive

The OCS shall provide an engineering data archive, including data storage, automated ingestion software, and an externally available archive interface.

Rationale: Engineering data is key to proper maintenance, troubleshooting, fault repair, and improverment of Observatory subsystems. Historical data are necessary for trend analysis.

REQ-L3-OAD-37489: Archive Longevity

The Science and Engineering Data Archives shall curate data for at least the 50-year lifetime of the Observatory.

Rationale: The Observatory will operate for 50 years and archival data may be valuable at any point during it operational lifetime.

REQ-L3-OAD-37492: Data Archive Interfaces

The OCS shall provide interfaces to the Science and Engineering Data Archives.

Rationale: The Data Archive shall support the creation and execution of queries to search and filter the data. The interface shall allow the creation of data bundles using constraints on the archived products meta-data and make these data bundles available for their export.
Notes: The Data Archive Interface may include both user interfaces and APIs (Application Program Interfaces) that allow users to explore the archived data. Some functionalities include: the execution of simple or complex data queries, the creation of new subsets of data from the query results, preview of the query results, data bundle download, etc.

REQ-L3-OAD-37496: On-Site Data Storage

The GMT shall provide an on-site data storage facility with sufficient capacity to store at least one month of science and engineering data.

Rationale: This is derived from OCD.
Notes: Regardless of where the science and engineering data archives are located, there needs to be a local facility for storing nightly observing data that is not susceptible to network outages between the summit and other locations.

REQ-L3-OAD-37500: Backup Archive Copy

The GMT shall provide a complete, off-site, backup copy of the science and engineering data archives.

Rationale: This archive copy provides a backup in case of disaster, and allows for higher reliability when combined with a smooth failover from the primary archive to the backup archive. More detail to be found in Section 6.5 in GMT-DOC-01582.
Notes: This will be part of the data integrity process for assuring data safety. This functionality could be provided by, for example, a cloud-based solution to the archive.
Science Data Archive Functionality
The Science Data Archive shall provide the following functionality:

Table 5-20: Science Data Archive Requirements

Requirement	Function	Documentation
REQ-L3-OAD-37511	Store Level 0 (raw data), Level 1 (instrument signatures removed) and Level 2 (calibrated data) processed science data.	Storing and serving reduced data in addition to raw data will enhance scientific productivity. Processed science data levels are defined in more detail in GMT-DOC-01582, *GMTO Science Archive*. Provenance will be tracked as part of Data Processing.
REQ-L3-OAD-37514	Record Instrument metadata	Section 3.3.1 of GMT-DOC-01582, including instrument mode and configuration, slit/fiber placement in multi-object spectrographs, image type, and a unique observation identifier
REQ-L3-OAD-37517	Record Telescope metadata	Section 3.3.2 of GMT-DOC-01582
REQ-L3-OAD-37520	Allow access to raw data within five minutes of the end of the science exposure	Section 3.2.1 of GMT-DOC-01582; this is Level 0 data.
REQ-L3-OAD-37523	Not preclude ingesting and serving extracted scientific data	Section 3.2.1 of GMT-DOC-01582; this is Level 2 data, and can be, for example, extracted spectra.
REQ-L3-OAD-	Have a 99.99% availability for	Section 3.2.1 of GMT-DOC-01582

37537	access (move to top)	
REQ-L3-OAD-37526	Archive science proposals and related information	Section 3.2.1 of GMT-DOC-01582; see section 5.2.1.
REQ-L3-OAD-37529	Control access to archived data by user and date.	Section 3.2.1 of GMT-DOC-01582
REQ-L3-OAD-37532	Allow exporting science data in the Flexible Image Transport System (FITS) data format.	This requirement is derived from the requirements for using common data formats and being compatible with the Virtual Observatory.
REQ-L3-OAD-37535	Provide data compliant with International Virtual Observatory Alliance standards.	
REQ-L3-OAD-37540	Provide an API (application program interface) for external and internal users to script archive queries	Section 6.2.4 of GMT-DOC-01582
REQ-L3-OAD-37543	Provide archive performance and usage metrics (top level)	Section 6.4 of GMT-DOC-01582
REQ-L3-OAD-37546	Develop a process to maintain data integrity (move to top)	Section 6.5 of GMT-DOC-01582

Rationale: The science data archive must provide the data necessary to properly reduce, analyze, and interpret the scientific observations produced by the Observatory. Interfaces must be user-friendly to make the information accessible to even inexperienced users.

5.6 Data Processing

Note that data reduction pipelines are to be supplied by each instrument (section 3.4.1). GMT Operations will take over those pipelines after delivery.

Data Processing Subsystem

The data processing shall provide the following functions:

Table 5-21: Data Processing Requirements

Requirement	Function	Documentation
REQ-L3-OAD-37558	Remove instrument signatures from raw data within 24 hours of availability of both the science and its associated calibration data.	Section 3.2.1 of GMT-DOC-01582; this is Level 1 data.
REQ-L3-OAD-37561	Identify relevant calibration data for each science exposure and associate that data with the science data.	Section 3.2.1 of GMT-DOC-01582
REQ-L3-OAD-37564	Track and make accessible to archive users the provenance (history) of Level 1 and higher data	Section 3.2.1 of GMT-DOC-01582
REQ-L3-OAD-37570	Provide an automated quality control process	Section 3.2.1 of GMT-DOC-01582
REQ-L3-OAD-37573	Calculate and provide access to reconstructed point-spread functions	Sections 3.7 and 6.2.1 of GMT-DOC-01582
REQ-L3-OAD-	Provide for re-reduction of raw data	Section 3.8 of GMT-DOC-01582;

37576	into Level 1 data	this is necessary because reduction algorithms may improve with time, or reduction bugs fixed in the software.
REQ-L3-OAD-37579	Allow the storage of multiple versions of reduced data in the archive	It may be advisable to re-reduce and store some level 1 or level 2 data, as improved reduction algorithms or calibrations become available. The newly reduced data shall not overwrite the previous one, but instead it shall be stored as a new version.

Rationale: To optimize the return on investment of the scientific observations, the Observatory must add value beyond simply supplying the raw observations.

REQ-L3-OAD-37567: Data Processing - Web-Interactive Data Reduction

The OCS shall provide a remotely accessible work space for interactive data reduction for individual scientists.

Rationale: A remotely accessible, centrally-controlled space for data reduction allows external users to reduce and analyze their scientific data, and/or data from the science archive, to produce publishable scientific results.
Notes: Sections 3.2.1, 3.6, and 6.2.2 of GMT-DOC-01582.

5.7 Communications Infrastructure

Observatory IT will provide communication between the facilities on the summit, the support sites, the base facility, and the outside world through the Observatory IT Network. Observatory IT is separate from the Observatory Computing Network (OCN) and the ISS network.
In general, hardware will be located within rooms in specific buildings, hence contained within the PBS of those buildings, while the connecting fibers will be part of Site Infrastructure.
Internet service to the GMT site during the construction phase is provided by a connection to the existing LCO network. The construction internet system has a bandwidth of approximately 100 Mbps.

5.7.1 Access Control

REQ-L3-OAD-38169: Network Access Control to Observatory IT Network

The GMT Observatory IT system shall provide access control from outside the Observatory IT Network into the Local Site IT Network.

Rationale: Authorized users must be able to access across networks, including from sites outside the GMT network infrastructure. This will allow vendors, partners, archive users, etc. to access appropriate portions of the GMT network.

REQ-L3-OAD-110066: Network Access Control from Observatory IT Network

The Observatory IT system shall provide access control from the Observatory IT Network into the Observatory Control Network.

Rationale: Authorized users must be able to access the Observatory Control Network from external networks. It will do this through the Observatory IT network, to provide a further level of security and control.

REQ-L3-OAD-110067: Network Access Control by Groups

The Observatory IT system shall provide access control using groups of users.

Rationale: Groups of users, such as all maintenance technicians, are more readily managed.

REQ-L3-OAD-110068: Network Access Control by Individual

The Observatory IT system shall provide access control by individual accounts.

Rationale: Customizing access control by individual, overriding or augmenting group control, is necessary to allow specific tasks for specific individuals.

REQ-L3-OAD-110069: Cross-Network User Access for CMMS

The Observatory IT network shall provide transparent user access from the CMMS to the Observatory Control Network.

Rationale: Maintenance tasks require user access to both the CMMS and the information and devices available on the Observatory Control Network. The system should pass along the user's access credentials so that it is not necessary to explicitly provide them multiple times.

REQ-L3-OAD-110070: Separating Security Data

The Observatory IT network shall separate security data from other data.

Rationale: Security may be supported by an external vendor, and they should only have access to data relevant to security functions such as security camera videos, alerts, and alarms.

5.7.2 Network Services

REQ-L3-OAD-38208: Network Quality of Service Protocol

The GMT networks shall implement a Quality of Service protocol that prioritizes operation-critical network traffic between the summit and remote sites.

Rationale: There are clear priorities for information transfer, e.g. science data transfer is higher priority than recreational video streaming. Quality of Service is affected by low throughput, dropped packets, errors, latency, jitter and out-of-order packet delivery. As part of the QoS Protocol, critical aspects will be identified for different types of network traffic between the summit and remote sites.

REQ-L3-OAD-110072: Maintenance Management Host

The Observatory IT network shall host the Computerized Maintenance Management System.

Rationale: The CMMS will be used for technical maintenance and troubleshooting on the mountain.

REQ-L3-OAD-110073: Surveillance Support

The Observatory IT network shall host video and audio surveillance information and control.

Rationale: Surveillance includes security, safety, and equipment monitoring functions. Surveillance information includes video, audio in the form of microphones and speakers.

REQ-L3-OAD-110074: Remote Observing Support

The Observatory IT network shall support remote observing from authorized external networks and authorized users.

Rationale: Remote observing will be available only from authorized sites and by authorized users. The form of user authorization may be from a single user profile, which may be shared between different external observers.

REQ-L3-OAD-110075: Secure External Communications

The Observatory IT system shall provide secure communication hardware and software to external sites.

Rationale: It is necessary to provide communication from within the GMT sites to external sites, including GMT partners, vendors, consultants, and others. Communication includes phone service and videoconferencing service.

REQ-L3-OAD-110076: Access to Models of Building and Subsystems

The Observatory IT network shall provide real-time access to building and subsystem models.

Rationale: Models include CAD drawings, building information models, EPDM. The model information must be accessible from all GMT sites, including the mountain, sea level facility, and U.S. facility.

REQ-L3-OAD-110077: Access to Support Software

The Observatory IT network shall provide real-time access to administrative and support software.

Rationale: Support software includes packages to manage the Observatory, and support Observatory functions. Examples include configuration management, accounting, etc. The specific set of software will evolve over time.

REQ-L3-OAD-110078: Wireless Communications in the Observing Chamber

The Observatory IT network shall provide wireless communications within the Observing Chamber covering the inner walls of the Upper Enclosure and the Observing Floor outside the azimuth disk.

Rationale: Wireless communication will more flexibly allow communications with and across the networks.

REQ-L3-OAD-110079: Wireless Communications on the CCF

The Observatory IT network shall provide wireless communications covering the top of the CCF while the telescope is pointed to zenith.

Rationale: Staff working on top of the CCF must be able to efficiently and effectively communicate to others elsewhere, including potentially external sites.

REQ-L3-OAD-110080: Wireless Communications on the IP Level

The Observatory IT network shall provide wireless communications covering the IP level of the Mount.

Rationale: Staff working on the IP level (e.g. on FP Instruments, M3, C-ADC, or AGWS) must be able to communicate efficiently and effectively to others elsewhere, including external sites.

5.7.3 Network Performance and Reliability

REQ-L3-OAD-38201: Observatory IT Availability during Operations

The Observatory IT shall provide internal reliability of 99.99% (TBC) during Operations, with the exception of scheduled maintenance downtime.

Rationale: Internal communications between networks and users is crucial for efficient operation of the Observatory. This requires a high overall uptime for internal components, and can be achieved using redundancy in the design.
Notes: This reliability value does not include unavailability due to scheduled IT maintenance. It also does not include the communication to the external world or between distinct GMT locations (Site, Base Facility, US Operations Center).

REQ-L3-OAD-38204: Communication Reliability - Uninterruptible Science Operations

Science operations shall not be interrupted if communications to the outside world is lost.

Rationale: Science operations should not depend on connectivity to outside entities that are beyond the control of the Observatory.

REQ-L3-OAD-38166: Observatory IT Bandwidth

The Observatory IT network shall have a bandwidth of at least 10 Gbit/sec.

Rationale: This is the bandwidth necessary for the predicted data flow to off-site locations during operations. See GMT-REF-03772 and GMT-DOC-03838.

5.7.4 Remote Observing Site Requirements

GMTO will support remote sites will want to create their own observing rooms to participate in science operations. These sites can also be used for collaborative work during the day, such as supporting commissioning teams on the mountain. In order to assure the robustness of these uses, GMTO has placed some minimal requirements on the remote sites. These requirements must be met in order to officially sanction the remote observing site.
The Base Facility's remote operations room will be one example that will be provided during Commissioning.

REQ-L3-OAD-110087: Remote Site Reliability

Authorized remote observing sites shall have a technical downtime of less than 0.1 hours/year during science operations.

Rationale: A high reliability will minimally impact science operations.
Notes: The effects of an instance of network loss can be minimized by having Science Operations on the mountain switch to another science program that can be run locally to GMTO. Also, should the network go down in the middle of a long science exposure, that science exposure need not be interrupted, and can finish with no technical downtime.

REQ-L3-OAD-110088: Remote Site Bandwidth

The bandwidth of authorized remote observing sites shall be at least 10 Gbit/sec.

Rationale: This bandwidth matches the Observatory IT network's minimum bandwidth.

REQ-L3-OAD-110089: Remote Site Latency

Authorized remote observing sites shall have a latency of less than 0.1 seconds.

Rationale: Delays longer than this will be annoying and disruptive to efficient remote operations.

5.8 Utilities

Utility requirements are primarily held in GMT-REQ-04995 GMT Utilities Architecture Document. The Utility One-Line Diagram GMT-REF-00805 provides details on how utilities are distributed through the telescope. GMT Utility Budget GMT-REF-00366 provides the calculations for all allocations.
Many of the electrical requirements in this and following utilities related sections are planned to be removed from this GMT Observatory Architecture Document. Most of the requirements listed here are planned to be contained in next revision of the GMT Electrical Power Systems document GMT-REF-00019. The GMT Electrical Power Systems document is intended to contain all level 3 electrical requirements and will be an applicable document to this GMT Observatory Architecture Document. Similarly, the GMT Reference for Regulations, Codes and Standards document GMT-REF-00229 is intended to be updated and become an applicable document. GMT-REF-00229 references many standards necessary for telescope operation but needs review for the scope of what standards must be met and what can be relaxed.

5.8.1 Utility Estimations, Allocations, and Limits

A margin strategy applies to assign utility allocations to systems of varying maturity levels. Initially, Utility Estimations are recorded in the Utility Budget GMT-REF-00366 for each component of a system based on report of subsystem design. In most applications, a 25% maturity margin is added to each of the utility estimations to produce the Subsystem Allocation maintained by the system lead. Simultaneity and Diversity factors are applied to the allocation through wraps and manifolds enabling the reduction of the total allocation. Then wraps and manifolds are designed to accommodate an additional 10% Systems Engineering Reserve. Manifolds are built with the next higher fitting on all outputs (which accommodates 2X the flow) and then each output has a reducer installed to meet the design flow rate. This Accommodation Factor enables the SE reserve to be applied without the need to redesign and build manifolds. Routing and cable ways are also required to have spare unoccupied space. Should a Subsystem's allocation be exhausted, any additional allocation must be formally requested from Systems Engineering to evaluate the impact and make a final decision.

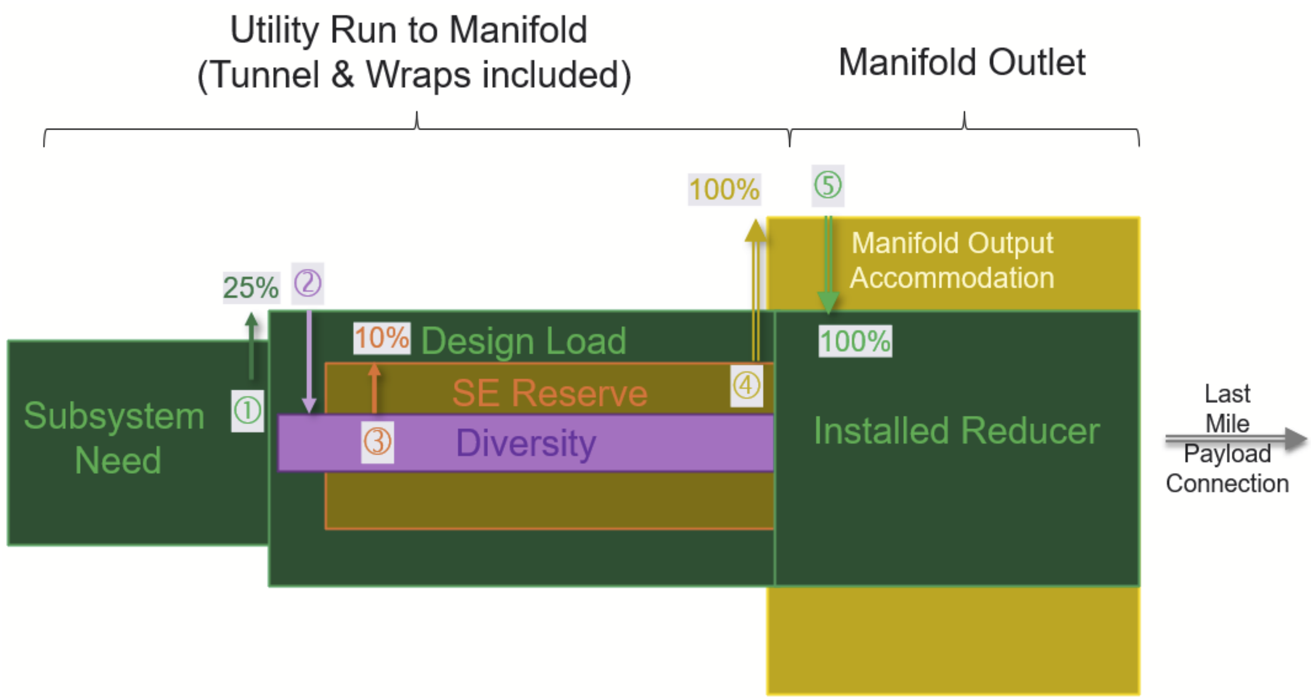

Figure 5-1: Utility Margin Allocation Strategy

5.8.2 Power and Grounding

Commercial power is provided to GMT by overhead 23kV power line from the nearest interconnected central system substation. The infrastructure shall include a central backup and conditioning power system, to provide uninterrupted and conditioned power to the observatory at all times.

REQ-L3-OAD-37590: Commercial Electrical Power - Capacity

The commercial electrical power connection shall enable power distribution to the summit, SS1, and SS2 at 23 kV TBC.

Rationale: The capacity of power is based on the GMT electrical power budget, GMT-REF-00366, and summarized in Table [ID 37722].

REQ-L3-OAD-37593: Commercial Electrical Power - Voltage

The commercial electrical power connection shall enable power distribution to the summit, SS1, and SS2 at 23 KV TBC.

Rationale: All sites on the GMT summit require connection to electrical service.

REQ-L3-OAD-37596: Commercial Power Type

380V 3-phase and 220V single-phase power at 50 Hz shall be provided to all support/summit facilities that require electrical power.

Rationale: The grid tied power is the most cost-effective way of providing power for the site.

REQ-L3-OAD-37602: Central Backup and Conditioning Power System

The GMT site infrastructure shall provide conditioned electrical backup power.

Rationale: Safe operation of the site requires that electric power remain available when commercial power is lost.

REQ-L3-OAD-37605: Central Backup Electrical Power System - Capacity

The central backup electrical power system shall provide a capacity of at least 2.9 MW TBC.

Rationale: The backup power system must be able to operate the entire observatory, but without full capability. The capacity value is based on the GMT electrical power budget, GMT-REF-00366, and summarized in Table [ID 37722].

REQ-L3-OAD-37611: Power Factor

The GMT shall condition the load such that the power factor at the pole 0 is no less than 0.93.

Rationale: As required by Chilean regulation (Norma Tecnica De Seguridad Y Calidad de Servicio 01/2016), a higher power factor reduces reactive power which is not usable, is often taxed, and can lead to instability in the supplied power.

REQ-L3-OAD-37614: Backup Power Generation

Site Infrastructure shall provide backup power generation that reach full capacity within 10 seconds TBR of loss of normal power.

Rationale: NFPA 70 (NEC) Section 110: Standards for Emergency and Stand-by Generators detail three ratings for power restoration in table 4.1(b):

- Type U (Uninterruptable)
- Type 10 (10 sec)
- Type 60 (60 sec)
- Type 120 (120 sec)
- Type M (Manual)

For any generator serving emergency lighting, the load must be picked up by the generator within 10 seconds. See section 7.9.1.2 of the Life Safety Code. Type 10 generators are a quality standard in generators that has been set for many years.

Additional backup power NFPA 70 (NEC) information can be found at 700.12 Emergency Systems and 701.11 Legally Required Standby Systems for regular installations. Hospital installations are found at 517.31 Emergency System and 517.42 Automatic Connection to Life Safety Branch.

REQ-L3-OAD-37620: Backup Power Generation Capacity/Autonomy

In the absence of commercial power, the site infrastructure provided backup power system shall be capable of automatically providing power to continue normal science operations for a minimum of 7 days.

Rationale: During any power outage, telescope science operations, including the capability to secure the telescope for weather conditions, should remain active. This includes power for Enclosure, Summit Utility Building, Exhaust Fans, Mount, Instruments, etc. See NFPA 70 (NEC) Section 110 for more details on automatic transfers.

REQ-L3-OAD-37626: Diesel Fuel

Site Infrastructure shall provide fuel to support emergency power.

Rationale: The summit has storage for fuel tanks. Fuel can support backup power generation, and other heavy equipment to conduct operations on the site.

REQ-L3-OAD-37629: Power Quality Remote Monitor

Site Infrastructure shall provide means to monitor power quality remotely and locally.

Rationale: Power monitoring improves troubleshooting and allows for logging of power history data to understand and improve power trends.

5.8.2.1 Load Classifications

Electric loads are classified into two categories according to their sensitivity to power interruptions:

- Critical loads cannot tolerate any power interruptions
- Essential loads require continued operation with emergency power

Additionally, life-safety electrical equipment, such as emergency lighting, is supplied and operated independently of the systems classified above.

REQ-L3-OAD-37637: Uninterruptable Power Supply (UPS)

Site Infrastructure shall provide a UPS system capable of providing continuous 380V 3-phase and 220V single-phase uninterrupted power at 50 Hz power for critical loads at the moment of loss of commercial power to the moment when backup power is fully running.

Rationale: Critical loads on UPS will avoid interruption of science operations.

REQ-L3-OAD-37640: UPS Capability

The UPS system shall be capable of supplying science operation power for a period no greater than 50 seconds TBR before switching to fully running backup power.

Rationale: Maintaining science operations of the observatory is one of the primary goals of the UPS.

REQ-L3-OAD-37643: Uninterruptable Power Supply (UPS) Redundancy

The uninterruptible power supply shall have N+1 redundant capability.

Rationale: Redundancy in the design ensures that UPS is available even in the cases of servicing or failure of system components.

REQ-L3-OAD-37646: Observatory Critical Loads

Observatory critical equipment and electronics shall be connected to the Site Infrastructure provided UPS System.

Rationale: Critical loads are necessary for science operations.
Notes: Critical loads are intolerant to large voltage oscillations or affected by short power interruptions. These loads must be powered by UPS. The critical loads include:

- SWC (Computing equipment, Control equipment and electronics, IT equipment) (Clean)
  - Must include HVAC cooling for computer rooms (Noisy)
- Instruments, AGWS, NGSAO, (Clean)
- Cryo-Cooling compressors and cold head(s) equipment (TBD)
- Circulation pumps for cryo-cooling (Noisy)
- Clean Dry Compressed Air compressors (Noisy)
- M1/M2/M3 (Clean/pumps and actuators better suited for Noisy)

- ADC (Clean)
- HBS & Drives (Noisy)
- Laser system components / LTWS (Clean)
- Mirror Coating Operations (Clean/ Noisy)

To avoid excessive noise by heavy duty equipment having effect on sensitive electronics, Clean Loads are connected to the Clean Power circuit and Noisy loads are connected to the Noisy Power circuit. Each circuit can employ filtering strategies tailored to the particular loads.

REQ-L3-OAD-37653: Power Supply for Sensitive Loads

Site Infrastructure shall provide a dedicated and separate circuit of power to supply sensitive loads that require high quality power.

Rationale: A dedicated circuit for sensitive loads allows for supplemental power conditioning if required.

REQ-L3-OAD-37656: Power Supply for Noisy Loads

Site Infrastructure shall provide a dedicated circuit to supply Noisy loads.

Rationale: Non-sensitive loads (such as drives, and motors) have the tendency to produce current noise. The impedance of these supply lines will produce voltage disturbances. Connecting non-sensitive electrical loads to a power supply line that is a separate branch from the line connecting to sensitive electronics gives the flexibility to provide specific power quality adjustments via additional filtering, or similar.

REQ-L3-OAD-37659: Observatory Essential Loads

Observatory essential loads connected to 220V 1-phase power or 380V 3-phase power that shall automatically switch to backup power upon loss of commercial power.

Rationale: Essential loads are those necessary for science operations not needed continuously. These are systems that can shut down when the commercial power is interrupted, but need to be restored after the emergency backup generators come online.

- Coolant pumps that are not supplying cooling to critical loads
- Compressed air that is not in service to critical loads
- Non-control components for:
    - Enclosure mechanisms
    - Ventilation
    - Non-HBS or Drive components for the Mount
    - Environmental Monitoring facility

REQ-L3-OAD-37669: Observatory Power Recovery Time

Observatory essential loads shall be restored to an operational state in no greater than 10 minutes.

Rationale: Limiting recovery time minimizes downtime and allows for continued science operations.

5.8.2.2 Lightning Protection

5.8.2.3 Grounding

REQ-L3-OAD-37677: Ufer Ground

Concrete-encased electrodes shall be installed in the building footings and slabs per the NFPA 70 (NEC) to create an Ufer ground to be bonded to the building frames, perimeter ground ring, and ground rods.

Rationale: Ufer grounds are often used by the military to increase the ability to provide a ground reference.

REQ-L3-OAD-37680: Ground Enhancing Chemicals

If allowed by local regulations, the perimetral ground ring, as well as the ground rods, should be installed with the addition of ground enhancing chemicals to lower the ground resistance.

Rationale: Improving the ground conductivity benefits the electrical system ground reference.

REQ-L3-OAD-37683: Safety Ground

Site Infrastructure shall provide a low-inductance safety ground system bonded to structures and enclosures to all loads.

Rationale: A safety ground maximizes protection from lightning and faulty electrical equipment. Safety ground is installed per the NFPA 70 (NEC). See Figure 5-2 for conceptual illustration.

REQ-L3-OAD-37692: Maximum Ground Resistance for Safety Ground

The resistance between the safety ground and any other ground shall be less than 10 Ohms(DWC).

Rationale: Minimizing the resistance between loads helps to keep all grounds at the same potential.

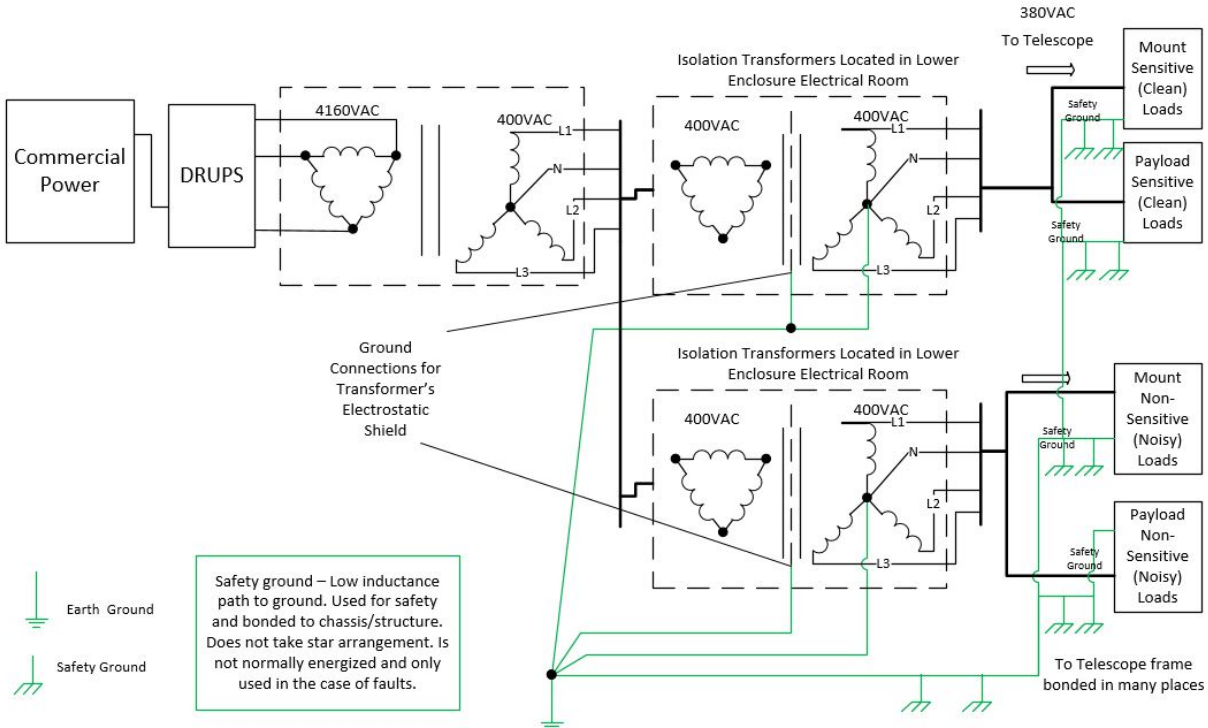

Figure 5-2: Conceptual Layout for Commercial, Backup, UPS Power and Isolated Grounds

5.8.2.4 Electromagnetic Compatibility

The telescope is a collection of cooperating subsystems, each of which can affect the operation of others if its electromagnetic emissions are excessively noisy. Requiring all equipment to meet normal FCC or CISPR emission standards reduces the risk of inter-system interference without increasing the cost of the telescope significantly. Variable frequency drive installations, due to their relatively high power and high potential for strong emissions, must be used in a carefully engineered installation to prevent interference with sensitive instrumentation on the telescope. Equipment should be designed to operate properly near commonly used communication systems and data links. Verification is negotiable.

REQ-L3-OAD-37698: EMC Emission Requirements for Unintentional Radiators

Unintentional radiators (digital devices with clocks greater than 9 kHz) shall meet the emission requirements of FCC Part 15 Class A or CISPR-11 and CISPR-22 standards.

Rationale: The observatory must impose methods to ensure electromagnetic harmony during telescope operation and maintenance. This requirement constraings unintentional radiators to reduce the chance that they interfere with other equipment. Referenced standards govern typical commercial equipment.
Notes: Commercial equipment containing CE or FCC markings may not require additional testing.

REQ-L3-OAD-37701: EMC Emission Requirements for Intentional Radiators

Intentional radiators, such as wireless access points, Bluetooth devices, and other such devices, shall comply with FCC part 15 and part 18, or CISPR-11 and CISPR-22 standards.

Rationale: The observatory must impose methods to ensure electromagnetic harmony during telescope operation and maintenance. This requirement constrains intentional radiators to ensure that their emissions are within a level that neighboring equipment should be capable of tolerating. Referenced standards govern typical commercial equipment.
Notes: Commercial equipment containing CE or FCC markings may not require additional testing.

REQ-L3-OAD-37704: EMC Emission Requirements for Power Drives

Due to the increased risk of EMI from variable frequency drives, the installation of variable frequency drives shall be designed to meet the IEC 61800-3 standard for emissions.

Rationale: The observatory must impose methods to ensure electromagnetic harmony during telescope operation and maintenance. This requirement constrains variable frequency drives to ensure that their emmissions are within a level that neighboring equipment should be capable of tolerating. Motor drives were identified as an EMI risk, and this is the relevant international standard for limiting their emissions.
Notes: Guidance for compliant installations is available from drive manufacturers. Verification by design is allowable by following manufacturer installation/design guidelines.

REQ-L3-OAD-37707: EMC Susceptibility Requirements to Unintentional Radiators

Electronic equipment installed on the GMT shall be designed to be compatible with equipment that meets FCC Part 15 Class A or CISPR-11/22 emission standards.

Rationale: The electrical environment at the telescope is expected to contain variable frequency drives, switching power supplies, and other electrically noisy devices. Telescope Controls and Instruments must cope with an industrial electrical environment containing variable frequency drives, switching power supplies, and other electrically noisy devices.
Notes: Commercial equipment containing CE or FCC markings may not require additional testing.

REQ-L3-OAD-37711: EMC Susceptibility Requirements to Intentional Radiators

Electronic equipment installed on the GMT shall be compatible with VHF/UHF radios up to 5W radiating power, Cell phones, and WIFI communications transmitting at a distance of 1 meter, which comply with FCC part 15 and part 18, or CISPR-11 and CISPR-22 standards.

Rationale: It is expected that equipment on the telescope will be exposed to RF fields from intentional radiators such as VHF radios, UHF radios, Cell phones, and WIFI communications.
Notes: Safety and performance critical equipment such as controls and instrumentation must be tested by the supplier or GMTO to verify that it functions properly in the presence of these emitters.

REQ-L3-OAD-37715: ESD Sensitivity

Electronic equipment installed on the GMT shall pass IEC 61000-4-2 Level 2 standards, with the exception of equipment marked as ESD (Electrostatic Discharge) sensitive, accompanied by documentation detailing proper handling procedures.

Rationale: The observatory must impose methods to ensure electromagnetic harmony during telescope operation and maintenance. This requirement sets the standard for ESD sensitivity for all electronic equipment at the observatory.ESD was identified as a hazard to equipment, and this is the relevant international standard governing immunity.

5.8.3 Water

5.8.3.1 Water Treatment and Distribution System

The site infrastructure includes a short pipeline to connect to the LCO water system at the LCO water tank (located just North of the GMT summit site). The site infrastructure includes water systems to distribute domestic and fire water to the summit and both support sites. The domestic and fire water systems include a water treatment system to monitor and control water quality.

REQ-L3-OAD-38384: Water Systems

The site infrastructure shall provide a water system interface to external water facilities to provide no greater than 128 m^3/day of water resources for operations for potable water and fire water.

Rationale: Water systems are required to conduct operations on the site. As detailed in the documents GMT Water System Concept of Operations and GMT Site Water Tanks BOD, water comes from Las Campanas Observatory (LCO) tank, filled with water that comes from two wells each capable of delivering a maximum amount of water of 20,000 m3/year each. LCO has two additional wells ready to operate that could provide 40,000 m3/year of water, but their use has not been approved by the Chilean authorities. Since GMT is a remote site and access to it could be affected by adverse environmental conditions and seismic activity, impeding the prompt delivery of water by truck or the delivery of parts needed to repair it, the GMT Water system shall consider a potable water reserve stored in tanks that would last 3 days while SS2 is at its peak occupancy.

5.8.3.2 Waste-Water Treatment Systems

The site infrastructure includes individual domestic waste-water plumbing and treatment systems for the summit and both support sites. The treatment plants will treat domestic waste-water to quality levels that allow for surface discharge of treated water according to Chilean standards. The waste-water treatment systems will only capture and treat human and kitchen waste.
Chemical waste water generated at the summit and SS1 will be captured and stored in holding tanks, which will be periodically drained and disposed of by vendors certified for the removal, treatment, and

disposal of chemical waste products. The chemical waste holding tanks will be included with the associated buildings, rather than with the site infrastructure.

REQ-L3-OAD-38393: Domestic Waste Water Treatment Systems - Standards

The domestic waste water treatment systems for all site facilities shall treat domestic waste water to a level that allows surface discharge according to Norma Chilena code standards.

Rationale: For safe and hygienic treatment of domestic waste water.

5.8.4 Utilities infrastructure

REQ-L3-OAD-38413: Standard Electronics Cabinets (SECs) Design

The GMT shall provide the design for SECs and their required hardware.

Rationale: SECs must be compatible with the cooling system of the GMT and be validated to remove a quantified amount of heat.
Notes: The requirements for SEC Providers are described in the SEC Providers DRD GMT-REQ-01280. User requirements reside in the SEC User DRD GMT-REQ-01454. The SEC to payload ICD is GMT-ICD-01455. A description of the SEC design is detailed in the SEC Design Concept GMT-DOC-01337. The Electronic Standards document GMT-REF-00191 contains additional SEC electrical design information.

REQ-L3-OAD-38417: System Procurement of Standard Electronics Cabinets (SECs)

Systems shall provide their associated SECs based off the GMT design.

Rationale: Systems are responsible for purchasing the SECs they use. The quantity of SECs reserved for each system and layout in the SEC Layout Drawing GMT-CAD-175159. Utility allocations to the SECs are detailed in Telescope Utilities Budget GMT-DOC-00366. The Telescope one-line drawing GMT-REF-00805 also details the high-level routing of utilities to SECs.

REQ-L3-OAD-38420: Standard Electronics Cabinets (SECs) Contents

Electrical hardware excluding cabling on the telescope shall be contained within Standard Electronics Cabinets (SECs), unless an exception is granted by systems engineering.

Rationale: Standardizing electronics cabinets will improve maintenance efficiency, promote quality control, and reduce spares count.

REQ-L3-OAD-38423: Non-Standard Electronics Cabinets (NSECs) Contents

Granted exceptions for electrical equipment incompatible with an SEC shall be contained in Non-Standard Electronics Cabinets (NSECs to be reviewed by GMT Systems Engineering).

Rationale: This is to allow the installation of equipment that cannot utilize the standard electronics cabinets. Derived requirement.
Notes: Standard cabinets will have limitations on space, power, and cooling capacities. The non-standard electronics cabinets are allocated in the Telescope Utilities Budget GMT-DOC-00366.

REQ-L3-OAD-38427: Utility and General Maintenance Support Facilities

The GMT shall provide facilities at the support sites 1 & 2 for utility distribution and general maintenance.

Rationale: This is required for interfacing to commercial power/network providers, distributing the services to support and summit sites, and providing general maintenance support for non-telescope equipment at a location away from the telescope.
Notes: Utility distribution includes main power distribution, backup generators, and network distribution. General maintenance includes mechanical and auto shops, and fuel storage for vehicles and generators.

REQ-L3-OAD-38431: Utilities Allocations

The Instruments usage of utilities shall not exceed the allocated quantities as identified in the Utilities Budget GMT-DOC-00366.

Rationale: The equipment and piping designed to distribute the common utilities to the instruments were designed for the budgeted capacities in GMT-DOC-00366.

REQ-L3-OAD-38438: Cable Trays

The Mount shall provide cable trays to allow efficient and safe installation of instruments and equipment.

Rationale: Cable trays allow instruments and equipment to be installed efficiently and will improve reliability by protecting their service lines.
Notes: GMTO will provide the cable trays for use by the instrumentation. All exceptional cases must be explicitly approved by GMTO during instrumentation design.

REQ-L3-OAD-38442: Utility Panels

The Mount shall provide utility panels to allow systems to connect to provided utilities.

Rationale: See Utility One-Line Diagram GMT-REF-00805 for planned utility panels and GMT-CAD-175159 for proposed locations on the mount.

5.9 Transport and Storage

REQ-L3-OAD-38446: Storage and Transporting Conditions

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

Rationale: This requirement is to ensure that equipment is protected when shipped or stored.
Notes: Direct flowdown from ORD.

REQ-L3-OAD-38450: Base Facility Warehouse

The GMT shall provide warehouse space at the Base Facility for the transshipment of material and supplies to the summit.

Rationale: This is required to support GMTO operations at Chile.
Notes: Warehouse space will be provided for supplies and small equipment. Major equipment will be delivered directly to the summit.

REQ-L3-OAD-38454: Equipment and Supply Storage

The GMT shall provide dry storage space at the observatory for the temporary storage of primary mirror cells and general storage of supplies and equipment.

Rationale: This is required for on-site storage of mirror cells prior to assembly as well as general storage for equipment and supplies.

REQ-L3-OAD-38457: Construction Lay-down Areas

The GMT shall identify lay-down areas for construction that will not inhibit access to the systems under construction.

Rationale: This is required for construction.

5.10 Interlock Safety System

REQ-L3-OAD-38461: Interlock and Safety System

The GMT shall provide an Interlock and Safety System.

Rationale: Required to maintain robust personnel and equipment safety even in the event of other system failures.
Notes: The ISS will operate on its own network, to make it robust against outages of the other networks.

REQ-L3-OAD-96039: Interlock and Safety System - IEC Standard

The GMT Interlock and Safety System design, development and implementation shall be performed in accordance with IEC 62061 guidelines.

Rationale: Industry standards on safety are required for the design, development and implementation of functional safety systems. The ISS Safety Related Control Functions, Safety Integrity and Safety functional requirements must be determined from the Hazard Analysis where the ISS has been identified as a control measure.
Notes: GMT requires the use of IEC 62061 beyond human safety to cover hazards that affect machine safety. The use of ISO 13849-1 is acceptable in the cases where safety-related components are not based on electrical or electronic systems.

REQ-L3-OAD-96040: Interlock and Safety System - SWC Standard

The GMT Interlock and Safety System design shall comply with GMT Software and Control Standards (GMT-REF-00029).

Rationale: The GMT Software and Control Standards describes the architecture of the Interlock and Safety System and requirements for the interfaces to the Observatory Control System and the controlled subsystem.

REQ-L3-OAD-38469: Hazard Analysis

GMT Interlock and Safety System safety-related control functions shall be determined from the outcome of a hazard analysis validated by GMT.

Rationale: IEC 62061 indicates that the first step in functional safety management is to perform a risk assessment of the machine to identify the hazards.
Notes: GMT System Safety Management Plan (GMT-DOC-00347) describes the process for developing a hazard analysis.

REQ-L3-OAD-38465: ISS PLCs

The GMT Interlock and Safety System shall use safety-rated Programmable Logic Controllers (PLCs) of no less than Safety Integrity Level 3 (SIL 3) rating.

Rationale: The highest SIL rating defined in the IEC 62061 standard is SIL 3. In order for safety-related control functions implemented by the ISS to reach SIL 3, the safety controller needs to be SIL 3.

REQ-L3-OAD-38473: Local Interlock and Safety System

The GMT Interlock and Safety System shall include local Interlock and Safety Systems that are responsible for the functional safety within each controlled subsystem.

Rationale: Controlled Subsystems should autonomously protect themselves from local hazards.
Notes: Local Interlock and Safety Systems are embedded in the controlled subsystems and its development is the responsibility of the controlled subsystem.

REQ-L3-OAD-38476: Global Interlock and Safety System

The GMT Interlock and Safety System shall include a Global Interlock and Safety System that is responsible for system-level functional safety.

Rationale: Hazards that involve all controlled subsystem or more than one controlled subsystem must be coordinated outside the controlled subsystem local ISS.

REQ-L3-OAD-96041: ISS Safe State on Failure

The GMT Interlock and Safety System shall in case of self-failure put the controlled subsystem in a safe state.

Rationale: In case of self-failure, the Interlock and Safety system is no longer available to detect and react to a hazard that could affect a controlled subsystem.
Notes: This includes software, hardware and safety communication failures. Safe state corresponds to a non-energized state of the outputs of the safety-related control functions associated to the controlled subsystem, the behavior of the controlled subsystem under in this safe state should be identified by the controlled subsystem hazard analysis and captured in the design of the Interlock and Safety System.

REQ-L3-OAD-96042: ISS Recovery Functionality

The GMT Interlock and Safety System shall include recovery functionality to recover a controlled subsystem from the actuation of a safety-related control function.

Rationale: A recovery functionality is necessary to remove the affected subsystem from an interlocked state (i.e. move a mechanism away from an over-travel limit). This recovery functionality will mute the safety-related control function only for a period. A hazard assessment is required to include this functionality.
Notes: The need of this function is determined with the safety-related control function requirements, and is not required to be included in every controlled subsystem if not needed.

REQ-L3-OAD-38498: ISS Emergency Stops (E-Stop)

The GMT Interlock and Safety System shall implement a system-wide Emergency Stop function that safely halts all mechanism movement in the Observatory.

Rationale: An emergency stop is an action that affects more than one controlled subsystem. The detection of emergency stop presses and propagation of emergency stop signals should be handled by a safety-rated, reliable system.
Notes: An overall hazard analysis will determine the optimal location of E-stop buttons.

REQ-L3-OAD-38484: ISS Indications and Alarms

The GMT Interlock and Safety System shall provide an audible and visible annunciator system for impending hazards or possible residual risks.

Rationale: An audible and visible indicator informs operators and maintenance personnel of an impending or residual risks of safety-critical activity. Design of the ISS will identify safety-critical activities.
Notes: The indicators should be placed at a safe distance from the hazard and in a visible location.

REQ-L3-OAD-96043: ISS Status Monitoring

The GMT Interlock and Safety System shall monitor and record continuous status information of all safety-related control functions.

Rationale: Continuous status information is recorded and maintained for both real-time status display as well as historic data needed for troubleshooting and preventative maintenance.

REQ-L3-OAD-96044: ISS Status Archive

The GMT Interlock and Safety System shall store all status information in the Engineering Archive.

Rationale: Historic information on the ISS status is useful during telescope operation, troubleshooting and preventive maintenance.

REQ-L3-OAD-38488: ISS Health and Status Display

The GMT Interlock and Safety System shall provide a health and status summary display.

Rationale: The summary display is a useful tool to inform night time operators and maintenance personnel the status of active safety-related control functions that could prevent the operation of controlled subsystems.

REQ-L3-OAD-96045: ISS Restricted Scope

The GMT Interlock and Safety System shall be limited to safety-related control functionality.

Rationale: The operation of the ISS is restricted to the implementation and control of safety-related control functions that will mitigate hazards to equipment and/or personnel.
Notes: The subsystem's Device Control System (DCS) is responsible for the control functions under normal operating conditions.

REQ-L3-OAD-96046: ISS Life Cycle

The GMT Interlock and Safety System life cycle shall be independent of the life cycle of Device Control Systems.

Rationale: The frequency of updates and changes in hardware and software of a Device Control System is much higher compared to the Interlock and Safety System. The ISS, as a safety system, is critical in the operation of the observatory and any change requires rigorous testing. To ensure the integrity of the safety system, while minimizing the effort required after DCS upgrades, the Interlock and Safety system needs to be as independent as possible from the Device Control Systems.
Notes: Changes in the interface between the ISS and DCS will require full revalidation of the safety system.

REQ-L3-OAD-96078: ISS Interface to the OCS

The GMT Interlock and Safety System shall interface with the Observatory Control System (OCS) for monitoring and archiving the Interlock and Safety System status.

Rationale: The Interlock and Safety System interfaces to the Observatory Control System to use the OCS core services and observatory data systems for archiving and visualization.

Notes: Interfaces are described in more details in the Software and Controls Standards document (GMT-REF-00029)

REQ-L3-OAD-96081: Global ISS Interface to controlled subsystems

The GMT Global Interlock and Safety System shall interface with the local Interlock and Safety Systems within each controlled subsystem.

Rationale: Architectural decision balancing roles of global and local functional safety.
Notes: Interfaces are described in more details in the Software and Controls Standards document (GMT-REF-00029)

6 Environmental, Health, and Safety

The GMT Design Safety Requirements (GMT-DOC-01578) describes compliance-based standards, policies, and procedures that GMT will follow.

REQ-L3-OAD-38510: Emergency Preparedness

The GMT shall provide a plan for emergency response consistent with OSHA 29 CFR 1910.38.

Rationale: Direct flowdown from ORD; OSHA standard.

REQ-L3-OAD-38513: Means of Egress

The Mount shall design for means of egress consistent with NFPA 101 and OSHA 29 CFR 1910.36–37.

Rationale: Mitigation determined by System Level Hazard analysis.

REQ-L3-OAD-38516: Emergency Lighting

Each subsystem shall design for emergency lighting consistent with NFPA 101.

Rationale: NFPA standard.

REQ-L3-OAD-38519: Construction Fire Safety

Fire safety during construction shall be consistent with the requirements of the International Building Code (IBC) and NFPA 241.

Rationale: IBC and NFPA construction standards.

REQ-L3-OAD-38522: Fire Protection

Fire protection shall be consistent with NFPA 101 based on an unusual structure occupancy type.

Rationale: NFPA standard. The content hazard classification should be deemed to be low hazard unless otherwise classified by local authority.

REQ-L3-OAD-38525: Fire Control

The GMT shall provide a plan for fire control that adheres to OSHA regulations 1910, Subpart L and 1910.39.

Rationale: OSHA regulations.
Notes: This covers hardware, including fire suppression devices, fire and smoke detection devices, and fire alarms, as well as personnel training.

REQ-L3-OAD-38529: Personal Protective Equipment

The GMT shall provide personal protective equipment for hazardous work situations that adheres to OSHA regulations 1910, Subpart I.

Rationale: OSHA regulations.
Notes: This includes the protective equipment as well as training in its use.

REQ-L3-OAD-38533: Electrical General Safety

The GMT shall provide a plan for electrical safety that adheres to OSHA 1910.303 for general electrical safety requirements.

Rationale: OSHA regulations.

REQ-L3-OAD-38536: Chemical Management

The GMT shall provide a plan for chemical management that adheres to OSHA 29 CPR 1910 Subpart H and 1910.200.

Rationale: OSHA regulation.

REQ-L3-OAD-38539: Safety Facilities

The GMT shall provide safety facilities for hazardous work situations and general environmental controls.

Rationale: OSHA standards.
Notes: This includes safety color code for marking physical hazards (OSHA 29 CPPT 1910.144 and 145); Permit-required confined spaces (OSHA 29 CPR 1910.146); walking-working surfaces (OSHA 29 CPR Subpart D); and materials handling and storage (OSHA 29 CPR 1910 Subpart N).

REQ-L3-OAD-38543: Equipment Safety, Lock-out/Tag-out

The GMT shall provide a lock-out/tag-out plan and appropriate procedures that adhere to OSHA 29 CPR 1910.147.

Rationale: OSHA standard.

REQ-L3-OAD-38546: Laser Control

The GMT shall provide a laser control and safety system that adheres to ANSI Z136.1.

Rationale: ANSI standard.

REQ-L3-OAD-38549: Electrical Safety

The GMT shall provide a plan and equipment for safe work on electrical systems that adheres to OSHA regulations 1910, Subpart S.

Rationale: OSHA regulation.

REQ-L3-OAD-38552: Mobile Equipment

The GMT shall provide procedures for safe operational of heavy mobile equipment that adheres to OSHA CFR 1910, Subpart F (powered platforms, manlifts, and vehicle-mounted work platforms), 1910.178 (powered industrial trucks), 1910.179 (overhead and gantry cranes), and 1910.194 (slings).

Rationale: OSHA regulations.

REQ-L3-OAD-38555: Industrial Hygiene

The GMT shall provide a plan for industrial hygiene that adheres to OSHA 29 CFR 1910, Subpart G.

Rationale: OSHA regulation.

REQ-L3-OAD-38558: Ergonomics

The GMT shall provide a guide for ergonomics.

Rationale: Best practices.

REQ-L3-OAD-38561: Safety Training

The GMT shall provide appropriate safety training for hazardous work situations and proper use of personal protective equipment.

Rationale: OSHA regulation.

REQ-L3-OAD-38564: Medical Services

The GMT shall provide medical services at the site to treat medical problems and emergencies that adhere to OSHA 29 CFR 1910 Subpart K.

Rationale: OSHA regulations. The site is isolated.
Notes: This includes a paramedic, ambulance and driver, as well as medical treatment kits in each building to treat minor medical problems. This also includes training in use of medical equipment and emergency response for the entire site staff.

7 Applicable Standards and Regulations

REQ-L3-OAD-26332: Building, Occupational, and Safety Code Compliance

The GMT shall be constructed in accordance with the building, occupational, and safety codes specified TBD.

Rationale: The standard guides the construction of secure and safe buildings, with lower risk and cost. It ensures the compatibility and integration of system.

REQ-L3-OAD-26335: Computer Aided Design Standards

The GMT shall comply with the GMT Computer Aided Design Standards (GMT-SWC-REF-00149).

Rationale: The CAD standards ensure the common formatting and treatment of all CAD products across the project.
Notes: This includes all mechanical and electrical drawings or other drawings/models that are produced for GMT.

REQ-L3-OAD-26339: Software and Controls Standards

The GMT shall comply with the GMT Software and Controls Standards (GMT-REF-00029).

Rationale: This requirement is derived from the desire to maximize observing efficiency. Standards are essential in order to achieve an integrated, maintainable and affordable control system. Defining software standards will reduce the number of products to support thereby optimizing staff efficiency. This requirement also guarantees the maintainability and robust integration of all the software subsystems.

Notes: Software standards will include, but is not limited to, operating systems, programming languages, databases, and distributed protocols. Hardware standards will include, but is not limited to, CPU architectures, PLCs, network adapters, field bus couplers, and power supplies.

REQ-L3-OAD-26343: Electronics Standards

The GMT shall comply with the GMT Electronics Standards (GMT-SE-REF-00191).

Rationale: The Electronic Standards ensure commonality of components to promote efficiency and maintainability.
Notes: Electronics standards will include cabling, connectors, cabinets and electronic equipment.

REQ-L3-OAD-26347: Power Quality

The Observatory subsystems shall comply with industry power quality standards as defined in TBD.

Rationale: The Electrical standards supplement local codes and standards and specifies some design choices. The intent is providing guidance for good energy efficiency, lower cost with power lost and operational performance.

REQ-L3-OAD-26350: Electromagnetic Interference (EMI) Standards

The Observatory subsystems shall comply with industry EMI standards for emissions and immunity as defined in TBD.

Rationale: The EMI standards ensure the compatibility and integration between different devices and equipment. It guarantees safe operation and design for Reliability. GMT design configuration that ensures interference-free operation; and clear concepts and doctrines that maximize operational effectiveness.

8 Throughput Budget

The table below contains throughput values averaged over 50 nm bandpass windows. The wavelength column contains the starting point of the integration. Cells with 0% denote where the particular configuration is not sensitive to light over that specific wavelength band.

Table 8-1: Throughput Budget through 50 nm Windows

Wavelength (microns)	DGNF Throughput	DGWF Throughput	FP Throughput
0.32	83.7%	0.0%	38.4%
0.37	83.6%	57.5%	68.1%
0.42	83.2%	66.9%	74.5%
0.47	82.6%	68.4%	76.6%
0.52	82.0%	70.2%	77.3%
0.57	81.3%	69.9%	77.5%
0.62	80.3%	68.1%	77.1%
0.67	79.0%	65.6%	76.3%
0.72	77.2%	62.8%	75.0%
0.77	74.1%	59.5%	72.2%
0.82	73.3%	58.2%	71.3%
0.87	76.6%	60.4%	74.8%
0.92	82.4%	64.6%	80.4%
0.97	86.0%	62.9%	84.2%

1.02	87.9%	5.9%	86.2%
1.07	89.4%	0.0%	87.6%
1.12	90.5%	0.0%	88.8%
1.17	91.4%	0.0%	89.8%
1.22	92.0%	0.0%	90.5%
1.27	92.4%	0.0%	91.0%
1.32	92.7%	0.0%	91.3%
1.37	92.8%	0.0%	91.6%
1.42	92.9%	0.0%	91.6%
1.47	92.9%	0.0%	91.7%
1.52	93.0%	0.0%	91.7%
1.57	93.0%	0.0%	91.8%
1.62	93.1%	0.0%	91.8%
1.67	93.1%	0.0%	91.8%
1.72	93.2%	0.0%	91.9%
1.77	93.3%	0.0%	92.0%
1.82	93.4%	0.0%	92.2%
1.87	93.5%	0.0%	92.3%
1.92	93.6%	0.0%	92.5%
1.97	93.7%	0.0%	92.6%
2.02	93.8%	0.0%	92.6%
2.07	93.8%	0.0%	92.7%
2.12	93.9%	0.0%	92.8%
2.17	93.9%	0.0%	92.8%
2.22	94.0%	0.0%	92.8%
2.27	94.0%	0.0%	92.9%
2.32	94.0%	0.0%	92.9%
2.37	94.1%	0.0%	92.9%
2.42	94.1%	0.0%	92.9%
2.47	94.1%	0.0%	93.0%
2.52	94.1%	0.0%	93.0%
2.57	94.1%	0.0%	93.0%
2.62	94.1%	0.0%	93.0%
2.67	94.1%	0.0%	93.0%
2.72	94.1%	0.0%	93.0%
2.77	94.1%	0.0%	93.0%
2.82	94.1%	0.0%	93.0%
2.87	94.1%	0.0%	93.0%
2.92	94.1%	0.0%	93.0%
2.97	94.1%	0.0%	93.0%
3.02	94.1%	0.0%	93.0%
3.07	94.1%	0.0%	93.0%
3.12	94.1%	0.0%	93.0%
3.17	94.1%	0.0%	93.0%
3.22	94.1%	0.0%	93.0%

3.27	94.1%	0.0%	93.0%
3.32	94.2%	0.0%	93.0%
3.37	94.2%	0.0%	93.1%
3.42	94.2%	0.0%	93.1%
3.47	94.2%	0.0%	93.1%
3.52	94.2%	0.0%	93.1%
3.57	94.3%	0.0%	93.1%
3.62	94.3%	0.0%	93.2%
3.67	94.3%	0.0%	93.2%
3.72	94.3%	0.0%	93.2%
3.77	94.4%	0.0%	93.2%
3.82	94.4%	0.0%	93.3%
3.87	94.4%	0.0%	93.3%
3.92	94.4%	0.0%	93.3%
3.97	94.5%	0.0%	93.3%
4.02	94.5%	0.0%	93.4%
4.07	94.5%	0.0%	93.4%
4.12	94.5%	0.0%	93.4%
4.17	94.6%	0.0%	93.4%
4.22	94.6%	0.0%	93.5%
4.27	94.6%	0.0%	93.5%
4.32	94.6%	0.0%	93.5%
4.37	94.7%	0.0%	93.5%
4.42	94.7%	0.0%	93.5%
4.47	94.7%	0.0%	93.6%
4.52	94.7%	0.0%	93.6%
4.57	94.7%	0.0%	93.6%
4.62	94.8%	0.0%	93.6%
4.67	94.8%	0.0%	93.6%
4.72	94.8%	0.0%	93.6%
4.77	94.8%	0.0%	93.7%
4.82	94.8%	0.0%	93.7%
4.87	94.8%	0.0%	93.7%
4.92	94.9%	0.0%	93.7%
4.97	94.9%	0.0%	93.7%
5.02	94.9%	0.0%	93.7%
5.07	94.9%	0.0%	93.8%
5.12	94.9%	0.0%	93.8%
5.17	94.9%	0.0%	93.8%
5.22	94.9%	0.0%	93.8%
5.27	94.9%	0.0%	93.8%
5.32	94.9%	0.0%	93.8%
5.37	95.0%	0.0%	93.8%
5.42	95.0%	0.0%	93.8%
5.47	95.0%	0.0%	93.8%

5.52	95.0%	0.0%	93.8%
5.57	95.0%	0.0%	93.9%
5.62	95.0%	0.0%	93.9%
5.67	95.0%	0.0%	93.9%
5.72	95.0%	0.0%	93.9%
5.77	95.0%	0.0%	93.9%
5.82	95.0%	0.0%	93.9%
5.87	95.0%	0.0%	93.9%
5.92	95.1%	0.0%	93.9%
5.97	95.1%	0.0%	93.9%
6.02	95.1%	0.0%	93.9%
6.07	95.1%	0.0%	93.9%
6.12	95.1%	0.0%	93.9%
6.17	95.1%	0.0%	94.0%
6.22	95.1%	0.0%	94.0%
6.27	95.1%	0.0%	94.0%
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6.37	95.1%	0.0%	94.0%
6.42	95.1%	0.0%	94.0%
6.47	95.2%	0.0%	94.0%
6.52	95.2%	0.0%	94.0%
6.57	95.2%	0.0%	94.0%
6.62	95.2%	0.0%	94.0%
6.67	95.2%	0.0%	94.0%
6.72	95.2%	0.0%	94.1%
6.77	95.2%	0.0%	94.1%
6.82	95.2%	0.0%	94.1%
6.87	95.2%	0.0%	94.1%
6.92	95.2%	0.0%	94.1%
6.97	95.3%	0.0%	94.1%
7.02	95.3%	0.0%	94.1%
7.07	95.3%	0.0%	94.1%
7.12	95.3%	0.0%	94.1%
7.17	95.3%	0.0%	94.2%
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7.57	95.4%	0.0%	94.2%
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13.52	95.5%	0.0%	94.3%
13.57	95.5%	0.0%	94.3%
13.62	95.5%	0.0%	94.3%
13.67	95.5%	0.0%	94.3%
13.72	95.5%	0.0%	94.3%
13.77	95.5%	0.0%	94.3%
13.82	95.5%	0.0%	94.3%
13.87	95.5%	0.0%	94.3%
13.92	95.5%	0.0%	94.3%
13.97	95.5%	0.0%	94.3%
14.02	95.5%	0.0%	94.3%
14.07	95.5%	0.0%	94.3%
14.12	95.5%	0.0%	94.3%
14.17	95.5%	0.0%	94.3%
14.22	95.5%	0.0%	94.3%
14.27	95.5%	0.0%	94.3%
14.32	95.5%	0.0%	94.3%
14.37	95.5%	0.0%	94.3%
14.42	95.5%	0.0%	94.3%
14.47	95.5%	0.0%	94.3%

14.52	95.5%	0.0%	94.3%
14.57	95.5%	0.0%	94.3%
14.62	95.5%	0.0%	94.3%
14.67	95.5%	0.0%	94.3%
14.72	95.5%	0.0%	94.3%
14.77	95.5%	0.0%	94.3%
14.82	95.5%	0.0%	94.3%
14.87	95.5%	0.0%	94.3%
14.92	95.5%	0.0%	94.3%
14.97	95.5%	0.0%	94.3%
15.02	95.5%	0.0%	94.3%
15.07	95.5%	0.0%	94.3%
15.12	95.5%	0.0%	94.3%
15.17	95.5%	0.0%	94.3%
15.22	95.5%	0.0%	94.3%
15.27	95.5%	0.0%	94.3%
15.32	95.5%	0.0%	94.3%
15.37	95.5%	0.0%	94.3%
15.42	95.5%	0.0%	94.3%
15.47	95.5%	0.0%	94.3%
15.52	95.5%	0.0%	94.3%
15.57	95.5%	0.0%	94.3%
15.62	95.5%	0.0%	94.3%
15.67	95.5%	0.0%	94.3%
15.72	95.5%	0.0%	94.3%
15.77	95.5%	0.0%	94.3%
15.82	95.5%	0.0%	94.3%
15.87	95.5%	0.0%	94.3%
15.92	95.5%	0.0%	94.3%
15.97	95.5%	0.0%	94.3%
16.02	95.5%	0.0%	94.3%
16.07	95.5%	0.0%	94.3%
16.12	95.5%	0.0%	94.3%
16.17	95.5%	0.0%	94.3%
16.22	95.5%	0.0%	94.3%
16.27	95.5%	0.0%	94.3%
16.32	95.5%	0.0%	94.3%
16.37	95.5%	0.0%	94.3%
16.42	95.5%	0.0%	94.3%
16.47	95.5%	0.0%	94.3%
16.52	95.4%	0.0%	94.3%
16.57	95.4%	0.0%	94.3%
16.62	95.4%	0.0%	94.3%
16.67	95.4%	0.0%	94.3%
16.72	95.4%	0.0%	94.3%

16.77	95.4%	0.0%	94.3%
16.82	95.4%	0.0%	94.3%
16.87	95.4%	0.0%	94.3%
16.92	95.4%	0.0%	94.3%
16.97	95.4%	0.0%	94.3%
17.02	95.4%	0.0%	94.3%
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17.47	95.4%	0.0%	94.3%
17.52	95.4%	0.0%	94.3%
17.57	95.4%	0.0%	94.3%
17.62	95.4%	0.0%	94.3%
17.67	95.4%	0.0%	94.3%
17.72	95.4%	0.0%	94.3%
17.77	95.5%	0.0%	94.3%
17.82	95.5%	0.0%	94.3%
17.87	95.5%	0.0%	94.3%
17.92	95.5%	0.0%	94.3%
17.97	95.5%	0.0%	94.3%
18.02	95.5%	0.0%	94.3%
18.07	95.5%	0.0%	94.3%
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18.77	95.5%	0.0%	94.3%
18.82	95.5%	0.0%	94.3%
18.87	95.5%	0.0%	94.3%
18.92	95.5%	0.0%	94.3%
18.97	95.5%	0.0%	94.3%

19.02	95.5%	0.0%	94.3%
19.07	95.5%	0.0%	94.3%
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22.82	95.5%	0.0%	94.3%
22.87	95.5%	0.0%	94.3%
22.92	95.5%	0.0%	94.3%
22.97	95.5%	0.0%	94.3%
23.02	95.5%	0.0%	94.3%
23.07	95.5%	0.0%	94.3%
23.12	95.5%	0.0%	94.3%
23.17	95.5%	0.0%	94.3%
23.22	95.5%	0.0%	94.3%
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23.37	95.5%	0.0%	94.3%
23.42	95.5%	0.0%	94.3%
23.47	95.5%	0.0%	94.3%

23.52	95.5%	0.0%	94.3%
23.57	95.5%	0.0%	94.3%
23.62	95.5%	0.0%	94.3%
23.67	95.5%	0.0%	94.3%
23.72	95.5%	0.0%	94.3%
23.77	95.5%	0.0%	94.3%
23.82	95.5%	0.0%	94.3%
23.87	95.5%	0.0%	94.3%
23.92	95.5%	0.0%	94.3%
23.97	95.5%	0.0%	94.3%
24.02	95.5%	0.0%	94.3%
24.07	95.5%	0.0%	94.3%
24.12	95.5%	0.0%	94.3%
24.17	95.5%	0.0%	94.3%
24.22	95.5%	0.0%	94.3%
24.27	95.5%	0.0%	94.3%
24.32	95.5%	0.0%	94.3%
24.37	95.5%	0.0%	94.3%
24.42	95.5%	0.0%	94.3%
24.47	95.5%	0.0%	94.3%
24.52	95.5%	0.0%	94.3%
24.57	95.5%	0.0%	94.3%
24.62	95.5%	0.0%	94.3%
24.67	95.5%	0.0%	94.3%
24.72	95.5%	0.0%	94.3%
24.77	95.5%	0.0%	94.3%
24.82	95.5%	0.0%	94.3%
24.87	95.5%	0.0%	94.3%
24.92	95.5%	0.0%	94.3%
24.97	57.3%	0.0%	56.6%