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)	G. Angeli/ B. Walls / J. Souza / A. Santana / B. Sitarski, A. Bouchez / B. Goodrich / A. Souza

				Logistics -> Move ORD and OAD into new template for export in DOORS. Underlying 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 4. Update for consistency with ISS Requirement	A. Bouchez/ R. Goodrich/ B. Sitarski/ A. Souza / M. Cox

				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.	

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 [ID 33672]: 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 [ID 33675]: 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)
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 [ID 33679]: Applicable Documents

Documen	Title	DocuShare Link

t Number		
GMT-DOC-03205	Concept of Operations	https://docushare.gmto.org/docushare/dsweb/Services/Document-58009
GMT-REF-00019 (To Be Updated)	GMT Electrical Power Systems	https://docushare.gmto.org/docushare/dsweb/Services/Document-7739
GMT-REF-00144	GMT Environmental Conditions document	https://docushare.gmto.org/docushare/dsweb/Services/Document-2646
GMT-REF-00229 (To Be Updated)	GMT Reference for Regulations, Codes and Standards	https://docushare.gmto.org/docushare/dsweb/Services/Document-7740
GMT-REF-00366 (To Be Updated)	GMT Telescope Utilities Allocation Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-57367
GMT-REF-00805	Telescope Utility One-Line Diagram	https://docushare.gmto.org/docushare/dsweb/Services/Document-57368
GMT-REF-03725	Spaces and Equipment Registry	https://docushare.gmto.org/docushare/dsweb/Services/Document-72199
GMT-REQ-03213	Science Requirements Document (SRD)	https://docushare.gmto.org/docushare/dsweb/Services/Document-57932
GMT-REQ-	Observatory Requirements	https://docushare.gmto.org/docushare/dsweb/Services/Document-57998

03214	Document (ORD)	
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://docushare.gmto.org/docushare/dsweb/Services/Document-14278

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 [ID 33683]: Referenced Documents

Document	Title	DocuShare Link

Number		
GMT-DOC-00128	GMT Site Master Plan (DRAFT)	https://docushare.gmto.org/docushare/dsweb/Services/Document-63574/
	NFPA-110	
GMT-AO-REF-00517	AOS Set Up Time Efficiency Performance Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-5948
GMT-AO-REF-00518	AOS IQ Error Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-5945
GMT-AO-REF-00519	AOS Flexure Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-10244
GMT-CAD-100708	Telescope Swept Volume	https://docushare.gmto.org/docushare/dsweb/Services/Document-9846
GMT-CAD-175159	Telescope Electronics Cabinet Envelope Layout	https://docushare.gmto.org/docushare/dsweb/Services/Document-57414
GMT-DOC-00010	GMT Optical Design	https://docushare.gmto.org/docushare/dsweb/Services/Document-4592
GMT-DOC-	Site-Specific	https://docushare.gmto.org/docushare/dsweb/Services/Document-20940

00127_A	Seismic Hazard Analysis (SSSHA) report	
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	TBD
GMT-DOC-01221	GMT Reliability, Availability, Maintainability, and Safety (RAMS) Plan	https://docushare.gmto.org/docushare/dsweb/Services/Document-48212
GMT-DOC-01244	GMT Fine Alignment and Phasing Plan	https://docushare.gmto.org/docushare/dsweb/Services/Document-38210
GMT-DOC-01337	GMT Standard Electronics Cabinet Design Concept	TBD
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/dsweb/Services/Document-48284
GMT-DOC-01584	GMT Metrics	https://docushare.gmto.org/docushare/dsweb/Services/Document-47810
GMT-DOC-01871	SRD to ORD Analysis	TBD
GMT-DOC-01901	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-EF-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	https://docushare.gmto.org/docushare/dsweb/Services/Document-2646

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	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	Standard Electronics Cabinet Requirements Document	TBD
GMT-REQ-01454	Standard Electronics Cabinet User Design Requireme	TBD

	nts Document	
GMT-SE-REF-00420	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.		http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1991PASP..103.1020R&data_type=PDF_HIGH&am

1991		p;whole_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 [ID 33688]: 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 [ID 33692]: 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 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. 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, LGS, WCCS, and AOTC.

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

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

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, and 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. 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.

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 GMT Observatory Control System (OCS) encompasses the software and hardware components necessary to control and monitor the GMT optical and electromechanical subsystems and to efficiently operate the GMT observatory.

The OCS consists of:

- **OCS Architecture,** providing the common infrastructure, standards, tools and processes used for efficient design, development, test, documentation and operation of the Observatory Control System. A model-based engineering (MBE) approach is used to speed up and standardize software development activities across all subsystems.
- **Core Frameworks,** used as abstraction layers for commonly used elements, such as device control, input/output modules, persistence, time distribution, data processing and user interface components. Frameworks support efficient development of core architectural elements, while providing flexibility to adopt new technologies in the future with minimal changes to existing code.
- **Core Services,** providing functionality available to all software components across the OCS, including the log service (history of events), alarm service (history of warnings and alarm conditions), telemetry service (monitored data values), configuration service (properties and settings), on-line documentation service (manuals, troubleshooting guides and on-line assistance) and system supervisor service (coordinate, monitor and manage software and hardware health).

- **Computer and Network platforms,** including the servers, consoles, switches and fiber optics required to support the distributed computing platform in the observatory.
- **Observing Execution System,** required for efficient observatory operation, including the Observing Tools (defining and evaluating detailed observations through science proposal management), Scheduler (short-term and long-term scheduling of observations), Sequencer (coordinating across subsystems for efficient execution), Laser Propagation (prevent damage to or interference with aircraft, spacecraft and other telescopes as a result of laser propagation) and Quality Monitoring.
- **Telescope Control System (TCS),** including the Pointing Kernel and Wavefront Control Kernel used for high-level control and coordination of device control subsystems to ensure the positional stability and image quality on the focal plane. They point the telescope and move AGWS probes to the corresponding targets, to achieve and maintain the nominal configuration, and to close the wavefront correction loops during the execution of an observation.
- **Data System,** including the Science Archive, Engineering Archive and Data Processing Pipelines
- **Software and Hardware simulators,** required for verification and validation of the OCS.
- **Control Systems,** necessary to control and monitor the GMT optical and electromechanical subsystems, including:
    - **Environmental Control Systems**: Environmental Monitor Facility (EMF) Control System
    - **Site, Enclosure and Facilities Control Systems**: Facilities Control System, Enclosure Control System
    - **Safety and Cabinets Control Systems**: Standard Electronic Cabinets (SEC) Control System, Global Interlock and Safety System
    - **Telescope Structure Control Systems**: Telescope Mount Control System
    - **Optics & Metrology Control Systems**: Primary Mirror (M1) Control System, Adaptive Secondary Mirror (ASM) Control System, Fast Steering Mirror (FSM) Control System, Secondary Mirror Positioner (M2P) Control System, Tertiary Mirror (M3) Control System, Corrector & Atmospheric Dispersion Compensator (C-ADC) Control System, Telescope Metrology System (TMS) Control System, Coating Facility Control System
    - **Wavefront Sensing Control Systems**: Acquisition, Guiding and Wavefront Sensors (AGWS) Control System, Wavefront Control Calibration (WFCCal) Control System, Wavefront Control Testbed (WFCT) Control System, Laser Guide Star (LGS) Control System, Laser Tomography Wavefront Sensor (LTWS) Control System, Natural Guide Star Wavefront Sensor (NGWS) Control System
    - **Instrument Control Systems**: Instrument Calibration System (ICS) Control System, Commissioning Camera (ComCam) Control System, G-CLEF Control System, GMACS Control System, Manifest Control System, GMTNIRS Control System, GMTIFS Control System

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 observing 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 observing 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 observing 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 observing 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 observing modes, while under continuous and high-bandwidth optical feedback control
- **Provide fast tip-tilt segment actuation** in the Natural Seeing observing 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 observing 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 observing 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 observing 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.

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 observing 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 [ID 33469]. 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 [ID 33469]: 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 [ID 33829]). 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.

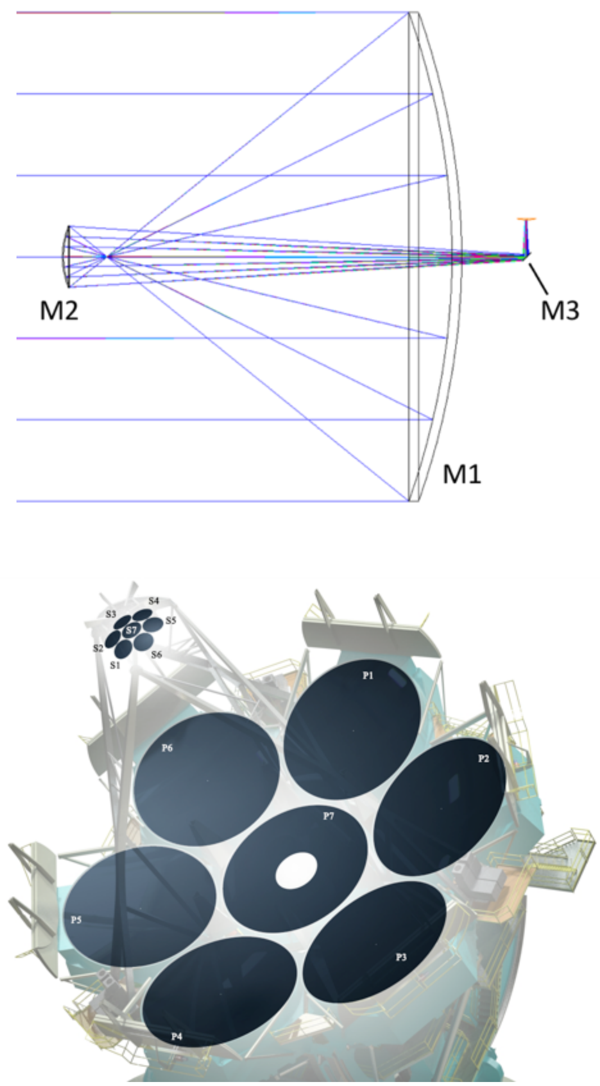


Figure 3-2 [ID 33829]: (Left) GMT optical design. (Right) M1 and M2 segmentation.

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 [ID 33472]).

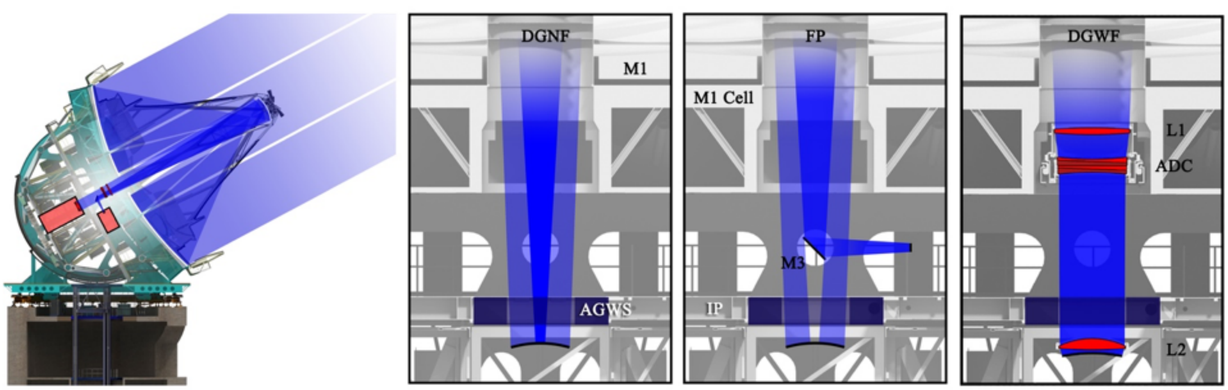


Figure 3-3 [ID 33472]: The GMT Optical Layouts

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 [ID 33473]) 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.

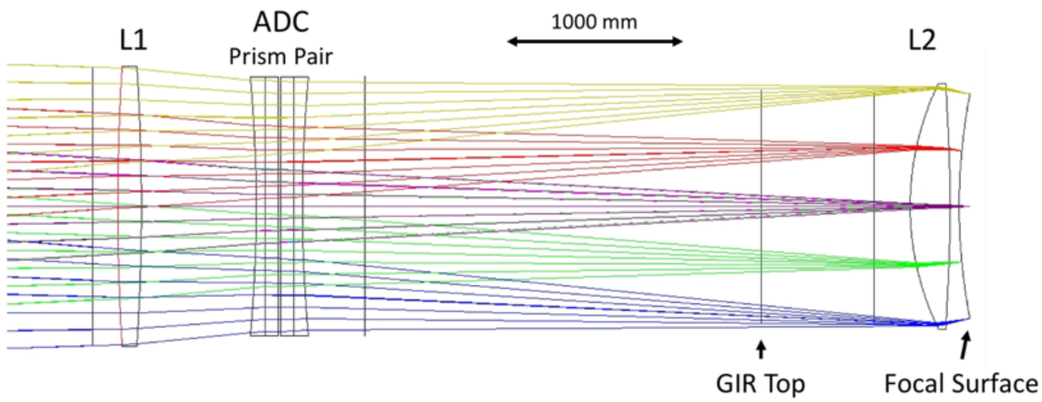


Figure 3-4 [ID 33473]: Corrector-Atmospheric Dispersion Compensator Optical Design

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 observing 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 [ID 33852].

Table 3-1 [ID 33852]: 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′	≤0.58 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 [ID 33910].

Table 3-2 [ID 33910]: 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 [ID 33934].

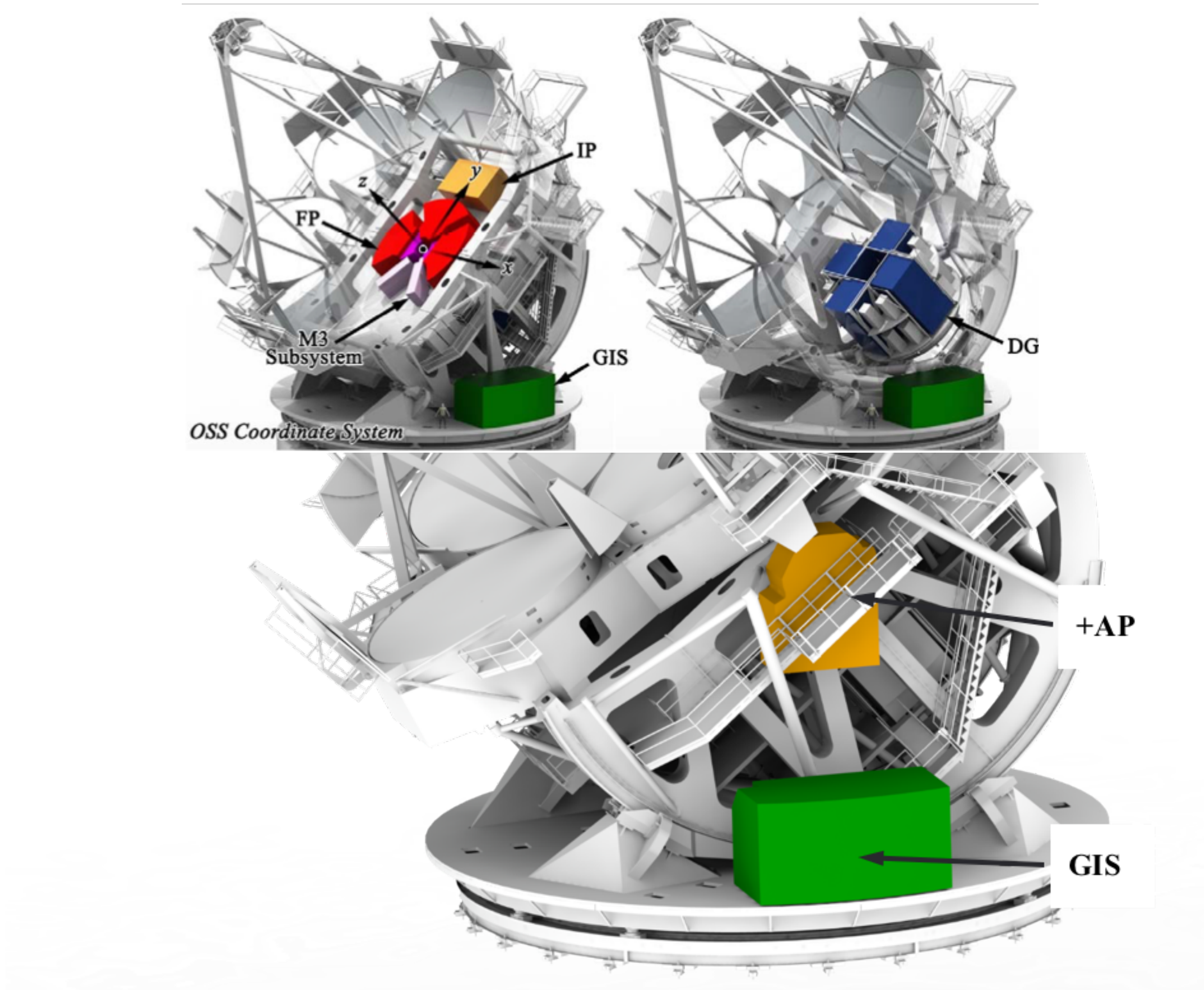


Figure 3-5 [ID 33934]: Instrument Focal Stations

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). Four Direct Gregorian instruments with identical volumes and 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 [ID 33478]. 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 [ID 33478]: 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 [ID 33946].

Table 3-3 [ID 33946]: 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 11 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 four 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 four 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 [ID 33479]), 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).

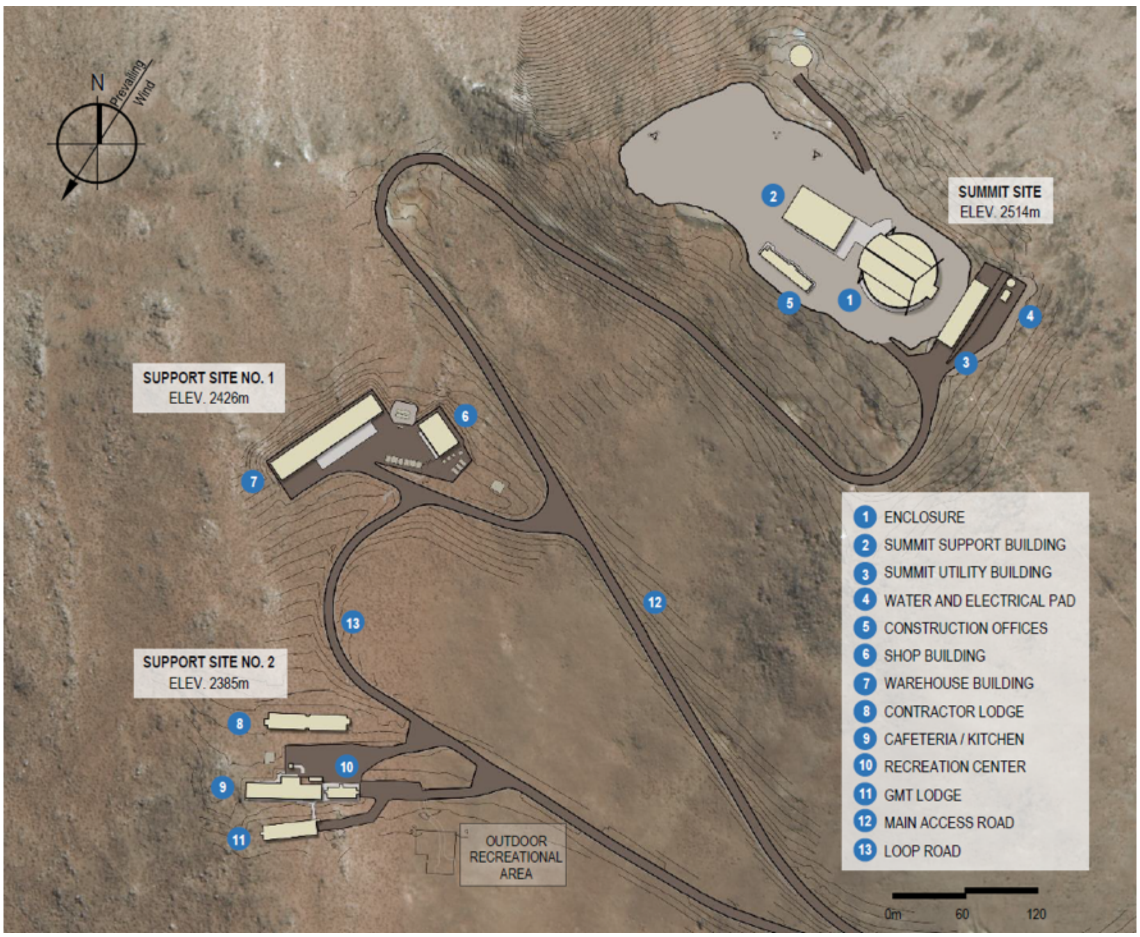


Figure 3-7 [ID 33479]: GMT Site Building Layout

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-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.

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 [ID 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.

REQ-L3-OAD-38166: Communications Systems

The site infrastructure shall provide telecommunications systems connecting the observatory to external communications facilities for a single-mode 2 Gbps circuit consisting of a minimum of 24 strands (TBC).

Rationale: Nightly data rates for adaptive optics need the capacity to handle a minimum of 9 TB of data over 12 hours.

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 [ID 33479]).

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 level 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.

3.2.2.3 Mobile Equipment

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

3.2.3 Enclosure

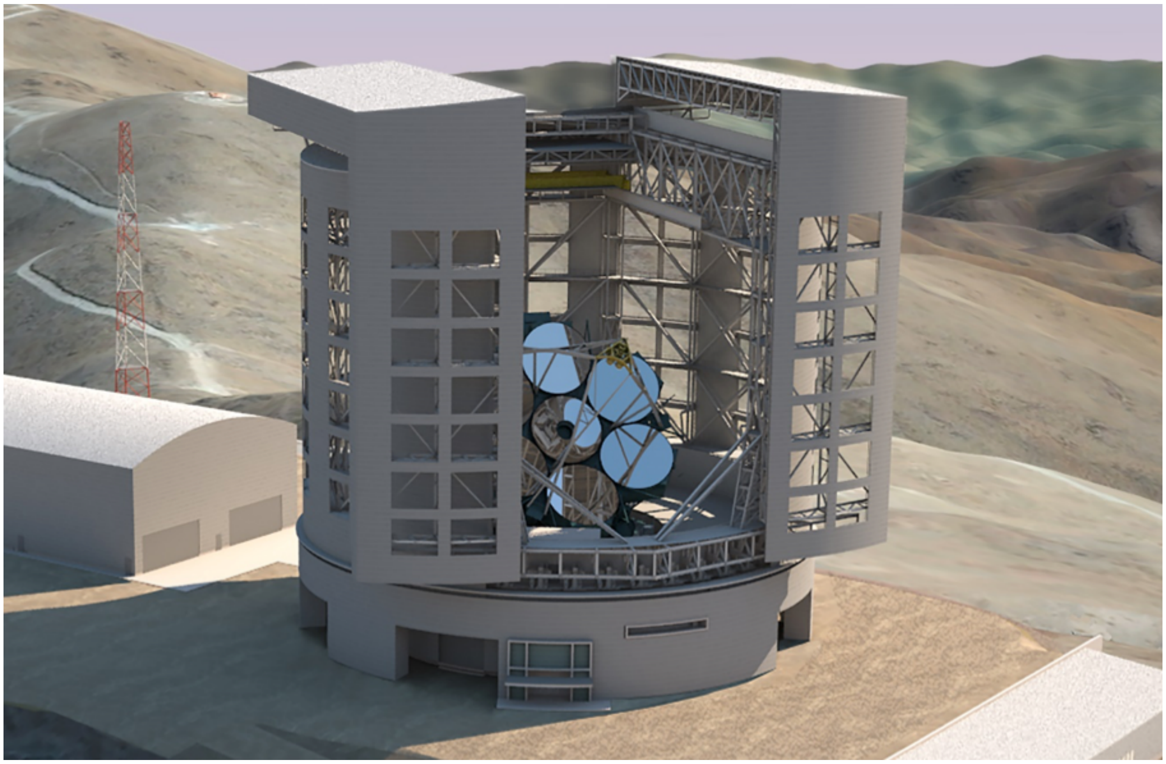


Figure 3-8 [ID 33480]: An Example of Enclosure Design

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.)

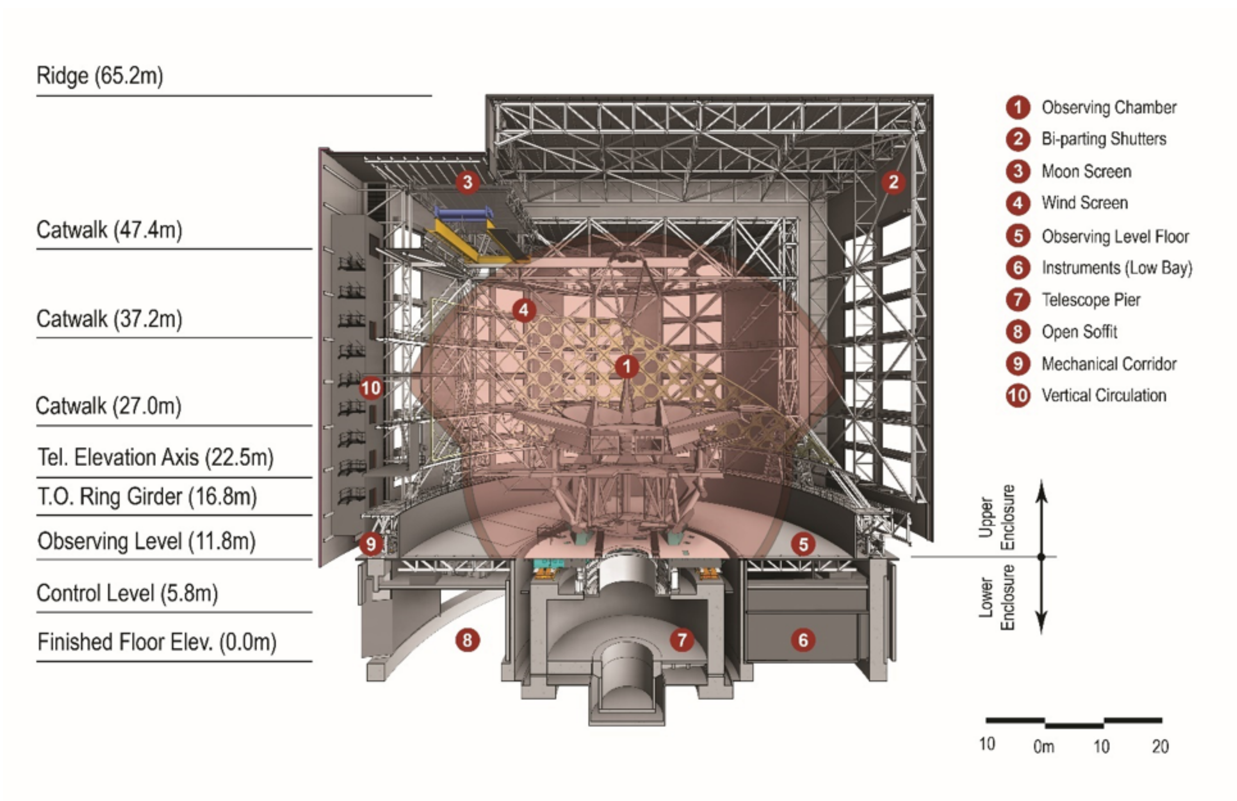


Figure 3-9 [ID 33481]: Components and Heights of the Enclosure

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.

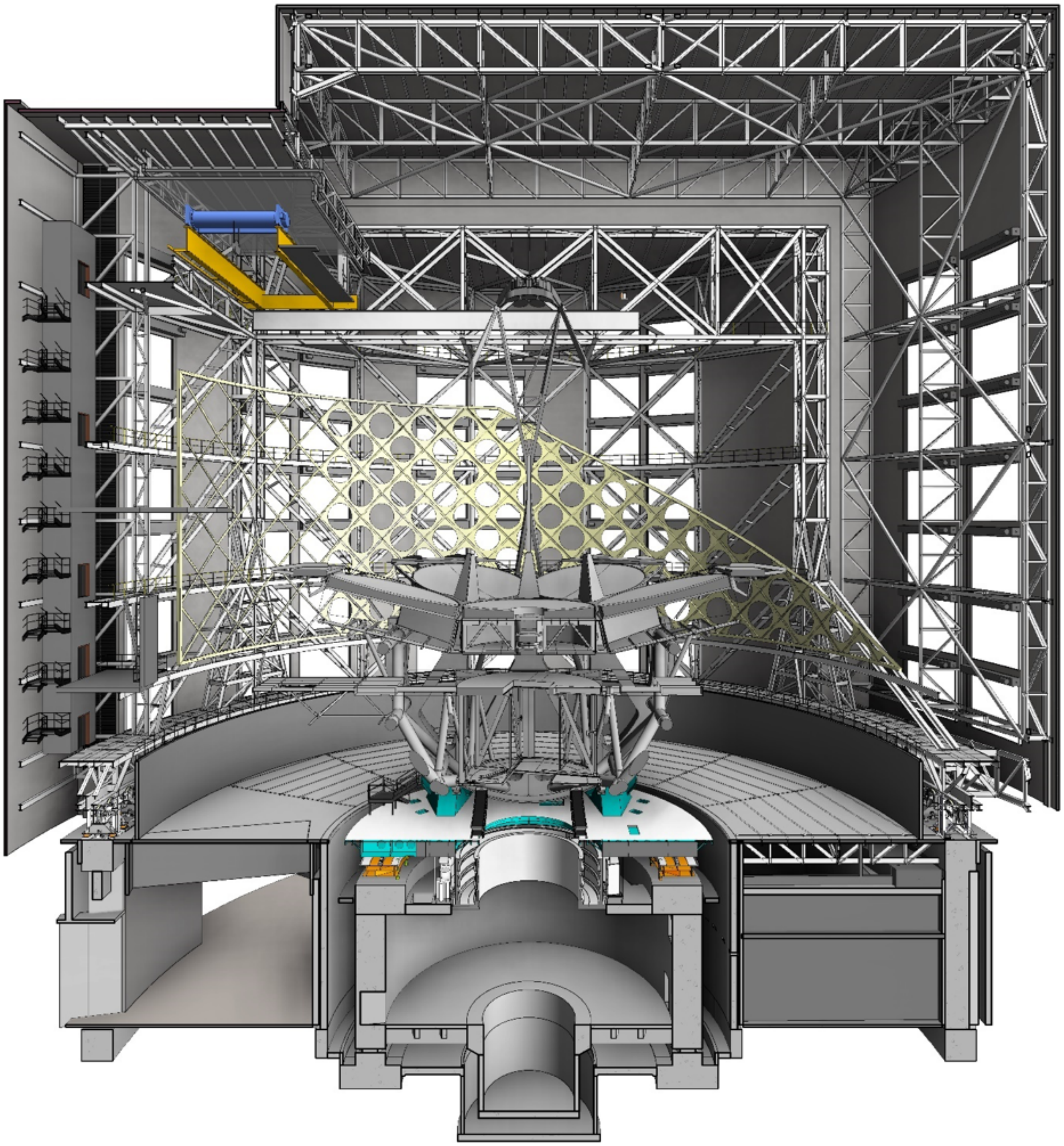


Figure 3-10 [ID 33482]: Cross Section of the Enclosure

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-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.

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 operation of the telescope and general services for each system as allocated in Table [ID undefined].

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-38235: Vacuum

Enclosure shall provide a source of vacuum capable of maintaining a minimum of 510 mm Hg of vacuum.

Rationale: Vacuum is a service necessary for the normal operation of various systems such the secondary mirror, DG stations and MANIFEST.

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

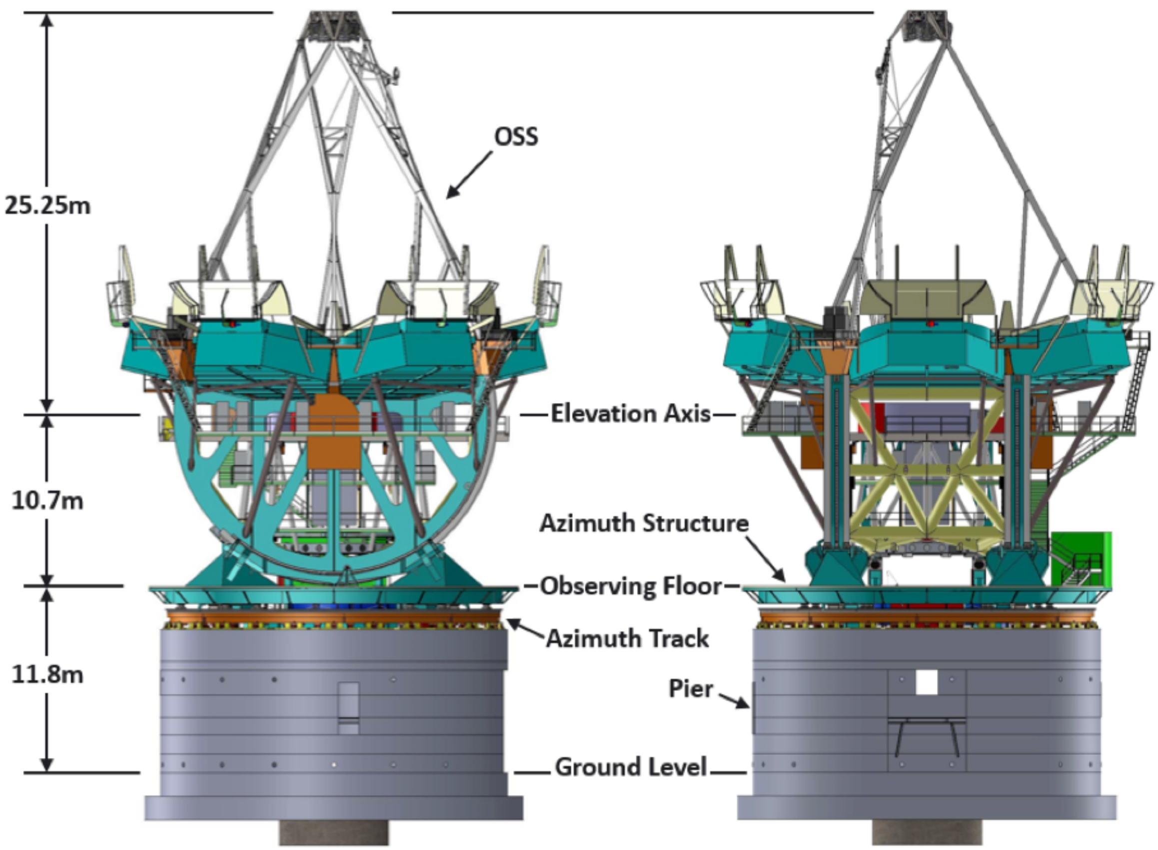


Figure 3-11 [ID 33483]: Telescope Dimensions

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

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

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

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

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.

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.

REQ-L3-OAD-69484: Telescope Instrument Platform

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

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.

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

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

REQ-L3-OAD-34368: Telescope GIR Diameter

The GIR shall have a nominal diameter of 9.380 m.

3.2.4.2 Mount Payload Support

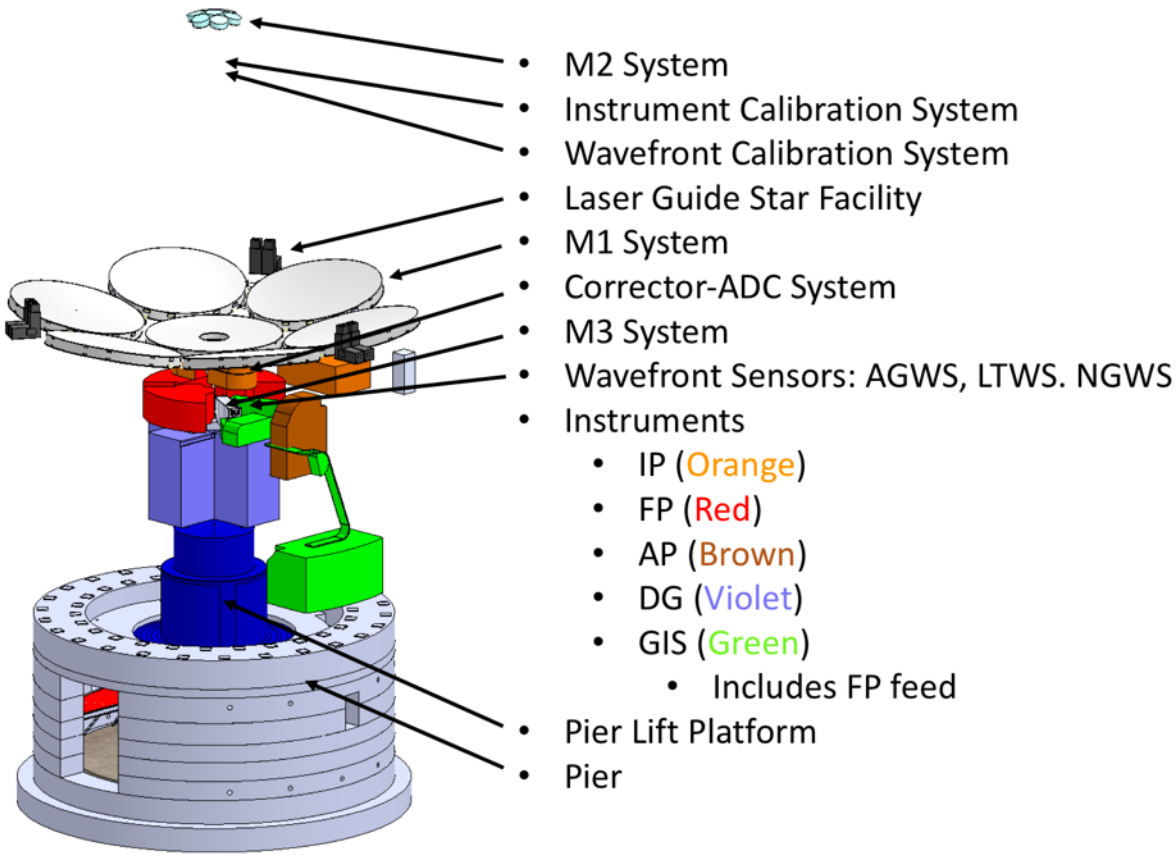


Figure 3-12 [ID 33484]: Mount Payloads (Mount Hidden)

Mount Subsystems Payloads

The GMT Mount shall support and point the payloads listed in Table [ID 34374].

Table 3-4 [ID 34374]: 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	4	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
- Four 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.

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-34447: M2 Array Diameter

The M2 array shall have a nominal outer diameter of 3.3 m.

Rationale: As described in Section 3.1.1, the secondary mirror forms a 1050 mm diameter clear aperture. The diameter of the array is based on the fundamental optical design of the telescope, see GMT Optical Design GMT-DOC-00010 for further details.

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.

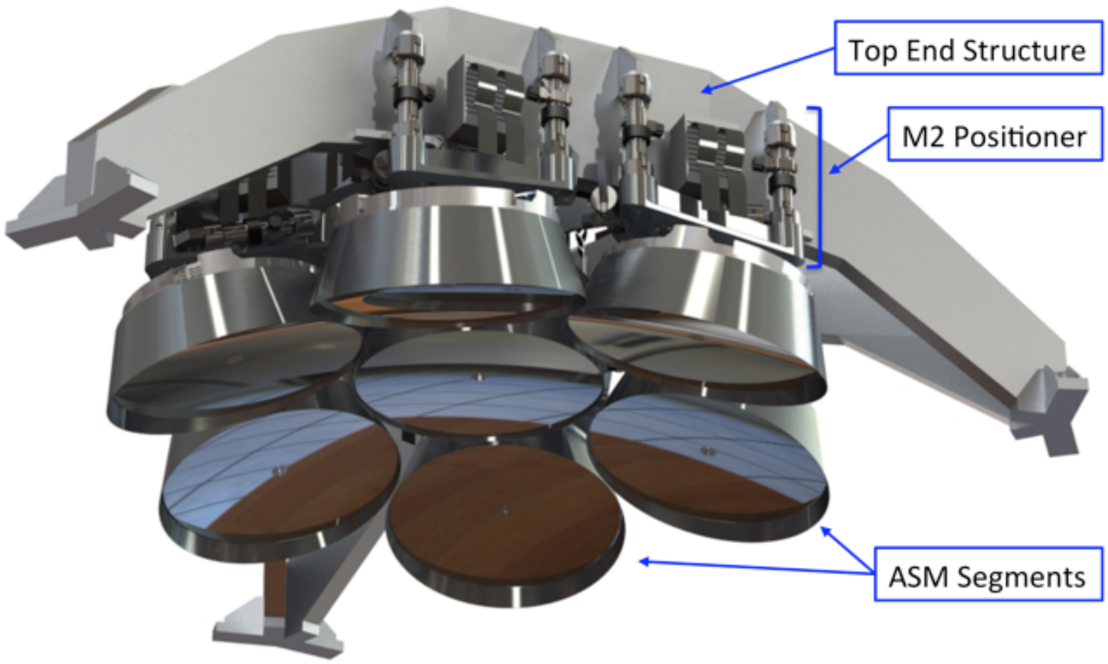


Figure 3-13 [ID 39036]: M2 Top End Exploded View

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 [ID 93824].

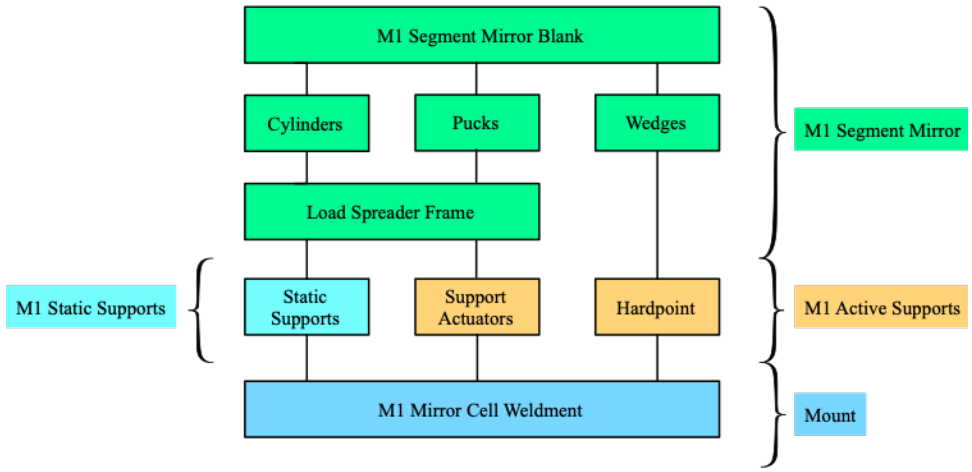


Figure 3-14 [ID 93824]: M1 Segment Overview

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 [ID 33486]. Figure [ID 33487] 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.

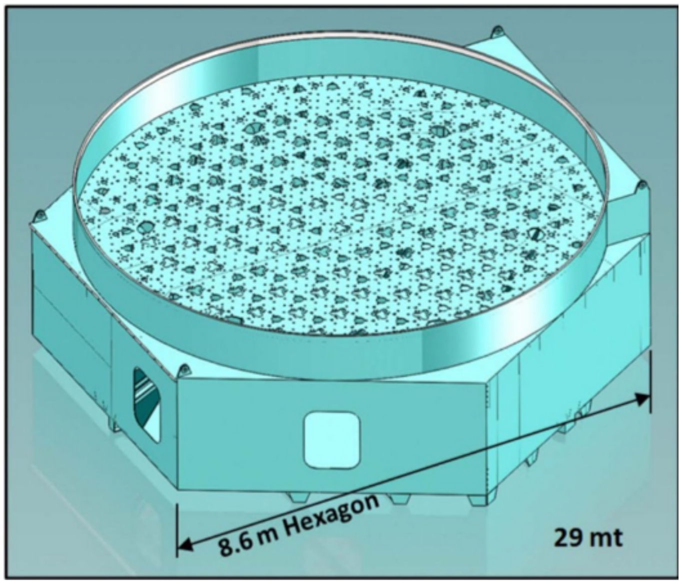


Figure 3-15 [ID 33486]: Weldment of the Off-Axis Cell

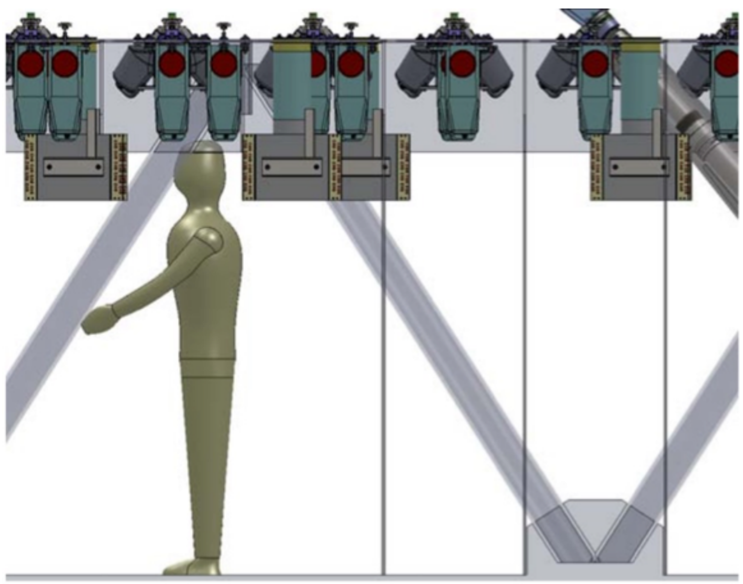


Figure 3-16 [ID 33487]: View of the actuators attached to the top plate.

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 [ID 33488]) 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 [ID-33489] as an example distribution of on-axis and off-axis static supports.

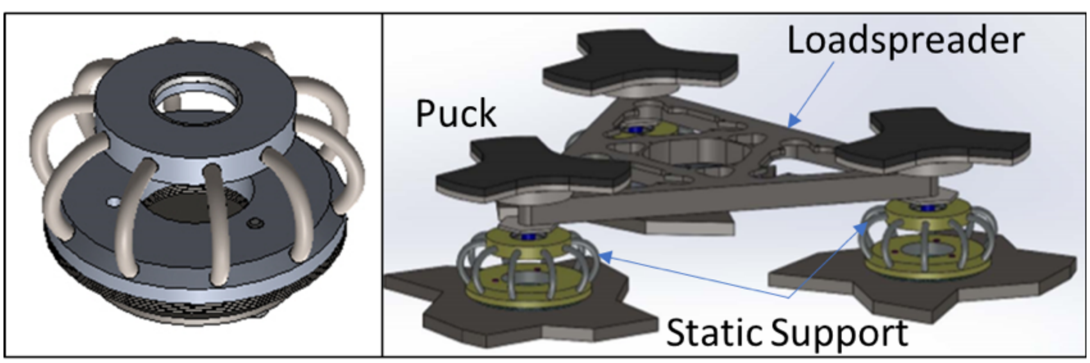


Figure 3-17 [ID 33488]: Static Support

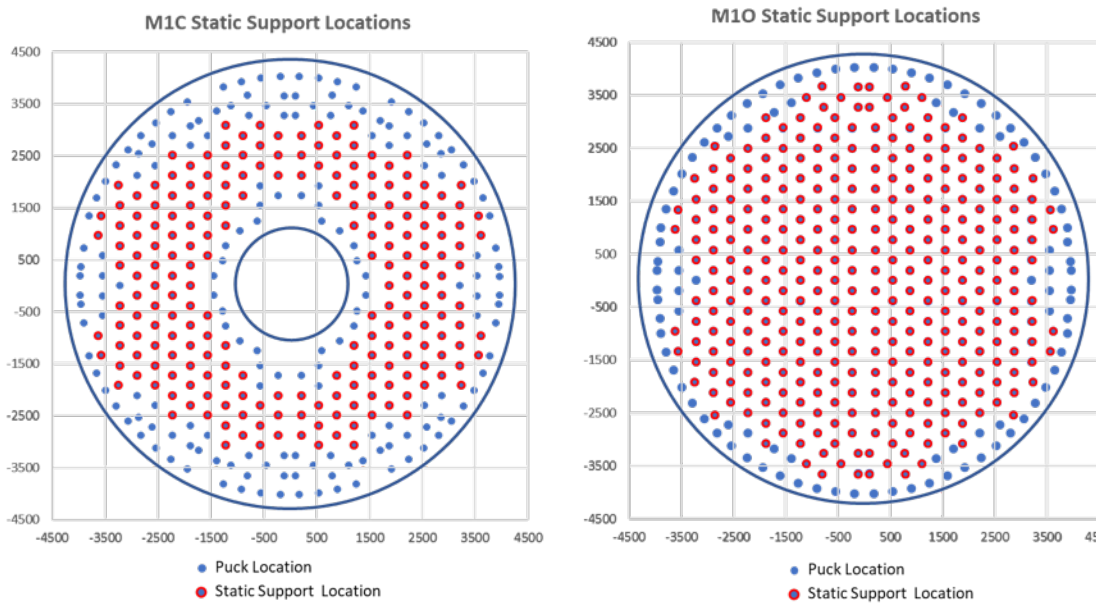


Figure 3-18 [ID 33489]: Example Distribution of Static Supports (in red) on M1O and M1C Cell

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 [ID 33490] 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.

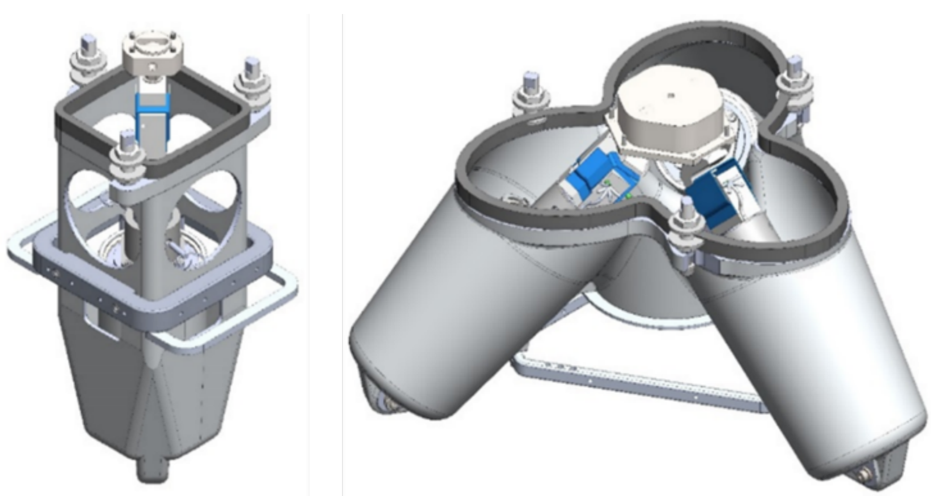


Figure 3-19 [ID 33490]: Example of Single-Axis and Triple Axis Actuators

Support Actuators

The M1 Cells shall contain a quantity of support actuators listed in Table [ID 34500].

Table 3-5 [ID 34500]: 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

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 [ID 33491]).

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.

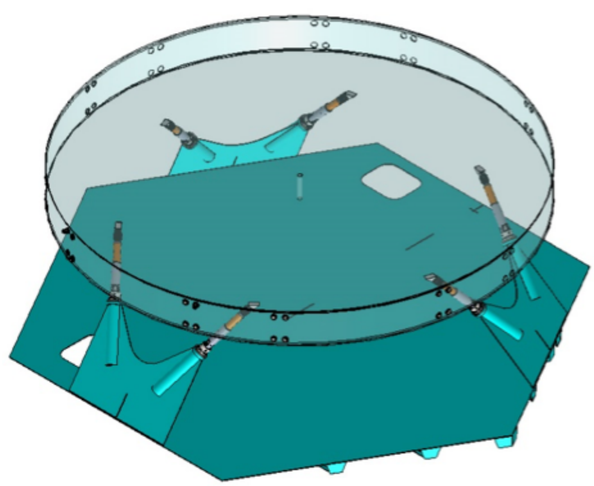


Figure 3-20 [ID 33491]: Hardpoint Assemblies in M1O Cell

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 [ID 33492] for illustrations of the heat exchanger assembly and Figure [ID 33493] for concept illustration of coolant circulation loop.

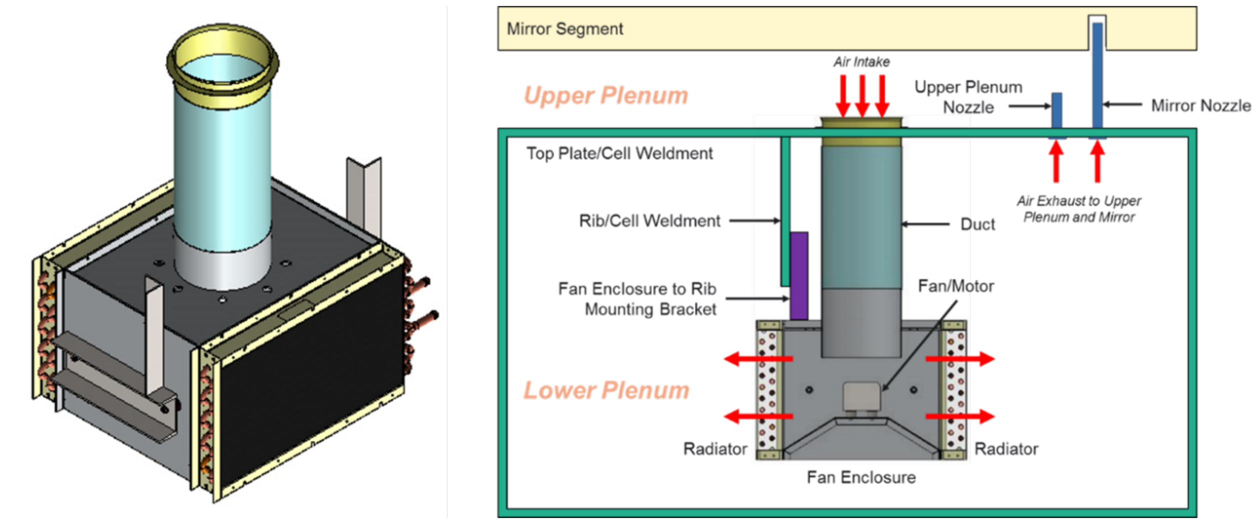


Figure 3-21 [ID 33492]: Conceptual M1 System Fan and Heat Exchanger Assembly for Thermal Control

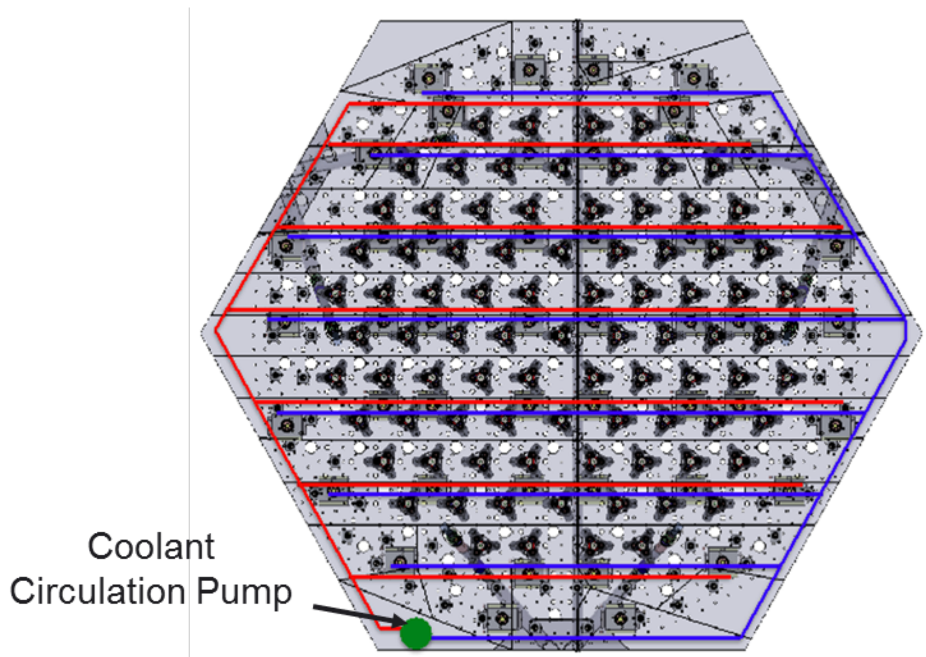


Figure 3-22 [ID 33493]: Coolant Circulation in M1 Mirror Cell

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 drives 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.

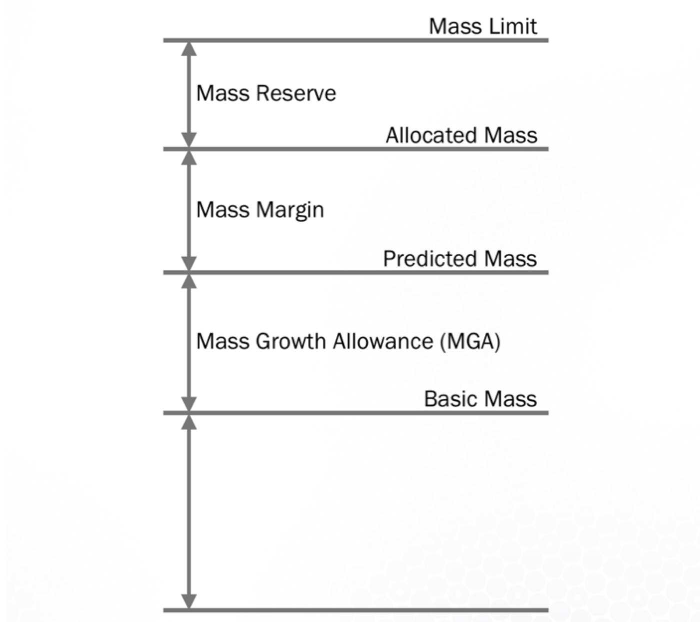


Figure 3-23 [ID 33494]: GMT Definitions of Mass Properties

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 1,481,973 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 TBD 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-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.

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.

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

The Gravity Invariant Instruments mass shall not exceed 20,100 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-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 [up to and including 2,312,520 kg]TBC.

Rationale: This is based on MTM's mass estimate, i.e. the Mount's Predicted Mass, with a 10% margin to define the Mount's Allocated Mass, and an additional 5% Mass Reserve to define the Mount's Mass Limit. The payload masses in the specified in GMT-REF-01575 plus the Mount Mass Limit give the Telescope Mass Limit for the OAD.

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 [ID 34616].

Table 3-6 [ID 34616]: 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
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		
REQ-L3-OAD-34692	DG Port A (Stowed)	8,663
REQ-L3-OAD-34695	DG Port B (Stowed)	6,038
REQ-L3-OAD-34698	DG Port C (Stowed)	8,663
REQ-L3-OAD-34701	DG Port D (Stowed)	6,038

Auxiliary Port Instruments		
REQ-L3-OAD-34705	AP Instruments "+X" (Gravity Invariant)	3,150
REQ-L3-OAD-34708	AP Instruments "-X" (Gravity Invariant)	3,150
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-34722	GIS G-CLEF Thermal Enclosure	10,920
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

3.3 Wavefront Control Architecture

3.3.1 Wavefront Control Modes

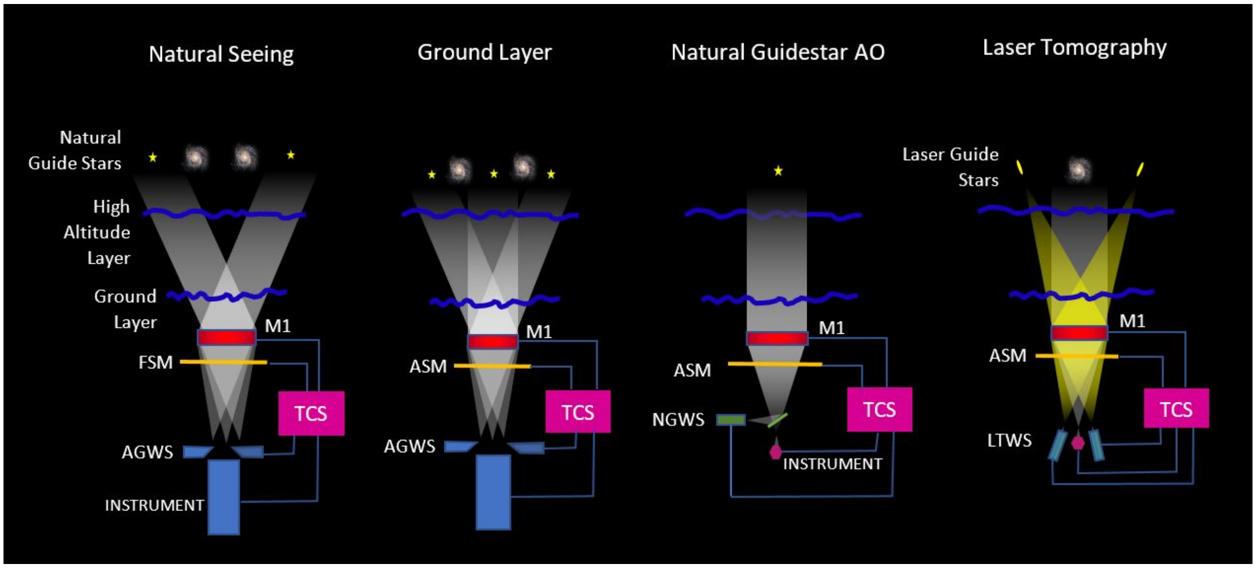


Figure 3-24 [ID 33495]: GMT Wavefront Control Modes

Wavefront Control Modes

The GMT shall provide the wavefront control modes specified in Table [ID 34741].

Table 3-7 [ID 34741]: 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	Image quality improvement 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 stars and one natural guide star for wavefront sensing.	7, 8

Notes: The four wavefront control modes (WFCM) are implemented by the Observatory Control System, and require various combinations of sensor and actuator systems to be used.

Rationale: These four wavefront control modes are necessary to meet the image quality requirements specified in the 15 ORD Observatory Performance Modes (see GMT-DOC-01369).

3.3.2 Natural Seeing

Please refer to the Natural Seeing Image Quality budget (GMT-DOC-00145) for analysis supporting allocations.

3.3.2.1 Control Strategy

The Natural Seeing wavefront control mode uses 4 wavefront sensors in the AGWS, and one in the instrument, to deliver image quality limited only by the site atmosphere. The measurements of these 5 wavefront sensors are used in 4 primary control loops to correct errors in the model trajectories of the optical degrees of freedom, and wind-induced vibrations and tracking errors.

A block diagram of the wavefront control strategy is provided in Figure [ID 33496]. For a detailed description of the control strategy, refer to GMT-DOC-01369.

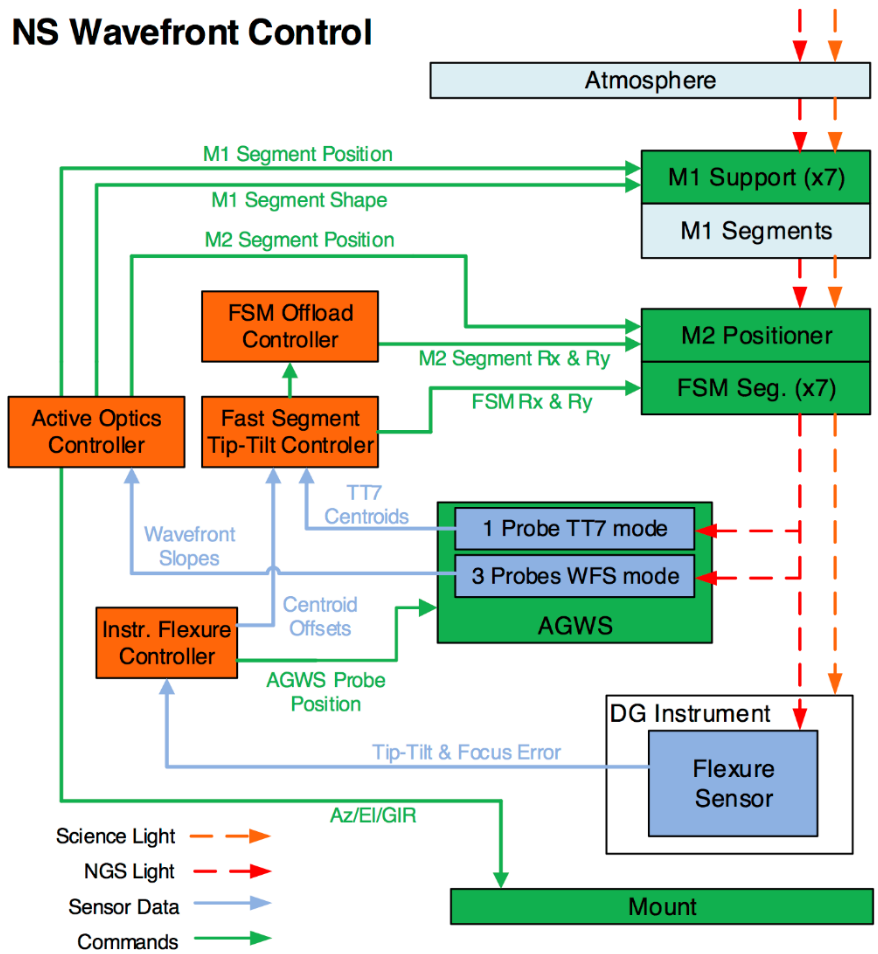


Figure 3-25 [ID 33496]: Natural Seeing Wavefront Control Block Diagram

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

The Active Optics Control Loop shall use the wavefront error measured by the AGWS at 3 locations in the Direct Gregorian focal plane at ≥ 0.03 Hz to correct gravity and thermal flexure of the Mount and optics.

Rationale: Wavefront measurements at 3 locations in the focal plane are necessary to unambiguously differentiate between aberrations generated at M1 and at M2.

Notes: All optical degrees of freedom are commanded to follow trajectories based on gravity and temperature models. This control loop corrects hysteresis and other model errors.

The following degrees of freedom are controlled by this control loop:

1. M1 rigid body motion, not including rotation around the Reference Optical Axis
2. 27 bending modes of each M1 segment

3. M2 rigid body motion, no including rotation around the Reference Optics Axis
4. Mount azimuth, elevation, and GIR rotation
5. AGWS WFS probe position in the focal plane (corrections for differential flexure)

The following degrees of freedom are not controlled by this control loop:

1. Rotation of M1 and M2 segments around the Reference Optical Axis. These modes are invisible and will be controlled only by the TMS.

2. Global image scale modes. 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, stretching in X and shrinking in Y, and the same rotated by 45°. They will be controlled only by M1 thermal control system limiting thermal gradients in the M1 segments.

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

The Fast Segment Tip-Tilt Control Loop shall use the segment tip-tilt error measured by the AGWS at one location in the Direct Gregorian focal plane at ≥ 200 Hz to correct Mount tracking errors and wind-induced vibrations in the Mount and main optics.

Rationale: One measurement location in the focal plane is sufficient to ensure the Natural Seeing image quality, despite tip-tilt anisoplanatism.

REQ-L3-OAD-34781: Instrument Flexure Control Loop

The Instrument Flexure Control Loop shall use image motion and focus error measured by the instrument Flexure Sensor at ≥ 0.03 Hz to correct differential flexure between the instrument and the AGWS.

Rationale: Differential flexure between the instrument and AGWS must be compensated by instrument measurements fed back to the TCS, which are used to update AGWS probe position and focus (large offsets) or modify the setpoint of the AGWS sensors (small offsets).

Notes: Instruments which do not provide a Flexure Sensor measuring image motion and focus error (e.g. the Commissioning Camera) may only achieve the specified Natural Seeing image quality over limited exposure times.

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

The FSM Offload Control Loop shall offload FSM segment R_X and R_Y degrees of freedom to the M2 Positioner.

Rationale: The FSM provides high bandwidth M2 Segment Rx and Ry control with a limited range of motion, while the M2 Positioner provides lower bandwidth with a wide range of motion. An offload from the FSM to M2 Positioner maximizes the available FSM stroke.

Notes: The preferred offload strategy is to low-pass filter the FSM commands and send this signal as an offset to the model-based M2 Positioner trajectory.

3.3.2.2 Controlled Degrees of Freedom

Natural Seeing Controlled Degrees of Freedom

The GMT in the Natural Seeing wavefront control mode shall actively control the optical degrees of freedom specified in Table [ID 34793].

Table 3-8 [ID 34793]: 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	M1	M1 segment rigid body position	7 × 6
REQ-L3-OAD-34806	M1	M1 segment shape	7 × 27 bending modes
REQ-L3-OAD-34810	M2	M2 segment rigid body position	7 × 6
REQ-L3-OAD-34814	M3	M3 piston, tip, and tilt	3

Notes: Analysis of the required number of controlled M1 bending modes is provided in GMT-DOC-03091.

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.

REQ-L3-OAD-34820: Active Optics Trajectories

The GMT shall control the optical degrees of freedom specified above to follow trajectories based on a model of the telescope gravity and thermal flexure, with offsets provided by the active optics control loops.

Rationale: Flexure rates for GMT will be up to 0.25 µm/s (M2 Ty 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 0.5-1.0 µm, continuous trajectories are necessary to maintain acceptable alignment and image quality between updates.

3.3.2.2.1 Mount System

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 [ID 33501]. 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 that –6 dB above 1.0 Hz. Stability phase margin should be at least 45 degrees and the stability gain margin should be at least 10 dB.

Rationale: Based on the Mount reference design.

Notes: Offsets to the Mount model-based 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.

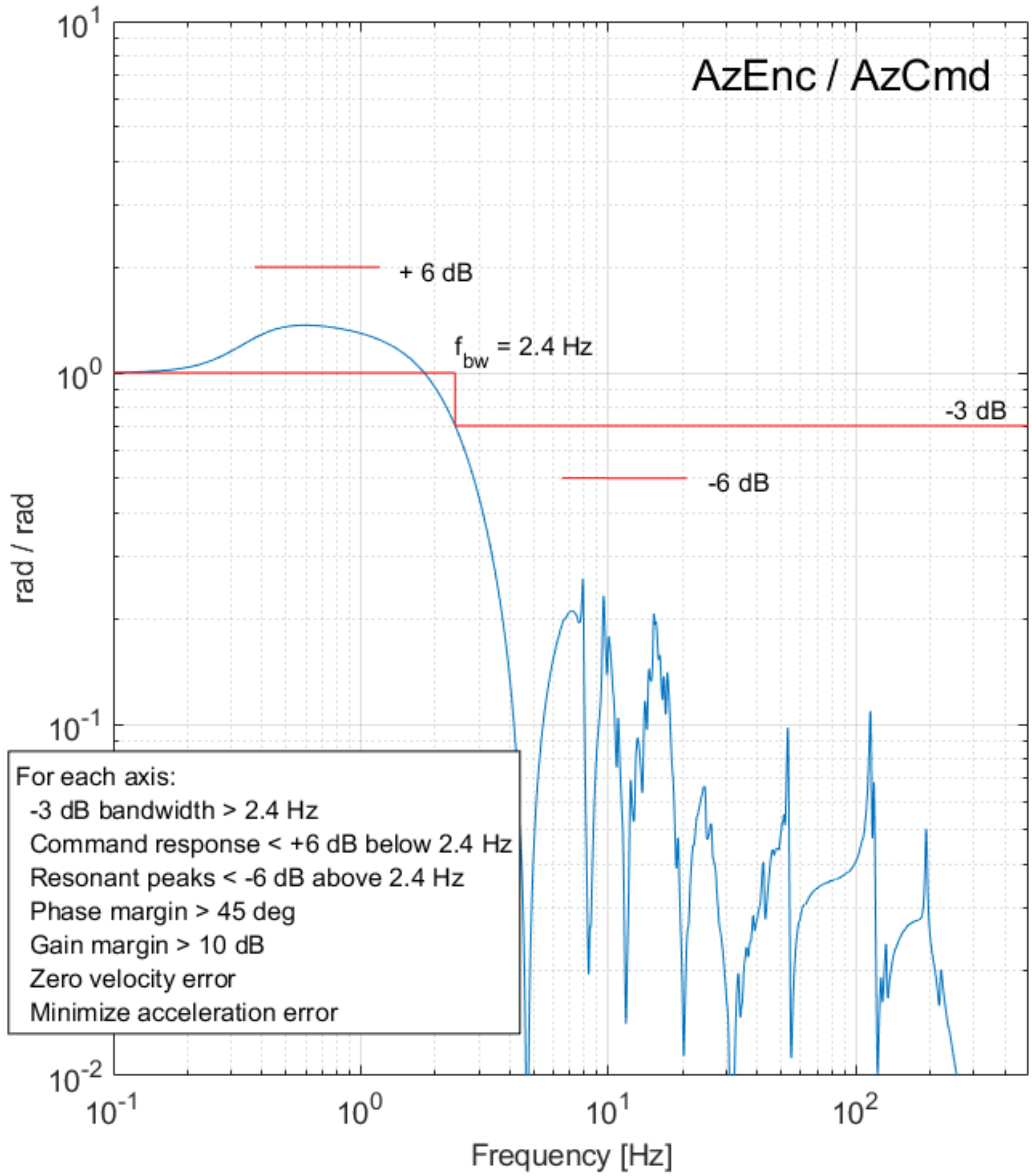


Figure 3-26 [ID 33501]: Mount Azimuth Axis Trajectory Correction Transfer Function Limits

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 [ID 33502]. 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: Based on the Mount reference design.

Notes: Offsets to the Mount model-based 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.

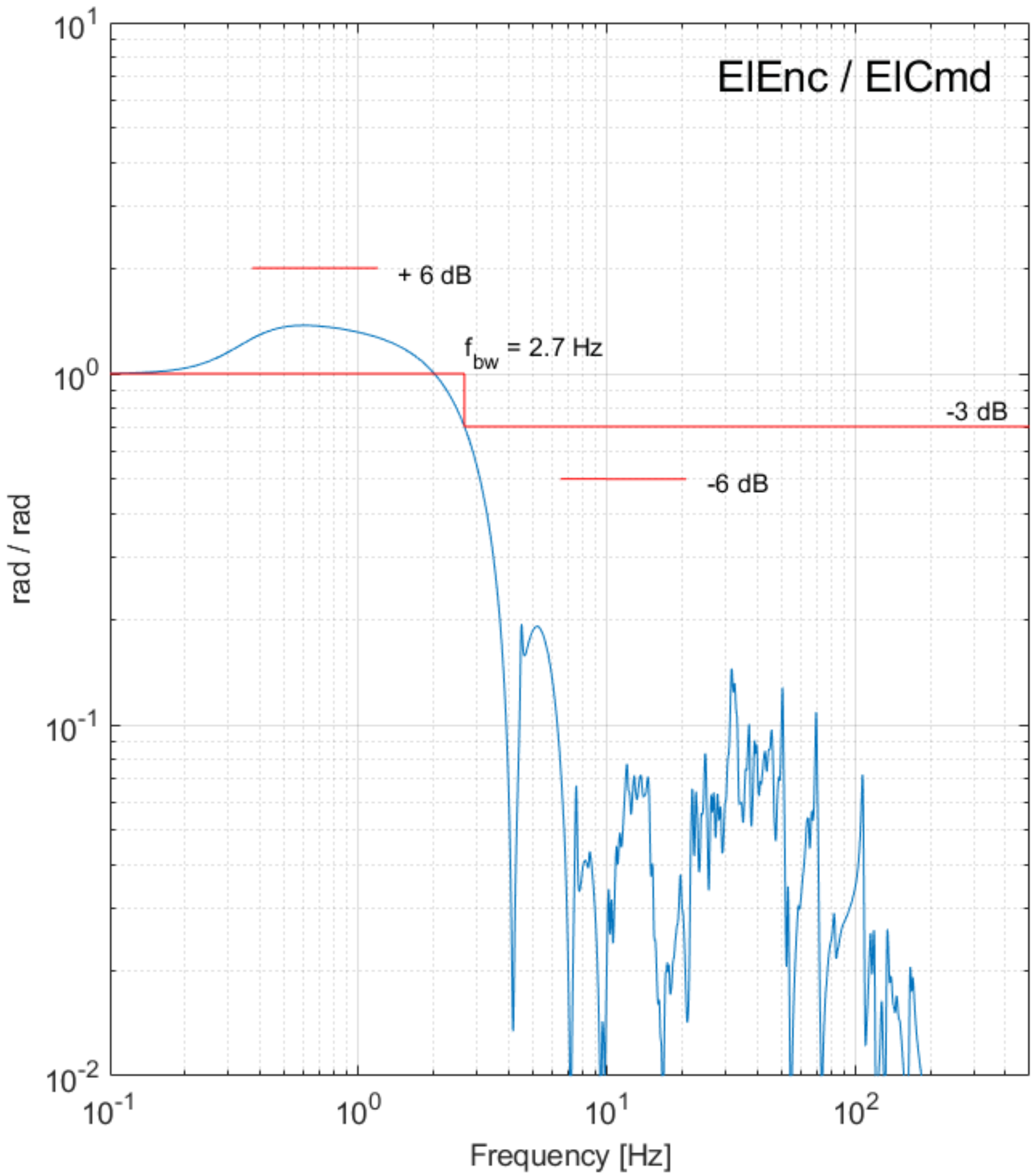


Figure 3-27 [ID 33502]: Mount Elevation Axis Trajectory Correction Transfer Function Limits

3.3.2.2.2 M1

M1 Segment Rigid Body Position Accuracy

The M1 System shall provide actuation of M1 segment rigid body positions with the accuracy specified in Table [ID 34838].

Table 3-9 [ID 34838]: M1 Segment Rigid Body 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

Notes:

- Although the standard mode of operation will be to use closed-loop feedback from the TMS to initially align the main optics and maintain alignment during slews, we nevertheless require that the M1 rigid body position actuation meet the same accuracy requirements as the TMS. This will enable rapid alignment without use of the TMS once open-loop models have been developed.
- The requirements are specified in the M1 Front Surface coordinate system (see GMT-REF-00189).

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 [ID 35266] [[7]].

M1 Segment Rigid Body Position Precision

The M1 System shall provide actuation of M1 segment rigid body positions with the precision specified in Table [ID 34866].

Table 3-10 [ID 34866]: M1 Segment Rigid Body Position Precision 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-34879	R_X	≤ 0.5 µrad
REQ-L3-OAD-34882	R_Y	≤ 0.5 µrad
REQ-L3-OAD-34885	R_Z	≤ 0.2 µrad

Notes:

- M1 segment rigid body position will follow a model-based trajectory with offsets based on TMS or AGWS WFS measurements. No requirement is specified on absolute accuracy due to the use of external feedback systems.
- The requirements are specified in the M1 Front Surface coordinate system (see GMT-REF-00189).

Rationale:

- **T_X, T_Y, T_Z, and R_Z:** All 6 rigid body degrees of freedom of the M1 segments will be corrected by the active optics control loop every ≤ 30 s, limited by actuator precision. R_X and R_Y precision errors can be ignored because they will be rapidly corrected at M2 by the Fast Segment Tip-Tilt control loop. Position errors due to M1 segment actuation precision have been allocated PSSN(0.5 µm) ≤ 0.9995 in the NSIQ budget. This has been flowed down via Monte Carlo simulations to the T_X, T_Y, T_Z, and R_Z precision errors listed here. The T_Z requirement is also consistent with a ≤0.1% probability of exceeding half of the ASMS piston stroke budget in [ref. M2 ASMS Stroke Requirements], though this is relevant only in the diffraction-limited observing modes.
- **$R_X$and R_Y:** R_X and R_Y errors at M1, corrected at M2, will lead to field-dependent segment phase piston error (see GMT-DOC-01369). 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.

M1 Segment Rigid Body Position Control Jitter

The M1 System shall provide actuation of M1 segment rigid body positions with the control jitter specified in Table [ID 34895].

Table 3-11 [ID 34895]: M1 Segment Rigid Body Position Control Jitter Requirements

Requirement ID	DOF	1σ Jitter	At Frequency
REQ-L3-OAD-34900	T_X	≤ TBD µm	> 0.01 Hz
REQ-L3-OAD-34904	T_Y	≤ TBD µm	> 0.01 Hz
REQ-L3-OAD-34908	T_Z	≤ TBD µm	> 0.01 Hz
REQ-L3-OAD-34912	R_X	≤ TBD µrad	> 0.01 Hz

REQ-L3-OAD-34916	R_Y	≤ TBD µrad	> 0.01 Hz
REQ-L3-OAD-34920	R_Z	≤ TBD µrad	> 0.01 Hz

Notes:

- Any drift in the M1 position actuation system over 100 s is included in this jitter requirement.
- The requirements are specified in the M1 Front Surface coordinate system (see GMT-REF-00189).

Rationale: Jitter in these degrees of freedom has been allocated PSSN(0.5 µm) ≤ TBD in the NSIQ budget. This has been flowed down via Monte Carlo simulations to the errors listed here.

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

The M1 System shall provide segment rigid body position actuation with a transfer function response to commands within the limits specified in Figure [ID 33503]. 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: TBD

Notes: Offsets to the M1 segment rigid body 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.

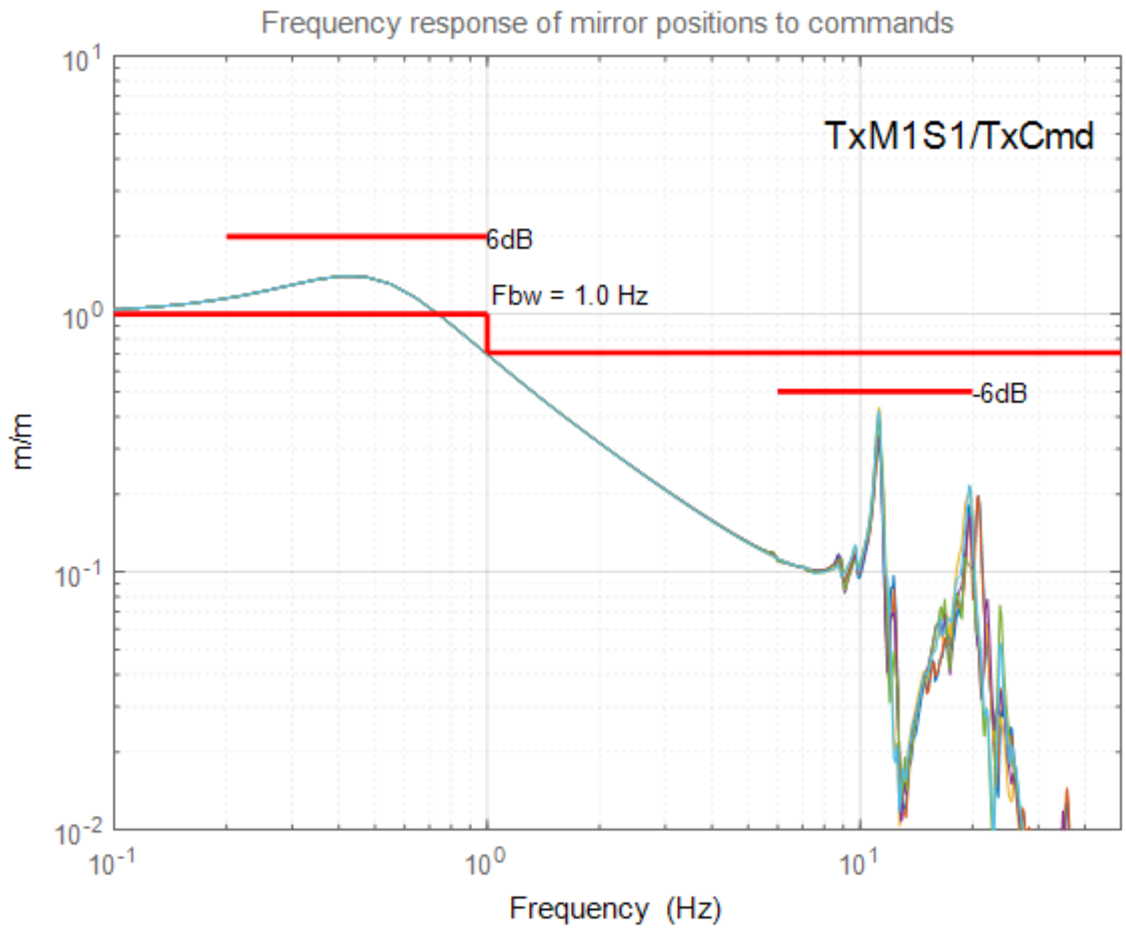


Figure 3-28 [ID 33503]: M1 Segment Rigid Body Position Transfer Function Limits

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

The M1 System shall provide actuation of M1 segment shape with an accuracy no greater than TBD nm RMS surface error.

Rationale: Given perfect knowledge of the Mount and M1 flexure, this requirement enables ≥ 99.9% probability of capture by the Active Optics control loops with the capture ranges specified in Table [ID-35266].

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

The M1 System shall provide actuation of M1 segment shape with a precision of ≤ 25 nm (TBC) RMS surface error.

Rationale: M1 segment shape errors will be corrected by the active optics control loop every ≤ 30 s, limited by actuation precision errors. These have been allocated PSSN(0.5 µm) ≤ 0.9995 in the NSIQ budget. The primary contributor is expected to the M1 support actuator force errors, which somewhat counter-intuitively lead to low-order figure errors (see GMT-DOC-03091). For these low-order errors, a surface error of 25 nm RMS (TBC) is found to be equivalent to PSSN(0.5 µm) = 0.9995.

Notes: All M1 shape errors other than support actuator force errors are assumed to be sufficiently persistent to be corrected 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 [ID 33504].

Rationale: TBD

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.

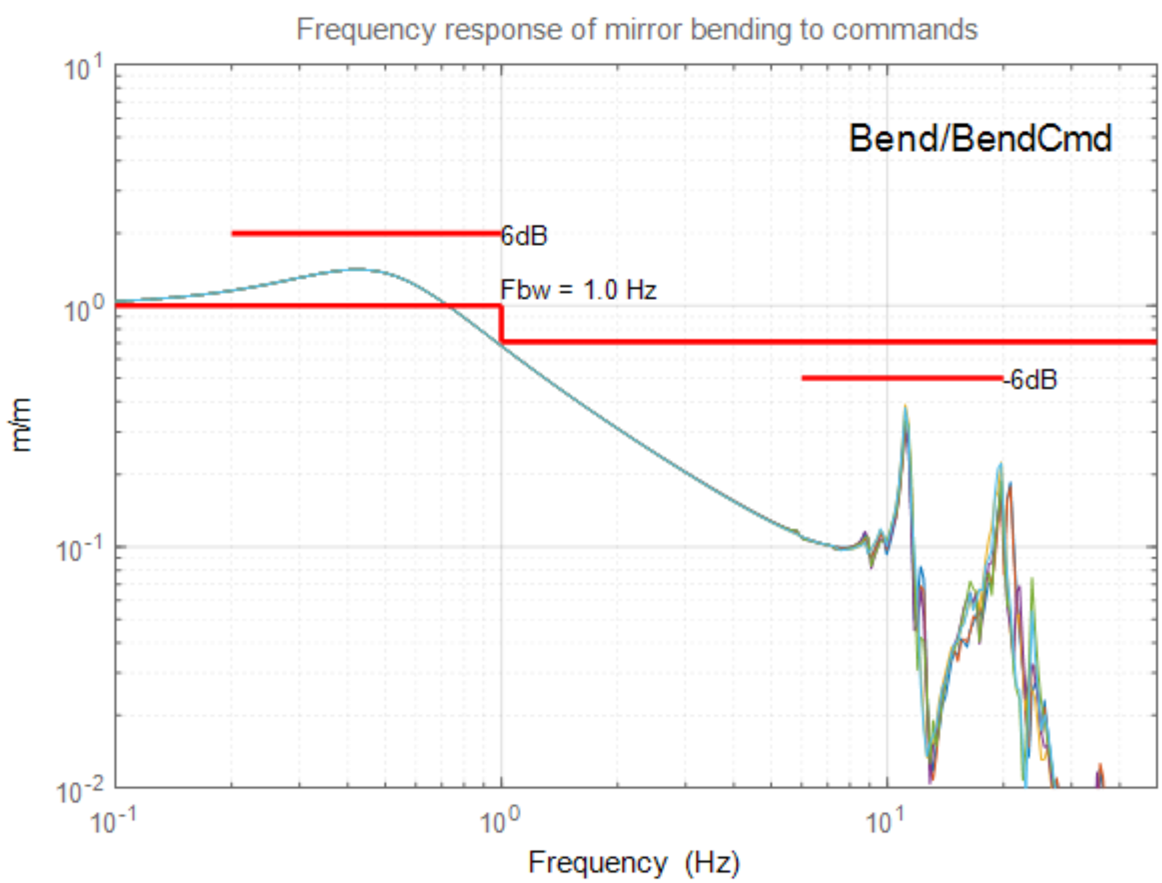


Figure 3-29 [ID 33504]: M1 Segment Shape Transfer Function Limits

3.3.2.2.3 M2

M2 Segment Rigid Body Position Accuracy

The M2 System shall provide actuation of M2 segment rigid body positions with the accuracy specified in Table [ID 34949].

Table 3-12 [ID 34949]: M2 Segment Rigid Body 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

Notes:

- Although the standard mode of operation will be to use closed-loop feedback from the TMS to initially align the main optics and maintain alignment during slews, we nevertheless require that the M2 rigid body position actuation meet the same accuracy requirements as the TMS. This will enable rapid alignment without use of the TMS once open-loop models have been developed.
- The requirements are specified in the M2 Front Surface coordinate system (see GMT-REF-00189).

Rationale: Given perfect knowledge of the Mount and M2 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 [ID-35266].

M2 Segment Rigid Body Position Precision

The M2 System shall provide actuation of M2 segment rigid body position with the precision specified in Table [ID 34977].

Table 3-13 [ID 34977]: M2 Segment Rigid Body Position Precision 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

Notes:

- M2 segment T_X, T_Y, T_Z, and R_Z degrees of freedom will follow a model-based trajectory with offsets based on TMS or AGWS WFS measurements. No requirement is specified on absolute accuracy due to the use of external feedback systems. The R_X and R_Y degrees of freedom will nominally be held at mid-range unless provided optical control loop feedback.
- The requirements are specified in the M2 Front Surface coordinate system (see GMT-REF-00189).

Rationale:

- **T_X, T_Y, T_Z, and R_Z:** These degrees of freedom of the M2 segments will be corrected by the active optics control loop every ≤ 30 s, limited by actuation precision errors. 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 precision errors listed here. The T_Z requirement is also consistent with a ≤0.1% probability of exceeding half of the ASMS piston stroke budget in REQ-L3-OAD-35449, though this is relevant only in the diffraction-limited observing modes.
- **$R_X$and R_Y:** These degrees of freedom of the M2 segments will be corrected by the Fast Segment Tip-Tilt control loop at ≥ 200 Hz update rate, limited by actuation precision errors. These errors have been allocated PSSN(0.5 µm) ≤ 0.9995 in the NSIQ budget. This has been flowed down via Monte Carlo simulations to the precision errors listed here.

M2 Segment Rigid Body Position Control Jitter

The M2 System shall provide actuation of M2 segment rigid body position with the control jitter specified in Table [ID 35006].

Table 3-14 [ID 35006]: M2 Segment Rigid Body Position Jitter Requirements

Requirement ID	DOF	1σ Jitter	at frequency
REQ-L3-OAD-35011	T_X	≤ TBD µm	> 0.01 Hz
REQ-L3-OAD-35015	T_Y	≤ TBD µm	> 0.01 Hz
REQ-L3-OAD-35019	T_Z	≤ TBD µm	> 0.01 Hz

REQ-L3-OAD-35023	R_X	≤ TBD μrad	> 1 Hz
REQ-L3-OAD-35027	R_Y	≤ TBD μrad	> 1 Hz
REQ-L3-OAD-35031	R_Z	≤ TBD μrad	> 0.01 Hz

Notes:

- Any drift in the M2 position actuation system over 100 s is in this jitter requirement.
- The requirements are specified in the M2 Front Surface coordinate system (see GMT-REF-00189).

Rationale:

- **T_X, T_Y, T_Z, and R_Z:** Jitter in these degrees of freedom has been allocated PSSN(0.5 μm) ≤ TBD in the NSIQ budget. This has been flowed down via Monte Carlo simulations to the errors listed here.
- **$R_X$and R_Y:** Jitter in these degrees of freedom has been allocated PSSN(0.5 μm) ≤ TBD in the NSIQ budget. This has been flowed down via Monte Carlo simulations to the errors listed here.

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

The M2 System shall provide actuation of the TX, TY, TZ, and RZ degrees of freedom with a transfer function response to commands within the limits specified in Figure [ID 33505].

Rationale: TBD

Notes: Offsets to the M2 segment rigid body 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.

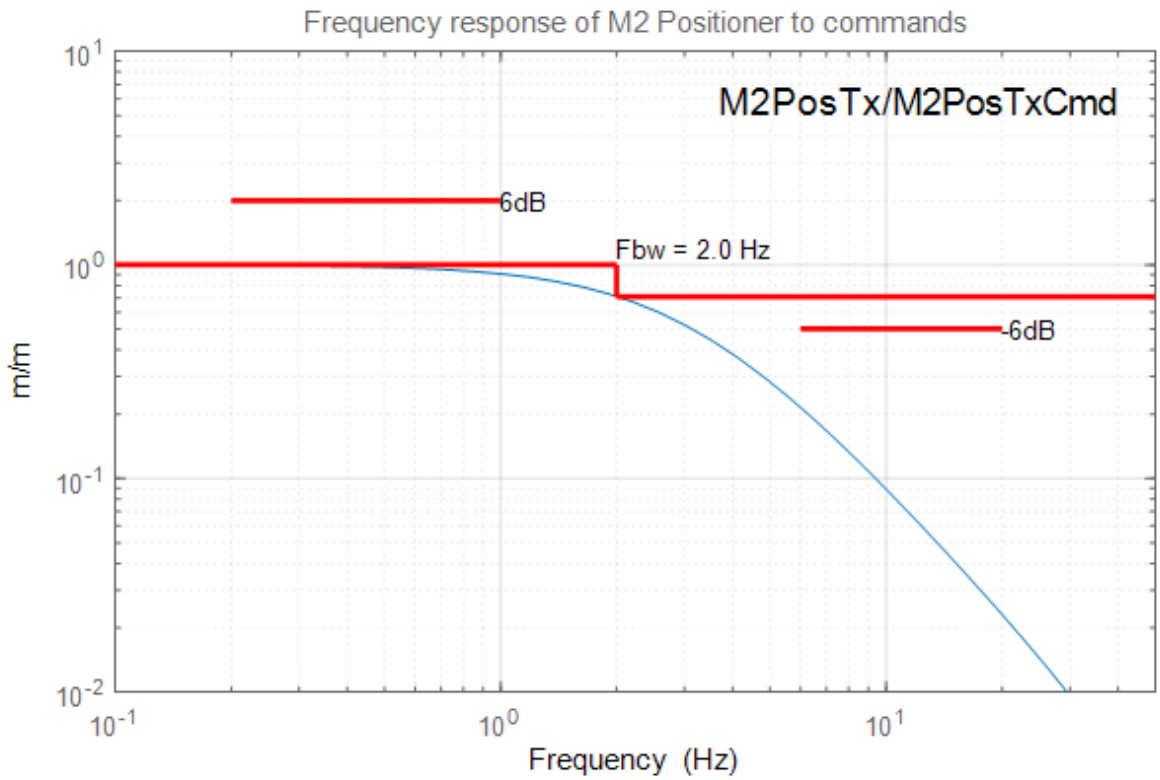


Figure 3-30 [ID 33505]: M2 Segment Tx, Ty, Tz, and Rz Transfer Function Limits

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

The M2 FSMS shall provide actuation of the segment R_X and R_Y degrees of freedom with a transfer function response to commands within the limit specified in Figure [ID 33506], when supported by a rigid base.

Rationale: The limiting transfer function requirement is derived from the KASI FSM prototype measured performance, with resonances suppressed, and is consistent with system segment tip-tilt RTF specified in REQ-L3-OAD-35337. It corresponds to a –3 dB bandwidth of 15 Hz when mounted on the telescope.

Notes: The FSM transfer function limit is specified by the function A(s) below.

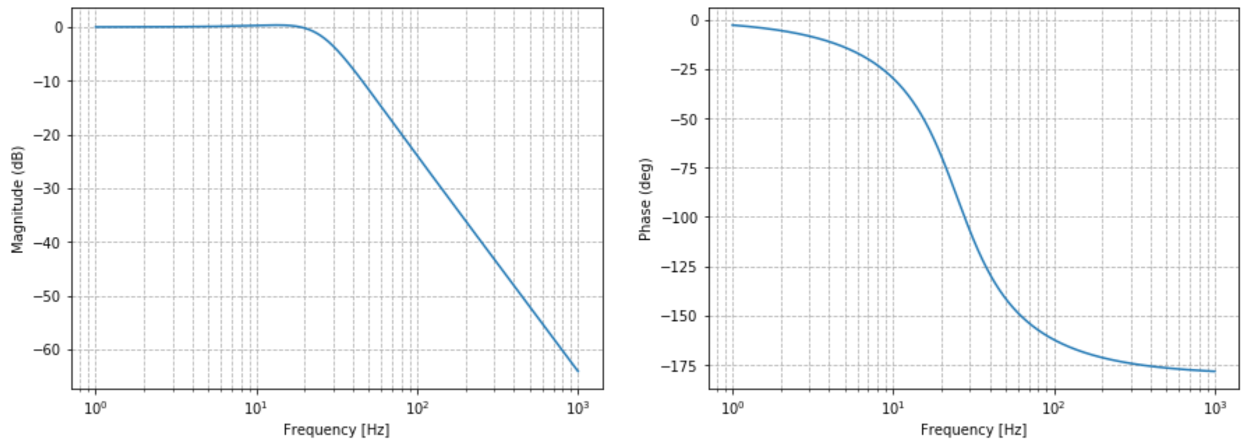


Figure 3-31 [ID 33506]: M2 FSMS Segment Rx and Ry Transfer Function Limits

$$A(s) = \frac{4\pi^2 f_z^2}{s^2 + s4\pi\delta_z f_z + 4\pi^2 f_z^2}$$

where s is the Laplace variable given by $s = 2i\pi\nu$ with ν the temporal frequency in Hertz, $f_z = 25$ Hz is the first resonant pole, and damping factor $\delta_z = 0.6$.

While a –3 dB bandwidth of 15 Hz is required on the telescope, this corresponds to a –29 Hz bandwidth for each segment when mounted on a rigid base.

3.3.2.2.4 M3

M3 Rigid Body Position Accuracy

The M3 System shall provide actuation of the M3 tip, tilt, and piston with the accuracy specified in Table [ID 35055].

Table 3-15 [ID 35055]: M3 Rigid Body Position Accuracy Requirements

Requirement ID	DOF	1σ Accuracy
REQ-L3-OAD-35059	R_X	≤ TBD μrad
REQ-L3-OAD-35062	R_Y	≤ TBD μrad
REQ-L3-OAD-35065	Piston	≤ TBD μm

Notes: The requirements are specified in the M3 coordinate system (see GMT-REF-00189).

Rationale: R_X and R_Y accuracy should be derived from the pupil motion capture range of the FP Instrument OIWFS. This has not been finalized.

M3 Rigid Body Position Repeatability

The M3 Subsystem shall provide actuation of the M3 tip, tilt, and piston with the repeatability specified in Table [ID 35073].

Table 3-16 [ID 35073]: M3 Rigid Body Position Precision Requirements

Requirement ID	DOF	1σ Accuracy
REQ-L3-OAD-35077	R_X	≤ 12 µrad (TBC)
REQ-L3-OAD-35080	R_Y	≤ 12 µrad (TBC)
REQ-L3-OAD-35083	Piston	≤ TBD

Notes:

- M3 will be controlled in closed-loop based on pupil measurements made by the FP Instrument On-Instrument Wavefront Sensor.
- The requirements are specified in the M3 coordinate system (see GMT-REF-00189).

Rationale: R_X and R_Y precision requirements are derived from the pupil motion budget. Piston precision will be driven by path length adjustment required during tip and tilt adjustment. Analysis has not yet been performed.

M3 Rigid Body Position Control Jitter

The M3 Subsystem shall provide actuation of the M3 tip, tilt, and piston with the control jitter specified in Table [ID 35092].

Table 3-17 [ID 35092]: M3 Rigid Body Position Jitter Requirements

Requirement ID	DOF	1σ Jitter	At frequency
REQ-L3-OAD-35097	R_X	≤ 1 µrad (TBC)	> 0.03 Hz
REQ-L3-OAD-35101	R_Y	≤ 1 µrad (TBC)	> 0.03 Hz
REQ-L3-OAD-35105	Piston	≤ TBD	> 0.01 Hz

Notes:

- Any drift in the M3 position actuation system over 30 s is included in this jitter requirement.
- The requirements are specified in the M3 coordinate system (see GMT-REF-00189).

Rationale: For R_X and R_Y, direct flowdown from pupil motion budget (old version: GMT-AO-REF-00519). Any drift or jitter below 0.03 Hz will be corrected by the 0.1 Hz update rate pupil alignment control loop.

REQ-L3-OAD-35112: M3 Rigid Body Position Transfer Function

The M3 System shall provide rigid body position actuation with a transfer function response to commands within the limits specified in Figure [ID 35115].

Rationale: TBD.

Notes: Offsets to the M3 rigid body position trajectory will typically be provided every 10 s. During target acquisition, they may be provided at up to 1 Hz update rate.

TBD

Figure 3-32 [ID 35115]: M3 Rigid Body Position Transfer Function Limits (TBD)

3.3.2.3 Wavefront Sensing and Metrology

Natural Seeing Wavefront Sensing and Metrology

The GMT in the Natural Seeing wavefront control mode shall measure the optical degrees of freedom at the minimum rates specified in Table [ID 35122].

Table 3-18 [ID 35122]: Natural Seeing Wavefront Sensing and Metrology

Requirement ID	System	Measurement	Rate
REQ-L3-OAD-35127	TMS	M1, M2, M3, C-ADC rigid body position w.r.t. OSS	≥ 0.1 Hz
REQ-L3-OAD-35131	AGWS	Wavefront error at ≥3 locations in DG focal plane with at least 24×24 sampling of the pupil. (WFS)	≥ 0.03 Hz
REQ-L3-OAD-35135	AGWS	Segment tip-tilt error (TT7)	≥ 200 Hz
REQ-L3-OAD-35139	Instrument	Image motion and global focus error	≥ 0.03 Hz

Notes: Each AGWS probe can be configured to measure the system wavefront sampled in various ways, including the wavefront slope sampled on a spatial scale < 1.05 m (WFS) and the average tip and tilt across each segment (TT7).

Instruments which do not provide a Flexure Sensor measuring image motion and focus error (e.g. the Commissioning Camera) may only achieve the specified Natural Seeing image quality over limited exposure times.

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.

3.3.2.3.1 TMS

TMS Capture Range

The TMS shall measure the locations of M1, M2, M3 and the C-ADC with the capture ranges specified in Table [ID 35150].

Table 3-19 [ID 35150]: TMS Capture Range Requirements

Requirement	DOF	Capture Range (surface)
REQ-L3-OAD-35154	M1 T_X & T_Y	± TBD mm
REQ-L3-OAD-35157	M1 T_Z	± TBD mm
REQ-L3-OAD-35160	M1 R_X & R_Y	± TBD mrad
REQ-L3-OAD-35163	M1 R_Z	± TBD mrad
REQ-L3-OAD-35166	M2 T_X & T_Y	± TBD mm
REQ-L3-OAD-35169	M2 T_Z	± TBD mm
REQ-L3-OAD-35172	M2 R_X & R_Y	± TBD mrad
REQ-L3-OAD-35175	M2 R_Z	± TBD mrad
REQ-L3-OAD-35178	M3 T_X & T_Y	± TBD mm
REQ-L3-OAD-35181	M3 T_Z	± TBD mm
REQ-L3-OAD-35184	M3 R_X & R_Y	± TBD mrad
REQ-L3-OAD-35187	M3 R_Z	± TBD mrad
REQ-L3-OAD-35190	C-ADC T_X & T_Y	± TBD mm
REQ-L3-OAD-35193	C-ADC T_Z	± TBD mm
REQ-L3-OAD-35196	C-ADC R_X & R_Y	± TBD mrad
REQ-L3-OAD-35199	C-ADC R_Z	± TBD mrad

Notes: The TMS capture range must be sufficient to accommodate all expected manufacturing and installation errors, and extreme flexure conditions of the telescope. Since a laser tracker network will be used as the Large Capture Range component of the TMS, this requirement primarily drives the tolerances on the required lines of sight of the laser trackers.
M1 and M2 displacements are expressed in the M1ST and M2ST coordinate systems, which are OSS

coordinates translated and rotated to the vertex of each segment. M3 displacements are in the M3 coordinate system, and C-ADC displacements are in the OSS coordinate system.

Rationale: Should be derived from the M1, M2, M3, and C-ADC motion budgets, with margin added.

TMS Accuracy

The TMS shall measure the locations of M1, M2, and M3 segments with the accuracy specified in Table [ID 35208].

Table 3-20 [ID 35208]: 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	≤ TBD µm
REQ-L3-OAD-35239	M3 T_Z	≤ TBD µm
REQ-L3-OAD-35242	M3 R_X & R_Y	≤ TBD µrad
REQ-L3-OAD-35245	M3 R_Z	≤ TBD µrad
REQ-L3-OAD-35248	C-ADC T_X & T_Y	≤ TBD µm
REQ-L3-OAD-35251	C-ADC T_Z	≤ TBD µm
REQ-L3-OAD-35254	C-ADC R_X & R_Y	≤ TBD µrad
REQ-L3-OAD-35257	C-ADC R_Z	≤ TBD µrad

Notes: The Telescope Metrology System (TMS) provides the feedback to initially align the telescope main optics (M1, M2, C-ADC, and M3), and maintain alignment during slews. Once guiding, feedback is provided by the wavefront sensors of the AGWS. The accuracy of the TMS must overlap the capture range of the AGWS.

Rationale: Consistent with ≥ 99.9% probability of capture by the Fast Segment Tip-Tilt and Active Optics control loops with the capture ranges specified in Table [ID 35266].

3.3.2.3.2 AGWS

AGWS Capture Range

The AGWS shall measure the system wavefront with the capture ranges specified in Table [ID 35266].

Table 3-21 [ID 35266]: AGWS Natural Seeing Mode Capture Range Requirements

Requirements	Measurement	Min. Capture Range
REQ-L3-OAD-35270	TT7	± 7.5 arcsec
REQ-L3-OAD-35273	WFS	± 1.6 arcsec

Notes: The Fast Segment Tip-Tilt control loop (using one AGWS probe in the TT7 configuration) is used to rapidly "stack" the segment images following TMS alignment. Residual wavefront error after stacking will then have less than ± 1.6 arcsec wavefront slope over each WFS subaperture and ≤ 12.2 µm RMS segment phase piston error.

Rationale: Ensures ≥ 99.9% probability of capture after TMS alignment (see analysis in GMT-DOC-01244 [7]).

AGWS Accuracy

The AGWS shall measure the system wavefront with the accuracy specified in Table [ID 35281].

Table 3-22 [ID 35281]: AGWS Natural Seeing Mode Accuracy Requirements

Requirements	Measurement	1σ Accuracy
REQ-L3-OAD-35285	TT7	≤ 28 mas
REQ-L3-OAD-35288	WFS	≤ 60 mas

Notes: The WFS requirement is stated in terms of the error in the average wavefront slope estimation over each subaperture, assuming 48×48 subapertures across the pupil.

Rationale:

- **Segment Tip-Tilt:** TBD
- **Wavefront Slope:** 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. See GMT-DOC-00145.

3.3.2.3.3 Instrument Flexure Sensor

Instrument Flexure Sensor Capture Range

Each Instrument operating in the NS mode shall provide a Flexure Sensor which measures the system wavefront with the capture ranges specified in Table [ID 35298].

Table 3-23 [ID 35298]: Instrument Flexure Sensor Capture Range Requirements

Requirements	Focal Station	Measurement	Min. Capture Range
REQ-L3-OAD-35303	DG	Image Motion	± 1.2 (TBC) arcsec
REQ-L3-OAD-35307	FP, AP, IP	Image Motion	± 1.5 (TBC) arcsec
REQ-L3-OAD-35311	All others	Focus	± (TBC) 5.0 mm

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.

Rationale:

- **Image Motion:** Sum of the total Guided Pointing Budget at FP focus (± 1.0 arcsec) and the maximum allowable Mount to Instrument interface flexure (MNT-XXX)
- **Focus:** Matches ± 5.0 mm allowable total axial position error, derived from NSIQ budget allocation.

Instrument Flexure Sensor Accuracy

Each Instrument operating in the NS mode shall provide a Flexure Sensor which measures the system wavefront with the accuracy specified in Table [ID 35322].

Table 3-24 [ID 35322]: Instrument Flexure Sensor Accuracy Requirements

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

Notes: The focus measurement accuracy is specified in term of RMS wavefront error.

Rationale: The combination of both errors has been allocated PSSN(0.5 µm) ≤ 0.9992. See analysis in GMT-SE-DOC-00145 Rev B.

3.3.2.4 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. Latency allocations for global and segment tip-tilt correction in the Natural Seeing mode are specified in Table [ID 70739].

Table 3-25 [ID 70739]: Natural Seeing Tip-Tilt Latency Budget

Requirement	Source	Latency [ms]	Comment
REQ-L3-OAD-70738	AGWS TT7 Readout	5.00	At 200 Hz frame rate
REQ-L3-OAD-70740	AGWS TT7 Slope Processing	0.50	From last pixel received to last slope transmitted
REQ-L3-OAD-70741	OCS TT7 Computation	0.50	Includes data transmission from AGWS and to FSMS
	Total Latency	6.00	

The degree of compensation of optical disturbances is specified as the envelope of the rejection transfer function (RTF) for each degree of freedom. These envelopes are based on a simple integrator controller, with actuators treated as second-order high-pass filters. In this case, the transfer function in the Laplace domain is given by

$$E(s) = \frac{1}{1 - \dfrac{4\pi^2 f^2 e^{-\tau s}(e^{-Ts} - 1) g_i}{T^2 s^2 (4\pi^2 f^2 + 4\pi f \delta s + s^2)}}$$

where the parameters f and δ are the pole frequency and damping factor of the actuator, T is the optical sensor integration time, τ is the control loop latency and g_i is the control loop integrator gain.

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

The Natural Seeing observing mode rejection transfer function for global and segment wavefront tip-tilt disturbances shall not exceed that in Figure [ID 33519].

Rationale: The specified rejection transfer function envelope is that for a simple integrator controller with the sensor and actuator parameters listed in Table [ID-35342]. More sophisticated controllers are expected to provide greater rejection and reduced overshoot.

Notes: The 0 dB crossing is at 7.4 Hz.

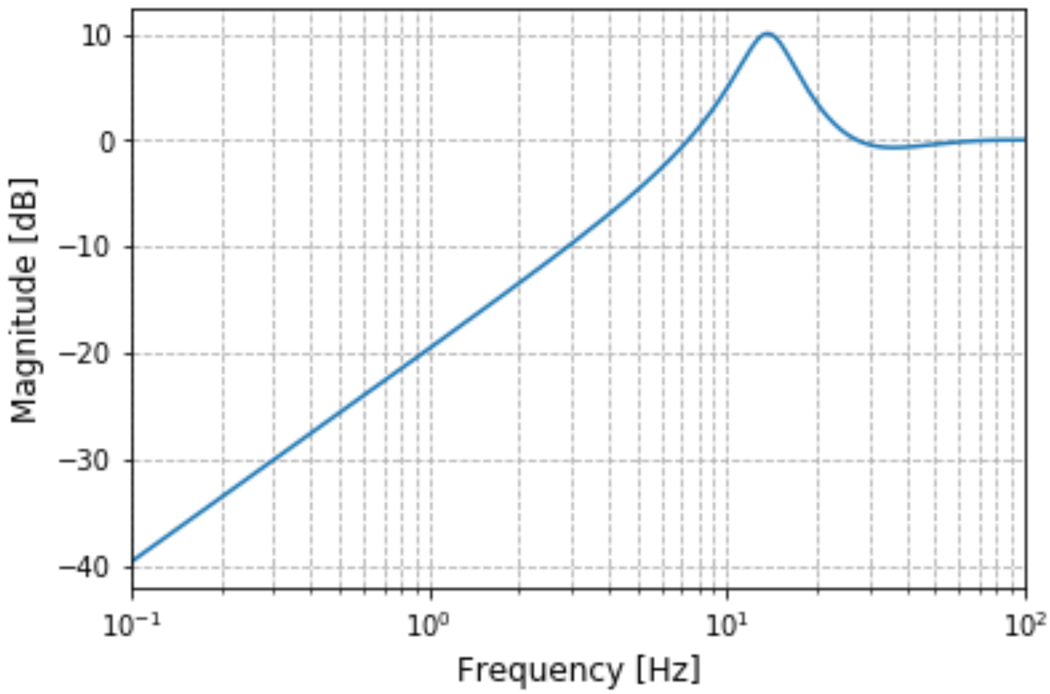


Figure 3-33 [ID 33519]: Natural Seeing Mode Tip-Tilt RTF Envelope

Table 3-26 [ID 35342]: Natural Seeing Tip-Tilt RTF Parameters

Parameter Name	Parameter	Value
FSM Pole Frequency	f	25 Hz
FSM Damping	δ	0.60
AGWS TT7 Sensor Integration Time	T	5.0 ms
Total Latency	τ	6.0 ms
Tip-tilt Controller Gain	g_i	0.3

REQ-L3-OAD-35344: Natural Seeing Active Optics Rejection Transfer Function

The Natural Seeing observing mode rejection transfer function for all controlled disturbances other than global and segment tip-tilt shall not exceed that in Figure [ID 33525].

Rationale: The specified rejection transfer function envelope is that for a simple integrator controller with the sensor and actuator parameters listed in Table [ID-35349].

Notes: The disturbances to which this RTF applies includes all those generated by the Mount, rigid body degrees of freedom of the M1 and M2 segments, and 27 M1 segment bending modes, except for segment and global tip-tilt.

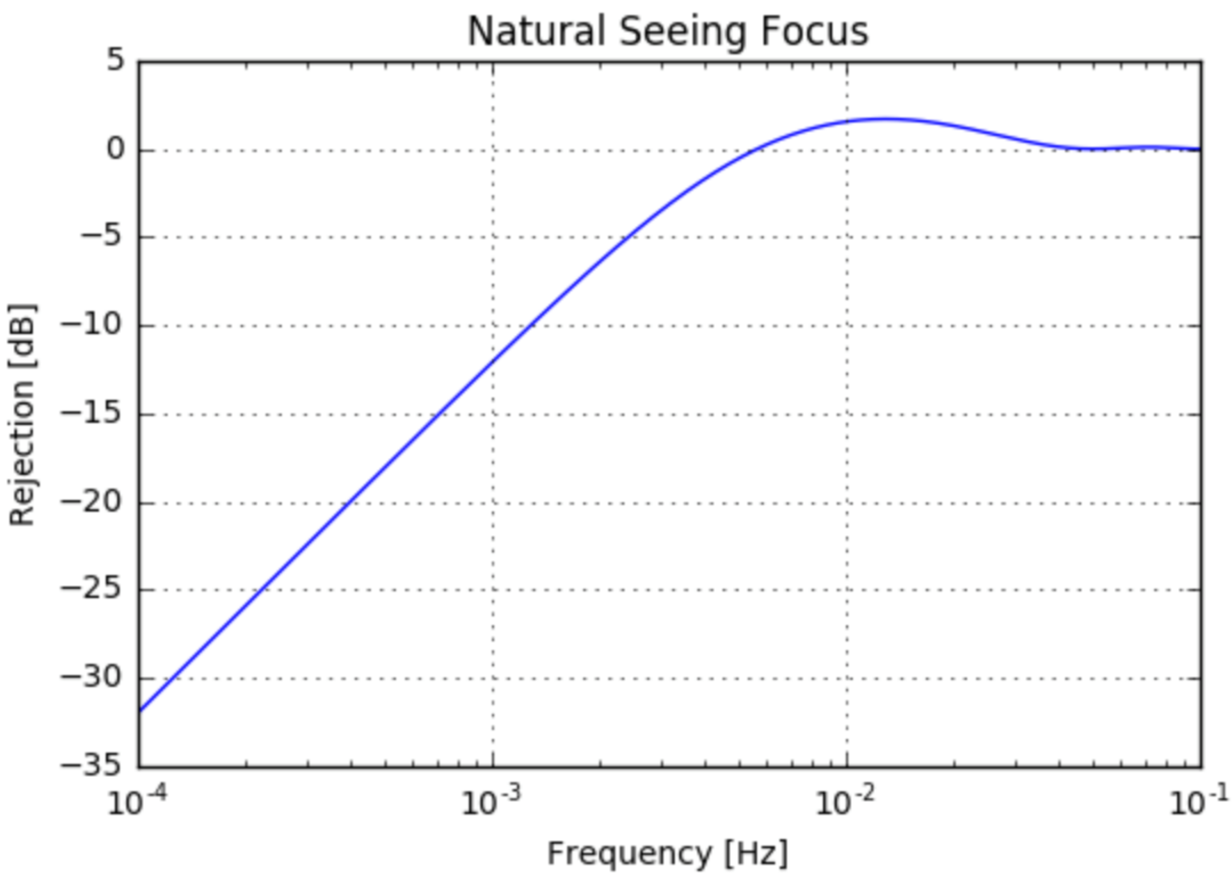


Figure 3-34 [ID 33525]: Natural Seeing Mode Active Optics RTF Envelope

Table 3-27 [ID 35349]: Natural Seeing Active Optics RTF Parameters

Parameter Name	Parameter	Value
Actuator Pole Frequency	f	1 Hz (TBC)
Actuator Damping	δ	0.75 (TBC)

AGWS WFS Integration Time	T	30 s
Total Latency	τ	15 ms (TBC)
Active Optics Controller Gain	g_i	0.5

3.3.3 Ground Layer Adaptive Optics

3.3.3.1 Control Strategy

The GLAO wavefront control mode uses 4 wavefront sensors in the AGWS, and one in the instrument, to deliver ground-layer turbulence corrected images at any focal station. The measurements of these 5 wavefront sensors are used in 4 primary control loops to correct errors in the model trajectories of the optical degrees of freedom. Segment phasing is not required in the GLAO wavefront control mode.

A block diagram of the wavefront control strategy is provided in Figure [ID 33531]. The Instrument Flexure Control Loop operates identically to that of the Natural Seeing wavefront control mode.

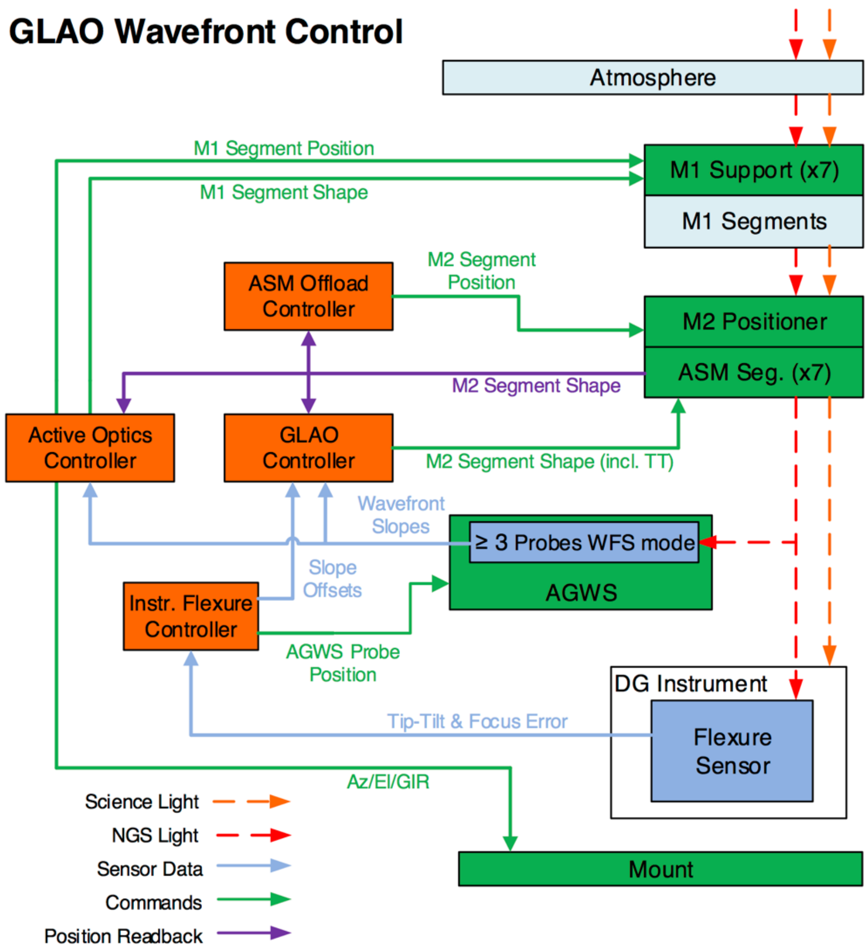


Figure 3-35 [ID 33531]: GLAO Wavefront Control Block Diagram

REQ-L3-OAD-35356: GLAO Control Loop

The GLAO Control 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-35360: Active Optics Control Loop in GLAO Mode

The Active Optics Control Loop in the GLAO control mode 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-35364: ASM Offload Control Loop in GLAO Mode

The ASM offload control loop in the GLAO control mode shall offload low-order face sheet bending modes 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.

3.3.3.2 Controlled Degrees of Freedom

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

The ASM in the GLAO wavefront control mode shall have at least 60 controlled modes per segment.

Rationale: Analysis in FWN70 demonstrates that 60 controlled Zernike (or Karhunen-Loève) modes per segment are sufficient to achieve the required image quality.

Notes: The driving requirements on the ASM flowed down from the NGAO wavefront control mode (OPM 9).

3.3.3.3 Wavefront Sensing

GLAO Wavefront Sensing and Metrology

The GMT in the GLAO wavefront control mode shall utilize the wavefront sensors specified in Table [ID 35378].

Table 3-28 [ID 35378]: GLAO Wavefront Sensing and Metrology

Requirement ID	System	Measurement	Rate
REQ-L3-OAD-35383	TMS	M1, M2, M3, C-ADC rigid body position w.r.t. OSS	≥ 0.1 Hz
REQ-L3-OAD-35387	AGWS	Wavefront error at 4 locations in DG focal plane with at least 48×48 sampling of the pupil. (WFS)	≥ 88 Hz
REQ-L3-OAD-35391	Instrument	Image motion and global focus error	≥ 0.03 Hz

Notes: The TMS and Instrument Flexure Sensor requirements are identical to the Natural Seeing wavefront control mode.

Rationale: A trade between the use of laser guide stars (LGS) and natural guide stars (NGS) concluded that the performance benefit of LGS GLAO was outweighed by the cost and efficiency benefits of an NGS GLAO architecture (see GMT-RVW-00407). While 3 NGS 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 88 Hz. For more detail, see FWN 89 and GMT-DOC-01533.

3.3.3.4 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. Latency allocations for the GLAO control loop are specified in Table [ID 70746].

Table 3-29 [ID 70746]: 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	

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

The GLAO observing mode rejection transfer function for all controlled disturbances shall not exceed that in Figure [ID 33532].

Rationale: The specified rejection transfer function envelope is that for a simple integrator controller with the sensor and actuator parameters listed in Table [ID-35403].

Notes: This RTF applies to all optical disturbances with spatial frequencies below ~1 m. The 0 dB crossing is at 5.7 Hz.

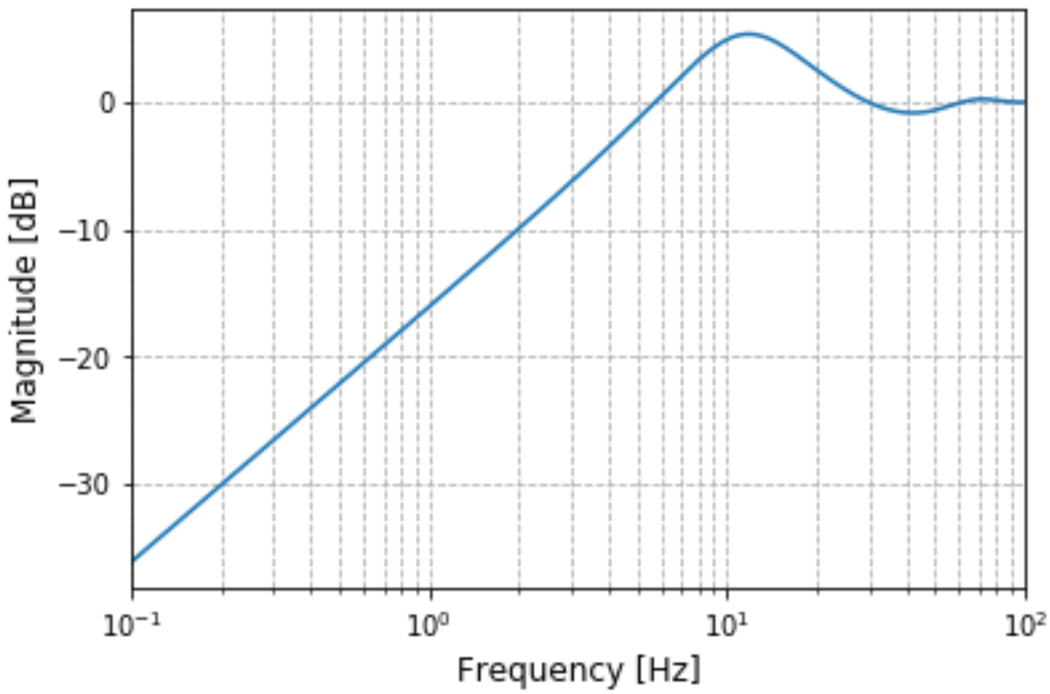


Figure 3-36 [ID 33532]: GLAO Control Loop RTF Envelope

Table 3-30 [ID 35403]: GLAO Control Loop RTF Parameters

Parameter Name	Parameter	Value
Actuator Pole Frequency	f	800 Hz
Actuator Damping	δ	0.75
AGWS WFS Integration Time	T	10.0 ms
Total Latency	τ	12.0 ms
GLAO Controller Gain	g_i	0.4

3.3.4 Natural Guide Star Adaptive Optics

3.3.4.1 Control Strategy

The NGAO wavefront control mode uses an on-axis Natural Guide Star Wavefront Sensor (NGWS) and the Adaptive Secondary Mirror (ASM) to correct telescope and atmospheric wavefront errors with high spatial and temporal bandwidth, over a field of view limited by atmospheric anisoplanatism. Instruments which use this mode will generally be located at either the FP or AP focal stations. The AGWS wavefront sensors, using the light of off-axis guide stars in the DG focal plane outside of the shadow of the M3 mirror, measure residual field-dependent aberrations. These are used to correct Mount tracking errors and position and shape errors of M1 segments. An On-Instrument Wavefront Sensor (OIWFS) within the instrument is used to correct flexure and errors in the non-common light path between the NGWS and instrument focal plane, and flexure of M3.

A block diagram of the wavefront control strategy is provided in Figure [ID 33538].

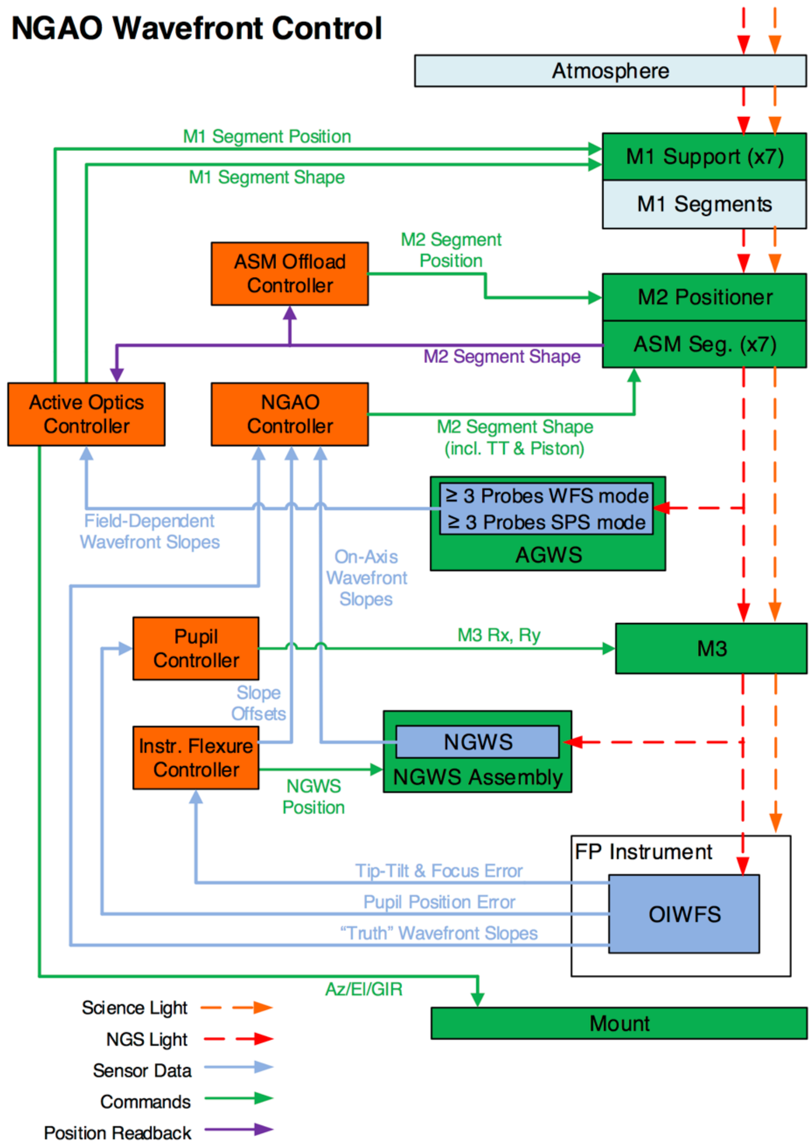


Figure 3-37 [ID 33538]: NGAO Wavefront Control Block Diagram

REQ-L3-OAD-35410: NGAO Control Loop

The NGAO Control Loop shall use the on-axis wavefront error measured by the NGWS to control all telescope and atmospheric phase errors with spatial scales >57 cm, including segment phase piston.

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 shall use the measurements of the AGWS Shack-Hartmann and phasing sensors simultaneously to control field-dependent aberrations (including field-dependent segment piston) in the science field of view.

Rationale: While the NGWS measures on-axis wavefront errors, the AGWS will measure residual telescope field-dependent aberrations and drive their compensation by acting on M1 segment position and shapes.

Notes: An M1 segment tilt compensated on-axis by the corresponding M2 segment tilt produces no errors on axis but a field-dependent segment piston aberration increasing linearly with the field angle.

REQ-L3-OAD-35414: Dynamic Calibration Control Loop in NGAO Mode

The Dynamic Calibration Control Loop in the NGAO control mode shall use the tip-tilt, focus, and low-order wavefront error measured by the instrument On-Instrument Wavefront Sensor to correct differential flexure and non-common path aberrations (NCPA) between the instrument and the NGWS.

Rationale: Differential flexure between the instrument and NGWS must be compensated by instrument measurements fed back to the TCS, which are used to update NGWS position and focus (large offsets) or modify the NGWS reference slopes (small offsets). Other non-common path aberrations can similarly be corrected by updating the NGWS reference slopes in the NGAO Controller.

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 shall use pupil position (chief ray angle) measured by the instrument On-Instrument Wavefront Sensor to correct the R_X and R_Y degrees of freedom of M3.

Rationale: The most significant error caused by tip or tilt of M3 will cause a pupil misalignment on the instrument (and NGWS). This must be detected by the instrument OIWFS and fed back to the OCS, which will command M3 to compensate. This will result in image motion, which will be corrected by the NGAO control loop.

Notes: The NGWS includes an independent internal pupil alignment control loop.

REQ-L3-OAD-97015: ASM Offload Control Loop in NGAO Mode

The ASM offload control loop in the NGAO control mode shall offload low-order face sheet bending modes 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.

3.3.4.2 Controlled Degrees of Freedom

REQ-L3-OAD-35423: ASM NGAO Controlled Degrees of Freedom

The ASM in the NGAO wavefront control mode shall have at least 600 controlled modes per segment.

Rationale: A budget allocation for fitting error of ≤ 70 nm RMS requires at least 600 modes per segment to be controlled (TBC).

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: ASM Segment "Best flat" Repeatability

The M2 ASM shall provide control of segment shape with an accuracy of ≤ 200 nm (TBC) RMS surface when applying a saved "best-flat" command.

Rationale: A 200 nm RMS surface error is significantly smaller than the atmospheric wavefront error (typically ~2 μm RMS), and sufficient to ensure rapid convergence of the Active Optics and Adaptive Optics control loops.

Notes: The reference "best-flat" shape of current-generation ASMs can be calibrated to ~20 nm RMS surface. However, this calibration is affected by gravity flexure, temperature, and humidity, and will degrade over time.

REQ-L3-OAD-35431: ASM Segment Shape Precision

The M2 ASM shall provide control of segment shape with a precision of ≤ 17.3 nm RMS surface.

Rationale: Allocation in NGAO WFE budget. It comprises M2 shape fabrication errors, wind-induced errors, and errors due to failed actuators or capacitive sensors.

REQ-L3-OAD-35435: ASM Segment Shape Control Jitter

The M2 System shall provide control of segment shape with a control jitter of ≤ 5 nm (TBC) RMS surface.

Rationale: Allocation in NGAO WFE budget.

ASMS Stroke Requirements

The M2 ASMS shall provide a range of actuation no less than that specified in Table [ID 35442].

Table 3-31 [ID 35442]: M2 ASMS Stroke Requirements

Requirement ID	DOF	Min. Stroke [surface]
REQ-L3-OAD-35446	Segment tip and tilt	45 µrad P-V
REQ-L3-OAD-35449	Segment piston	50 µm P-V
REQ-L3-OAD-35452	Higher-order modes	10 µm P-V

Notes: The segment tip-tilt and piston requirements must be met simultaneously. High order errors may be combined by root-sum-square with these.

Rationale:

Flowed down from 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 x 5 x sigma results in a requirement of ≥ 45 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 x 5 x sigma results in a requirement of ≥ 50 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 40% margin, is 1.0 µm RMS surface. Defining P-V as 2 x 5 x sigma results in a requirement of ≥ 10 µm P-V surface.

REQ-L3-OAD-35459: ASM Segment Shape Transfer Function

The M2 ASM 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 [ID 87082], when supported by a rigid base.

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.

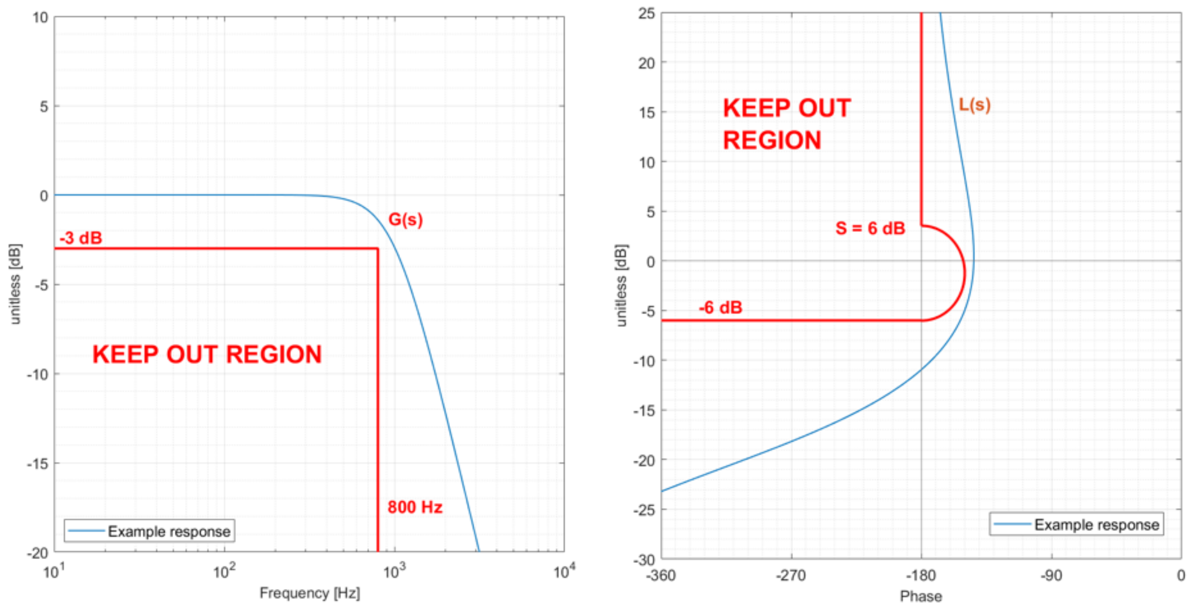


Figure 3-38 [ID 87082]: ASMS Transfer Function Limits

3.3.4.3 Wavefront Sensing

NGAO Wavefront Sensing and Metrology

The GMT in the NGAO wavefront control mode shall utilize the wavefront sensors specified in Table [ID 35470].

Table 3-32 [ID 35470]: NGAO Wavefront Sensing and Metrology

Requirement ID	System	Measurement	Rate
REQ-L3-OAD-35475	TMS	M1, M2, M3, C-ADC rigid body position w.r.t. OSS	≥ 0.1 Hz
REQ-L3-OAD-35479	AGWS	Wavefront error at ≥3 locations in DG focal plane with at least 24×24 sampling of the pupil. (WFS)	≥ 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-35487	NGWS	On-axis wavefront error with at least 90×90 sampling of the pupil	≥ 1000 Hz
REQ-L3-OAD-35491	Instrument	Image motion and global focus error	≥ 0.03 Hz
REQ-L3-OAD-35495	Instrument	Low-order (~16×16) wavefront error	≥ 0.03 Hz
REQ-L3-OAD-35499	Instrument	Pupil position (chief ray angle) error	≥ 0.03 Hz

Notes: The TMS requirements are identical to the Natural Seeing wavefront control mode.

Rationale:

- **AGWS**: The AGWS WFS is used for initial 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 keep the fitting error limited by the ASM actuator count.
- **Instrument:** To maintain the specified image quality, the instrument OIWFS must measure flexure and non-common path aberrations between the instrument focal plane and NGWS. The feedback on pupil alignment is required by the pupil motion allocation (Section 4.7).

REQ-L3-OAD-35507: Direct Feed Wavefront Sensor 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 [ID-33546].

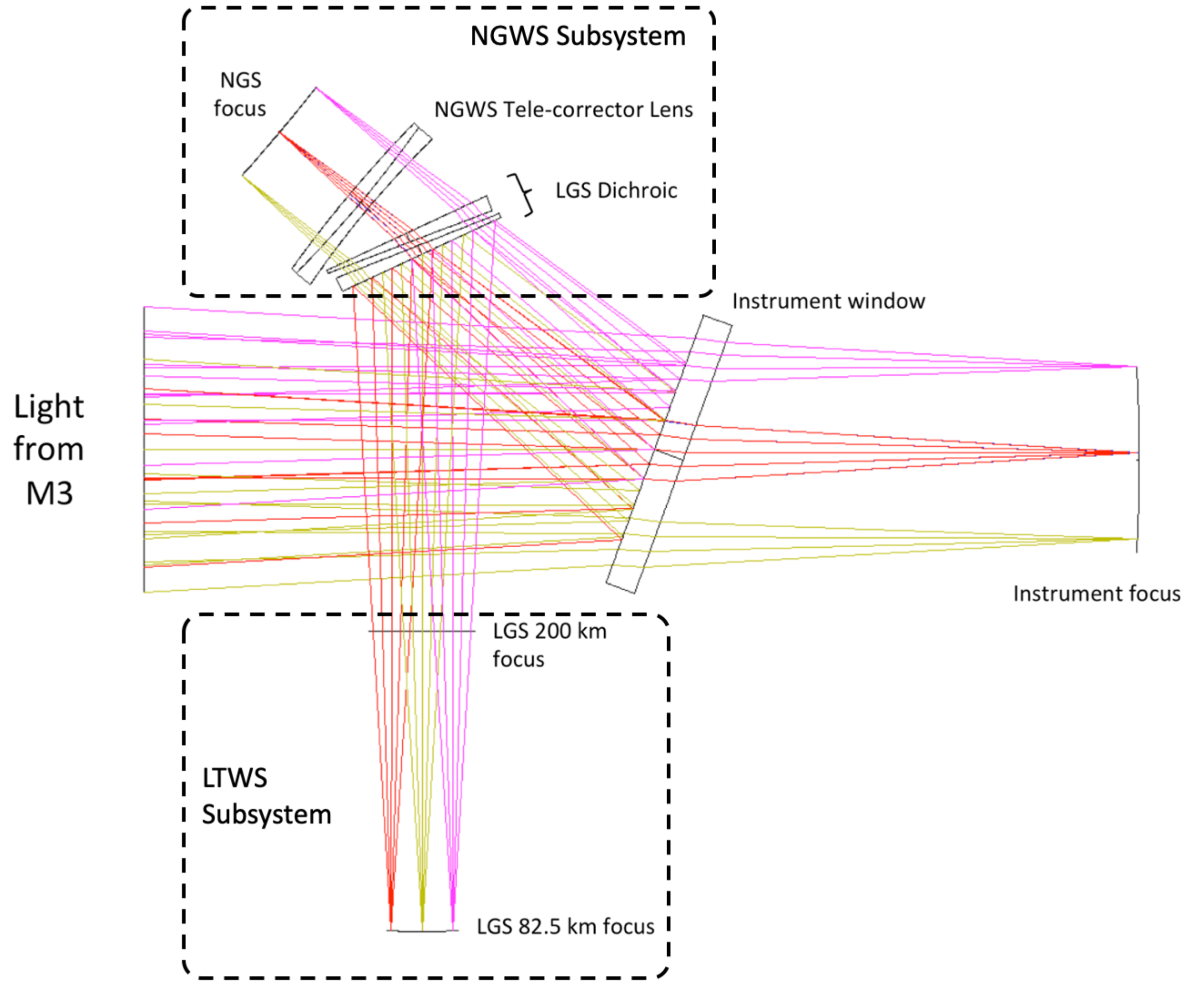


Figure 3-39 [ID 33546]: Direct Feed NGAO and LTAO Wavefront Sensing Architecture

REQ-L3-OAD-35512: Natural Guide Star Wavefront Sensor

The NGWS shall be a pyramid wavefront sensor.

Rationale: A pyramid wavefront sensor is sensitive to both continuous wavefront errors and phase errors across a discontinuous pupil, while maintaining low aliasing error.

Notes: While the pyramid wavefront sensor can sense phase errors across gaps, it is susceptible to phase wrapping when the wavefront error across the gap exceeds one half of the wavelength.

REQ-L3-OAD-35516: NGWS Sensitivity

The NGWS shall measure the wavefront error of an R = 10 guide star with a measurement error of ≤ 45 nm RMS wavefront at ≥1000 Hz (TBC).

Rationale: The NGAO wavefront error budget allocated ≤ 55 nm RMS to measurement error, and ≤ 60 nm RMS to temporal error. This requires a minimum of 1000 Hz frame rate (see ARC-AO-DOC-00011).

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 for NGAO

The AGWS in the NGAO wavefront control mode shall measure on-axis and field-dependent segment phase piston with the accuracy specified in Table [ID 35526].

Table 3-33 [ID 35526]: 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: Sufficient for NGWS segment phase piston capture with ≥ 99.9% probability (TBR), and within WFE budget allocation for a potential future MCAO capability.

NGWS Capture Range

The NGWS shall have the capture ranges specified in Table [ID 35543].

Table 3-34 [ID 35543]: NGWS Capture Range Requirements

Requirements	Degree of Freedom	Min. Capture Range	Rationale
REQ-L3-OAD-35548	Tip and Tilt	± 0.5 arcsec (TBC)	Sum of maximum flexure allotted to AGWS, Mount, M3, and Instrument in [Guided Pointing Budget].
REQ-L3-OAD-35552	Focus	± 2.0 mm (TBC)	Instrument axial position tolerance.
REQ-L3-OAD-35556	Segment phase piston	± 1 µm (TBC)	On-axis segment phase piston error after AGWS feedback is specified to be ≤

			50 nm RMS with 80% sky coverage. However, error at 99% sky coverage is TBD…
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 [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.

3.3.4.4 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. Latency allocations for the NGAO control loop are specified in Table [ID 70754].

Table 3-35 [ID 70754]: 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	

REQ-L3-OAD-35570: NGAO Rejection Transfer Function

The NGAO observing mode rejection transfer function for all controlled disturbances shall not exceed that in Figure [ID 33547].

Rationale: The specified rejection transfer function envelope limits the overshoot of the RTF that could otherwise excite the ASM resonant mode, called the "reference body mode", at ~130 Hz.

Notes: The example RTF shown in blue utilizes a double integrator controller. This RTF applies to all optical disturbances with spatial frequencies below 0.5 m. The 0 dB crossing is at ~30 Hz.

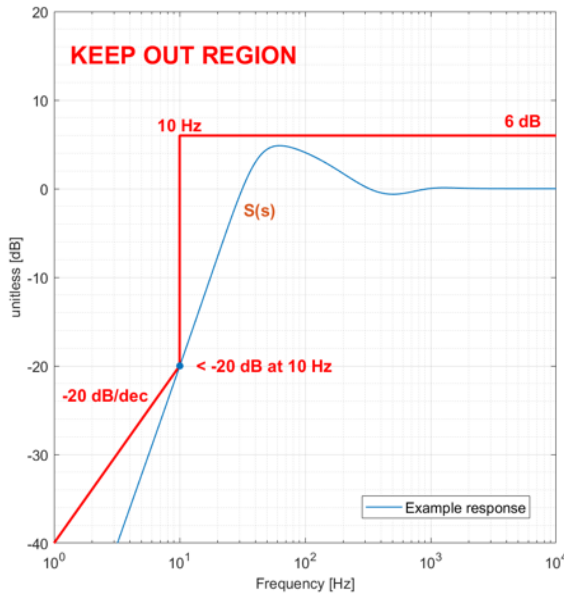
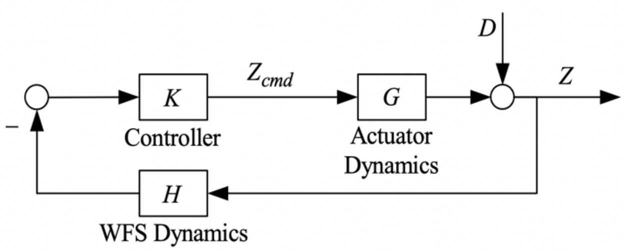


Figure 3-40 [ID 33547]: NGAO RTF Limits

The Adaptative Optics (AO) control loop for one control mode response is shown below:



The signals are the mode response Z (piston, tip, tip, etc.), the modal command , and the wavefront disturbance D. The actuator dynamics $G(s)$ is the response of the adaptive secondary mirror from the modal command to the modal response of the face-sheet. The AO controller is $K(s)$. The dynamics of the Wave Front Sensor (WFS) is $H(s)$. An approximate model of the WFS is:

$$H(s) = \frac{1 - e^{-sT_i}}{sT_i} \times e^{-s\tau_\ell} \approx e^{-s\tau_w}$$

Where is the integration time, is the latency time (the sum of readout, slope processing, and computation times), and is the approximate total delay.

The Loop Transfer Function (LTF) response of the AO control loop is:

$$L(s) = G(s)K(s)H(s)$$

And the Rejection Transfer Function (RTF) is:

$$S(s) = \frac{Z}{D} = \frac{1}{1+L(s)}$$

Requirement 35570 (NGAO RTF) provides a bound for $L(s)$, which must be satisfied for each modal response.

The ideal response is computed with the following systems:

$$G(s) = \frac{\omega_1^2}{s^2 + 2\zeta_1\omega_1 s + \omega_1^2} \text{ where } \omega_1 = 2\pi f_1,\ f_1 = 1000 \text{ [Hz] and } \zeta_1 = 0.7$$

$$H(s) = e^{-s\tau_w}\text{, where } T_i = 1.00 \text{ [msec]}, \tau_\ell = 0.80 \text{ [msec], and } \tau_w = 1.30 \text{ [msec]}$$

$$K(s) = \frac{2\pi f_c(s + 2\pi f_2)}{s^2}\text{, whre } f_c = 41 \text{ [Hz] and } f_2 = 25 \text{ [Hz]}$$

3.3.5 Laser Tomography Adaptive Optics

This section is under construction.

3.3.5.1 Control Strategy

3.3.5.2 Controlled Degrees of Freedom

3.3.5.3 Wavefront Sensing

3.3.5.4 Disturbance Rejection

3.3.6 Calibration

Regular calibration of the AO system will be necessary. It is advantageous to have calibration light go through as much of the operational optical path as possible, hence calibration payloads will be mounted on a deployable arm that positions them near or at the prime focus.

3.3.6.1 Wavefront Control Calibration System

REQ-L3-OAD-35586: Wavefront Control Calibration System

The GMT shall provide, at the telescope, a system for calibrating all deformable mirrors and wavefront sensors required for each of the AO observing modes.

Rationale: This requirement is a flowdown from the SRD and is addressed by the WCCS.

REQ-L3-OAD-35589: WCCS Retracted Position

The Mount shall retract WCCS Deployment Mechanism(s) 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 Deployment Mechanisms shall vignette the projected calibration source beams by less than 5% [goal: 0%].

Rationale: The AOS and instrumentation sources require even illumination of the pupil. Vignetting of the beam by the deployment mechanism will cause loss of illumination at those points in the pupil.

Notes: This requirement only applies to the contribution of the deployment mechanism.

WCCS Deployment Accuracy

The WCCS deployment shall position the WCCS relative to the true prime focus of the primary mirrors to the following tolerances:

Table 3-36 [ID 35599]: WCCS Deployment Accuracy

Degree of freedom	Requirement #	Value	Documentation
Maximum position error in OSS Tx and Ty	REQ-L3-OAD-35605	≤ 1.5 mm P–V	Loose tolerance due to ability to realign M2 to the WCCS.
Maximum position error in OSS Tz	REQ-L3-OAD-35609	≤ 1.0 mm P–V	Loose tolerance due to ability to realign M2 to the WCCS.

Maximum position error in OSS Rx and Ry	REQ-L3-OAD-35613	≤ 17 mrad P–V	Loose tolerance due to ability to realign M2 to the WCCS.
Maximum vibration at >10 Hz	REQ-L3-OAD-35617	≤ 2.0 µm RMS	Tolerance derived for the WCCS LTAO Source optical design.

Notes: These accuracies are to be maintained over all zenith angles. The WCCS itself will align to a tighter tolerance once it has been deployed. The Telescope Metrology System may be used to maintain this accuracy.

Rationale: The WCCS must accurately represent a point source at the prime focus of the telescope.

REQ-L3-OAD-35622: WCCS Off-Telescope

The WCCS shall be available in the M2 Test Lab for testing and calibrations.

Rationale: M2 testing, or integration of instruments with the WFCS, require the WCCS in the M2 Test Lab. This can be accomplished by building a duplicate WCCS or by moving the WCCS between the telescope to the M2 Test Lab.

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 observing 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 [ID 35728].

Table 4-1 [ID 35728]: 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 ε = 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 α = 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-AO-REF-00518) for vibration is 1 mas for all sources not associated with wind. NGAO is the limiting observing mode for vibration. Thus, any actuators involved in the response to wind loads are also not included, such as:

- Azimuth Drives
- Elevation Drives
- GIR drives
- Primary mirror pneumatic actuators
- Hard points
- M2 positioner
- ASM subsystem
- FSM subsystem

A full count of potential sources, background on analysis, and justification for the budget are given in (GMT-DOC-03140) “GMT Self-Induced Vibration.” The analyses so far have focused on the sources identified as most likely to be problematic, and thus results and allocations are made at a source level and not yet at a subsystem level. The budget is given in Table [ID 35781]. The allocation column has the allocation for RMS jitter for each source. These were allocated in an ad-hoc manner, but are close to the response given by results from the two major analysis studies. It should be noted that allocations and source levels from the 2015 NCE analyses are likely to change, while the ATA analysis of the M1 fans is fairly robust. The Draft Required Filtered Individual Source Input column catalogs potential requirements for sources. The source input level in N RMS is computed by starting with the input spectra in $\frac{N}{\sqrt{Hz}}$, applying a weighting function, and taking the H_2norm of the result. The weighting function is given by:

$$W(f) = \begin{cases} \left(\frac{f}{60}\right)^2 & f < 60 \\ 1 & 60 \le f \le 100 \\ \frac{1}{\left(\frac{f}{100}\right)^2} & f > 100 \end{cases}$$

where f is frequency in Hz. The lower 60 Hz corner is driven by the crossover frequency given by the NGAO TT rejection transfer function given by Figure [ID 33547]. The higher 100 Hz corner is given by the observed roll-off frequency observed in the transfer function from vibration source to focal plane, as documented “GMT Self-Induced Vibration” (GMT-DOC-03140).

Table 4-2 [ID 35781]: Source Vibration (non wind) Budget

Requirement	Element	Source	Allocation [mas RMS]	Filtered Individual Source Input [N RMS]	Notes

REQ-L3-OAD-35788	All Instruments	Cryo-Cooler Heads	0.3	5.2	Justified by 2015 NCE analysis
REQ-L3-OAD-35794	All	SECs	0.1	0.5	Justified by 2015 NCE analysis
REQ-L3-OAD-35800	M1	M1 Coolant Pumps	0.3	0.8	Justified by 2015 NCE analysis
REQ-L3-OAD-35806	M1	M1 Fans	0.7	0.03	Justified by 2018 ATA analysis
REQ-L3-OAD-35812	All	Other Sources (On telescope)	0.4		
REQ-L3-OAD-35816	Facilities	Other Sources (Off telescope)	0.4		
		Total Budget	1.00		

The allocations are listed in milliarcseconds of RMS jitter (RSS of both axes). The RMS jitter is the RMS of the average motion of the intersection of the chief rays of the seven telescope segments with the focal plane, with respect to the center of the focal plane.

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 [ID 35832], on-axis.

Table 4-3 [ID 35832]: 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 [ID 35838], averaged over a 10 arcmin field of view.

Table 4-4 [ID 35838]: 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.

FP NGAO On-Axis Wavefront Error Allocations

The GMT operating in the FP configuration and NGAO wavefront control mode shall maintain wavefront error allocations no greater than those specified in Table [ID 35844] on-axis when using an R=10 guide star at 30° zenith angle.

Table 4-5 [ID 35844]: FP NGAO On-Axis Wavefront Error Budget

Requirement	Error Term	WFE (nm RMS)		Description
		Alloc.	CBE	
	Thermal	21.2	19.1	
REQ-L3-OAD-38842	Dome Seeing	20.0	18.8	Optical turbulence from Enclosure, Mount, etc.
REQ-L3-OAD-38847	Mirror Seeing	7.1	3.2	Optical turbulence at M1 and M2
	Opt. Design & Phasing	45.0	46.9	
REQ-L3-OAD-38855	Design Aberrations	0.0	0.0	Telescope design aberrations on-axis
REQ-L3-OAD-38860	Segment Phasing	45.0	46.9	Error due to uncontrolled segment phase piston
	Segment Shape & Align.	5.0	42.7	
REQ-L3-OAD-38868	M1 Segment Shape	30.0	15.0	M1 segment shape errors after active optics
REQ-L3-OAD-38873	M2 Segment Shape	34.6	34.6	M2 segment shape errors
REQ-L3-OAD-96801	M1 Segment Position	0.0	0.0	M1 segment positioner precision
REQ-L3-OAD-96802	M2 Segment Position	20.0	20.0	M2 segment positioner precision
REQ-L3-OAD-96803	Instrument Position	0.0	0.0	Instrument displacement with respect to focal placement

	Tracking and Vibration	48.0	46.1	
REQ-L3-OAD-38881	Dynamic Control	14.2	14.2	Image motion and blur caused by telescope control
REQ-L3-OAD-38886	Wind Residual	32.8	30.0	Wind image motion and blur after tip-tilt correction
REQ-L3-OAD-38891	Vibration Residual	30.8	30.8	Vibration image motion and blur after tip-tilt
REQ-L3-OAD-38896	Instrument Sensor	6.2	6.2	Instrument flexure sensor tip-tilt and focus error
REQ-L3-OAD-38901	SWC DAR	6.2	6.2	Error in differential atmospheric refraction correction
	Turbulence Correction	89.1	85.0	
REQ-L3-OAD-38909	ASM Errors	71.1	70.5	ASM fitting error, latency, and repeatability
REQ-L3-OAD-38914	NGWS Errors	53.6	47.5	NGWS measurement and temporal errors
REQ-L3-OAD-38919	OCS Latency	3.0	0.8	OCS estimation and latency
	AO Calibration	75.7	75.7	
REQ-L3-OAD-38927	ASM/System Calibration	50.0	50.0	ASM-NGWS interaction matrix, control models, etc.
REQ-L3-OAD-38932	NGWS Calibration	30.0	30.0	Pyramid optical errors, pupil mapping errors
REQ-L3-OAD-38937	Truth Sensor Calibration	30.0	30.0	Truth sensor optical errors
REQ-L3-OAD-38942	Residual NCPA	28.3	28.3	Non-common path aberrations after Truth sensor

REQ-L3-OAD-38947	Pupil Alignment	25.0	25.0	Dynamic pupil alignment errors on NGWS & Truth
	Total	**144.7**	**139.5**	
	Requirement	**150**	150	ORD-25705
	Margin	39	55	

Notes: These allocations represent the median performance over the standard year, but the analysis to date has been against median environmental conditions (eg. median turbulence strength and wind speed). These requirements are the basis for the key subsystem requirements specified in Section 3.

Rationale: These allocations meet the image quality requirement ORD-25705 with margin, while being consistent with the expected distribution of errors between subsystems.

Folded Port Laser Tomography Adaptive Optics with 50% Sky Coverage (on-axis)

The GMT Operating in the FP optical layout and the LTAO wavefront control mode, with 50% sky coverage, shall maintain image quality allocations no less than those specified in Table [ID XXX], on-axis.

Table 4-6 [ID 96730]: FP NGAO On-Axis Wavefront Error Budget

Requirement	Error Term	WFE (nm RMS)		Description
		Alloc.	CBE	
	Thermal	30.8	28.8	
REQ-L3-OAD-96732	Dome Seeing	30.0	28.2	Optical turbulence from Enclosure, Mount, equipment, etc.
REQ-L3-OAD-96733	Mirror Seeing	7.1	5.9	Optical turbulence at M1 and M2
	Optical Design & Phasing	100.0	96.2	
REQ-L3-OAD-96735	Design Aberrations	0.0	0.0	Telescope design aberrations on-axis
REQ-L3-OAD-96736	Segment Phasing	100.0	96.2	Error due to uncontrolled segment phase piston
	Segment Shape & Align.	54.8	48.2	

REQ-L3-OAD-96738	M1 Segment Shape	30.0	15.0	M1 segment shape errors after active optics
REQ-L3-OAD-96739	M2 Segment Shape	34.6	34.6	M2 segment shape errors
REQ-L3-OAD-99065	M1 Segment Position	0.0	0.0	M1 segment positioner precision
REQ-L3-OAD-99066	M2 Segment Position	30.0	30.0	M2 segment positioner precision
	Tracking and Vibration	174.9	172.2	
REQ-L3-OAD-96741	Dynamic Control	35.1	34.6	Image motion and blur caused by telescope control
REQ-L3-OAD-96742	Wind Residual	73.4	73.4	Wind image motion and blur after tip-tilt correction
REQ-L3-OAD-96743	Vibration Residual	46.2	46.2	Vibration image motion and blur after tip-tilt
REQ-L3-OAD-96744	Instrument OIWFS	147.6	144.5	Instrument image motion and focus sensing error
REQ-L3-OAD-96745	SWC DAR	6.2	6.2	Error in differential atmospheric refraction correction
	Turbulence Correction	161.4	156.3	
REQ-L3-OAD-96747	ASM Errors	71.1	70.5	ASM fitting error, latency, and repeatability
REQ-L3-OAD-96748	LTWS Errors	80.3	74.3	LTWS fitting, measurement, and temporal errors
REQ-L3-OAD-96759	Instrument OIWFS	36.1	35.1	Instrument OIWFS truth sensing errors
REQ-L3-OAD-96749	OCS Latency	5.0	1.7	OCS estimation and latency
REQ-L3-OAD-96760	Tomography	115.0	112.7	On-axis tomographic error

REQ-L3-OAD-96761	Anisoplanatism	0.0	0.0	Angle between guide stars and science target
	AO Calibration	85.7	85.7	
REQ-L3-OAD-96751	ASM/System Calibration	50.0	50.0	ASM-NGWS interaction matrix, control models, etc.
REQ-L3-OAD-96752	LTWS Calibration	30.0	30.0	Error in reference slopes, pupil size/distortion
REQ-L3-OAD-96753	Instrument OIWFS Calibration	30.0	30.0	Truth sensor optical errors
REQ-L3-OAD-96754	Residual NCPA	49.2	49.2	Non-common path aberrations after calibration and truth sensor correction
REQ-L3-OAD-96755	Pupil Alignment	25.0	25.0	Dynamic pupil alignment errors on NGWS & Truth WFS
	Total	**279.2**	**271.8**	
	Requirement	**280**	**280**	ORD-25594 (280 nm RMS median)
	Margin	**21**	**67**	

Notes: These allocations represent the median performance over the standard year, but the analysis to date has been against median environmental conditions (eg. median turbulence strength and wind speed). These requirements are the basis for the key subsystem requirements specified in Section 3.

Rationale: These allocations meet the image quality requirement ORD-25594 with a margin of 21 nm RMS wavefront error while being consistent with the expected distribution of errors between subsystems.

Folded Port Laser Tomography Adaptive Optics with 80% Sky Coverage (on-axis)

The GMT Operating in the FP optical layout and the LTAO wavefront control mode, with 50% sky coverage, shall maintain image quality allocations no less than those specified in Table [ID XXX], on-axis.

Table 4-7 [ID 96764]: FP NGAO On-Axis Wavefront Error Budget

Requirement	Error Term	WFE (nm RMS)		Description
		Alloc.	**CBE**	

	Thermal	30.8	28.8	
REQ-L3-OAD-96766	Dome Seeing	30.0	28.2	Optical turbulence from Enclosure, Mount, equipment, etc.
REQ-L3-OAD-96767	Mirror Seeing	7.1	5.9	Optical turbulence at M1 and M2
	Optical Design & Phasing	99.9	86.0	
REQ-L3-OAD-96769	Design Aberrations	0.0	0.0	Telescope design aberrations on-axis
REQ-L3-OAD-96770	Segment Phasing	99.9	86.0	Error due to uncontrolled segment phase piston
	Segment Shape & Align.	54.8	48.2	
REQ-L3-OAD-96772	M1 Segment Shape	30.0	15.0	M1 segment shape errors after active optics
REQ-L3-OAD-96773	M2 Segment Shape	34.6	34.6	M2 segment shape errors
REQ-L3-OAD-99067	M1 Segment Position	0.0	0.0	M1 segment positioner precision
REQ-L3-OAD-99068	M2 Segment Position	30.0	30.0	M2 segment positioner precision
	Tracking and Vibration	257.5	249.3	
REQ-L3-OAD-96775	Dynamic Control	35.1	34.6	Image motion and blur caused by telescope control
REQ-L3-OAD-96776	Wind Residual	73.7	73.7	Wind image motion and blur after tip-tilt correction
REQ-L3-OAD-96777	Vibration Residual	46.2	46.2	Vibration image motion and blur after tip-tilt
REQ-L3-OAD-96778	Instrument OIWFS	239.7	231.0	Instrument image motion and focus sensing error

REQ-L3-OAD-96779	SWC DAR	6.2	6.2	Error in differential atmospheric refraction correction
	Turbulence Correction	169.4	163.9	
REQ-L3-OAD-96781	ASM Errors	71.1	70.5	ASM fitting error, latency, and repeatability
REQ-L3-OAD-96782	LTWS Errors	80.3	74.3	LTWS fitting, measurement, and temporal errors
REQ-L3-OAD-96783	Instrument OIWFS	62.6	60.6	Instrument OIWFS truth sensing errors
REQ-L3-OAD-96784	OCS Latency	5.0	1.7	OCS estimation and latency
REQ-L3-OAD-96785	Tomography	115.0	112.7	On-axis tomographic error
REQ-L3-OAD-96786	Anisoplanatism	0.0	0.0	Angle between guide stars and science target
	AO Calibration	85.7	85.7	
REQ-L3-OAD-96788	ASM/System Calibration	50.0	50.0	ASM-NGWS interaction matrix, control models, etc.
REQ-L3-OAD-96789	LTWS Calibration	30.0	30.0	Error in reference slopes, pupil size/distortion
REQ-L3-OAD-96790	Instrument OIWFS Calibration	30.0	30.0	Truth sensor optical errors
REQ-L3-OAD-96791	Residual NCPA	49.2	49.2	Non-common path aberrations after calibration and truth sensor correction
REQ-L3-OAD-96792	Pupil Alignment	25.0	25.0	Dynamic pupil alignment errors on NGWS & Truth WFS
	Total	**341.0**	**327.0**	
	Requirement	**350**	**350**	ORD-25649 (350 nm RMS median)

	Margin	**79**	**125**	

Notes: These allocations represent the median performance over the standard year, but the analysis to date has been against median environmental conditions (eg. median turbulence strength and wind speed). These requirements are the basis for the key subsystem requirements specified in Section 3.

Rationale: These allocations meet the image quality requirement ORD-25649 with a margin of 79 nm RMS wavefront error while being consistent with the expected distribution of errors between subsystems.

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 [ID 35855].

Table 4-8 [ID 35855]: 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

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 [ID 35888].

Table 4-9 [ID 35888]: 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 with respect to OSS coordinates	≤ 260 µrad
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

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 [ID 35920].

Table 4-10 [ID 35920]: 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

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 [ID 35952].

Table 4-11 [ID 35952]: 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 [ID 35984].

Table 4-12 [ID 35984]: 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 [ID 36016].

Table 4-13 [ID 36016]: 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	≤ 0.5 mm

		OSS coordinates	
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

$$z = \frac{r^2}{R + \sqrt{R^2 - (k-1)r^2}}$$

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 [ID 36053] 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 [ID 36053]: Manufacture Dimentional 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

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 [ID 33633]. 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.

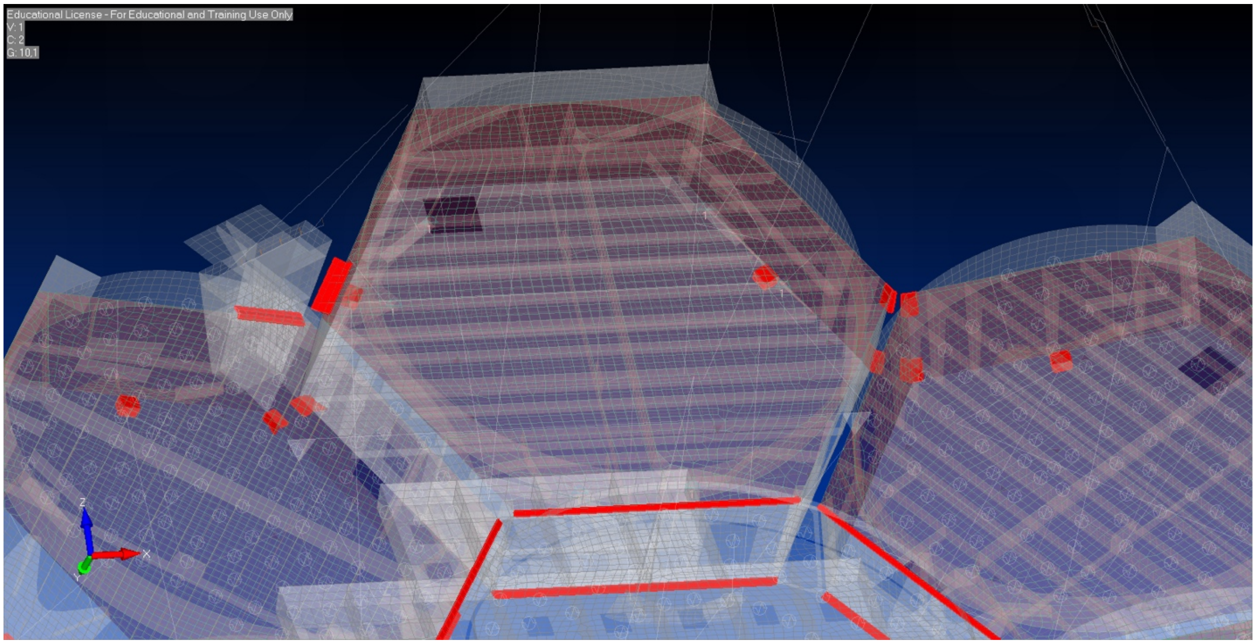


Figure 4-1 [ID 33633]: Mounting Surfaces of the M1 Cell into the CCF

M1 cell mounting accuracy

The M1-A coordinate system shall deviate from the M1-T within limits specified in Table [ID 36089].

Table 4-15 [ID 36089]: 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	≤ 125 µrad

		respect to M1-T dRz coordinate system	
REQ-L3-OAD-36114	Mount	M1 Cell M1-A dRz with respect to M1-T dRz coordinate system	≤ 125 µrad

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.

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 [ID 36136].

Table 4-16 [ID 36136]: 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

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 [ID 36168].

Table 4-17 [ID 36168]: 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,	M2 segment Ry rotation	± 3000 µrad

	FSMS		
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 [ID 36203].

Table 4-18 [ID 36203]: 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*

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

Rationale: Modeling and simulations of SLE estimated that this range of motion will have less than 0.5% of probability of damaging the mirror.

Table 4-19 [ID 36234]: 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*

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 [ID 70870]: 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 Rotational Positioning Accuracy	0.02	REQ-L3-OAD-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

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.

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-36368: Target Acquisition Accuracy

Each instrument should be capable of acquiring science targets to within 0.17 arcsec RMS from the center of the instrument's field of view.

Rationale: This applies after an initial acquisition that centers relatively bright alignment stars in their alignment boxes or fibers. It includes the uncertainty in the relative coordinates of science targets and alignment stars. The value is driven by the width of typical slits or fibers on multi-object spectrographs.

Notes: Flexure between the instrument focal plane and the AGWS may cause targets to deviate by up to 3 arcsec from their expected position in the instrument's focal plane. Using open-loop lookup tables for flexure compensation, it should be possible to reduce this to 0.5 arcsec or less. The field of view of the OIWFS must accommodate these pointing and flexure errors. This requirement then assumes an acquisition step in which optical feedback of the focal plane as seen by the instrument is used to further refine the centering of the focal plane to put science targets into the appropriate locations within the instrument's input field of view.

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 [ID 33646] through the UV and visible regime (left) and through the infrared (right).

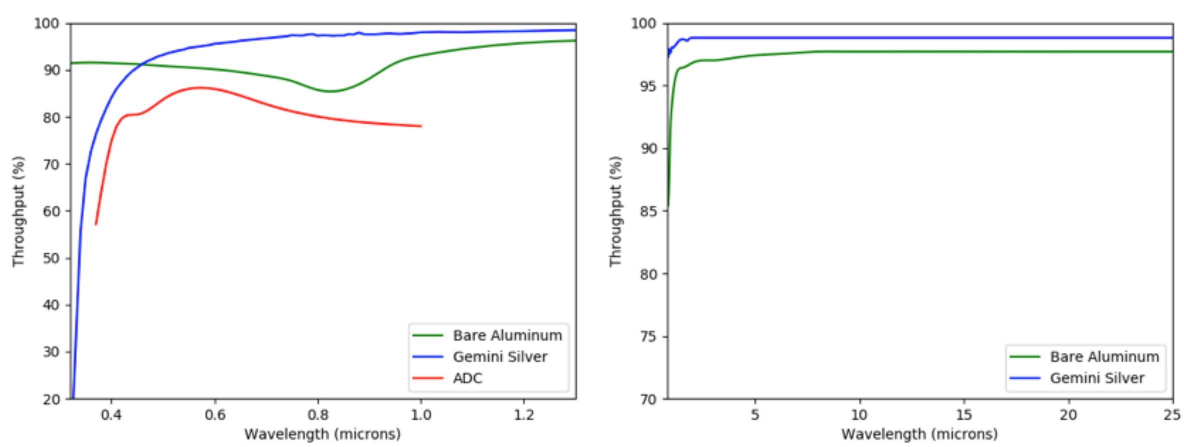


Figure 4-2 [ID 33646]: Throughputs of bare aluminum, 4-layer Gemini protected silver, and the transmission of the ADC (bare aluminum data from RMI, Gemini Silver from Boccas et al. 2014, and C-ADC from GMT-REF-00364.

The throughput as a function of configuration is plotted in Figure [ID 33647] 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.

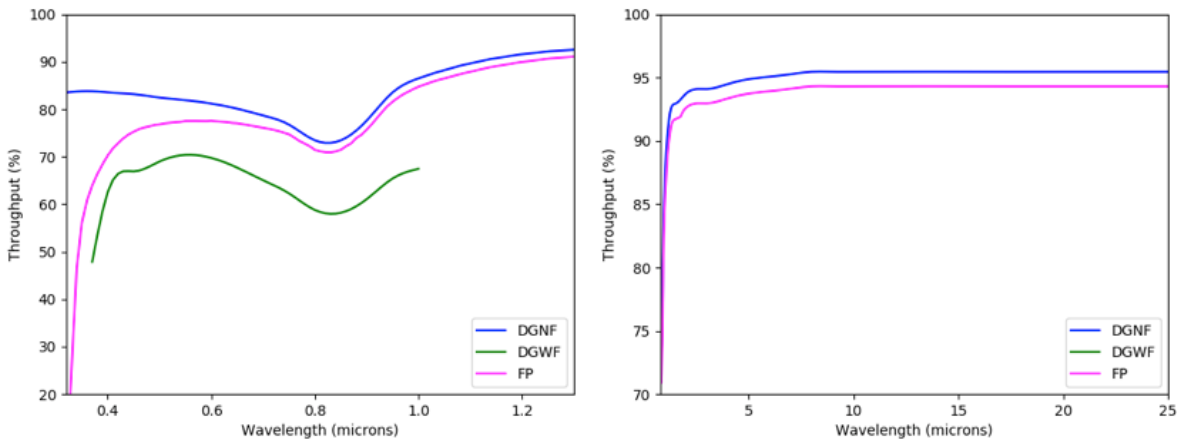


Figure 4-3 [ID 33647]: Throughput through each telescope configuration as a function of wavelength assuming M1 and M2 are coated with bare aluminum and M3 is coated with Gemini protected silver.

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 observing 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

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 [ID 33648] shows the decrease in throughput as a function of field angle due to vignetting.

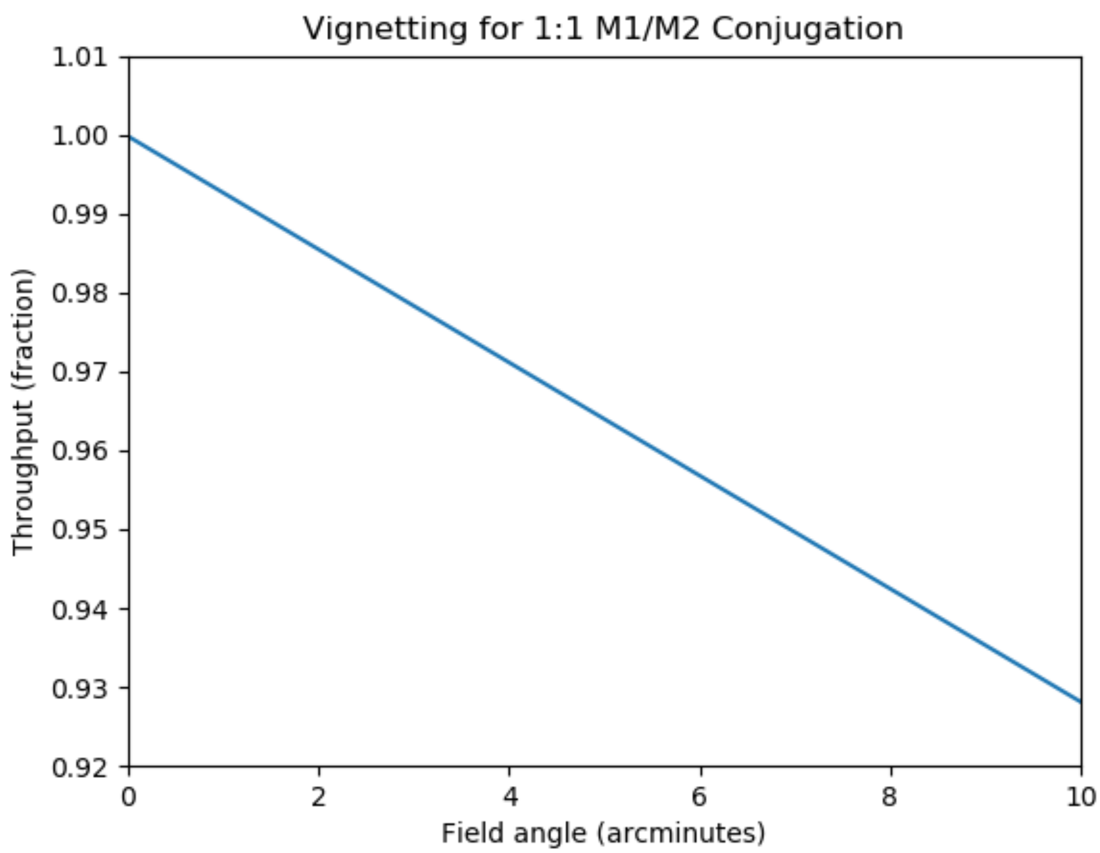


Figure 4-4 [ID 33648]: Vignetting as a Function of Field Angle

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 [ID 36406]. 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 [ID 36406]) is TBD and will be presented in GMT-REF-03242 when mature.

Table 4-21 [ID 33649]: 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 4-22 [ID 36406]: 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			

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 Nighttime Stray Light

REQ-L3-OAD-36482: Maximum Stray Light, Night

The GMT shall be able to perform observations with stray light illumination in the science field of view that is ≤ 0.10% of the local sky background at any point across the field of view.

Rationale: 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.

Notes: GMT-DOC-01871

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. Complete baffle design is TBD, but future considerations should take into account the double-bounce.

REQ-L3-OAD-36490: M1 Baffle

The GMT shall have an M1S7 baffle at the central hole of the segment.

Rationale: This is to block rays traveling from M1 to M2 and from M2 to the focal plane. This will also reduce the amount of stray light and dust reaching the C-ADC and science instruments from sources outside of the beam.

Notes: GMT-DOC-03137

REQ-L3-OAD-36494: M2 Baffle

The GMT shall have a baffle on M2.

Rationale: This baffle would be designed so that the gaps between the M2 segments and around the edges of the M2 mirror will prevent contamination from the night sky and astronomical sources. This will also provide a clean, circular obscuration to the telescope where only the central M1/M2 pair is obscured.

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

During daytime operations, the dome shall be light-tight.

Rationale: Stray light can very much impact calibrations, which are often taken during the day. Light-tightness can be ensured by using weather-proof seals and coatings and ensuring that all vents can be tightly closed.

REQ-L3-OAD-36510: Enclosure surfaces

The enclosure shall have medium-reflectivity surfaces or be painted with medium-reflectivity paint.

Rationale: 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.

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. The inner radius shall be equal to the clear aperture of the segment.

Rationale: This will prevent scattered light from entering the primary beam.

Notes: GMT-TEL-DOC-00703

4.8.5 Daytime Stray Light

REQ-L3-OAD-36519: Maximum Stray Light, Day

The GMT shall be able to produce daytime calibration data with stray light in the calibration field that is $\leq$ 0.1% of the calibration source's flux.

Rationale: An internal flat-field calibration source is needed to have pixel-to-pixel relative sensitivity calibration for flux calibrations. For photometric accuracies ~1%, calibration must be an insignificant contributor to the uncertainty.

General policies, such as having no visible LEDs, should be enforced in order to decrease the probability of having large sources of stray light in the enclosure. The enclosure itself should be well-sealed so that no excess light from outside is allowed in the enclosure.

A stray light analysis and baffle design plan is TBD and will be presented in GMT-REF-03244 when mature.

Notes: GMT-DOC-01871

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 [ID 36532] for DGNF (no C-ADC) and FP.

Rationale: Based on the optical design, mirror coating baselines, and science requirements.

Notes: GMT-DOC-01871

Table 4-23 [ID 36532]: 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 cold stop	10.64%	9.04%	12.24%	10.64%
•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 [ID 36538].

Table 4-24 [ID 36538]: TBD

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 [ID 36547].

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 4-25 [ID 36547]: 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 [ID 36556] over a 10-hour period.

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 4-26 [ID 36556]: 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.

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.

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.

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).

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 [ID 61186].

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 [ID 61186]: 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 [ID 61191].

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 [ID 61191]: 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 [ID 61196].

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 [ID 61196]: 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 [ID 61201].

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 [ID 61201]: 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 [ID 36625].

Table 5-5 [ID 36625]: 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 [ID 36631].

Table 5-6 [ID 36631]: 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 equipment 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.

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-L4-OAD-82925: All standardized software user interfaces shall be accessible from remote workstations by users with the appropriate access credentials.

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-L4-OAD-85101: The OCS shall include a design system for developing consistent graphical user interfaces.

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-L4-OAD-92315: The OCS shall include graphical user interfaces for observatory operations.

The OCS shall include graphical user interfaces for observatory operations.

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.

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 [ID 36763].

Table 5-7 [ID 36763]: 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 [ID 36783].

Table 5-8 [ID 36783]: 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.

5.3.3 Telescope Scheduling

The GMT shall provide software tools to support telescope proposal implementation and scheduling, including the functionalities described in Table [ID 36811].

Table 5-9 [ID 36811]: Telescope Scheduling Requirements

Function	Requirement	Documentation
Results of TAC rankings and recommendations	REQ-L3-OAD-36816	This allows the scheduler to assign appropriate nights to different observing 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 observing modes.
Success metrics for scheduling process	REQ-L3-OAD-36825	Scheduling success metrics shall include those in section 10 of GMT-DOC-01584.

5.3.4 Observing Execution

Observing Program Execution

The GMT shall provide software tools to execute Observing Programs, including the functionalities described in Table [ID 36831].

Table 5-10 [ID 36831]: 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.

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 Observing Mode Support

The GMT software tools shall support the operating and observing 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 observing 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 [ID 36875]) shows which steps are important for each reconfiguration.

Table 5-11 [ID 36875]: 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].

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].

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.

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 observing 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 observing 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 observing 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 [ID 36907]).

Table 5-12 [ID 36907]: 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	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	300	This includes deployment or retraction, as well as	C-ADC

	necessary)		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-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	Instrument

			Image Quality Budget will be met.	
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

The GMT shall support the following times for steps involved in target acquisition in GLAO mode (Table [ID 61353]).

Table 5-13 [ID 61353]: 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° 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	AGWS

			positions.	
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 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 mode	10	A rapid-convergence algorithm that does not average over atmospheric seeing.	M1, M2, OCS
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	OCS

			centering, target acquisition is complete and the observing sequence is started.	

The GMT shall support the following times for steps involved in target acquisition in NGAO mode ([Table [ID 61355]]).

Table 5-14 [ID 61355]: 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 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 account the wind speed and direction relative to the	Enclosure

			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 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-OAD-70849	Start dynamic calibration loop	30	Measure and correct instrument-to-NGWS flexure and non-common path errors. At the end of this step the NGAO Image Quality Budget will be met.	NGWS, 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	OCS

			started.	

The GMT shall support the following times for steps involved in target acquisition in LTAO mode (Table [ID 61357]).

Table 5-15 [ID 61357]: 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 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 account the wind speed and direction relative to the telescope pointing (at the new target). Vent positioning is not critical to	Enclosure

			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 will be met.	TMS
REQ-L3-OAD-70856	LGS acquisition	60*	Independent of NGS acquisition. Identifies laser spots and corrects laser	LGS

			pointing.	
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 tip-tilt sensor. At the end of this step the Instrument Acquisition Pointing Budget will be met.	M1, M2, OCS
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	NGWS, LTAO

			will be met.	
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

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: 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.

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: 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.

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: The GMT shall offset distances of < 5 arcsec on sky in no more than 5 seconds of time in Natural Seeing observing mode.

The GMT shall offset distances of < 5 arcsec on sky in no more than 5 seconds of time in Natural Seeing observing 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: 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 observing mode.

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 observing 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: 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 observing mode.

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 observing 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: The GMT shall offset distances of < 5 arcsec on sky in no more than 2.5 seconds of time in diffraction-limited observing modes.

The GMT shall offset distances of < 5 arcsec on sky in no more than 2.5 seconds of time in diffraction-limited observing 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: 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 observing modes.

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 observing 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: 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 observing modes.

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 observing 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.

REQ-L3-OAD-80387: Observatory Subsystem On-Sky Initialization Time

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 [ID 37059]: 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

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, the M1 covers. Secondary protection may be provided by the Enclosure rotation, the wind screen, the moon shade, and the telescope position.

REQ-L3-OAD-92314: The GMT Observatory subsystems shall transition from their environmental standby state to their science operations state in no more than TBD minutes.

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 [ID 37092]: 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**

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 [ID 37281].

Table 5-18 [ID 37281]: 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 Subsystem	0
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**

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, communications, and vacuum 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.

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.

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 [ID 37443]: Transportation of Components between Buildings

Requirement	Subsystem	Buildings	Documentation
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.
REQ-L3-OAD-37452	ASM	Summit Support Building – Enclosure	Supplied by the ASM.
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

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.

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 [ID 37507]: 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-37537	Have a 99.99% availability for access (move to top)	Section 3.2.1 of GMT-DOC-01582
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

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 [ID 37554]: 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-37576	Provide for re-reduction of raw data into Level 1 data	Section 3.8 of GMT-DOC-01582; 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.

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.

Notes: Sections 3.2.1, 3.6, and 6.2.2 of GMT-DOC-01582.

5.7 Utilities

Many of the electrical requirements in this and following 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.

Utilities described below serve as the life blood of the site and are needed for the most basic operations. The requirements for this section detail the methods and capacities needed to fulfill the overall capabilities of the consumers of utilities on the site. Tables and diagrams in this section illustrate the major needs of the site and telescope. The Utility One-Line Diagram GMT-REF-00805 can be referred to for details on how utilities are distributed through the telescope.

5.7.1 Utility Estimations, Allocations, and Limits

Three categories of utility allocations exist for the purposes of gathering and planning for the future maturity of systems. At the lowest level, Utility Estimations are recorded in the Utility Budget GMT-REF-00366 for each component of a system based on their most recent design. Above that, the System

Utility Allocation grants a 20% growth budget maintained by the system lead. At the highest level, Systems Engineering reserves an additional 10% margin called the SE Accommodation Limit, which is a not to exceed value given to designers of the utility systems, facilities and the mount to ensure that systems are designed with this additional capacity, and that all the routing and cable ways can contain the growth of these utilities. Should the 20% Utility Allocation margin be exhausted by the system lead,any additional allocation must be formally requested from systems engineering who will make the final decision.

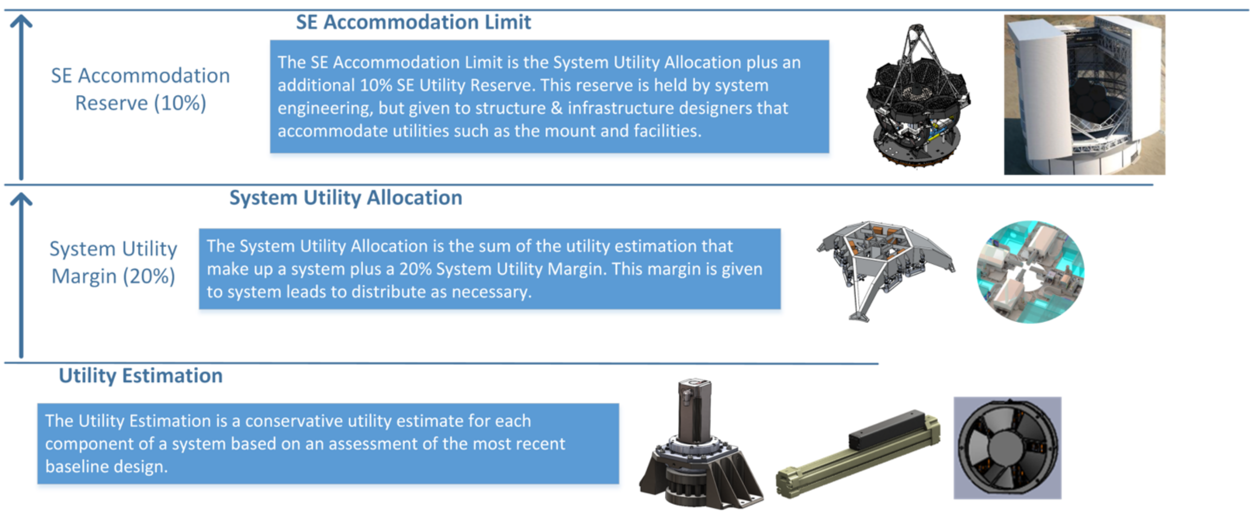


Figure 5-1 [ID 66365]: Illustration of Utility Margins

5.7.2 Power and Grounding

The GMT provides a connection to a commercial electrical power source, via transmission line, to SS1. The infrastructure will include a central backup power system, also located at SS1 which provides power to the observatory when commercial power service is lost. Commercial and backup power is provided to the facilities via the site electrical power distribution system.

REQ-L3-OAD-37590: Commercial Electrical Power - Capacity

The commercial electrical power connection shall have a capacity no greater than 10.5 MW.

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 Electrical Power System

The GMT site infrastructure shall include a means for generating electrical backup power during a loss of commercial power or emergency conditions.

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 TBC 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 Capability

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-37623: Backup Power Manual Switchover

Transfer from backup power to commercial power shall require manual initiation and occur without power interruption.

Rationale: Manual transfer allows for an operator to assess safe transfer back to commercial power.

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.

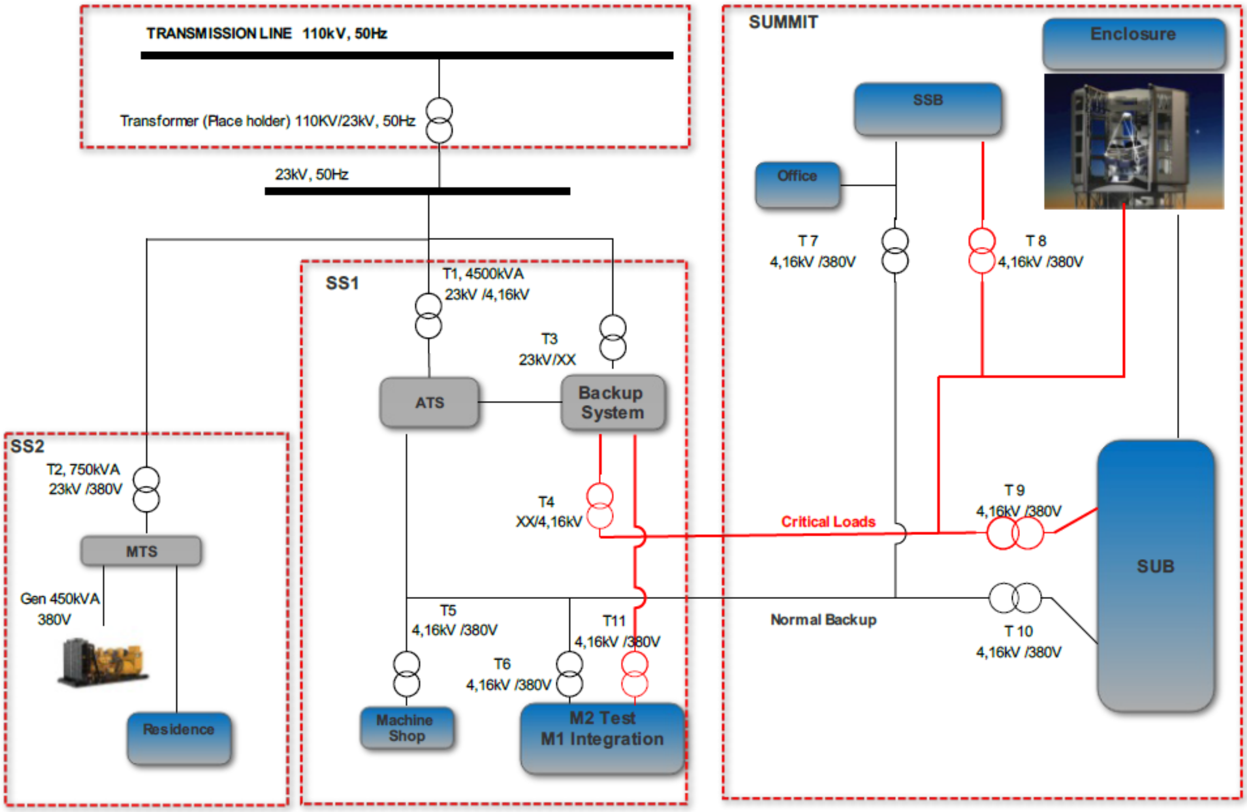


Figure 5-2 [ID 33650]: Conceptual Site Electrical Distribution. Key: Summit Support Building (SSB); Summit Utility Building (SUB); Automatic Transfer Switch (ATS); Manual Transfer Switch (MTS); Support Site 1 (SS1); Support Site 2 (SS2).

5.7.2.1 Load Classifications

Electric loads are classified into three categories according to their sensitivity to power issues:

- Critical loads cannot tolerate any power interruptions
- Essential loads require continued operation with emergency power
- Non-essential loads are not required for science operations

In addition, there will be life-safety electrical equipment, such as emergency lighting, that will be supplied and operate independently of the other systems.

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. See Figure [ID 33651] for conceptual illustration.

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 TBC 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 system 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 Power.

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) (Sensitive)
    - Must include HVAC cooling for computer rooms (Noisy)
- Instruments, AGWS, NGSAO, (Sensitive)
- 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 (Sensitive)
- HBS & Drives (Noisy)
- Laser system components / LTWS (Sensitive)
- Mirror Coating Operations (Sensitive / Noisy)

To try to avoid ground loops, Critical Loads will have two supplies, one for sensitive electronics, and one for components that may generate noise on their lines often known as dirty power. The GMT provides isolated grounds for each supply whose respective components are connected in a star arrangement, for each will help to avoid ground loops and excessive noise by heavy duty equipment.

REQ-L3-OAD-37653: Power Supply for Critical Sensitive Loads

Site Infrastructure shall provide a dedicated and separate branch of power to supply sensitive critical loads with improved power quality.

Rationale: A dedicated branch of supply lines for sensitive electronics allows for supplemental line conditioning for improved power quality. Noisy loads connect to the Non-Sensitive branch.

REQ-L3-OAD-37656: Power Supply for Critical Non-Sensitive Loads

Site Infrastructure shall provide a dedicated and separate branch of power lines to supply critical loads for non-sensitive electronics.

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 shall be connected to 220V 1-phase power or 380V 3-phase power that upon loss of commercial power will automatically switch to backup 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 on line.

- 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

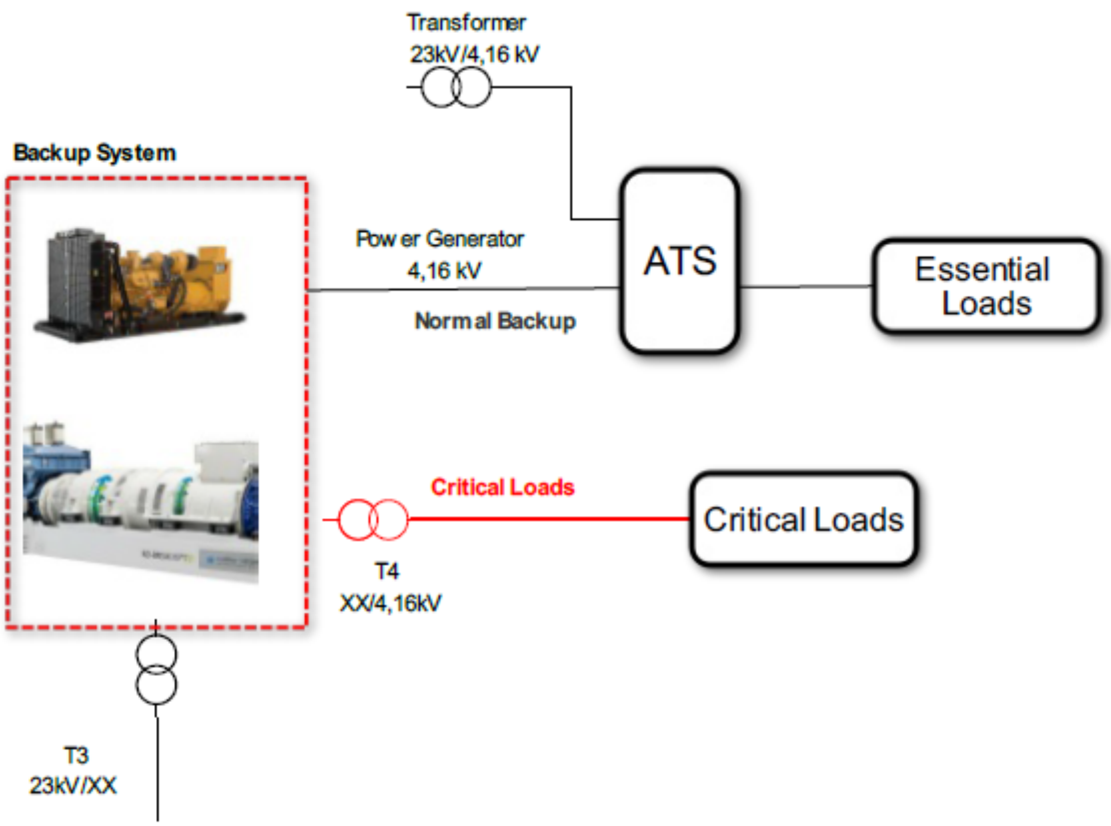


Figure 5-3 [ID 33651]: Conceptual Backup System via Automatic Transfer Switch to Essential Loads and via Dynamic-UPS to Critical Loads.

REQ-L3-OAD-37664: Observatory Non-Essential Loads

Observatory non-essential loads shall be connected to commercial power.

Rationale: Non-Essential loads are systems that are not required for science operations and can be turned off for the duration of a commercial power failure. Non-Essential loads include:

- HVAC systems in non-essential areas
- SS2 (has its own generators)
- Machine shop

Notes: It may not be practical to provide separate power feeds for essential and non-essential loads and thus it may become an operational procedure to suspend the operation of some equipment, such as machine shop equipment, while using emergency generator power.

REQ-L3-OAD-37669: Observatory Essential Load Recovery Time

Observatory essential loads shall recover from the moment of a restored loss of power to an operational state in no greater than 10 minutes (TBC).

Rationale: Limiting recovery time minimizes downtime and allows for continued science operations.

5.7.2.2 Lightning Protection

REQ-L3-OAD-37673: Lightning Protection

Site Infrastructure, Facilities and Enclosure shall deliver a lightning protection system according to Standard for the Installation of Lightning Protection Systems NFPA 780, IEC 62305, and IEEE Std 998.

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

Notes: See GMT-REF-00229 -

GMT Reference

for Regulations,

Codes and

Standards

5.7.2.3 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 [ID 33652] for conceptual illustration.

REQ-L3-OAD-37686: Signal Ground

Site Infrastructure shall provide a low-noise ground reference for critical sensitive loads.

Rationale: Signal ground takes measures to provide improved power quality with minimized risks for ground loops for electronics that benefit from a low-noise ground reference.

REQ-L3-OAD-37689: Minimum Ground Resistance for Signal Ground

The resistance between the signal ground and any other ground shall be less than 3 Ohms (DWC).

Rationale: Minimizing the resistance between loads helps to keep all grounds at the same potential. Loads using the signal ground have a stricter requirement than loads that only use the safety ground, as they are the most sensitive.

REQ-L3-OAD-37692: Minimum 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.

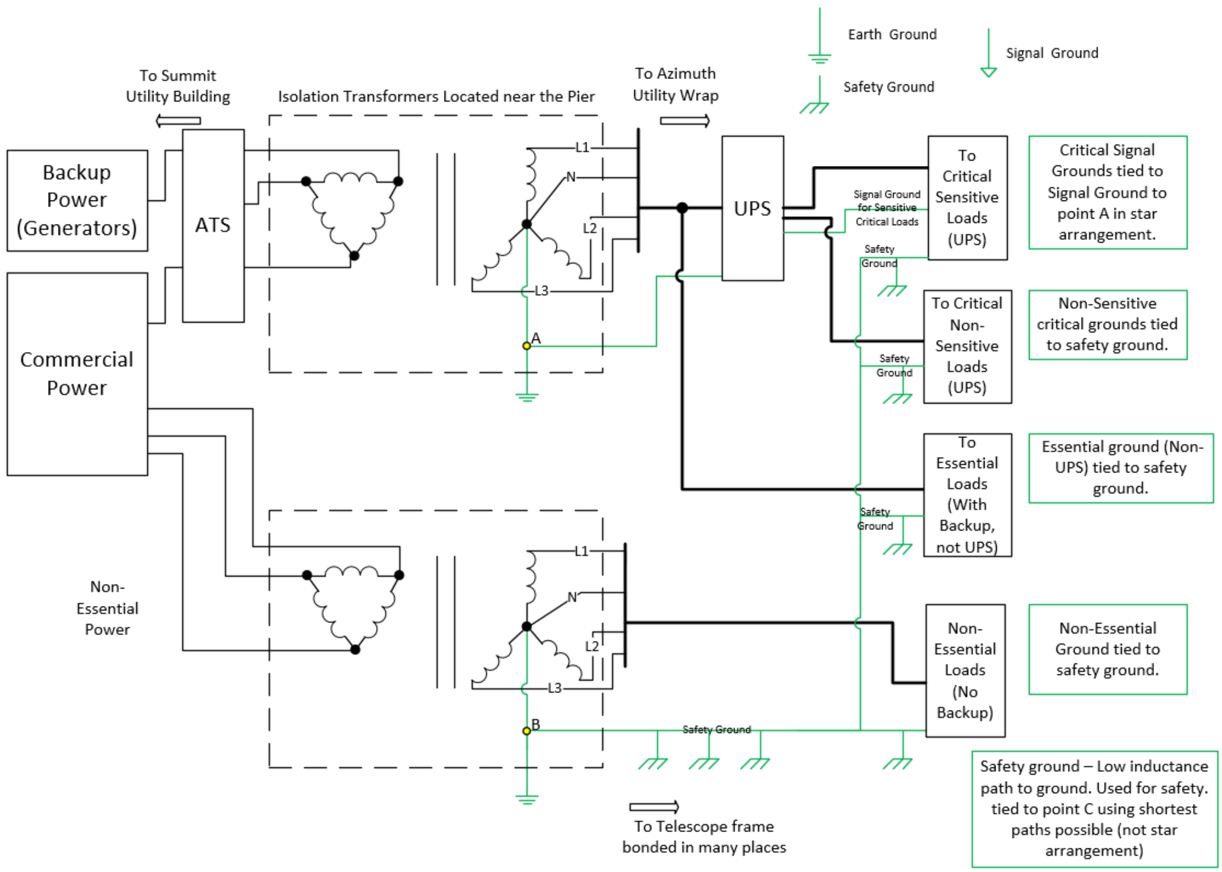


Figure 5-4 [ID 33652]: Conceptual Layout for Commercial, Backup, UPS Power and Isolated Grounds

5.7.2.4 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.

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.

Notes: Commercial equipment containing CE or FCC markings is readily acceptable for operation on the GMT with no additional testing necessary.

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.

Notes: Commercial equipment containing CE or FCC markings is readily acceptable for operation on the GMT with no additional testing necessary.

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.

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 are readily acceptable for operation on the GMT with no additional testing necessary.

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.

5.7.2.5 Power Allocations

Power Allocation for GMT Telescope Key Locations

The GMT shall provide electrical power for key GMT locations per Table [ID 37722].

Table 5-22 [ID 37722]: Site Power Allocations

Requirement	Location Load\Allocation	UPS Power (kVA)	3-Φ Utility Power (kVA)	1-Φ Utility Power (kVA)
On-Telescope				
REQ-L3-OAD-37729	Azimuth Wrap (Azimuth + Elevation + GIR)	327.9	387.9	97.2
REQ-L3-OAD-37734	Azimuth Wrap Only	46.2	73.7	7.0
REQ-L3-OAD-37739	Elevation Wrap (Elevation + GIR)	281.7	314.2	90.2
REQ-L3-OAD-37744	Elevation Only	185.1	305.5	69.2
REQ-L3-OAD-37749	GIR Wrap (GIR + DG)	96.6	8.7	21.0
REQ-L3-OAD-37754	DG Wraps (qty 4)	23.2	0	6.9
REQ-L3-OAD-37759	Single DG Wrap	5.8	0	1.7
Off-Telescope				
REQ-L3-OAD-37765	Enclosure: Upper/Lower & Service Bays	744.3	2182.7	N/A
REQ-L3-OAD-37770	Summit Utility Building	1228.5	2390.6	N/A
REQ-L3-OAD-37775	Summit Support Building	280	777.5	N/A
REQ-L3-OAD-37780	Summit Office Building	13.2	106.9	N/A
REQ-L3-OAD-37785	Water Plant	0.0	186	N/A
REQ-L3-OAD-37790	Support Site 1: Wavefront Control Testbed	260.5	813.1	N/A
REQ-L3-OAD-37795	Machine Shop	0.0	194.3	N/A

REQ-L3-OAD-37800	Support Site 2: Residence	0.0	462	N/A
Totals				
REQ-L3-OAD-37806	Facilities System	2526.5	7113.1	N/A
REQ-L3-OAD-37811	Telescope System	327.9	485.1*	N/A
REQ-L3-OAD-37816	Combined Site Total	10452.5	N/A	N/A

Notes: 1-Φ loads are absorbed into the 3-Φ loads for the Off-Telescope and Total values.

Rationale: Table [ID 37722] provides the peak estimates for system loads by location including additional uncertainty contingency held by Systems Engineering, per GMT-REF-00366 GMT Telescope Utilities Allocation Budget.

Power Allocation for GMT Systems

The GMT shall provide electrical power for GMT systems per Table [ID 37826].

Table 5-23 [ID 37826]: TBD

Req Id	System Load\Allocation	UPS Power (kVA)	3-Φ Utility Power (kVA)	1-Φ Utility Power (kVA)
REQ-L3-OAD-37832	Mount	17.8	143.0	1.2
REQ-L3-OAD-37837	WCCS & ICS Subsystems	2.6	1.2	1.2
REQ-L3-OAD-37842	M1 System	17	171.2	49.6
REQ-L3-OAD-37847	ASM Subsystem	13.9	0.0	2.4
REQ-L3-OAD-37852	FSM Subsystem	6.7	0.0	0.0
REQ-L3-OAD-37857	C-ADC Subsystem	3.2	0.0	0.0
REQ-L3-OAD-37862	M3 Subsystem	5	0.0	0.0
REQ-L3-OAD-37867	TMS Subsystem	4.7	0.0	0.0
REQ-L3-OAD-37872	NGWS/LTWS Subsystem	7.9	0.0	0.0
REQ-L3-OAD-37877	AGWS Subsystem	6.2	0.0	0.0

REQ-L3-OAD-37882	LGSS Subsystem	28	36	0.0
REQ-L3-OAD-37887	GIS Instrument System	31.9	0.1	5.8
REQ-L3-OAD-37892	AP Instrument System	21.1	0.2	6.5
REQ-L3-OAD-37897	IP Instrument System	10.6	0.1	3.2
REQ-L3-OAD-37902	DG Instrument System	39.6	0.4	12.1
REQ-L3-OAD-37907	FP Instrument System	26.4	0.3	6.4
REQ-L3-OAD-37912	Control Network System	13.2	0.0	0.0

Rationale: Table [ID 37826] provides the peak estimates provided by system which includes additional uncertainty contingency held by each system, per GMT-REF-00366 GMT Telescope Utilities Allocation Budget.

5.7.3 Cooling

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.

5.7.3.1 Glycol Based

REQ-L3-OAD-37923: Ambient Tracking Chilled Fluid (ATCF-8)

Site Infrastructure shall provide ATCF-8 delivered at its points of use at 8 °C below ambient temperature ± 0.5 °C for the regular operating conditions temperature range.

Rationale: Regular operating conditions temperature range are defined in Observatory Requirements Document.

REQ-L3-OAD-37926: Fixed Temperature Chilled Fluid (FTCF)

Site Infrastructure shall provide FTCF delivered at its points of use at 6 °C ± 0.5 °C.

Rationale: Laser Systems and the GIS Instrument, GCLEF, require fixed temperature coolant for their normal use.

REQ-L3-OAD-37929: GIR 2nd Stage Tracking Chilled Fluid (G2CF)

Site Infrastructure shall provide G2CF delivered at its points of use at 2.5 °C below ambient temperature ± 0.5 °C for the regular operating conditions temperature range.

Rationale: G2CF is expected to be derived from ATCF-8. The flow required for its production has been rolled into a Telescope System called Shared Utilities with allocations shown in Table [ID 37970]. Regular operating conditions temperature range are defined in Observatory Requirements Document GMT-REQ-03214.

REQ-L3-OAD-37932: Freezing Capability of Glycol Based Chilled Fluid

The Site Infrastructure provided glycol based fluids shall be unable to produce ice crystals for the survival conditions temperature range.

Rationale: Survival conditions temperature range are defined in Observatory Requirements Document.

REQ-L3-OAD-37935: Glycol Fluids Systems Allocations

Site Infrastructure shall provide glycol fluids to systems as allocated in Table [ID 37970].

Rationale: See GMT-REF-00366 GMT Telescope Utilities Allocation Budget for allocation breakdowns.

REQ-L3-OAD-37938: Hydrostatic Bearing Oil Cooling

Site Infrastructure shall provide a cooling system for the oil fed to the hydrostatic bearing system so that it flows out of the pads at ambient temperature ±1 °C.

Rationale: The coolant is provided by the SEF according to the ICD specified by the Mount.

5.7.3.2 Cryogenic Based

REQ-L3-OAD-37945: Liquid Nitrogen (LN2) Storage

Site Infrastructure shall provide storage of a minimum of 35000 liters of LN2 to service mirror coating and instrument cooling needs.

Rationale: Reserves of liquid nitrogen are necessary for normal operation of instrument cryostats and mirror coating production.

REQ-L3-OAD-37948: Cryo-cooling Lines

Site Infrastructure shall provide Cryo-cooling capability at TBD K to all instrument stations.

Rationale: The cryo-cooling lines (typically helium) run through rigid piping and several cable wraps over long distances. These require installation and connection installed during construction.

REQ-L3-OAD-37952: Cryo-cooling Configurability

The cryo-cooling system capability shall be configurable so that multiple circuits can supply a range of cryo coolant flows.

Rationale: Because cryo-cooling demands for future instruments are unknown, cryo-cooling must have the flexibility to increase or decrease cooling capacity to the various instrument stations.

REQ-L3-OAD-37955: Cryo-cooling Capacity

Cryo-cooling system shall have the capacity to support a minimum of 7 simultaneous instrument stations.

Rationale: Cryo-cooling demands of future instruments are unknown.

REQ-L3-OAD-69513: Local Instrument Cryogen Hold Time

Local instrument cryogen dewars shall have a hold time of at least 26 hours without being refilled from cryogen storage dewars.

Rationale: Maintenance tasks to refill local dewars should not be needed more than once per day. A hold time of 26 hours allows for some variation in day-to-day scheduling of the maintenance task to refill the local dewars.

Notes: This applies only to dewars containing liquid cryogen. Not all instruments will have such dewars.

5.7.3.3 Refrigerant Based

REQ-L3-OAD-37959: Refrigerant

Liquid refrigerant shall be provided to the top end secondary mirror for enthalpy based cooling of its instrumentation and electronics at a TBD temperature.

Rationale: See telescope Utility One-Line Diagram GMT-REF-00805 for distribution information.

5.7.3.4 Cooling Allocations

Cooling Allocation for GMT Systems

The GMT shall provide cooling services for GMT Systems per Table [ID 37970].

Table 5-24 [ID 37970]: Telescope Flow Rates with System Contingencies

Req Id	System Load \ Allocation	ATCF -8 (lpm)	ATCF -8 (kW)	FTC F (lpm)	FTC F (kW)	G2C F (lpm)	G2C F (kW)	Refrigerant (liq lpm)	Refrigerant (kW)
REQ-L3-OAD-37982	Mount	217.5	111.4	0.0	0.0	0.0	0.0	0.0	0.0
REQ-L3-OAD-37992	WCCS & ICS Subsystem	18.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
REQ-L3-OAD-38002	M1 System	474.4	225.3	0.0	0.0	0.0	0.0	0.0	0.0
REQ-L3-OAD-38012	ASM Subsystem	18.0	2.4	0.0	0.0	0.0	0.0	3.6	9.6
REQ-L3-OAD-38022	FSM Subsystem	18.0	2.4	0.0	0.0	0.0	0.0	TBD	TBD
REQ-L3-OAD-38032	C-ADC Subsystem	18.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0

REQ-L3-OAD-38042	M3 Subsystem	36.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0
REQ-L3-OAD-38052	TMS Subsystem	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
REQ-L3-OAD-38062	NGWS/LTWS Subsystem	54.0	7.2	0.0	0.0	30.6	3.6	0.0	0.0
REQ-L3-OAD-38072	AGWS Subsystem	39.7	4.8	0.0	0.0	0.0	0.0	0.0	0.0
REQ-L3-OAD-38082	LGSS Subsystem	54.0	4.7	35.6	18.0	20.3	2.9	0.0	0.0
REQ-L3-OAD-38092	Shared Utilities System	50.8	13.7	0.0	0.0	0.0	0.0	0.0	0.0
REQ-L3-OAD	GIS Instrument System	154.8	34.8	18	6.6	8.4	1.2	0.0	0.0

- 3810 2									
REQ-L3-OAD-38112	AP Instrument System	92.2	19.2	0.0	0.0	10.8	1.2	0.0	0.0
REQ-L3-OAD-38122	IP Instrument System	46.1	9.6	0.0	0.0	5.4	0.6	0.0	0.0
REQ-L3-OAD-38132	DG Instrument System	166.4	36	0.0	0.0	21.6	2.4	0.0	0.0
REQ-L3-OAD-38142	FP Instrument System	84.3	24	0.0	0.0	21.6	2.4	0.0	0.0
REQ-L3-OAD-38152	Control Network System	90	12	0.0	0.0	0.0	0.0	0.0	0.0

Rationale: Table [ID 37970] provides the peak estimates provided by system including additional uncertainty contingency held by each system, per GMT-REF-00366 GMT Telescope Utilities Allocation Budget.

5.7.4 Communications Infrastructure

5.7.4.1 Internet Communication Transmission and Distribution Systems (from Site)

The site infrastructure will include a connection to a commercial internet service provider, via a transmission line to the GMT site. Internet connections to the summit, SS1, and SS2 will be provided by the site communications distribution system.

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.

REQ-L3-OAD-38166: Communications Systems

The site infrastructure shall provide telecommunications systems connecting the observatory to external communications facilities for a single-mode 2 Gbps circuit consisting of a minimum of 24 strands (TBC).

Rationale: Nightly data rates for adaptive optics need the capacity to handle a minimum of 9 TB of data over 12 hours.

REQ-L3-OAD-38169: Telecommunications

IT shall provide telecommunication between the facilities on the summit, the support site, the base facility, and connection to external commercial providers.

Rationale: Flowdown from ORD.

Notes: IT is a Corporate function, but responsive to Project needs.

REQ-L3-OAD-38173: IT Infrastructure

The GMT IT infrastructure shall adhere to the Corporate IT Security Policy (TBD).

Rationale: IT security is a Corporate function, but the Project is expected to adhere to Corporate policies and procedures.

REQ-L3-OAD-38176: Observatory Control Network

The GMT shall provide a computer network infrastructure on the summit to support the observatory operation including the control and monitor of all observatory subsystems.

Rationale: A dedicated network is required for the control and monitoring of distributed subsystem control systems.

REQ-L3-OAD-38179: Observatory Control Network Independence

The Observatory Control Network shall be independent of the IT and ISS networks for performance and security reasons.

Rationale: Independent networks are organized to maximize control and safety parameters.

REQ-L3-OAD-38182: Observatory Control Network Internet Connectivity

The Observatory Control Network shall have access to the internet.

Rationale: The Observatory Control Network benefits from being able to send and receive data from the internet.

REQ-L3-OAD-38185: Independent ISS Network

The GMT shall provide a safe-rated communications network, independent from the Observatory Control and IT Networks, required to ensure functional safety.

Rationale: Safety systems should be immune to network outages and an independent ISS network removes this dependence. Critical data for equipment and personal safety shall not be mixed with non-safety information.

Notes: The ISS has ultimate responsibility for functional safety.

REQ-L3-OAD-38188: Low-Latency Network

The GMT shall provide a Low-latency network (LLN) for communication with subsystems required for fast Wavefront Control.

Rationale: This LLN is part of the Observatory Control Network. Wavefront control for diffraction-limited observing requires large amounts of data to be transferred and processed with minimal latency.

REQ-L3-OAD-38191: Absolute Time Reference

The GMT shall provide the capability to obtain and distribute an absolute time reference accurate to 1 millisec.

Rationale: Absolute timing requirements for some science data require 10 millisec accuracy.

Notes: This is not relevant to relative time references for distributed components. Other requirements on latency and data rates from the distributed components will drive the relative time reference precision.

Reliability Requirements

The GMT shall provide the Reliability Requirements from Table [ID 38196].

Table 5-25 [ID 38196]: Communications reliability requirements

Function	Requirement	Documentation

Communications reliability to the outside world of 99.999% during operations	REQ-L3-OAD-38201	Derived from Section 4.2.7.2 in OpsCon
Uninterrupted local science operations if communications to the outside world is interrupted	REQ-L3-OAD-38204	
Cabling redundancy for critical components	REQ-L3-OAD-38206	Minimize downtime from cabling problems

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-38211: Wireless Communications

The GMT shall allow wireless communications to be used for the operation of subsystems.

Rationale: Technologies such as Wifi and Bluetooth will be allowed for data transfer between rotating and non-rotating parts of the enclosure.

5.7.5 Air, Gas, and Vacuum

REQ-L3-OAD-38218: Clean, Dry Compressed Air Temperature

The Clean, Dry Compressed Air pressure shall be delivered at its points of use at ambient temperature ± 1.0 °C for the regular operating conditions temperature range.

Rationale: Regular operating conditions temperature range is defined in Observatory Requirements Document.

REQ-L3-OAD-38221: Clean, Dry Compressed Air Pressure

The Clean, Dry Compressed Air pressure shall be delivered at its points of use at a minimum of 414 kPa (60 PSI) and a maximum of 1040 kPa (150 PSI).

Rationale: The primary mirrors are the largest and most critical consumers of Clean, Dry Compressed Air. Because damage may occur to the primary mirrors if pressures exceed the recommended amount, M1 System will have redundant equipment to limit higher pressures from reaching their points of use.

REQ-L3-OAD-38224: Purge Air

Facilities shall provide a source of clean, dry air (or nitrogen) at locations where instruments or optical systems are operated.

Rationale: Purge Air provides positive pressure to prevent condensation and reduce dust accumulation on sensitive optics.

Notes: Dry N2 may be used to backfill dewars and vacuum systems during servicing operations.

REQ-L3-OAD-38228: Purge Air Temperature

The Purge Air utility shall be delivered at its points of use at ambient temperature ± 1.0 °C for the regular operating conditions temperature range.

Rationale: Regular operating conditions temperature range is defined in Observatory Requirements Document.

REQ-L3-OAD-38231: Shop Compressed Air

Facilities shall provide a source of compressed air to support installation and maintenance of the telescope as allocated in GMT-DOC-00366.

Rationale: Air tools are necessary for maintenance and installation.

Notes: Filtering Shop air to some degree may be necessary to avoid residue from accidental sprays of unfiltered "dirty" air near optics. Exclusive connectors may be necessary to avoid contamination.

5.7.5.1 Air, Gas, and Vacuum Allocations

Air, Gas and Vacuum Allocation for GMT Systems

The GMT shall provide Air, Gas and Vacuum services for GMT Systems per Table [ID 38246].

Table 5-26 [ID 38246]: Air Gas & Vacuum Systems Allocations

Req Id	System Load / Allocation	Shop Compressed Air (lpm)	Clean, Dry Compressed Air (lpm)	Purge Air (lpm)	Vacuum (mmHg)	CO_2 (liquid kg/min)
REQ-L3-OAD-38255	Mount	33.6	0	0	0	0

REQ-L3-OAD-38262	WCCS & ICS Subsystem	0	0	0	0	0
REQ-L3-OAD-38269	M1 System	235.2	346.1	0	0	0
REQ-L3-OAD-38276	ASM Subsystem	33.6	12	0	450	0
REQ-L3-OAD-38283	FSM Subsystem	0	0	0	12.6	0
REQ-L3-OAD-38290	C-ADC Subsystem	33.6	0	4.8	0	0
REQ-L3-OAD-38297	M3 Subsystem	33.6	0	4.8	0	0
REQ-L3-OAD-38304	TMS Subsystem	0	0	0	0	0
REQ-L3-OAD-38311	NGWS/LTWS Subsystem	0	0	14.4	0	0
REQ-L3-OAD-38318	AGWS Subsystem	33.6	0	4.8	0	0
REQ-L3-OAD-38325	LGSS Subsystem	0	4.8	33.6	0	0
REQ-L3-OAD-38332	Optics Servicing System	5	1585	0	0	2.3
REQ-L3-OAD-38339	GIS Instrument System	100.8	0	9.6	TBD	0
REQ-L3-OAD-38346	AP Instrument System	67.2	0	9.6	TBD	0
REQ-L3-OAD-38353	IP Instrument System	33.6	0	4.8	TBD	0
REQ-L3-OAD-	DG	134.4	0	19.2	TBD	0

38360	Instrument System					
REQ-L3-OAD-38367	FP Instrument System	134.4	0	19.2	TBD	0
REQ-L3-OAD-38374	Control Network System	0	0	0	0	0

Rationale: Table [ID 38246] provides the peak estimates provided by system including additional uncertainty contingency held by each system, per GMT-REF-00366 GMT Telescope Utilities Allocation Budget.

5.7.6 Water

5.7.6.1 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.

5.7.6.2 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.

5.7.6.3 Deionized Water

REQ-L3-OAD-38397: De-Ionized (DI) Water

Optics Servicing shall provide De-Ionized (DI) Water for In-Situ wash and re-coating needs.

Rationale: DI water is necessary for mirror coating and cleaning.

Notes: A portable system is desirable to accommodate both needs.

REQ-L3-OAD-38400: De-Ionized (DI) Water Storage

Optical Servicing shall provide non-reactive storage tanks for DI Water Storage.

Rationale: 570 liters is a one-month supply for mirror coating and cleaning.

Notes: Two tanks are expected to support portable DI Water supply.

REQ-L3-OAD-38403: De-Ionized (DI) Water Production Capability

The de-ionized water supply shall be capable of producing a minimum of 570 liters in no greater than 24 hours.

Rationale: Mirror coating and cleaning require a bath size of 570 liters per cleaning.

5.7.6.4 Water Allocations

Observatory provides water services for on-telescope and Summit Support Building operations per Table [ID 38411].

Table 5-27 [ID 38411]: Telescope System Water Allocations

Req Id	\ Allocation System Load \	De-Ionized Water (lpm)	Tap Water (lpm)	Drainage Capability (lpm)

REQ-L3-OAD-96796	Optics Servicing	50	-	-
REQ-L3-OAD-96797	Enclosure	-	50	100
REQ-L3-OAD-96798	Mount	-	50	100
REQ-L3-OAD-96799	Facilities	-	50	100

5.7.7 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-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.

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.

5.8 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-801G.

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.

5.9 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.

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.

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 provide 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 ensures the compatibility and integration between different devices and equipment. It guarantee safe operation and design for Reliability. GMT design configuration that ensures interference-free operation; and clear concepts and doctrines that maximize operational effectiveness.

8 Wavefront Control Summary Tables

Table 8-1 [ID 38571]: Natural Seeing Mode Controlled Degrees of Freedom Summary

System	DOF	Min. range	Accuracy	Precision	Jitter	Bandwidth
Mount	Azimuth	360?	TBD	N/A	N/A	2.0 Hz
Mount	Elevation	30?-89.5?	TBD	N/A	N/A	1.8 Hz
M1	T_X & T_Y	± TBD mm	≤ 75 µm	≤ 0.5 µm	≤ TBD µm at >0.01 Hz	1 Hz
M1	T_Z	± TBD mm	≤ 4.3 µm	≤ 0.5 µm	≤ TBD µm at >0.01 Hz	1 Hz
M1	R_X & R_Y	± TBD mrad	≤ 1.8 µrad	≤ 0.5 µrad	≤ TBD µrad at >0.01 Hz	1 Hz
M1	R_Z	± TBD mrad	≤ 190 µrad	≤ 0.2 µrad	≤ TBD µrad at >0.01 Hz	1 Hz
M2	T_X & T_Y	± TBD mm	≤ 75 µm	≤ 1.0 µm	≤ TBD µm at >0.01 Hz	1 Hz
M2	T_Z	± TBD mm	≤ 4.3 µm	≤ 1.0 µm	≤ TBD µm at >0.01 Hz	1 Hz
M2	R_X & R_Y	± TBD mrad	≤ 15 µrad	≤ 0.1 µrad	≤ 0.1 µrad at >1 Hz	25 Hz

M2	R_Z	± TBD mrad	≤ 1600 µrad	≤ 0.5 µrad	≤ TBD µrad at >0.01 Hz	1 Hz
M3	R_X & R_Y	± TBD mrad	≤ TBD µrad	≤ 12 µrad	≤ TBD µrad at >0.03 Hz	1 Hz
M3	Piston	± TBD mm	≤ TBD µm	≤ TBD µm	≤ TBD µm at >0.01 Hz	1 Hz

Table 8-2 [ID 38573]: Natural Seeing Mode Observed Degrees of Freedom Summary

System	DOF	Min. capture range	1σ Accuracy	Min. sampling
TMS	All main optics DOF	Table 3-19	Table 3-20	0.1 Hz
AGWS	Segment Tip-tilt	± 7.5 arcsec	≤ 56 mas	200 Hz
AGWS	Wavefront Error	± 1.6 arcsec	≤ 60 mas	0.03 Hz
Instrument (DG)	Image Motion	± 1.2 (TBC) arcsec	≤ 10 mas	0.03 Hz
Instrument (other)	Image Motion	± 1.5 (TBC) arcsec	≤ 10 mas	0.03 Hz
Instrument	Focus	± (TBC) 5.0 mm	≤ 100 nm	0.03 Hz

9 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 9-1 [ID 38578]: 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%
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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%