



**SUBSYSTEM REQUIREMENTS
DOCUMENT**

FOR

**THE LASER GUIDE STAR FACILITY
(LGSF)**

TMT.AOS.DRD.08.003.REL02

March 18, 2009

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1. INTRODUCTION

1.1 INTRODUCTION

This is the Thirty Meter Telescope (TMT) Laser Guide Star Facility (LGSF) Design Requirements Document (DRD). The requirements in this document flow down from the level 1 requirements defined in the TMT Observatory Requirement Document (ORD) and the TMT Observatory Architecture Document (OAD).

1.2 PURPOSE

The purpose of this document is to provide a comprehensive definition of the LGSF requirements. This document replaces the Initial Functional Performance Requirements Document (IFPRD) of the LGSF developed during the LGSF Conceptual Design Phase. It does not replace the LGSF Operational Concept Definition Document (OCDD), which is a supporting document of the LGSF DRD.

The intended audience for this document is primarily the developers and reviewers of the LGSF and associated sub-systems.

1.3 SCOPE.

The LGSF is responsible for generating the artificial laser guide stars required by the TMT Laser Guide Star (LGS) AO systems. The LGSF uses multiple sodium lasers to generate and project several LGS asterisms from a laser launch telescope located behind the TMT secondary mirror.

At early light, the LGSF will generate the asterism of the TMT Narrow Field Infrared Adaptive Optics System (NFIRAOS). The LGS measurements will be used to perform the AO high-order wavefront reconstruction and to obtain near diffraction-limited images at near-infrared wavelengths.

The LGSF includes the laser system, the beam transfer optics and laser launch telescope system and the associated laser safety system. It does not include the TMT AO systems and in particular NFIRAOS.

Section 1 contains information about this document. Section 2 contains information about the LGSF system and Section 3 contains the requirements. Paragraphs in Section 3 marked as "Discussion" are for information only and are not requirements.

1.4 APPLICABLE DOCUMENTS

- AD1 Operations Concept Document (OCD), ([TMT.OPS.MGT.07.002](#))
- AD2 Observatory Requirements Document (ORD), ([TMT.SEN.DRD.05.001](#))
- AD3 Observatory Architecture Document (OAD), ([TMT.SEN.DRD.05.002](#))
- AD4 TMT Software Management Plan (SMP), ([TMT.SEN.SPE.08.002](#))
- AD5 TMT Laser Safety Program, (TMT.PMO.MGT.XX.XXX)

1.5 REFERENCE DOCUMENTS

- RD1 LGSF Operational Concept Design Document, (TMT.AOS.CCD.05.033)
- RD2 LGSF Servicing Operation Document (LGSF SOP), (TMT.SEN.TMT.08.001)
- RD3 STR to LGSF ICD, ([TMT.SEN.ICD.07.024](#))
- RD4 SUM to LGSF ICD, ([TMT.SEN.ICD.XX.XXX](#))
- RD5 TCS to LGSF ICD, ([TMT.SEN.ICD.07.025](#))
- RD6 TSS to LGSF ICD, ([TMT.SEN.ICD.07.026](#))
- RD7 NFIRAOS to LGSF ICD, ([TMT.SEN.ICD.07.027](#))
- RD8 LGSF to AOESW ICD, ([TMT.SEN.ICD.XX.XXX](#))
- RD9 LGSF to DMS ICD, ([TMT.SEN.ICD.XX.XXX](#))
- RD10 OSS to LGSF ICD, ([TMT.SEN.ICD.XX.XXX](#))
- RD11 LGSF to SCMS, ([TMT.SEN.ICD.XX.XXX](#))

1.6 CHANGE RECORD

Revision	Date	Section	Modifications
DRF01	March 24, 2008	All	C. Boyer: Initial draft based on IFPRD document
DRF02	May 19, 2008	All	C. Boyer: some TBD solved, more requirements on deployable ducts
REL01	December 05, 2008	All	C. Boyer: Include SE group comments
REL02	February 25, 2009	All	C. Boyer: Include Larry Stepp's comments, add interface with SCMS, replace 3x50W lasers with 9x25W lasers, add requirement regarding the short term and long term power stability of the lasers, add requirements regarding the LGSF shutters to be closed in the event of a power failure, add requirements regarding operating the LGSF control systems as standalone systems

1.7 ABBREVIATIONS

- AG** – Asterism Generator
- AO** – Adaptive Optics
- AOESW** – AO Executive Software
- AOSQ** – Adaptive Optics Sequencer
- ASCAM** – All Sky Camera
- APS** – Alignment and Phasing System
- AZOP** – Azimuth Optical Path

BOCAM – Boresighted Camera
BTO – Beam Transfer Optics
BTOOP – Beam Transfer Optics Optical Path
CC – Component Controller
CIS – Communication and Information System
CW – Continuous Wave
DC – Detector Controller
DM – Deformable Mirror
DIMM – Differential Image Motion Monitor
DMS – Data Management System
DOB – Diagnostic Optical Bench
DOP – Deployable Optical Path
DRD – Design Requirement Document
DS – Diagnostic System
ECRS – Elevation Coordinate System
EL – Electronics
ELOP – Elevation Optical Path
EMD – Enclosure MASS-DIMM system
EQT – Equipment
ESW – Observatory Executive Software
FoV – Field of View
FSM – Fast Steering Mirror
GLAO – Ground Layer Adaptive Optics
ICD – Interface Control Document
IFPRD – Initial Functional Performance Requirements Document
IFU – Integral Field Unit
IR – Infra Red
ISQ – Instrument Sequencer
LAS – Laser System
LGS – Laser Guide Star
LGSF – Laser Guide Star Facility
LIS – Laser Interlock System
LLT – Laser Launch Telescope
LLTB – Laser Launch Telescope Bench
LSE – Laser Service Enclosure
LSQ – Laser Sequencer

LSS – Laser Safety System
LTCS – Laser Traffic Control System
M1 – TMT Primary Mirror
M2 – TMT Secondary Mirror
M3 – TMT Tertiary Mirror
MASS – Multi Aperture Scintillation Sensor
MCAO – Multi Conjugate Adaptive Optics
MIRAO – Mid InfraRed Adaptive Optics
MOAO – Multi Object Adaptive Optics
NFIRAOS – Narrow Field Infrared Adaptive Optics System
NSCU – NFIRAOS Science Calibration Unit
NGS – Natural Guide Star
OAD – Observatory Architecture Document
OCD – Operations Concept Document (Level 1 document)
OCDD – Operational Concept Definition Document
OIWFS – On Instrument Wavefront Sensor
ORD – Observatory Requirement Document
OSS – Observatory Safety System
POW – Power, lighting and grounding system
RMS – Root Mean-Squared
RTC – Real Time Controller
SAF – Safety
SCMS – Site Conditions Monitoring System
SFG – Sum Frequency Generation
STR – Telescope Structure
SUM – Summit Facility
TBC – To Be Confirmed
TBD – To Be Defined
TCS – Telescope Control System
TE – Top End
TESS – Top End Support Structure
TT – Tip/Tilt
TTF – Tip Tilt Focus
TMT – Thirty Meter Telescope
TSS – Telescope Safety System
TTP – Tip/Tilt Platform



TWFS – Truth Wavefront Sensor

ULAO – Up Link Adaptive Optics

USAF – US Air Force

WFE – Wavefront Error

WFS – Wavefront Sensor

2. OVERALL DESCRIPTION

2.1 PERSPECTIVE

The LGSF is composed of 3 main sub-systems:

- (i) The Laser System (LAS), which includes the lasers, the Laser Service Enclosure (LSE) and all associated electronics. The laser service enclosure housing the lasers is located within the $(-X_{ECSR}, -Y_{ECSR})$ location of the telescope azimuth structure. The Laser System provides the light source for generating the artificial stars in the sodium layer at 90 – 110 km altitude.
- (ii) The Beam Transfer Optics (BTO) and Laser Launch Telescope (LLT) System, which is responsible for taking the beams at the output of the laser system and transferring them across the telescope azimuth structure, up the telescope elevation structure and then launching them from the LLT located behind the TMT secondary mirror.
- (iii) The Laser Safety System (LSS), which is composed itself by several sub-systems dedicated to:
 - a. Protecting people and observatory systems from laser light,
 - b. Protecting aircraft from laser illumination,
 - c. Protecting neighboring telescopes from laser beams within their field of view, if needed.

The following figure is a block diagram of the TMT early light AO systems.

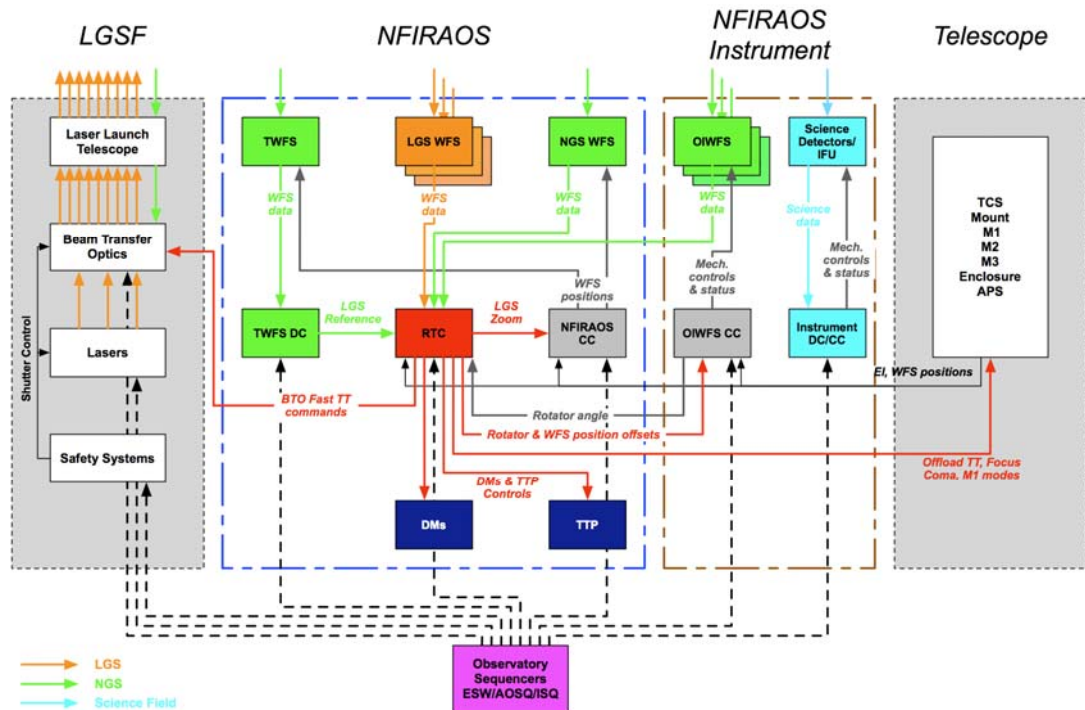


Figure 1: TMT early light AO systems showing the LGSF and its sub-systems, NFIRAOS and a NFIRAOS instrument

The LGSF interfaces with several other observatory, telescope and AO systems, including but not limited to, the Telescope Structure, the Enclosure, the Summit Facilities, the Telescope Control System, the Telescope Safety System, NFIRAOS, the AO Executive Software, the Data Management System and the Site Conditions Monitoring System.

The main control systems of the LGSF (LAS Control System, BTO/LLT Control System and LSS Control System) are all under the control of the AO Sequencer (which is a sub-system of the AO Executive Software) during daytime and nighttime operations.

A more detailed block diagram of the BTO/LLT System is given Figure 2. The BTO/LLT is composed of several sub-systems:

- The Beam Transfer Optics Optical Path, which consists of:
 - i. The Azimuth Optical Path, which transfers the beams from the laser room to a location nearby and underneath the telescope elevation axis.
 - ii. The Deployable Optical Path, which transfers the beams from the previous location across to the $-X_{ECSR}$ telescope elevation journal via the telescope elevation axis.
 - iii. The Elevation Optical Path, which transfers the beams from the $-X_{ECSR}$ telescope elevation journal up to the laser launch telescope via the $(-X_{ECSR}, +Y_{ECSR})$ vertical column of the telescope elevation structure and the connecting tripod leg.
- The LGSF Top End, which consists of the BTO and LLT components located behind the TMT secondary mirror.

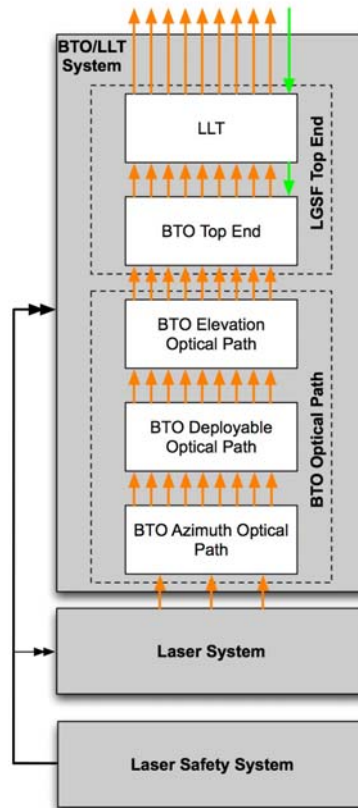


Figure 2: LGSF BTO/LLT system block diagram

2.2 SYSTEM FUNCTIONS

The LGSF will provide the following system functions:

- Project the early light NFIRAOS asterism.
- Project other asterisms as required by the AO modes described in the ORD (AD2).
- Switch rapidly between asterisms.
- Generate LGS with signal level and image quality consistent with the early light NFIRAOS WFE budget defined in ORD [AD2].
- Use multiple lasers and be operational with one laser down.
- Use solid state, sum frequency generation (SFG) lasers with either continuous wave (CW) or mode locked CW pulse format.
- Use conventional optics for the Beam Transfer Optics and launch the AO asterisms from a Laser Launch Telescope located behind the TMT secondary mirror.
- Operate the lasers in fixed gravity vector with the Laser Service Enclosure located within the telescope azimuth structure.
- Transfer the laser beams to the telescope elevation structure using a deployable beam transfer optics path, and park this system to allow observations without LGS, as well as access to instruments located in the vicinity.
- Provide the necessary safety systems that are required with the use of the LGSF lasers.
- Be upgradeable to generate LGS with signal level and image quality consistent with the upgraded version of NFIRAOS WFE budget defined in ORD [AD2].

2.3 USER AND OPERATOR CHARACTERISTICS

The LGSF will be under the full control of the AO Sequencer during daytime and nighttime operation modes. This includes startup, calibration, observation and shutdown operation modes. These modes are fully described in the LGSF OCDD [RD1]. The LGSF control systems will work as autonomous systems and will include engineering user interfaces for engineering maintenance purposes.

The users of the LGSF sub-systems will be:

- The telescope operators. During night-time operations, the telescope operators will be able to perform all basic functions of the LGSF, such as configuring the system, propagating an asterism, stopping LGS propagation, closing/opening LGSF shutters, parking the LGSF and assessing the LGSF overall health.
- The laser technicians/engineers. During daytime operations, the laser technicians/engineers will perform all the functions required to start and align the lasers and adjust the laser performances. During nighttime operations, the laser technicians/engineers will perform all the functions required to monitor and maintain the laser performances and to shutdown the lasers at the end of the LGS observations. During scheduled maintenance periods, the laser technicians/engineers will perform all the maintenance activities required by the lasers.
- The AO technicians/engineers. During daytime operations including calibration and maintenance periods, the AO technicians/engineers dedicated to the LGSF will be able to perform all the functions of the LGSF required to startup and calibrate the LGSF. During scheduled maintenance periods, the AO technicians/engineers will

perform all the maintenance activities (including BTO optics cleaning) required by all the LGSF sub-systems excluding the lasers.

2.4 EXTERNAL INTERFACES

The LGSF has several interfaces with:

- The summit facilities (SUM),
- The observatory safety system (OSS),
- The observatory communication and information system (CIS),
- The telescope sub-systems including:
 - i. The power, lighting and grounding system (POW),
 - ii. The telescope safety system (TSS),
 - iii. The telescope structure (STR),
 - iv. The telescope control system (TCS),
- The AO systems including:
 - i. NFIRAOS,
 - ii. The AO Executive Software (AOESW),
- The observatory software system including:
 - i. The data management system (DMS),
- The Site Conditions Monitoring System (SCMS).

The LGSF Context Diagram is given in Figure 3.

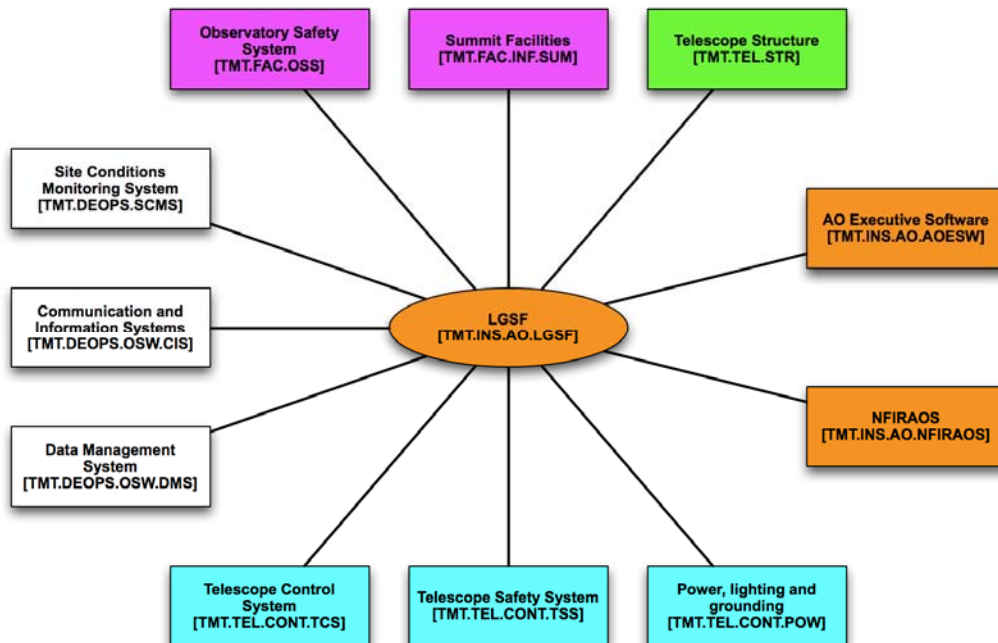


Figure 3: LGSF context diagram



2.5 CONSTRAINTS

None

2.6 ASSUMPTIONS AND DEPENDENCIES

None

3. SPECIFIC REQUIREMENTS

3.1 INTERFACE REQUIREMENTS

3.1.1 Interface with the summit facilities (SUM)

[REQ-2-LGSF-005] The LGSF shall have services and utilities interfaces with the Summit Facilities as described in the SUM to LGSF ICD [RD4].

3.1.2 Interface with the observatory safety system (OSS)

[REQ-2-LGSF-0010] The LGSF shall interface with the Observatory Safety System (OSS) as described in the OSS to LGSF ICD [RD10].

Discussion: The content of this ICD is TBD.

3.1.3 Interface with the observatory communication and information system (CIS)

[REQ-2-LGSF-0015] The LGSF shall interface with the Communication and Information System (CIS) as described in the document TBD.

Discussion: The content of this ICD is TBD.

3.1.4 Interface with the power, lighting and grounding system (POW)

[REQ-2-LGSF-0020] The LGSF shall interface with the Power, Lighting and Grounding System as described in the document TBD.

Discussion: The content of this ICD is TBD.

3.1.5 Interface with the telescope safety system (TSS)

[REQ-2-LGSF-0025] The LGSF Laser Interlock System shall interface with the TSS as described in TSS to LGSF ICD [RD6].

Discussion: The TSS will generate to the Laser Interlock System a signal indicating, if it is safe or not for the telescope and enclosure point of view, to propagate the LGS signal.

3.1.6 Interface with the telescope structure (STR)

[REQ-2-LGSF-0030] The LGSF Laser System shall have a structural and mechanical interface with the telescope azimuth structure as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0031] The LGSF Laser System shall have an access and handling interface with the telescope azimuth structure as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0032] The LGSF Laser System shall have services and utilities interface with the telescope azimuth structure as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0033] The BTO Optical Path of the LGSF shall have a structural and mechanical interface with the telescope azimuth and elevation structures as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0034] The BTO Optical Path of the LGSF shall have an access and handling interface with the telescope azimuth and elevation structures as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0035] The BTO Optical Path of the LGSF shall have services and utilities interface with the telescope azimuth and elevation structures as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0036] The LGSF Top End shall have a structural and mechanical interface with the telescope top end as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0037] The LGSF Top End shall have an access and handling interface with the telescope top end as described in STR to LGSF ICD [RD3].

[REQ-2-LGSF-0038] The LGSF Top End shall have services and utilities interface with the telescope top end as described in STR to LGSF ICD [RD3].

3.1.7 Interface with the telescope control system (TCS)

[REQ-2-LGSF-0050] The LGSF BTO/LLT Control System shall have a software and control interface with the TCS as described in TCS to LGSF ICD [RD5].

Discussion: The TCS will publish the actual and destination zenith angle and the actual and destination rotator angle to the LGSF BTO/LLT Control System.

3.1.8 Interface with NFIRAOS

[REQ-2-LGSF-0060] The LGSF BTO/LLT Control System shall have a software and control interface with the NFIRAOS RTC for the control of the LGSF Fast Steering Mirrors as described in NFIRAOS to LGSF ICD [RD7].

[REQ-2-LGSF-0061] The LGSF Laser Interlock System shall interface with the NFIRAOS RTC to receive RTC interlock events as described in NFIRAOS to LGSF ICD [RD7].

3.1.9 Interface with the AO Executive Software (AOESW)

[REQ-2-LGSF-0070] The LGSF BTO/LLT Control System shall have a software and control interface with the AO Sequencer as described in LGSF to AOESW ICD [RD8].

[REQ-2-LGSF-0071] The LGSF Laser System Control System shall have a software and control interface with the AO Sequencer as described in LGSF to AOESW ICD [RD8].

[REQ-2-LGSF-0072] The LGSF Laser Safety Control System shall have a software and control interface with the AO Sequencer as described in LGSF to AOESW ICD [RD8].

3.1.10 Interface with the data management system (DMS)

[REQ-2-LGSF-0080] The LGSF BTO/LLT Control System shall have a software and control interface with the Data Management System (DMS) as described in LGSF to DMS ICD [RD9].

[REQ-2-LGSF-0081] The LGSF Laser System Control System shall have a software and control interface with the Data Management System (DMS) as described in LGSF to DMS ICD [RD9].

[REQ-2-LGSF-0082] The LGSF Laser Safety Control System shall have a software and control interface with the Data Management System (DMS) as described in LGSF to DMS ICD [RD9].

3.1.11 Interface with the science conditions monitoring system (SCMS)

[REQ-2-LGSF-0090] The LGSF Top End shall have a structural and mechanical interface with the Enclosure MASS-DIMM System of the Science Conditions Monitoring System (SCMS) as described in the LGSF to SCMS ICD [RD11].

[REQ-2-LGSF-0091] The LGSF Top End shall have a services and utilities interface with the Enclosure MASS-DIMM System of the Science Conditions Monitoring System (SCMS) as described in the LGSF to SCMS ICD [RD11].

3.2 GENERAL CONSTRAINT REQUIREMENTS

3.2.1 Lifetime

[REQ-2-LGSF-0140] The LGSF except the lasers shall be able to operate and meet all the requirements for 50 years with preventive maintenance.

REQ-2-LGSF-0141] The lasers shall be able to operate and meet all the requirements for 10 years with preventive maintenance

Discussion: Preventive maintenance means servicing, repairing, and replacing components and sub-systems based on their expected lifetime, as opposed to their failure. The lifetime requirement for the lasers differs from the observatory lifetime, 50 years, [REQ-1-ORD-1000], because the lasers system will be upgraded after a few years of operation (less than 10 years of operation).

3.2.2 Standards

[REQ-2-LGSF-0150] The LGSF shall be designed for maintainability, including use of standard components where possible, and standardization on metric hardware.

Discussion: This requirement flows down the OCD [AD1] and in particular the requirement [REQ-1-OCD-3000].

[REQ-2-LGSF-0160] The LGSF software shall comply with the TMT Observatory software standards and software development process specified in the TMT Software Management Plan [AD4].

3.2.3 Sub-system Decomposition

[REQ-2-LGSF-0200] The LGSF shall be decomposed further into the following sub-systems as described in Table 1:

Sub-system name	WBS element	Sub-system description
Laser System (LAS)		
LASERS	TMT.INS.AO.COMP.SLASR.LASERS	The sodium lasers and associated electronics
LSQ	TMT.INS.AO.COMP.SLASR.LSQ	The lasers sequencer which coordinates the operations of the lasers
LSE	TMT.INS.AO.LGSF.LSE	The Laser Service Enclosure, which houses the laser and associated electronics.
BTO/LLT System		
BTO Optical Path (BTO OP)		
- AZOP	TMT.INS.AO.LGSF.BTO.AZOP	The BTO Azimuth Optical Path, which transports the laser beams from the output of the LSE to a location nearby and underneath the telescope elevation axis. This section of the BTO Optical Path includes the Beam Splitter Assemblies.

- DOP	TMT.INS.AO.LGSF.BTO.DOP	The BTO Deployable Optical Path, which transfers the beams from the previous location across to the $-X_{E CRS}$ telescope elevation journal via the telescope elevation axis. This section of the BTO Optical Path is retractable to allow on-axis observations. This section includes active arrays to track the telescope elevation, re-arrange the asterism beams and correct for pointing and centering alignment errors in the path.
- ELOP	TMT.INS.AO.LGSF.BTO.ELOP	The Elevation Optical Path, which transfers the beams from the $-X_{E CRS}$ telescope elevation journal up to the laser launch telescope via the $(-X_{E CRS}, +Y_{E CRS})$ vertical column of the telescope elevation structure and the connecting tripod leg. This section of the BTO Optical Path includes relay optics and active arrays to compensate for alignment issues along the path.
LGSF BTO/LLT Top End (LGSF TE)		
- TESS	TMT.INS.AO.LGSF.BTO.TESS	The Top End Support Structure, which consists of the structure that supports the BTO/LLT components located behind the TMT Secondary Mirror.
- DOB	TMT.INS.AO.LGSF.BTO.DOB	The Diagnostic Optical Bench located at the telescope top end and dedicated to measure the pointing and centering errors of the LGS. These error signals are used to control the active arrays of the BTO Optical Path. The Diagnostic Optical Bench also supports the quarter wave plate and the beam dump assembly.
- DS	TMT.INS.AO.LGSF.BTO.DS	The Diagnostic System, which includes the near and far field cameras located on the DOB and the associated computing system.
- AG	TMT.INS.AO.LGSF.BTO.AG	The Asterism generator, which

- LLTB	TMT.INS.AO.LGSF.BTO.LLTB	transforms the LGS transporting pattern into the requested asterism The LLT and associated support structure, the flexure compensation system and the K mirror. The LLT projects the required asterism to the sky.
BTO/LLT Electronics and Control System		
- CC	TMT.INS.AO.LGSF.BTO.CC	The BTO/LLT Component Controller, which controls all the BTO/LLT moving mechanisms.
- EL	TMT.INS.AO.LGSF.BTO.EL	The BTO/LLT electronics, which includes all the electronics needed to control all the BTO/LLT moving mechanisms.
BTO/LLT Equipment		
EQT	TMT.INS.AO.LGSF.BTO.EQT	The BTO/LLT Test and Handling Equipment
Laser Safety System (SAF)		
ASCAM	TMT.INS.AO.LGSF.SAF.ASCAM	All Sky Cameras
BOCAM	TMT.INS.AO.LGSF.SAF.BOCAM	Bore-sighted Camera
LTCS	TMT.INS.AO.LGSF.SAF.LTCS	Laser Traffic Control System
LIS	TMT.INS.AO.LGSF.SAF.LIS	Laser Interlock System

Table 1: LGSF sub-system decomposition

3.3 ENVIRONMENTAL CONSTRAINTS

[REQ-2-LGSF-0250] The LGSF shall be able to operate and meet all the requirements at altitudes varying between 0 meters and 4200 meters.

Discussion: The TMT Observatory site has not been selected yet and is expected to be one of the following locations: Cerro Armazones, Chile or Mauna Kea, Hawaii. The altitudes of the two sites are different: 3059 m for Cerro Armazones and 4200m for Mauna Kea. In addition, components of the LGSF, such as the lasers, will be operated at the LGSF and/or Laser vendor facilities, which are expected to be at much lower altitudes.

[REQ-2-LGSF-0270] The LGSF shall be able to operate under the observing operating conditions listed in Table 2:

Ambient temperature range	Armazones: 274.5 K to 286.6 K (1.5 °C to 13.5 °C) Mauna Kea: 271.4 K to 280.8 K (-2 °C to 8 °C)
Ambient relative air humidity	All non-condensing conditions

External mean wind velocity range at 20m above ground, all directions relative to the telescope azimuth	Armazones: 0 m/s to 17.4 m/s Mauna Kea: 0 m/s to 14.7 m/s
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Table 2: Observing operating conditions

[REQ-2-LGSF-0280] The LGSF shall be able to operate in servicing and maintenance mode under the non-observing conditions listed in Table 3:

Ambient temperature range	268 K to 298 K (-5 °C to 25 °C)
Ambient relative air humidity	0% to 100%, condensing

Table 3: Non-observing conditions

[REQ-2-LGSF-0290] The LGSF shall be able to survive the operational basis survival conditions described in Table 4 without damage:

Ambient temperature range	268 K to 298 K (-5 °C to 25 °C)
Ambient relative air humidity	0% to 100%, condensing

Table 4: Operational basis survival conditions

Discussion: The operational basis survival conditions for seismic events are **TBD**.

[REQ-2-LGSF-0300] The LGSF shall be designed to withstand operational basis survival conditions when there is no power to the observatory.

[REQ-2-LGSF-0302] The LGSF shall be designed such that loss of power will not cause damage to the LGSF and to the observatory.

[REQ-2-LGSF-0310] The LGSF shall be able to survive the accelerations due to the 1000-year return period earthquake conditions (described in Table 5), in any direction, without damage to the LGSF itself or other telescope sub-systems, but allowing major realignments (as stated in Table 7):

LGSF Components	Earthquake dynamic acceleration corresponding to a 1000-year return period earthquake	Requirement No.
LGSF Top End	6g (TBC)	[REQ-2-LGSF-0311]
LGSF BTO Azimuth Optical Path	1.5 to 2 g (TBC)	[REQ-2-LGSF-0312]
LGSF BTO Deployable Optical Path	4 g (TBC)	[REQ-2-LGSF-0313]
LGSF BTO Elevation Optical Path	6g (TBC)	[REQ-2-LGSF-0314]
LGSF Laser System	1.5 to 2 g (TBC)	[REQ-2-LGSF-0315]
LGSF All Sky Cameras	TBD	[REQ-2-LGSF-0316]

Table 5: LGSF acceleration requirements due to the 1000-year return period earthquake conditions

Discussion: Note that the LGSF All Sky Cameras will be installed outside but in the vicinity of the TMT enclosure.

[REQ-2-LGSF-0320] The lowest resonant frequencies of the LGSF sub-systems shall be as specified in Table 6:

LGSF Components	Lowest resonant frequency	Requirement No.
-----------------	---------------------------	-----------------

LGSF Top End	15Hz	[REQ-2-LGSF-0321]
LGSF BTO Azimuth Optical Path	TBD	[REQ-2-LGSF-0322]
LGSF BTO Deployable Optical Path	TBD	[REQ-2-LGSF-0323]
LGSF BTO Elevation Optical Path	TBD	[REQ-2-LGSF-0324]
LGSF Laser System	TBD	[REQ-2-LGSF-0325]
LGSF All Sky Cameras	TBD	[REQ-2-LGSF-0326]

Table 6: LGSF sub-systems lowest resonant frequencies

[REQ-2-LGSF-0330] After a 1000-year return period earthquake, the time to inspect and repair the LGSF components shall be as described in Table 7:

LGSF Components	Time to inspect	Time to repair	Requirement No.
LGSF Top End	4 hours	1 week	[REQ-2-LGSF-0331]
LGSF BTO Azimuth Optical Path	2 hours	4 hours	[REQ-2-LGSF-0332]
LGSF BTO Deployable Optical Path	4 hours	1 day	[REQ-2-LGSF-0333]
LGSF BTO Elevation Optical Path	2 hours	4 hours	[REQ-2-LGSF-0334]
LGSF Laser System	6 hours	1 week	[REQ-2-LGSF-0335]
LGSF All Sky Cameras	2 hours	1 week	[REQ-2-LGSF-0336]

Table 7: LGSF time to inspect and repair after a 1000-year period return earthquake conditions

3.4 FUNCTIONAL AND PERFORMANCE REQUIREMENTS

3.4.1 Main requirements

3.4.1.1 Asterism generation requirement

[REQ-2-LGSF-0400] The LGSF shall be able to project the NFIRAOS asterism, which consists of 6 LGS, 5 equally spaced on a circle of radius of 35 arcsec and one additional on-axis guide star.

Discussion: NFIRAOS is the TMT early light LGS Multi Conjugate Adaptive Optics (MCAO) system.

[REQ-2-LGSF-0410] The LGSF shall be able to project the MIRA0 asterism, which consists of 3 LGS equally spaced on a circle of radius of 70 arcsec.

[REQ-2-LGSF-0420] The LGSF shall be able to project the MOAO asterism, which consists of 8 LGS, 3 equally spaced on a circle of radius of 70 arcsec and 5 equally spaced on a circle of radius of 150 arcsec.

[REQ-2-LGSF-0430] The LGSF shall be able to project the GLAO asterism, which consists of 5 LGS, 4 equally spaced on a circle of radius of 510 arcsec and one additional on-axis guide star.

[REQ-2-LGSF-0440] The LGSF shall be able to project additional asterisms with up to 9 LGS and radii varying from 5 arcsec to 510 arcsec.

Discussion: The LGSF asterisms for the early light and first decade AO systems are represented in Figure 4.

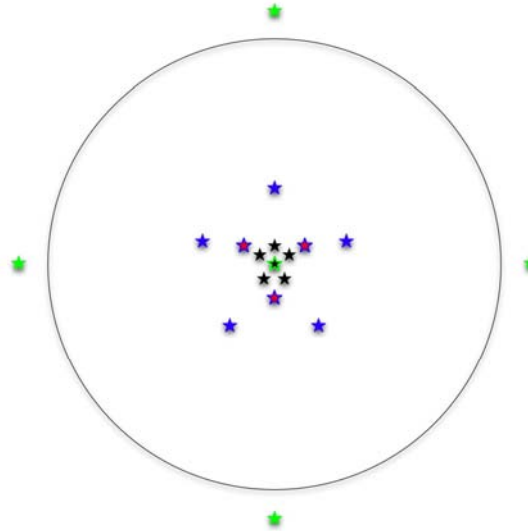


Figure 4: LGSF asterisms: NFIRAOS (black), MIRAO (red), MOAO (blue), GLAO (green)

[REQ-2-LGSF-0450] The LGSF shall be able to switch between asterisms within 2 minutes.

3.4.1.2 LGSF asterism stability

[REQ-2-LGSF-0500] The LGSF asterisms shall remain fixed relative to the AO system LGS WFS line-of-sight as the telescope tracks a science field for exposure times of up to 60 minutes, with 1-axis, 1-sigma tip/tilt error for each laser beam of no more than 0.050 arcsec (TBC).

3.4.1.3 LGSF brightness, beam quality and polarization

[REQ-2-LGSF-0550] The LGSF system shall generate Laser Guide Stars with a signal level of $6.86 \cdot 10^6$ photons/m²-sec at the TMT primary mirror for the case of zenith pointing, a sodium column density of $4 \cdot 10^{13}$ ions/m² and one-way atmospheric transmittance of 0.84.

Discussion: The sodium column density and the one-way atmospheric transmittance values are our reference case, and are representative of medium conditions.

[REQ-2-LGSF-0560] The LGSF shall be upgradeable to provide Laser Guide Stars with a signal level of $37.1 \cdot 10^6$ photons/m²-sec at the TMT primary mirror for the case of zenith pointing, a sodium column density of $4 \cdot 10^{13}$ ions/m² and one way atmospheric transmittance of 0.84.

[REQ-2-LGSF-0570] The LGSF parameters for tilt-removed laser beam quality, Laser Launch Telescope aperture, and high-order optical aberrations shall yield an output laser beam with 85% of its energy contained in a far-field $1/e^2$ diameter no greater than 0.62 arcsec before atmospheric turbulence effects are considered.

Discussion: This corresponds to 1.2 times the diffraction limited of $1/e^2$ beam diameter, for a near field $1/e^2$ diameter of 0.3m at the LLT.

A Beam Cleanup AO system may be included in the design, to correct the aberrations on the out-going laser beams. The Beam Cleanup AO system will include one slow WFS and possibly up to one DM per laser beam.

[REQ-2-LGSF-0580] The LGSF system shall generate Laser Guide Stars which are 98% circularly polarized.

3.4.1.4 LGSF blind pointing accuracy

[REQ-2-LGSF-0600] The LGSF blind pointing accuracy shall be at least 1 arcsec (TBC) on the sky relative to the telescope line-of-sight.

3.4.1.5 LGSF Optical throughput

[REQ-2-LGSF-0650] The end-to-end LGSF optical throughput (from the output of the lasers to the output of the laser launch telescope) shall be at least 0.75 at a wavelength of 589.3nm, with a goal of 0.9.

3.4.1.6 Telescope flexure compensation

[REQ-2-LGSF-0700] The LGSF shall be capable of correcting for the effects of flexure of the telescope top end structure by up to ± 15 mm in translation (perpendicular to the M1 optical axis), ± 2.5 mrad in tilt (relative to the M1 optical axis) and ± 4 mm in axial motion (along the primary mirror optical axis relative to the M1 vertex) over the operating zenith angles between 1 and 65 degrees and at any observing temperature.

Discussion: Compensation of the top end flexure is essential to meet the LGS stability requirements defined in [REQ-2-LGSF-0500] and the blind pointing accuracy requirement defined in [REQ-2-LGSF-0600].

3.4.1.7 Wind cross section requirement

[REQ-2-LGSF-0750] The maximum transverse cross sectional area of the LGSF Top End shall be less than 4 m².

[REQ-2-LGSF-0760] The maximum transverse cross sectional area of the section of the LGSF BTO ELOP more than 14.4m above the telescope elevation axis, shall be less than 6 m².

3.4.1.8 LGSF vignetting requirement

[REQ-2-LGSF-0800] The LGSF components located at the telescope top end shall fit within a cylinder 3.6 meters in diameter centered on the M1 optical axis.

[REQ-2-LGSF-0810] Excepting the deployable portion, the LGSF BTO Optical Path shall fit within the shadow of the telescope truss elements, and/or elevation journal and shall not vignette the telescope beam.

3.4.1.9 LGSF Control System requirements

[REQ-2-LGSF-0850] The LGSF shall include all necessary control systems to generate the required asterisms with the required beam signal level and quality (including as well monitoring, calibration and alignment tools).

[REQ-2-LGSF-0860] The components of the LGSF Control System located within the Observatory Computer Room shall use no more than 15 U.

[REQ-2-LGSF-0870] The components of the Control System of the LGSF upgrade located within the Observatory Computer Room shall use no more than 20 U.

Discussion: 1 U is the standard unit of measure for designating the vertical usable space, or height of racks and cabinets. This unit of measurement refers to the space between shelves on a rack. 1 U is equal to 1.75 inches or 4.445 cm.

3.4.1.10 Mass, center of gravity, moment of inertia and volume requirements

[REQ-2-LGSF-0900] The LGSF mass budget shall be as described in Table 8:

TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Table 13: Center of gravity and moment of inertia of the BTO ELOP

[REQ-2-LGSF-0920] The center of gravity and corresponding moment of inertia of the LGSF Top End shall be as described in Table 14:

Coordinate System	Center of gravity (m)						Moment of inertia (kg x m ²)			
	X	Tol X	Y	Tol Y	Z	Tol Z	Alignment of axes	Ix	Iy	Iz
ECRS	0.040	±0.434	-0.207	±0.426	26.245	±0.354	TBD	TBD	TBD	TBD

Table 14: Center of gravity and moment of inertia of the LGSF Top End

[REQ-2-LGSF-0930] The maximum volume and location of the LSE shall be as illustrated in the drawing TBD.

[REQ-2-LGSF-0932] The maximum volume and location of the additional LSE for the LGSF upgrade shall be as illustrated in the drawing TBD.

[REQ-2-LGSF-0934] The maximum volume and location of the deployed BTO Deployable Optical Path shall be as illustrated in the drawing TBD.

[REQ-2-LGSF-0935] The maximum volume and location of the retracted BTO Deployable Optical Path shall not shall be as illustrated in the drawing TBD.

[REQ-2-LGSF-0936] The maximum swept volume of the BTO Deployable Optical Path shall be as illustrated in the drawing TBD.

[REQ-2-LGSF-0938] The maximum volume of the BTO Elevation Optical Path shall be as illustrated in the drawing TBD.

[REQ-2-LGSF-0940] The maximum volume of the BTO Azimuth Optical Path shall be as illustrated in the drawing TBD.

[REQ-2-LGSF-0942] The maximum volume of the LGSF Top End shall be as illustrated in the drawing TBD.

3.4.1.11 LGSF power consumption, power dissipation and coolant requirements

Discussion: A glycol-water coolant shall be supplied by the observatory facility. The temperature of the coolant supplied will be ~ 3 °C below ambient.

3.4.1.11.1 LGSF components located within telescope azimuth structure:

[REQ-2-LGSF-0950] The total power consumption of the LGSF components located within the telescope azimuth structure shall not exceed TBD Watts.

[REQ-2-LGSF-0952] The total power dissipation into the environment of the LGSF components located within the telescope azimuth structure shall not exceed TBD Watts.

[REQ-2-LGSF-0954] The coolant requirements of the LGSF components located within the telescope azimuth structure shall comply with Table 15:

LGSF LAS and BTO AZOP	Type	Value	Requirement
Coolant Fluid	Chilled glycol (percentage TBD)	-	[REQ-2-LGSF-0955]
Supply temperature	-	TBD °C	[REQ-2-LGSF-0956]
Max coolant pressure	-	TBD psig	[REQ-2-LGSF-0957]
Flow rate	-	TBD litres/second	[REQ-2-LGSF-0958]
Max pressure drop	-	TBD psi	[REQ-2-LGSF-0959]

Table 15: Coolant requirements of the LGSF LAS, LSE and BTO AZOP

Discussion: This includes the Laser System (LSE, Lasers and associated electronics) and the LGSF Beam Transfer Optics Azimuth Optical Path.

3.4.1.11.2 LGSF components located at the telescope top end:

[REQ-2-LGSF-0970] The total power consumption of the LGSF components located at the top end of the telescope shall not exceed TBD Watts.

[REQ-2-LGSF-0972] The total power dissipation into the environment of the LGSF components located at the top end of the telescope shall not exceed TBD Watts.

[REQ-2-LGSF-0974] The coolant requirements of the LGSF components located at the top end of the telescope shall comply with Table 16:

LGSF Top End	Type	Value	Requirement
Coolant Fluid	Chilled glycol (percentage TBD)	-	[REQ-2-LGSF-0975]
Supply temperature	-	TBD °C	[REQ-2-LGSF-0976]
Max coolant pressure	-	TBD psig	[REQ-2-LGSF-0977]
Flow rate	-	TBD litres/second	[REQ-2-LGSF-0978]
Max pressure drop	-	TBD psi	[REQ-2-LGSF-0979]

Table 16: Coolant requirements of the LGSF Top End

Discussion: This includes the LGSF Top End and part of the Beam Transfer Optics Elevation Optical Path (components located on the telescope tripod leg).

3.4.1.11.3 LGSF BTO Deployable Optical Path:

[REQ-2-LGSF-0990] The total power consumption of the LGSF Beam Transfer Optics Deployable Optical Path shall not exceed TBD Watts.

[REQ-2-LGSF-0992] The total power dissipation into the environment of the LGSF Beam Transfer Optics Deployable Optical Path shall not exceed TBD Watts.

[REQ-2-LGSF-0994] The coolant requirements of the LGSF Beam Transfer Optics Deployable Optical Path shall comply with Table 17:

BTO DOP	Type	Value	Requirement
Coolant Fluid	Chilled glycol (percentage TBD)	-	[REQ-2-LGSF-0995]
Supply temperature	-	TBD °C	[REQ-2-LGSF-0996]
Max coolant pressure	-	TBD psig	[REQ-2-LGSF-0997]
Flow rate	-	TBD litres/second	[REQ-2-LGSF-0998]
Max pressure drop	-	TBD psi	[REQ-2-LGSF-0999]

Table 17: Coolant requirements of the LGSF DOP

3.4.1.12 LGSF emission requirement

[REQ-2-LGSF-1050] The LGSF shall not emit light into the enclosure.

3.4.1.13 LGSF vibration requirements

[REQ-2-LGSF-1100] The vibrations coupled by the LGSF Laser System into the telescope shall be less than TBD.

Discussion: This includes the LSE, the lasers and the BTO Azimuth Optical Path for the early light LGSF.

[REQ-2-LGSF-1110] The vibrations coupled by the LGSF Upgrade Laser System into the telescope shall be less than TBD.

Discussion: This includes the additional LSE, additional lasers and modification of the BTO Azimuth Optical Path for the LGSF Upgrade.

[REQ-2-LGSF-1120] The vibrations coupled by the BTO Deployable Optical Path into the telescope shall be less than TBD.

[REQ-2-LGSF-1130] The vibrations coupled by the LGSF Top End into the telescope shall be less than TBD.

3.4.1.14 LGSF startup and shutdown time requirements

[REQ-2-LGSF-1150] The LGSF shall be startup and ready for operation at the end of the day in less than 3 hours.

Discussion: This includes the time to turn on all the LGSF systems, check their status and check the LGSF alignment.

[REQ-2-LGSF-1160] The LGSF shall be shutdown at the end of the night in less than 30 minutes.

3.4.2 Laser System Requirements

3.4.2.1 Laser Requirements

3.4.2.1.1 Laser power requirements

[REQ-2-LGSF-1200] The early light LGSF shall produce a total of at least 150W of 589.3nm light generated by solid-state, sum frequency generation (SFG) lasers, with either a continuous wave (CW) or mode locked CW pulse format.

Discussion: This requirement flows down the OAD [AD3] and in particular the requirements, [REQ-1-OAD-0550], [REQ-1-OAD-2915] and [REQ-1-OAD-2925]. Note, that the laser power and pulse format for the LGSF upgrade may be different and will flow down the OAD requirement, [REQ-1-OAD-2955].

[REQ-2-LGSF-1210] The lasers shall provide a coupling efficiency of at least 130 photons- $m^2/s/W/ion$ (TBC) with the mesospheric sodium layer.

Discussion: This power level and coupling efficiency yield the required photon return for the estimated optical throughput and sodium layer parameters.

3.4.2.1.2 Number of lasers and power per beacon requirements

[REQ-2-LGSF-1220] The LGSF shall implement nine 25W lasers of the type defined in [REQ-2-LGSF-1200].

Discussion: The early light LGSF will be populated with only 7 x 25W lasers. The NFIRAOS asterism includes six 25W LGS. A spare laser is added for redundancy.

Note also that 25W per beacon at this coupling efficiency is required to satisfy the early light NFIRAOS wavefront error budget during all times, including times with low sodium column density. At a minimum, a reduced power level of 17W per beacon provides acceptable performance during times of low sodium column density and satisfies the early light NFIRAOS wavefront error budget during times with median or high sodium column density.

[REQ-2-LGSF-1225] The short-term (defined as a 5–minutes period) power stability of each laser shall be at least 5%.

[REQ-2-LGSF-1226] The long-term (defined as a 12–hours period) power stability of each laser shall be at least 15%.

[REQ-2-LGSF-1230] The LGSF shall be able to project the NFIRAOS asterism with any six of the nine lasers.

[REQ-2-LGSF-1240] The LGSF shall be able to project the MIRAO asterism with any one of a subset of 3 lasers.

Discussion: A minimum of 8W per beacon at this coupling efficiency is required to satisfy the MIRAO performance requirements during all times, including times with low sodium column density.

[REQ-2-LGSF-1250] The LGSF shall be able to project the GLAO asterism with any five of the nine lasers.

[REQ-2-LGSF-1255] The LGSF shall be able to project the MOAO asterism with any eight of the nine lasers.

3.4.2.1.3 Laser beam performance requirements

[REQ-2-LGSF-1260] Ninety five per cent of the transmitted laser beam energy shall be contained in a 1.1 times diffraction-limited core, with a **goal** of 1.01.

[REQ-2-LGSF-1270] The laser output beams shall be 98% linearly polarized.

[REQ-2-LGSF-1280] Each laser shall include internal sensors to monitor laser power, wavelength and line width, temporal pulse format, polarization state and beam quality.

[REQ-2-LGSF-1290] Each laser shall include fully automated diagnostic tests and alignment procedures.

3.4.2.1.4 Laser shutter requirements

[REQ-2-LGSF-1300] Each laser shall include a laser shutter, capable of absorbing the full laser power indefinitely.

[REQ-2-LGSF-1301] The laser shutter shall be designed to automatically close in the event of a power failure.

[REQ-2-LGSF-1310] Each laser shall propagate the laser beam in less than 2 seconds from the shuttered mode.

Discussion: In this mode, the laser is turned ON (the lasers are turned on during the day), in high power mode but shuttered with the laser shutter.

3.4.2.1.5 Low power mode requirement

[REQ-2-LGSF-1320] Each laser shall provide a low power mode, to be used for internal LGSF alignment and diagnostics, in which one or all laser beams may be propagated at an average power of 50 milliwatts.

Discussion: This requirement may be met by a separate low-power "surrogate" laser whose output can be fed into the optical system coincident with the Laser System beams (i.e. HeNe 594.1nm).

3.4.2.1.6 Wavelength shift requirement

[REQ-2-LGSF-1330] If a CW or mode-locked CW pulse format is utilized, each laser shall provide a means to tune on and off the sodium D2 line within 5 milliseconds with a frequency shift of 10 GHz and a power stability of 3%.

Discussion: This feature will be used to measure the strength of Rayleigh backscatter for LGS WFS calibration.

3.4.2.1.7 Pulsed laser requirements

[REQ-2-LGSF-1340] If a pulsed laser is utilized for the LGSF upgrade system, the laser propagation of each laser shall be synchronized with the readout of the LGS wavefront sensors to a temporal accuracy of 1 μ s.

Discussion: Whether the Laser System or the LGS WFS System shall provide the drive signal is TBD.

[REQ-2-LGSF-1350] If a pulsed laser is used with a dynamically refocused LGS WFS for the LGSF upgrade system, the RMS jitter in the timing signal relative to the center-of-gravity of the laser pulse power shall not exceed 10 nsec.

Discussion: This corresponds to an RMS focus error of about 6 nm due to the uncertainty in tracking the range to the guidestar.

3.4.2.1.8 Laser startup/shutdown requirements

[REQ-2-LGSF-1360] Each laser shall start up automatically from a cold start in no longer than 30 minutes.

[REQ-2-LGSF-1370] Each laser shall shutdown automatically in no longer than 30 minutes.

[REQ-2-LGSF-1380] Each laser shall be able to implement an emergency shutdown, which shall shutdown the Laser System instantaneously while minimizing the damage to the laser.

3.4.2.1.9 Laser location requirement

[REQ-2-LGSF-1390] The lasers and associated electronics shall be located in the Laser Service Enclosure (LSE).

Discussion: The LSE provides a class 10,000 clean room environment. The LSE environmental requirements are given in [REQ-2-LGSF-1520], [REQ-2-LGSF-1530], [REQ-2-LGSF-1540].

3.4.2.1.10 Laser mass and volume requirements

Discussion: The lasers consist of the nine laser heads and the wavelength and control system electronics.

[REQ-2-LGSF-1400] The total mass allocated for the laser heads and electronics shall not exceed 2000kg.

Discussion: The total mass allocated for the Laser System is 17000 kg and is defined in [REQ-2-LGSF-0902]. This mass includes the weight of the lasers, associated electronics and laser service enclosure.

[REQ-2-LGSF-1410] The volume of each laser head shall not exceed 0.6m (L) x 0.9m (D) x 1.2m (H).

[REQ-2-LGSF-1420] The volume of the wavelength and control system electronics shall not exceed TBDm (L) x TBDm (D) x 0.8m (H).

Discussion: The wavelength and control system electronics will service all 9 lasers (2U/laser head)

[REQ-2-LGSF-1430] The distance between the laser head and the wavelength and control system electronics shall not exceed **TBD** m.

3.4.2.1.11 Laser power consumption, power dissipation and coolant requirements

[REQ-2-LGSF-1440] The total power consumption of the laser heads and wavelength and control system electronics shall not exceed 20000 Watts.

[REQ-2-LGSF-1442] The power dissipation of the heads and wavelength and control system electronics to the ambient of the Laser Service Enclosure shall be less than 1000 Watts.

3.4.2.2 Laser Service Enclosure (LSE)

3.4.2.2.1 Location requirements

[REQ-2-LGSF-1500] The LSE of the early light LGSF system shall be mounted within the (-X_{ECS}, -Y_{ECS}) quadrant of the telescope azimuth structure.

[REQ-2-LGSF-1510] The additional LSE of the upgraded LGSF system shall be mounted within the (-X_{ECS}, +Y_{ECS}) location of the telescope azimuth structure.

Discussion: This means that the LSE and the lasers inside the LSE will be operated in a fixed gravity vector.

3.4.2.2.2 Clean, temperature controlled room, gown room requirements

[REQ-2-LGSF-1520] The LSE shall provide a class 10,000 clean room environment.

[REQ-2-LGSF-1530] The LSE shall include a gown room.

[REQ-2-LGSF-1540] The LSE shall be temperature controlled with the temperature adjusted to be between the dome ambient temperature and 5°C below the dome ambient temperature but never less than the minimum dome ambient temperature defined in [REQ-2-LGSF-0270]. The temperature within the room shall be maintained to an accuracy of ±0.5°C of the set point.

Discussion: The dome ambient temperature may vary between +1.5°C to +13.5°C (Armazones site) or -2°C to +8°C (Mauna Kea site). Refer to requirement [REQ-2-LGSF-0270].

[REQ-2-LGSF-1545] The relative humidity within the LSE shall be maintained in the range of **TBD** and **TBD**.

3.4.2.2.3 Power consumption and power dissipation

[REQ-2-LGSF-1550] The power consumption of the LSE shall be less than **TBD** Watts.

[REQ-2-LGSF-1560] The heat leakage of the LSE into the telescope environment shall be less than **TBD** Watts.

3.4.2.2.4 Mass requirement

[REQ-2-LGSF-1570] The LSE weight shall not exceed 8800 kg.

Discussion: The total mass allocated for the Laser System is 17000 kg and is defined in the [REQ-2-LGSF-0902]. This mass includes the weight of the lasers, associated electronics and laser service enclosure.

Discussion: The volume of the first light LGSF LSE and additional LSE for the LGSF Upgrade are given in [REQ-2-LGS-0930] and [REQ-2-LGSF-0932] respectively.

3.4.2.3 Laser System Control System

[REQ-2-LGSF-1700] The Laser System (LAS) shall implement a control system, which controls and synchronizes the multiple lasers of the Laser System and which monitors the Laser System performance.

Discussion: The LAS control system may be constituted of several systems: one controller per laser and a laser sequencer module to sequence the operations of the 9 lasers.

[REQ-2-LGSF-1710] The LAS control system shall be compliant with the TMT Observatory Software standards defined in [AD4].

[REQ-2-LGSF-1720] The LAS Control System shall interface with the AO Sequencer to receive commands and parameter messages and to send back response, status or event messages as described in the LGSF to AOESW ICD [RD8].

[REQ-2-LGSF-1725] The LAS Control System shall be able to operate as a standalone system and shall work without the need for interfaces to other TMT sub-systems.

[REQ-2-LGSF-1730] All laser diagnostic tests and alignment procedures shall be available via the LAS Control System to the TMT dedicated personnel.

Discussion: These operations would be performed routinely by the TMT lasers engineers/technicians.

3.4.3 Beam Transfer Optics and Laser Launch Telescope System Requirements

3.4.3.1 Beam Transfer Optics (BTO)

3.4.3.1.1 BTO main requirements

[REQ-2-LGSF-1800] The BTO shall use conventional optics to transport the beams from the Laser Room to the Laser Launch Telescope.

[REQ-2-LGSF-1810] The BTO shall transport the beams from the exit of the Laser System (located in the $(-X_{\text{ECSR}}, -Y_{\text{ECSR}})$ quadrant of the telescope azimuth structure) to the entrance pupil of the Laser Launch Telescope.

3.4.3.1.2 BTO optical performance requirements

[REQ-2-LGSF-1820] The BTO shall include relay optics to reimage the Laser System exit aperture onto the LLT entrance pupil.

[REQ-2-LGSF-1830] The optical performance of the as-built BTO shall be consistent with the LGSF requirement for the beam quality of the far-field laser beacon, with a nominal

requirement for 95 per cent of the transmitted energy to be contained in a 1.05 times diffraction-limited core at a wavelength of 589 nm.

Discussion: This includes any wavefront aberrations induced by failure to align the laser beams to the LLT entrance pupil.

[REQ-2-LGSF-1840] The optical throughput of the BTO shall be at least 0.85 at a wavelength of 589 nm, with a **goal** of 0.95.

3.4.3.1.3 Quarter wave plate requirements

[REQ-2-LGSF-1850] The BTO shall include one or more quarter-wave plates to convert the laser beams from linear to circular polarization at the output of the LLT.

Discussion: Circular polarization will enhance the sodium return by a factor, which is dependant to the laser propagation with respect to the earth magnetic field line and which is therefore site dependant.

[REQ-2-LGSF-1860] The quarter-wave plates shall be automated if periodic adjustments are required when optical elements are recoated or the laser asterism is switched between the different AO modes.

3.4.3.1.4 Beam performance monitoring requirements

[REQ-2-LGSF-1870] The BTO shall be able to monitor the individual laser beam power at or near the entrance pupil of the LLT when the Laser System is operated in the full or low power mode.

[REQ-2-LGSF-1880] The BTO shall be able to monitor at a rate of 10 Hz, laser beam alignment and quality at or near the entrance pupil of the LLT when the Laser System is operated in the full or low power mode.

[REQ-2-LGSF-1890] The BTO shall be able to monitor laser beam polarization state at or near the entrance pupil of the LLT when the Laser System is operated in the full or low power mode.

3.4.3.1.5 Automated optical alignment requirement

[REQ-2-LGSF-1900] The BTO shall include automated optical alignment mechanisms for the BTO Optical Path to maintain laser beam alignment and beam quality at the entrance pupil to the LLT.

Discussion: The BTO Optical Path may include automated relay optics and several beam steering mirrors per beam.

3.4.3.1.6 Beam splitting MIRA0 requirements

[REQ-2-LGSF-1910] The BTO shall include automated beamsplitter assemblies and beam steering mirrors to split one laser beam into the required number of MIRA0 LGS based on the operating lasers.

[REQ-2-LGSF-1920] The time to set a beamsplitter configuration shall not exceed 10 seconds.

3.4.3.1.7 Asterism generation requirement

[REQ-2-LGSF-1930] The BTO shall include an automated asterism generator, which formats the required asterism from the input beams.

3.4.3.1.8 Fast Steering Mirrors requirements

[REQ-2-LGSF-1940] The BTO shall include an automated fast steering mirror for each laser beacon to maintain stable laser pointing and to compensate for turbulence-induced pointing error.

[REQ-2-LGSF-1950] The fast steering mirrors shall be driven based upon the pointing errors measured by the LGS wavefront sensors as computed by the AO Real Time Control (RTC) System, at update rates of up to 800Hz.

[REQ-2-LGSF-1960] The -3dB closed loop bandwidth of the fast steering mirrors shall be at least 5% of the fast steering mirror update rate.

[REQ-2-LGSF-1970] The dynamic range of the fast steering mirrors shall be 10 arcsec on the sky with a precision of 0.01 arcsec.

Discussion: The Fast Steering Mirrors may be located in the AO system instead in order to eliminate the latency caused by the time of flight of the laser beams to the sodium layer.

3.4.3.1.9 Diagnostic sensors requirement

[REQ-2-LGSF-1980] The BTO shall include a sensor to diagnose the optical alignment and measure the optical transmittance of the LLT by observing several stars (simultaneously or sequentially) over the LLT FoV.

Discussion: The broadband optical performance and throughput of this sensor should be sufficient to align the LLT with the accuracy required to meet the LLT optical performance.

3.4.3.1.10 LGSF Top End shutter requirements

[REQ-2-LGSF-1990] The BTO shall include automated shutter(s) to block the laser beams at or near the entrance pupil of the LLT.

Discussion: This shutter is referenced at the LGSF Top End shutter.

[REQ-2-LGSF-1991] The LGSF Top End shutter shall be designed to automatically close in the event of a power failure.

[REQ-2-LGSF-2000] The LGSF Top End shutter shall be located following the BTO beam alignment and quality sensors in order to carry out beam diagnostics without projecting the laser beams through the LLT.

Discussion: The LGSF Top End shutter may be used also to direct the beams to the power meter.

3.4.3.1.11 BTO operation mode requirement

[REQ-2-LGSF-2010] The BTO shall be able to operate with the required level of performance and stability at zenith angles varying between 1 and 65 degrees.

3.4.3.1.12 BTO Deployable Optical Path specific requirements

[REQ-2-LGSF-2020] The BTO Deployable Optical Path shall be parked (i) to allow observations with the on axis instrument located on the $-X_{\text{ECSR}}$ Nasmyth platform and (ii) to prevent vignetting of the on-axis instrument field of view.

[REQ-2-LGSF-2030] The BTO Deployable Optical Path shall never vignette the field of view of the off-axis instruments located on the $-X_{\text{ECSR}}$ Nasmyth platform whatever the telescope orientation

[REQ-2-LGSF-2040] In its parked configuration, the BTO Deployable Optical Path shall not block access to instruments located on the $-X_{\text{ECSR}}$ Nasmyth platform whatever the telescope orientation

[REQ-2-LGSF-2050] Interference between BTO Deployable Optical Path and access to the instruments located on the $-X_{\text{ECRS}}$ Nasmyth platform shall be minimized.

[REQ-2-LGSF-2060] The BTO Deployable Optical Path shall be remotely deployed/parked in less than 30 seconds without human intervention.

[REQ-2-LGSF-2070] The BTO Deployable Optical Path shall be manually deployed/parked in less than 30 minutes by one person.

[REQ-2-LGSF-2080] The BTO Deployable Optical Path shall be jointed to allow the telescope to move at zenith angles varying between -1 and 90 degrees (horizon).

[REQ-2-LGSF-2090] The optics located within the BTO Deployable Optical Path shall not be contaminated by ambient air and dust at any time during deployment, while parked or during operation.

[REQ-2-LGSF-2100] Once deployed, the BTO Deployable Optical Path shall provide a light tight environment.

[REQ-2-LGSF-2110] The BTO Deployable Optical Path shall have a very high positioning repeatability as required to propagate laser beams to the LGSF Top End within the acquisition field of the diagnostics sensors and for operation elevation angles varying from 1 to 65 degrees.

3.4.3.1.13 BTO upgrade requirements

[REQ-2-LGSF-2200] The BTO design shall include the possibility to add an upgrade path to an Uplink AO (ULAO) system to pre-compensate the outgoing laser beams for the impact of atmospheric turbulence and optimize the laser beacon spot size on the sky.

Discussion: This upgrade may include a high-speed wavefront sensor, one or more deformable mirrors, and possibly one or more additional lasers to produce low altitude laser guidestars via Rayleigh backscatter. Further requirements will be defined eventually.

[REQ-2-LGSF-2210] The BTO design shall provide an upgrade path to the higher laser power levels required in the OAD [AD3], [REQ-1-OAD-2955].

3.4.3.2 Laser Launch Telescope (LLT)

3.4.3.2.1 LLT location requirement

[REQ-2-LGSF-2300] The LLT shall be mounted behind the secondary mirror of the telescope.

3.4.3.2.2 LLT clear aperture requirement

[REQ-2-LGSF-2310] The LLT clear aperture diameter shall have a nominal value of 0.5 m.

Discussion: This is consistent with the LGSF requirement for far-field laser beacon beam width specified in [REQ-2-LGSF-0570].

3.4.3.2.3 LLT magnification requirement

[REQ-2-LGSF-2320] The LLT shall expand the input laser beams to a $1/e^2$ energy diameter of 0.3 m.

Discussion: This is consistent with the LGSF requirement for far-field laser beacon beam width specified in [REQ-2-LGSF-0570].

3.4.3.2.4 LLT exit window requirement

[REQ-2-LGSF-2330] The LLT optical design shall include an exit window to protect the LLT optics against weather.

3.4.3.2.5 LLT optical performance requirements

[REQ-2-LGSF-2340] The optical performance of the as-built LLT shall be consistent with the LGSF requirement for the beam quality of the far-field laser beacon, with a nominal requirement for 95 per cent of the transmitted energy to be contained in a 1.05 times diffraction-limited core at a wavelength of 589.3 nm.

Discussion: This is consistent with the LGSF requirement for far-field laser beacon beam width specified in [REQ-2-LGSF-0570].

[REQ-2-LGSF-2350] As an **option**, the LLT shall include actuators for remote initial or periodic optical alignment adjustments that would be performed at zenith angle.

3.4.3.2.6 LLT FOV requirement

[REQ-2-LGSF-2360] The LLT Field of View (FoV) shall be circular with a 510 arcsec radius without vignetting.

3.4.3.2.7 LLT Focus requirement

[REQ-2-LGSF-2370] The LLT shall be focused at an adjustable range between 85 and 235 km.

3.4.3.2.8 LLT optical throughput requirements

[REQ-2-LGSF-2380] The optical throughput of the LLT shall be at least 0.90 at a wavelength of 589.3 nm, with a goal of 0.95.

[REQ-2-LGSF-2390] The optical throughput of the LLT shall be at least 0.70 at a wavelength of 532 nm, with a goal of 0.95, to support a potential upgrade to an Uplink AO (ULAO) system.

[REQ-2-LGSF-2400] The broadband optical throughput and performance of the LLT shall be adequate to enable the optical performance of the LLT to be characterized by observing stars.

3.4.3.2.9 LLT operation requirement

[REQ-2-LGSF-2410] The LLT shall be able to operate with the required level of performance at zenith angles varying between 1 and 65 degrees.

3.4.3.2.10 LLT cover requirement

[REQ-2-LGSF-2420] The LLT shall include an automatically controlled cover, which may be opened and closed in less than 10 seconds.

Discussion: The purpose of the LLT cover is to protect the LLT window when the LGSF system is not used. It is not a shutter, refer to the safety requirements [REQ-2-LGSF-3650] and [REQ-2-LGSF-3660].

3.4.3.2.11 LLT upgrade requirement

[REQ-2-LGSF-2430] The LLT design shall provide an upgrade path to the higher laser power levels required in the OAD [AD3], [REQ-1-OAD-2955].

3.4.3.3 BTO/LLT Control System

[REQ-2-LGSF-2500] The BTO/LLT System shall include a control system, which controls and monitors all the functions of the BTO and of the LLT.

[REQ-2-LGSF-2510] The BTO/LLT control system shall be compliant with the TMT Observatory Software standards defined in [AD4].

[REQ-2-LGSF-2520] The BTO/LLT Control System shall interface with the AO Sequencer to receive commands and parameter messages and to send back response, status or event messages as described in the LGSF to AOESW ICD [RD8].

[REQ-2-LGSF-2530] The BTO/LLT Control System shall be able to operate as a standalone system and shall work without the need for interfaces to other TMT sub-systems.

3.4.4 Laser Safety System Requirements

[REQ-2-LGSF-2600] The LGSF shall include all the necessary safety systems and safety rules defined for the class 4 lasers used in the LGSF system.

Discussion: These safety standards are described in the TMT Laser Safety Program [AD5].

[REQ-2-LGSF-2610] The LGSF Safety System shall monitor and protect the system from damage and personnel injury under the following conditions:

- stray light caused by scatter or misalignment,
- smoke produced by laser damage,
- seismic events,
- AO system failures,
- TCS failures.

3.4.4.1 System damage and personnel injury protection

3.4.4.1.1 Safety shutter requirements

[REQ-2-LGSF-2700] The Laser Safety System shall include one or several Safety Shutters located at the output of the Laser System.

[REQ-2-LGSF-2710] The Safety Shutter(s) shall be able to block the beams in less than 0.1 seconds and safely absorb the full Laser System power until the internal Laser Shutters are deployed.

Discussion: Each laser includes a laser shutter as defined in [REQ-2-LGSF-1300].

[REQ-2-LGSF-2711] The Safety Shutter(s) shall be designed to automatically close in the event of a power failure.

3.4.4.1.2 Laser Interlock System requirements

[REQ-2-LGSF-2720] The Laser Safety System shall implement a Laser Interlock System, which (i) monitors interlocks and events from each of the TMT systems that contribute to the overall safety of the observatory when operating with laser guide stars, and (ii) takes the appropriate actions on basis of those interlocks and events.

Discussion: On basis of those interlocks and events, the Lasers Interlock System may control the different shutters of the LGSF or if necessary shutdown the lasers.

[REQ-2-LGSF-2730] Inputs to the Laser Interlock System shall include, but are not limited to, the following potential safety events:

- Aircraft detection,
- Neighbor telescope interference,
- Earthquake detection,
- LGSF system faults (laser faults, LGSF shutter faults, Laser Service Enclosure or BTO access doors open, smoke detection, lost of signal on the BTO alignment and

diagnostic sensors, BTO temperature and coolant flow sensor out of range, Laser Safety System faults...),

- AO system faults (LGS WFS lost of signal),
- Telescope not ready for laser propagation (enclosure not rotated, or telescope not tracking etc...).

[REQ-2-LGSF-2740] The Laser Interlock System shall not rely upon software whenever possible.

[REQ-2-LGSF-2750] When a software interface is required with the Laser Interlock System, the communications protocol shall include a heartbeat signal to the Laser Interlock System. Loss of the heartbeat signal shall be treated as a safety event and the Laser Interlock System shall take the appropriate actions.

[REQ-2-LGSF-2760] The Laser Interlock System shall monitor the status of all the LGSF shutters: (i) the Laser Shutters, (ii) The Safety Shutters and (iii) the BTO shutter(s) in a way that does not depend upon software interface.

3.4.4.2 Aircraft illumination protection

[REQ-2-LGSF-2800] The LGSF Safety System shall monitor and protect aircraft from accidental laser illumination.

Discussion: The requirements in this section flow down the OAD [AD3] and in particular the requirement, [REQ-1-OAD-7510]. It may be possible that the proposed architecture, based on several wide field cameras and one infrared narrow field camera, will be replaced with a simpler architecture with only one boresighted camera with a larger field of view.

3.4.4.2.1 All sky camera requirements

[REQ-2-LGSF-2810] The Laser Safety System shall include one or more all-sky cameras to detect the navigation lights of nearby aircraft at elevation angles above ~7.5 degrees and to a range of 20 kilometers.

[REQ-2-LGSF-2820] The all sky cameras shall be installed in the vicinity of the telescope.

Discussion: Several cameras may be required because of the size of the enclosure and the requirement for the all sky cameras to monitor a 165 degrees field of view.

[REQ-2-LGSF-2830] Aircraft locations and trajectories shall be computed to provide at least 1 minute warning before aircraft interference with the beams, and be reported to the control system of the Laser Safety System.

[REQ-2-LGSF-2840] The laser beams shall be shuttered automatically at least 5 seconds before the aircraft illumination.

3.4.4.2.2 Boresighted camera requirements

[REQ-2-LGSF-2850] The Laser Safety System shall implement one boresighted infrared camera to be mounted on the telescope and to detect aircraft approaching the immediate vicinity of the laser beams at ranges between 1.5 and 10 kilometers along the TMT line-of-sight.

[REQ-2-LGSF-2860] The boresighted camera shall be mounted on the telescope and boresighted to the telescope pointing.

[REQ-2-LGSF-2870] The boresighted camera shall also be used to detect clouds prior to their interference with the laser beams.

[REQ-2-LGSF-2880] Detection of aircraft with the boresighted camera shall be computed to provide detection at least 1 second before the aircraft illumination occurs.

[REQ-2-LGSF-2890] Detection of clouds with the boresighted camera shall be computed to provide detection at least 1 second before the clouds interference occurs.

[REQ-2-LGSF-2900] The laser beams shall be shuttered automatically at most 0.1 second after the boresighted camera detection (i.e 0.9s before the aircraft illumination or the cloud interference with the laser beams).

3.4.4.3 Neighboring telescope protection from laser beam interference

[REQ-2-LGSF-3000] The LGSF Safety System shall monitor and protect neighboring telescopes from projection of the laser beams within their field of view.

[REQ-2-LGSF-3010] The Laser Safety System shall monitor the telescope pointing and open shutter status of nearby telescopes, if any, through an internet-based interface to avoid interference between TMT laser propagation and astronomical observations by other telescopes.

[REQ-2-LGSF-3020] Laser propagation interferences with other telescopes field of view shall be detected with at least a 5 second warning and be reported to the control system of the Laser Safety System.

[REQ-2-LGSF-3030] The laser beams shall be shuttered automatically at least 1 second before the laser propagation interference with another telescope.

3.4.4.4 Satellite illumination protection

Discussion: As stated in the OAD [AD3] requirement [REQ-2-OAD-7515], the Observatory procedures and the Observatory Executive Software shall protect satellites from accidental laser illumination. The approach to avoiding satellite illumination of earth-orbiting satellites is TBD, with two principal options:

- *The Laser Safety System monitors public domain internet services providing satellite element sets. In this case, any potential interference should be detected with a least a 5 second warning and be reported to the control system of the Laser Safety System. Then the laser beams shall be shuttered automatically within 1 second of satellite illumination.*
- *The Observatory Executive Software contains a table of acceptable science targets for laser propagation for each night, along with a table of predictive avoidance (blackout) times as provided by the USAF Space Command. In this case, the Observatory Executive Software shall manage the LGS observations to avoid satellite illumination. This option is the baseline option for satellite illumination protection as described in the OAD requirement, [OAD-1-REQ-7515].*

[REQ-2-LGSF-3100] As a goal, the Laser Safety system shall monitor the domain internet services providing satellite element sets and shall detect any potential interference with a 5 second warning.

[REQ-2-LGSF-3110] In this case, the laser beams shall be shuttered automatically at least 1 second before the satellite illumination.

3.4.4.5 Laser Safety System Control System

[REQ-2-LGSF-3200] The Laser Safety System (LSS) shall include a control system, which controls and monitors all the functions of the Laser Safety System.

[REQ-2-LGSF-3210] The LSS control system shall be compliant with the TMT Observatory Software standards defined in [AD4].

[REQ-2-LGSF-3220] The LSS Control System shall interface with the AO Sequencer to receive commands and parameter messages and to send back response, status or event messages as described in the LGSF to AOESW ICD [RD8].

[REQ-2-LGSF-3230] The LSS Control System shall be able to operate as a standalone system and shall work without the need for interfaces to other TMT sub-systems.

3.5 SYSTEM ATTRIBUTES

3.5.1 Reliability

[REQ-2-LGSF-3300] The unscheduled LGSF downtime shall not exceed 0.5% of the overall science time budget.

3.5.1.1 Laser System

[REQ-2-LGSF-3350] The unscheduled Laser System downtime shall not exceed 0.26% of the overall science time budget.

Discussion: the Laser System downtime budget can be decomposed further:

- 0.25% for the Lasers
- 0.01% for the Laser Service Enclosure

The downtime budget for the Lasers (P_{LASER}) can be computed via the following formula:

$$P_{LASER} = 1 - P_{LAS9} - P_{LAS8} = 1 - (1 - p)^9 - \frac{9!}{8!} (1 - p)^8 p$$

where P_{LAS9} is the probability to have all nine lasers available, P_{LAS8} is the probability to have eight of the nine lasers available and only one down, and p is the downtime budget corresponding to the probability to have one laser down.

[REQ-2-LGSF-3360] At least eight of the nine lasers shall be available 99.75% of the science time budget.

[REQ-2-LGSF-3370] The unscheduled Laser Service Enclosure downtime shall not exceed 0.01% of the overall science time budget.

[REQ-2-LGSF-3380] The unscheduled individual laser downtime budget shall not exceed 0.85% of the overall science time budget.

3.5.1.2 BTO/LLT System

[REQ-2-LGSF-3400] The unscheduled downtime budget of the BTO/LLT System shall not exceed 0.23% of the overall science time budget.

3.5.1.3 Laser Safety System

[REQ-2-LGSF-3450] The unscheduled downtime budget of the Laser Safety System shall not exceed 0.01% of the overall science time budget.

Discussion: This requirement may be broken down further eventually.

3.5.2 Safety and Security

3.5.2.1 Laser System

[REQ-2-LGSF-3500] The lasers shall include internal safety systems to automatically shutter the beams and/or perform an emergency shutdown if required by system or subsystem failure.

[REQ-2-LGSF-3510] The Laser Service Enclosure shall be equipped with all the safety features to protect personnel and hardware from injury and damage.

Discussion: This includes, but is not limited to, fire detection, power failure, emergency shutdown button, laser safety etc.

3.5.2.2 Beam Transfer Optics and Laser Launch Telescope System

[REQ-2-LGSF-3600] The lasers beams, from the output of the Laser Service Enclosure and up to the output of the Laser Launch Telescope, shall be fully enclosed, with no light leakage into the TMT enclosure under normal operating conditions.

Discussion: The enclosure of the LGSF BTO Optical Path and LGSF Top End will also protect the optical surfaces from contamination.

[REQ-2-LGSF-3610] The LGSF Top End shall be designed so that nothing can fall from the LGSF Top End (including coolant, cleaning fluids, particles, bolts (and other hardware), covers, etc...), even under maximum likely earthquake conditions.

[REQ-2-LGSF-3620] The LGSF BTO Optical Path shall be designed so that nothing can fall from the LGSF BTO Optical Path (including coolant, cleaning fluids, particles, bolts (and other hardware), covers, etc...), even under maximum likely earthquake conditions.

[REQ-2-LGSF-3630] It shall not be possible to retract the BTO Deployable Optical Path when the laser beams are propagated.

[REQ-2-LGSF-3640] It shall not be possible to propagate the laser beams if the BTO Deployable Optical Path is not deployed.

[REQ-2-LGSF-3650] It shall not be possible to open the LGSF Top End shutter if the LLT cover is closed.

[REQ-2-LGSF-3660] It shall not be possible to close the LLT cover if the LGSF Top End shutter is open.

3.5.2.3 Electromagnetic compatibility

[REQ-2-LGSF-3680] The LGSF shall be designed to ensure that it will not emit electromagnetic radiation at any frequency that will adversely interfere with other electronic systems of the observatory.

Discussion: This flows down the ORD (AD2), and in particular the requirement [REQ-1-ORD-7410]. This requirement should be detailed further.

3.5.3 Maintainability

3.5.3.1 Laser System

[REQ-2-LGSF-3700] All periodic maintenance of the Laser System including but not limited to alignment and components replacement shall be performed by dedicated TMT personnel while the Laser System remains mounted on the telescope.

3.5.3.2 BTO/LLT System

[REQ-2-LGSF-3750] All periodic maintenance of the BTO/LLT System including but not limited to cleaning, alignment, components replacement shall be performed by TMT personnel while the BTO/LLT System remains mounted on the telescope.

Discussion: This implies that all the optical surfaces of the BTO/LLT System are accessible for cleaning without the need of removing modules of BTO/LLT System from the telescope.

3.5.3.3 Laser Safety System

[REQ-2-LGSF-3800] All periodic maintenance of the Laser Safety sub-systems located within the telescope including but not limited to alignment, components replacement shall

be performed by dedicated TMT personnel while the Laser Safety System remains mounted on the telescope.

[REQ-2-LGSF-3810] All periodic maintenance of the all sky camera units, located within the vicinity of the telescope, including but not limited to alignment, components replacement shall be performed by dedicated TMT personnel without the need to remove modules from the all sky camera units.

3.6 ACCESS AND HANDLING

[REQ-2-LGSF-3900] The LGSF installation, removal and servicing procedures including inspections for damage after an earthquake shall be achievable using the crane systems and the telescope top end platform as defined in the OAD [AD3], and summarized here for convenience in Table 18:

LGSF Components	OAD crane systems [AD3]	Reach (relative to TCRS z-axis)	Telescope orientation
LGSF Top End	10 metric tonne enclosure base mounted jib crane in conjunction with the telescope top end platform [REQ-1-OAD-6213] [REQ-1-OAD-5325]	22.5m ≤ R ≤ 29m	Horizon pointing [REQ-1-OAD-2990]
LGSF BTO Elevation Optical Path	20 metric tonne enclosure base mounted crane equipped with a man-basket [REQ-1-OAD-6210] & [REQ-1-OAD-6212]	17m ≤ R ≤ 25.7m	Horizon pointing [REQ-1-OAD-2992] & [REQ-1-OAD-2994]
LGSF BTO Deployable Optical Path and part of the LGSF BTO Elevation Optical Path	500kg mobile platform lift [REQ-1-OAD-6250]	9m reach	Zenith pointing [REQ-1-OAD-2996]
Lasers Systems	Laser Service Enclosure crane [REQ-1-OAD-6240]	TBD	NA

Table 18: TMT crane systems and LGSF access

[REQ-2-LGSF-3910] The LGSF shall comply with the servicing operations defined in the LGSF Servicing Operation Document [RD2].

3.6.1 Laser System

[REQ-2-LGSF-4000] The nine laser heads and associated wavelength and control system electronics shall be designed for separate installation/removal into/from the Laser Service Enclosure, within 1 day, with a crew of 2 plus crane operator and safety personnel.

Discussion: This installation time does not include the time necessary to assemble and align the lasers. Similarly, the removal time does not include the time necessary to pack the lasers and associated electronics.

[REQ-2-LGSF-4010] The LSE shall be designed for assembly within the telescope azimuth structure by individual components and not as a modular unit, within 5 days, with a crew of 2 plus crane operator and safety personnel.

Discussion: This does not include the LSE floor, LSE walkways and LSE crane, which will be installed while the telescope azimuth structure is erected.

[REQ-2-LGSF-4020] Access for handling of all the components located within the LSE (lasers and associated electronics) shall be provided via adequate hatches in the roof (TBC).

3.6.2 BTO/LLT System

[REQ-2-LGSF-4100] The LGSF Top End shall be designed for installation/removal to/from the telescope in one unit, within 1 day, with a crew of 2 plus crane operator and safety personnel.

[REQ-2-LGSF-4110] The LLT of the LGSF Top End shall be designed for installation/removal to/from the telescope, within 1 day, with a crew of 2 plus crane operator and safety personnel.

[REQ-2-LGSF-4120] The opto-mechanical components and the associated electronics enclosures of the LGSF BTO Optical Path shall be designed for installation/removal, within 2 days, by one person plus crane operator and safety personnel.

Discussion: The ducts are not included in this requirement. This requirement may be broken down to specific requirements for the BTO Azimuth Optical Path, the Deployable Optical Path and the Elevation Optical Path.

[REQ-2-LGSF-4130] The ducts of the LGSF BTO Optical Path shall be designed for installation/removal, within 1 day, by one person plus crane operators and safety personnel.

Discussion: The ducts will be installed while the telescope structure is erected. It is not expected to remove the ducts during the lifetime of the LGSF, except if major damage occurs requiring replacing some parts of the ducts.

[REQ-2-LGSF-4140] The LGSF BTO/LLT sub-systems shall be designed for installation/removal using handling fixtures.

3.6.3 Laser Safety System

[REQ-2-LGSF-4200] The Laser Interlock System shall be designed for installation/removal by individual components, within 2 hours, by one person plus crane operator and safety personnel.

[REQ-2-LGSF-4210] The components of the aircraft detection system located within the telescope shall be designed for installation/removal by individual components, within 1 hour, by one person plus crane operator and safety personnel.

[REQ-2-LGSF-4220] The all sky camera units shall be designed for installation/removal by individual components, within 1 day, with a crew of 2.

[REQ-2-LGSF-4230] The Laser Traffic Control System shall be designed for installation/removal by one unit, within 1 hour, by one person.

3.7 OTHER REQUIREMENT

None



4. APPENDIX