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Australian National University

System Subsystem Specifications

Prepared For

Advanced Instrumentation and Technology Centre

ANU College of Engineering and Computer Science

Prepared By

Alex Dalton	**Brian Ma**	**Chris Leow**
(uxxxxxxx)	(uxxxxxxx)	(uxxxxxxx)
Steve Lonergan	**Wenjie Mu**	**Paul Apelt**
(uxxxxxxx)	(uxxxxxxx)	(uxxxxxxx)

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Acronyms

AITC Advanced Instrumentation and Technology Centre.

ANU Australian National University.

AO Adaptive Optics.

AOI Adaptive Optics Imaging.

AOTP Adaptive Optics system for space debris Tracking and Pushing.

BTO Beam Transfer Optics.

CAN Controller Area Network.

EC Electronics Cabinet.

EOS Electro-Optic Systems.

GSL Guide Star Laser.

LGS Laser Guide Star.

LH Laser Head.

MSIR More Specific Information Required.

OCS Observatory Control System.

OOS Out of Scope.

SERC Space Environment Research Centre.

SSS System Subsystem Specification.

1 Scope

This section outlines the scope of this document, the context of the project, and the scope of the project. It also defines aspects of the system that have been deemed to be out of scope.

1.1 Document Scope

The scope of this document is to convey the Subsystem Requirements that correspond to the 1.8m telescope, the Toptica GSL, the EOS GSL and the ANU GSL. A metric has also been provided to articulate how each requirement will be verified. This document then identifies all conflicts between the Subsystem Requirements and suggests potential resolutions.

1.2 Project Context

1.2.1 The Telescope

The EOS 1.8m telescope is currently used for satellite and space debris tracking at Mt Stromlo Observatory in Canberra. This telescope is also the site of the Space Environment Research Centre (SERC) project to build an Adaptive Optics Imaging (AOI) system for satellite imaging, and an Adaptive Optics system for space debris Tracking and Pushing (AOTP).

1.2.2 Guide Star Laser Optics

In Adaptive Optics (AO) a GSL is required to produce an artificial star in the atmosphere, which can be used to measure phase distortions caused by atmospheric turbulence above the telescope. This artificial star is known as a Laser Guide Star (LGS). Using a GSL is the current optimum method of creating a light source with acceptable return photon flux and manoeuvrability to track fast moving objects such as satellites.

1.2.3 Adaptive Optics Projects

The Advanced Instrumentation and Technology Centre (AITC) is in the process of developing multiple AO systems for various projects, including the SERC AOI and AOTP systems. They also have an invested interest in the demonstration of ANU's GSL prototype, as it is predicted to be a cheaper and more effective product for AO systems around the world.

1.2.4 System Interface

The AITC has expressed a preferential preliminary concept for the System Interface that would enable all three GSL solutions to be interfaced to the telescope simultaneously. However, it has also been recognised that this may not be possible within the constraints of the 1.8m telescope and the three GSL systems. Note that simultaneous interfacing does not imply simultaneous propagation of the lasers.

1.3 Project Scope

The minimum project scope is to define and provide the requirements to interface the commercial Toptica GSL, the EOS GSL, and the ANU GSL on the EOS 1.8m telescope located at the Mt Stromlo Laser Ranging Facility, Canberra, Australia.

1.4 Out of Project Scope

The capabilities/attributes defined to be Out of Scope (OOS) of the project objectives and deliverables for the Interface System are outlined as below:

a. Beam transfer optics from the laser to the laser launch telescope

b. Laser launch telescope

2 Interfaces and Constraints

2.1 Interfaces and Constraints Outline

The interfaces and constraints of the system that fall within the definition of the Scope Statement (section 1.3) are outlined from a top level perspective Figure 1. There are four major groupings of interfaces within the top level System Interface; 1. 1.8m telescope and dome, 2. EOS GSL, 3. Toptica GSL, 4. ANU GSL. Each of these interfaces are further broken down to Physical, Electrical, Optical, Logical and Environmental. The number referencing system applied to the interfaces and constraints will be utilised as a frame work to ensure all requirements are addressed in the System Subsystem Specification (SSS) project artifact.

figures/interface-tree.pdf

Figure 1: Interface Tree

3 Requirements and Constraints

While the 1.8m telescope and Toptica GSL systems have already been designed and completely built, the EOS GSL and the ANU GSL have not. The requirements and constraints that these two lasers will add to our system interface are therefore yet to be finalised. Any numeric requirements for these two systems that may be subject to change, or have not been finalised, are displayed with appropriate error bounds.

3.1 Telescope Floor Layout

The telescope is split into four floors: the basement, entry, middle and observation floors. This is shown visually in Figure 6 in Appendix C. The basement is the lowest floor, and it is not used in this project. The entry floor is the floor with the main entrance. The entry floor is split into an outer stationary section and an inner rotating section. Above the entry floor is the middle floor. The top floor of the telescope is the observation floor. The observation floor is the major location for the laser-telescope interface.

3.2 Requirements Verification Matrix

The Requirements Verification Matrix, Table 1, shall provide a framework for verification of the system interface against the requirements, and that each requirement is quantitative.

The verification of each requirement shall be performed either by inspection (I), analysis / design (A), demonstration (D), testing (T) or a combination thereof.

At the time of project handover (19 May 2017) some requirements still require more information, or more specific values. These have been augmented with the comment 'More Specific Information Required (MSIR)' and an explanation of the extra information that is required, where possible. This comment was not added to any of the Australian National University (ANU) GSL requirements, as it is already well established that these are still largely unknown and subject to change.

Aside from the MSIR comment, other information included in the *Comment* section of the Matrix include a reference that indicates the source of the information for the particular requirement, the note 'Preference' to indicate that a particular requirement is not as strict as others, references to figures located in the Appendix are made when appropriate, and a note has been made if multiple sources provided differing information for a particular requirement.

Reference	Description	Verification				
		I	A	D	T	Comments
1.1.1	The telescope dictates that the System shall be fixed to the telescope via the following parts: COM-T1252-1-ANU, COM-T1252-2-ANU, COM-T1245-1-ANU, COM-T1245-2-ANU.	×				[1]
1.1.2	The telescope dictates that the System not obtrude more than 1000mm from the 1.8m telescope mounting position.	×				Measured 02/03/17
1.1.3	The telescope dictates that the System shall not extend more than 610mm above the 1.8m telescope's mounting plate on the left side.	×				Measured 02/03/17
1.1.4	The telescope dictates that the System shall not extend above the 1.8m telescope's mounting plate on the right side.	×				See Figures 7, 9, 11
1.1.5	The telescope dictates that the System shall not place more than 50MPA on any bolt into the telescope.		×			[2]
1.1.6	The telescope dome dictates that all systems components be able to pass through the entry level door or the observation shutters.	×				[3]. See Figure 5.
1.1.7	The telescope dome dictates that the observation shutters have dimensions of 1800mm by 2900mm for the purpose of passing components into the dome.	×				[3]
1.1.8	The telescope dictates that entry level door has dimensions of 2700mm by 2200mm.	×				[3]
1.1.9	The telescope dome dictates that the total mass of the System is constrained by the need for the Observer floor of the dome to remain level, which will depend on 16 Firestone Marsh Mellows Isolators (Product Code: W22-358-0187).		×			[4]. MSIR
1.1.10	The telescope dictates that the System shall be mounted to the telescope using no more than the available holes as shown in Figure 7.	×				[1]
1.1.11	The telescope dictates that peripheral electronics required on the observation floor shall be contained within a bench space of 2000 × 600 × 500mm (l × w × h) or an additional space of 2800 × 700 × 1200mm (l × w × h) .	×				Measured 21/04/17. See Figures 9,10a,10b.

Reference	Description	Verification				
		I	A	D	T	Comments
1.1.12	The telescope dictates that peripheral electronics on the entry floor shall not occupy more than 3±3m^2 of floor space.	×				Measured 31/03/17. See Figure 13.
1.1.13	The telescope dictates that peripheral electronics on the entry floor shall not exceed 2500mm in height.	×				Measured 31/03/17
1.1.14	The telescope dictates that peripheral electronics on the middle floor shall not occupy more than $2 \pm 1\,\mathrm{m}^2$ of floor space.	×				Measured 31/03/17. See Figure 12.
1.1.15	The telescope dictates that peripheral electronics on the middle floor shall not exceed 1900mm in height.	×				Measured 31/03/17
1.1.16	The telescope dictates that equipment used on the middle floor must pass through a 1400mm × 600mm access hatch.	×				[3]. See Figure 8.
1.1.17	The telescope dictates that all equipment be mounted on the rotating part of the telescope.	×				[1]
1.1.18	The telescope dictates that the Beam Transfer Optics (BTO) of 325 × 250 × 155 mm(l × w × h) fit between the laser beams and the central elevation axis port.	×				[1]
1.2.1	The telescope dictates that three phase power outlets can be installed if three phase power is required.	×				[5]
1.2.2	The telescope dictates that the System must not draw more than 60 ± 20A of electricity, including equipment already installed.		×			EOS Staff have indicated power consumption of existing telescope components is 'low' [5]. MSIR: how low?
1.2.3	The telescope dictates that the System shall require no more than 6 standard electrical plugs (240 V, 10A) on the top floor of the telescope.	×				Measured 24/03/17

Reference	**Description**	**Verification**				
		I	**A**	**D**	**T**	**Comments**
1.2.4	The telescope dictates that the System shall require no more than 3 standard electrical plugs on the second floor of the telescope.	×				Measured 24/03/17
1.2.5	The telescope dictates that the System shall require no more than 6 standard electrical plugs on the first floor of the telescope.	×				Measured 24/03/17
1.3.1	The telescope dictates that incoming laser beams be 2.8mm in width at the $1/e^2$ intensity point of the Gaussian beam.		×			[6]
1.3.2	The telescope requires any free laser beams conform to AS/NZS 2211.1:2004.		×			[6]
1.3.3	The telescope requires any free laser beams conform to ANSI Z136.1-2014 *Safe Use of Laser for Indoors* and Z136.6-2015 *Safe Use of Laser for Outdoors*.		×			[7]
1.4.1	The telescope dictates that a Controller Area Network (CAN) bus should be used for communication via the EOS Observatory Control System (OCS) whenever and wherever possible.	×				[5]
1.4.2	The telescope dictates that if 1.4.1 can not be complied with, communication be performed using Ethernet infrastructure.	×				[5] Preference.
1.4.3	The telescope dictates that System communication between the dome and the wider system occurs via Ethernet infrastructure.	×				[5]
1.4.4	The telescope dictates that the fibre communication network in the dome cannot be used for the logical interface of the laser control system.	×				[5]
1.4.5	The telescope dictates that 4 Ethernet connections to the EOS OCS are available within the telescope.	×				[5]
1.4.6	The telescope dictates sub-components be controlled by the EOS OCS.	×				[5]
1.4.7	The telescope dictates that automated and remotely accessible laser control systems using the EOS OCS are used wherever possible.	×				[5] Preference.

Reference	Description	Verification				
		I	A	D	T	Comments
1.4.8	The telescope dictates sub-components have access to accurate weather data from the dome, external meteorology station and metal truss sensors via the EOS OCS.		×			[5]
1.5.1	The telescope dictates that the System shall account for temperatures up to 28±2°C.				×	[8]
1.5.2	The telescope dictates that the temperature and humidity shall never drop below the dew point.	×				[5]
1.5.3	The telescope dictates that the System shall account for a maximum vibrational input of as specified by the power spectral density specified in figure 4.				×	[8]
1.5.4	The telescope dome dictates that the System shall exist within a dirty and dusty environment.	×				[8]. MSIR: how dirty?
2.1.1	The EOS GSL dictates that the Laser Head (LH) be mounted on 3 carbon fibre breadboards.	×				[9]
2.1.2	The EOS GSL dictates that the System include 3 breadboards with dimensions of 1800 × 800 × 100 mm (l×w×h).	×				[9]
2.1.3	The EOS GSL dictates that the System include 3 breadboards with a minimum space of 250 mm between them.	×				[9]
2.1.4	The EOS GSL dictates that the gravitational orientation of the System does not change after the EOS GSL is mounted and calibrated.	×				[9]
2.1.5	The EOS GSL dictates that the 3 EOS GSL breadboards be aligned such that all through holes are concentric.				×	[9]
2.1.6	The EOS GSL dictates that the System include 3 EOS GSL breadboards each with optical components weighing 150 ± 50kg.				×	[9]
2.1.7	The EOS GSL dictates that $1/3 \pm 1/6$ of the central EOS GSL breadboard will be free space (ie free volume).	×				[9]

Reference	Description	Verification				
		I	A	D	T	Comments
2.1.8	The EOS GSL dictates that the System include an auxiliary Electronics Cabinet (EC) with dimensions of 500 × 500 × 1750 mm (l×w×h).	×				[9]
2.1.9	The EOS GSL dictates at least 10 power cables must enter the EOS breadboards collectively.	×				[9]
2.1.10	The EOS GSL dictates that 10 ± 2 cooler pipes must enter the EOS GSL breadboards collectively.	×				[9]
2.1.11	The EOS GSL requires that coolers be attached to the System at a distance constrained only by the size of the telescope dome, and the vibrational impact on the lasers.	×				[9]
2.1.12	The EOS GSL requires that a TermoTek P307-14176 420W cooler with dimensions of 653 × 483 × 267 mm (l×w×h) be connected to the System.	×				[9, 10]
2.1.13	The EOS GSL requires that a ThermScientific Accel 250V LC cooler with dimensions of 487 × 232 × 620 mm (l×w×h) be connected to the System.	×				[9, 11]
2.1.14	The EOS GSL requires that a ThermScientific Accel 250V LC cooler with mass of 30kg be connected to the System.	×				[9, 11]
2.1.15	The EOS GSL requires that a TermoTek P307-14176 420W cooler with mass of 40kg be connected to the System.	×				[9, 10]
2.1.16	The EOS GSL requires that the System accounts for the currently unknown vibration from the coolers.	×				[9]. MSIR
2.1.17	The EOS GSL dictates that a deionised water and OptiShield Plus solution be used as a coolant.		×			[9]
2.1.18	The EOS GSL dictates that any coolant additives be 100% soluble in de-ionized water.		×			[9]
2.1.19	The EOS GSL requires that the Thermo-Scientific cooler is re-filled with ≤2.8L of water as necessary.		×			[11]. MSIR: how often?

Reference	Description	Verification				
		I	A	D	T	Comments
2.1.20	The EOS GSL requires that the TermoTek cooler is re-filled with ≤2L of water as necessary.		×			[10] MSIR: how often?
2.2.1	The EOS GSL requires 2.4kW of power via a standard single phase (230V / 10A) power socket.			×		[9]
2.2.2	The EOS GSL requires that at most 2 cooling units be connected to the System.	×				[9]
2.2.3	The EOS GSL requires 2 ± 1 standard power plugs for the EC.	×				[9]
2.2.4	The EOS GSL requires 2kW (at 230V/50Hz) via a single phase power socket for the ThermScientific Accel 250V LC cooler.	×				[9]
2.2.5	The EOS GSL requires 1.5kW (at 230V/50Hz) via a single phase power socket for the TermoTek P307-14176 420W cooler.	×				[9]
2.2.6	The EOS GSL dictates that the current coolant have a conductivity <1500 μS/cm for OptiShield concentrations < 2.5%.		×			[9]
2.3.1	The EOS GSL dictates that a final beam size between 10 μm and 5mm is required.		×			[9]
2.4.1	The EOS GSL requires that one Ethernet cable be connected for engineering and maintenance.	×				[9]
2.4.2	The EOS GSL requires that Ethernet communication with the EOS GSL be conducted using SSH command line protocol.		×			[9]
2.4.3	The EOS GSL requires that CAN bus protocol be used for control.	×				Not currently implemented [9]
2.4.4	The EOS GSL requires connection to the EOS OCS for control and monitoring.				×	[9]
2.5.1	The EOS GSL requires no special ambient temperature conditions.			×		[9]
2.5.2	The EOS GSL dictates that one of the 3 EOS GSL breadboard shall contain several beam dumps which will produce heat.	×				[9]. MSIR: how much heat?

Reference	Description	Verification				
		I	A	D	T	Comments
2.5.3	The EOS GSL dictates that the central board will contain a peltiair box which will produce 15 ± 5 W of excess heat.	×				[9]
2.5.4	The EOS GSL requires that it is not exposed to vibration an order of magnitude greater than the power spectral density shown in figure 3.				×	[9]
2.5.5	The EOS GSL requires air quality to 10 000 class clean room standards.		×			[9]
2.5.6	The EOS GSL requires that the area in which the System is located has an anti-static floor.	×				[9]
2.5.7	The EOS GSL requires that the area in which the System is located has a non-conductive floor.	×				[9]
2.5.8	The EOS GSL requires humidity below 50%.				×	[9]
2.5.9	The EOS GSL requires that the 1050nm laser assembly be kept at a temperature of 20±1°C.	×				[9]
2.5.10	The EOS GSL requires that the amplifier components of the 1342nm laser assembly be kept at a temperature of 17±1°C.	×				[9]
4.1.1	The ANU GSL dictates that the System shall account for a LH of 610 × 305 ×305 mm (l×w×h).	×				[12]
4.1.2	The ANU GSL dictates that the System shall account for an auxiliary EC of at maximum 900 × 900 ×1750mm (l×w×h).	×				[12]
4.1.3	The ANU GSL dictates that the ANU GSL LH be field replaceable.			×		[12]
4.1.4	The telescope dictates that the ANU GSL be connected to a power supply via 1 standard power socket	×				[12]
4.5.1	The ANU GSL requires that area in which the laser is located to have anti-static floor.	×				[12]
4.5.2	The ANU GSL requires that area in which the laser is located to have non-conductive floor.	×				[12]

Reference	Description	Verification				
		I	A	D	T	Comments

Table 1: Requirements Verification Matrix

3.3 Conflict Identification

Conflicts between the requirements identified above are presented here in Table **??**. This table lists the numeric references for requirements which are in conflict, describes the nature of the conflict, and lists potential solutions. When listing the conflicting requirements, brackets are used to indicate that requirements conflict when considered cumulatively.

Conflicting Requirements	**Conflict Description**	**Potential Solutions**
1.1.11 and 1.1.12 with 2.1.8, confidential Toptica dimensions, 4.1.2, 2.1.12, 2.1.13	Space constraints for auxiliary equipment (electronics cabinets and coolers).	There is enough floor space and all of the cabinets are within the height restriction at the present time.
1.2.2 with 2.2.1, 2.2.2, 2.2.3, 2.2.4, 2.2.5, Confidential Toptica requirements	Limitations of the available power draw. All lasers together at maximum power draw need slightly over 40A at standard 230V.	Determine the exact power draw available as it may not be an issue. Do not operate more than one laser at a time.
1.5.3 with 2.1.16 and 2.5.4	Vibration limitations due to multiple GSL systems. Vibrations are too big for the EOS laser, need more information on Toptica GSL and ANU GSL.	Physical isolation of GSL systems through vibration absorbing mounts
1.5.2 with 2.5.8 and (confidential Toptica 3.5.4)	Humidity could reach higher than tolerable limit.	Construct a climate-controlled environment around the System.
1.5.4 with 2.5.5	Air quality may not be sufficient for laser propagation. Need to measure air quality in dome.	Construct a climate-controlled environment around the System.
1.3.2 and 1.3.3 with 2.3.1 and (confidential Toptica, and ANU GSL requirements)	Possibility that laser beams don't conform to Australian safety standards	Ensure that any free laser beams conform with AS/NZS 2211.1:2004 and ANSI Z16.1-2014.
1.2.3 and 1.2.4 and 1.2.5 with 2.2.1 and 2.2.3 and 2.2.4 and 2.2.5, **??**, and (Toptica GSL power socket requirements)	Required power sockets exceeds available. While there are sufficient sockets in the dome, there may not be enough on the Observation Floor, where most of the equipment will be.	Extension cords and power boards.

Conflicting Requirements	Conflict Description	Potential Solutions
1.1.5 with 2.1.2, 2.1.3, 2.1.6, **??**, **??**, (ANU GSL size and weight)	The size and mass of the System may place an unacceptable stress on the bolts mounting it to the telescope.	Additional supports loading either the Observation floor or off the top of the telescope.
1.4.1 and 1.4.3 with (Toptica and ANU GSL) communication protocols	The communication protocols of the ANU GSL may not be CAN or Ethernet standard.	Custom interfaces can be developed if necessary.
1.5.1 with 2.5.9, **??**, (confidential Toptica 3.5.1-3)), 2.5.10, 2.5.2 2.5.3	The temperature of the System might exceed the ability of the System to cool it adequately. The dome is not actively cooled and can reach a temperature of 28°.	Install additional coolers/increase cooler workload/Turn things off.
The telescope dome floor with 2.5.6, 2.5.7, **??**, **??**, 4.5.1, 4.5.2	The telescope dome floor is conductive and may produce static electricity	Non-conductive and anti-static mats.
1.4.7 and 1.4.6 with (System compatibility with CAN bus protocol)	Possibly unable to achieve remote control due to incompatible communication protocols	Develop bespoke interface between systems.
1.4.5 with 2.4.1, 2.4.4, (confidential Toptica)	That there may be less Ethernet ports in the dome that link to the EOS Control Room than are required by the System.	Install extra ports

4 System Specifications

	EOS GSL	**Toptica GSL**	**ANU GSL**	**Total**	**Required by Telescope/Dome**
Laser Head Mass (kg)	450±150	80	MSIR		<2000
Laser Head Size (mm^3)	(1800×800×800)	(925×720× 440)	MSIR		MSIR
Electronics Cabinet Mass (kg)	MSIR	600	MSIR		1
Electronics Cabinet Size (mm^3)	(500×500×1750)	(930×910×1726)	'likely to be no bigger than (930×910×1726)' [12]	(500×500×1750) + (930×910×1726)	2
Cooler Mass (kg)	30 + 40	-	-	30 + 40	1
Cooler Size (mm^3)	(653×483×26) + (487×232×620)	-	-	(653×483×26) + (487×232×620)	2
Power Draw (W)	2400+2000+1500	≤1000	MSIR		MSIR
Power Sockets	2±1+1+1+1+1	1	MSIR		14

Table 3: Subsystems v Key Requirements

1. While the mass of any of these individual components is not constrained by the telescope or dome, the total mass of the System is constrained by (1.1.9).
2. While the size of any of these individual components is not constrained by the telescope or dome, the total size of all these components is constrained by the total space within the dome.

Note: Once again, the comment 'MSIR' indicates that more information is required. In this table, this comment has been used to indicate that many requirements for the ANU GSL are still unknown.

figures/HighLevelInterface-eps-converted-to.pdf

Figure 2: High Level System Interface

4.1 High Level Interface Description

The High Level Interface shown in Figure 2 illustrates how the various components within the System will need to interact. The numbers in the figure are a reference to the descriptions provided below in Table 4.

Reference	Description	Interface	Requirement
1.	Control interface between ANU GSL and the EOS control room	CAN interface via Ethernet	(1.4.1), (1.4.3), (1.4.5), (1.4.2)
2.	Control interface between EOS GSL and EOS control room	CAN for control and Ethernet for SSH.	(2.4.2). (2.4.3)
3.	Control interface between Toptica GSL and EOS control room	[redacted]	([redacted])
4.	Control interface between Telescope/Dome and EOS control room	CAN interface via Ethernet	(1.4.1), (1.4.5)
1.	Power interface between Dome and ANU GSL	1 socket, UNKNOWN power draw	(??)
2.	Power interface between Dome and EOS GSL	2±1 socket(s) for the electronics cabinet, 1 socket for the laser head, 2.4kW power draw for the GSL, 1 socket and 2kW for the Thermo-Scientific Cooler, 1 and 1.5kW socket for the Termotek Cooler	(2.2.1), (2.2.3), (2.2.4), (2.2.5)
3.	Power interface between Dome and Toptica GSL	[redacted] socket(s) and ≤1kW for the Toptica GSL and it's peripherals	(??), ([redacted])
1.	Water interface between Dome and Toptica GSL	MSIR: ask James Webb	

2.	Water interface between Dome and EOS GSL	2.8L of water in the TermoTek cooler to be replaced when required, 2L of water in the Thermo-Scientific cooler to be replaced as required	(2.1.19), (2.1.20)
1.	Air interface between Dome and ANU GSL	Unknown Requirements	air
2.	Air interface between Dome and EOS GSL	Air quality to ISO class 7 clean room standards	(2.5.5)
3.	Air interface between Dome and Toptica GSL	Air with an ambient temperature of between -10°C and 20°C	(**??**), (**??**)

Table 4: High Level Interface Description

References

[1] Mark Blundell. Personal Communication 24/03/17.

[2] Nick Herald. Personal Communication 24/03/17.

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[7] JCY Chin and P Wizinowich. Keck II laser guide star AO system and performance with the TOPTICA/MPBC laser. *SPIE ...*, 2016.

[8] Alex Stuchbery and Elliot Thorn. Vibrational and Thermal Measurements of Laser Guide Star Adaptive Optics for Tracking Space Debris. AITC, Canberra, Australia, January 2015.

[9] James Webb. Personal Communication 24/03/17.

[10] TermoTek. Termotek p300 series chiller. Manual. URL `http://www.termotek-ag.com/uploads/tx_usertermotek/P300_01.pdf`.

[11] Ideal Vacuum. Thermo scientific polar series accel 250 lc, 115v, 250w cooling/heating recirculating chiller. Website. URL `http://www.idealvac.com/product.asp?pid=5598`.

[12] Céline d'Orgeville. Personal Communication 24/03/17.

Appendix

A Power Spectral Densities

figures/PSDL-small.png

Figure 3: Power spectral density which caused the EOS GSL to fail in 2015.

figures/PSDT-small.png

Figure 4: Power spectral density of the vibration of the mounting plate on the telescope while tracking a target. Red line indicates level of peaks from figure 3.

B Main Shutter

figures/Main_shutter-edit.png

Figure 5: Main shutter of EOS 1.8m telescope

C Telescope levels

figures/WholeDome-b-small.png

Figure 6: Entry, middle and observation floors of the EOS 1.8m telescope

D Mounting Plate

figures/MountingPlate.PDF

Figure 7: Mounting Plate of EOS 1.8m Telescope

E Observation Floor Hatch

figures/hatch-edit-small.png

Figure 8: Removable floor hatch on observation floor in EOS 1.8m telescope

F Observation Floor Bench Space

figures/Bench-edit-small.png

Figure 9: Bench space available on the observation floor

G Photographs of Observation Level

figures/Side_View_1.jpg

(a) Observation level: side view

figures/Second_Bench_Space.jpg

(b) Observation level: second bench space

Figure 10: Photographs of observation level of EOS 1.8m telescope

H Photograph of Mounting Plate

figures/Mounting_Plate_3.jpg

Figure 11: Photograph of mounting plate (observation level)

I Photographs of Middle Level

figures/Middle_Floor_Space_1.jpg

(a) Middle level floor space

figures/Middle_Floor_Height_1.jpg

(b) Middle level floor height

figures/Middle_Floor_Height_2.jpg

(c) Middle level floor height

Figure 12: Photographs of middle level highlighting floor space and height

J Photographs of Entry Level

figures/Entry_Floor_Space_1.jpg

(a) Entry level floor space

figures/Entry_Floor_Space_2.jpg

(b) Entry level floor space

figures/Entry_Floor_Space_3.jpg

(c) Entry level floor space

Figure 13: Photographs of middle level highlighting floor space and height