Australian National University

Updated System Subsystem Requirements

Prepared For

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Acronyms

ANU Australian National University.

BTO Beam Transfer Optics.

CAN Controller Area Network.

EC Electronics Cabinet.

EOS Electro-Optic Systems.

GSL Guide Star Laser.

LH Laser Head.

MSIR More Specific Information Required.

OCS Observatory Control System.

1 Requirements and Constraints

While the 1.8m telescope has 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.

1.1 Telescope Floor Layout

The telescope is split into four floors: the basement, entry, middle and observation floors. This is shown visually in Figure 5 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.

1.2 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 6, 8, 10
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 4.
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 ideally be mounted to the telescope using no more than the available holes as shown in Figure 6. Additional holes may be drilled upon approval, if required.	×				[1, 5]
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 8,9a,9b.

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 $6m^2$ of floor space.	×				Measured 18/8/17.
1.1.13	The telescope dictates that peripheral electronics on the entry floor shall not exceed 1950mm in height.	×				Measured 18/8/17
1.1.14	The telescope dictates that peripheral electronics on the middle floor shall not occupy more than $3m^2$ of floor space.	×				Remeasured 18/8/17.
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 1140mm × 520mm access hatch.	×				Measured 18/8/17
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.	×				[6]
1.2.2	The telescope dictates that the System must not draw more than 80A of three-phase equivalent electricity, including equipment already installed. Power can be supplied in both 3 phase (415V AC at 32A), or single phase (3 x 240V AC at 32A)		×			[7]
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 18/08/17
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 18/8/17

Reference	Description	Verification				
		I	A	D	T	Comments
1.2.5	The telescope dictates that the System shall require no more than 8 standard electrical plugs on the first floor of the telescope.	×				Measured 18/08/2017
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.		×			[8]
1.3.2	The telescope requires any free laser beams conform to AS/NZS 2211.1:2004.		×			[8]
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.	×				[6]
1.4.2	The telescope dictates that if 1.4.1 can not be complied with, communication be performed using Ethernet infrastructure.	×				[6] Preference.
1.4.3	The telescope dictates that System communication between the dome and the wider system occurs via Ethernet infrastructure.	×				[6]
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.	×				[6]
1.4.5	The telescope dictates that 3 free Ethernet connections to the EOS OCS are available within the telescope. 1 on the observation deck and 2 in the electrical cabinet on the entry floor.	×				Counted 6/10/17.
1.4.6	The telescope dictates sub-components be controlled by the EOS OCS.	×				[6]
1.4.7	The telescope dictates that automated and remotely accessible laser control systems using the EOS OCS are used wherever possible.	×				[6] Preference.
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.		×			[6]
1.5.1	The telescope dictates that the System shall account for temperatures up to 30±2°C.				×	[9, 10]

Reference	Description	Verification				
		I	A	D	T	Comments
1.5.2	The telescope dome dictates that the System shall not produce excessive hot air turbulence within the dome	×				[11] U: Enclosure and venting system ensure it's met
1.5.3	The telescope dictates that the temperature and humidity shall never drop below the dew point.	×				[6]
1.5.4	The telescope dictates that the System shall account for a maximum vibrational input of as specified by the power spectral density specified in figure 3.				×	[9]
1.5.5	The telescope dome dictates that the System shall exist within a dirty and dusty environment. U: the breadboards will be fully enclosed and airtight.	×				[9]
2.1.1	The EOS GSL dictates that the Laser Head (LH) be mounted on either 2 or 3 carbon fibre breadboards.	×				[12], The number of breadboards required was not confirmed. 2 breadboards was the most likely scenario
2.1.2	The EOS GSL dictates that the System includes breadboards with dimensions of 1500 × 750 × 105 mm (l×w×h).	×				[13]
2.1.3	The EOS GSL dictates that the minimum spacing of 250 mm exists between breadboards.	×				[5]
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.	×				[5]
2.1.5	The EOS GSL dictates that the EOS GSL breadboards be aligned such that all through holes are concentric.				×	[5]
2.1.6	The EOS GSL dictates that the space between concentric through holes of the EOS GSL breadboards are not obstructed.				×	[5]
2.1.7	The EOS GSL dictates that the System include 3 EOS GSL breadboards each with optical components weighing 150 ± 50kg.				×	[5]

Reference	Description	Verification				
		I	A	D	T	Comments
2.1.8	The EOS GSL dictates that $1/3 \pm 1/6$ of the central EOS GSL breadboard will be free space (ie free volume).	×				[5]
2.1.9	The EOS GSL dictates that the System include an auxiliary Electronics Cabinet (EC) with dimensions of 500 × 500 × 1750 mm (l×w×h). [This cabinet will be within 2m of the system.]	×				[5], **Citation**
2.1.10	The EOS GSL dictates at least 10 power cables must enter the EOS breadboards collectively.	×				[5]
2.1.11	The EOS GSL dictates that 10 ± 2 cooler pipes must enter the EOS GSL breadboards collectively.	×				[5]
2.1.12	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.	×				[5]
2.1.13	The EOS GSL requires a generic 400W water cooler	×				[5, 14, 15]
2.1.14	The EOS GSL requires that the System accounts for the currently unknown vibration from the coolers.	×				[5]. MSIR
2.1.15	The EOS GSL dictates that a deionised water and OptiShield Plus solution be used as a coolant.		×			[5]
2.1.16	The EOS GSL dictates that any coolant additives be 100% soluble in de-ionized water.		×			[5]
2.1.17	The EOS GSL requires that the cooler is re-filled with ≤2.8L of water as necessary.		×			[16, 15]. MSIR: how often?
2.1.18	The EOS GSL requires that the cooler is re-filled with water as necessary.		×			[14] MSIR: how often? Dependent on cooler, as only one generic 400W cooler is needed [15]

Reference	Description	Verification				
		I	A	D	T	Comments
2.1.19	The EOS GSL requires that ethylene glycol is not used in the coolers.		×			[17]
2.2.1	The EOS GSL requires at most 2.4kW of power via a standard single phase (230V / 10A) power socket.	×				[18]
2.2.2	The EOS GSL requires that it is most likely 1 cooling unit is connected to the System.	×				[18]
2.2.3	The EOS GSL requires , $1+1$ power plugs for chillers or oscillator. If the latter is in the clean room, 1 standard power plug for the EC in dome.	×				[15]
2.2.4	The EOS GSL requires up to 2.4kW (at 230V/50Hz) via a single phase power socket for the Cooler selected	×				[15]
2.2.5	The EOS GSL dictates that the current coolant have a conductivity <1500 μS/cm for OptiShield concentrations $< 2.5\%$.		×			[5]
2.4.1	The EOS GSL requires that one Ethernet cable be connected for engineering and maintenance.	×				[5]
2.4.2	The EOS GSL requires that Ethernet communication with the EOS GSL be conducted using SSH command line protocol.		×			[5]
2.4.3	The EOS GSL requires that CAN bus protocol be used for control.	×				Not currently implemented [5]
2.4.4	The EOS GSL requires connection to the EOS OCS for control and monitoring.				×	Via 1 CAN bus [18]
2.5.1	The EOS GSL requires ambient temperature between 0–40°C, but could work in lower temperatures.			×		[15]
2.5.2	The EOS GSL dictates that one of the 3 EOS GSL breadboard shall contain several beam dumps which will produce heat.	×				[5]. MSIR: how much heat?
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.	×				[5] MSIR

Reference	Description	Verification				
		I	A	D	T	Comments
2.5.4	The EOS GSL requires that it is not exposed to vibration an order of magnitude greater than currently unknown tolerances.				×	[5] MSIR further testing to be undertaken [19]
2.5.5	The EOS GSL requires air quality to ISO class 7 clean room standards.		×			[5]
2.5.6	The EOS GSL requires that the area in which the System is located has an anti-static floor.	×				[5]
2.5.7	The EOS GSL requires that the area in which the System is located has a non-conductive floor.	×				[5]
2.5.8	The EOS GSL requires humidity below 50%.				×	[5]
2.5.9	The EOS GSL requires that the amplifier components of the 1342nm laser assembly be kept at a temperature of 17±1°C.	×				[5] This is achieved by the cooler.
3.1.1	The ANU GSL dictates that the ANU shall account for a LH of 610 × 305 ×305 mm (l×w×h). U: width will increase is AEC is further than 2 m away from the laser head	×				[20]
3.1.2	The ANU GSL dictates that the LH be mounted the EOS carbon fibre breadboard on which the BTO are mounted.	×				[11]
3.1.3	The ANU GSL dictates that the System shall account for an auxiliary EC of at maximum 660×660×1300mm (l×w×h).	×				[21]
3.1.4	The ANU GSL dictates that the ANU GSL LH be field replaceable.			×		[20]
3.1.5	The telescope dictates that the ANU GSL be connected to a power supply via 1 standard power socket	×				[20]
3.2.1	The ANU GSL requires less than 800W of cooling.	×				[21]
3.2.2	The ANU GSL requires air quality to ISO class 7 clean room standards surrounding the laser-head	×				[11]
3.2.3	[The ANU GSL requires an operating temperature of 10° - 30° C]	×				[21]

Reference	Description	Verification				
		I	A	D	T	Comments
3.2.4	[The ANU GSL requires a non-operational temperature of greater than 5° C, unless anti-freeze is used]	×				[21]
3.2.5	The ANU GSL requires a combined flow rate of 8L/min		×			[21]
3.2.6	The ANU GSL requires uses CAN bus over Ethernet for communication		×			[21]
3.2.7	The ANU GSL requires cooling at potentially two different temperature points, for the amplifiers and the oscillators.		×			[21]
3.3.1	The ANU GSL requires approximately 800W of power for the auxiliary electrical cabinet	×				[22]

Table 1: Requirements Verification Matrix

1.3 Conflict Identification

Conflicts between the requirements identified above are presented here in Table 2. 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 2.1.9, 3.1.3, 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	Limitations of the available power draw. All lasers together at maximum power draw need approximately 33A 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.
1.5.4 with 2.1.14 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, or relocation of oscillators and other vibration sensitive components.
1.5.3 with 2.5.8	Humidity could reach higher than tolerable limit.	Construct a climate-controlled environment around the System. Accounted for in current designs.
1.5.5 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. Accounted for in current designs.
1.3.2 (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
1.2.3 and 1.2.4 and 1.2.5 with 2.2.1 and 2.2.3 and 2.2.4	Required power sockets may exceed 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. Relocation of components has removed issue at present time.

Conflicting Requirements	**Conflict Description**	**Potential Solutions**
1.1.5 with 2.1.2, 2.1.3, 2.1.7 (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.	Current system allows for more weight to be applied, further testing with paneling and cabling attached to the frame will need to be tested.
1.4.1 and 1.4.3 and 3.2.6 with (ANU GSL) communication protocols	ANU GSL will use CAN bus over Ethernet as preferred communication protocol method	All designs should attempt to accommodate for CAN bus
1.5.1 with, 2.5.9, 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 30°	Controlled using active cooling on air filtration intake design.
The telescope dome floor with 2.5.6, 2.5.7,	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, **??**	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.

Table 2: Requirement Conflict Identification

2 System Specifications

	EOS GSL	**ANU GSL**	**Total**	**Required by Telescope/Dome**
Laser Head Mass (kg)	450±150	MSIR		<2000
Laser Head Size (mm^3)	(1800×800×800)		MSIR	
Electronics Cabinet Mass (kg)	MSIR	MSIR		1
Electronics Cabinet Size (mm^3)	(500×500×1750)	(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	MSIR		MSIR
Power Sockets	1 + 1 + 1 [18]	1 + 1 [21]		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.

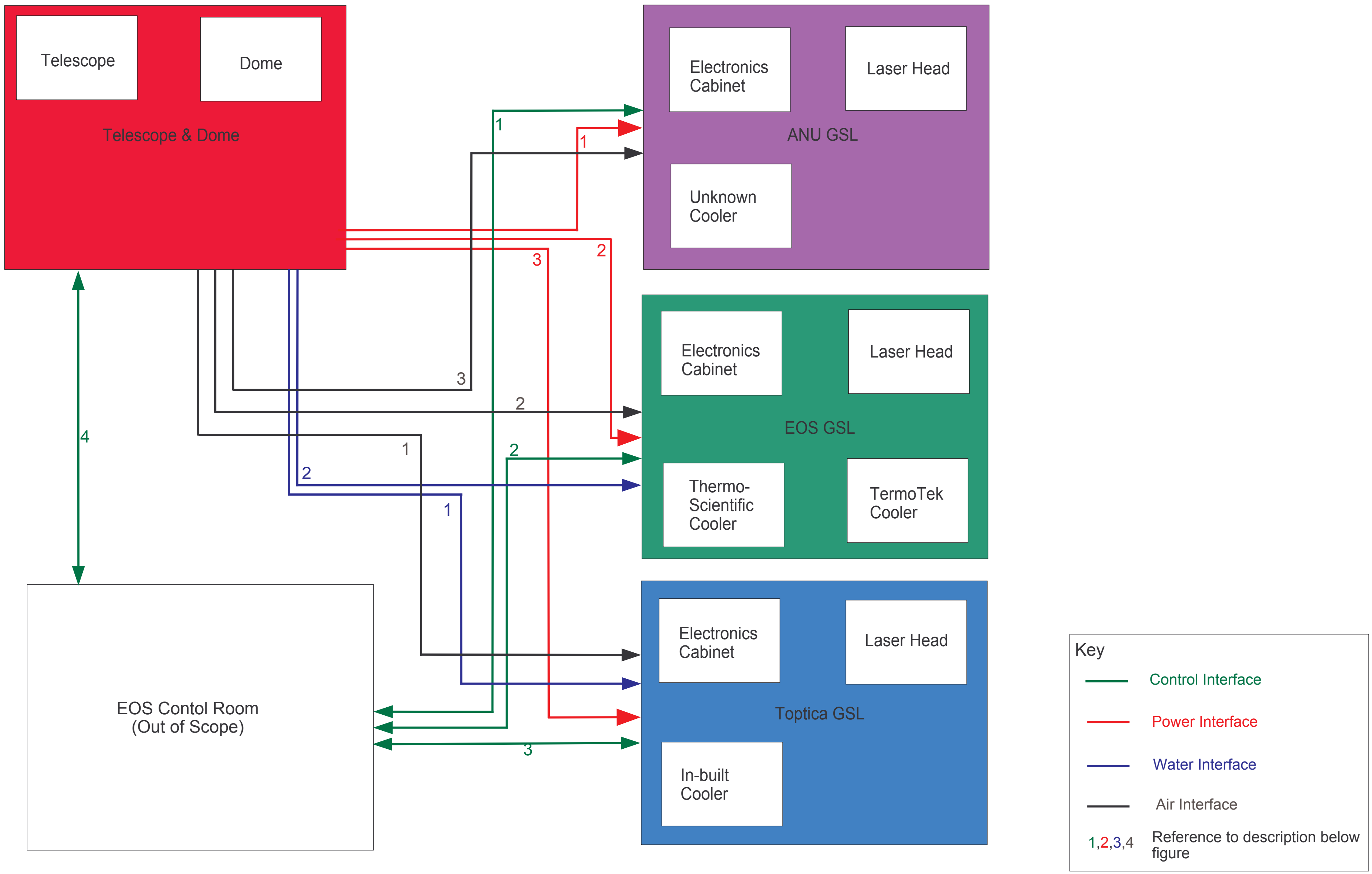


Figure 1: High Level System Interface

2.1 High Level Interface Description

The High Level Interface shown in Figure 1 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)
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	1 socket for AEC, 240V <10A 1 socket for the cooler	(2.2.1), (2.2.3), (2.2.4),
2.	Water interface between Dome and EOS GSL	A cooler capable of removing 400W of heat is required	(2.1.17), (2.1.18)
1.	Air interface between Dome and ANU GSL	Ambient temperature between 10°C and 30°C [21]	
2.	Air interface between Dome and EOS GSL	Air quality to ISO class 7 clean room standards	(2.5.5)

Table 4: High Level Interface Description

References

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

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

[3] EOS Space Systems. Eos dome solidworks models.

[4] Firestone. Marsh mellow vibration isolation design manual. Website. URL `http://www.airsprings.com.au/products/firestone-marsh-mellow-isolators/`.

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

[6] Questions for jack, chris and alex, 2017. URL `https://docs.google.com/document/d/1PZMPgJY84uTnZW2wFvkKtPzhNCKQLoRuLgusiIJmgYE/edit`. Google Drive Link to Artifact.

[7]

[8] Céline d'Orgeville, Francis Bennet, Mark Blundell, Rod Brister, Amy Chan, Murray Dawson, Yue Gao, Nicolas Paulin, Ian Price, Francois Rigaut, Ian Ritchie, Matt Sellars, Craig Smith, Kristina Uhlendorf, and Yanjie Wang. A sodium laser guide star facility for the ANU/EOS space debris tracking adaptive optics demonstrator. In Enrico Marchetti, Laird M Close, and Jean-Pierre Véran, editors, *SPIE Astronomical Telescopes + Instrumentation*, page 91483E. Australian National University, Canberra, Australia, SPIE, July 2014.

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

[10] Alex Stuchbery. Personal Communication 25/08/17.

[11] Céline d'Orgeville. Client Meeting 06/09/17. .

[12] James Webb. Personal Communication 18/08/17. .

[13] Mark Blundell. Personal Communication 18/08/17. .

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

[15] James Webb. Personal Communication 08/09/17. .

[16] 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`.

[17] Yue Gao. Personal Communication 29/09/17.

[18] James Webb. Personal Communication 22/09/17. .

[19] James Webb and Mark Blundell. Stakeholder Meeting 22/09/17.

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

[21] Greg Fetzer. Personal Communication 22/09/17. .

[22] Greg Fetzer. Personal Email Communication 19/09/17. .

Appendix

A Power Spectral Densities

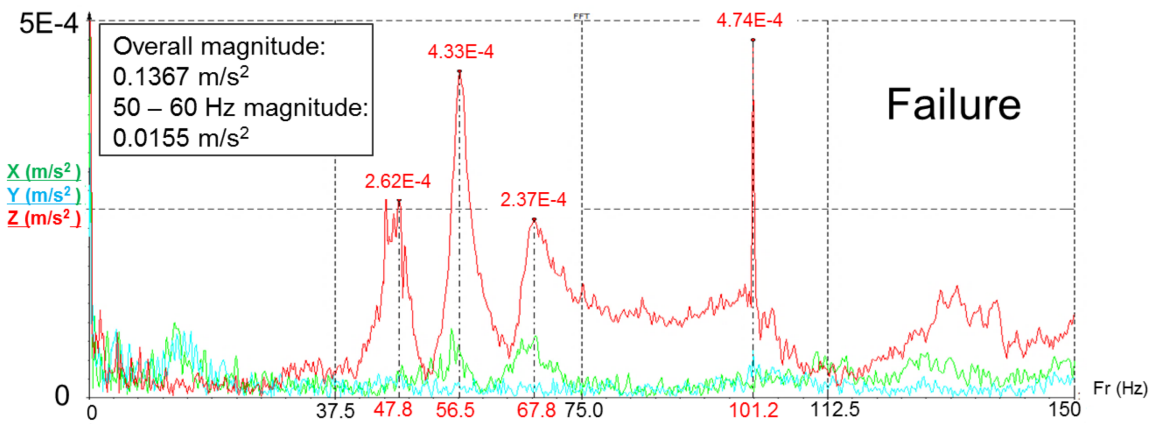


Figure 2: Power spectral density which caused the EOS GSL to fail in 2015.

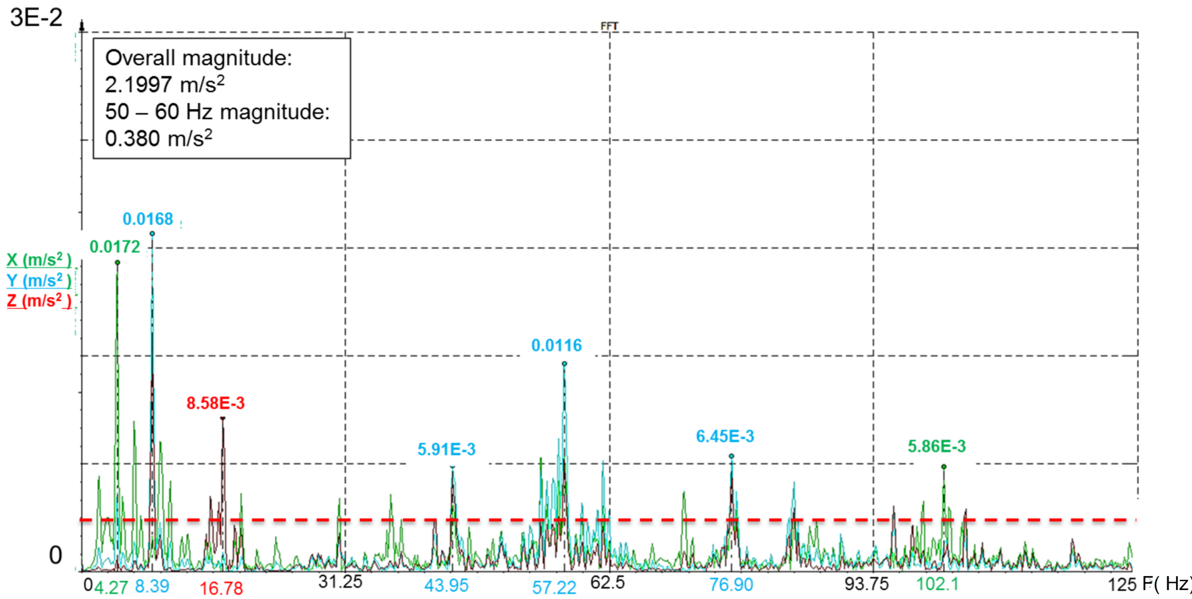


Figure 3: Power spectral density of the vibration of the mounting plate on the telescope while tracking a target. Red line indicates level of peaks from figure 2.

B Main Shutter

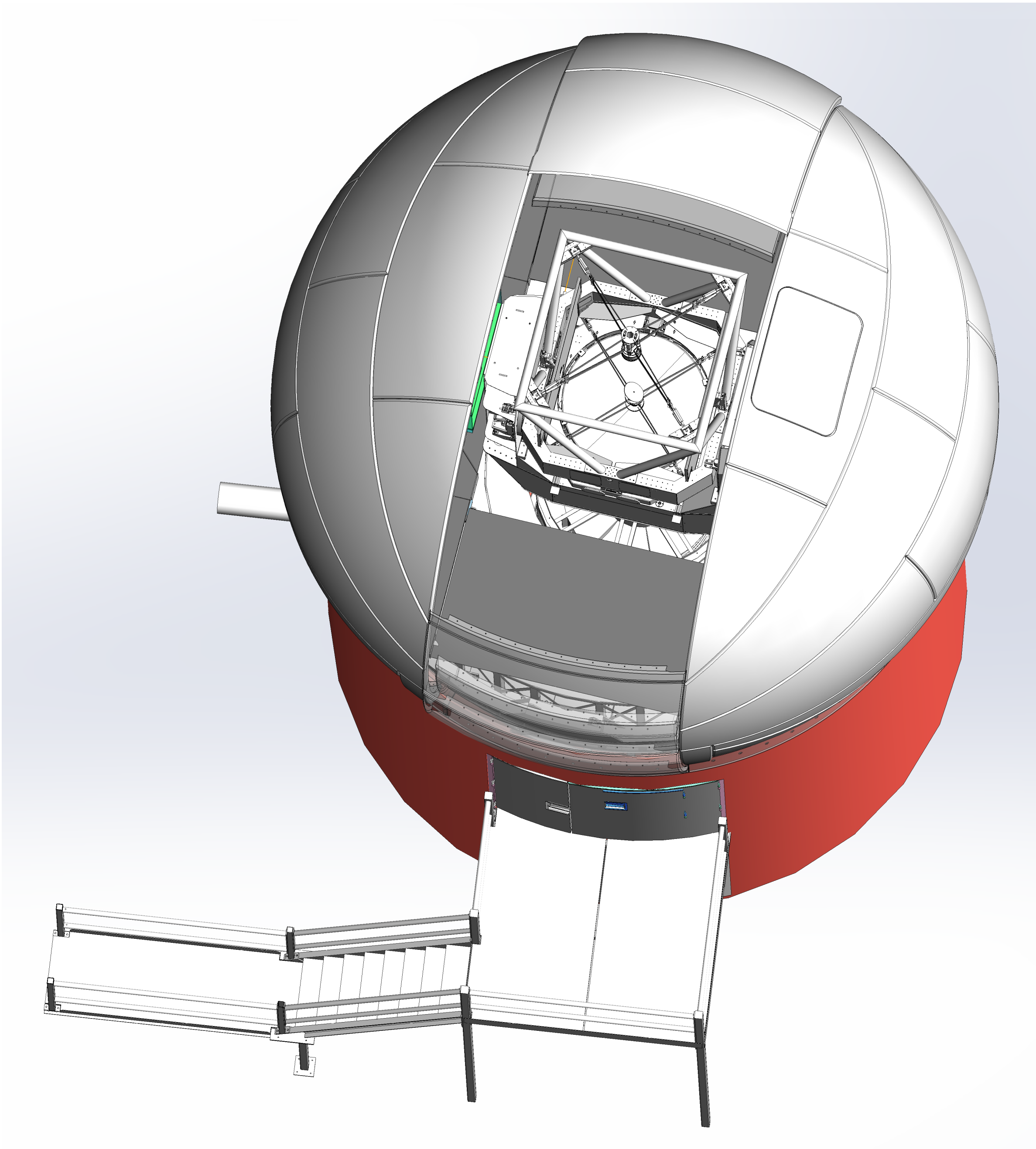


Figure 4: Main shutter of EOS 1.8m telescope

C Telescope levels

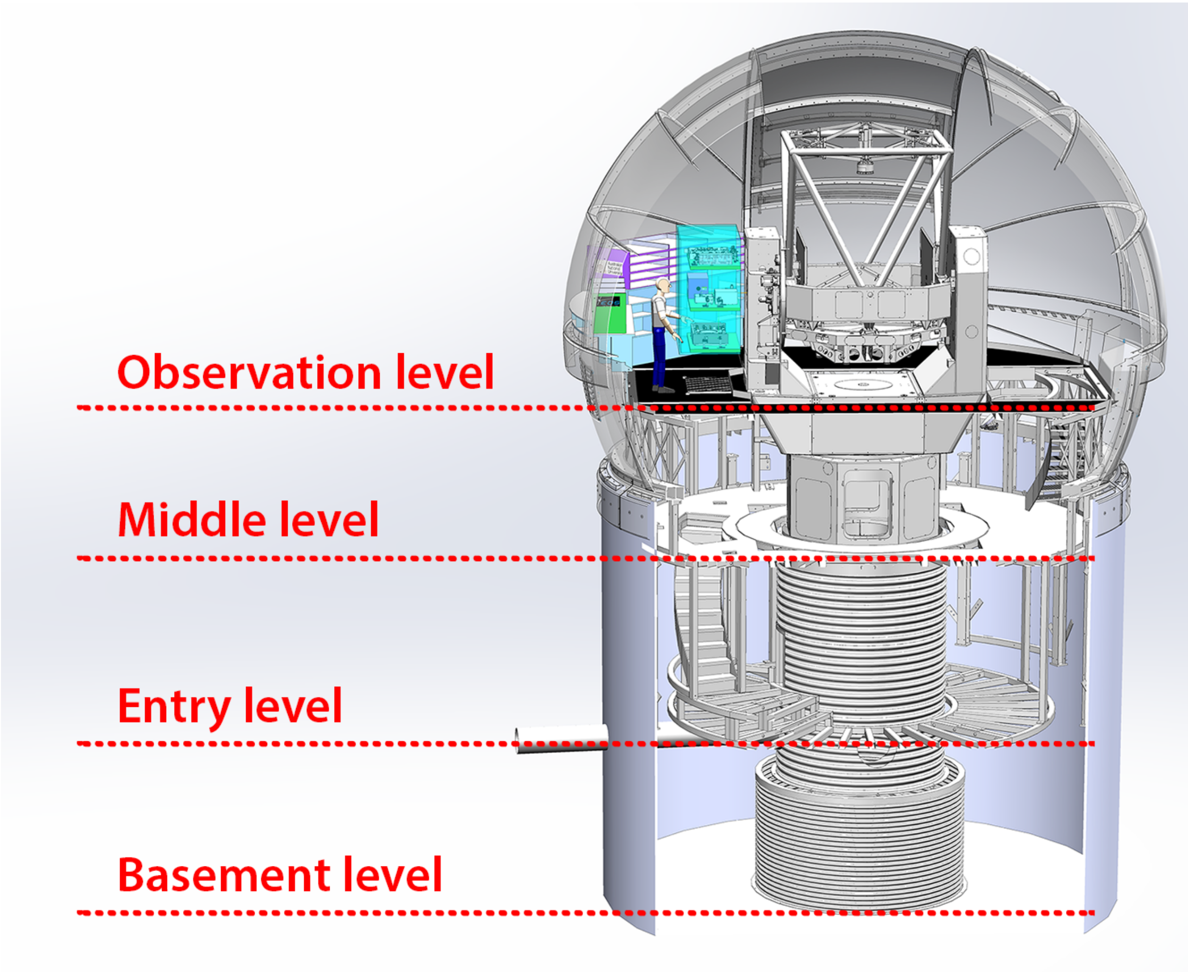


Figure 5: Entry, middle and observation floors of the EOS 1.8m telescope

D Mounting Plate

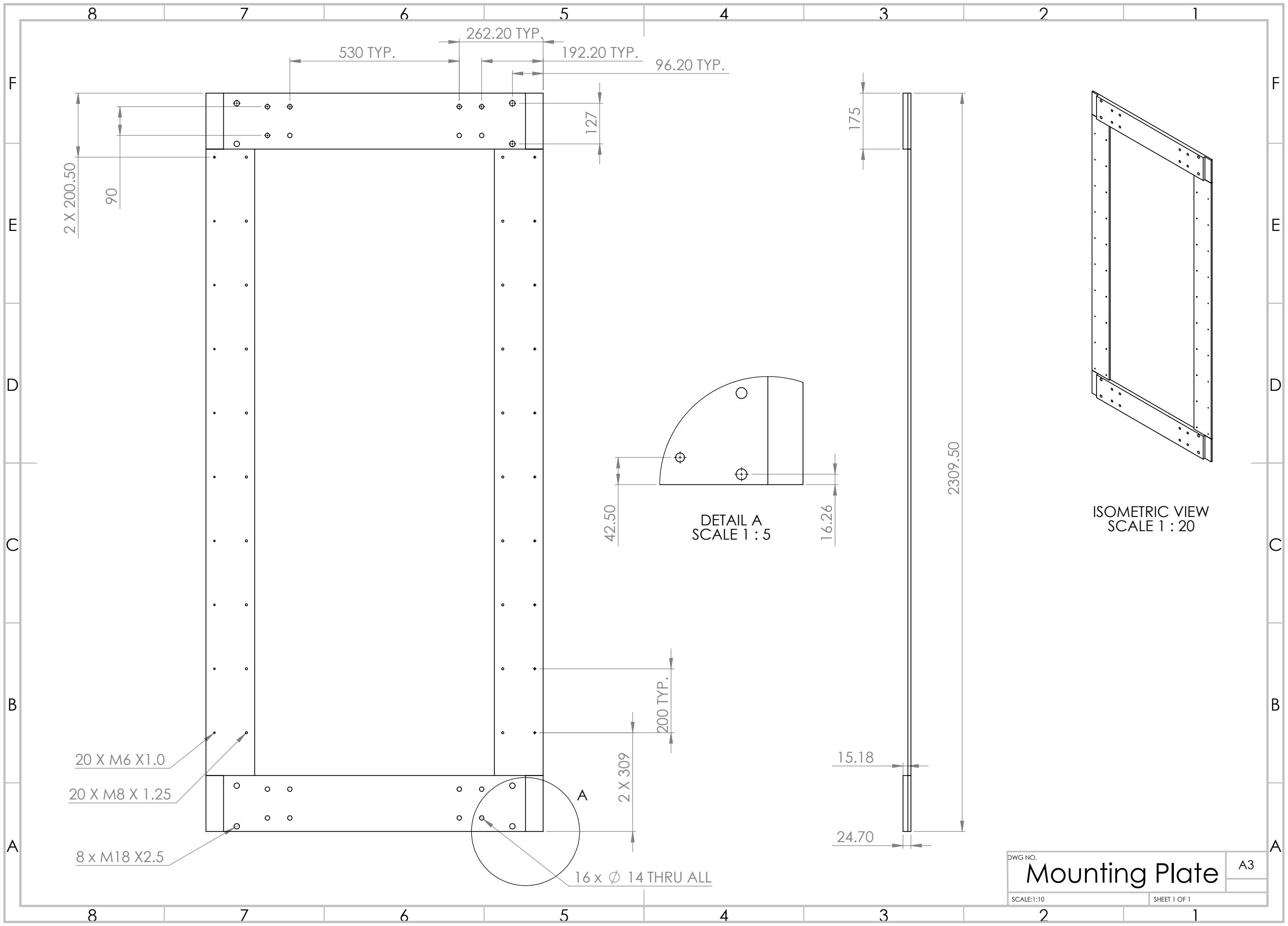


Figure 6: Mounting Plate of EOS 1.8m Telescope

E Observation Floor Hatch

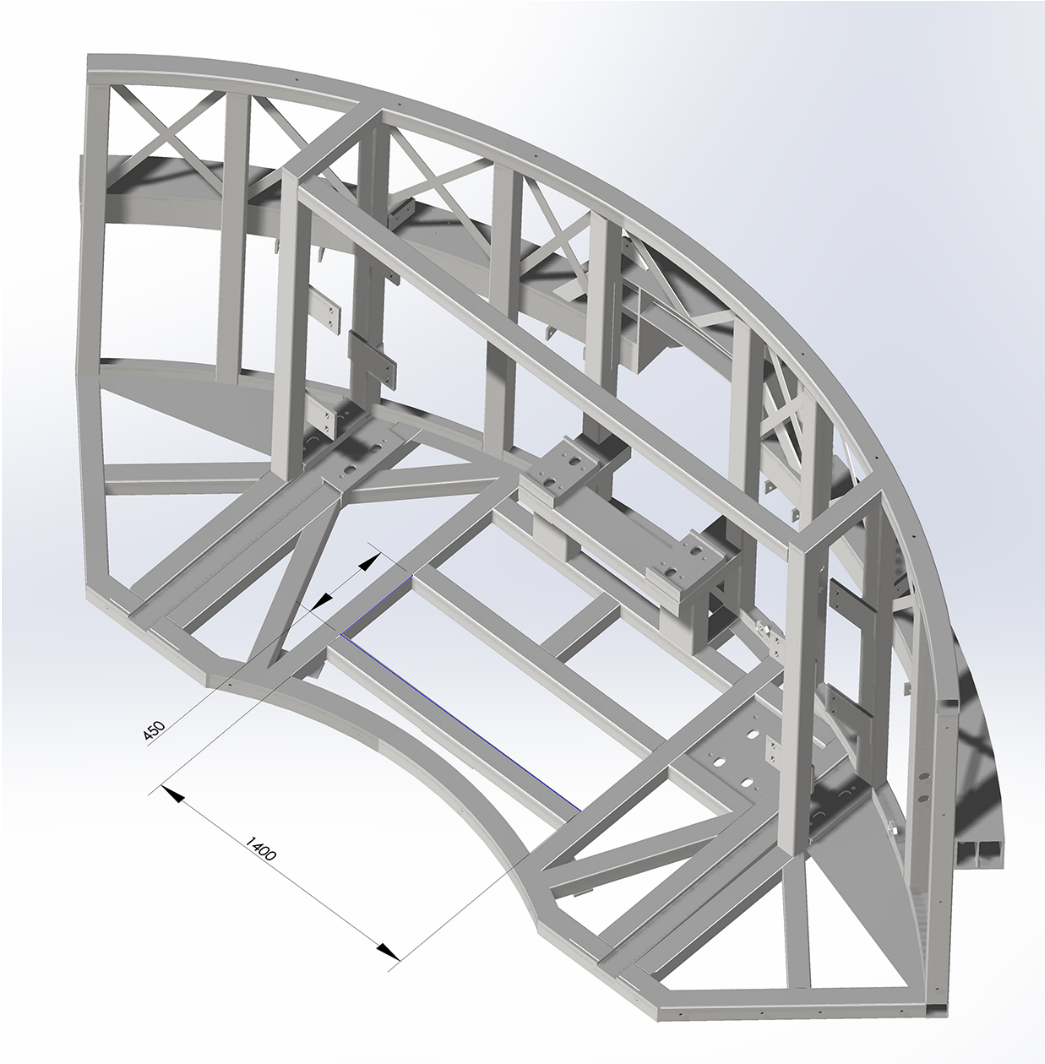


Figure 7: Removable floor hatch on observation floor in EOS 1.8m telescope

F Observation Floor Bench Space

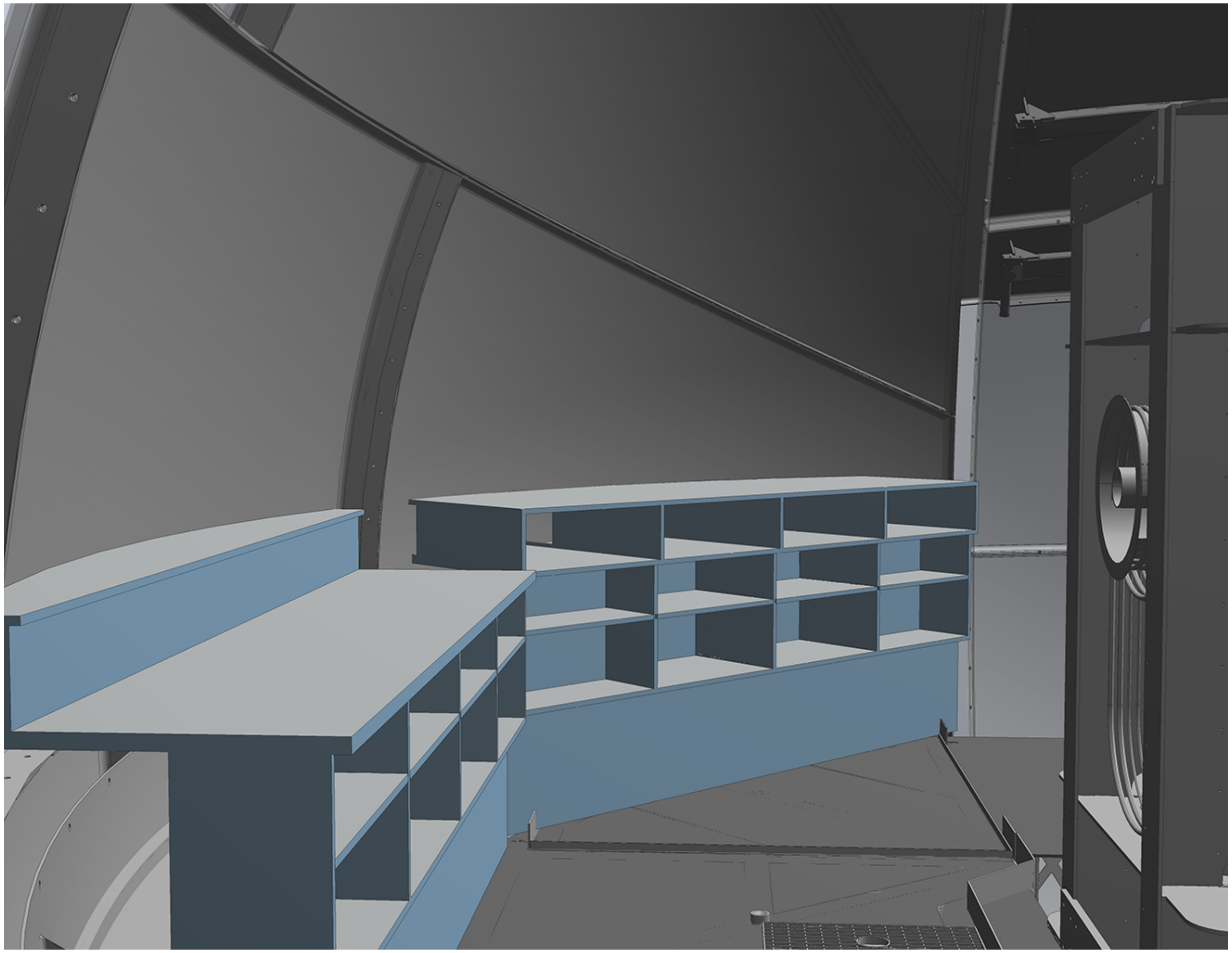
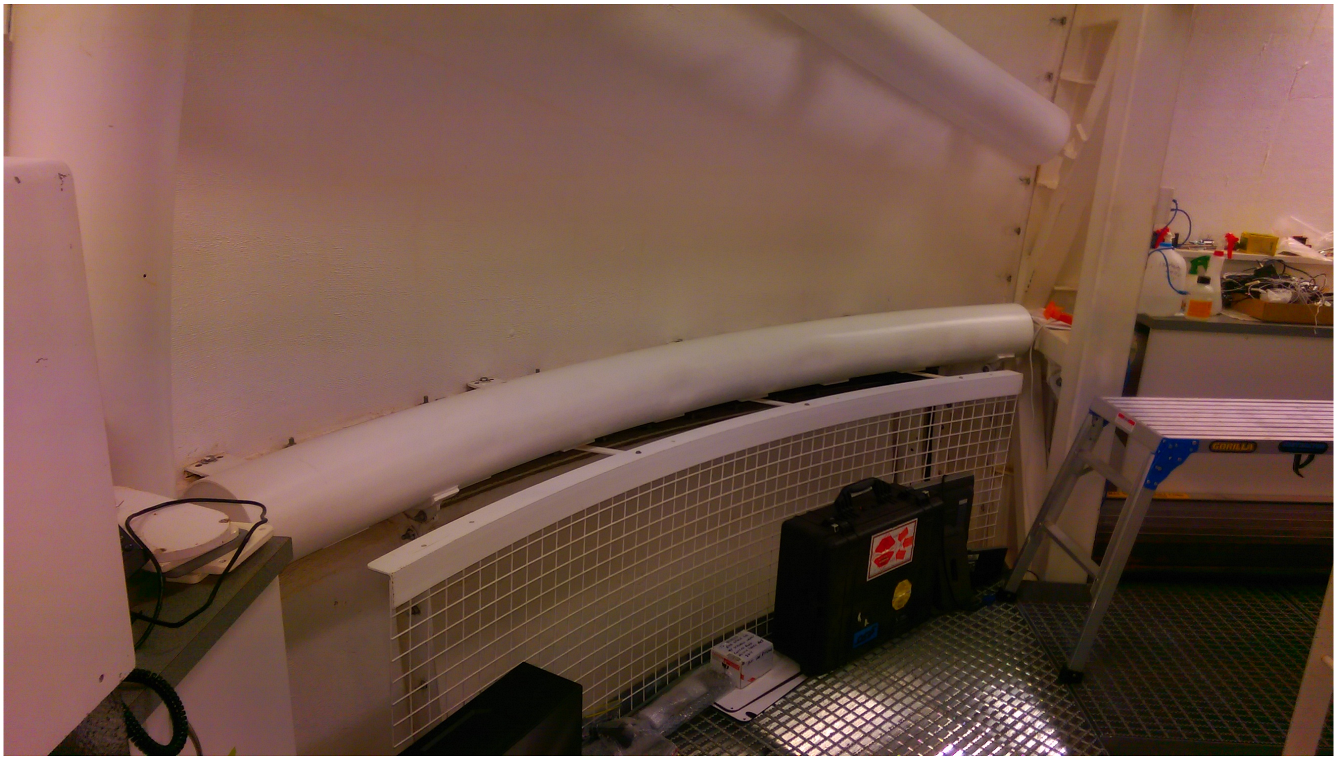


Figure 8: Bench space available on the observation floor

G Photographs of Observation Level

(a) Observation level: side view



(b) Observation level: second bench space

Figure 9: Photographs of observation level of EOS 1.8m telescope

H Photograph of Mounting Plate

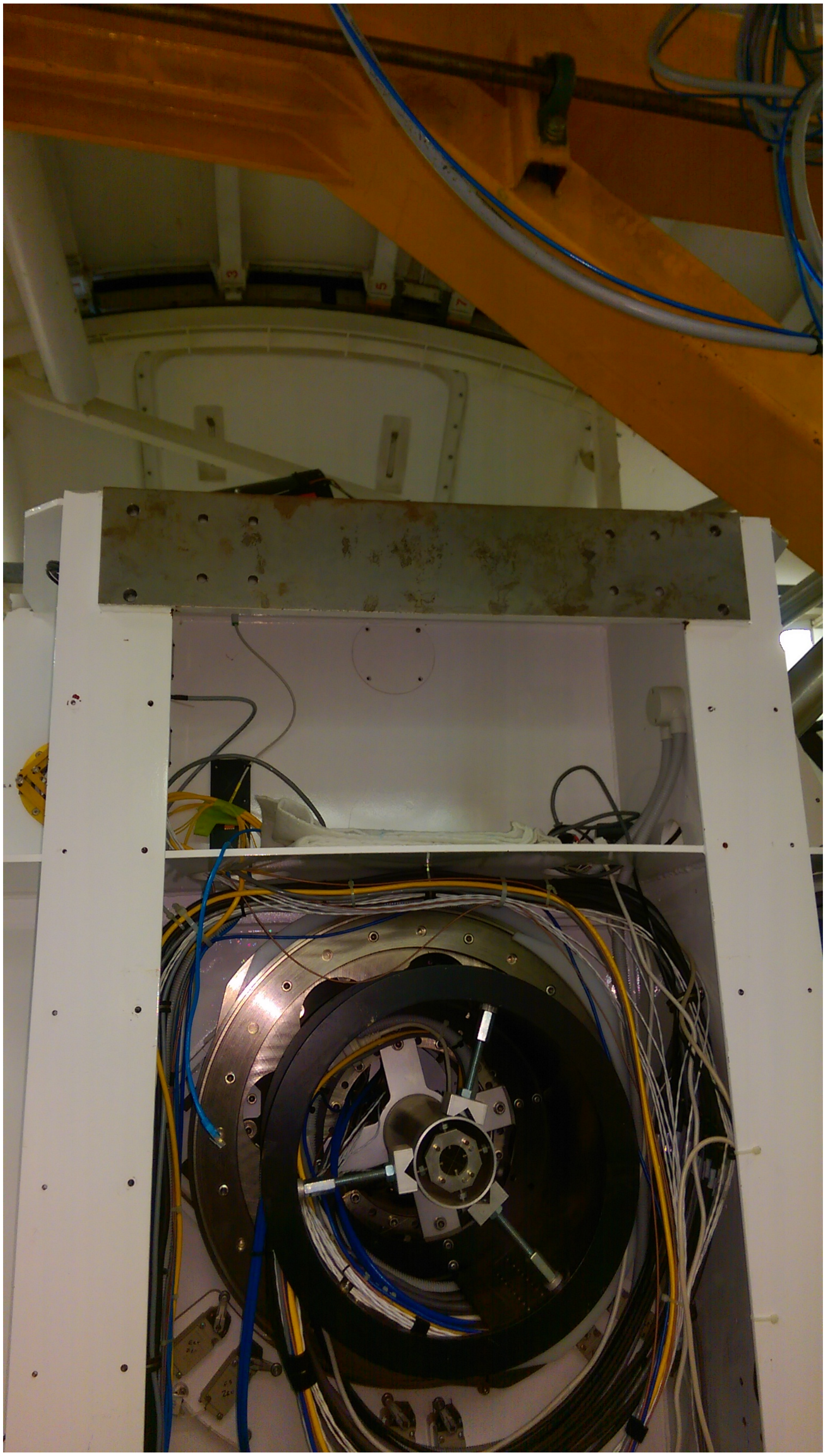


Figure 10: Photograph of mounting plate (observation level)

I Photographs of Middle Level

(a) Middle level floor space (b) Middle level floor height (c) Middle level floor height

Figure 11: Photographs of middle level highlighting floor space and height

J Photographs of Entry Level

(a) Entry level floor space (b) Entry level floor space (c) Entry level floor space

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