SST Programme: STR-CAM Interface Control Document

SST-PRO-ICD-007

Version: 1b

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1 Introduction

1.1 Scope

The Small-Sized Telescopes (SSTs) will be provided as an in-kind contribution (IKC) for the southern site (CTA-S) of the Cherenkov Telescope Array Observatory (CTAO). Each SST is composed by four subsystems: a Mechanical Structure (SST-MECH), an Optics Assembly (SST-OPT), a Telescope Control System (SST-TCS) and a Cherenkov Camera (SST-CAM). The SST IKC is organized as a Program (SST-PRO), containing two projects, the SST Structure (SST-STR), and the SST Camera project.
The division of responsibility between these two projects can be seen in Figure 1.
This document is about the interfaces between the subsystems managed by the two projects.

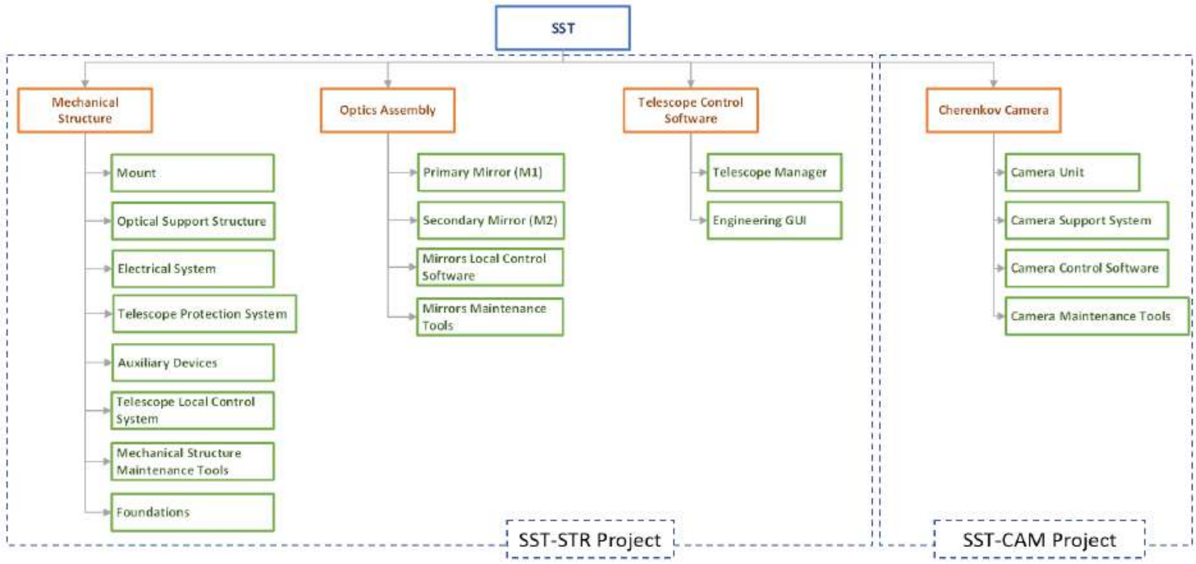

Figure 1: Telescope Product Tree – This document controls the interfaces between SST-STR and SST-CAM.

1.2 Purpose

The purpose of this Interface Control Document (ICD) is to define the design of the interfaces between the elements of the CTA Small-Size-Telescope managed by the SST-STR projects and those managed by the SST-CAM project, ensuring compatibility among involved interface ends by specifying form, fit, and function.
The ICD is managed by the SST Program Systems Engineer and represents an agreement between the relevant actors. The actors in this ICD are the INAF and the SST-CAM consortium, which is composed by the institutions from Germany, UK, Netherlands, Japan and Australia. This ICD is used:

1. to document the interface definition,
2. to control the evolution of the interface,
3. to document the design solutions to be adhered to, for a particular interface,
4. as one of the means to ensure that the supplier design (and subsequent implementation) is consistent with the interface requirements,
5. as one of the means to ensure that the designs (and subsequent implementation) of the participating interface ends are compatible.

This Interface Control Document (ICD) documents and tracks the necessary information required to effectively define the interfaces of elements managed by the two projects (SST-STR and SST-CAM), as well as any rules for communicating between the projects. Its intended audience is the Engineering personnel of the SST Program, and stakeholders interested in the interfacing of these systems.

1.3 Applicable Documents

[AD1] Small Sized Telescopes (SST) to Foundation at CTAO-South ICD - CTA-ICD-TEL-405000-0001_1a

[AD2] CTAO Array Clock System (CLK) to Telescope ICD - CTA-ICD-SEI-000000-0035-1a, 2023-05-30

1.4 Reference Documents

[RD1] CTA Top-level Data Model Specification (CTA-SPE-OSO-000000-0001)
[RD2] R1/Event Data Model Specification (CTA-SPE-COM-000000-0002)
[RD3] ASTRI Technical Design Report - MAN-PO/140530
[RD4] SST Optical Design - (SST-OPT-DSR-001)
[RD5] CTA-TRE-COM-303000-0001 2g ACADA Architecture Design
[RD6] CTA-TRE-COM-003000-0001 3b ACADA Use Cases
[RD7] CTA-SPE-COM-303000-0001 2i Requirement Specification for ACADA
[RD8] SST Camera Structural Analysis Report (SST-CAM-ANR-008)
[RD9] SST Camera Design Report (SST-CAM-DSR-001)
[RD10] SST Top Level &Trade-Off Analysis Report (SST-PRO-ANR-006)
[RD11] CTA Telescope State Machine, Doc. No. CTA-SPE-ACD-000000-0001, Issue 2, Rev e, 17.3.2020

[RD12] CTA Interface Control Document for ACADA – Generic Telescope Control, Doc. No. CTA-ICD-SEI-000000-0002, Issue 2, Rev.: h, 30.4.2020

1.5 General Specification and Standard Documents

[SD1] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on Machinery, and amending Directive 95/16/EC

[SD2] MILITARY HANDBOOK: ELECTRONIC RELIABILITY DESIGN HANDBOOK - MIL-HDBK-338B

[SD3] MILITARY HANDBOOK: RELIABILITY PREDICTION OF ELECTRONIC EQUIPMENT- MIL-HDBK-217F

[SD4] Basis of Structural Design - EN Eurocode 0

[SD5] Steel – Design of Steel Structures – All parts - EN Eurocode 3

[SD6] Design of Composite Steel and Concrete Structures – All parts - EN Eurocode 4

[SD7] Design of Aluminium Structures – All parts - EN Eurocode 9

[SD8] Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements - EN 61010-1

[SD9] Safety of machinery, Functional safety of safety-related electrical, electronic and programmable electronic control systems - EN 62061,

[SD10] Safety of machinery -- Safety-related parts of control systems -- Part 1: General principles for design - EN ISO 13849-1

[SD11] Safety of Machinery – Emergency Stop – Principles for design - EN ISO 13850

[SD12] Low-voltage electrical installations - EN 60364 series

[SD13] Basic and safety principles for man-machine interface, marking and identification - Identification of equipment terminals, conductor terminations and conductors, 2010 - EN 60445,

[SD14] Insulation coordination for equipment within low-voltage systems - EN 60664 series,

[SD15] Reliability Modelling and Prediction reference - MIL-STD-756B

[SD16] System Safety - MIL-STD-882E

[SD17] Procedures for performing a Failure Mode, Effects and Criticality Analysis reference - MIL-STD-1629A

[SD18] EMC Directive 2004/108/EC

[SD19] Electromagnetic Compatibility (EMC) - EN 61000 series

[SD20] Functional Safety and IEC 61508, Functional safety of electrical/electronic/programmable electronic safety-related systems

[SD21] IEC 61131-3, Programmable controllers - Part 3: Programming languages

[SD22] Lightning protection standard - EN 62305:2011

[SD23] Cleanrooms and associated controlled environments — Part 1 - ISO 14644-1:2015

[SD24] ECSS-Q-ST-80C Rev.1 (15 February 2017)

[SD25] CTA-STD-OSO-000000-0002 1h CTA SW Licensing Policy

[SD26] CTA-SPE-OSO-000000-0001 1b Top-level Data Model

[SD27] CTA-SPE-COM-000000-0002 1e R1-Event Data Model

[SD28] CTA-STD-OSO-000000-0001 1a Software Programming Standards

1.6 Definition of Terms and Abbreviations

ACADA	Array Control and Data Acquisition System
ACS	ALMA Common Software
ASTRI	Astrophysics with Italian Replicating Technology Mirrors
CTA	Cherenkov Telescope Array
CTAO	Cherenkov Telescope Array Observatory
CoG	Center of Gravity
HW	Hardware
IACT	Imaging atmospheric Cherenkov telescope
ICD	Interface Control Document
LST	Large Sized Telescope
MST	Medium Sized Telescope
SST	Small Sized Telescope
SST-CAM	SST Camera
SST-STR	SST Structure
SW	Software
TBD	To be determined
TDC	To be confirmed
TMS	Telescope Mechanical structure
VHE	Very High Energy

1.7 Definition of Terms and Abbreviations

TERM	DEFINITION
SST Programme	The overall SST organisational structure containing the SST-STR and SST Cam projects.
SST-STR	The SST Structure, consisting of elements under the control of the SST-STR Project.
SST-CAM	The SST Camera, consisting of elements under the control of the SST-CAM Project.
Central Facilities	Used as a catch-all in this document for on-site facilities not located at the Telescope Unit.
On-site Data Centre Farm	The central computing and storage facility on which all data is stored and all software installed.
Clock Distribution	The part of the central facility responsible for the provision and distribution of clocks for the precise time-tagging of images recorded by the Camera Unit.
Central Power Distribution	The part of the central facility responsible for distributing power to each Telescope Unit.
Central Site Safety System	The part of the central facility responsible for human safety, coordinating and acting upon safety information from all telescopes and other devices.
SST Software	All SW installed on the Farm that is under the responsibility of the SST Programme.
Telescope Manager	Part of the SST SW dealing with the high-level control interface to ACADA.
Camera Manager & DAQ	The SST SW dealing with the control of the Camera Unit and Camera Support Systems. Part of SST-CAM.
Structure Manager	The SST SW dealing with the control of the Structure. Part of the SST-STR.
Telescope Unit	All elements of a telescope located locally at that telescope.
Foundation	The physical foundation on which the Telescope Structure is mounted. Part of the Telescope Unit.
Interface Cabinet	The CTAO-controlled interface for power, network and timing connection to the telescope.
Telescope Structure	The telescope mechanical structure, drives and optics.
Telescope Network Distribution System	The interface point from the Network Interface Cabinet to the telescope. Includes any patch panels, switches, associated mounting / housing and any fibre or copper cables routed about the Telescope Structure.
Telescope Control System	The control system for the telescope drives and any other active elements.
Telescope Safety System	Elements of the telescope explicitly for human safety, such as limit switches and access switches.
Telescope Power System	The interface point from the Power Interface Cabinet to the telescope. Includes any required hardware, associated mounting / housing and any cables routed about the Telescope Structure to other telescope elements.
Camera Unit	The physical camera as attached to the telescope structure.
Camera Support Systems	All support items required at the telescope to operate the Camera Unit, including the camera chiller, pipes.

2 System description

2.1 Local Reference Coordinate System

The Coordinate System used throughout this document is Cartesian with right-handed orthogonal axes. The orientation of the axes is as depicted in Figure 2:

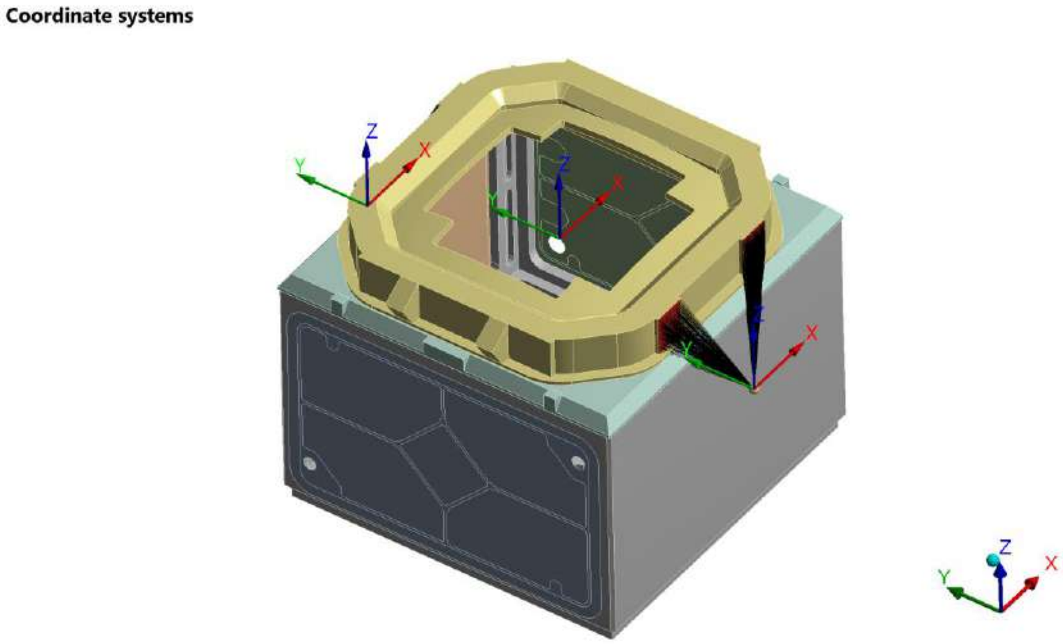

Figure 2: Camera Reference Coordinate System

Z axis, parallel to the optical axis of the telescope, directed away from the primary mirror
Y axis, is the parallel telescope axis of rotation along the azimuth (i.e. the vertical axis) directed towards the ground (nadir) in the parked position,
X axis, parallel to the axis of elevation of the telescope, completing a right-handed triplet
The axes origin is the centre of the camera nominal optical focal plane, that is, its intersection with the telescope nominal optical axis. This places the rear side of the Focal Plane Plate at Z = -83.2mm

2.2 Camera Unit weight, dimensions and location

The total weight of the Camera Unit during Operations is 92 kg, and includes:

- Electronics boards mounted on their dedicated mechanical sub-frames;
- Camera Unit internal cooling systems (e.g., heat exchanger, fans);
- Cooling liquid inside the heat exchanger and the internal pipes;
- Lids, and relative electric set (motors, control boards, sensors);
- Connectors;
- Window and relative support;
- Calibration system;
- Gaskets, fasteners, mechanical ancillaries.

This Figure 3 does not include the external pipes, cables and connectors connected to the camera during operations.

The Camera CoG, is located as shown in Table 1.

Table 1. Cherenkov Camera CoGs

	Lids Closed	Lids open
X (mm)	-8.6	-8.5
Y (mm)	25.8	26.7
Z (mm)	300.5	290.1

The moments of inertia are given in Table 2.

Table 2. Camera moments of inertia

	Lids Closed	Lids open
I1(kg*m^2)	14.23	13.96
I2 (kg*m^2)	13.04	12.35
I3 (kg*m^2)	6.34	6.76

The overall dimensions of the Camera Unit containment box are given in Table 3 and Figure 3.

Table 3: Camera containment box dimensions

	Lids Closed	Lids open	Lids moving*
X (mm)	587	587	587
Y (mm)	689 (lifting eye to motor)	733(door tips)	1312.5 (doors horizontal)
Z (mm)	542 (Base to motors)	542(Base to motors)	861.2 (doors vertical)

* maximum extension of containment considering full range of motion of lids.

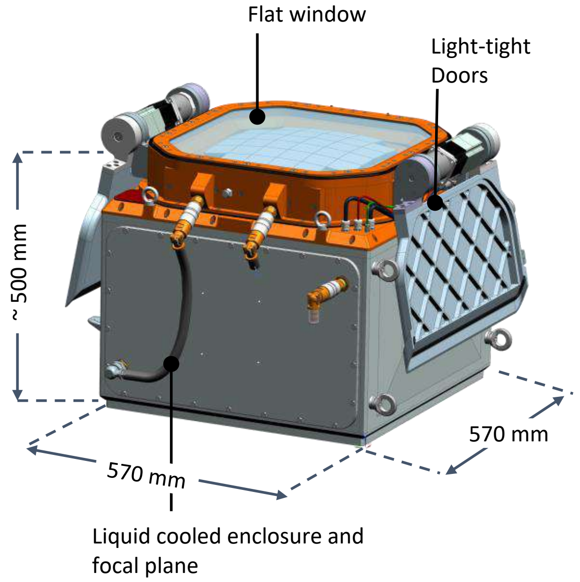

Figure 3: Camera dimensions

2.3 General cable requirement

In general, all cables used for the camera shall be fire-resistant according to IEC 60332-1-2 FT1 VW1 or relevant local regulations (TBC by STR and CTAO).

2.4 Chiller specs and location

The chiller unit specifications are reported in Table 4. A final choice between the two models is pending.

Table 4: Chiller properties.

Parameter	Spec.	Thermex Solutions	Laser Chill
Operating voltage	230V / 50Hz	220-240V / 50Hz	220-240V / 50Hz
Cooling capacity	at least 1.5 kW	3 kW	2.15 kW
Heating power	Must Heat	2 kW	1 kW
Rated operating altitude	2100 m ASL	2000 m ASL	TBD
Operating ambient temperature range	[-15, +35]	[-20, +35]	[-20, +48]
Survival ambient temperature range	[-15, +35]	[-20, +90]	[-20, +48]
Settable T Range	At least [+8, +12]	[+5, +15]	[+4, +12]
Temperature Stability	< ±0.4°C	±0.2°C	±0.2°C
Flow rate	>10 l/min	54 l/min	10 - 20 l/min
Delivery Pressure	3 - 6 bar	3 bar	2.9 - 5 bar
Tank capacity	>20L	75 l	20 l
Weight (unfilled)	110 kg	180 kg	107 kg
Foot print (mm x mm)	<1m x <1m	683 x 1103	800 x 800
Height (mm)	<2m	1090	800
Protection level	IP54	IP55	IP55
Pipe connections	3/4" or 1" FBSP	1" FBSP	1" FBSP
Remote on/off	Required	Yes	Yes
Control connection	RJ45	RJ45	RJ45
Control interface	TCP or UDP	Modbus TCP/IP	Modbus TCP/IP

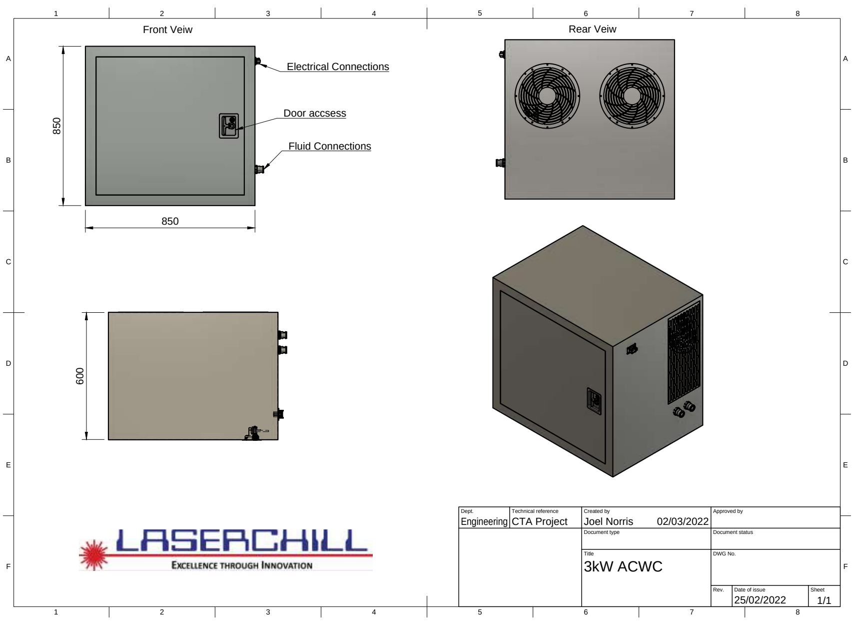

Figure 4: Laserchill Chiller Mechanical Drawing

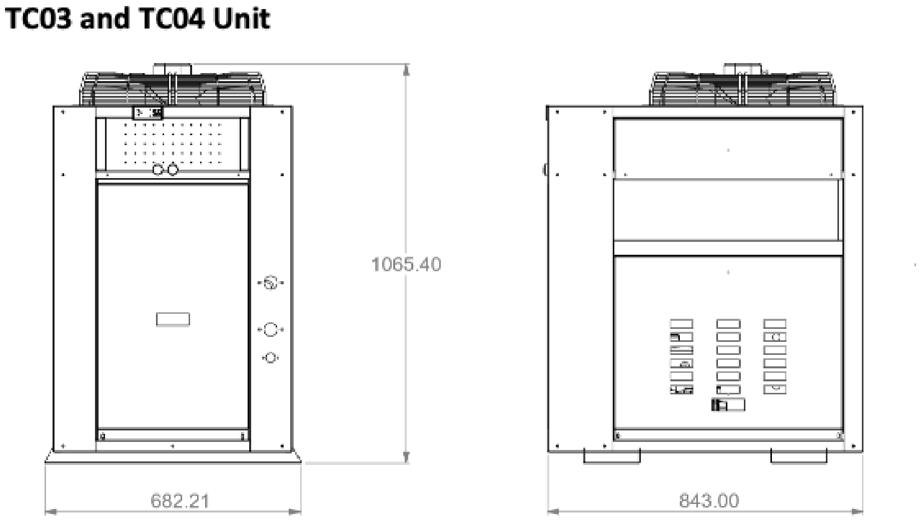

Figure 5: Thermex Chiller mechanical drawing

The proposed chiller location w.r.t. the telescope foundation is the following:

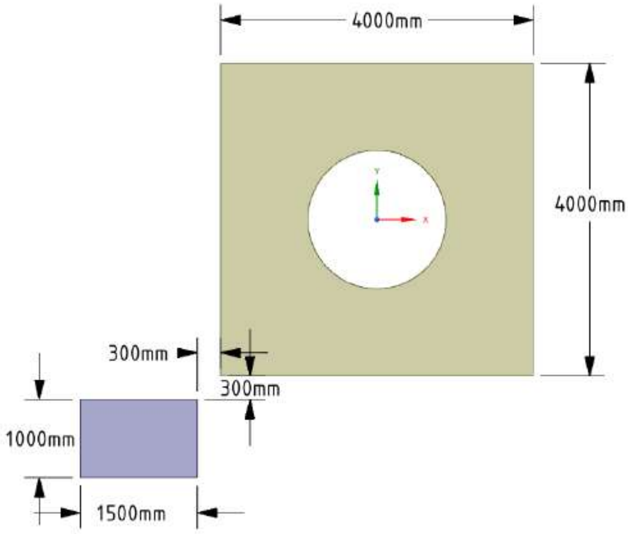

Figure 6: chiller location

2.5 Telescope Optical Specifications

The optical layout selected for CTA-SST is based on a Schwarzschild-Couder configuration (SC) consisting of three optical surfaces (Figure 7): the primary mirror (M1), the secondary mirror (M2), and the curved focal surface (FS) populated with SiPM sensors.

The effective focal length of the obtained optical system is F = 2154 mm. The distance between M1 and M2 is 3108.4 mm = F/q, where q = 0.6888 is the first Schwarzschild aplanat parameter. The distance between M2 and FS is 519.6 mm = F(1 − α), where α = 0.7573 is the second parameter, which together with q defines the Schwarzschild aplanatic solution.
The plate scale is 37.5 mm/°.

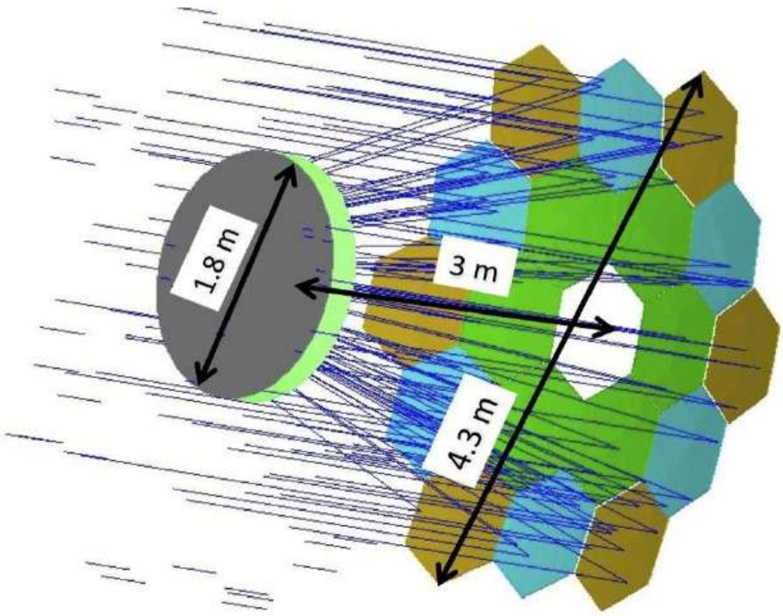

Figure 7: The Schwarzschild-Couder optical design adopted for CTA-SST.

The nominal focal plane shape is the surface of sphere of radius 1060mm centred at: X=0; Y=0; Z=-530mm.
The distance from rear of camera to the apex of the sphere with mirror M2 at its unadjusted Z resting position is 497.4mm, as seen in Figure 7

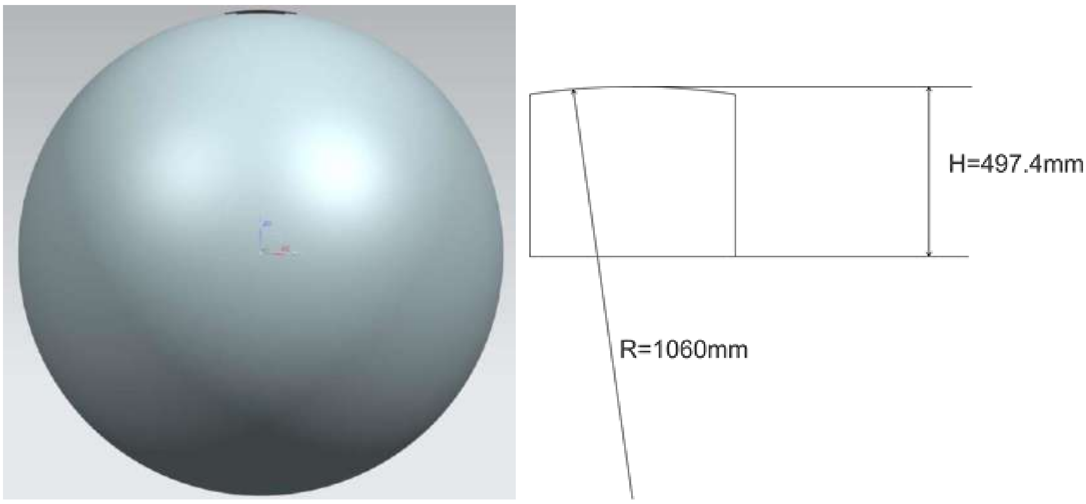

Figure 8, Left: spherical surface defining the nominal focal plane. Right: Simplified drawing of the location of the nominal focal plane surface with respect to the rear of the camera.

The effective focal plane is a tiled approximation of this spherical surface, with 50% of the tiled area above the sphere surface, and 50% below.
The perimeter of the focal surface is a polygon of area 87179mm^2. The actual area of active silicon is 6mmx6mm (pixel) x 64 (pixels) x32 (tiles) = 73728mm^2 (see Figure 9).

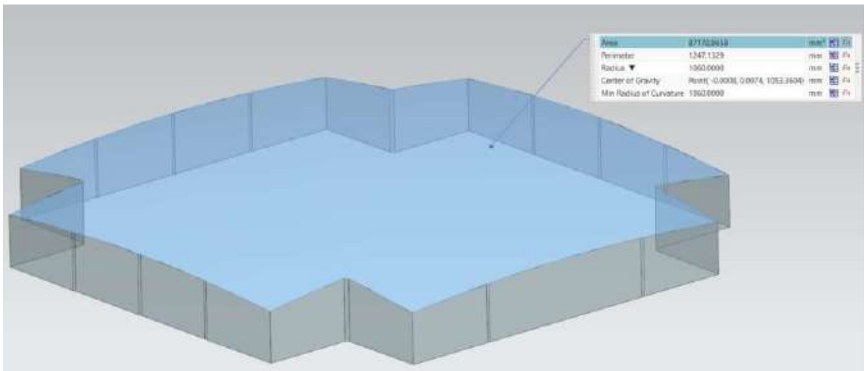

Figure 9: Shape and area of the Focal Surface.

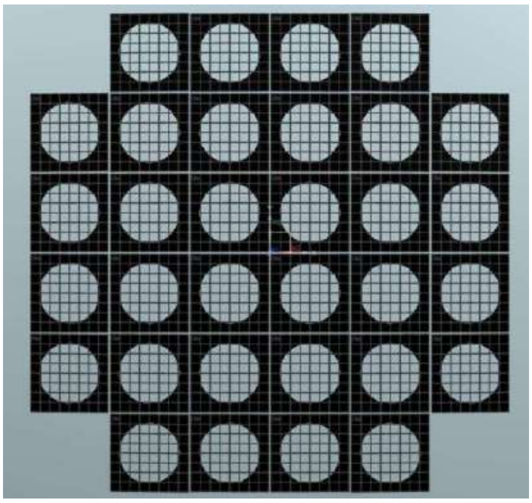

Figure 10: Intersection between the surfaces of the SiPM tiles and the nominal Focal Plane. The lighter areas lie above the focal plane, the black areas below.

3 Interface Identification List

The interfaces between the Structure, Optics and Camera are listed in Table 5 and Figure 11.

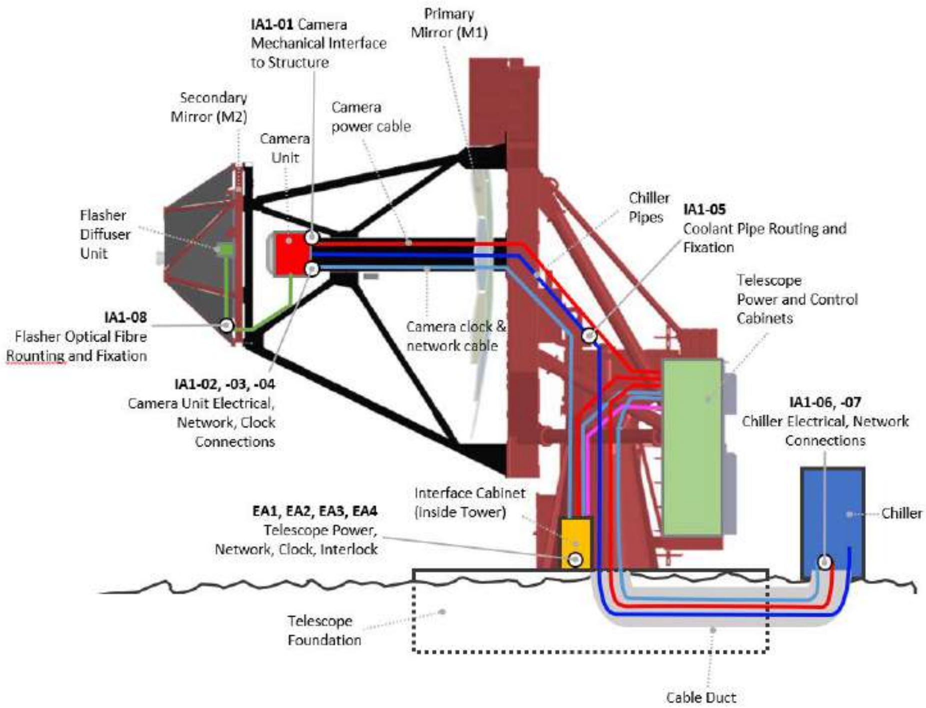

Figure 11: Overview of the Telescope system, with the camera subsystems

Table 5: List of the Telescope Interfaces

Code	Interface
	Mechanical Structure to Camera
IA1-01	Camera Unit Mechanical Fixation
IA1-02	Camera Unit Electrical Connection
IA1-03	Camera Unit Network Connection
IA1-04	Camera Unit Clock Connection
IA1-05	Coolant Pipe Routing and Fixation
IA1-06	Chiller Electrical Connection
IA1-07	Chiller Network Connection
IA1-08	Flasher Diffuser Cable Routing and Fixation
IA1-09	Pointing Model Data
IA1-10	Camera Unit Installation, Access and Removal
	Optics Assembly to Camera
IA2-01	Camera Unit Optics
IA2-02	Flasher Unit Fixation to M2
	Telescope Control Software to Camera
IB1-01	Camera SW to Telescope Manager

4 Interfaces Description and Requirements

IA1-01 Camera Unit Mechanical Fixation

Mechanical fixation to the telescope structure is via six M12 bolts inserted into the rear of the camera via an interface flange at the end of the central support structure (see Figure 12 and Figure 13). The flange also has two asymmetric conical slots for guiding two alignment dowels placed on the camera back side. A 3D CAD model in the form of a STEP file is provided. Detailed design, tolerances and material are specified in the attached drawing (see Figure 13).
On the Camera side, the corresponding plate design is shown in Figure 15 (TBC by CAM). This plate is a single machined aluminium piece, with six blind holes for attachment to the Telescope. Each hole contains an M12 Helicoil insert. To minimise the thickness of the plate, whilst providing adequate hole depth, some machined "bushes" are used, also shown in detail in Figure 15.
Specification for M12 bolts to be used is TBD by CAM.

Figure 12: Camera Upper Support Structure, showing the interface flange where the Camera is connected.

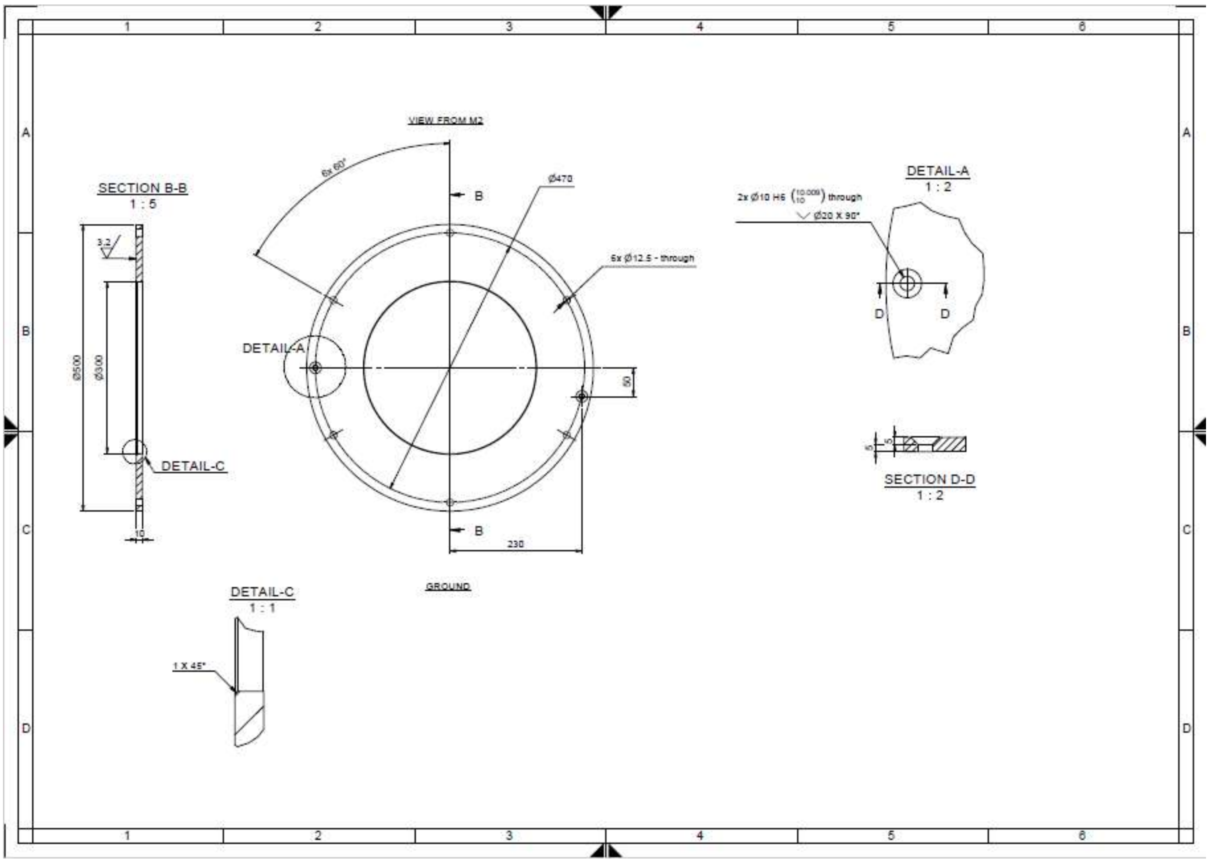

Figure 13: Mechanical drawing of camera support flange.

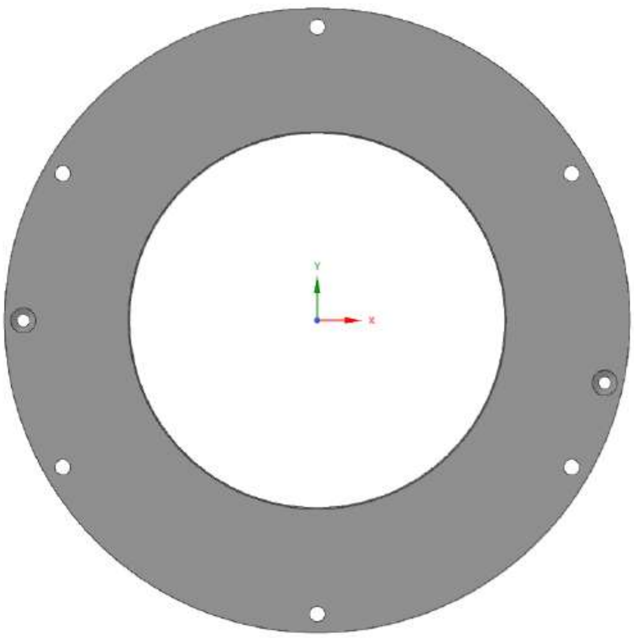

Figure 14: View of the flange from M2, as it happens when one installs the Camera. M2 is in the Z+ direction, ground is Y-, X is parallel to the elevation axis.

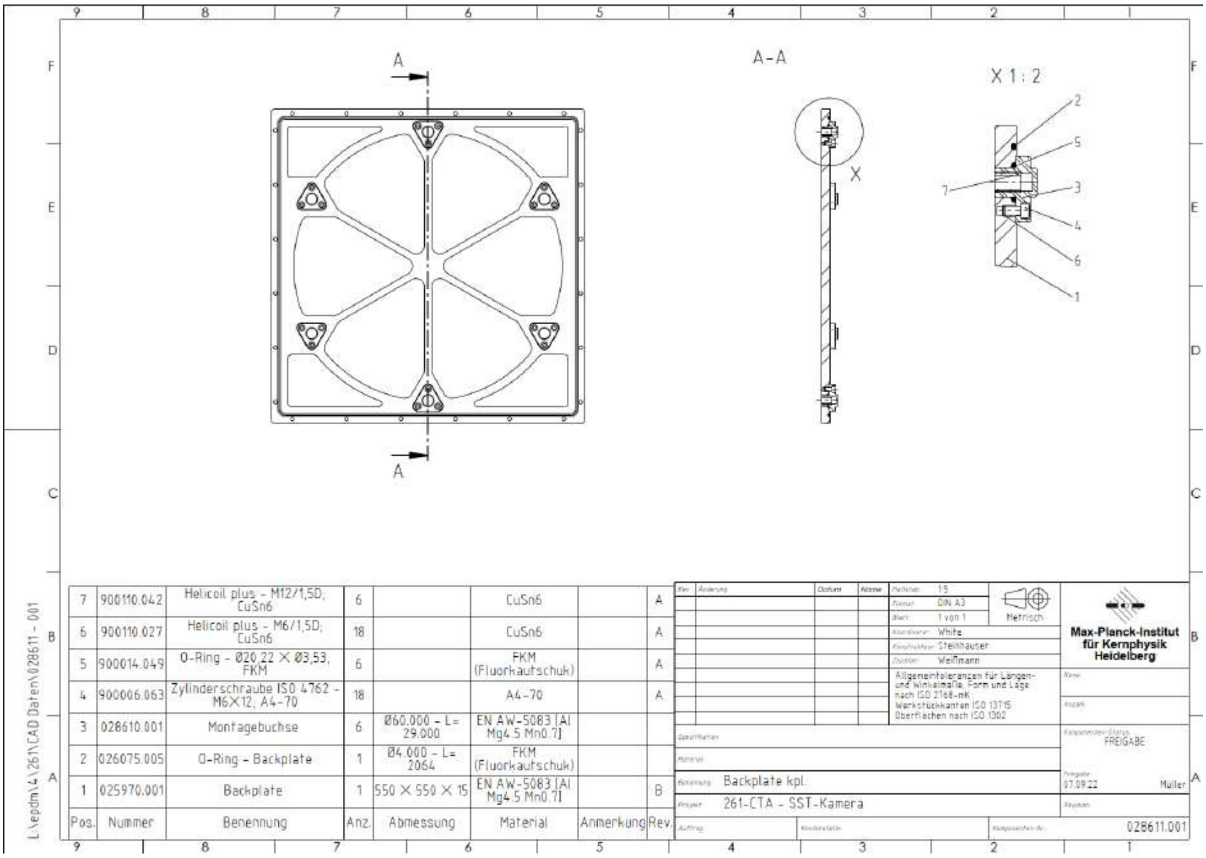

Figure 15: Current design of Camera Backplate, showing the six slots for the helicoids. The alignment pins are missing in this version.

IA1-02 Camera Unit Electrical Connection

The Camera Unit will require a single power connection via a cable mounted on the telescope structure. The power cable is part of the Telescope Power System and thus is responsibility of the STR.

- Cable requirements:
  - single-phase 230 AC 50 Hz, shielded
  - standard 16A rating or better
  - acceptable Voltage drop: 5%
  - UV resistance
  - Cable-chain compatibility
  - Compatibility with connector
- Cable length: 10 m
- Cable model: TBC by CAM, suggested Igus Chainflex CF891.15.03 or similar
- Cable route through cable chains:
  - 2.7 m (Camera to EL CW entrance), 90deg bend
  - 1.5 m (EL cable wrap), 90deg bend
  - 3.7 m (all the way down to AZ drape entrance), 90deg bend
  - 1.2 m (to the entrance into the Interface Cabinet)
  - Minimum cable bending radius around route: 150 mm, located at exit from Elevation cable chain into tower (see Figure 17).
- Cable route and fixation on structure and mast:
  - Required maximum cable protection from elements (mainly UV radiation). Design is TBD by STR. It is advised to route the cable inside mast, and exit through a cable gland close to the camera interface flange, on the bottom side of it to maximize shadowing. Alternatively, routing can be done through corrugated pipes, already fixed to the outside of the structure.
- Cable strain relief at camera end: TBC by STR - probably not needed, cable is self-supporting for the span of the slack
- Cable slack at camera end: TBC by STR - 30 cm
- Cable wiring connection inside Telescope Control Cabinet: TBD by STR
- Connector type at the Camera Unit:
  - IP68-rated bulkhead connector (Fischer DEE 104 Z040-8).
  - Fischer WSO 104 Z040-80+ right-angle plug
- Pin map of the power cable to the camera from the Telescope Power System: TBD by STR, depends on cable model specs
- Earthing scheme: the Camera Protective Earth (PE) is through the cable and isolated from the mechanical structure. Protective Earth (PE) and Neutral (N) are separate conductors (IEC 60364 TN-S). The cable is connected to ground at the Telescope Cabinet side. The camera outer case is isolated from the internal elements and from the PE of the cable, and it's earthed via the telescope structure.
- Lightning protection scheme: Inside the Camera there is a DEHN DSH TN 255 FM - a 35kA, DIN rail mounted spark-gap-based type 1 and type 2 combined lightning current and surge arrester.

Figure 16: Side view of the Telescope pointing at Zenith with Camera (ASTRI) mounted on support mast.

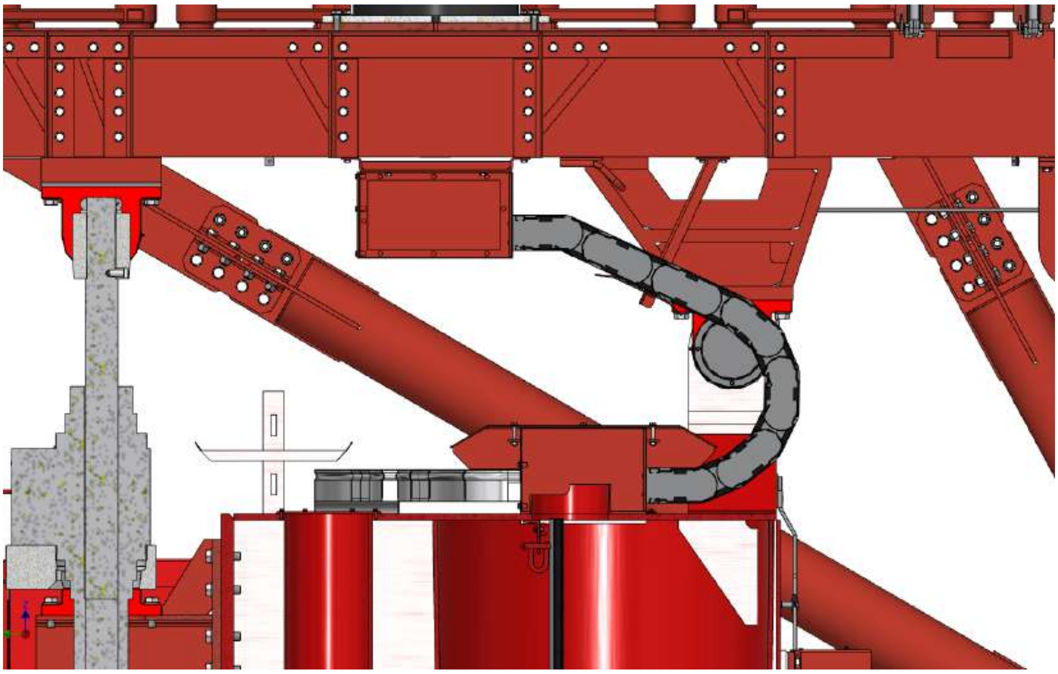

Figure 17: Side view of back of M2, showing the Elevation cable Chain.

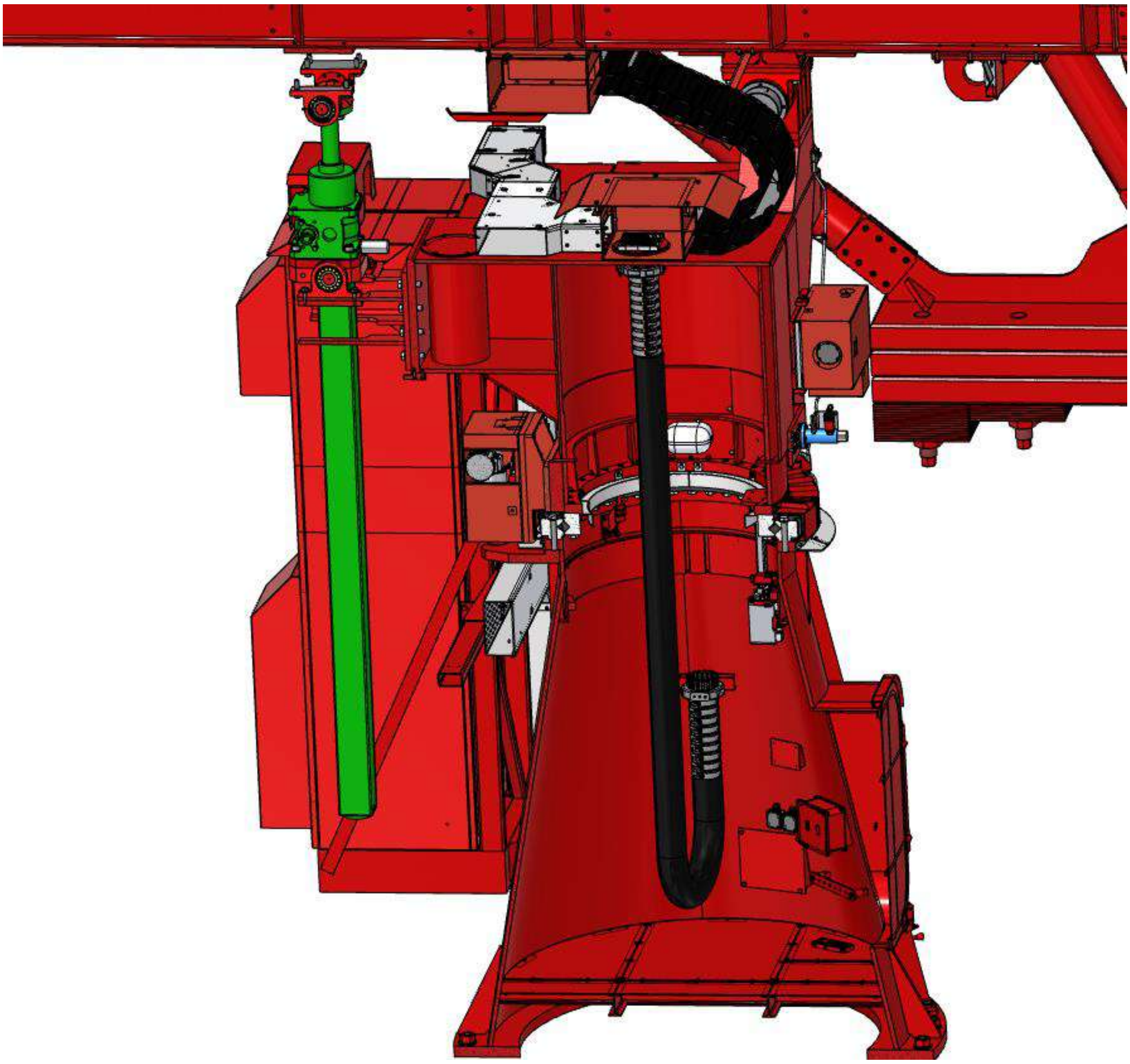

Figure 18: Cross-section of Telescope tower, with the Azimuth cable drape shown.

IA1-03 Camera Unit Network Connection

A 12-core fibre-optic cable is mounted on the telescope and connected to the camera for all data, clock provision, control and monitoring on separate fibres. This cable is regarded as part of the camera (with connection details to the camera controlled internally as part of the SST-CAM Project), with the mechanical attachment and routing interface to the Telescope Structure as part of IA1-05 and the interface to the Telescope Network Distribution System via a fibre-fanout and patch panel as IA1-03 and IA1-04 for the data and clock respectively. TBD by CAM: design of this patch panel.

- Camera network requirements
  - Bandwidth: 1x10Gbps + 1x Gbps + 1x White Rabbit
  - Redundancy: 1x10Gbps + one loopback to detect fibre problems
- Cable length: 10m
- Cable model specs: 12-core single-mode G.657A2 fibres inside a Neutrik opticalCON MTP 12 LITE cable (NKO12SA-L-0-15) with IP65-rated MPO (MTP) connectors at each end.

- Cable route through cable chains: as Power Cable up until the bottom of the Telescope tower, and then it goes to the network patch panel
- Cable route and fixation on structure and mast: as Power Cable, but without lightning protection.
- Cable strain relief at camera end: as Power Cable (IA1-02)
- Cable slack at camera end: as IA1-02
- Cable Plug at Interface cabinet: directly splice or have connectors (Camera decision)
- Cable Plug at Camera Unit: Neutrik NO12FDW-A chassis connector

IA1-04 Camera Unit Clock Connection

The Clock connection is carried through the Network Connection so the physical interfaces are the same as IA1-03. The actual clock synchronization is provided via the White Rabbit system, a profile of the Precision Time Protocol (PTP, IEEE 1588-2019). All other information and requirements about this interface are described in [AD2].

IA1-05 Coolant Pipe Routing and Fixation

Pipe diameter: ½” bore
Pipe model and insulation sheath: TBD by STR, suggested model is TF-TU25-08
Coolant composition, mass flow rate and maximum temperature increase: TBD by CAM

Pipe routing, first tract:
The pipe goes straight up from the cable duct exiting the foundation inside the Telescope Tower to the Elevation cable chain at the top of the Telescope support Tower.
TBD by STR: strain relief at the top of the AZ Fork. Suggested solutions are: install rotary joint at the entrance to EL cable chain, or no torsion relief, at all, relying on normal ±270° of a 3m long pipe. Advantages are less bends and separation point inside tower. Disadvantages are tightness of said bend. Alternative possibility to be investigated is to do without the rotary joint, and see how much the pipes can be torsioned (pair of ½” pipes ~2m long rotated by +-270 degrees).

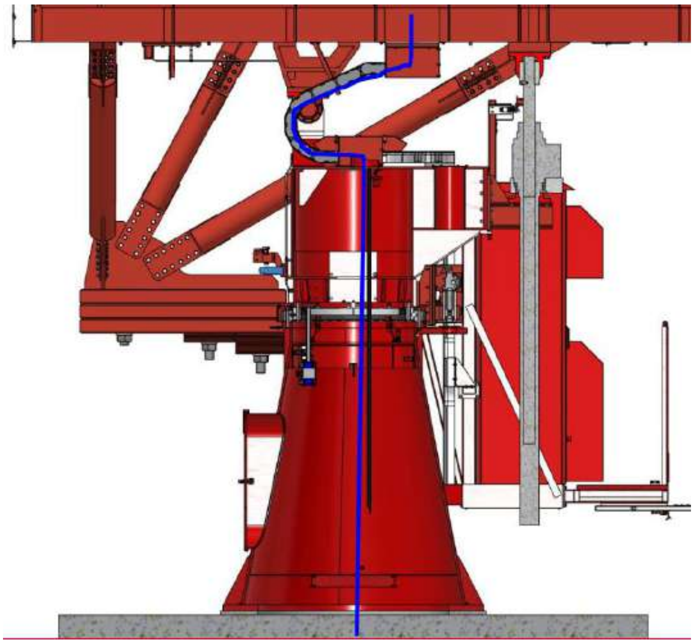

Figure 19: Path of the first tract of the coolant pipe route

Pipe routing: second tract:
Exiting the EL cable chain at two sides, running exteriorly to the bottom side of central tube, fixed to it with clamps, fixation design TBC by STR..

Length of the pipework inside the telescope would be about 9.2 m from the top of the concrete slab to the Camera interface flange. To this it should be added the length of the underground conduit: 4 m would be the bare minimum, considering the closest possible position of the chiller to the slab.

As for connectors, I 90deg bends are needed at the entrance and exit of the Elevation cable wrap, and at the entrance of the azimuth cable drape. So three 90deg connectors in total.
The piping would be split like so:
2.7 m (Camera to EL CW entrance), 90deg bend
1.5 m (EL cable wrap), 90deg bend
3.7 m (all the way down to AZ drape entrance), 90deg bend
1.2 m (to the entrance into the conduit) + 4m o r longer inside conduit

Water condensation on cold pipe: Should not be an issue. Air inside base is kept dry. Membranes are present so that water running on cables/pipes outside cannot flow inside.

Pipe model TBD.
For detailed specifications of pipe connections, see Figure 20.

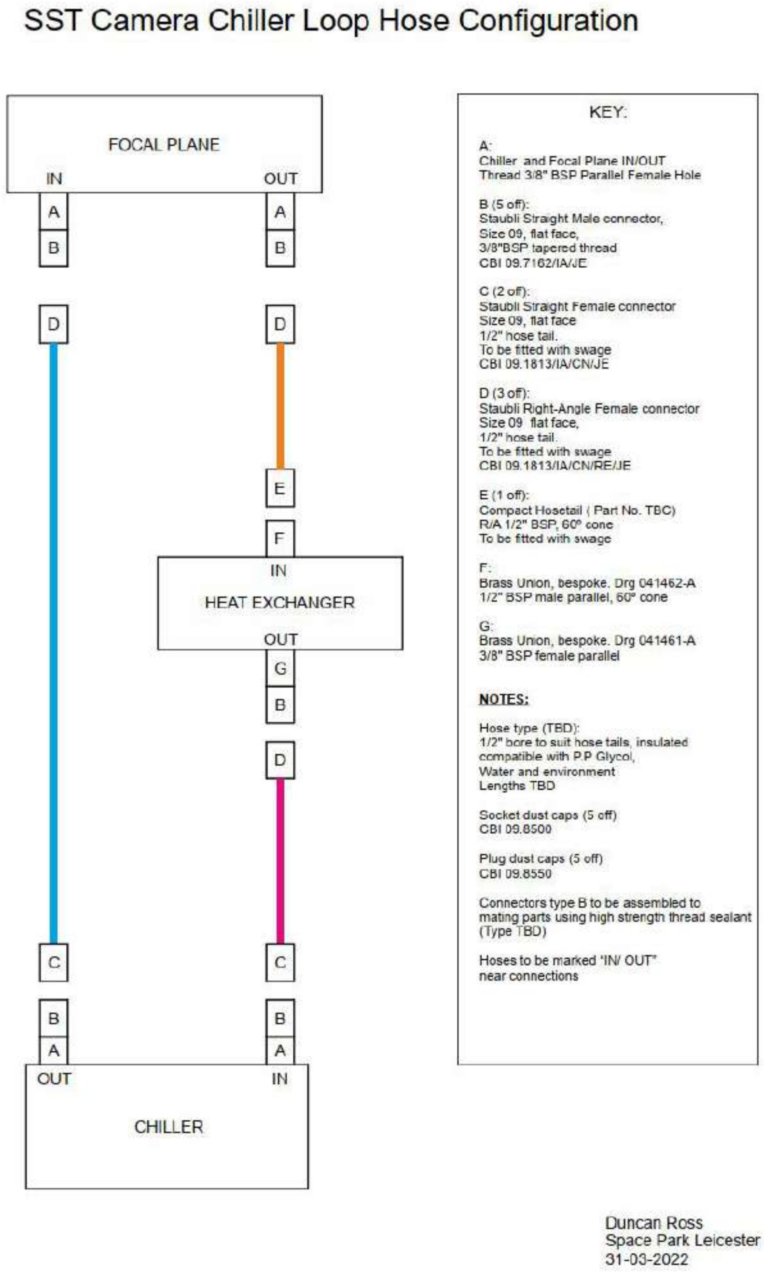

Figure 20: Diagram of Chiller Coolant Hoses Specifications

IA1-06 Chiller Electrical interface

- Cable requirements:
    - single-phase 230 AC 50 Hz, shielded
    - standard 16A rating or better
    - acceptable Voltage drop: TBD by CAM
    - Cable-chain compatibility
    - Compatibility with Chiller connector TBD by CAM
- Cable length: 7m (TBC by STR, after design of Chiller foundation is done)

- Cable model specs (current limits, bending radius, sheath type): TBD by STR.
- Cable route: from Telescope Control Cabinet through AZ drape, to foundation to chiller support structure, details TBD by STR
- Cable fixation on structure and mast: TBD by STR
- Cable duct in Foundation, see [AD1].
- Cable wiring connection inside Telescope Control Cabinet: TBD by STR
- Grounding scheme: the Chiller Protective Earth (PE) is through the cable and isolated from the mechanical structure. Protective Earth (PE) and Neutral (N) are separate conductors (IEC 60364 TN-S) TBC by STR.
- TBD by CAM: Lightning protection scheme and devices at Chiller side to be added here by Camera Team.
- TBD by STR: Telescope Control Cabinet-side ones to be added by STR.
- Absence of lightning protection rod to chiller is TBC by CAM, as it lies barely inside of telescope protected area. Connection to earth/foundation is TBD.

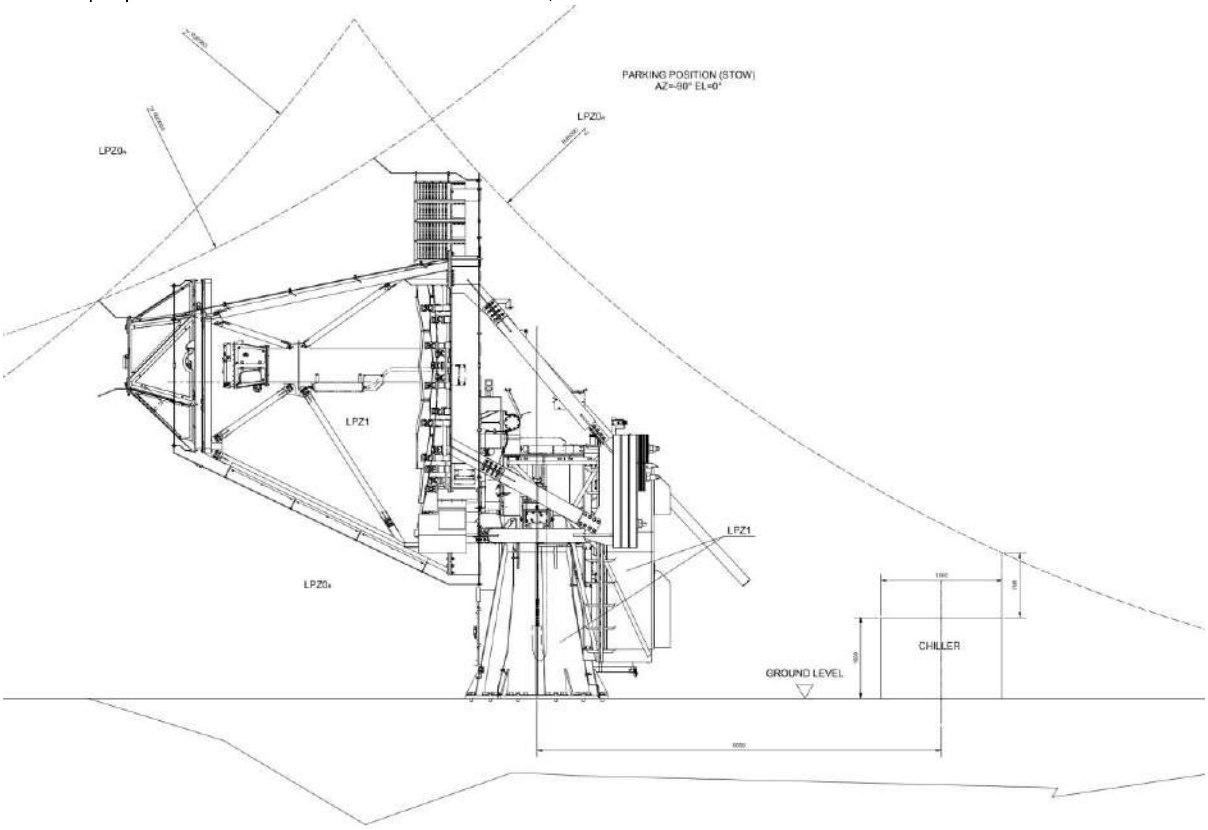

Figure 21: Lightning-protected area around telescopes, method of rolling spheres.

IA1-07 Chiller Network connection

- Cable length: 7m (TBC on STR after design of foundation/Chiller plinth)
- Cable model specs (bending radius, sheath type): Standard Ethernet Cat 6a cable, shielded (TBC by Camera), 100 Mbps connection.
- Cable route through cable chains: TBD by STR
- Cable fixation on structure and mast: TBD by STR
- Cable duct in Foundation: see [AD1].

- Cable connection to Telescope Switch inside Telescope Control Cabinet: TBD, on STR to provide.
- Cable connection to Chiller: TBD, on camera team to provide.
- Lightning protection scheme and devices:
    - On STR side, responsibility of STR
    - On CAM side, TBD by CAM

IA1-08 Flasher Unit Optical Fibre cable

See Section 7.6.3 of [RD9] for more details. There is a change with respect to that: in the current design, the Flasher Unit at the back of M2 will be connected to the camera using a copper Ethernet cable, and not an optical fibre.

- Cable type: Standard Ethernet Cat 6a (TBC by CAM), with custom signals.
- Cable maximum length is ~20 m (TBC by CAM)
- Cable specification (bending radius, sheath type, maximum length): TBD by CAM
- Cable route and fixation on structure and mast: route the cable inside the mast to the centre of M1 as for the other camera cables, then along the lower M2 support strut together with the rest of the M2 actuator cables. TBC by STR.
- Cable connectors: TBD by CAM
- Cable lightning protection: TBD by CAM

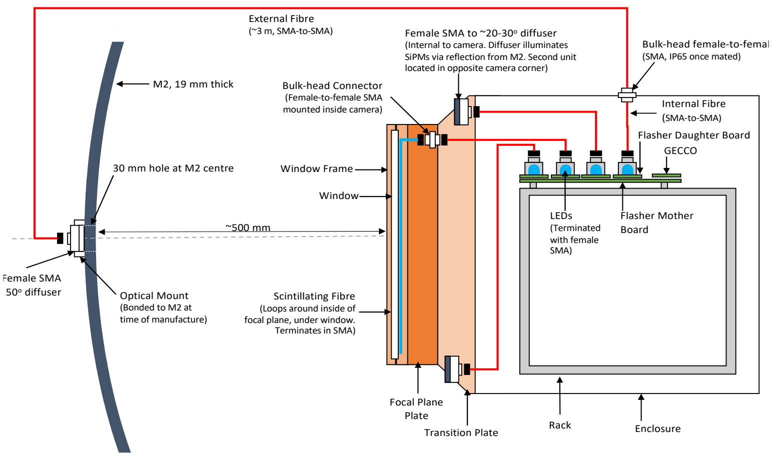

Figure 22: Flasher Unit Architecture. In the newest design, the red line connecting the Camera Unit to the Flasher Unit at the centre of the M2 mirror is a Cable.

IA1-09 Pointing Model Data

- Telescope pointing model: this is the mechanical bending model of the structure, that allows the transformation of the motor encoder positions into telescope pointing information and ultimately into telescope pointing direction in sky coordinates. The Camera might need to access these information for condition monitoring purposes.
  Model configuration data format, storage and access protocols, all TBD.
- Data necessary to determine rough Telescope Astrometric Pointing (from STR to CAM):
    - Nominal sky pointing position (in Sky Coordinates) when available (i.e., during the tracking of a source in the sky).
    - Nominal Altitude and Azimuth positions otherwise.

- The frequency of the above must be at least 10 Hz.
    - PMC camera images with their timestamps and ancillary information (e.g., camera optics and filter used, temperature …)
    - Data format and transmission protocol of the above are TBD.
- Data necessary to determine astrometric plate solutions for refining the pointing model and performing structure and optics condition monitoring (from CAM to STR):
    - Slow Signal Data: the Camera will provide continuous Slow Signal Data with a measurement of the sky brightness with an exposure of 1ms and a frequency of 10 Hz, see Section 7.3.4 in [RD9]. This allows the measurement of the position and brightness of stars on the focal plane between magnitudes 3 and 7. This data is available whenever the SiPMs are powered on and the Camera lids (doors) are open. Data format and transmission protocol are TBD.
    - Variance of Cherenkov Data. The variance of the fast signal waveforms in pixels not containing Cherenkov images (i.e. "Background" pixels) is directly proportional to the intensity of the incoherent background light, and can also used to determine positions of stars in the focal plane. In this case, the speed of determination of the variance depends on the Cherenkov data rate, which in turn depends on the brightness of the background light and the Camera trigger settings.
      Data format and transmission protocol follows the ACADA R1 ICDs.

IA1-10 C.U. Installation, Access and Removal

Four different options (based on the SST team experience and ASTRI MA outcomes) are presented to CTAO, See Section 5.4 of [RD10]. At the time of writing, there is no evidence of a net convenience for a specific option. A further investigation is necessary taking into account the outcomes form the ongoing integration campaign of ASTRI-MA.

- Camera installation and removal mechanism: TBD by STR
- Camera lifting points and location: four lifting eyelets at the top of the camera enclosure (see Figure 23).
- Camera occupancy: see IA1-01.
- Camera transportation access points:
    - Wooden storage crate:
        - The camera can be kept in the crate and be manoeuvred to the vehicle and directly loaded using a fork-lift or similar.
        - The camera can be kept in the crate and then be placed on a wheeled trolley to be manoeuvred to the vehicle and directly loaded using a ramp.
        - The camera can be removed from the crate in the warehouse using an engine hoist, or similar, and manoeuvred to the vehicle and directly loaded.
    - Wheeled, custom container:
        - The camera can be manoeuvred to the vehicle using a wheeled container and directly loaded using a ramp. The camera attaches to the base of the wheeled container via the Telescope Interface Plate (see Figure 24).

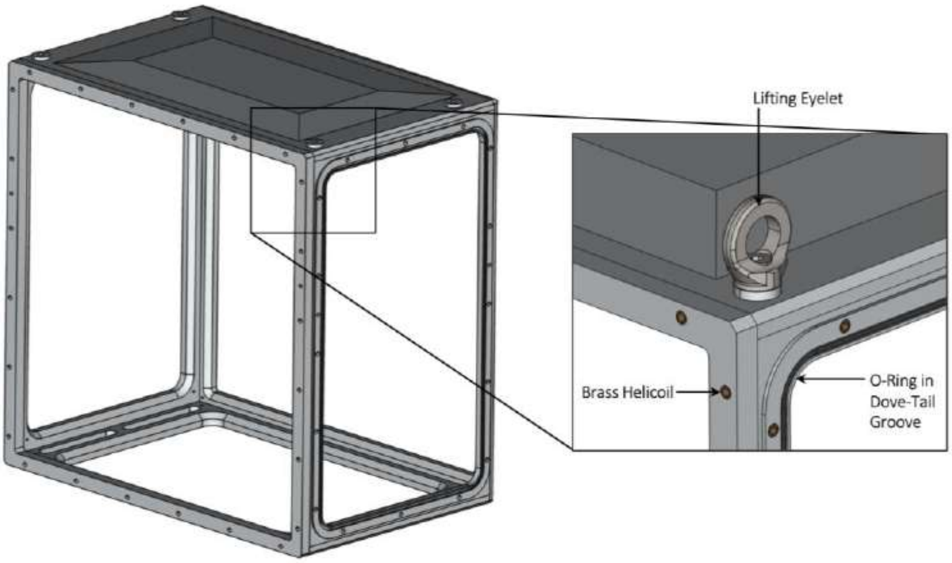

Figure 23: Frame Assembly with mounting eyelets.

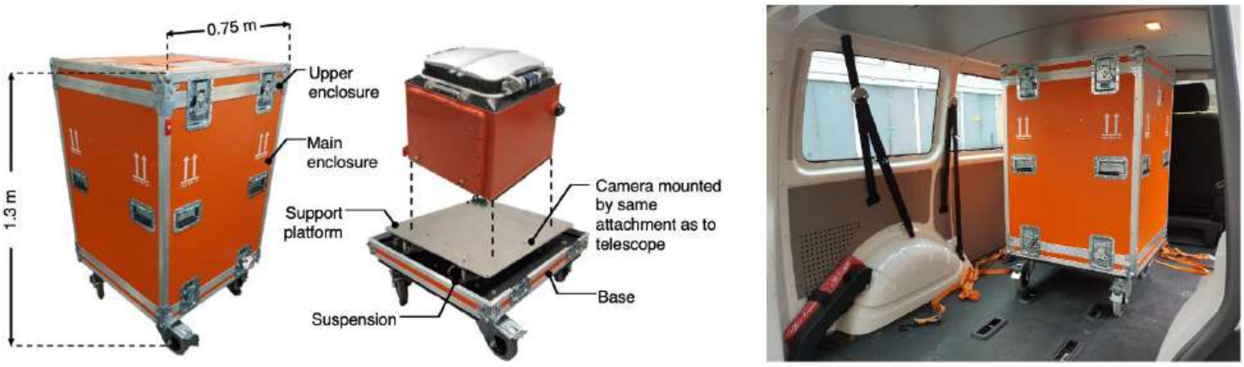

Figure 24: The custom wheeled transport container used for CHEC-S.

IA2-01 Camera Unit Optics

- Nominal Focal Plane shape and position: see Section 2.5.
- Images of the Sky: Ghosts, PSF estimation (for condition monitoring): the Camera will provide continuous Slow Signal Data with a measurement of the sky brightness with an exposure of 1ms and a frequency of 10 Hz, see Section 7.3.4 in [RD9]. The presence of misaligned mirrors or otherwise relevant PSF degradation can be detected from this data.
- Homogeneity of flasher light reflected by M2 (for condition monitoring). The Flasher Assembly has two LEDs that are fibre coupled to 20-30° diffusers in the focal plane corners, titled to illuminate the camera focal plane via reflection from M2 mirror when installed on the telescope. Optics of these reflections on M2 are TBD by CAM.

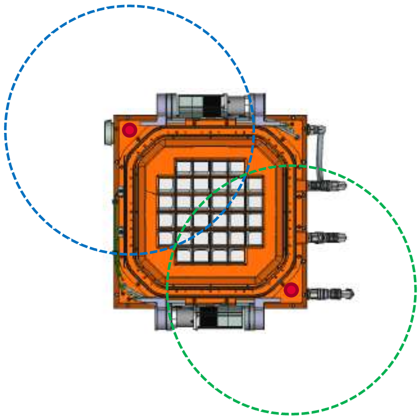

Figure 25: Illumination pattern of the two corner flashers as seen from the M2 mirror.

IA2-02 Flasher Unit Optics

For the calibration of the camera response, it is necessary to have an illumination system. Part of this system is a Flasher Unit at the M2 centre, that sends pulses of light onto the camera through a non-coated opening in the centre of the M2 mirror (see Figure 22).

- Mechanical fixation to M2 Hole: TBD by STR, proposal see Figure 26, design and fabricate a supporting plate surrounding the hole at the centre of the back of M2 and gluing it to back surface of M2 with the same procedure as for the pads for the mirror actuators.
- M2 hole position and diameter: TBC by STR, for proposal see Figure 26

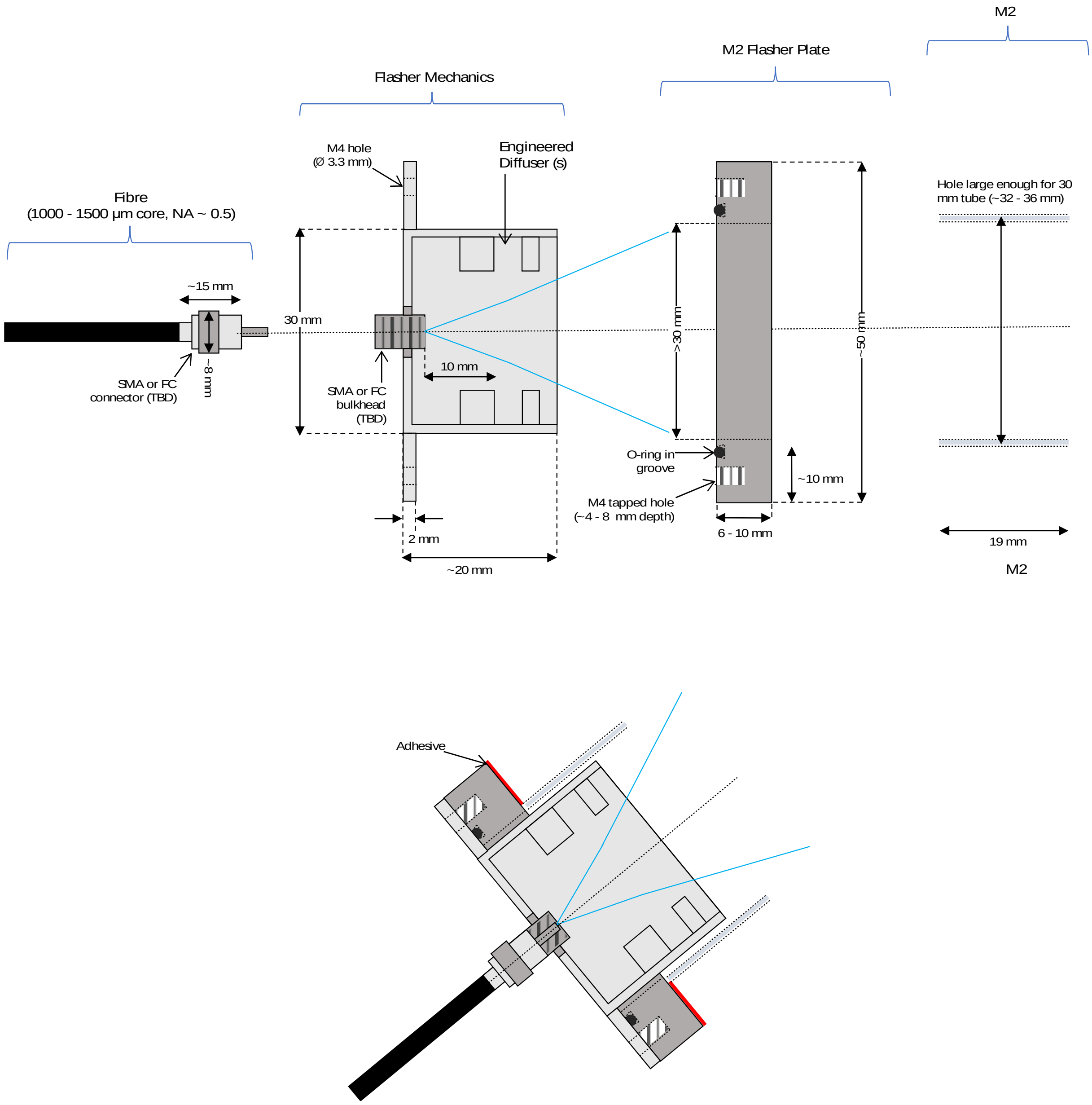

Figure 26: Sketch of flasher mechanics coupled to M2.

IB1-01 SST Camera Manager to Telescope Manager SW

Documentation of the control interface to the Camera from the Telescope Manger is controlled by the ACADA – Telescope Control ICDs [RD11]. A schematic view of the interfaces can be seen in Figure 27.
The Camera Manager must also comply with the Generic State Machine defined in [RD11].
The detailed Monitor and Housekeeping, Camera Data, Trigger, Status and Configuration interfaces are defined or will be defined in the corresponding ACADA ICDs.
The Camera Manager will be implemented within the ACS framework and mirror those aspects of the Telescope-ACADA interface that are relevant to the Camera.
Reference ACS IDL files for the Telescope and the Camera Managers are available at: https://gitlab.cta-observatory.org/cta-computing/common/acada-array-elements/telescope-icd

A reference implementation code (in Java) for the Camera Manager and Telescope Manager exist at: https://gitlab.cta-observatory.org/cta-computing/common/acada-array-elements/dummy-telescope.

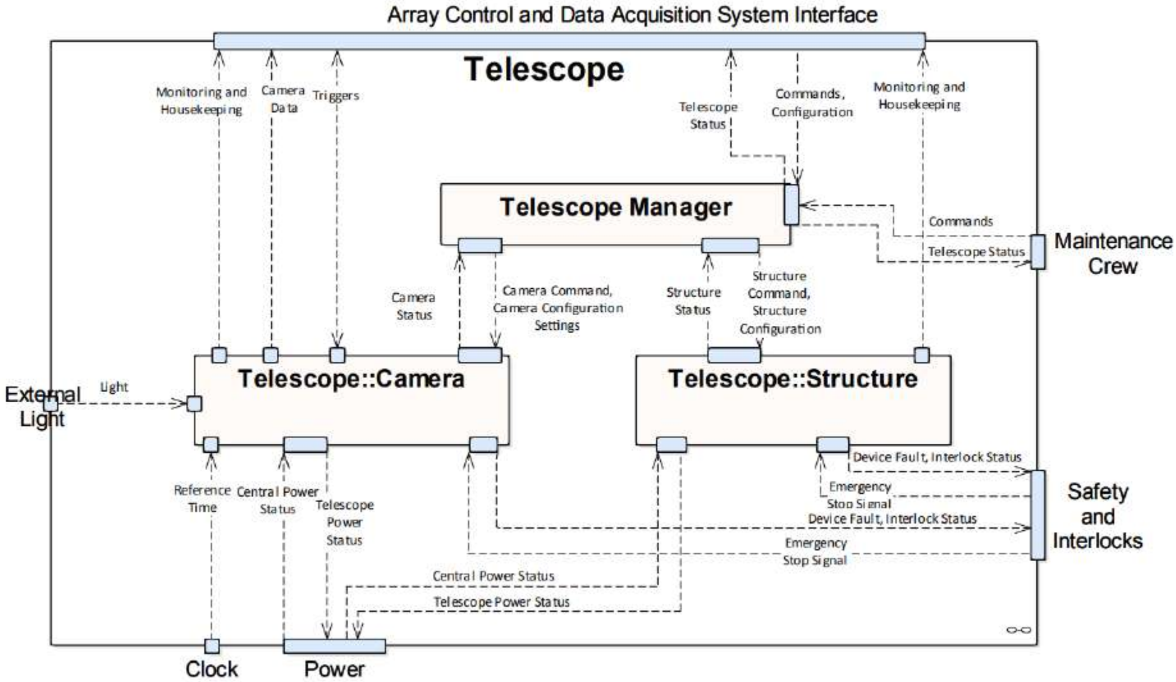

Figure 27: Telescope Control Interfaces, as defined in [RD12].

5 Responsibilities and Deliverables

Scope of supply by STR

- Finalize the design of the above interfaces (see TBCs and TBDs assigned to STR).
- Procure the camera and chiller electrical power cable, excluding the connectors.
- Assemble cables, if usage of pre-assembled cables is not possible
- Route all cables, communication fibers and coolant pipes to any part of the camera to the telescope cabinet or to the telescope patch panel.
- Develop the procedure for mounting the camera, the chiller and the flasher unit onto the telescope.
- Design, fabricate and install Flasher Unit support plate onto centre of M2 mirror.

Scope of supply by CAM

- Finalize the design of the above interfaces (see TBCs and TBDs assigned to CAM).
- Procure all connectors,
- Procure the camera and chiller network cables
- Procure the chiller coolant pipes
- Procure the Flasher unit control cable.