SST Programme:

Top Level &Trade-Off Analysis Report

SST-PRO-ANR-006

Version 1b

Prepared by:		
Primo Attinà (INAF)		SST-PRO
Latest Release Checked by:		
Alessio Trois (INAF)		SST-PRO PRM
Salvatore Scuderi (INAF)		SST-STR PM
Emma Rebert (OP-INSU)		SST-FRC PM
Richard White (MPIK)		SST-CAM PM
Nicola La Palombara (INAF)		SST-PRO QM
Alberto Macchi (INAF)		SST-PRO CADM
Approved by:		
Gianpiero Tagliaferri (INAF)		SST-ESC

Current Release				
Ver.	Created	Comment	Distribution	Editor(s)
1aD	9/8/2022	First Document emission This document close two DVER panel dispositions from DVER panel report [AD2] . REC-SST-ER #01 (see 33, 35 and 38) about optimise the assembly strategy in situ. REC-SST-ER #07 (see page 31) about the evaluation of M1 Dish options proposed by OP-INSU. REC-SST-ER #09 (see 33, 35 and 38). improving the overall access concept of the SST in view to enhance its maintainability	SST Team	Primo Attinà
1a	20/10/2022	Editorial corrections, update pbs figure	SST Team	Alessio Trois

Version History				
Ver.	Created	Comment	Distribution	Editor(s)

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1 Introduction

1.1 Scope & Purpose

The SST Telescope architecture baseline was presented at the KO of Bridging Phase on July 2022. This baseline (named Agreement Baseline) confirms the Baseline presented at the DVER in summer 2021. The actions and recommendation from DVER jointly with an updating of JAMA level B requirements and the outcomes from the bridging phase are combined for the identification of:

- the level B (Top Level) requirements status revision for their implementation the SST baseline and decomposition on lower levels;
- possible design option which introduces improvement of SST architecture.

In this context the SST-PRO Team identifies in this document a set of possible SST telescope architecture options which can allow to achieve the advantages summarised in the following:

- simplify the internal as well as external interfaces;
- improve RAMS;
- optimise resources.

N.B. The contents of this document are dedicated to the trade-off concerning the SST Telescope Architecture only. Other trade-off internal to the SST-STR as well as SST-CAM and not impacting the SST-TEL Architecture, are not part of this document.

1.2 Applicable Documents

[AD1] SST JAMA Level B requirements
[AD2] CTA-SST Engineering Review Panel Report CTA-RER-SST-305000-0001_2a Issue 2, Rev. 0, 2020-09-01
[AD3] SST Engineering Review – DMA Disposition CTA-INS-SST-305000-0001, 2020-11-02
[AD4] SST Project Management Plan SST-PRO- PLA-001-2a, August 2022
[AD5] SST Programme Configuration and Data Management plan SST-PRO-PLA-002 2a, August 2022
[AD6] ISO 16290:2013 - Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment

1.3 Reference Documents

[RD1] SST Telescope Architecture and Design Report SST-PRO-DSR-002-1a, August 2022
[RD2] SST-MES-TRE-001_1aD, M1 Dish optimisation Report analysis, August 2022
[RD3] SST-MEC-ANR-008 - SST Mechanical Structure: Structural Analysis Report
[RD4] SST-PRO-SPE-001 – Telescope Technical Requirements Specification

1.4 Definition of Terms and Abbreviations

1.4.1 Abbreviations and Acronyms

AIT	Assembly Integration and Testing
AIV	Assembly Integration and Verification
BKO	Bridging phase Kick-Off
CDR	Critical Design Review
CTA	Cherenkov Telescope Array
CTAO	Cherenkov Telescope Array Observatory
FAR	Final Acceptance Review
FRC	France Contribution
DR	Delivery Review
DVER	Design Verification Engineering Review
ERIC	European Research Infrastructure Consortium
IKC	In Kind Contribution
ESC	Executive Steering Committee
INAF	Istituto Nazionale di Astrofisica
INSU	Institut National des Science de l'Univers
KO	Kick-Off
MPIK	Max-Planck-Institut für Kernphysik
OP	Observatoire de Paris – PSL, CNRS
PA	Product Assurance
PBS	Product Breakdown Structure
PM	Project Manage
PR	Product Review
PMP	Programme Management Plan
PO	Project Office
PQR	Production Qualification Review
PR	Product Review
PRM	Programme Manager
PRR	Production Readiness Review
PSE	Programme System Engineer
QA	Quality Assurance
QM	Quality Manager
RAMS	Reliability, Availability, Maintainability & Safety
SE	System Engineer
SST	Small Size Telescope
TRR	Test Readiness Review
WBS	Work Breakdown Structure
WP	Work Package
WPD	Work Package Description

1.4.2 Glossary

TERM	DEFINITION
"As Built" Configuration	The as-built configuration or applied configuration is defining the as-built status per each serial number of Configuration Item (CI) subject to formal acceptance.
"As Designed" Configuration	The as-designed configuration or Applicable configuration is defining the current design status of a Configuration Item (CI)
AIV	AIV is the Assembly Integration and Verification, which is referred to the integration activities related with the verification of the system or sub-system. In the framework of SST for briefness this term includes also the Assembly Integration and Testing which is related with the integration activities and testing to be performed during the integration at system and subsystem levels
Baseline	Set of information which describes exhaustively a situation at a given instant of time or over a given time interval.
Change	Vehicle for proposing modifications to an approved baselined data or the business agreement.
Configuration	Functional or physical Characteristics of a product defined in configuration definition documents subject to configuration baseline.
Configuration Item	Aggregation of hardware, software, processed materials, services or any of its discrete portions, that is designated for configuration management and treated as a single entity in the configuration management process. **NOTE:** A configuration item can contain other lowerlevel configuration item(s).
Deviation	Written authorization to depart from the originally specified requirements for a product prior to its production.
Firmware	Firmware is software programmed onto an electronic device which is treated like a pure hardware.
Executive Steering Committee	The SST Executive Steering Committee (ESC) is the high-level decision-making body which will manage the strategic direction of the Programme and will be in charge of overseeing progress and facilitating global collaboration among the participating groups.
Institutes	Research Institutes involved in the SST Programme.
Contractor	Industry involved in the SST Programme which has a contract with an institute
SST-PRO	It is the team composed by Institutes and Contractors responsible, involved in the production of SST telescopes elements, which coordinate the project level activities.
Hardware	Hardware is a single or an assembly of physical electronic devices which cannot be changed in its user environment.
Item	Any part, component device, sub-unit, unit, equipment or device that can be individually considered.
Model	Physical or abstract representation of relevant aspects of an item or process that is put forward as a basis for calculations, predictions or further assessment useful for the preparation of SST production
Partners	are those entities taking responsibility for IKC delivery by signing IKC agreements with CTAO, plus any organisation identified by these signing entities as playing an essential role in SST delivery. The institutes are the partners of the CTA-SST consortium.
Product	A product (hardware, software, service) required in the frame of the program and included as element of the product tree having a unique identifier. A product may be deliverable or not.
Product Breakdown Structure	Hierarchical structure depicting the product orientated breakdown of the project into successive levels of detail down to the configuration items necessary to deliver the required functions. The Product Breakdown Structure (PBS) in general is influenced by Institutes/partners decisions to group certain products or by program history. It identifies products and their interfaces; it serves as the basis for the WBS
Service	Service is the result of at least one activity necessarily performed at the interface between the SST consortium and CTA and is generally intangible.
Software	Set of computer programs, procedures, documentation and their associated data.
SST-E2E	The SST end-to-end telescope, or simply SST, will consist of the SST Structure and the SST Camera (including all mechanics, mirrors, auxiliary devices and required software), integrated and commissioned on-site including all required documents. It ends at (and integrates into CTA via) the system interfaces specified by the CTA PBS.
SST Consortium	The SST Consortium then consists of the Partners and their associated Teams, where a Team is a set of individuals within a single organisation at a single location (such as a University group).
System	An entity of products assembled or working together for a well-defined specified purpose. In SST the term system can be utilised in alternative to Telescope End-to-End.
Sub-System	Like a system but a lower level. In SST the SST system is composed by the subsystem SST-MECH, SST-OPT, SST-TCS and SST-CAM.
Waiver	Written authorization to use or release a product which does not conform to the specified requirements
Work Breakdown Structure	Hierarchical representation of the activities necessary to complete a project.

2 System Overview

When a VHE gamma-ray interacts with the atoms and ions in the upper levels of the atmosphere, it induces a cascade of secondary particles which propagate over many kilometres at nearly the speed of light through the atmosphere. These particles emit Cherenkov light, forward-beamed with an opening angle of about one degree. A Cherenkov light event consists of a time-correlated multi-photon image with a typical timescale of ~10 ns. Cascades originate at an altitude of ~10 km above ground and create a light pool on the ground of ~120 m radius. Telescopes placed on the ground, containing large reflectors, focus the light to and imaging camera. Such Cherenkov cameras must be highly pixelated, cover a large field of view, and be able to detect UV/blue light down to the single photon levels with exposure times of approximately a billionth of a second. To provide a high imaging sensitivity over an extensive energy range, from a few tens of GeV up to a few hundreds of TeV, the Cherenkov Telescope Array Observatory (CTAO, see web page link at https://www.cta-observatory.org) will be made of sub-arrays with three different types of telescopes: large-sized (LST, 23 m diameter), medium-sized (MST, 12 m diameter) and small-sized (SST, 4 m diameter) telescopes. They are distributed in two observing sites, the Northern one in La Palma, the Canary Islands, and the Southern one in the Chilean Andes in the Paranal area. The CTA South "Alpha Configuration" would include LSTs, MSTs and SSTs. In particular, it envisages the construction and installation of 42 SSTs (a number that could increase up to 70 in future upgrades).

The SSTs are developed by an international consortium of institutes that will provide them as an in-kind contribution to CTAO. The SSTs rely on a Schwarzschild-Couder-like dual-mirror polynomial optical design, with a primary mirror of 4 m diameter, and are equipped with a focal plane camera based on SiPM detectors covering a field of view of ~9°. They are sensitive in the band from ~0.5 TeV up to ~300 TeV, providing the Observatory with sensitivity to the highest energies. The current SST concept has been validated by developing the prototype dual-mirror ASTRI-Horn Cherenkov telescope and the CHEC-S Cherenkov camera. Table 2-1 reports main properties of the Small-Sized telescope (SST).

Table 2-1. Small-sized telescope main properties

Small-Sized telescope (SST) main properties:	
Optical Design	modified Schwarzschild-Couder
Primary reflector diameter	4.3 m
Secondary reflector diameter	1.8m
Effective mirror area (including shadowing)	>5 m^2
Focal length	2.15 m
Total weight	17.5 t
Field of view	>8.8 deg
Number of pixels in SST Camera	2048
Pixel size (imaging)	0.16 deg
Photodetector type	SiPM

Telescope data rates (before array trigger)	>600 Hz
Telescope data rates (readout of all pixels; before array trigger)	2.6 Gb/s
Positioning time to any point in the sky (>30° elevation)	90s
Pointing Precision	< 7 arcsecs

2.1 SST Telescope Product Breakdown Structure

The toplevel product breakdown structure of the SST Telescope is give in Figure 2-1: SST Telescope Product Breakdown Structure.

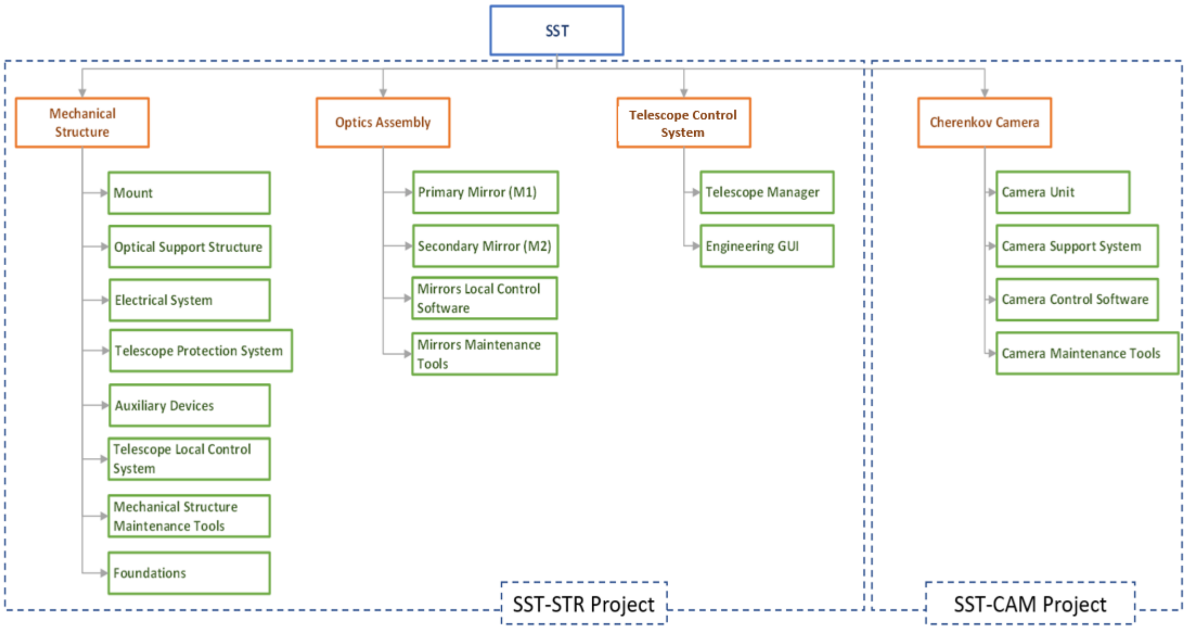


Figure 2-1: SST Telescope Product Breakdown Structure

The SST Consortium responsibility is considering the levels detailed in the following bullets.

- *SST Telescope (SST-TEL):* It is the whole contribution of the SST Consortium to CTA. It consists in the provision of all the equipment necessary to perform the imaging of the Cherenkov Light, providing the whole telemetry, both scientific and engineering, and guarantee an autonomous managing of the telescope equipment's.
- *Mechanical Structure (STR-MEC)*: The Telescope Mechanical Structure (TMS) includes all the hardware and software that allow the telescope to point to different parts of the sky with the required performances. All mechanical parts (structural elements, bolts, screws, bearings, gears, springs, bumpers, accessories) needed to support the telescope optics to collect light

are part of the TMS. The TMS provides the motion capabilities that allow the Telescope to point and track over its specified range. All the electromechanical parts are provided with power and communication via dedicated supply lines. The TMS is fixed to the concrete foundation by means of anchor bars.

- *Optics Assembly (SST-OPT):* The Optical Assembly (Optics) includes the primary and secondary mirror and their control hardware.

- *Telescope Control System (SST-TCS):* The Telescope Control System (TCS) interfaces the Telescope with the CTAO facility (ACADA). The TCS includes a Telescope Engineering GUI to operate the SST Telescope in standalone mode during installation, calibration and maintenance activities.

- *Cherenkov Camera (SST-CAM):* The SST Camera comprises all the hardware, software and documentation associated with Cherenkov image detection, digitisation, trans project and pre-processing. The SST Camera is modular, it consists of a number of subsystems These modular subsystems greatly simplify the organisation and division of activities within the production phase, and also form the basis of the international SST Camera Project (SST Camera).

The SST Structure (SST-STR) is composed by the Mechanical Structure, Optics Assembly and Telescope Control System.

3 Analysis of SST-CTAO Top-Level inputs to SST team

The design, development and on-site implementation of SST telescopes must comply with JAVA Level B requirements: the top-level input of CTAO to the SST team. Level B requirements are decomposed in lower-level requirements applicable to the various elements of SST Product Breakdown Structure. With the aim of proceeding in this direction, an analysis of the Level B requirements was carried out in the bridging phase, in light of the consolidation of SST team and the achievement of a greater maturity of the programme. The analysis reflects the discussion performed by the SST Team and CTAO in 2021 and early 2022. The compliance matrix presented in [RD4] overcome the hereafter analysis.

3.1 Organization of requirements/goals review

Analysis of all the SST Level B requirements consists in:

- Identification of PBS item for which the requirement (directly or decomposed) is the design driver
- Assessment of the level of confidence

This analysis is provided by the SST PRO.

Each Level B identified the assumed item (system) of the PBS which is driven by the requirements. This original assumption is now assessed taking into account the effective high-level PBS (sec. 2.1), consolidated in the framework of SST Bridging Phase.

Furthermore, the SST PRO has classified the Level B requirements in four classes, which scheme is reported in Table 3-1.

Table 3-1: Level B requirements confidence classes

A	B	C	D
CLEAR	**UNCLEAR**	**CRITICAL**	**INFORMATION ONLY**
The Requirement is well understood and satisfied by actual design	To Be Clarified/ Rephrased	The requirements are difficult to assess	The requirements are not used for the SST design

In the next sections the outcomes of the Level B requirements analysis are presented in a tabular form. The sections are organised on the basis of item and requirements tags.

4 CTAO JAMA level B requirements analysis

4.1 B-ENV requirements for Telescope

Summary of B-ENV for Telescope requirements analysis reported in Table 4-1 and Table 4-2.

Table 4-1 B-ENV for Telescope requirements analysis part 1

	Category	Req. ID	Req. Name	Description	Tag	SST Comments	Design Driver for	Classification
1	Enviromental	B-ENV-0135	Atmospheric Pressure	Performance requirements must be met in the atmospheric pressure range of 770 +/- 50 mbar.		It is not clear exactly which requirements are regarded as "Performance". Whilst in many cases it is obvious, it would be more clear is the term "Performance" referred to specific (tagged) requirements. Inconsistency with ENV-0210: are performance requirements applicable in all states, or only in Observing? The req can be split in more specific requirements: i.e Specific lubricant for atmospheric pressure range shall be used for the actuation mechanism	Mechanical Structure Optics Camera	B
2	Enviromental	B-ENV-0210	Observation Temperature	Performance requirements for observations must be met within the ambient temperature range -5ºC to 25ºC		This is considered the operative temperature. The term "observations" could be replaced with a referral to the Observing State. Or removed entirely as "applicable state" is aditional field, but either way should be made consistent with e.g. ENV-0225 where no state is referred to.	Mechanical Structure Optics Camera	B
3	Enviromental	B-ENV-0220	Survival Temperature	Damage must not occur due to ambient temperatures within the range -15ºC to 35ºC when in the Safe State		This is the no operative temperature. The assumptios are the following. In the range -(5°/15°) and +/25°/35°) the telescope: a) can work but the performances are not guaranteed b) can have a no permanent malfuntcion, which disappears when the telescope temperature returns to the operating range. Is "Damage" defined formally in the glossary? Again - inconsistency in referring to states in requirements - either do it for all, or use the "applicable state" field. Damage in CTA requirements may be opposed to Collapse (for earthquakes). Example: damage means that the structure is deformed in a permanent way (R > Re = yield stress); collapse means that the structure broke (R > Rm)	Mechanical Structure Optics Camera	B
4	Enviromental	B-ENV-0225	Survival Temperature Without Power	Damage must not occur due to ambient temperatures within the range -10ºC to 30ºC when no power is available.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
5	Enviromental	B-ENV-0230	Temperature Gradient	Performance requirements for observations must be met during air temperature gradients of less than 7.5ºC/h				A
6	Enviromental	B-ENV-0235	Precision Pointing Temperature Gradient	It must be possible to achieve precision pointing under temperature gradients of up to 3ºC/h		This requirement should be associated with performance stabilities. This requirements should be a lower level requirement, defined by worst case analisys performed at telescope level.	Mechanical Structure Optics Camera	B
7		B-ENV-0250	Survival temperature gradients	Damage must not occur due to air temperature gradients of up to 0.5ºC/min for 20 minutes when in the Safe State		Is "Damage" defined formally in the glossary? Again - inconsistency in referring to states in requirements - either do it for all, or use the "applicable state" field.	Mechanical Structure Optics Camera	B
8	Enviromental	B-ENV-0310	Observation Humidity	Performance requirements for observations must be met within the relative humidity range 2% to 90%, provided the condition for operation with un-misted mirrors (B-ENV-0330) is met.		the requirements should be defined for all the critical elements in the optical path exposed to the external environmental, i.e. mirrors as well as Camera window	Mechanical Structure Optics Camera	B
9	Enviromental	B-ENV-0320	Survival humidity	Damage must not occur due to relative humidity within the range 2% to 100% when in the Safe State or when no power is available.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
10	Enviromental	B-ENV-0330	Mirror Misting	Telescopes must operate with un-misted mirrors when the dew point temperature is at least 2ºC lower than the ambient temperature.		worst case at 90% of humidity => Td-Ta=5°. Telescope must operate is assumed to be no un-misted of surfaces in the optical path	Mechanical Structure Optics Camera	B
11	Enviromental	B-ENV-0410	Rain in 24 hours	Damage must not occur due to rain precipitation of up to 200mm in 24 hours.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
12	Enviromental	B-ENV-0420	Rain in 1 hour	Damage must not occur due to rain precipitation of up to 70mm in 1 hour.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
13	Enviromental	B-ENV-0430	Rain wind speed	Damage beyond the Serviceability Limit State must not occur due to precipitation in the form of rain, snow or hail for (10 minute average) wind speeds of up to 90km/h.		definition of Serviceability Limit State should be defined as a requirement. Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
14	Enviromental	B-ENV-0460	Rain during transition	During transitions, damage must not occur due to rainfall of up to 2 mm/hour.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
15	Enviromental	B-ENV-0520	Survival snow load (North)	Damage beyond the Serviceability Limit State must not occur on the CTA-N site whilst in the Safe State due to snow loads of up to 200kg / m^2		This requirement should be not applicable to SST, located on CTA-S only		E
16	Enviromental	B-ENV-0525	Survival snow load (South)	Damage beyond the Serviceability Limit State must not occur on the CTA-S site whilst in the Safe state due to snow loads of up to 20kg / m^2		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
17	Enviromental	B-ENV-0530	Hailstone damage	Damage must not occur due to the impact of 5 mm diameter hailstones with kinetic energy of 0.2 Joule.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
18	Enviromental	B-ENV-0620	Survival ice load (North)	Damage beyond the Serviceability Limit State must not occur due to an ice thickness (on all surfaces) of up to 20 mm.		This requirement should be not applicable to SST, located on CTA-S only		B

Table 4-2 B-ENV for Telescope requirements analysis part 2

	Category	Req. ID	Req. Name	Description	Tag	SST Comments	Design Driver for	Classification
19	Enviromental	B-ENV-0625	Survival ice load (South)	Damage beyond the Serviceability Limit State must not occur due to an ice thickness (on all surfaces) of up to 20 mm.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
20	Enviromental	B-ENV-0710	Observation Wind Speed	Performance requirements for observations must be met under 10 minute average wind speeds of up to 36 km/h		Average it is not taking in account wind gust	Mechanical Structure Optics Camera	B
21	Enviromental	B-ENV-0715	Precision Pointing Wind Speed (North)	It must be possible to achieve precision pointing on the CTA-N site under 10 minute average wind speeds of up to 15 km/h		This requirement should be not applicable to SST, located on CTA-S only		B
22	Enviromental	B-ENV-0716	Precision Pointing Wind Speed (South)	It must be possible to achieve precision pointing on the CTA-S site under 10 minute average wind speeds of up to 11 km/h		Average it is not taking in account wind gust	Mechanical Structure Optics	B
23	Enviromental	B-ENV-0720	Transition Wind Speed	During transitions, damage must not occur on-site due to 10 minute average wind speeds of up to 50 km/h and damage beyond the Serviceability Limit State must not occur due to 10 minute average wind speeds of up to 60 km/h.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics	B
24	Enviromental	B-ENV-0730	Survival wind speed (North)	Damage must not occur at the CTA-N site due to 10 minute average wind speeds of up to 100 km/h, and damage beyond the Serviceability Limit State must not occur due to 10 minute average wind speeds of up to 120 km/h when in the Safe State		This requirement should be not applicable to SST, located on CTA-S only		E
25	Enviromental	B-ENV-0735	Survival wind gust (North)	Damage beyond the Serviceability Limit State must not occur on the CTA-N site due to wind gusts (1s) of up to 200 km/h		This requirement should be not applicable to SST, located on CTA-S only		E
26	Enviromental	B-ENV-0740	Survival wind speed (South)	Damage must not occur at the CTA-S site due to 10 minute average wind speeds of up to 80 km/h, and damage beyond the Serviceability Limit State must not occur due to 10 minute average wind speeds of up to 100 km/h when in the Safe State		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics	B
27	Enviromental	B-ENV-0745	Survival wind gust (South)	Damage beyond the Serviceability Limit State must not occur on the CTA-S site due to wind gusts (1s) of up to 170 km/h		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics	B
28	Enviromental	B-ENV-0810	Solar radiation level	Damage must not occur due to solar radiation of up to 1200 W/m^2 (averaged over 1 hour) at a maximum ambient temperature of 35ºC when in the Safe state.		Is "Damage" defined formally in the glossary?	Mechanical Structure Optics	B
29	Enviromental	B-ENV-0820	UV resistance	All components exposed to direct solar radiation must be UV resistant.		Is this requirement needed? UV damage could be considered covered by ENV-0810 above. Unclear what UV resistant means.	Mechanical Structure Optics	B
30	Enviromental	B-ENV-0915	Dust and sand	Damage must not occur due to an environment with up to 2.9 x 10^5 particles of ≥5µm size per m³ of air for 90% of the time at 2m above ground. Note: This limit corresponds to the definition of ISO-Class 9 of ISO14644-1 for particles of this size.		90% of time is referred to the whole exposition of the telescope to this environment. The requirement in this form is not applicable to mirrors as does not define the amount of damage to the coating. Actually I am not sure is applicable to mirrors full stop...	Mechanical Structure Optics Camera	C
31	Enviromental	B-ENV-1010	Aggressive atmosphere (North)	Damage must not occur on the CTA-N site due to the following Aggressive Atmospheric Concentration ranges when in the Safe State: NO, NO 2 , SO 2 < 3ppb		This requirement should be not applicable to SST, located on CTA-S only		E
32	Enviromental	B-ENV-1020	Aggressive atmosphere (South)	Damage must not occur on the CTA-S site due to the following Aggressive Atmospheric Concentration ranges when in the Safe State: NO, NO 2 , SO 2 < 4ppb		Is the safe state period forecast defined by CTAO? We know that this cannot be verified because the atmosphere is not aggressive at all so it is quite difficult to reproduce in labs. In my opinion if stays with these percentages is not useful so maybe can be removed.	Mechanical Structure Optics Camera	B
33	Enviromental	B-ENV-1110	Earthquake damage limitation (South)	Damage beyond the Damage Control Limit State must not occur at the CTA-S site due to the following ground accelerations: Peak horizontal ground acceleration up to 0.26g, peak vertical ground acceleration up to 0.3 g, with a 10% probability of exceeding these figures within 10 years (reference return period 95 years)		It is not clear what is the frequency spectrum and what is the overall probability of the earthquakes. Is "Damage" defined formally in the glossary?	Mechanical Structure Optics Camera	B
34	Enviromental	B-ENV-1115	Earthquake damage limitation (North)	No damage must not occur at the CTA-N site due to peak horizontal ground acceleration up to 0.05 g and peak vertical ground acceleration up to 0.05 g.		This requirement should be not applicable to SST, located on CTA-S only		E
35	Enviromental	B-ENV-1120	Earthquake collapse prevention (South)	Damage beyond the Collapse Prevention Limit State must not occur at the CTA-S site due to the following ground accelerations: Peak horizontal ground acceleration up to 0.49g, peak vertical acceleration up to 0.6 g, with a 10% probability of exceeding these figures within 50 years (reference return period 475 years)		Is "Damage" defined formally in the glossary? It is not clear what is the frequency spectrum and what is the overall probability of the earthquakes.	Mechanical Structure Optics Camera	B
36	Enviromental	B-ENV-1430	Survival Illumination	Damage must not occur due to illumination levels of up to 10^6 photons ns^−1 cm ^−2 in any state.		Damage=no permanent degradation Spectrum / wavelength of light here unclear. The effect on camera photosensors at 1000 nm is much lower in the camera than 400 nm (for example).	Mechanical Structure Optics Camera	B

4.2 B-ENV requirements for Telescope

Summary of B-TEL requirements for Telescope analysis in *Table 4-3*

Table 4-3 B-TEL for Telescope requirements

	Category	Req. ID	Req. Name	Description	Tag	SST Comments	Design Driver for	Classification
37	Performances	B-TEL-0040	Online Astrometric Accuracy	The Online Astrometric Accuracy of the Telescope whilst Tracking must be < 60 arcseconds. Astrometric data delivered to the OES must have a period of validity ending not earlier than 5 seconds before the time of delivery.		The wording "a period of validity ending not earlier than 5 seconds before the time of delivery." is not immediately clear and could possibly be improved. OES is outdated	Mechanical Structure Optics Camera	B
38	Interface	B-TEL-0050	Camera Fixation	A suitable Telescope Structure / Camera Unit mechanical interface must be provided to ensure a safe and stable fixation which ensures appropriate focal plane positioning.		This should be moved to level C requirements since the adequacy of the Camera/Telescope interface is design-specific, and the appropriate requirements that constrain it be flowed down from environmental, optical and safety reqs	Mechanical Structure Optics Camera	B
39	Performances	B-TEL-0060	Electromagnetic Compatibility	The Telescope Structure and Camera Unit (as well as its full cooling system) must be electromagnetically compatible, with noise generated by each sub-system having an acceptable level of impact on the performance of the other. The Cherenkov Telescope sub-systems should also be designed to tolerate EM noise associated with local maintenance and engineering activities.		Does anyone know what is the issue with the "suitable reference standard"? EN 61000 series, "Electromagnetic Compatibility (EMC)" is not good?	Mechanical Structure Optics Camera	B
41	Performances	B-TEL-0090	Signal to Noise	The overall optical efficiency of the full Cherenkov Telescope to background light (including night sky background and albedo - following the Background Light Reference Spectrum and integrated over the full response of the Telescope), ε bg , must be such that ε sig / sqrt (ε bg) >0.35. ε sig is the integral over the Cherenkov Reference Spectrum .				A
42	Performances	B-TEL-0095	UV Light Contribution	The optical elements of the Cherenkov Telescope (mirrors and camera) must jointly ensure by design that wavelengths below 290 nm in the Cherenkov light spectrum from local muons contribute less than 5% to the observed muon Image Amplitude.				A
51	Performances	B-TEL-0250	Tracking	The Telescope must be able to Track any Astrophysical Target for all azimuth angles and for elevation angles 20-89.2 degrees with an instantaneous accuracy of <0.1 degrees on both axes for 99% of the tracking time.		The Alt-Az telescopes have several blind spots in Az and Elevation, the is better to specify the maximum traking time with a given precision. Morover, this requirement should be looser in case of Fast Repointing, see comment to B-TEL-0215	Mechanical Structure Telescope Control System	B
54	Maintenence	B-TEL-0340	Camera Loading / Unloading	Camera Unit loading and unloading procedures must be clearly documented, specifying the levels of personnel and equipment needed for the procedure to be safely completed within one working day.		This requirement mixes up the availability of documentation, personnel, equipment, safety and time. What we need to have specified is: what's the maximum number of person-hours allowed for a camera unloading? What's the maximum level of expertise of the operators involved? What are the safety rules to be applied? What equipment is available/admitted for such a procedure? I.e., can we count on a crane+operator or should it be achievable with only platforms/ladders? Is aerial work (climbing) at all allowed?	Mechanical Structure Optics Telescope Control System Camera	B
57	Safety	B-TEL-0430	Observation Pointing Safety	In case a Telescope is unable to reach the Safe state/parking position, there must be procedures and plans in place to ensure that damage due to the sun does not occur. It must be possible for two local CTAO personnel to complete a preventative action within 30 minutes at the Telescope, without a connection to the mains power supply.		This requirents is not clear. To be discussed with CTAO.	Mechanical Structure Telescope Control System	E
59	Maintenence	B-TEL-0450	Pointing Calibration Run Frequency	Telescope Structures must not require dedicated pointing or PSF calibration observations with an annual average of more than 3 hours per month of Grey Time plus 6 hours per month of Bright Moon Time.		It is not understood why this is not on the Telescope System (i.e. 1 SST), rather than the Structure (which indeed includes most of the optical system, but if we use the Cherenkov camera as a PSF/pointing monitor, the it's part of the optical system) What's Grey/Bright Moonlight Time? Is Cloudy Time included?	Mechanical Structure Optics Telescope Control System Camera	B
60	Performances	B-TEL-0460	Calibration by External Illuminating Device	The full field of view must not be obstructed by any part of the Telescope Structure in an azimuth range of at least 270º for all elevations at or above the horizontal.			Mechanical Structure Optics Telescope Control System Camera	A
61	Interface	B-TEL-0500	Fixation to Foundation	Telescopes must provide sufficient design information and a suitable interface to ensure that the Telescope Structure is sufficiently well anchored to withstand the expected static and dynamic loads.		This requirements is not clear. The SST Telescope could just provide to CTAO the static and dynamical analysis and the final design of the Telescope and its foundation. Superseded by infrastructure ICD?	Mechanical Structure Optics Telescope Control System Camera	B
62	Interface	B-TEL-0510	Interface Cabinet	Telescopes must connect to all of the on-site infrastructure systems using the Interface Cabinet provided as part of the on-site infrastructure.		This requirements is not clear. Better to refer to the Electrical/Power/Infrastructure ICD.	Mechanical Structure Optics Telescope Control System Camera	B
63	Operations	B-TEL-0520	Structure Lifetime	The structural elements of a Telescope Structure must be designed for an operational Lifetime of 30 years.				A
66	Safety	B-TEL-0580	Drive Control Safety	Telescope drive control systems must be provided with safety interlocks that prevent injury to personnel or damage to telescopes that might result from inadvertent operation, human error, or mechanical or control system failure.		This requiremnts must refer to an International Standard about functional safety etc.	Mechanical Structure	B

4.3 B-TEL requirements for Camera

Summary of B-TEL requirements for Camera analysis in

Table 4-4, *Table* 4-5, *Table* 4-6

Table 4-4 B-TEL requirements for Camera analysis part 1

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
72	Performances	B-TEL-1010	Intensity Resolution	The required fractional Intensity Resolution for Cherenkov signals in each Camera pixel for a specified background level of 0.24 photons ns -1 sr -1 cm -2 (black curve) and for the highest NSB levels required for a given telescope type (red curve) is given in the Figure below and Table attached. Intensity measurements must be possible for 0-4000 photon signals. The average intensity resolution should be calculated for the Reference Gamma-Ray Flux . Figure : Fractional rms intensity resolution σ I /I per pixel for different Cherenkov light signal amplitudes, expressed in photons (p.e.). All sources of fluctuations, including Poisson fluctuations in photon number and calibration uncertainties (excluding uncertainties on average camera efficiency/throughput), must be included. Curves are shown for the nominal (black line) and high NSB (red line) cases.		is Monte Carlo simulation an CTAO furnished Item? It is unclear who is responsible for the MC results that are used here. In general the distinction between validation and verification is messy, and this is highlighted by this requirement. The plan for verification of this is to make a Level C requirement on Charge Resolution as measured in the lab. This Level C can then be veriified with said lab measurments directly. All that remains is to prove (validate) that the Level C requirement on lab Charge Res is sufficient to satisfy the required Level B Intensity Resolution. To do this validation, a MC model of the camera is made. MC sims are run of the lab setup, and compared directly to measurements to show they match. That same model is then plugged into the CTA full SST simulations and used to produce intensity resolution plots from Chrenkov light. So then the responsibilities are: * MC model of the camera: SST * MC simulation of the lab: SST * Lab measurements: SST * Full scale SST simulations: CTAO/ASWG (using the model we deliver to them) * Analysis of full scale simulations to produce intensity resolution: unclear	Telescope Control System Camera	B
73	Performances	B-TEL-1030	Time Resolution	The rms difference in the reconstructed signal arrival time for any two simultaneously illuminated pixels in the Camera with amplitudes of five photoelectrons must not exceed 2 ns. This is for a specified background level of 0.125 photoelectrons/ns.		Photoelectrons are used here as a background level, but some other requirements are use photons. Note 0.125 pe/ns is 125MHz, but the expected rate (and that required by the intensity res curve) is 40 MHz for the SST at nominal illumination. Why specify this as pixel-to-pixel and e.g. 1410 as relative to uniform illumination. As it stands this is a pain to calculate in the lab (for uniform illumination the dt between all pixels with all other pixels must be found), and is open to interpretation about how many pixels to simultaneously illuminate. Suggest to re-thing the timing requirements using an error budget and sharing the break down.	Telescope Control System Camera	B
74	Performances	B-TEL-1100	Camera Mechanics	The Camera Unit must either be sufficiently mechanically stable that the contribution (due to variation in pixel position relative to the Camera Unit casing) to the absolute post-calibration pointing accuracy is negligible, or a mechanism must be provided to monitor pixel positions with sufficient accuracy that the absolute pointing needs can be met.		For pointing needs the requirement should be on the relative positions of the optical elements of both Telescope Structure and Camera, this assumes we derive our pixel position using some elements on the Camera casing, which is design specific, so should be level C.	Telescope Control System Camera	B
75	Performances	B-TEL-1160	Deadspace	The angular distance of any non-photosensitive gap between directly adjacent pixels, measured along the line joining their centres, must be less than 25% of the maximum allowed angular Pixel Pitch at any place within the required cFoV . Any regions of dead-space larger than this, including dead-spaces by construction, are considered to contribute to the total number of unavailable pixels.		Completely unclear if 25% really matters here. Doubt that there is a curve anywhere showing e.g. trigger efficiency vs. pixel gap. For early CHEC-M results, anything up to 100% (i.e. 1 dead pixel) made no obvious difference to performance.	Telescope Control System Camera	B
76	Performances	B-TEL-1170	Photon Detection Efficiency	The average efficiency of the focal plane detectors (i.e. conversion efficiency from photons to photoelectrons), weighted by the reference Cherenkov spectrum (see figure) in the wavelength range 300-550 nm, including dead-space and the efficiency of any focal plane optics/windows etc, must be >20 %. Figure : Reference spectra for night sky background (NSB) light and Cherenkov light from γ -ray initiated air-showers at ground-level. The Cherenkov light spectrum is shown including the transmission from an atmospheric depth of 240 g/cm 2 at 20 ◦ zenith angle, corresponding to the shower maximum of ≈100 GeV γ -ray showers, and detected at 2000 m above sea level. The Cherenkov spectrum is scaled to 100 photons/m 2 in the wavelength range from 300–600 nm, a value typical for γ -ray showers of about 500 GeV viewed at small core distances. Note that the NSB spectrum given is most appropriate for dark sky (moonless) observations, but the same spectral shape can be assumed for the full range of required operational NSB levels.				A
77	Interface	B-TEL-1240	Trigger Monitoring	Times at which the Camera trigger was enabled and disabled must be recorded and sent to the OES as part of a monitoring stream.		OES is outdated. To be linked to the dedicated ICD (CTA-ICD-ACA-303000-0001).	Telescope Control System Camera	B
78	Interface	B-TEL-1250	Pixel Readout	The Camera must be able to deliver signal amplitude information from all camera pixels in each event together with all available time domain information, unless it can be shown that for a given partial readout scheme, using end-to-end simulations, that the achievable sensitivity is not reduced by more than 3 %. Incomplete or mixed Events will be dropped and count towards deadtime and/or availability.				A
79	Interface	B-TEL-1260	Deadtime	The fraction of the time during a continuous observation, at the required minimum Event Rate (B-*ST-1280), that the camera is unable to identify or record events (the Deadtime) must be <5 %.		Agree with the statement in the notes - but then make that a requirement. This is not an interface req.	Camera	B
80	Interface	B-TEL-1265	Busy Triggers	A Camera must generate and send trigger timestamps to the OES whenever possible in the Observing State, even if it cannot provide data for a given Event.		OES is outdated. To be linked to the dedicated ICD (CTA-ICD-ACA-303000-0001).	Telescope Control System Camera	B
81	Interface	B-TEL-1270	Deadtime Measurement	The Deadtime of the Camera must be continuously monitored. The availability for trigger or readout of an individual Camera in any given Event must be derivable by the OES.		OES is outdated. To be linked to the dedicated ICD (CTA-ICD-ACA-303000-0001).	Telescope Control System Camera	B

Table 4-5 B-TEL requirements for Camera analysis part 2

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
82	Performances	B-TEL-1275	Minimum Shower Fraction	During Observations, the fraction of Trigger Timestamps delivered by Cameras to the OES that are associated with air showers must always exceed 10%.		What happens if there's a huge cloud overhead and the event rate drops to 5 Hz (easy for an SST), then the injected pedestals etc can creep past 10%. Would prefer to have an additional absolute number here for the rate ("for air shower rates >100 Hz or something"). OES is outdated.	Telescope Control System Camera	**B**
83	Availability	B-TEL-1295	Pixel Availability	During observations, at least 95% of all Camera pixels must be available and usable for data analysis. In addition, continuous regions of non-functioning pixels must not exceed 2% of all camera pixels. Pixels excluded due to NSB levels beyond those required are not included in this budget.				**A**
84	Functional	B-TEL-1300	Muon Trigger	The Camera must be able to trigger on, and flag prior to transmission of R1 data to the OES, fully contained (within the sensitive area of the camera) muon rings, from muons impacting the mirror with an energy > 20 GeV with an overall efficiency greater than 90% (excluding dead-time). The fraction of falsely flagged muons in the data stream to OES may be high as long as this efficiency requirement is met and the overall Local Event limit (B-*ST-1305) is not exceeded.		OES is outdated.	Telescope Control System Camera	**B**
85	Functional	B-TEL-1310	Camera Trigger Classes	The Camera must assign to each Camera Event a class which indicates the desired action of the OES on receipt of the associated trigger timestamp, and which is permanently associated with the Event data itself. The trigger class will indicate if the Event is locally triggered or selected for calibration or engineering purposes, a potential sub-array level shower Event or some other class.		OES is outdated.	Telescope Control System Camera	**B**
86	Functional	B-TEL-1320	Image Amplitude Monitoring	During Observations, the Camera must determine and monitor its image intensity threshold, characterised by I_thresh, with an rms accuracy of at most 7%.		The wording " an rms accuracy of at most 7%." is unclear (or just, wrong), either " an rms accuracy of at least 7%." or "an rms uncertainty of at most 7%." "During Observations" implies continuously, or discretly? So is this in the Observing state? Or just before and after (counting as dead time perhaps)?	Camera	**C**
87	Design Constarains	B-TEL-1350	Flat-Fielding	Cameras must include a flat-fielding device or devices which provide pulsed illumination of all camera pixels with an intensity between 100 and 400 photons per pulse and a time duration in the range 1-10 ns FWHM, at a rate of at least 100 Hz. The mean wavelength of the pulsed light source should lie within 50 nm of the peak of the instrument response convolved with the Reference Cherenkov Spectrum . The pattern of illumination across the full camera field of view must be known at the level of 2%. Locally initiated flat-fielding Events must be flagged as such. Additionally, it must be possible for the OES to initiate flat-fielding Event collection.		OES is outdated	Telescope Control System Camera	**B**
88	Interface	B-TEL-1360	Forced Triggers	It must be possible for Cameras to Trigger at a specified absolute time on request from OES, and flag the generated Event as OES requested.		To what precission, with what hold-off (i.e. how long will the cameras get to "prepare"... 1 ms... 10 s??), do cameras have to continue normal data taking until that time (and how early do we stop), and is this only when the camera is already in Observing, or will such commands come in e..g Ready and then the cameras must go to Observing, wait, trigger, then come back? Much more detail is neeeded. OES is outdated	Telescope Control System Camera	**B**
89	Functional	B-TEL-1370	Pedestal Subtraction	During Observations the Camera must measure the Pedestal in each pixel and the event-to-event rms of this quantity with an uncertainty no greater than 20% of the event-to-event rms or 1.2 photons (if greater). The Pedestal must be subtracted from the data prior to delivery to the OES (R1 level) and the Pedestal value being subtracted made available to the OES at least once every 2 seconds as part of the monitoring stream.		It is unclear if the Pedestal value that is subtracted needs to be made available to OES every time it changes (of course - it should be). Would consider splitting the information that must be sent from the frequency it must be sent at in the requirement.	Telescope Control System Camera	**B**
90	Performances	B-TEL-1380	Systematic Pixel Timing Uncertainty	The rms uncertainty on the mean relative reconstructed arrival time in every Camera pixel for uniform simultaneous pulsed illumination (<5 ns FWHM) must not exceed 1 ns for amplitudes in the range 20 to 2000 photons per pixel.				**A**
91	Performances	B-TEL-1390	Linearity	The average pixel response for input signals between 10 and 1000 pe must be known to better than 8% rms at all times. The pixel-wise transfer (or response) function should be monitored at sufficient intervals to ensure that this requirement is always met.				**A**
92	Performances	B-TEL-1410	Camera Trigger Timing	The rms uncertainty on the Trigger Timestamp of a Camera relative to the time of arrival of light at the focal plane must be less than 5 ns for an instantaneous flash of total amplitude 200 photoelectrons, involving 10 pixels or more, and at any position in the field of view. This is for a specified background level of 0.125 photoelectrons/ns.		Background level in photoelectrons inconsistent with other requirements now updated to photons.	Camera	**B**
93	Interface	B-TEL-1420	Trigger Timestamp Delivery	Trigger Timestamp Information must be issued by the Camera to the OES with a time delay of < 0.5 seconds from the light falling onto the Camera photodetector plane.		OES is outdated		**A**
94	Performances	B-TEL-1430	Post-Calibration Trigger to Image Timing Uncertainty	The difference between the mean reconstructed pixel time in a cleaned gamma-ray image and the Trigger Timestamp associated with this Camera Event must be determined with an rms uncertainty of less than 2 ns after calibration. This is for a specified background level of 0.125 photoelectrons/ns. This value includes all statistical and systematic contributions to the uncertainty.		Background level in photoelectrons inconsistent with other requirements now updated to photons. Notes also out of date. The SST team are not responsible for (and have no control over) image cleaning. The reconstructed event time is clearly critical, but to verify this requirement the SST team should be provided with the intended algorithm / tool. The key difference here between this and what is easy to check in the lab, is the time gradient introduced by the Cherenkov light. Would somehow rephrase to place this on simulations? In general several the timing requirements are outdated and a confused muddle of responsibilities. Now that the Sys Arch has been defined, suggest to make a clear error budget and assign requirements to Systems.	Camera	**C**

Table 4-6 B-TEL requirements for Camera analysis part 3

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
95	Performances	B-TEL-1440	Post-Calibration Trigger Timing	The rms uncertainty on the post-calibration Trigger Timestamp of a Camera relative to the time of arrival of light at the focal plane must be less than 2 ns for an instantaneous flash of total amplitude 200 photoelectrons, involving 10 pixels or more, and at any position in the field of view. This is for a specified background level of 0.125 photoelectrons/ns.		Background level in photoelectrons inconsistent with other requirements now updated to photons. It should really be made clearer how this fits with 1410... does this calibration have to be done already for R1.	Camera	**C**
96	Design Constarains	B-TEL-1520	Maximum Solar Concentration	Telescopes should never concentrate sun light to power densities greater than 5 kW/m 2 when in their parked position. Areas and times at which power densities greater than 2 kW/m 2 occur must be identified and clearly documented by telescope providers.		"should" is not clear	Mechanical Structure Optics Telescope Control System Camera	**B**
97	Operations	B-TEL-1540	Camera Lifetime	Cameras must be designed for an operational Lifetime of 15 years.		The SST Cameras shall be designed for an operational Lifetime of 15 years. No idea how to verify this... Surely MTBF and spares + maintenance requirements cover this. i.e. if we meet the maintenance requirements then we must meet this requirement? Would be useful to see examples of how others plan to verify this - should surely be the same for all cameras.	Camera	**C**
98	Data	B-TEL-1610	R1 Event Data	Camera Event Data delivered to the OES (R1 level) must be time-ordered and use a compact common format, occupying at most 16-bits per sample timeslice for data-cube information.		This requirent can be replaced by one that make direct reference to the R1 Data definition document (CTA-ICD-ACA-303000-0001). Since it's a functional requirement on the data format, not a performance requirement on the data quality. OES is outdated	Camera	**B**
99	Data	B-TEL-1630	R1 Intensity Resolution	It must be possible to extract a signal estimate from the R1 data delivered to OES, using previously determined per-pixel coefficients, to reach the Intensity resolution shown in the figure below and table attached, degraded with respect to B-TEL-1010. Figure : Fractional rms intensity resolution σ I /I per pixel for different Cherenkov light signal amplitudes, expressed in photons (p.e.). All sources of fluctuations, including Poisson fluctuations in photon number, must be included. Curves are shown for the nominal NSB (solid line) and high NSB (dashed line) cases.		This requirement can be replaced by one that make direct reference to the R1 Data definition document (CTA-ICD-ACA-303000-0001). Technically it's very useful to separate data quality from data format for the camera team. The R1 doc doesn't have enough information. OES is outdated	Telescope Control System Camera	**B**
100	Data	B-TEL-1640	R1 Time Uncertainty	It must be possible to extract pixel signal timing information from the R1 data delivered to OES, using previously determined per-pixel coefficients, such that the time resolution requirement (B-TEL-1030) relaxed by a factor of 1.5 is satisfied.		This requirent can be replaced by one that make direct reference to the R1 Data definition document. It could be very helpful for the camera team to understand how well we need to calibrate on the Camera Server vs. what has to be achieved off line.	Telescope Control System Camera	**B**
101	Data	B-TEL-1650	R1 Trigger Time Information	In addition to an absolute time derived from the system wide precision time distribution system, the (R1) Event data sent to the OES must contain an event sequence number and/or NTP-based event time identifier, to be used for monitoring and diagnostic purposes.		OES-->ACADA; This requirements is not clear and part of the Interface between the Telescope Control Software and ACADA.	Telescope Control System Camera	**B**
102	Functional	B-TEL-1660	Survival Illumination Recovery Time	The Camera must be able to recover full performance capabilities within 1 minute of the end* of any transient illumination up to the survival limit.		1 min may be too short to recover. For PMTs the camera would have some active shutdown of HV. Once the source is gone, then it's very quick to ramp the HV back up. For SiPMs with bias resistor, the current is automatically limited.. so no damage occurs. But the SiPM gets warm... even with the best active control, it may be tough to reach full performance again in 1 min. I think the 1 min is really completely arbitrary, but it could be okay - we are deveopling a test to check this now (it depends on the SiPM type and bias circuit - so has changed from CHEC-S). Could also add a statement that beyond this time for any pixels not removed it counts towards dead time and/or availability.	Camera	**C**
103	States & Modes	B-TEL-1710	Camera Transition Time: Safe to Standby	The Camera must transition from the Safe State to the Standby State in less than 90 minutes		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Telescope Control System Camera	**B**
104	States & Modes	B-TEL-1720	Camera Transition Time: Standby to Ready	The Camera must transition from the Standby State to the Ready State in less than 3 minutes		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Telescope Control System Camera	**B**
105	States & Modes	B-TEL-1730	Camera Transition Time: Ready to Observing	The Camera must transition from the Ready State to the Observing State in less than 30 seconds. The opposite transition must be possible on the same timescale.		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Telescope Control System Camera	**B**
106	States & Modes	B-TEL-1740	Camera Transition Time: Return to Safe	The Camera must transition from the Observing, Ready or Standby State to the Safe State in less than 5 minutes.		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Telescope Control System Camera	**B**
107	States & Modes	B-TEL-1750	Camera Transition Time: Off to Safe	The Camera must transition from the Off State to the Safe state in less than 4 minutes.		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Telescope Control System Camera	**B**

4.4 B-TEL requirements undefined

Summary of B-TEL requirements for undefined item in Table 4-7

Table 4-7 B-TEL requirements for undefined item.

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
108	Undefined	B-TEL-2000	Engineering GUI	A common engineering GUI must be used by all Telescopes, with full functionality provided by the GUI. Aspects which may not be relevant to a given Telescope are disabled in that particular instance of the GUI.		This requirents is generic Who is responsible for this GUI?	Telescope Control System	B

4.5 B-TEL requirements for Control System

Summary of B-TEL requirements for Control System in Table 4-8

Table 4-8 B-TEL requirements for Control System

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
40	States & Modes	B-TEL-0070	Enable Trigger	Telescopes must initiate a transition of the Camera to the Observing State (enable trigger) as soon as the Structure's pointing direction is within the defined tolerance of the requested Target position.		"As soon as" should be quantified. We have online pointing precssion and frequency requirements, so can just put a time here.	Telescope Control System Camera	B
46	Interface	B-TEL-0200	Repositioning Requests	The Telescope Structure must respond to repositioning and Tracking requests issued from the OES using both Equatorial and Horizon coordinate systems, or a Target Name in cases where Equatorial and Horizon coordinates are inappropriate. Such Targets will be listed in a common database provided.		This refer to the Telescope control system. Also the need to accept a Target name and then access a database to retrive the coordinates is not effective. The scheduler always know the coordinates of the targets. What is the requirement For solar system objects ? Requirement also needs to be reviewed because it is inconsistent with the ACADA Generic Telescope Control. In fact, in that document (CTA-ICD-SEI-000000-0002 Issue 2, Rev.: h, 30.4.2020 Page 49 of 56), there's a footnote saying "This interface does not use the part using the Target names, instead is uses the proper motion parameter of the sky-target data structure passed from the ACADA to the telescope". I think the usage of a common database should be removed from the requirement. OES is outdated	Mechanical Structure Telescope Control System	B
47	Design	B-TEL-0205	Trajectory Calculation	The Telescope Structure must adhere to common standards [ref] for all astrometric calculations.		The ACADA Generic Telescope Control document specifies a SkyEquatorialTrajectory to be passed to the Telescope Control System in case of e.g. a Proper Motion Target (planet or the like). This supersedes the need of Telescope-local astrometric calculation, at least for what regards the most demanding ones, such as proper motions of planets, comets and the like. In any case there's a preliminary CTA - Programming Standards SYS-STAND/161012 v0.2 05 March 2017 that lists common library recommendations for astrometry (ERFA/SOFA for C++ and AstroPy for Python and JSOFA for Java). Maybe those should become requirements.	Mechanical Structure Telescope Control System	B
48	Functional	B-TEL-0215	Fast Repositioning	If indicated by the use of an urgency flag, the Telescope Structure must slew to the new position using the most direct route and in the fastest possible time within safety constraints.		If one is to comply with the ACADA Generic Telescope Control document, there's an isUrgent flag in the goToSkyTarget() call: "If isUrgent is TRUE, the repositioning is performed in the fastest possible trajectory irrespective the expected duration of the observation (see B-TEL-0260). Note that it may not be possible to perform the whole expected observation dura- tion without applying a re-slewing in order to avoid end-switches, however the tracking time should be at least 10 minutes." This places an additional requirement on the minimum duration of an observation performed after fast repositioning, which does not appear here, nor the link or waiver to requirement B-TEL-0260. Also, this requirement should specify what the "safety constraints" are, such as avoiding the moon or other bright objects, and/or minimizing the structure vibrations / dynamical loads. Furthermore, it should indicate what's the maximum acceptable loss, if any, of optical performance and pointing accuracy following a Fast Repositioning.	Mechanical Structure Telescope Control System	B
52	Functional	B-TEL-0260	Range Optimisation	When repositioning, the Telescope Structure must optimise the telescope motion such that it will not approach the end of the azimuth range (requiring a 360 degree adjustment) within the next block of observations (the planned duration of the observation will be sent from OES). An exception is for urgent repositionings, where this is not required and the shortest route to the target position should be taken.		This req shall be splitted in two. OES is outdated	Mechanical Structure Telescope Control System	B
53	Functional	B-TEL-0280	Condition Monitoring	The condition of key Telescope Structure elements must be continuously monitored, to allow early identification of problems and increased availability due to replacement of parts prior to failure, following the Condition Monitoring Plan.		The Conditioning Monitoring plan shall be available as applicable documet to accept this reuirement. But this plan is CTAO or SST deliverable? or better if there is one at telescope level we should be responsible for it, shouldn't we? Why does this requirement only apply to the Structure? The Camera Unit should also have a Condition Monitoring Plan, and follow it.	Mechanical Structure Telescope Control System	B
58	Interface	B-TEL-0440	Structure Pointing Information	The Telescope Structure must provide its nominal current pointing direction (in Horizon coordinates) on request from the OES, independently of the Telescope and Camera States.		This requirements is not clear. To be discussed with CTAO. Is the req superseded by ACADA ICD? OES is outdated	Mechanical Structure Telescope Control System	B

4.6 B-TEL requirements for Control System

Summary of B-TEL requirements for Control Optics in *Table 4-9*

Table 4-9 B-TEL requirements for Optics

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
43	Performances	B-TEL-0120	Mirror Reflectivity	The initial average specular reflectivity of all Telescope Structure reflective surfaces must be >85% at all wavelengths from 300-550 nm.				**A**
44	Performances	B-TEL-0125	Mirror Degradation	The loss in specular reflectivity of all Telescope Structure reflective surfaces must be <4% per year at all wavelengths from 300-550 nm.				**A**
45	Performances	B-TEL-0135	Optical PSF Monitoring	The value of the optical PSF 80% containment diameter (θ 80) must be known with <10% uncertainty throughout the required field-of-view during all Observations. Telescope Structures must acquire point-spread-function measurements as often as needed to achieve this requirement.		We are not sure if we are able to verify this requirement using the Cherenkov Camera. Mounting the optical camera to do it will imply one night downtime for the telescope tested. The plan was to use the pointing system (stars) in the camera to monitor the PSF. But the idea that it is always known across the entire FoV to <10% is really hard to prove.. and first we must prove that we can do it at all (with certain star fields etc) using the Cherenkov camera. The other option is to prove that it never changes with an extended campaign (repeated mountings of the optical camera) on the prototype, and then a once-per year check or something with the Cherenkov camera to star fields that can work.	Mechanical Structure Optics Camera	**C**
65	Operations	B-TEL-0540	Mirror Lifetime	Mirror facets must be designed for an operational Lifetime of 15 years, during which recoating may be expected on a frequency of less than once every 6 years.		This requirement should refer to telescope main optical surfaces not to a mirror facet (that is a solution) because there is not any requirements saying what Optical configuration shall be adopted for SST and how mirror shall be build (monolitithic of segmented).	Mechanical Structure Optics	**B**

4.7 B-TEL requirements for Mechanical Structure

Summary of B-TEL requirements for Mechanical Structure in Table 4-10

Table 4-10 B-TEL requirements for Mechanical Structure

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
49	Performances	B-TEL-0230	Azimuth Range	The Telescope Structure must have a minimum azimuth range of movement of 510 degrees, with the central 360 degrees used for standard Observations.		if you use a range of ±270° you have bigger advandages. The zero point should be Est (west) at North/South to avoid the 0-360 discontinuity at North.	Mechanical Structure Telescope Control System	**B**
50	Performances	B-TEL-0240	Elevation Range	The Telescope Structure must be capable of repointing in the elevation range 0-91 degrees, with the range 20-89.2 degrees usable for standard Observations.		Assesment to be verified during bridging phase	Mechanical Structure Telescope Control System	**C**
55	Physical Constrains	B-TEL-0400	Parked Position	Telescope Structures must have a reference 'Parked' position, corresponding to the Safe and Standby states, in which the Structure is mechanically secured and this situation is signaled to the SAS. The Parked position may vary during a year, but must always be fixed for any given 24 hour period.		We need a definition of parking position. Just a note. The current design of SST telescope has only one position in azimtuh and elevation where it can be locked	Mechanical Structure Telescope Control System	**B**
56	Performances	B-TEL-0420	Unparked Position	Telescope Structures must have a default position into which they unpark, during transition from Standby to Ready State, and return to prior to parking, at a minimum elevation at which all azimuthal angles are accessible.		We need a definition of Telescope Home Position. I.e. the Home position is defined as the initial Azimuth and Elevation of the telescope axes at the beginning of the night. When the telescope is at the home position it is ready to slew to any sky position. So the home position can be the park position with stow pin unlocked. In this case the state machine should be modified.	Mechanical Structure Telescope Control System	**B**
64	Operations	B-TEL-0530	Drive Lifetime	Telescope drive systems, including servos and gears, must be designed for an operational Lifetime of 15 years.		Please replace gears with geraboxes	Mechanical Structure Optics Camera	**B**
67	States & Modes	B-TEL-0710	Structure Transition Time: Safe to Standby	The Telescope Structure must transition from the Safe State to the Standby State in less than 30 minutes		In general, we have requirements for the state transitions of the Strcuture and Camera but not for the telescope. There should be a requirement saying: The Telescope shall implement the finite state machine described in [ref] . There is only : B-ONSITE-0620. The req is already defined in the dedicated ICD CTA-ICD-SEI-000000-0002 (command ACADA-TEL-I-310).	Mechanical Structure Telescope Control System	**B**
68	States & Modes	B-TEL-0720	Structure Transition Time: Standby to Ready	The Telescope Structure must transition from the Standby State to the Ready State in less than 3 minutes		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Mechanical Structure Telescope Control System	**B**
69	States & Modes	B-TEL-0730	Structure Transition Time: Ready to Observing	The Telescope Structure must transition from the Ready State to the Observing State in less than 2 minutes. The opposite transition must be possible on the same timescale.		Not defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Mechanical Structure Telescope Control System	**C**
70	States & Modes	B-TEL-0740	Structure Transition Time: Return to Safe	The Telescope Structure must transition from the Observing, Ready or Standby State to the Safe State in less than 5 minutes.		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Mechanical Structure Telescope Control System	**B**
71	States & Modes	B-TEL-0750	Structure Transition Time: Off to Safe	The Telescope Structure must transition from the Off State to the Safe state in less than 4 minutes.		Defined in the dedicated ICD CTA-ICD-SEI-000000-0002.	Mechanical Structure Telescope Control System	**B**

4.8 B-TEL requirements for Mechanical Structure

Summary of B-ONSITE requirements for Telescope in Table 4-11.

Table 4-11 B-ONSITE requirements for Telescope

	Category	Req. ID	Req. Name	Description	Tag	SST Comments	Design Driver for	Classification
144	Interface	B-ONSITE-0100	Power Control	It must be possible for the System power to be controlled both remotely via the SAS and by a person present at the System location.		This is not clear. To be discussed with CTAO	Mechanical Structure Optics Telescope Control System Camera	B
146	Safety	B-ONSITE-0140	Sudden Loss of Power	In exceptional cases a sudden loss of power to Systems may occur and must not cause damage beyond the serviceability limit state.		It is not clear what serviceability limit state means.	Mechanical Structure Optics Telescope Control System Camera	B
148	Safety	B-ONSITE-0160	Movement Notification	An audible and visible alarm signal must be generated before any potentially dangerous mechanical motion of the system commences.		is there any safety standard reference?		A
149	Safety	B-ONSITE-0170	Safety Signalling	The System must have all the safety subsystems, signs, and acoustic signaling, needed to prevent human injuries.		is there any safety standard reference?		A
150	Safety	B-ONSITE-0180	Movement Control	Safety mechanisms must exist to ensure that the system can never move in an uncontrolled manner.		is there any safety standard reference?		A
151	Safety	B-ONSITE-0190	Emergency Stop	If there is a risk of human injury or death associated with mechanical motions of the System, then a general emergency stop function must be provided which in case of an emergency situation will stop all significant motions of all structural elements with the fastest controllable deceleration, such that no additional risks would be introduced.		is there any safety standard reference?		A
152	Safety	B-ONSITE-0200	Safety and Alarm System Connection	The status of system safety interlocks must be provided to the Safety and Alarm System.		is there any safety standard reference?		A
155	Safety	B-ONSITE-0310	Lightning Protection	Systems must be protected with a Class 1 lightning protection system in accordance with the international lightning protection standard IEC 62305-1-4:2010.12.		is there any safety standard reference?		A
156	Design Constarains	B-ONSITE-0320	Fire Protection	Systems must be designed for compliance with fire regulations as stipulated in the European standard EN 1991.				A
157	Design Constarains	B-ONSITE-0330	Flood Protection	Systems must be designed to prevent all effects of water collection caused by surface water runoff.		Is there any reference standard?	Telescope Control System	B
158	Design Constarains	B-ONSITE-0410	Light Pollution	Systems must not produce light with an isotropic equivalent flux greater than 3x10^6 photons ns^-1 at source in the wavelength range 300-550 nm during observations in the absence of specific calibration instructions from OES.		Is there any reference standard?	Telescope Control System	B
159	Design Constarains	B-ONSITE-0420	Radio Frequency Interference	Systems must be compliant with standard X on radio frequency interference.		X must be defined and if it can not be defined urgently then the requirement should be rephrased or removed.	Telescope Control System	B
160	Maintenence	B-ONSITE-0510	Maintenance Plans	Maintenance planning and procedures for covering access to, and repair / replacement of, any LRU must be provided.				A
161	Operational	B-ONSITE-0520	Spare Parts	The level of spare parts needed for long-term System maintenance must be documented.				A
162	Operational	B-ONSITE-0530	Documentation	Systems must be fully documented in terms of operational use and composition/design.				A
163	States & Modes	B-ONSITE-0620	State Machine	All Systems must implement a state machine compliant with the diagram shown.		Refer to the dedicated ACADA ICD	Telescope Control System	B
164	States & Modes	B-ONSITE-0630	State Transitions	Transitions between the Safe, Standby, Ready and Observing states must not require any intervention in the field.		Refer to the dedicated ACADA ICD	Telescope Control System	B
165	States & Modes	B-ONSITE-0710	Remote Control	It must be possible to remotely control and monitor the System from the Data Centre using the OES.		Refer to the dedicated ACADA ICD	Telescope Control System	B
166	States & Modes	B-ONSITE-0720	Local Control Mode	Systems must implement a local control mode for maintenance and diagnostic purposes, during which remote operation of safety-relevant sub-systems is blocked. OES must be informed when the System enters Local Mode.		Refer to the dedicated ACADA ICD	Mechanical Structure Telescope Control System Camera	B
176	Interface	B-ONSITE-0810	Absolute Time	The system must make use of the absolute time provided by the Central Computer Time Synchronisation System for all calculations for which a time is needed and as the reference in all log and alarm messages.		ICD is needed	Telescope Control System Camera	B

4.9 B-ONSITE requirements for Telescope Control System

Summary of B-ONSITE requirements for Telescope Control System in Table 4-11.

Table 4-12 B-ONSITE requirements for Telescope Control System

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
145	States & Modes	B-ONSITE-0110	Power On	When the system is in Remote Mode it must automatically transition from the Off state to the Safe state when power is provided.		Refer to the dedicated ICD	Telescope Control System Camera	B
147	States & Modes	B-ONSITE-0150	Safe State Transition	When in remote mode, Systems may not initiate a transition out of the Safe state into the Standby State unless instructed by the OES.		Refer to the dedicated ICD OES is outdated	Telescope Control System	B
153	States & Modes	B-ONSITE-0210	Automatic Transition	The System must initiate a transition to the Safe State if communication with OES is lost for > 1 minute.		Refer to the dedicated ACADA ICD in which it is mentioned a dedicated state (fault). OES is outdated	Telescope Control System	B
154	States & Modes	B-ONSITE-0220	Loss of Clock Connection	When in the Ready or the Observing state, the System must initiate a transition to the Standby State if the connection to the Central Computer Time Synchronisation System is lost for more than >20 minutes.		Refer to the dedicated ACADA ICD in which it is mentioned a dedicated state (fault).	Telescope Control System	B
167	Interface	B-ONSITE-0730	Local Errors	If the System encounters an error that impacts on proper function/perfomance, this must be reported to the OES. If recovery from the error is possible, the OES must be notified again when recovery is complete.		Refer to the dedicated ACADA ICD	Mechanical Structure Telescope Control System Camera	B
168	States & Modes	B-ONSITE-0740	Local Error Recovery	All foreseeable error recovery mechanisms must be attempted automatically. In case recovery fails the System must move automatically to a State that prevents damage to instrumentation.		Refer to the dedicated ACADA ICD in which it is mentioned a dedicated state (fault). There may be error cases that lead to contradiction with B-ONSITE-0150, which states that once in Safe a System may not move back to Standby without instruction from OES. In case on a local error, such as the Camera Manager SW crashing, then the Camera will move to Safe after 1 min (under B-ONSITE-0210 it will have lost communication to OES). Once the Camera Manager SW automatically recovers (as it should according to this requirement), then the Camera will remain in Safe (as only OES can move the Camera back to Standby)... which could be interpreted as not recovering from the error automatically.	Telescope Control System	B
169	Functional	B-ONSITE-0750	Alarm Generation	If an error leads to the situation where recovery is not possible and a safe state cannot be reached without human intervention then an Alarm must be raised and the System must enter the Fault State.		Refer to the dedicated ACADA ICD	Telescope Control System	B
170	Interface	B-ONSITE-0760	State Change Notification	The system must notify the OES whenever it changes State.		Refer to the dedicated ACADA ICD	Telescope Control System	B
171	Interface	B-ONSITE-0770	Problem Notification	The system must inform the OES whenever component problems or failure lead to a situation where full performance cannot be met, and provide on request the status of all compromised or problematic LRUs, to support observation and maintenance planning. Such notifications must be categorised in terms of severity.		Refer to the dedicated ACADA ICD	Telescope Control System	B
172	States & Modes	B-ONSITE-0780	Configuration Settings	It must be possible for the system to load configuration settings delivered via the OES in preparation for a State Transition.		Refer to the dedicated ACADA ICD	Telescope Control System	B
173	Interface	B-ONSITE-0790	Command Response	The system must respond to commands from the OES, acknowledging receipt of command within 50 ms and with verification of completion of the action (or occurrence of an error) reported within 50 ms of the time of completion or failure.		Refer to the dedicated ACADA ICD	Telescope Control System	B
174	Functional	B-ONSITE-0795	Command Verification	Commands received by the System must be verified for validity; any commands that exceed safety limits of the System must be rejected and a warning raised.		Refer to the dedicated ACADA ICD	Telescope Control System	B
175	Interface	B-ONSITE-0800	Transition Interruption	It must be possible for OES commands to interrupt transitions between states. When interrupted, the System must return to the original state within the corresponding transition time.		The wording "within the corresponding transition time" could be clearer. For example, going from Standby to Safe, that then get's cancelled, and the System has to get back to Standby... the amount of time allowed to do this is the Safe-Standby time, or the Standby-Safe time? It's fairly obvious that is should be the Safe-Standby time, but the way it's worded does not rule out the opposite interpretation. OES is outdated Refer to the dedicated ACADA ICD.	Telescope Control System	B
177	Interface	B-ONSITE-0820	Monitoring Data	The system must make sufficient monitoring data available to OES for the purposes of diagnosis of component degradation or failure and all necessary information to support science data analysis. The transfer rate of such information must be controllable by the OES.		Refer to the dedicated ACADA ICD	Telescope Control System	B
178	Interface	B-ONSITE-0830	Logging	The actions of the System must be logged via OES. Logging levels must be configurable and follow the defined standards.		Refer to the dedicated ACADA ICD	Telescope Control System	B
179	Data	B-ONSITE-0840	Monitoring Stream Content	In addition to the value, monitoring streams must contain the following information: variable name, time stamp, host component, units.		Refer to the dedicated ACADA ICD	Telescope Control System	B
180	Interface	B-ONSITE-0850	Monitoring Points	The system must expose monitoring points to the OES up to a maximum of 1000 monitoring points per Controllable System.		Refer to the dedicated ACADA ICD	Telescope Control System	B
181	Functional	B-ONSITE-0700	Automatic Alarm Recovery	Systems must automatically implement standard recovery procedures in the case of Alarms occurring internally to the System.		Refer to the dedicated ACADA ICD	Telescope Control System	B

4.10 B-SST requirements for Telescope

Summary of B-SST requirements for Telescope in Table 4-13.

Table 4-13 B-SST requirements for Telescope

	Category	Req. ID	Req. Name	Description	Tag	SST Comments	Design Driver for	Classification
112	Performances	B-SST-0110	Mirror Area	The Geometrical Mirror Area of an SST Telescope Structure, corrected for the effect of shadowing by the camera and its support structure (and if present the secondary mirror), must be >5 m 2 for all angles within the required Camera Field of View .				A
113	Performances	B-SST-0130	Optical PSF Quality	The SST Telescope must focus light on to the focal surface with an optical PSF θ 80 of <0.25 degrees, up to 3.2 degrees from the centre of the cFoV.				A
114	Performances	B-SST-0140	Optical Time Dispersion	The SST Telescope must focus light (over 80% of the required camera field of view diameter) with an rms optical time spread of <1.5 ns.				A
115	Performances	B-SST-0210	Repositioning Time	The SST Telescope must be able to rotate from any point to any other point in the sky above 30° in elevation within 70 seconds at wind speeds below 36 km/h and making use of the full azimuthal and elevation movement ranges, in response to a repositioning request flagged as time critical.				A
116	Availability	B-SST-0310	Telescope Availability	The availability of each SST Telescope Structure during observation time must be > 98.5%				A
117	Operations	B-SST-0320	Telescope Preventive Maintenance	The preventive maintenance of a single SST Telescope Structure on-site must require on average < 0.5 person hours / week		This requirement is critical because we showed (RfI Review) that even if for a small amount of time we are not able to satisfy it	Mechanical Structure Optics Telescope Control System Camera	C
118	Operations	B-SST-0330	Telescope Corrective Maintenance	The corrective maintenance of a single SST Telescope Structure on-site must require on average < 1 person hours / week			Mechanical Structure Optics Telescope Control System Camera	C
119	Performances	B-SST-0610	Average Power Consumption during Observations	The average power consumption by a single SST Structure during Observations must not exceed 4 kW.		Structure or Telescope?	Mechanical Structure Telescope Control System Camera	B
120	Performances	B-SST-0620	Peak Power Consumption during Observations	The peak power consumption by a single SST Structure during Observations must not exceed 11 kW.		We don't really understand the term "peak" here. There is always some timescale invovled. For example for the first 100 microseconds after turn on some electronics can draw a huge amount of power.. but over 1 s, the amount is low. So "peak" should be in the glossary with a timescale, or a timescale should be added to these requirements. If peak means absolute maximum over any timescale down to the ns then we might fail this.	Mechanical Structure Telescope Control System Camera	B
121	Performances	B-SST-0630	Peak Power Consumption in the Safe State	The peak power consumption by a single SST Structure in the Safe State must not exceed 2 kW.		Structure or Telescope?	Mechanical Structure Telescope Control System Camera	B
122	Performances	B-SST-0640	Annual Average Power Consumption in the Safe State	The average power consumption over a full year by a single SST Structure in the Safe State must not exceed 0.5 kW.		Structure or Telescope?	Mechanical Structure Telescope Control System Camera	B
123	Physical Constrains	B-SST-1110	Focal Plane Positioning in x and y	The centre of the focal plane instrumentation of the Camera Unit must be positioned (in the direction perpendicular to the optical axis) by the Telescope Structure to within 0.12 degrees of the optical axis during Observations.		What about alignement of tilt/rotation?	Mechanical Structure Optics Camera	B
143	Functional	B-SST-1680	Observation Illumination	SSTs must be capable of gamma-ray observations with uniform night sky background illumination levels up to at least 4.3 photons ns −1 sr −1 cm −2 in the wavelength range 300-650 nm with the Moonlight Reference Spectrum .				A
144	Interface	B-ONSITE-0100	Power Control	It must be possible for the System power to be controlled both remotely via the SAS and by a person present at the System location.		This is not clear. To be discussed with CTAO	Mechanical Structure Optics Telescope Control System Camera	B
146	Safety	B-ONSITE-0140	Sudden Loss of Power	In exceptional cases a sudden loss of power to Systems may occur and must not cause damage beyond the serviceability limit state.		It is not clear what serviceability limit state means.	Mechanical Structure Optics Telescope Control System Camera	B
148	Safety	B-ONSITE-0160	Movement Notification	An audible and visible alarm signal must be generated before any potentially dangerous mechanical motion of the system commences.		is there any safety standard reference?		A
149	Safety	B-ONSITE-0170	Safety Signalling	The System must have all the safety subsystems, signs, and acoustic signaling, needed to prevent human injuries.		is there any safety standard reference?		A
150	Safety	B-ONSITE-0180	Movement Control	Safety mechanisms must exist to ensure that the system can never move in an uncontrolled manner.		is there any safety standard reference?		A
151	Safety	B-ONSITE-0190	Emergency Stop	If there is a risk of human injury or death associated with mechanical motions of the System, then a general emergency stop function must be provided which in case of an emergency situation will stop all significant motions of all structural elements with the fastest controllable deceleration, such that no additional risks would be introduced.		is there any safety standard reference?		A
152	Safety	B-ONSITE-0200	Safety and Alarm System Connection	The status of system safety interlocks must be provided to the Safety and Alarm System.		is there any safety standard reference?		A
155	Safety	B-ONSITE-0310	Lightning Protection	Systems must be protected with a Class 1 lightning protection system in accordance with the international lightning protection standard IEC 62305-1-4:2010.12.		is there any safety standard reference?		A
156	Design Constarains	B-ONSITE-0320	Fire Protection	Systems must be designed for compliance with fire regulations as stipulated in the European standard EN 1991.				A
157	Design Constarains	B-ONSITE-0330	Flood Protection	Systems must be designed to prevent all effects of water collection caused by surface water runoff.		Is there any reference standard?	Telescope Control System	B
158	Design Constarains	B-ONSITE-0410	Light Pollution	Systems must not produce light with an isotropic equivalent flux greater than 3x10^6 photons ns^-1 at source in the wavelength range 300-550 nm during observations in the absence of specific calibration instructions from OES.		Is there any reference standard?	Telescope Control System	B
159	Design Constarains	B-ONSITE-0420	Radio Frequency Interference	Systems must be compliant with standard X on radio frequency interference.		X must be defined and if it can not be defined urgently then the requirement should be rephrased or removed.	Telescope Control System	B
160	Maintenence	B-ONSITE-0510	Maintenance Plans	Maintenance planning and procedures for covering access to, and repair / replacement of, any LRU must be provided.				A
161	Operational	B-ONSITE-0520	Spare Parts	The level of spare parts needed for long-term System maintenance must be documented.				A
162	Operational	B-ONSITE-0530	Documentation	Systems must be fully documented in terms of operational use and composition/design.				A
163	States & Modes	B-ONSITE-0620	State Machine	All Systems must implement a state machine compliant with the diagram shown.		Refer to the dedicated ACADA ICD	Telescope Control System	B
164	States & Modes	B-ONSITE-0630	State Transitions	Transitions between the Safe, Standby, Ready and Observing states must not require any intervention in the field.		Refer to the dedicated ACADA ICD	Telescope Control System	B
165	States & Modes	B-ONSITE-0710	Remote Control	It must be possible to remotely control and monitor the System from the Data Centre using the OES.		Refer to the dedicated ACADA ICD	Telescope Control System	B
166	States & Modes	B-ONSITE-0720	Local Control Mode	Systems must implement a local control mode for maintenance and diagnostic purposes, during which remote operation of safety-relevant sub-systems is blocked. OES must be informed when the System enters Local Mode.		Refer to the dedicated ACADA ICD	Mechanical Structure Telescope Control System Camera	B
176	Interface	B-ONSITE-0810	Absolute Time	The system must make use of the absolute time provided by the Central Computer Time Synchronisation System for all calculations for which a time is needed and as the reference in all log and alarm messages.		ICD is needed	Telescope Control System Camera	B

4.11 B-SST requirements for Camera

Summary of B-SST requirements for Camera in the Table 4-16.

Table 4-14 B-SST requirements for Camera.

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
124	Performances	B-SST-1130	Field of View Diameter	The Field of View diameter of the SST Camera Unit must be at least 8 degrees.				A
125	Performances	B-SST-1150	Angular Pixel Pitch	The average SST Camera angular pixel pitch must be <0.25 degrees for pixels situated on a hexagonal grid, or 0.25/1.075 deg for pixels on a square grid.				A
126	Design Constarains	B-SST-1180	Focal Plane Instrumentation	The SST Camera Unit focal plane must be fully instrumented with photosensitive pixels (in compliance with the dead-space requirement B-TEL-1160) up to a radius of at least 3.4 degrees.				A
127	Performances	B-SST-1210	Integration Window	Pixel signal integration must be possible within a time window of between 20 and 30 ns with respect to the Camera trigger time for signals in the range 0-400 photons. The start time of this integration window must be adjustable with respect to the trigger time in steps not larger than 2 ns.				A
128	Performances	B-SST-1220	Readout Window	The time window within which a Cherenkov signal can be reconstructed must be at least 80 ns.				A
129	Performances	B-SST-1230	Minimum Image Amplitude	For gamma-ray initiated showers with the Reference Gamma Spectrum , the Cherenkov light intensity that is needed to generate a Camera trigger with a probability of at least 50 % over 90 % of the solid angle within the required camera field of view and with any image orientation, must be smaller than: I thresh × (F NSB / 0.24 ns −1 sr -2 cm -2) 1/2 photons over the full required NSB range or I thresh if F NSB < 0.24 ns −1 sr -2 cm -2 . The value of the threshold image amplitude I thresh must be < 250 photons in the wavelength range 300-550 nm. F NSB is given as the light flux at ground level in the wavelength range from 300-650 nm and can be assumed to follow the Background Light Spectrum .		Same comment of B-TEL-1010	Camera	B
130	Performances	B-SST-1235	Minimum Proton Image Amplitude	For proton initiated showers following the Reference Proton Spectrum , the Cherenkov light intensity that is needed to generate a local camera trigger with a probability of at least 50% over 90% of solid angle of the required camera field of view and with any image orientation, must be < 480 photons.		Same comment of B-TEL-1010	Camera	B
131	Functional	B-SST-1280	Event Rate	The SST Camera must be able to collect and deliver for further processing Events arriving at a sustained event rate of at least 600 Hz with a random distribution in time.		This requirement mix functional and Interface requirements (CTA-ICD-ACA-303000-0001). Would prefer to make if clear that the camera should build events and buffer them waiting for array triggers as a separate requirement to delivering them. This is important because we wont be able to deliver events at 600 Hz calibrated to R1 under normal conditions - as we will break the 2Gbps rule to ACADA. So - separate R0 and R1 rates. This "600 Hz" R1 mode is only useful for debugging / commissioning and would only be useful for single telescope operation (the array SST trigger rate will never be 600 Hz), and in that case exceeding the 2 Gbps is presumabbly fine (as there arent 50 SSTs sending data).	Camera	B
132	Interface	B-SST-1285	Trigger Rate Cap	The SST Camera must deliver Trigger information to the OES at a rate (averaged over 100 ms) of less than 1200 Hz for events arriving at random.		OES is outdated	Camera	B
133	Interface	B-SST-1305	Local Event Rate	The Camera must deliver events without associated array level coincidences (Local Events) to the OES at a rate of less than 120 Hz. Such events must be flagged as Local Events.		OES is outdated	Telescope Control System Camera	B
134	Interface	B-SST-1450	Camera Output Data Rate	The Camera must deliver Event data (including both Local Events and Array-Level Events) to the OES at a rate never (in any second) exceeding 2 Gb/s.		Same comment of req B-SST-1280. At 600 Hz R1 we break 2 Gb/s (hitting 2.55 Gb/s). Under expected MC stero rate (340 Hz) and our expected local trigger (60 Hz) we're at 1.96 Gbps... so the 2 Gb/s should be okay under normal operation, but not at 600 Hz R1 (which we will never have). OES is outdated	Telescope Control System Camera	B
135	Availability	B-SST-1550	Camera Availability	The availability of each SST Camera during observation time must be > 98.5%.				A
136	Operational	B-SST-1560	Camera Preventive Maintenance	The preventive maintenance of a single SST Camera on-site must require on average < 0.5 person hours / week.				A
137	Operational	B-SST-1565	Camera Corrective Maintenance	The corrective maintenance of a single SST Camera on-site must require on average < 1 person hours / week.				A
138	Performances	B-SST-1570	Peak Camera Power Consumption during Observations	The peak power consumption by a single SST Camera during Observations, including its full cooling system (but excluding the Camera Server), must not exceed 4 kW.				A
139	Performances	B-SST-1580	Average Camera Power Consumption during Observations	The average power consumption by a single SST Camera during Observations must not exceed 3 kW.				A
140	Performances	B-SST-1590	Peak Camera Power Consumption in the Safe State	The peak power consumption by a single SST Camera in the Safe State, including its full cooling system (but excluding the Camera Server), must not exceed 1 kW.		In extreme cold conditions, the cooling system can exceed 1kW power consumption.	Camera	C
141	Performances	B-SST-1600	Annual Average Camera Power Consumption in the Safe State	The average power consumption over a full year of a single SST Camera in the Safe State, including its full cooling system (but excluding the Camera Server), must not exceed 0.5 kW.				A
142	Performances	B-SST-1670	Maximum Routine Illumination Recovery Time	Each pixel in an SST Camera must be able to recover full performance capabilities within 1s following (i.e. once the source of light has been removed) maximum routine illumination of 2000 ph ns -1 in the wavelength range 300 - 650 nm.		Same comment as B-TEL-1660 Again - 1 s is probably difficult for the SiPM to thermally recover. 10 s or 30? I also do not like tha this is on "any" pixel. The implication is that to verify we must check 1 pixel (and all of them) and then all combinations up to all 2048 pixels. The thermal situation is quite different for 1 pixel to 10 to 2048. I feel here that there is some information lost when going from the specific cases this requirement was developed for (planets and stars) and the general wording here... this is in the notes, but would prefer to speficify the number of pixels. For example in the worst case field, how many pixels would be likely to see this level, and under what NSB? I'm guessing ~ a dozen across the camera, moving as the camera tracks a source, with ~100 MHz NSB.	Camera	C

4.12 B-SST requirements for Telescope Control System

Summary of B-SST requirements for Telescope Control System in the Table 4-15.

Table 4-15 B-SST requirements for Telescope Control System.

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
147	States & Modes	B-ONSITE-0150	Safe State Transition	When in remote mode, Systems may not initiate a transition out of the Safe state into the Standby State unless instructed by the OES.		Refer to the dedicated ICD OES is outdated	Telescope Control System	B
145	States & Modes	B-ONSITE-0110	Power On	When the system is in Remote Mode it must automatically transition from the Off state to the Safe state when power is provided.		Refer to the dedicated ICD	Telescope Control System Camera	B
153	States & Modes	B-ONSITE-0210	Automatic Transition	The System must initiate a transition to the Safe State if communication with OES is lost for > 1 minute.		Refer to the dedicated ACADA ICD in which it is mentioned a dedicated state (fault). OES is outdated	Telescope Control System	B
154	States & Modes	B-ONSITE-0220	Loss of Clock Connection	When in the Ready or the Observing state, the System must initiate a transition to the Standby State if the connection to the Central Computer Time Synchronisation System is lost for more than >20 minutes.		Refer to the dedicated ACADA ICD in which it is mentioned a dedicated state (fault).	Telescope Control System	B
167	Interface	B-ONSITE-0730	Local Errors	If the System encounters an error that impacts on proper function/perfomance, this must be reported to the OES. If recovery from the error is possible, the OES must be notified again when recovery is complete.		Refer to the dedicated ACADA ICD	Mechanical Structure Telescope Control System Camera	B
168	States & Modes	B-ONSITE-0740	Local Error Recovery	All foreseeable error recovery mechanisms must be attempted automatically. In case recovery fails the System must move automatically to a State that prevents damage to instrumentation.		Refer to the dedicated ACADA ICD in which it is mentioned a dedicated state (fault). There may be error cases that lead to contradiction with B-ONSITE-0150, which states that once in Safe a System may not move back to Standby without instruction from OES. In case on a local error, such as the Camera Manager SW crashing, then the Camera will move to Safe after 1 min (under B-ONSITE-0210 it will have lost communication to OES). Once the Camera Manager SW automatically recovers (as it should according to this requirement), then the Camera will remain in Safe (as only OES can move the Camera back to Standby)... which could be interpreted as not recovering from the error automatically.	Telescope Control System	B
169	Functional	B-ONSITE-0750	Alarm Generation	If an error leads to the situation where recovery is not possible and a safe state cannot be reached without human intervention then an Alarm must be raised and the System must enter the Fault State.		Refer to the dedicated ACADA ICD	Telescope Control System	B
170	Interface	B-ONSITE-0760	State Change Notification	The system must notify the OES whenever it changes State.		Refer to the dedicated ACADA ICD	Telescope Control System	B
171	Interface	B-ONSITE-0770	Problem Notification	The system must inform the OES whenever component problems or failure lead to a situation where full performance cannot be met, and provide on request the status of all compromised or problematic LRUs, to support observation and maintenance planning. Such notifications must be categorised in terms of severity.		Refer to the dedicated ACADA ICD	Telescope Control System	B
172	States & Modes	B-ONSITE-0780	Configuration Settings	It must be possible for the system to load configuration settings delivered via the OES in preparation for a State Transition.		Refer to the dedicated ACADA ICD	Telescope Control System	B
173	Interface	B-ONSITE-0790	Command Response	The system must respond to commands from the OES, acknowledging receipt of command within 50 ms and with verification of completion of the action (or occurrence of an error) reported within 50 ms of the time of completion or failure.		Refer to the dedicated ACADA ICD	Telescope Control System	B
174	Functional	B-ONSITE-0795	Command Verification	Commands received by the System must be verified for validity; any commands that exceed safety limits of the System must be rejected and a warning raised.		Refer to the dedicated ACADA ICD	Telescope Control System	B
175	Interface	B-ONSITE-0800	Transition Interruption	It must be possible for OES commands to interrupt transitions between states. When interrupted, the System must return to the original state within the corresponding transition time.		The wording "within the corresponding transition time" could be clearer. For example, going from Standby to Safe, that then get's cancelled, and the System has to get back to Standby... the amount of time allowed to do this is the Safe-Standby time, or the Standby-Safe time? It's fairly obvious that is should be the Safe-Standby time, but the way it's worded does not rule out the opposite interpretation. OES is outdated Refer to the dedicated ACADA ICD.	Telescope Control System	B
177	Interface	B-ONSITE-0820	Monitoring Data	The system must make sufficient monitoring data available to OES for the purposes of diagnosis of component degradation or failure and all necessary information to support science data analysis. The transfer rate of such information must be controllable by the OES.		Refer to the dedicated ACADA ICD	Telescope Control System	B
178	Interface	B-ONSITE-0830	Logging	The actions of the System must be logged via OES. Logging levels must be configurable and follow the defined standards.		Refer to the dedicated ACADA ICD	Telescope Control System	B
179	Data	B-ONSITE-0840	Monitoring Stream Content	In addition to the value, monitoring streams must contain the following information: variable name, time stamp, host component, units.		Refer to the dedicated ACADA ICD	Telescope Control System	B
180	Interface	B-ONSITE-0850	Monitoring Points	The system must expose monitoring points to the OES up to a maximum of 1000 monitoring points per Controllable System.		Refer to the dedicated ACADA ICD	Telescope Control System	B
181	Functional	B-ONSITE-0700	Automatic Alarm Recovery	Systems must automatically implement standard recovery procedures in the case of Alarms occurring internally to the System.		Refer to the dedicated ACADA ICD	Telescope Control System	B

4.13 B-SST requirements for undefined item

Summary of B-SST requirements for undefined item in the Table 4-16. All the requirements of Table 4-16 are considered for information only (category E).

Table 4-16 B-SST requirements for undefined item.

	Category	Req. ID	Req. Name	Description	Tags	SST Comments	Design Driver for	Classification
109	Undefined	B-SST-0010	Monte Carlo Verification	Monte Carlo simulations must demonstrate that the SST sub-system fulfils the complete set of SST sub-system performance requirements when situated in the layout given in [1] located at CTA-S.		This requirement is not applicable to SST . This is a requiremet for the verification of the SST Array performances not for the verification of the SST Telescope performance. This is part of the validation process, by the means of Monte Carlo simulation which should be CTAO furnished item. There are some Level B performance requirements on e.g. instensity resolution. The MC simulations show that meeting such requirements is sufficient to meet the higher level requirements on sensitivity etc. In the case that we keep this, it can be reworded (for example as proposed in the next column)		**E**
110	Undefined	B-SST-0020	Post-Calibration Astrometric Accuracy	The Post-Calibration Astrometric Accuracy of an SST Telescope whilst Tracking during Precision Pointing Conditions , must be <7 arcseconds.		It is not applicable to SST. There is not any requirement stating that the SST Telescope that must provide to DPPS the Astrometric calibration algorithms.		**E**
111	Undefined	B-SST-0030	Standard Post-Calibration Astrometric Accuracy	The Post-Calibration Astrometric Accuracy of an SST Telescope whilst Tracking must be < 20 arcseconds under standard observing conditions .		It is not applicable to SST. There is not any requirement stating that the SST Telesscope d that must provide to DPPS the Astrometric calibration algorithms.		**E**

5 SST Telescope Trade-Offs

Figure 5-1 reports the SST Telescope architecture option trade-off identified by SST-PRO with the aim to improve the SST baseline. These System Level design options have been identified taking into account:

- DVER outcomes ([AD2] and [AD3];
- Early consideration from the CTAO (ref. Monthly System Engineering Meeting);
- Relevant consideration from the team about Instrument improvement;

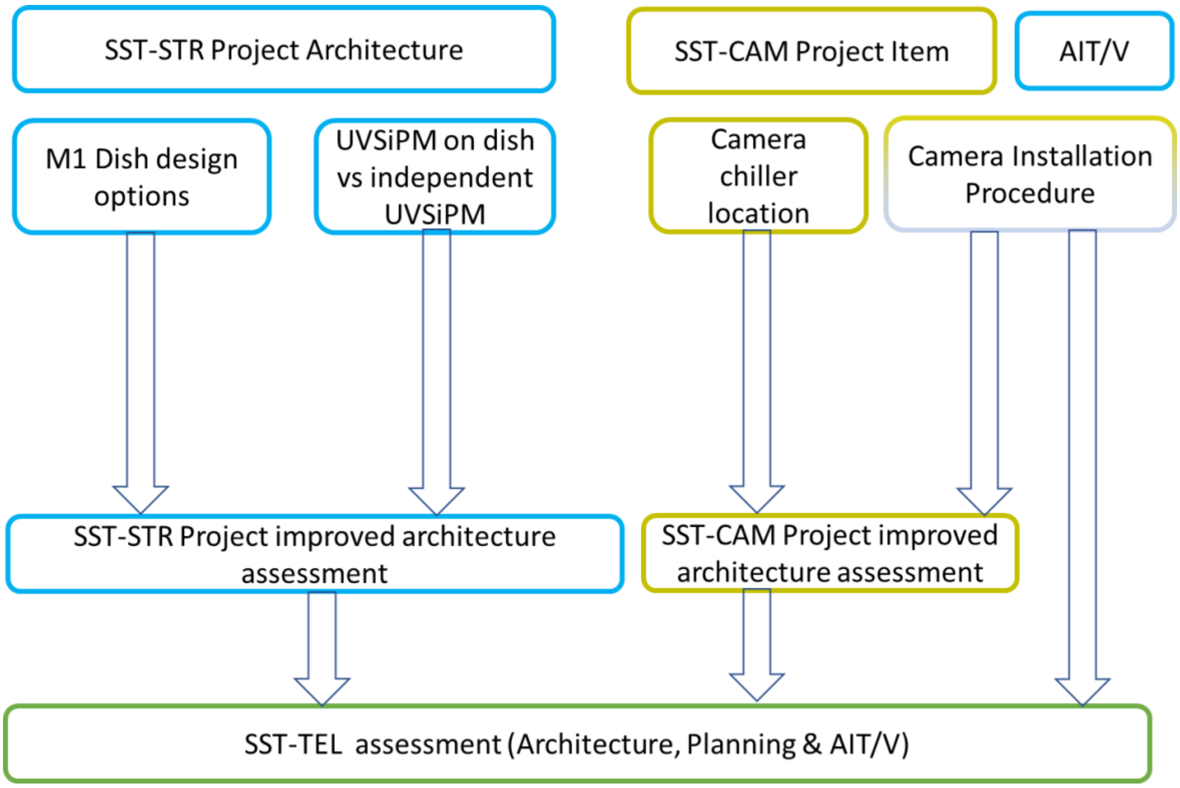


Figure 5-1: SST Trade-off tree

Trade-off analysis identifies the more promising option at the level of subsystem. A further assessment is necessary for the final validation at the telescope level. This final assessment is tracked case by case.

For the SST Telescope level trade-off in Figure 5-1 a comparative multi-parameters criteria methodology is adopted.

The comparative multi-parameters consider six parameters, i.e:

- Cost,
- Performances,

- Resources,
- AIT/V schedule,
- Maintainability
- Solution maturity (TRL).

The parameters can be corrected by a weight factor. Table 5-1 shows the criterion adopted for the comparative trade-off analysis. The rankings of the various options were collegially defined in dedicated working session of the SST System Engineers.

Table 5-1: Criterion of SST comparative trade-off analysis

	Description	Range	Rules
Cost	This is a ranking. Cost is defined considering the subdivision of range for the n options.	Ranking between the realated cost of n options (n for better cost)	Minimum detectable cost difference is 5% of higher cost option
Performance	Requirements or peculiar feature of the object. It is a combination of maximum three parameters. For each identified parameter the value is 1 for threshold - 2 for breakthrough - 3 for objective.		1= within the requirement, 2=improvement of 10%, 3= more than 10%
Resources	Resurces are what the object impose or request for it implementation at the level of telescope. It is a combination of maximum three parameters. For each identified parameter the value is 1 for threshold - 2 for breakthrough - 3 for objective.		1= within the requirement, 2=improvement of 10%, 3= more than 10%
AIT Schedule	This is a ranking. AIT Schedule is defined considering the subdivision of range for the n options.	Ranking between the related AIT schedule duration of n options (n for the shortest schedule)	AIT schedule can include also the activities at telescope level, if evaluable. Minimum detectable difference is 10% of higher FTE option
Maintainability	This is a ranking. The value is defined considering the subdivision of the range for the n options	Ranking between related reliability of n options (n for better RAMS)	If possible the comparison is on the basis of numerical terms for Reliability and accessibility. For all the others the comparison is on the basis of engineering qualitative evaluation
TRL	1 to 9 according to ISO 16290:2013 classification 1 – basic principles observed 2 – technology concept formulated 3 – experimental proof of concept 4 – technology validated in lab 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies) 7 – system prototype demonstration in operational environment 8 – system complete and qualified 9 – actual system proven in operational environment (competitive production, commercialization) in		

For cost, AIT and maintainability the ranking is a graded list based on the options comparison. For equivalent rank the same value for more options is allowed. For TRL, the ranking is a graded list from 1 to 9 according to ISO classification [AD6].

Performance and resources are defined by a combination of others sub-parameters. **Error! Reference source not found.**Figure 5-2 shows an example of trade-off outcomes.

The option 0 in each trades-off identifies the current SST baseline (ref. BKO). The hexagon with larger covered area identifies the optimal solution. In the cases of Figure 5-2 the option 3 appears the optimal one (larger blue area).

Criteria	Quotation
Cost	ranking between n options (n for better cost)
Performances	1 for threshold - 2 for breakthrough - 3 for objective
Resources (direct/indirect)	1 for threshold - 2 for breakthrough - 3 for objective
Reliability	ranking between n options (n for the highest reliability)
TRL	1 to 9 according to ISO classification
Options #	3

	scale	weight	option 0	option 1	option 3
Cost	3	-	2	2	3
Performances	9	-	5	7	7
PSF	3	2	1	2	3
Pointing accuracy		1	3	3	1
Resources	9		5	7	6
Mass	3	2	1	3	2
Power		1	2	1	2
Maintenability		1	3	2	2
AIT Schedule	3	-	2	1	3
Maintainability	3	-	2	1	2
TRL	9	-	9	7	6

normalised value		option 0	option 1	option 3
	Cost	6	6	9
	Performances	5	7	7
	Resources	5	7	6
	AIT Schedule	6	3	9
	Maintainability	6	3	6
	TRL	9	7	6

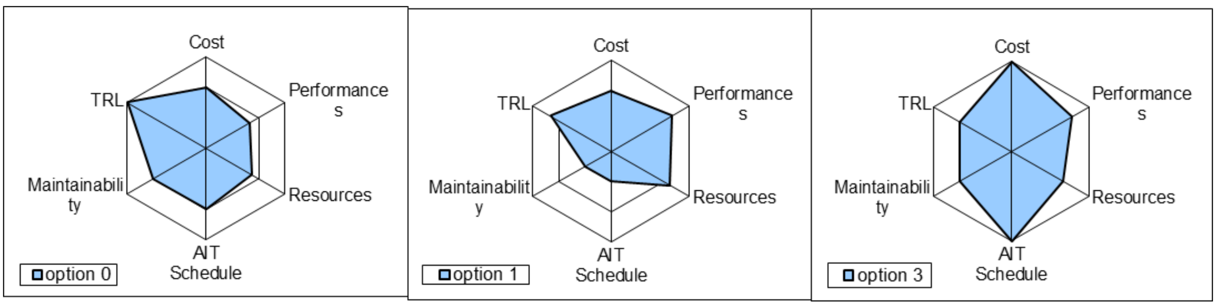


Figure 5-2: Example of comparative Trade-off analysis

5.1 M1 dish design trade-off

Current M1 dish baseline has a heritage from ASTRI-horn prototype and it is also adopted by INAF in the ASTRI-MA. An alternative was proposed by OP in the framework of DVER. In consideration of the potential advantages the DVER panel review board [AD2] provided the recommendation No REC-SST-ER #07 (see [AD3]) reported in the following.

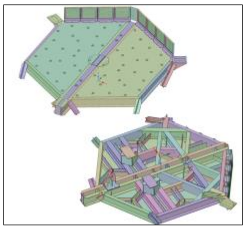
"The panel recommends to further study the feasibility of modifying the M1 mirror dish structure using a beam structure, pending that the current overall structure design is kept unchanged (as an example: similar displacement & loads at interfaces with the overall structure)."

M1 mirror dish option has been investigated by OP as a "stand-alone" element of SST-MEC. The M1 analysis campaign is summarised in [RD2]. The outcomes of this analysis allow the comparison with the current baseline.

Table 5-2 reports a description of the two M1 mirror dish options.

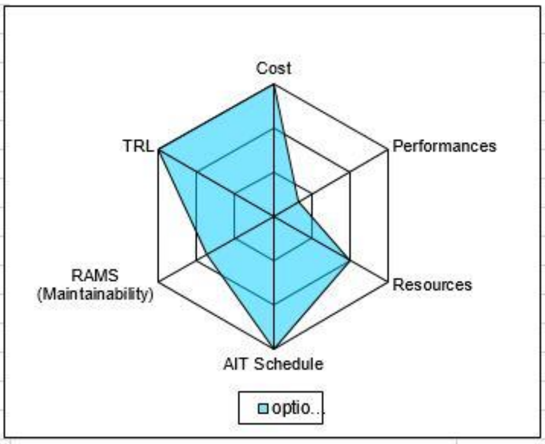
Figure 5-3 is the outcomes of the M1 Dish comparative analysis.

Table 5-2: M1 Dish design options description

Options	Concepts	Main consideration on System
0 M1 Dish structure separated in two parts for logistics	**M1 Dish Structure with single functional structure (Current baseline, heritage of ASTRI-MA)** 	**Advantages:** - Well proven solution adopted in ASTRI Horn and ASTRI-MA **Drawbacks**: - Accessibility to M1 alignment actuators
1 M1 Dish structure like option 0 with optimization of back structure .	**M1 Dish with single structural function** **Like Option 0 introducing:** **- Slight modification of M1 structure** **- Optimization/improvement of the supporting beam structure** 	**Advantages:** - Mass saving by the means of a slight revision of current baseline design - improvement of dynamics behaviour **Drawbacks**: - Uncertainty about maintaining the current level of stability gurantee by Option 0 (the baseline)

Criteria	Quotation			
Cost	ranking between n options (n for better cost)			
Performances	1 for threshold - 2 for breakthrough - 3 for objective			
Resources (direct/indirect)	1 for threshold - 2 for breakthrough - 3 for objective			
RAMS	ranking between n options (n for the highest reliability)			
TRL	1 to 9 according to ISO classification			
Options #	2			
	scale	weight	option 0	option 1
Cost	2	-	2	2
Performances	9	-	2	5
Dynamic behaviour	3	3	1	3
Static behaviour (optics displacements)		4	2	2
Static behaviour (maximal stresses)		3	2	3
Compliance with existing structure I/F		1	3	3
Mechanical IF with EBB		3	1	3
N/A				
Resources	9		6	6
Mass	3	2	2	2
Manufacturability		1	2	2
Transportability		1	2	2
N/A				
AIT Schedule	2	-	2	2
RAMS (Maintainability)	2	-	1	1
Reliability	2	1	2	2
Availability		1	1	2
Maintainability		1	2	2
Safety		1	2	2
TRL	9	-	9	7

normalised value		option 0	option 1
	Cost	9	9
	Performances	2	5
	Resources	6	6
	AIT Schedule	9	9
	RAMS (Maintainability)	5.25	6
	TRL	9	7



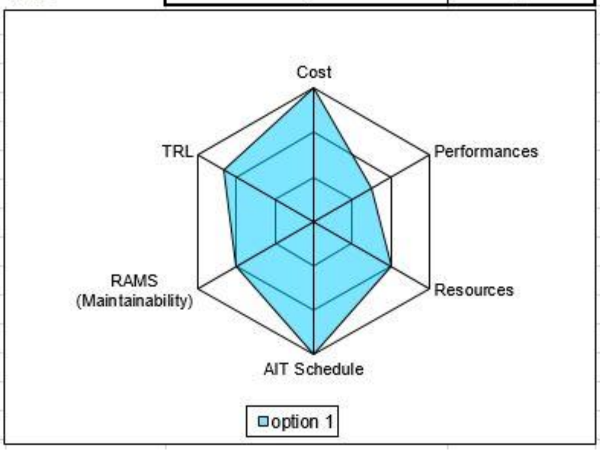


Figure 5-3: M1 Dish design options comparative analysis summary

Conclusions

The option 1 appeared the more appealing for performances and resources and it was recommended for their implementation. Final decision for adoption needed an assessment at telescope level at the g-level induced by earthquake. The assessment reported in [RD3] demonstrated the validity of the new design that it has been assumed as new baseline for the M1 dish.

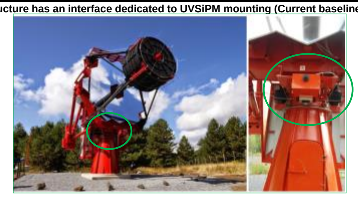
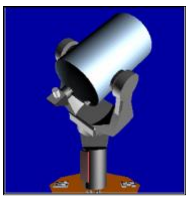
5.2 UVSiPM pointing and location

UVSiPM is a device foreseen for calibration purpose of the telescope by the CTAO's calibration group. It is not part of SST-TEL. Anyhow the SST-TEL baseline presented at DVER assumed the accommodation of this device on each of the SST Telescope, on the bottom side of the M1 Dish and co-aligned with the telescope optical axis. The device mounts a collimator that therefore looks in a field-of-view co-aligned with the SST-CAM. Even if the object is used sporadically to carry out calibrations, the structural design of the SSTs must include the presence of this device and appropriate mechanical and electrical interfaces. In the framework of SST bridging phase an option, consisting in the availability of UVSiPM mated with its own pointing mount, was compared with the DVER baseline.

Table 5-3 reports a description of the two UVSiPM pointing options.

Figure 5-4 is the outcomes of the pointing and location options.

Table 5-3: UVSiPM pointing and location options description

Options	Concepts	Main consideration on System
0 UVSiPM Mounted on the M1 Dish	**M1 Dish Structure has an interface dedicated to UVSiPM mounting (Current baseline, heritage of ASTRI-MA)** 	**Advantages:** - Well proven solution adopted in ASTRI Horn which allows to have a device intrinsecately observing the same boresight of SST telescope **Drawbacks**: - Implementation of a dedicated mechanical, electrical and data interface on all the SST Telescope - The SST design, especially for the worst conditions, must take into account the presence of UVSiPM.
0 UVSiPM indipendent from the SST Telescope	**UVSiPM is decoupled from the SST Telescope** N.B. UVSiPM is an item which is not part of SST-TEL. It is foreseen for SST calibration purpose only as a tool from calibration group 	**Advantages:** - SST design not conditioned by the possible accommodation on M1 Dish of UVSiPM **Drawbacks**: - No drawbacks are envisaged in nominal design/use of SST Telescope. The telescope manufacturer will have to add support equipment for: transportation (e.g. dolly), pointing and command management. UVSiPM pointing will be commanded indipendently from SST Telescope

Criteria	Quotation			
Cost	ranking between n options (n for better cost)			
Performances	1 for threshold - 2 for breakthrough - 3 for objective			
Resources (direct/indirect)	1 for threshold - 2 for breakthrough - 3 for objective			
AIT Schedule	ranking between n options (n for shortest schedule)			
RAMS	ranking between n options (n for the highest reliability)			
TRL	1 to 9 according to ISO classification			
Options #	2			
	scale	weight	option 0	option 1
Cost	2	-	1	2
Performances	9	-	6	3
Alignment	2	1	2	1
N/A				
N/A				
N/A				
Resources	9		3	6
Mass on telescope	2	2	1	2
Cabling on telescope		1	1	2
N/A				
N/A				
AIT/V	2	-	1	2
Maintainability	2	-	1	2
TRL	9	-	9	5

normalised value		option 0	option 1
	Cost	4,5	9
	Performances	6	3
	Resources	3	6
	AIT/V	4,5	9
	Maintainability	4,5	9
	TRL	9	5

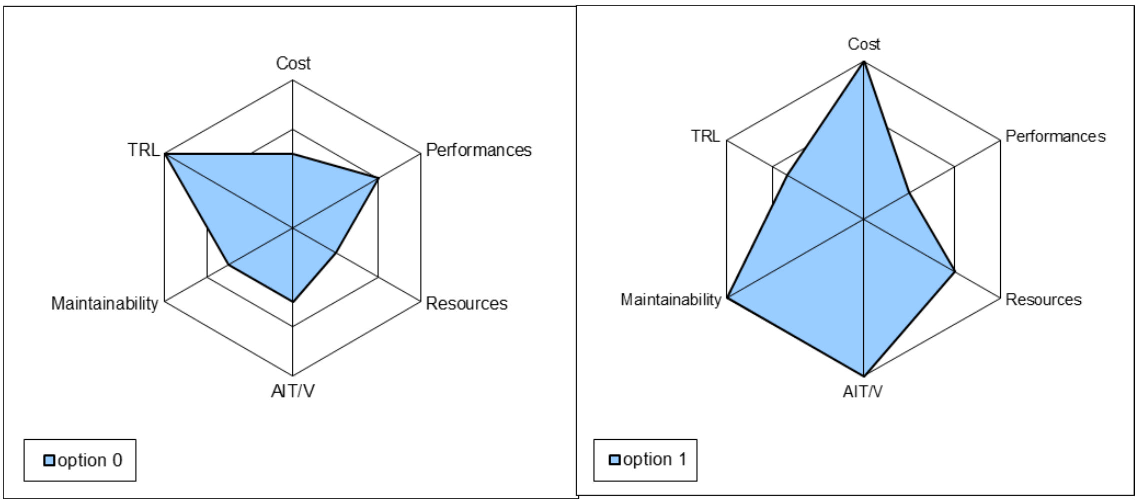


Figure 5-4: UVSiPM pointing and location options comparative analysis summary

Preliminary conclusions

In the prospective of the SST consortium, for which the focus is the optimization of SST design, the option 1 is considered the more pragmatic and simpler to adopt. With option 1 the UVSiPM needs its own pointing device. However, the increased complexity of UVSiPM is not comparable to the benefits of removing a mechanical and electrical interface from the SST baseline, combined with the reduction of structural cases to be analysed. If no drawbacks are envisaged the option 1 is confirmed for the SST consolidation phase.

5.3 SST-CAM Chiller Location

The SST-CAM implements a thermal control solution, based on heat exchanger, fans and a liquid refrigerant circuit. For heat transport external to SST-CAM unit a chiller unit, connected to the SST-CAM by a piping, have to be located as close as possible to the SST-CAM. SST DVER baseline presented the chiller location close to the SST basement. This baseline was evaluated in the bridging phase taking into account the two candidate chillers for which a test campaign is underway for the final selection. In Figure 5-5 the characteristics of the largest chiller candidate is reported. The chiller power is 3 KWatt.

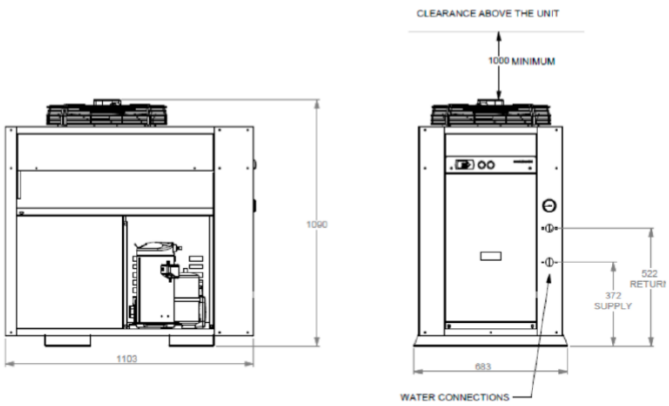


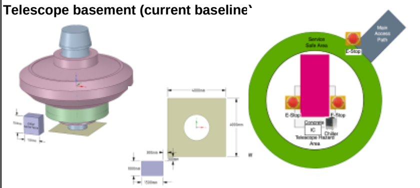
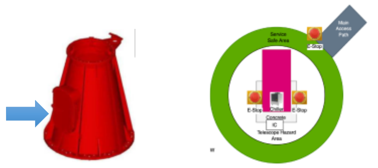
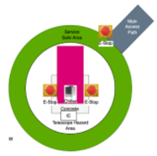
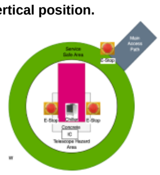
Figure 5-5: SST-CAM largest candidate chiller size

In consideration of CTAO remarks about the needs to guarantee the area around the telescope as free as possible from auxiliary telescope equipment (i.e., chiller and I/F cabinet) further chiller accommodation options were evaluated by the SST team in the framework of bridging phase. These options evaluated the largest candidate chiller size, with margin. No others chiller product is considered because SST-CAM is in a very advance status of production organization. Moreover, chiller selection is common with MST.

Table 5-4 reports a description of the four chiller location options.

Figure 5-6 is the outcomes of the chiller location comparative analysis.

Table 5-4: SST-CAM Chiller location options description

Options	Concepts	Main consideration on System
0 Chiller located close to the SST Telescope Basement	**The chiller is mounted at ground level, close to the SST Telescope basement (current baseline`** 	**Advantages:** - Largest challenge of routing pipes around the azimuth axis is now well proven (tested with CHEC-S on ASTRI-Horn). Validation by on going life testing in Australia outback is on going - Chiller choice (size, mass, power) only very loosely constrained by infrastructure & telescope design - Ease access to chiller for maintenance **Drawbacks**: - At least some protection for the chiller from inclement weather conditions (in addition to IP rating) likely needed - Exposed to accidental damage during the movement of vehicles in the SST telescope area - Maximum height constraint
3 Chiller mounted inside the SST Telescope Base Structure	**The chiller is mounted inside the telescope Base Structure (solution tested via ASTRI-Horn).** 	**Advantages:** - Minimises the required telescope basement size - Largest challenge of routing pipes around the azimuth axis is now well proven (tested with CHEC-S on ASTRI- **Drawbacks**: - Revision of current SST design needed - Couples the SST design to the chiller choice - Severly constrains the chiller size and power consumption - Vibration coupling with telescope (including acoustic) - Constraint in chiller accessibility for maintenance - Requires chiller pipes to be routed around the azimuth axis
4 Chiller mounted on the external side of SST Telescope Base Structure	**The chiller is mounted on the external side of Base Structure by the means of a bracket, rotating in azimuth, but not altitude (solution tested via GATE / GCT).** 	**Advantages:** - Minimises the required telescope basement size - Chiller embedded inside the telescope layout (no additional ground work needed) - Reduction of chiller piping length & routing around only alt. rotating axis **Drawbacks**: - Option feasibility needs a dedicated study & -revision of current SST design needed - Couples the SST design to the chiller choice - Constrains the chiller size and mass - Increase of telescope weight - Vibration coupling with telescope - Constraint in chiller accessibility for maintenance
5 Chiller embedded in the SST Telescope couterweight	**The chiller is incorporated into the counterweight by means of a tilting mechanism to maintain the vertical position.** 	**Advantages:** - Minimises the required telescope basement size - Chiller embedded inside the telescope layout (no additional ground work needed) - Reduction of chiller piping length & no routing around either rotating axis **Drawbacks**: - Option feasibility needs a dedicated study & revision of current SST design needed - Couples the SST design to the chiller choice - Constrains the chiller size and mass - Increase of telescope weight - Additional mechanism impacting RAMS - Vibration coupling with telescope - Constraint in chiller accessibility for maintenance

Criteria	Quotation					
Cost	ranking between n options (n for better cost)					
Performances	1 for threshold - 2 for breakthrough - 3 for objective					
Resources (direct/indirect)	1 for threshold - 2 for breakthrough - 3 for objective					
AIT Schedule	ranking between n options (n for shortest schedule)					
RAMS	ranking between n options (n for the highest reliability)					
TRL	1 to 9 according to ISO classification					
Options #	4					
	scale	weight	option 0	option 1	option 2	option 3
Cost	4	-	4	3	2	1
Performances	9	-	9	5	2	5
Level of Induced Vibration	4	2	3	2	1	2
N/A						
N/A						
N/A						
Resources	9		9	9	3	6
Mass on telescope	4	2	3	3	1	2
Chiller piping lenght and complexity			1	2	3	2
N/A						
N/A						
AIT/V	4	-	3	2	2	1
Maintainability	4	-	3	1	2	1
TRL	9	-	9	9	6	5

normalised value		option 0	option 1	option 2	option 3
	Cost	9	6,75	4,5	2,25
	Performances	9	5	2	5
	Resources	9	9	3	6
	AIT/V	6,75	4,5	4,5	2,25
	Maintainability	6,75	2,25	4,5	2,25
	TRL	9	9	6	5

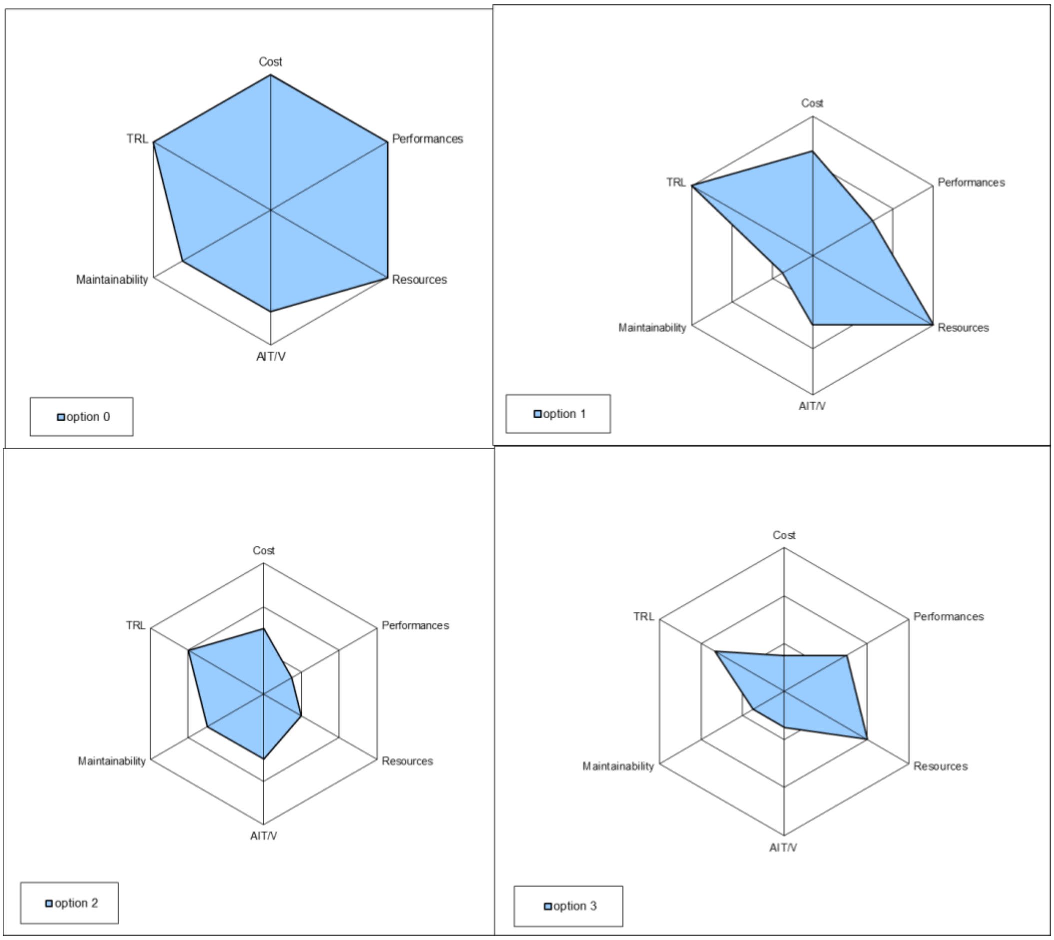


Figure 5-6: SST-CAM Chiller location options comparative analysis summary

Preliminary conclusions

From the comparative analysis the current baseline (improved by further analysis) is confirmed. The chiller can be located close to the basement (30 cm). All the other options imply limitation in chiller size, increase of complexity for maintenance or a significant revision of the SST structure design. With respect to the original baseline presented at DVER, the position of chiller is now defined while the concrete basement for chiller is not considered strictly necessary (life test on Australia outback are with chiller candidates placed on soil). If no drawbacks are envisaged the option 0 is confirmed for the SST consolidation phase.

5.4 SST-CAM Access

The assembly / disassembly protocol of the SST-CAM unit is very critical as frequent interventions for maintenance, the manoeuvring space has constraints and safety must be guaranteed in the best possible way. This topic is of extreme interest to CTAO being the preventive and corrective subject of time constraints (for maintenance cost containment) as stated in the following requirements:

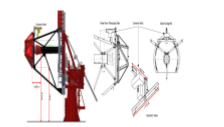
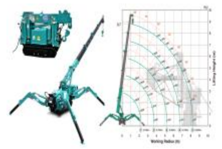
- **B-SST-1560 Camera Preventive Maintenance**: The preventive maintenance of a single SST Camera on-site must require on average < 0.5 person hours / week.
- **B-SST-1565 Camera Corrective Maintenance.** The corrective maintenance of a single SST Camera on-site must require on average < 1 person hours / week.

Consequently, the SST-CAM access was evaluated and four different options (based on the SST team experience and ASTRI MA outcomes) presented to CTAO. The DVER baseline (option 0) was the only verified on ASTRI Horn by the means of Camera Check and adopted in ASTRI-MA.

Table 5-5 reports a description of the four SST-CAM access options.

Figure 5-7 is the outcomes of the SST-CAM access options comparative analysis.

Table 5-5: SST-CAM unit access options description

Options	Concepts		Main consideration on System
0 On-telescope hoist	• A lifting hoist system (see Fig) is attached prior to the telescope structure temporarily prior to the camera installation using a cherry picker. • The camera is unloaded from the truck either via a ramp, a small lift, or otherwise, placed on a small trolley or a lift with wheels if not already in the custom wheeled container. • The camera is moved to the base of the telescope, under and to the side of the focal plane position to avoid the lower support arm of the structure. • The camera is attached to the hoist system via an appropriate harness to distribute the load evenly. • The camera is moved up, then sideways (once the support arm is cleared), then up and into position at the focal plane. • Once the camera is installed, the hoist is removed using a cherry picker.		**Advantages:** - Design of hoist exists - No special crane or crane training needed **Drawbacks**: - Needs prior installation and subsequent removal of hoist - Needs cherry picker maneuvering inside telescope structure - Needs extra truck, lift, trolley with wheels. - Needs camera harness for stabilization - Camera can swing against mirror/structure - Complex camera hoisting maneuver
1 Separate crane	• A small crane, which could be driven to the telescope prior to installation (or even transported on the same truck as the camera) and is positioned appropriately at the telescope. There are many examples of possible cranes, including small modern devices such as the MC285C-3 pictured in Fig 6 that could be used. • The camera is either: o unloaded from the truck via a ramp, wheeled to a position for crane attachment, and then attached, or o attached to the crane directly from the back of the pick-up truck. Either way, lifting again requires an appropriate harness to distribute the load evenly. • Guide lines are attached to the camera and help by hand from the ground to ensure the camera movement is controlled. • The camera is moved up and over the telescope, and lowered into place at the focal plane.		**Advantages:** - Camera movement can be controlled better - Simple camera placement (direct lowering from above) - - - - **Drawbacks:** - Crane deployment can take a lot of time - Needs cherry picker maneuvering inside telescope structure - Needs extra truck and specialized trained people - Needs camera harness for stabilization - Camera can swing against mirror/structure -
2 Integrated pickup+crane	• A pick-up (or larger) truck with an appropriate integrated crane is used (e.g., Figure). • The camera is either: o unloaded from the truck via a ramp, wheeled to a position for crane attachment, and then attached, or o attached to the crane directly from the back of the pick-up truck. Either way, lifting again requires an appropriate harness to distribute the load evenly. • Guide lines are attached to the camera and help by hand from the ground to ensure the camera movement is controlled. • The camera is moved up and over the telescope, and lowered into place at the focal plane.		**Advantages:** - Camera movement can be controlled better - Simple camera placement (direct lowering from above) - Single vehicle for camera transportation and hoisting - - - **Drawbacks:** - Needs specialized trained people - Needs cherry picker maneuvering inside telescope structure - Needs camera harness for stabilization - Camera can swing against mirror/structure - -
3 Scissor lift	• A scissor lift (such as the Weiss SAB AR-78 shown in Fig 7, right) is positioned under the telescope to the side of the central arm. Positioning is “off centre” to avoid the arm. • The camera is unloaded from the truck either via a ramp, a small lift, or otherwise, placed on a small trolley or a lift with wheels if not already in the custom wheeled container. • The camera is moved to the scissor lift and attached to some custom mechanics or small hoist on the scissor lift. • The scissor lift is move upwards, with up to two workers on the lift with the camera. Once the height of the focal plane is reached, the camera is moved into position using on-board mechanics / hoist. • This method has the advantage that only one item of equipment and a single upwards “trip” is needed for both camera positioning and securing (see next Section).		**Advantages:** - Camera doesn't need to be hoisted - Only one vehicle needed for lifting both people and camera - Fastest operation - Similar to operations already done at Serra La Nave on ASTRI Camera - - **Drawbacks**: - Needs specialized trained people - Needs lift maneuvering inside telescope structure - Needs extra truck to transport lift and camera, and special hoist on lift - Complex maneuvre - -

Criteria	Quotation					
Cost	ranking between n options (n for better cost)					
Performances	1 for threshold - 2 for breakthrough - 3 for objective					
Resources (direct/indirect)	1 for threshold - 2 for breakthrough - 3 for objective					
AIT Schedule	ranking between n options (n for shortest schedule)					
RAMS	ranking between n options (n for the highest reliability)					
TRL	1 to 9 according to ISO classification					
Options #	4					
	scale	weight	option 0	option 1	option 2	option 3
Cost	4	-	4	1	3	2
Performances	9	-	3	5	5	7
Safety	4	2	1	2	2	3
N/A						
N/A						
N/A						
Resources	9		2	2	4	1
Reusability of special equipment	4	2	2	2	3	1
Special Equipment		2	3	1	2	2
Complexity		1				
N/A						
AIT/V (including deployment of cherry picker)	4	-	1	2	3	4
Maintainability	4	-	2	2	2	2
TRL	9	-	6	5	5	6
normalised value	Cost		9	2,25	6,75	4,5
	Performances		3	5	5	7
	Resources		2	2	4	1
	AIT/V (including deployment		2,25	4,5	6,75	9
	Maintainability		4,5	4,5	4,5	4,5
	TRL		6	5	5	6

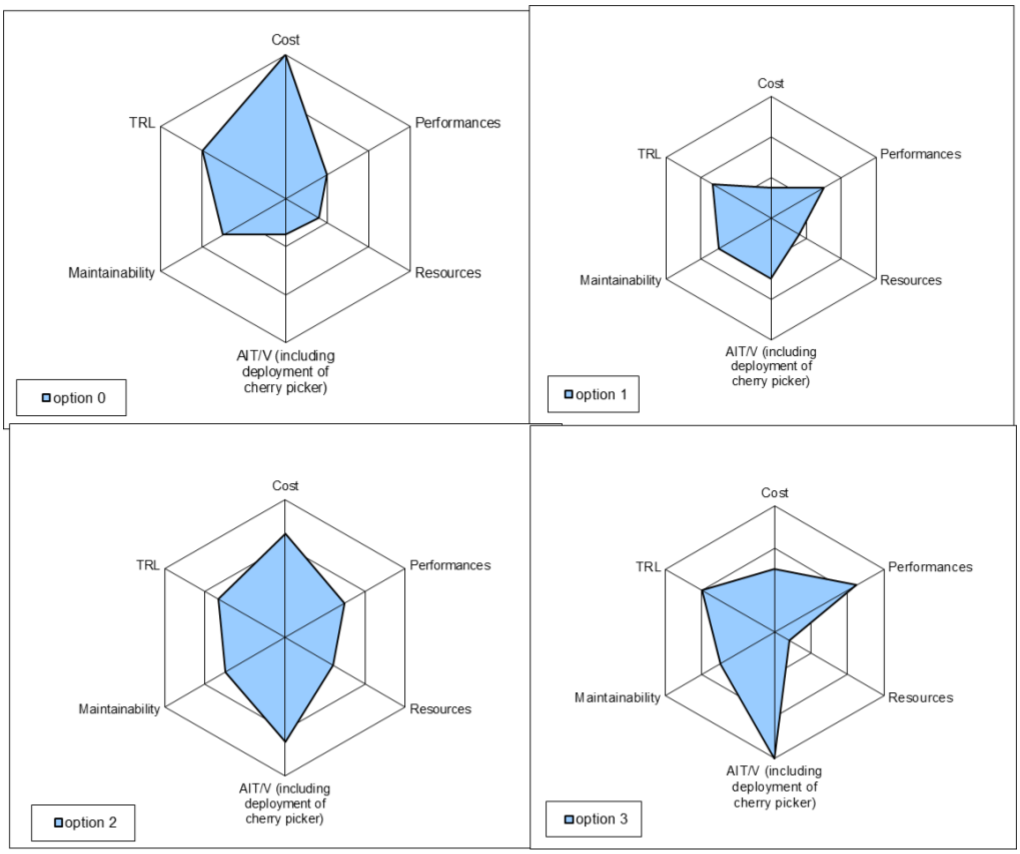


Figure 5-7: SST-CAM unit access options comparative analysis summary

Preliminary conclusions

From the comparative analysis there is no evidence of a net convenience for a specific option. A further investigation is necessary taking into account the outcomes form the on-going integration campaign of ASTRI-MA.

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