ASTRI Mini-Array
Stellar Intensity Interferometry Instrument
Requirements Specifications

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TABLE OF CONTENTS

INDEX OF FIGURES & TABLES

DOCUMENT HISTORY		
Issue	**Date**	**Modification**
1.0	15/12/2020	First release
2.0	02/03/2021	Second release
2.1	14/03/2021	Second release (revised)
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2.6	14/05/2021	Second release (revised)

1 Introduction

The ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) Mini-Array is an INAF project finalized to the construction of nine identical dual-mirrors Cherenkov gamma-ray telescopes that will be installed at the site of the Teide Observatory in Tenerife (Spain) to study astronomical sources emitting in the TeV spectral band. Besides carrying out a scientific program in the Very High Energy Gamma-ray band, the ASTRI Mini-Array will also perform stellar intensity interferometry observations of bright stars.

1.1 Purpose

This is the user requirement document of the ASTRI Stellar Intensity Interferometry Instrument (SI^3) and is part of the documentation describing the system requirements specifications of the ASTRI Mini-Array. It is directed to ASTRI members involved in the construction and development of the SI^3.

1.2 Scope

This document describes the ASTRI SI^3, a fast single photon counting instrument for performing intensity interferometry observations of bright stars with the ASTRI Mini-Array.

1.3 Content

After providing an overview of the ASTRI SI^3 instrument and the related functional workflow, the document gives details of the product breakdown structure of the project and lists all the expected basic requirements of the instrument, including the functional, interface and top-level design requirements reported in the ASTRI Mini-Array Stellar Intensity Interferometry Conceptual Design Document (ASTRI-INAF-DES-7400-001; [RD4]). For the requirements at the telescope and/or array level, we make reference to the ASTRI Mini-Array Stellar Intensity Interferometry Science Requirements document (ASTRI-INAF-SCI-7400-001; [RD3]).

1.4 Definitions and Conventions

1.4.1 Abbreviations and acronyms

The following abbreviations and acronyms are used in this document:

AIT	Assembly Integration and Testing
AIV	Assembly Integration and Verification
ADAS	Array Data Acquisition System
ASIC	Application Specific Integrated Circuits
ASTRI	Astrofisica con Specchi a Tecnologia Replicante Italiana

AR	Camera Acceptance Review
ATRR	Acceptance Test Readiness Review
BEE	Back End Electronics
CDR	Critical Design Review
CFI	Customer Furnished Item
CITIROC	Cherenkov Image Telescope Integrated Read Out Chip
COTS	Commercial Off The Shelf
EMC	Electro Magnetic Compatibility
FEE	Front End Electronics
FEM	Finite Element Analysis
FPGA	Field Programmable Gate Array
FMECA	Failure Mode Effects and Criticality Analysis
HW	Hardware
IAC	Instituto de Astrofísica de Canarias
INAF	Istituto Nazionale di Astrofisica
ITW	Integration Time Window
KOM	Kick Off Meeting
LLI	Long Lead Items
MIUR	Ministero dell'Istruzione, dell'Università e della Ricerca
NSB	Night Sky Background
OPC-UA	Open Platform Communications - Unified Architecture
PA	Product Assurance
PBS	Product Breakdown Structure
PCB	Printed Circuit Board
PDE	Photon Detection Efficiency
PDM	Photon Detection Module
PDR	Preliminary Design Review
PR	Cameras Production Review
QA	Quality Assurance
QR	Qualification Review
QTRR	Qualification Test Readiness Review
RAM	Reliability, Availability and Maintainability

RR	Camera Requirements Review
SCADA	Supervisory Control And Data Acquisition system
SE	System Engineering
SII	Stellar Intensity Interferometry
SI^3	Stellar Intensity Interferometry Instrument
SiPM	Silicon Photo-Multiplier
SLN	Serra La Nave
SMM	Structural Mathematical Model
SOW	Statement of Work
SW	Software
TCS	Telescope Control Software
TE	Test Equipment
TMM	Thermal Mathematical Model
VCD	Verification Control Document
VDB	Voltage Distribution Box
VHE	Very High Energy
WR	White Rabbit

1.4.2 Definitions

1.4.2.1 Definition of type of technical requirements

The definitions for the various categories of requirements listed in this document are the following:

- **Environmental.** These are all the requirements related to a product or the system environment during its life cycle; this includes the natural environments and induced environments (e.g. radiation, electromagnetic, heat, vibration and contamination).
- **Functional and Performance.** These are all the requirements that define what the product shall perform, in order to conform to the needs statement or requirements of the user.
- **Design.** These are all the requirements related to the imposed design and construction standards such as design standards, selection list of components or materials, interchangeability, safety or margins.
- **Physical.** These are all the requirements that establish the boundary conditions to ensure physical compatibility and that are not defined by the interface requirements, design and construction requirements, or referenced drawings.
- **Interface.** These are all the requirements related to the interconnection or relationship characteristics between the product and other items.
- **Product assurance.** These are all the requirements related to the relevant activities covered by the product assurance.
- **Verification.** These are all the requirements related to the Verification methods requested by the project.
- **Packaging, Transportation and Handling.** These are all the requirements related to the relevant activities to the final delivery of the products.

1.4.2.2 Definition of the requirements verification methods

Verification shall be accomplished by one or more of the following verification methods:

1. test (including demonstration);
2. analysis (including similarity);
3. review-of-design;
4. inspection.

a. All safety critical functions shall be verified by test.
b. Verification of software shall include testing in the target hardware environment.

1.4.2.2.1 Test

a. Verification by tests shall consist of a measure of the performance and functionality of the product under simulation conditions comparable to those of the destination environment.
b. The analysis of data derived from testing shall be an integral part of the test and the results shall be included in the test report.
c. When the test objectives include the demonstration of qualitative operational performance, the execution shall be observed, and results recorded.
d. A test programme shall be prepared for each product
e. The test programme shall be coordinated with the integration flow.
f. Tests performed as part of the integration flow to check quality and status of the in-progress configuration (including interfaces), having a formal verification purpose, shall be included in the test programme.
g. The test programme shall be defined in the Assembly, Integration and Test plan.

1.4.2.2.2 *Analysis*

a. Verification by analysis shall consist of performing theoretical or empirical evaluation using techniques agreed with the Customer.

NOTE Techniques comprise systematic, statistical and qualitative design analysis, modelling and computational simulation.

b. Verification by similarity shall be part of the verification by analysis.

c. Similarity analysis shall provide evidence that an already qualified product fulfils the following criteria:
   1. The already qualified product was not qualified by similarity.
   2. The product to be verified is an off-the-shelf item without modifications already subjected to qualification.

d. Similarity analysis shall define differences that can dictate complementary verification activities.

e. An analysis programme shall be defined in the Verification Plan (VP).

1.4.2.2.3 *Review-of-design (ROD)*

a. Verification by Review-of design (ROD) shall consist of using approved records or evidence that unambiguously show that the requirement is met.

NOTE Examples of such approved records are design documents and reports, technical descriptions, and engineering drawings.

b. A review-of-design programme shall be defined in the Verification Plan (VP).

1.4.2.2.4 *Inspection*

a. Verification by inspection shall consist of visual determination of physical characteristics.

NOTE Physical characteristics include constructional features, hardware conformance to document drawing or workmanship requirements, physical conditions, software source code conformance with coding standards.

b. An inspection programme shall be defined in the Verification Plan (VP).

1.4.2.3 Definition of the codes of the requirements

The requirement code is defined as follows: ASTRI-XXXX-YYYY.

- The XXXX digits refer to the identification code of the element the requirement refers to as defined in the product tree (see Figure 3-4).
- The YYYY digits refers to the type of requirements and coding is reported in Table 1.

Type of requirement	Code
Environmental	1000
Functional and Performance	2000
Design	3000
Physical	4000
Interface	5000
Product Assurance	6000
Verification	7000
Package, Transportation and Handling	8000

Table 1: Definition of code for type of requirement.

For the requirements listed in this document the code will be ASTRI-7400-YYYY. In the tables that follow, only the code referring to the type of requirement is then shown.

1.4.2.4 Definitions of States

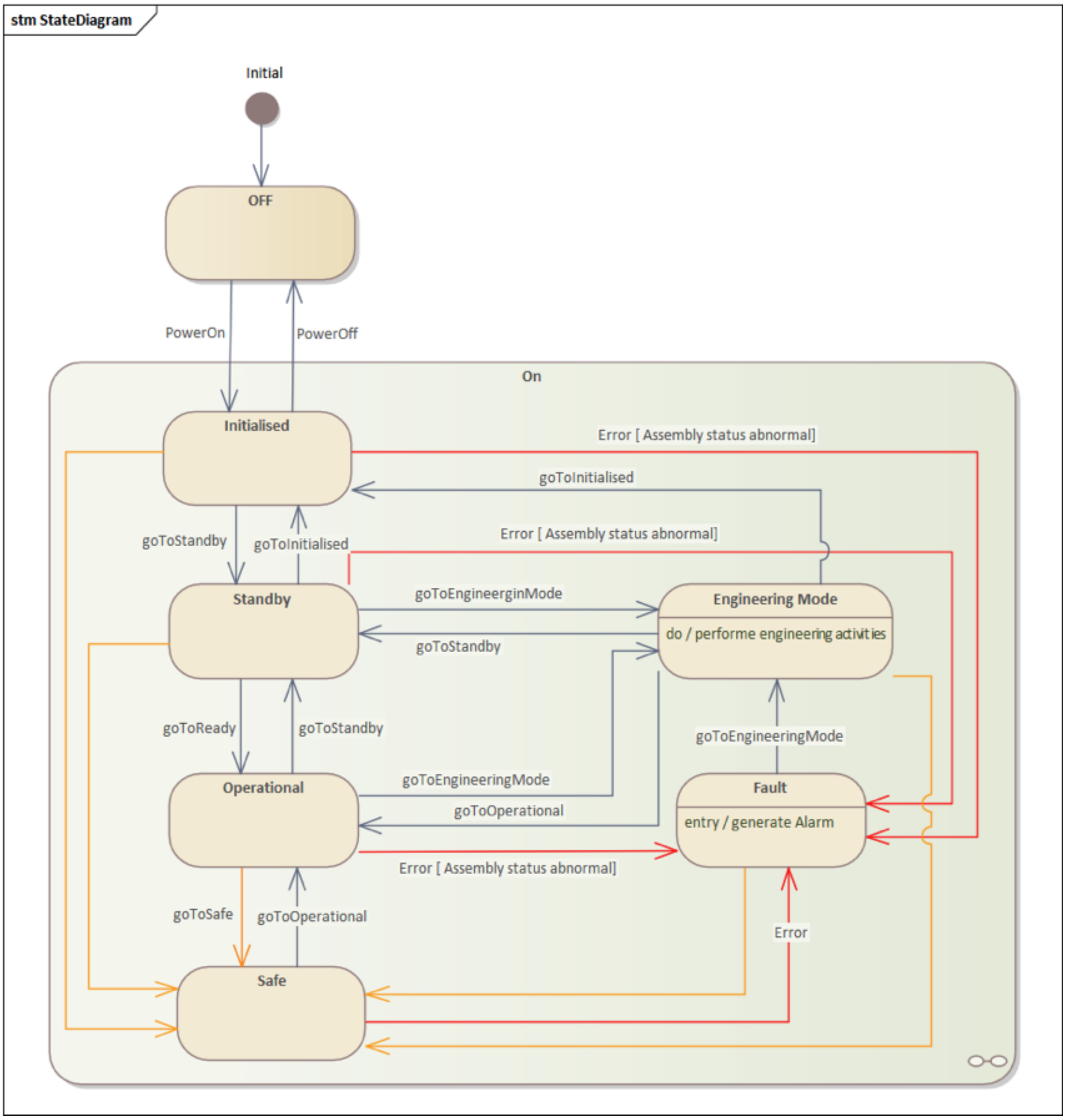

Figure 1-1: ASTRI SI^3 state machine

- **Off State:** The SI^3 is entirely without electrical power.
- **On State:** The SI^3 is powered-on, and available to operate under the sub-states described below:
- **Initialised State**: the state of the SI^3 after power on. All Local Control systems (LCSs) are powered-on. The LCS software is running, initialized and the

communication with the SI^3 Local Supervisor is established. The SI^3 is in parking position, a configuration suitable for survival in extreme environmental conditions.

- **Standby State**: a state in which the SI^3 is still in safe configuration (but the SI^3 stow-pins are disengaged). All SI^3 LCSs are ready to receive commands. SI^3 Drive system is powered-on. The SI^3 is ready to perform a transition to the operational State.
- **Operational State**: the SI^3 state associated with operations (e.g. pointing and tracking a sky object), with configuration dictated by performance requirements. Two Operational sub-states (not represented in the figure) could be present:
  - **nominal:** the SI^3 can be operated with full performances;
  - **degraded:** the SI^3 can be operated with reduced performances.
- **Safe State**: if dangerous conditions are present, the SI^3 goes into a state where the SI^3 is considered exposed to “normal” risk for damage or loss. This is also the configuration designed for survival in extreme conditions, minimising the use of power. The SI^3 is in parking position and only some (TBC) SI^3 LCSs are still providing basic status and monitoring information to the SI^3 Local Supervisor.
- **Fault State**: the SI^3 has encountered a serious problem, which means it is currently unable to meet the requirements associated with one of the standard states. Alarm shall be generated by the SI^3 LCS.
- **Engineering Mode State**: a logical state designed to facilitate SI^3 maintenance and engineering activities. This state is unavailable for routine operations and can be entered only upon request by SI^3 experts.

1.4.2.5 Definitions of Modes

- **Local Mode**: mode of operation of a field-deployed Controllable System activated and deactivated by a person physically present at the Interface Cabinet associated with the system. Whilst in Local Mode all remote actions that could endanger the safety of a local person are prevented. Local Mode supports engineering and maintenance activities.
- **Remote Mode**: Mode of operation of a Controllable System to allow control by a person not present at the Array Element Location, available when not disabled at the Interface Cabinet. Remote mode supports observatory science operation and system/array-level engineering activities.

1.4.2.6 Definitions of Conditions and Limits

- **Observation Conditions**. Environmental conditions under which full operation of the ASTRI mini-array must be possible without incurring into damage.
- **Normal Conditions**. Environmental conditions under which standard operations, engineering and maintenance activities may be undertaken, during day or night.
- **Transition Conditions**. Environmental conditions under which environmental parameters may exceed those of the observing state, whilst the system is transitioning to an initialized state.
- **Survival Conditions**. Environmental conditions expected to occur with a probability of roughly 2% per year at the array site. The level of damage incurred under survival conditions must not exceed the serviceability limit state.
- **Serviceability Limit**. Damage can be repaired in-situ using available spare parts and a normal level of on-site manpower.
- **Collapse Prevention Limit**. The structure is heavily damaged, with very limited residual strength and stiffness, yet it retains structural integrity and can resist collapse. Repairs may require additional resources beyond those usually available on-site.

1.4.2.7 System Related Definitions

The specific definitions for the SI^3 adopted in this document are:

- **Degree of coherence.** Measurement of the spatial or temporal correlation between the photons fluxes of a star received at two telescopes.
- **Focal Plane Optics (FPO).** Sub-assembly of SI3 containing all the optical elements of the instrument, including a filter wheel.
- **Front End Electronics (FEE).** Sub-assembly of the SI^3 made of a 2x2 detector array of SiPM, the readout board (PRE-FEE), and the module that performs signal conditioning.
- **Focal Plane Module (FPM).** Sub-assembly made of the Focal Plane Optics and part of the Front End Electronics (detector and PRE-FEE).
- **Back End Electronics (BEE).** Sub-assembly of SI 3 that acquires the signals from the Front End Electronics and streams them to the Supervisory Control And Data Acquisition system.

- **Pixel.** A single quadrant of the 2x2 detector array of the SI^3.
- **Event.** Single electrical signal from a pixel of the SI^3, including time and amplitude information.
- **Timestamp**. Temporal tag of an event produced by the BEE.
- **DL0 data structure**. Level 0 data structure of a timestamp, delivered by the BEE to SCADA. It consists of 5 Bytes per event and has a highly compressed format containing information on the detector pixel and the timestamp.
- **Time Synchronization System**. A system designed to keep clocks synchronized to sub-ns accuracy for SI^3 event time tagging at each ASTRI telescope for the whole duration of an observing run.

2 Related Documents

1.5 Applicable Documents

[AD1] ASTRI Quality Plan: ASTRI-INAF-PLA-3000-001

[AD2] ASTRI Common Technical Standard: ASTRI-INAF-SPE-2000-003

[AD3] ASTRI Mini Array Environmental Conditions: ASTRI-INAF-SPE-2000-002

[AD4] ASTRI Mini Array Product Tree: ASTRI-INAF-DES-2000-001

[AD5] ASTRI Mini Array Optical design description: ASTRI-INAF-DES-7200-001

[AD6] ASTRI Mini Array Telescope Mechanical Structure Design Requirements Specification: ASTRI-INAF-SPE-7100-001

1.6 Reference Documents

[RD1] ASTRI Mini-Array Operation Concept: ASTRI-INAF-SPE-1000-001

[RD2] ASTRI Mini-Array Core Science at the Observatorio del Teide, Vercellone, S. et al. (2021), Journal of High Energy Astrophysics, in preparation

[RD3] ASTRI Mini-Array Stellar Intensity Interferometry Instrument Science Requirements: ASTRI-INAF-SCI-7400-001

[RD4] ASTRI Mini-Array Stellar Intensity Interferometry Conceptual Design Document: ASTRI-DES-7400-001

[RD5] Bonanno, G. & Romeo, G., “Elettronica di Front-End per modulo di Interferometria di Intensità”: ASTRI-INAF-REP-7400-001

3 Overview of the System

The ASTRI Stellar Intensity Interferometry Instrument (SI^3) is conceived to implement Stellar Intensity Interferometry (SII) on the ASTRI Mini-array [RD1, RD2]. It is a fast single photon counting instrument for performing intensity interferometry observations of bright stars. SI^3 is designed to perform accurate measurements of single photon arrival times (1 ns) in a narrow band optical window (3-8 nm) centered at a wavelength in the range 420-500 nm [RD3, RD4]. Measurements with the SI^3 instruments mounted on the telescopes of the array will be used to determine the second order degree of spatial and temporal coherence of a star.

The ASTRI SI^3 is deployed in front of the Cherenkov camera through a dedicated arm to carry out intensity interferometry observations in the nights around Full Moon. It performs the following operations (Figure 3-1):

- Positioning instrument on target
- Reducing angle of incidence and filtering photons
- Powering on and controlling the detectors and electronics
- Detecting photons
- Reading signal from detectors
- Conditioning signal
- Acquiring detector and time reference signals
- Transferring and storing science and housekeeping data to SCADA
- Processing and analyzing data and generating scientific products

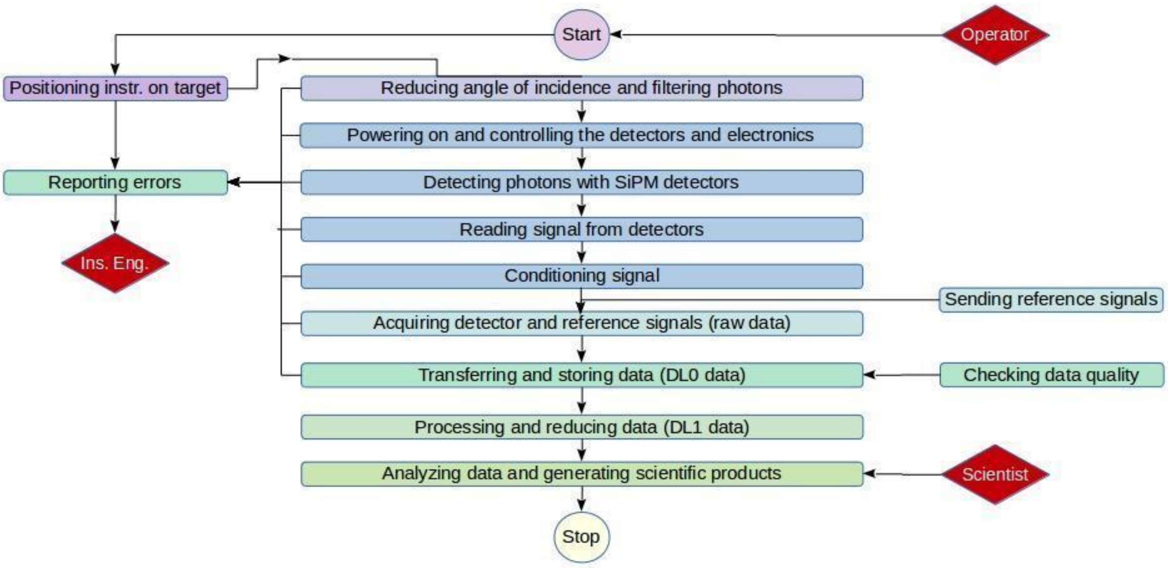

Figure 3-1: ASTRI SI^3 functional workflow.

Each function is associated to a specific instrument sub-system, as follows (see the block diagram in Figure 3-2):

- Positioning instrument on axis → Positioning arm
- Reducing angle of incidence and filtering photons → Focal plane Optics (FPO)
- Powering on and controlling the detectors and FEE → Voltage Distribution Board (VDB) and Control and Communication Unit (CCU)
- Detecting photons → Focal plane Detectors
- Reading signal from detectors → Preamplification Front End Electronics (PRE-FEE)
- Conditioning signal → Front End Electronics (FEE)
- Acquiring detector and time reference signals → Back End Electronics (BEE)
- Transferring and storing science and housekeeping data to SCADA → Local

Acquisition and Control System

- Processing and analyzing data and generating scientific products → Science data processing system

The sub-assembly made of the Focal Plane Optics (FPO) and the Preamplification FEE (PRE-FEE) is the Focal Plane Module (FPM) placed on the Positioning arm.

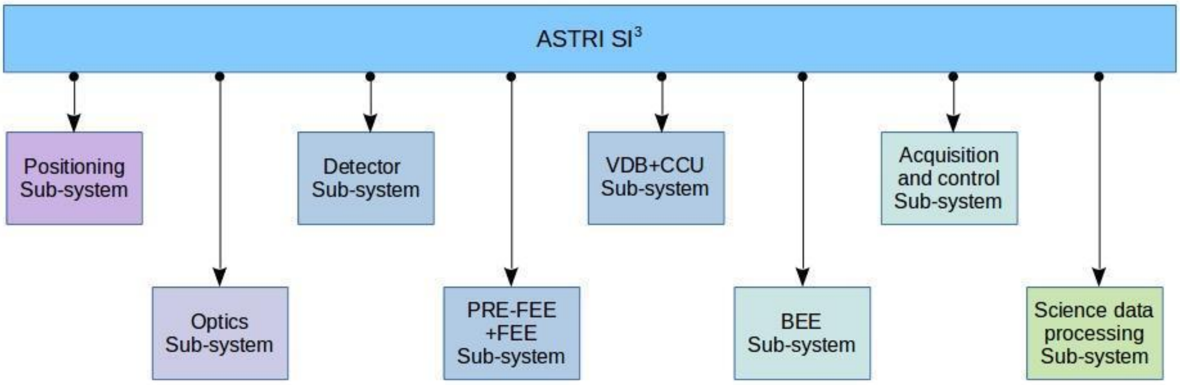

Figure 3-2: ASTRI SI^3 block diagram.

The block diagram in Figure 3-2 is exploded in the following Figure to show the entire product breakdown structure (PBS) of the instrument.

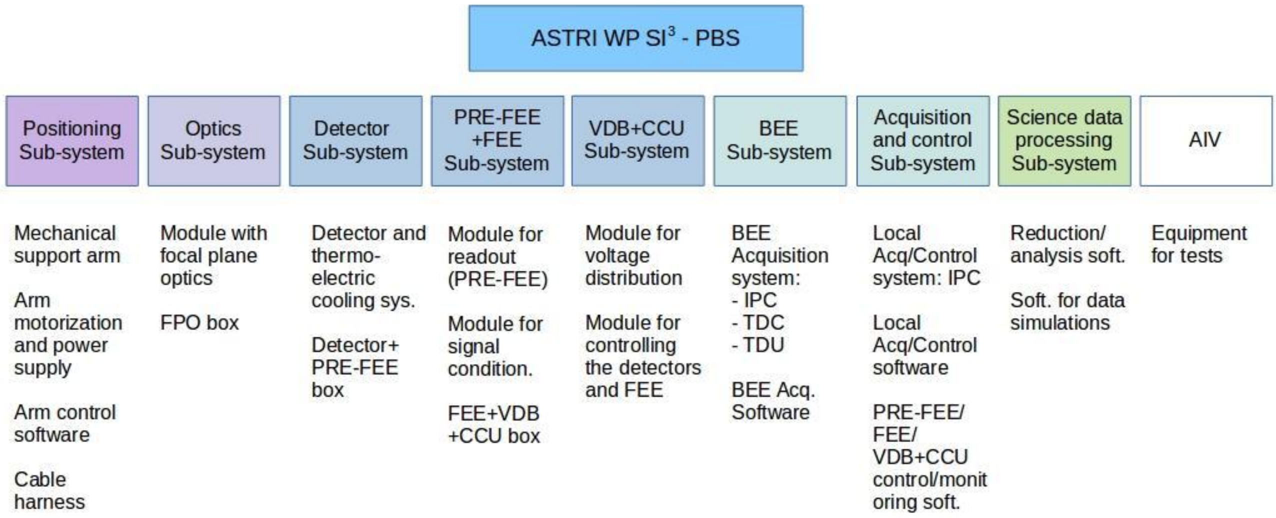

Figure 3-3: ASTRI SI^3 Product Breakdown Structure.

Apart from the Positioning sub-system, a prototype version of all the other components of the instrument will be produced in INAF, and tested by INAF personnel in the Catania and Asiago laboratories and at the ASTRI-Horn telescope in Serra La Nave (Catania, Italy). A prototype version of the positioning sub-system and the production of the final version of the 9 instruments will be outsourced.

The product tree of the PBS (with each element of the SI^3 uniquely identified by a code) is shown in Figure 3-4.

- **WP 7.4 Stellar Intensity Interferometry Instrument**
  - 7.4.1 Positioning sub-assembly
    - 7.4.1.1 Mechanical support arm
    - 7.4.1.2 Arm motorization and power supply
    - 7.4.1.3 Arm control software
    - 7.4.1.4 Cable harness
  - 7.4.2 Optics sub-assembly
    - 7.4.2.1 Module with focal plane optics
    - 7.4.2.2 Optics box
  - 7.4.3 Detector sub-assembly
    - 7.4.3.1 Detector and thermo-electric cooling system
    - 7.4.3.2 Detector + PRE-FEE box
  - 7.4.4 PRE-FEE + FEE sub-assembly
    - 7.4.4.1 Module for detector readout (PRE-FEE)
    - 7.4.4.2 Module for signal conditioning
    - 7.4.4.3 FEE+VDB+CCU box
  - 7.4.5 VDB + CCU sub-assembly
    - 7.4.5.1 Module for voltage distribution
    - 7.4.5.2 Module for controlling the detectors and FEE
  - 7.4.6 BEE sub-assembly
    - 7.4.6.1 BEE acquisition system
    - 7.4.6.2 BEE acquisition software
  - 7.4.7 Acquisition/control sub-assembly
    - 7.4.7.1 Local acquisition and control system
    - 7.4.7.2 Local acquisition and control software
    - 7.4.7.3 PRE-FEE/FEE/VDB+CCU control/monitoring soft.
  - 7.4.8 Science data proc. sub-assembly
    - 7.4.8.1 Reduction/analysis software
    - 7.4.8.2 Simulation software
  - 7.4.9 AIV sub-assembly
    - 7.4.9.1 Equipment for tests

Figure 3-4: ASTRI SI^3 product tree.

Following the product tree, the main components of the SI^3 are:

Positioning sub-assembly: The positioning sub-assembly holds the parts of the SI^3 that go in front of the Cherenkov camera during the SII observations (Focal Plane Module, made of the Focal Plane Optics, the Detector, and the PRE-FEE). It deploys them on and removes them from the optical axis in front of the Cherenkov camera.

Optics sub-assembly: The optics sub-assembly is a group of optical elements (1 spherical mirror, 3 lenses, 1 interferometric filter) that reduces the angle of incidence of the incoming rays, selects a narrow wavelength range, and focuses photons on the detector sub-assembly. It also contains a filter wheel with a selection of filters.

Detector sub-assembly: The detector sub-assembly is a special chip package that hosts a 2x2 detector array (4 pixels) and cools it through a Peltier Thermo-Electric Cooler. It detects photon events and transforms them in an electric signal.

Front end electronics sub-assembly: The Front End electronics (FEE) sub-assembly is made of a board that reads the 4 signals of the 2x2 SiPM detectors array (PRE-FEE) and sends them to a module that performs signal conditioning. The latter converts the pulse from the PRE-FEE to a signal compatible with the LVTTL standard, after a suitable amplification stage [RD5].

Voltage distribution and Control and Communication Unit sub-assembly: This sub-assembly delivers the power supply with the required voltage to the detector and FEE sub-systems. It also contains the Control and Communication Unit that provides the control of the detector and FEE through a microprocessor and a dedicated embedded firmware.

Back End Electronics sub-assembly: The Back End Electronics (BEE) sub-assembly acquires the LVTTL signals from the FEE and streams them to SCADA. It is made of a Time-to-Digital-Converter (TDC) board and a Time Distribution Unit (TDU), both mounted on an industrial PC (IPC). This sub-assembly delivers the SI^3 software that performs the acquisition of the signals from the FEE and the time reference signal, and the software that monitors the detector and the FEE through the acquisition of housekeeping data.

Local Acquisition and Control sub-assembly: The local acquisition and control sub-assembly acquires the data from the BEE and transfers them to the Local Bulk Repository for storing them. This sub-assembly also delivers the software that performs the aforementioned operations.

Science data processing sub-assembly: The Science data processing sub-assembly realizes the software for reducing and analyzing the raw data, and for simulating the performance of the instrument.

Assembly Integration and Verification sub-assembly: The Assembly Integration and Verification (AIV) sub-system performs the final integration of the various components and tests the functioning of the instrument.

The boundaries of the hardware/software systems of SI^3, and the flow of information between SI^3 and the external environment of the ASTRI Mini-array are shown in Figure 3-5, while the logical view and internal/external connections of the subsystems of SI^3 are shown in Figure 3-6.

The ASTRI SI^3 interfaces with:

- The Telescope Optical System, which feeds the SI^3 with the light from stars and the sky background
- The Telescope Power System, which delivers the required power supply
- The Time Synchronization (and Distribution) System, which is designed to keep clocks synchronized to sub-ns accuracy for SI^3 event time tagging. This system allows time tagging of any event recorded by every SI^3 of the ASTRI array.
- The Supervisory Control and Data Acquisition System (SCADA), that provides the hardware and software systems needed to store the data and control all the operations carried out at the ASTRI array site. SCADA is a central control system which interfaces and communicates with all equipment and dedicated software installed On-Site.

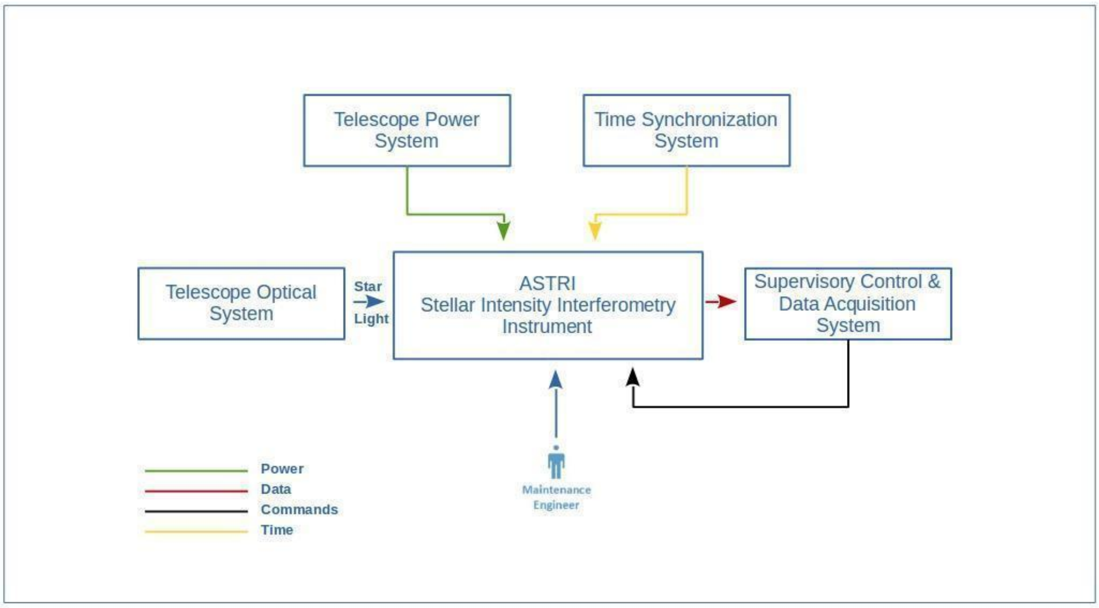

Figure 3-5: ASTRI SI^3 context diagram.

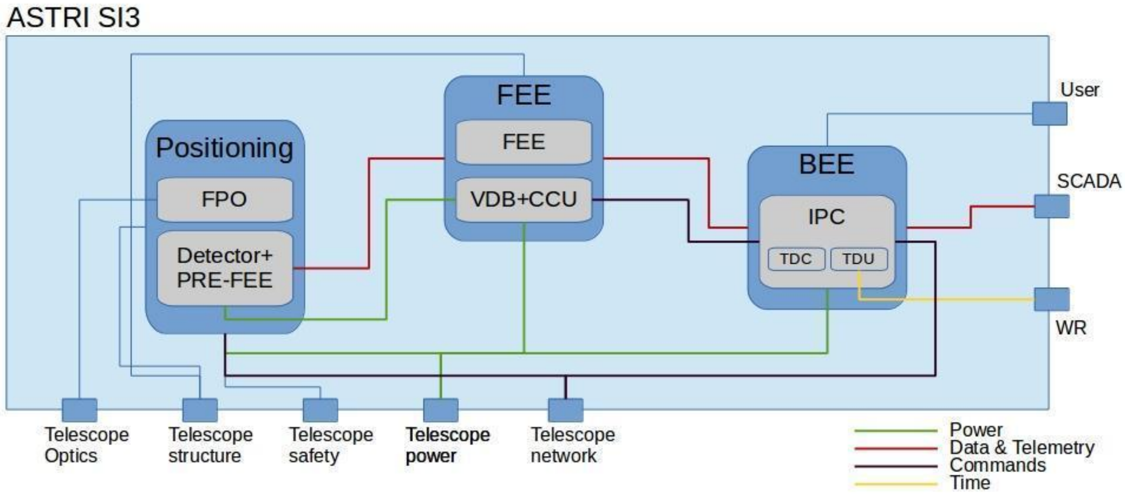

Figure 3-6: ASTRI SI[3] logical view and internal/external connections.

4 Environmental Requirements

For the environmental requirements applicable to SI^3 we refer to the document ASTRI Mini Array Environmental Conditions (ASTRI-INAF-SPE-2000-002, [AD1]). They are summarized in the following Table.

Parameter	Normal	Observation	Transition	Survival
Air pressure	750±50 mbar			
Air temperature	-5°C to +25 °C		For T<-5°C or T>25°C to Safe State	-10°C to +30°C without power; -15°C to +35°C in Safe State
Temperature gradient	N/A	7.5°C/h	> 7.5°C/h	0.5°C/min for 20 mins
Relative humidity	2% to 90%		>90%	2% to 100%
Rain	none		≤2mm in 1h	≤70mm in 1h; ≤200mm in 24h;
Snow	none		none	≤200 kg/m2 on horizontal surface <50cm
Hailstone	none		none	∅ =5 mm, E = 0.2 J
Wind		≤36km/h for 10 mins	≤50 km/h for 10mins; serviceability limit state: <60km/h for 10mins	≤100km/h for 10mins; serviceability limit state: ≤120km/h for 10 mins in safe state; serviceability limit state: ≤120km/h for 10 mins in safe state; serviceability limit state: ≤248km/h for 1s (gust); serviceability limit state: ≤90km/h for 10 mins (precipitations hail / snow/ rain);
Solar radiation	1200 W/m^2 (averaged over 1 hour) T≤ 35ºC in the safe state			
Dust and sand	none		none	2.9 x 10^5 particles of ≥5µm size per m^3 of air for 90% of the time at 2m above ground
Illumination	none		none	≤10^6 photons ns^{-1} cm^{-2}
Earthquakes	none			horizontal ground acceleration ≤0.06g; peak vertical ground acceleration < 0.06g

Table 2: Environmental requirements applicable to ASTRI SI^3.

5 Functional and Performance Requirements

Code	Name	Description	M
2010	Average detection efficiency	The average efficiency of the SI^3, weighted with a reference spectrum of an O-through-G star in a narrow optical band (3-8 nm) and centered around a wavelength in the range 420-500 nm, shall be larger than 8.5%. This value includes the detector Photon Detection Efficiency (PDE) and dead space, the efficiency of the telescope and focal plane optics, and the transmission efficiency of the narrow band filter.	A
2020	Dark count rate	The detectors shall have a dark count rate per pixel not exceeding 500 kcounts/s at 25°C or 50 kcounts/s at -20°C (assuming an over voltage of 3V).	T
2030	Maximum level of Night Sky Background (NSB)	The SI^3 shall be able to perform observations with uniform night sky background illumination levels up to 0.1 photons ns^{-1} sr^{-1} cm^{-2} in a narrow optical band (3-8 nm) centered around a wavelength in the range 420-500 nm, using as reference spectrum that of Moonlight.	A
2050	Pixels availability	During observations, 100% of the detector pixels must be available and usable for data analysis.	A
2070	Detecting and tagging events	The BEE shall be able to detect each photon-event from the FEE and associate to it a timestamp with a relative (among telescopes) time accuracy of less than 0.5 ns.	A
2090	Maximum jitter	The maximum jitter of the FEE and BEE acquisition sub-systems shall be less than 0.5 ns.	A
2100	Event frequency	The SI^3 shall collect and deliver events arriving at an average rate up to 100 Mevents/s (total on the 4 pixels) with a random distribution in time.	T
2120	Double hit resolution per pixel	Two events occurring in the same pixel of the detector shall be resolved if separated by more than 6 ns.	T
2140	Double hit resolution per detector	Two events occurring in different pixels of the detector shall be resolved if separated by more than 1 ns.	T
2150	VDB+CCU voltage distribution	The VDB+CCU shall provide the power supply to the detectors and the TEC onboard the chip package, the PRE-FEE and the FEE, distributing all the needed voltage rails.	I
2160	Linearity	Departure from linearity of the detectors and FEE shall be less than 15% for photon rates up to 25 MHz per pixel (100 MHz on the 4 pixels).	T

2200	Event timestamp	The SI^3 shall deliver the timestamp of each event to the SCADA acquisition system using the DL0 data structure.	A
2220	Data rate	The SI^3 shall collect and deliver events to the SCADA at a maximum data rate of 500 MB/s.	T
2300	Positioning accuracy	The position of all components of the FPM of SI^3 shall be known with an accuracy smaller than the tolerances listed in Table 3.	A
2310	Repositioning accuracy	The FPM of SI^3 shall reposition in the nominal observing position with an accuracy of +/- 1 mm and +/- 0.07 degrees in tilt.	T
2400	Remote control	The SI^3 shall be controllable in remote mode via an OPC-UA server interface.	T
2410	Local control	The SI^3 shall implement a local control mode for maintenance and diagnostic purposes, during which remote operation of safety-relevant sub-systems is blocked. SCADA shall be informed when a SI^3 enters Local Mode.	A/ T
2420	State Machine	The SI^3 system shall implement a state machine according to Figure 1-1. The state machine will be accessible via the OPC-UA server.	A
2440	State change and SCADA	The SI^3 shall notify SCADA whenever it changes State.	T
2450	Maximum power of the electrical interface	The maximum power consumption of SI^3 shall not exceed that provided by the telescope power system.	A
2460	Power outage	The SI^3 shall not be damaged beyond the serviceability limit state in case of sudden power outage.	A
2500	Absolute time	The SI^3 shall use the absolute time provided by the Time Synchronization System as the reference in all log and alarm messages.	A
2600	Data processing	The SI^3 data processing system performs all the operations for reducing and analyzing the raw data, producing the data products, and simulating the performance of the instrument. It shall be capable of processing a maximum volume of 110 TB of data per month in single packets of 150 GB.	A
2620	Final science-processed data output	The size of the final processed data ready for scientific analysisshall not exceed 18 TB per month.	A

Table 3: Optical tolerances for the SI^3 FPM and its internal elements. In bold we highlight the required deployment and stability tolerances for the SI^3 (rigid body) optical module from the deployment arm. The worst offender parameters are the relative tilt between the optical axis of M2 and the optical axis of the SI^3 module (see the ASTRI Mini-Array Stellar Intensity Interferometry Conceptual Design Document; ASTRI-INAF-DES-7400-001).

Element	**Deployment & stability tolerances**				
-	**Δx mm**	**Δy mm**	**Δz mm**	**ΔTx deg**	**ΔTy deg**
SI^3 module rigid body	**+/- 1**	**+/- 1**	**+/- 1**	**+/- 0.07**	**+/- 0.07**
M3	+/- 1	+/- 1	+/- 1	+/- 0.07	+/- 0.07
L1	+/- 0.2	+/- 0.2	+/- 0.2	+/- 0.05	+/- 0.05
Filter	+/- 0.2	+/- 0.2	+/- 0.2	+/- 0.05	+/- 0.05
L2	+/- 0.2	+/- 0.2	+/- 0.2	+/- 0.05	+/- 0.05
L3	+/- 0.2	+/- 0.2	+/- 0.2	+/- 0.05	+/- 0.05

6 Design Requirements

Code	Name	Description	M
3000	Positioning	The SI^3 shall have a positioning arm that deploys (removes) the FPM on (from) the focal plane between the Cherenkov Camera and the secondary mirror of the ASTRI telescope.	I
3010	Photosensitive focal plane	The SI^3 must be fully instrumented with 4 photosensitive (photon counter) pixels of 3x3 mm^2, arranged in a 2x2 array layout positioned on the instrument focal plane.	I
3012	Detector operating temperature	The detector shall be thermalized and maintained at a temperature of -20 +/- 1 ^{0}C.	D
3015	Minimum field of view	The SI3 shall deliver a minimum sensed Field of View (FoV) 1.2 times larger than the optical PSF (90% containment radius) to cope with the telescope tracking errors.	D
3020	Maximum field of view	The SI3 shall deliver a maximum sensed FoV between 1.3 and 1.4 times larger (in area) than the instrument PSF (90% containment radius) to minimize sky background contamination and maximize the signal-to-noise ratio.	D
3030	Focal plane optics	The optics sub-assembly shall have a portion of the optical path partially collimated, where to insert a narrow band (3-8 nm) filter.	D
3035	Filter collection	The optics sub-assembly shall have a collection of filters to perform multi-narrow-band observations of the continuum and/or of specific spectral lines.	D
3040	Angle of incidence	A fraction larger than 70% of the optical rays shall have an angle of incidence on the narrow band filter smaller than 15 degrees.	D
3060	Light pollution	The SI^3 shall not produce light during observations.	I
3080	Input voltage	The input voltage of the VDB+CCU shall be 24 V.	D
3090	Housekeeping data acquisition	The CCU shall acquire the housekeeping data (voltage, current levels, temperatures) of the VDB, and shall control the detectors by acquiring the detector operating temperature and by setting the voltage to compensate for temperature variations.	D
3100	Time synchronization system	The SI^3 shall have a time synchronization system based on the White Rabbit technology.	D
3110	Scientific data	The SI^3 shall deliver the scientific data to the Array Data Acquisition System via File Transfer Protocol (DL0 files in	D

		telemetry format).	
3120	Controlling and monitoring the instrument	The SI^3 shall have a Local Control and Monitoring software running on the CCU and an Industrial Computer (IPC). The SI^3 Local Control and Monitoring software shall use an OPC-UA protocol to communicate with the Telescope Control System and the Monitoring system. The software shall deliver to the Telescope Control System and the Monitoring system all monitoring data and error conditions, and shall receive from them the instrument status.	D
3200	Positioning - Structural resistance 1	The Positioning sub-system must withstand static and dynamic loads due to the environmental conditions of the telescope installation site, as well as the force due to the telescope itself, according to the actual standards (NTC2018, Eurocodes 0-1-3-8-9).	D
3210	Positioning - Structural resistance 2	If the static and dynamic loads calculated according to the standards indicated at the spec. number 3200 of the present document, result smaller than the loads indicated at environmental group specs of the document ASTRI-SPE-7300-001, these last ones shall be used for the design.	D
3220	Positioning - Use of nonmagnetic materials for the Positioning sub-system	The Positioning sub-system shall be manufactured with nonmagnetic materials. Exceptions shall be accorded by the Customer.	D
3230	Positioning - Magnetic interferences	Fans, motors or other electric/magnetic components possibly mounted on the Positioning sub-system shall not cause interference with the instrument electronics.	D
3240	Positioning - Design standards	The design of the item Positioning sub-system shall be compliant with the following standards: 2006/42/CE (Machinery Directive), 2014/35/UE (Low Voltage Directive), 2014/30/UE (ECM Directive).	D
3250	Positioning - Position status	The position and the motion/not-motion status of the positioning arm shall always be known by the software.	D
3260	Positioning - Safety of motion	The automatic motion of the positioning arm shall prevent injuries to people.	D
3270	Positioning - Protection against casualties by moving parts	All the moving parts possibly mounted on the Positioning sub-system that may cause casualties shall be protected by accidental contact.	D
3280	Positioning - Moving with wind	The positioning arm shall be able to move with wind up to 50 km/h in any orientation when mounted at the telescope.	D

3290	Positioning - Opening time	The positioning arm shall reach the observing position from the parking position in no more than 60 s.	D
3300	Positioning - External surface conformation	The external surface of the Positioning sub-system shall be arranged not to present cavities or pockets that may permit the gathering up of water or dust.	D
3310	Positioning - Glossy surfaces	The outer surfaces of the Positioning sub-system shall not exhibit glossy or reflective surfaces.	D
3320	Positioning - Hail impact protection	The Positioning sub-system shall have protection against hail impact of at least 0.2 J.	D
3330	Positioning - Fan inlet protection	The inlet of the fans, if used, shall be protected by a filter of at least the ISO coarse class as per UNI EN ISO 16890:2017.	D
3340	Positioning - Fan filters	The filters protecting the fans inlet, if used, shall be easily replaceable when the instrument is installed at the telescope.	D
3350	Fan maintenance	If used, the fans of the Positioning sub-system shall be easily replaceable even with the instrument installed at the telescope.	D

7 Physical Requirements

Code	Name	Description	M
4000	Weight arm	The weight of the positioning sub-assembly shall be less than 30 kg.	I
4010	Weight optics and detector	The weight of the optics plus detector sub-assemblies shall be less than 5 kg.	I
4020	Weight FEE	The weight of the FEE sub-assembly shall be less than 8 kg.	I
4030	Weight BEE	The weight of the BEE sub-assembly shall be less than 20 kg.	I
4050	Size FPO	The length of the FPO module (from the spherical mirror up to the focal plane) shall be between 180 mm and 220 mm.	I
4060	Size PRE-FEE and FEE	The maximum size of the PRE-FEE shall be 60 mm x 60 mm x 50 mm and that of the FEE shall be 300 mm x 300 mm x 150mm.	I
4070	Size BEE	The maximum size of the BEE sub-assembly shall be 450 mm x 500 mm x 250 mm.	I
4080	Clearance FPO from camera lid	The minimum clearance of the FPO sub-assembly from the lid of the Cherenkov camera, when closed, shall be 20 +/- 1 mm.	I
4100	Volume	The overall dimensions of the Positioning sub-system shall be such as to allow an easy mounting on the telescope, the design of which will be provided by the Customer.	A
4150	Interference SI^3/Cherenkov camera	The opening/closing operations of the Cherenkov camera lids shall not interfere with the SI^3 positioning arm.	A
4200	Corrosion resistance	All parts of the Positioning sub-system must be protected from corrosion against atmospheric agents with the following concentrations: NO<3 ppb, NO2<3 ppb, SO2<3 ppb. The properties of the anti corrosion treatment shall be agreed with the Customer.	A
4210	Painting	All exposed surfaces of the Positioning sub-system must be painted with color RAL 3016.	A
4220	Painting standards	Painting shall be compliant with the standard UNI EN 12206-1:2005.	A

8 Interface Requirements

Code	Name	Description	M
5000	FPO optical interface	The FPO shall receive light from the telescope optical system.	I
5002	Arm safety	The positioning arm shall communicate with the telescope safety system.	I
5005	Arm network interface	The positioning arm shall communicate with the telescope network.	I
5010	Arm mechanical interface	The telescope shall have an anchoring system for holding the positioning arm.	I
5015	FEE mechanical interface	The telescope shall have an anchoring system for holding the FEE box.	I
5017	Bolts standards	The connection elements used to fix the Positioning sub-system to the telescope shall comply with EN 14399.	I
5018	Mounting ambiguity	The mechanical interface between the Positioning sub-system and the telescope shall permit a mounting without ambiguity, by means of Poke Yoke systems or mounting reference.	I
5020	Arm electrical interface	The positioning arm requires a 24 V power supply.	I
5025	VDB electrical interface	The VDB+CCU requires a 24 V power supply.	I
5027	BEE electrical interface	The BEE requires a 24 V power supply.	I
5030	Time Synchronization System interface	The SI^3 shall have a timing link to a White Rabbit switch via a Single Fiber Bi-directional SFP transceiver.	I
5040	Data interface	For the scientific and housekeeping data the SI^3 shall have a dedicated link to the Camera Server of the ADAS system via a Fiber Bi-directional SFP+ transceiver.	I
5050	Command interface	For the instrument control the SI^3 shall have a link via an ethernet cable.	I
5055	CCU internal command interface	The CCU shall communicate via an ethernet link.	I
5080	Local control interface	The SI^3 shall implement an engineering interface for the local control. The FEE shall be controllable in local mode through a standard serial port and the BEE through a command interface.	I

9 Product Assurance (PA) induced requirements

Code	Name	Description	M
6010	Quality Plan	A specific quality plan compliant with the ASTRI quality plan [AD2] shall be produced and implemented for all the activities related to the SI^3 production.	I
6020	System Lifetime	System shall be designed for an operational Lifetime of 15 years.	A
6035	System Test	The positioning arm shall be able to perform 5 parking/observing position movements and vice versa in 11 minutes without overheating or malfunctions of any component.	T
6040	User and Maintenance manuals	System user and maintenance manuals shall be delivered.	I
6050	Bill of materials	The system shall come with a complete Bill of Materials.	I
6060	Spare parts	System documentation shall contain the list of spare parts related to the system lifetime.	I
6070	Drawings	The system shall be delivered with a complete set of mechanical, electrical and electronics drawings.	I
6080	RAMS Analysis	The design of the system shall be accompanied by a RAMS analysis as outlined in the quality plan.	I
6090	ID Card	Each system shall be delivered with a specific ID card that summarizes its main parameters and characteristics.	I
6100	ID Code	An ID code shall be stamped on each system.	I
6110	Preventive maintenance	The on-site preventive maintenance of the system shall require on average < XX person-hours / week.	D
6120	Corrective maintenance	The on-site corrective maintenance of a single system shall require on average < 1 person-hours / week.	D
6130	Medium Voltage marks	The opening panels of the SI^3 shall have the tag "Medium Voltage".	I
6140	Loading and unloading procedures	System 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.	D
6150	SI^3 Operations	System operations shall be compliant with norm ISO 12100:2010 (clause 5).	D

6160	Machinery Directive compliance	The system shall be produced in such a way as to guarantee safe handling by operators and in compliance with the machinery directive 2006/42 / EC.	D
6170	ISO 12100 Standard compliance	In the design of the system inherently safety measures shall be taken as per standard ISO 12100:2010 (clause 4).	D
6180	EN60204 Standard compliance	The instrument shall be equipped with systems able to guarantee protection from permanent damage against electrostatic discharges, voltage fluctuations, electromagnetic disturbances and incorrect connection of cables, in compliance with the EN 60204/1 directive.	D
6200	Components datasheet	The mechanical and electrical components and any consumables used to build the instrument shall be accompanied by adequate documentation.	I
6210	Fan L10	The fans, if provided, must have an L10 of not less than 70000 hours.	A
6220	Connectors marking	The electrical connectors on the instrument must be recognizable by affixing permanent labels, markings or other. Recognition must be possible in any position where the connector is accessed.	I
6230	Hazardous materials	Any use of hazardous materials in the instrument (CLP Regulation 1272/2008, June 1, 2005, table 3, and subsequent amendments and additions) must be agreed with the Customer.	D
6240	Plastic materials: flammability	Any plastic material used for the instrument shall have the UL94 V-0 flammability classification.	D
6250	Materials datasheet	The materials used for the realization of the instrument must be accompanied by documentation certifying their physical, mechanical and technological properties.	D
6260	CE markings of the materials	All the materials used for the instrument shall be CE marked.	D

10 Verification Requirements

Code	Name	Description	M
7010	Test Report	Whenever a Test (T) is explicitly requested by the specifications, it is necessary to produce a report showing that it has been carried out.	I
7020	VCD Matrix	A document with the verification matrix (VCD) showing total compliance with the Client's requirements must trace all the specifications.	I
7030	FEM	Finite Element Analysis model (if applicable) must be preferred whenever the required verification method is Analysis (A).	I
7040	Test and Procedures Plan	The procedures and test plan must be included with the supply of the instruments.	I

11 Handling, packaging, transportation requirements

Code	Name	Description	M
8010	System Packaging	System packaging shall prevent damages during transportation.	I
8020	Box sensors	Shock and temperature sensors shall be applied on the SI^3 box in order to verify if transportation fulfils the conditions reported in ASTRI-7300-8020 e ASTRI-7300-1500.	I
8030	Transportation and storage temperature	The SI^3 shall suffer no damage when the ambient temperature is in the range -20ºC to 80ºC and no power is available.	A
8060	ID Code	Each element used for the packaging of the system (box, barrier bag, etc.) shall be marked with a System Identification (ID) code.	I
8070	ASTRI and INAF Logo	The System shall be tagged with the INAF and ASTRI logo.	I