ASTRI Mini-Array
Software Product Breakdown Structure

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Version	***Date***	***Modification***
2.1	Feb 3, 2020	Version aligned with Architecture V 2.1
2.2	Apr 16, 2020	Version aligned with Architecture V 2.2
2.3	Nov 9, 2020	Changes after the Concept Design Review. Version aligned with Architecture V 2.3
2.4	Apr 9, 2021	Aligned with version 2.4 of applicable documents
2.5	Jun 18, 2021	Aligned with version 2.5 of applicable documents. No changes with respect to version 2.4

1. Introduction

The **ASTRI Mini-Array (MA)** is an INAF ground-based project to construct, deploy and operate a set of nine identical dual-mirror Cherenkov gamma-ray telescopes, and several other auxiliary equipment and infrastructures. The ASTRI Mini-Array scientific objective is to exploit the imaging atmospheric Cherenkov technique to measure the energy, direction and arrival time of gamma-ray photons arriving at the Earth from astrophysical sources. In the almost unexplored energy range 1-300 TeV this technique requires an array of optical telescopes (~ 4 m in diameter) at a site located at an altitude of > 2000m. The telescopes will have reflecting mirrors focusing the Cherenkov UV-optical light produced by atmospheric particle cascades (air-showers), initiated by the primary gamma-ray photons entering in the atmosphere, onto ultrafast (nanosecond timescale) cameras. Most of the collected data will come from the large number of charged primary cosmic-ray initiated air-showers, which will also be recorded, then appropriate data analysis methods will be employed to reduce the level of this background and allow an efficient detection of gamma-rays coming from astrophysical sources.
Besides the gamma-ray scientific program, the ASTRI Mini-Array will also perform:

- Stellar Hambury-Brown intensity interferometry: each of the telescopes of the ASTRI Mini-Array will be equipped with an intensity interferometry module. The Mini-Array layout with its very long baselines (hundreds of meters), will allow, in principle, to obtain angular resolutions down to 50 micro-arcsec. With this level of resolution, it will be possible to reveal details on the surface of bright stars and of their surrounding environment and to open new frontiers in some of the major topics in stellar astrophysics.
- Direct measurements of cosmic rays: 99% of the observable component of the Cherenkov light is hadronic in nature. Even if the main challenge in detecting gamma-rays is to distinguish them from the much higher background of hadronic Cosmic Rays, this background, recorded during normal gamma-ray observations, will be used to perform direct measurements and detailed studies of the Cosmic Rays themselves.

The ASTRI MA telescopes (including the Cherenkov Camera) are an updated version of the ASTRI-Horn Cherenkov Telescope operating at Serra La Nave (Catania, Italy) on Mount Etna.

The nine telescopes will be installed at the Teide Astronomical MA System, operated by the Instituto de Astrofisica de Canarias (IAC), on Mount Teide (~2400 m a.s.l.) in Tenerife (Canary Islands, Spain).

The ASTRI MA System will be operated by INAF on the basis of a host agreement with IAC.

1.1. Purpose

This document contains the ASTRI Mini-Array Software PBS.

1.2. Scope

This document applies to all application- and domain-level software for the MA software project.

2. Applicable documents

[AD1] N. Parmiggiani et al., ASTRI MA Glossary, ASTRI-INAF-LIS-2100-001 , issue 2.5
[AD2] A. Bulgarelli, G. Tosti, et al., ASTRI MA Data Model, ASTRI-INAF-DES-2100-003, issue 2.5
[AD3] A. Bulgarelli, G. Tosti, et al., ASTRI MA Top Level Use Cases, ASTRI-INAF-SPE-2100-001, issue 2.5
[AD4] A. Bulgarelli,, et al., ASTRI MA Top Level Software Architecture, ASTRI-INAF-DES-2100-001, issue 2.5
[AD5] ASTRI-MA Software Engineering Management Plan: ASTRI-INAF-PLA-2100-001, issue 1.0
[AD6] ASTRI Mini-Array Data & Documentation Management Plan, ASTRI-INAF-PLA-1000-003, issue 1.2

3. General description

The **ASTRI Mini-Array (MA)** is an INAF project to construct and operate an experiment to study gamma-ray sources emitting at very high energy in the TeV spectral band. The ASTRI MA consists of an array of nine innovative Imaging Atmospheric Cherenkov Telescopes that are an evolution of the two-mirror ASTRI Horn telescope successfully tested since 2014 at the Serra La Nave Astronomical Station of the INAF Observatory of Catania. Each telescope will be equipped with the new version of the ASTRICAM Silicon photomultiplier Cherenkov Camera. The main science goals of the ASTRI MA are described in [AD4]; they encompass both galactic and extragalactic science, using a well defined and limited number of targets.
The ASTRI Mini-Array's nine telescopes will be distributed at one hundred meters of distance from each other at the Teide Astronomical Observatory, operated by the Instituto de Astrofisica de Canarias (IAC), on Mount Teide (~2400 m a.s.l.) in Tenerife (Canary Islands, Spain). The ASTRI MA will be operated by INAF on the basis of a host agreement with IAC.

4. ASTRI MA Software PBS

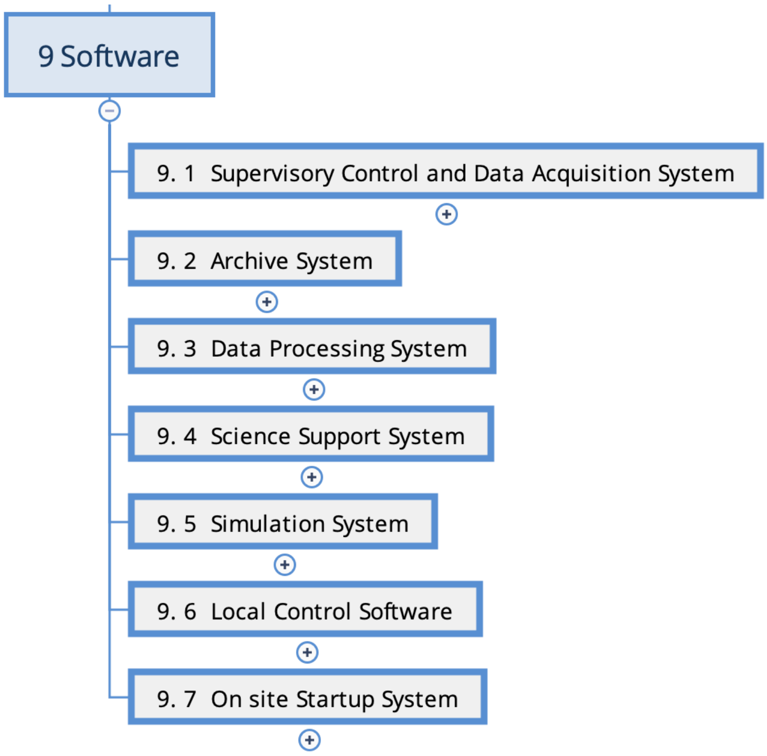


Figure 1: ASTRI MA Software PBS

The ASTRI MA Software system manages observing projects, observation handling, array control and monitoring, data acquisition, archiving, processing and simulations of the Cherenkov and Intensity Interferometry observations, including science tools for the scientific exploitation of the ASTRI MA data.

4.1. Supervisory Control And Data Acquisition System

The software system that controls all the operations carried out at the MA site. SCADA has a Central Control System which interfaces and communicates with all assemblies and dedicated software installed at the site. It is responsible for the execution of the Scheduling Blocks to perform observations.

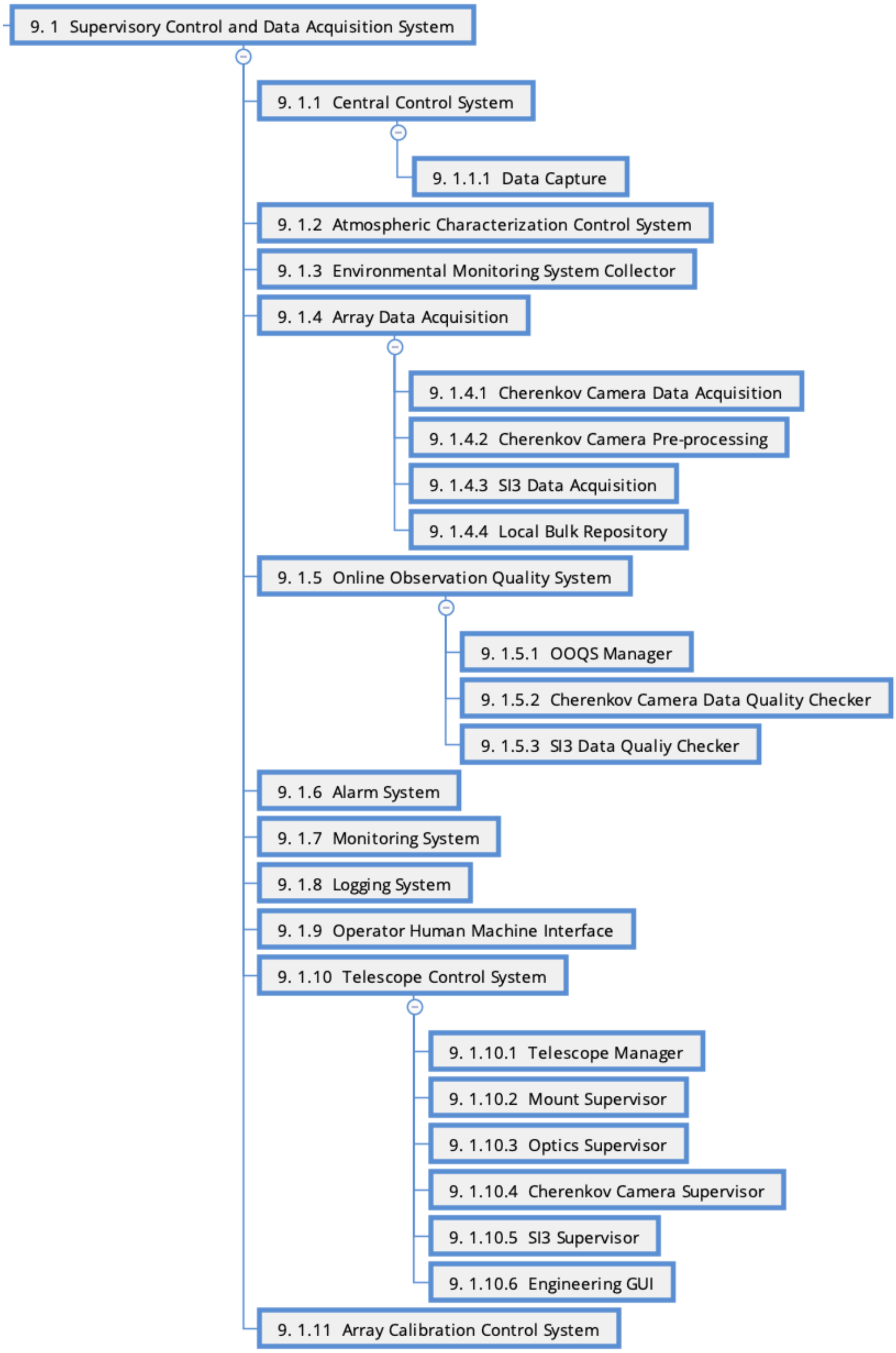


Figure 2: SCADA System

4.1.1. Central Control System

It coordinates the sequence of operations, coordinating the control systems and collectors, and sequences start, shutdown and configuration of the on-site MA Systems, checks the status of the assemblies, get the Scheduling Blocks and select the Observing Block; interprets the Observing Mode specified to command downstream to the telescopes and other subsystems; a Data Capture that save the information associated with the execution of an Observing Block necessary to perform the scientific data processing of the acquired data;

4.1.1.1. Data Capture

It is part of the Central Control System and provides the bridge between these two domains. Data capture takes the instrument-centric, time-ordered stream of data, collects and extracts those items needed in the science domain, and re-organizes them to be useful in data processing. Practically, it is responsible for collecting the auxiliary data associated with the Observing Block execution (a Run).

4.1.2. Atmosphere Characterization Control System

The software system used to control, configure and get the status of all assemblies of the Atmosphere Characterisation System and is part of the SCADA system.

4.1.3. Environmental Monitoring System Collector

The system that acquires monitoring points, alarms, errors, status and logs from the Environmental Monitoring System assemblies to check the assemblies status and reliability.

4.1.4. Array Data Acquisition System

The software system that acquires the data from the Cherenkov cameras and the SI^3 devices.

4.1.4.1. Cherenkov Camera Data Acquisition

A software component that acquires the R0 (raw) data, as a bit stream packet by packet from the Cherenkov camera BEE via TCP/IP and generates the DL0 files in telemetry format, one for each telescope and for each Run, which are saved in a Local Bulk Repository.

4.1.4.2. Cherenkov Camera Pre-processing

A software component that: (i) performs the translation from binary data to alphanumeric data (FITS), ready for the Stereo Event Builder and for the Data Processing System; (ii) splits the different CAM data sub-types contained into the R0 data level (EVT, CAL, HK, VAR) in different data streams and FITS files; (iii) performs the time reconstruction common to the Stereo Event Builder and the Data Processing System.

4.1.4.3. SI3 Data Acquisition

It acquires the DL0 files (raw) data from the SI3 Back End Electronics via FTP for each telescope and for each Run.

4.1.4.4. Local Bulk Repository

The on-site temporary storage of the data acquired by the Array Data Acquisition system.

4.1.5. Online Observation Quality System

The software system that provides quick-look results of the Cherenkov and Intensity Interferometry observation during the data acquisition to give feedback to the Operator.

4.1.5.1. OOQS Manager

The ACS component that is interfaced with the Central Control System and manages the internal components of the OOQS.

4.1.5.2. Cherenkov Camera Data Quality Checker

The software component that performs a data quality check at telescope level of the data products DL0.CAM.

4.1.5.3. SI3 Data Quality Checker

The software component that shall perform a data quality check at telescope level of the DL0.SI3 and DL1.SI3 data products.

4.1.6. Alarm System

The software system that provides the service that gathers, filters, exposes and persists all the relevant alarms raised by both assemblies and devices (such as telescopes) and SCADA processes under the supervision of the SCADA system. It also creates and filters new alarms based on a selection of the most critical monitoring points.

4.1.7. Monitoring System

The software system that provides the services that gather monitoring (about 20000 monitoring points as time series data at typically ~1 Hz rates) from all assemblies and devices of the ASTRI MA System, including the Environmental Monitoring System and saves them in the Monitoring Archive. It provides a post facto framework for the evaluation and analysis of abnormal situations.

4.1.8. Logging System

The software system that gets logging information from relevant software and hardware components that generate logs and stores them.

4.1.9. Operator Human Machine Interface

The web client connected to the SCADA web server. It is an easily accessible, all-in-one-place near-real-time overview of the Mini-Array status that can be used for night and day operations for the main control and monitoring of the MA.

4.1.10. Telescope Control System

The software system responsible for coordinating all Telescope assemblies, starting up, configure, and shutting down the assemblies of the Telescope, supervising optical system control, telescope mount control and instrument control (Cherenkov Camera, Optical Camera and SI^3).

4.1.10.1. Telescope Manager

The software component responsible for coordinating all TCS subsystems and starting up and shutting down the system.

4.1.10.2. Mount Supervisor

The software component that controls and monitors the mount LCS and other auxiliaries.

4.1.10.3. Optics Supervisor

The software component that controls and monitors the Optics LCS and the Optical Camera LCS.

4.1.10.4. Cherenkov Camera Supervisor

The software component that controls and monitors the Camera LCS.

4.1.10.5. SI3 Supervisor

The software component that provides an interface to the SI^3 LCS.

4.1.10.6. Engineering GUI

The GUI provided by the telescope manager to interact with all TCS subsystems that shall be accessed remotely for troubleshooting and maintenance.

4.1.11. Array Calibration Control System

The software system used to control, configure and manage the status of all assemblies of the Array Calibration System and is part of the SCADA system.

4.2. Archive System

The software system that provides a central repository for all persistent information of the MA system such as Observing Projects, observation plans, raw and reduced scientific data, device monitor data, MA system configuration data (past, present and planned), logs of all operations and schedules.

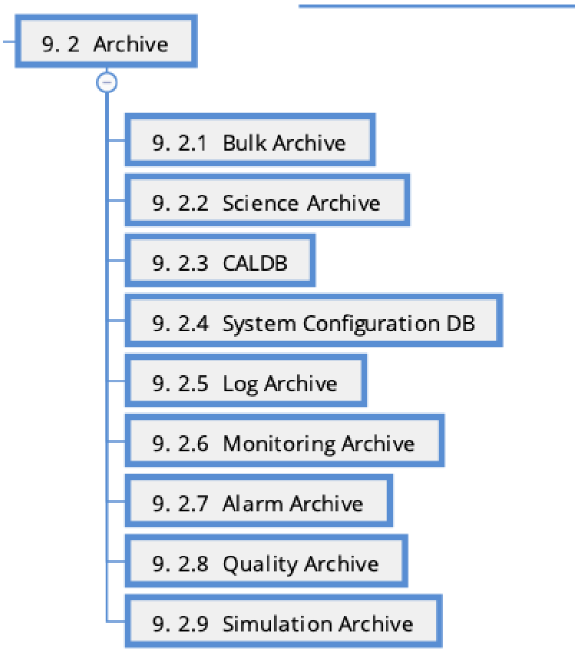


Figure 3: Archive System

4.2.1. Bulk Archive

The archive that stores raw data from the Cherenkov camera, SI3 and other assemblies, acquired by the Array Data Acquisition System.

4.2.2. Science Archive

The archive service that stores data products of the following data models: (i) Observing Projects DM; (ii) Science DM and connected DMs; (iii) High-level (DL3) scientific data and data products (i.e., event lists and IRFs).

4.2.3. CALDB

The dedicated calibration database, organized following HEASARC's CALDB format, that stores IRFs, LUTs, ML-MODELs, and other instrumental and pre-computed quantities available for being used throughout the entire scientific data reduction chain.

4.2.4. System Configuration DB

The archive system to store the configurations described by the System Configuration Data Model.

4.2.5. Log Archive

The archive system that stores the logs produced by all components and acquired by the Logging System.

4.2.6. Monitoring Archive

The archive system that stores all the Monitoring Data Model subtypes (e.g. monitor device, environmental data) acquired by the Monitoring System.

4.2.7. Alarm Archive

The archive system that stores the alarms produced by all components and the monitoring data acquired by the Alarm System to generate alarms.

4.2.8. Quality Archive

The archive system that stores the Cherenkov and Intensity Interferometry observations data quality results produced by the Online Observation Quality System.

4.2.9. Simulation Archive

The archive system that contains all the Monte Carlo simulation events simulated by the Simulation System for the different MA configurations.

4.3. Data Processing System

The software system that calibrates, reduces and analyses the acquired data. This system is also used to check the quality of the final data products.

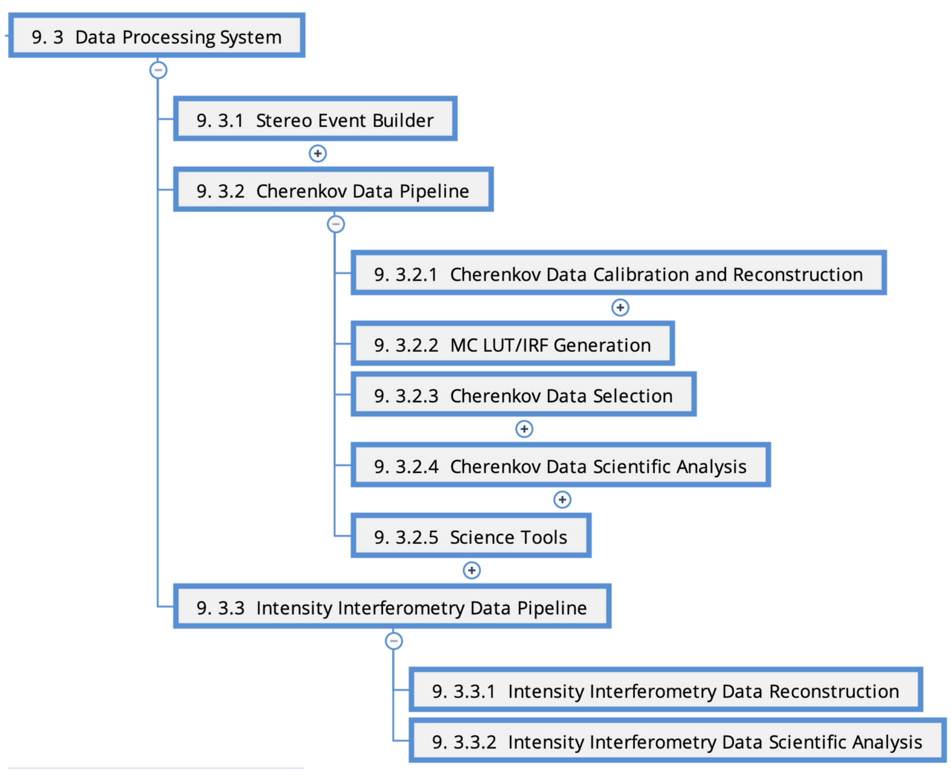


Figure 4: Data Processing System

4.3.1. Stereo Event Builder

The software system that performs the off-line software stereo array trigger of Cherenkov data.

4.3.2. Cherenkov Data Pipeline

The software component that: (i) generates short-term data products/processing results to give feedback to the Operator and Astronomer on-duty, and (ii) generates final Data Release Products/Processing data products. The same data reduction chain applies both for real (EVT) and simulated Monte Carlo (MC) data.

4.3.2.1. Cherenkov Data Calibration and Reconstruction

The Cherenkov Data Calibration and Reconstruction shall perform the following steps: (i) event calibration (from DL0 to DL1a), and (ii) reconstruction (from DL1a to DL2b).

4.3.2.2. MC/LUT IRF Generation

The software tool that generates LUTs and low-level IRFs for Cherenkov data reconstruction and scientific analysis.

4.3.2.3. Cherenkov Data Selection

The software component that performs the generation of the stereo event-list (from DL2b to DL3) and the IRF3 generation.

4.3.2.4. Cherenkov Data Scientific Analysis

The software system used to analyze DL3 data to get, in an automated way, preliminary and final science products (DL4) from the Data Processing System, such as detection plots, spectra, sky-maps, and light-curves, starting from the fully reduced data (EVT3/IRF3).

4.3.2.5. Science Tools

The software tools used to analyze the DL3 data to get final scientific products (DL4).

4.3.3. Intensity Interferometry Data Pipeline

The software component that is devoted to the data reconstruction and scientific analysis of the Intensity Interferometry data.

4.3.3.1. Intensity Interferometry Data Reconstruction

The software component that determines the time tags of each event from the raw data acquired with the Time-to-Digital-Converter (where the signal of the SI^3 is sent). This is done independently for each telescope.

4.3.3.2. Intensity Interferometry Data Scientific Analysis

The software component that implements all algorithms needed to perform the calculation of the diagram of the temporal correlation per each pair of telescopes. This is done independently for all pairs of telescopes (36 baselines).

4.4. Science Support System

The main interface for Science User to the MA system and provides them with easy-to-use HMI for the detailed specification of observations. The main products generated by this system are the Scheduling Blocks. The Science Support System also contains the Science Gateway, a web interface that shall be used to access high-level science-ready data and data products produced by the Data Processing System.

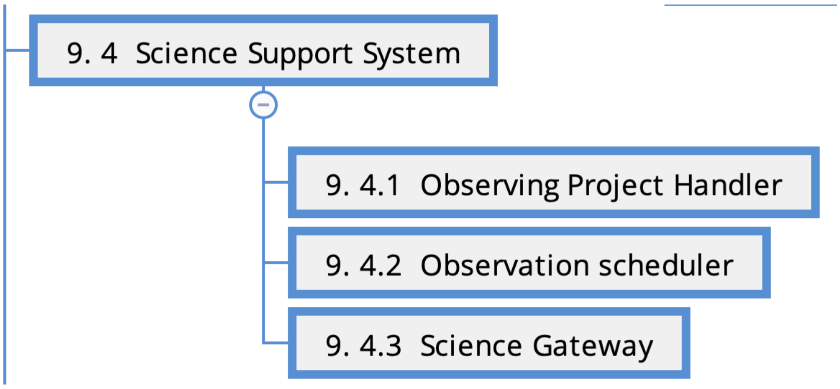


Figure 5: Science Support System

4.4.1. Observing Project Handler

The software component that allows ASTRI Science Users to submit Observing Projects finalized to perform scientific, technical, calibration and intensity interferometry observations with the ASTRI MA.

4.4.2. Observation Scheduler

The software tools (Visibility Checker and a Sensitivity Calculator, collectively called Observation Scheduler) used, to check the visibility of the proposed target and, giving the expected IRFs produced using the MC simulated data, to provide an estimate of the observation time needed to reach the scientific goal of the proposal.

4.4.3. Science Gateway

The software system that provides a web interface used to access high-level science-ready data and data products (event lists and IRFs) produced by the Data Processing System and to download Science Tools.

4.5. Simulations System

The system that provides simulated scientific data for the development of reconstruction algorithms and for the characterisation of real observations.

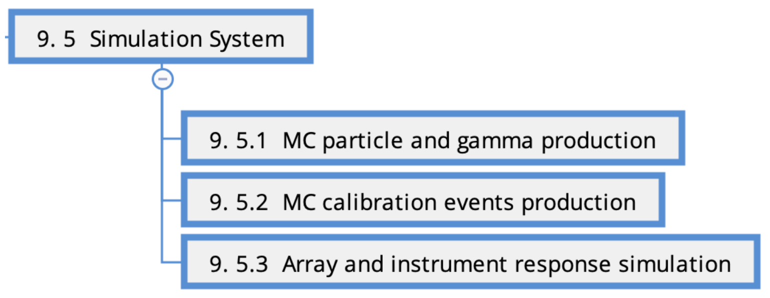


Figure 6: Simulation System

4.5.1. MC particle and gamma production

The software component that performs the simulation of atmospheric showers using the *CORSIKA* code.

4.5.2. MC calibration event production

The simulation for calibration purpose of events due to muon-tracks in the atmosphere or pulsed light sources.

4.5.3. Array and instrument response simulation

The simulation of the telescope response will be simulated with the sim_telarray package.

4.6. Local Control Software

The software part of a **Local Control System**.

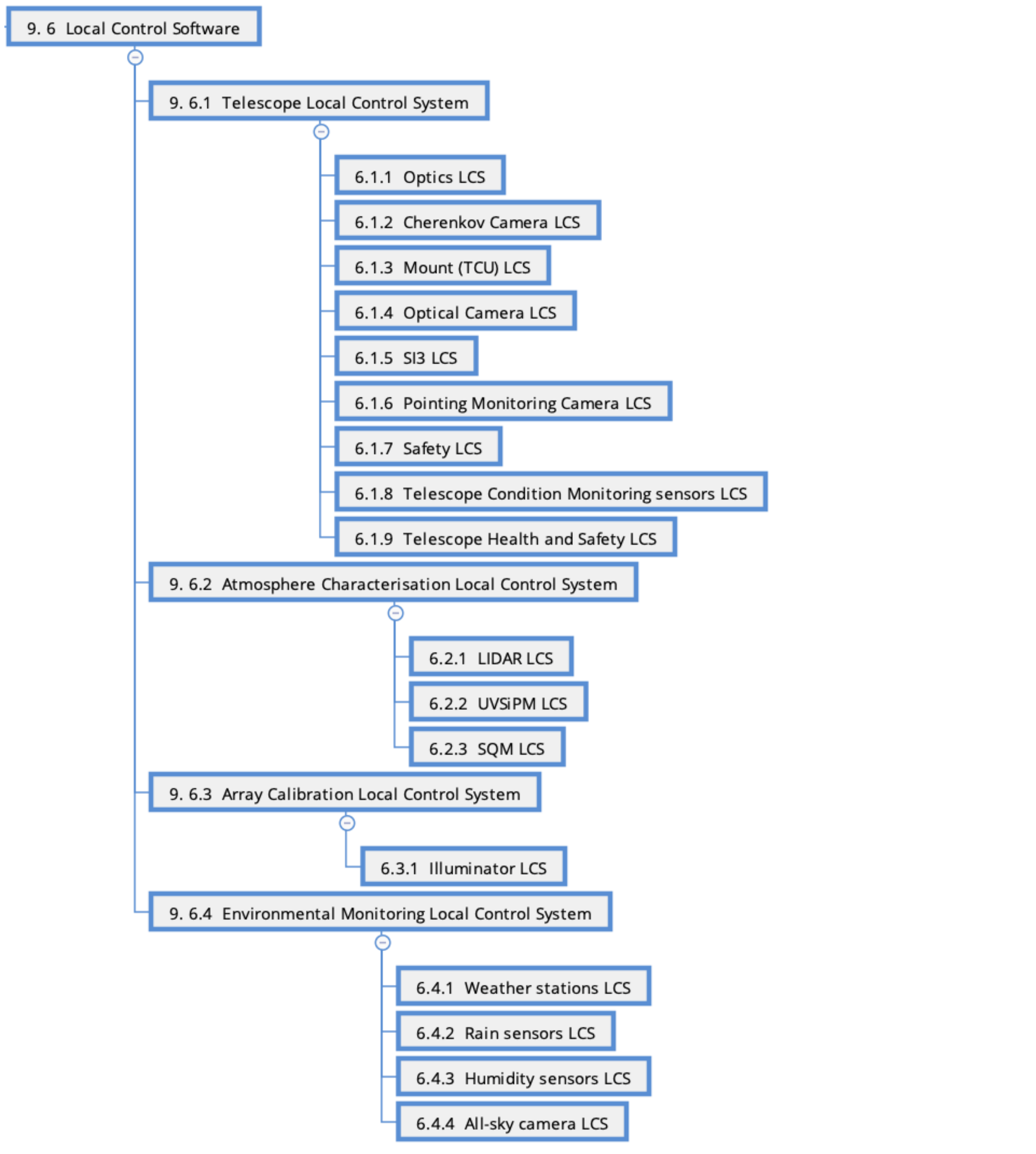


Figure 7: Local Control Software

4.6.1. Telescope Local Control System

It is a set of Local Control Software and hardware to control the different assemblies of the telescope.

4.6.1.1. Optics LCS

It is responsible for the control of the M2 mirror (focusing) and of the special mechanism that will be used to align the M1 segments during the telescope commissioning and maintenance.

4.6.1.2. Cherenkov Camera LCS

The local control software that runs on the Back End Electronics (BEE) of the Cherenkov Camera. It is responsible for the management, in terms of control and monitoring operations, of all the hardware subsystems attached to the BEE which compose the Cherenkov Camera.

4.6.1.3. Mount (TCU) LCS

It is responsible for the control of the motion of the mechanical structure (including the kinematic chains and the drives). This system runs on the Telescope Control Unit (TCU).

4.6.1.4. Optical Camera LCS

The local control software of the Optical Camera.

4.6.1.5. SI3 LCS

The local control software of the SI^3.

4.6.1.6. Pointing Monitoring Camera LCS

The local control software of the Pointing Monitoring Camera.

4.6.1.7. Telescope Health and Safety LCS

It is responsible for monitoring the status of all telescope subsystems and for the startup and shutdown of all the assemblies mounted on the telescope, including the instruments and the commissioning and maintenance mechanisms that will be temporarily mounted on the Mount Assembly. This system runs on a Telescope Health Control Unit (THCU) and shall be able to receive triggers from the telescope Safety Unit in case of any hazards requiring the telescope to reset to safe state.

4.6.2. Atmosphere Characterisation Local Control System

The set of hw and Local Control Software to control the different assemblies of the Atmosphere Characterisation System. It provides an OPC-UA interface that is used by the Atmosphere Characterisation Control System.

4.6.2.1. LIDAR LCS

The local control software of the LIDAR.

4.6.2.2. UVISiPM LCS

The local control software of the UVSiPM.

4.6.2.3. SQM LCS

The local control software of the SQM.

4.6.3. Array Calibration Local Control System

It is a set of hw and Local Control Software to control the different assemblies of the Array Calibration System.

4.6.3.1. Illuminator LCS

It is the local control software of the Illuminator.

4.6.4. Environmental Monitoring Local Control System

It is a set of hw and Local Control Software to control the different elements of the Environmental Monitoring System.

4.6.4.1. Weather station LCS

It is the local control software of the Weather Stations.

4.6.4.2. Rain sensors LCS

It is the local control software of the Rain Sensors.

4.6.4.3. Humidity sensors LCS

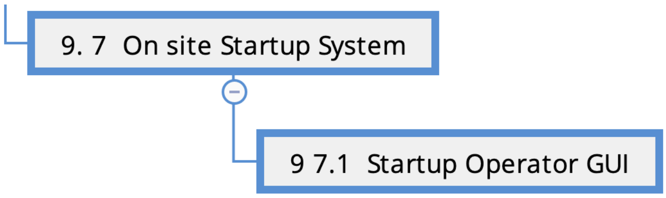
It is the local control software of the Humidity Sensor.

4.6.4.4. All-Sky camera LCS

The local control software of the All-Sky Camera that evaluates the cloudiness around the pointing direction of the current ASTRI MA observation.

4.7. On site Startup System

It manages the sequence of the startup and shutdown of the critical on-site systems.



4.7.1. Startup Operator GUI

The GUI of the Startup System;