The SCADA Software System of the ASTRI Mini-Array: Architecture, Control Workflow, and Operational Integration

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for the ASTRI Project

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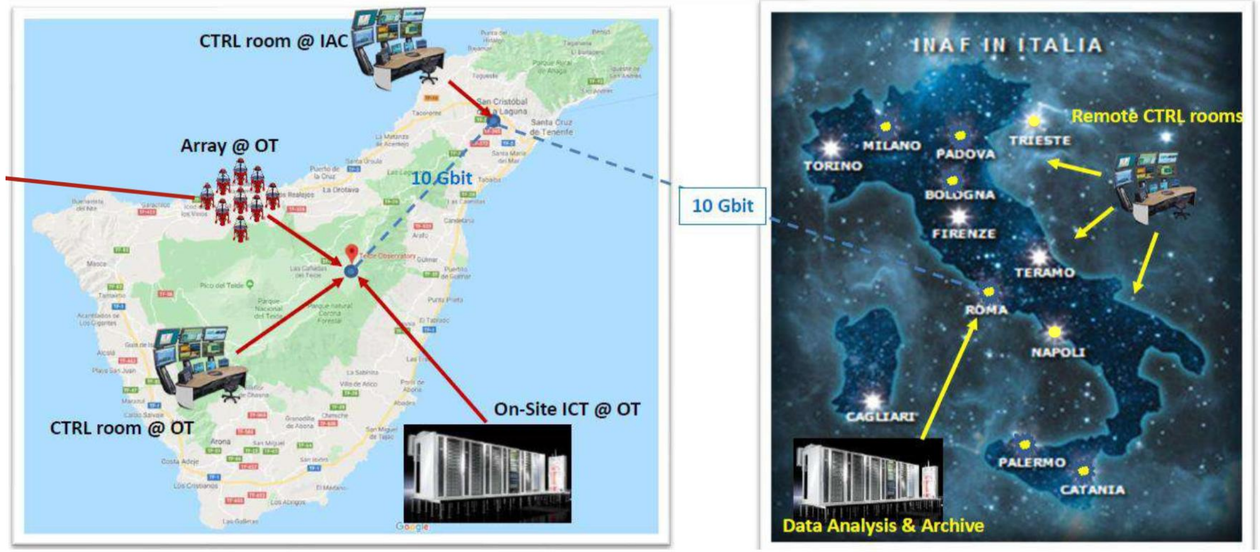
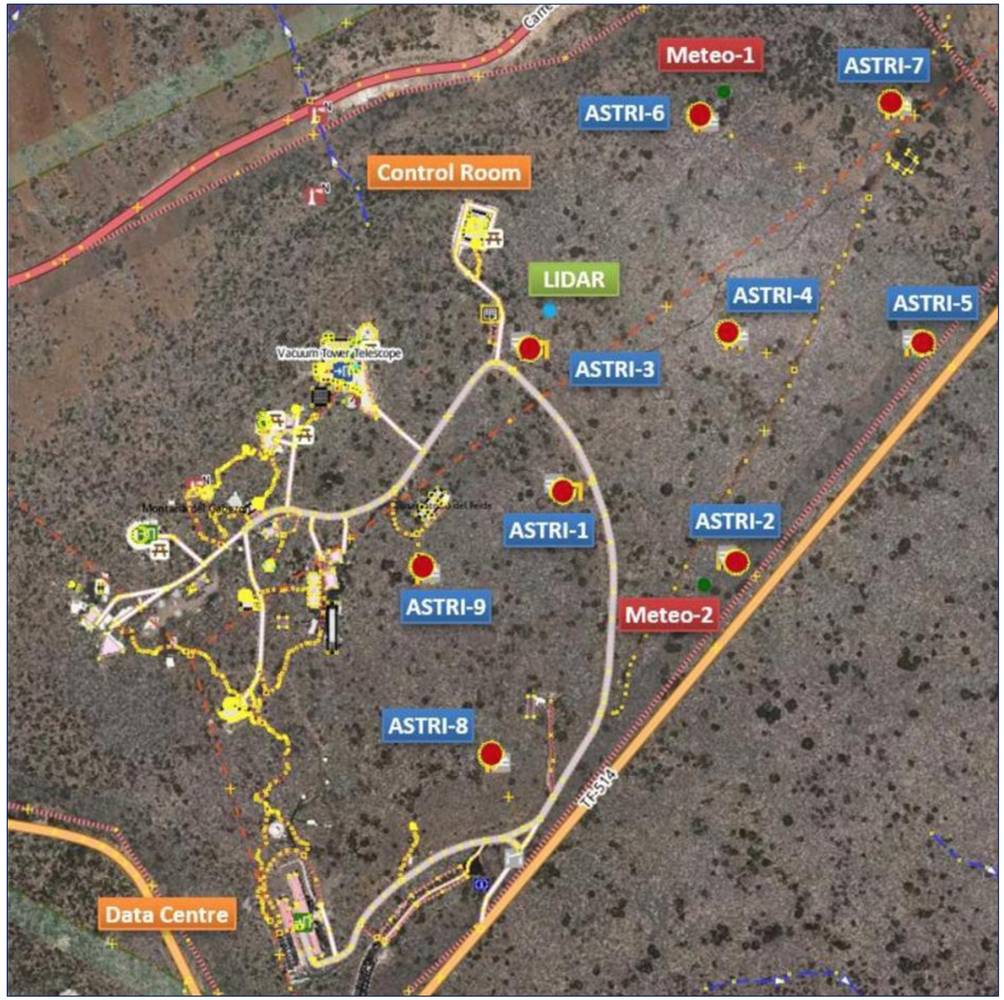
ASTRI: from system components…

The ASTRI Mini-Array (MA) System Components:

- **Telescope Array System:** 9 Telescopes with hardware, including Cherenkov Camera and Stellar Intensity Interferometry Instrument.
- **Atmosphere Characterisation System:** 1 LIDAR, 3 Sky-Quality Meters, 1 UVSiPM
- **Environmental Monitoring System** (Multiple Weather Stations, Humidity/Rain sensors, All-sky camera)
- **Telescope Power Management System** (Transformer Station)
- **Information Communication Technology** (On-site Data Centre, Control Room)
- **Safety and Security system**
- On- and Off-site **Data** and **Operation Centres** (Tenerife & Italy)



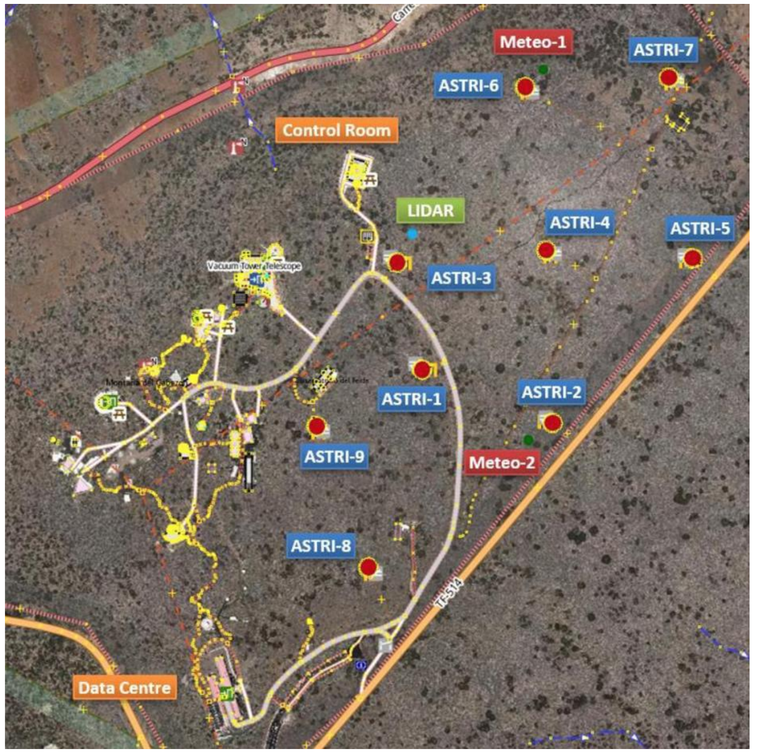


ASTRI at Teide Observatory, in Tenerife, and Italy

… to project objectives

ASTRI Project Objectives:

- **Science Program:** 4yr (Core Science Program) + 4yr (Observatory)
- Important **Synergies** with Northern facilities (CTAO-N, MAGIC, VERITAS, HAWC, LHAASO)
- **ASTRI Mini-Array Unprecented Performances:** Multi-TeV range (1-200 TeV), Wide FoV ($\sim 10°$), Excellent off-axis performance, Angular Resolution ($\sim 3'$ at 10 TeV), Energy Resolution ($\sim 10\%$ at 10 TeV)
- **Remote Control and Operations**



ASTRI End-to-end Approach: manage operations to connect all project steps, from integration of hardware/software components, through operations, to reaching project goals and communicate final scientific products.

How?

Supervisory Control And Data Acquisition (SCADA) System

SCADA & the ASTRI MA Software Architecture

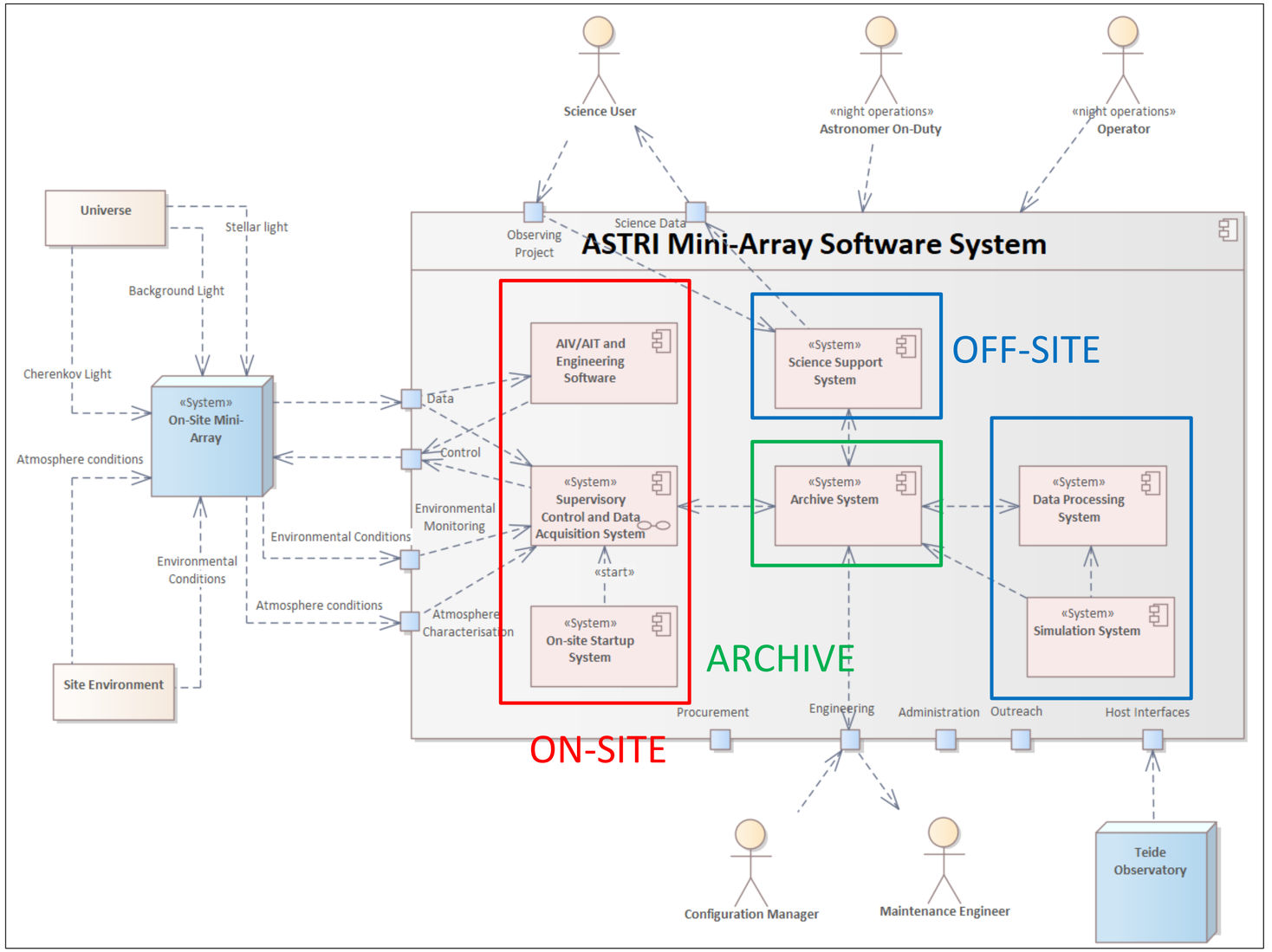
SCADA (On-site) can:

- Interface, control, monitor, manage alarms of all software subsystems and assemblies
- Automatically execute start-up operations needed for observations.
- Perform Data Acquisition
- Perform On-line Data Quality (OOQS)
- Automatically react to critical conditions to bring ASTRI in a safe state

Complemented by:

- On-site Startup System
- AIV/AIT and Engineering Software
- Archive System
- Data Processing System (Off-site)
- Science Support System
- Simulations System

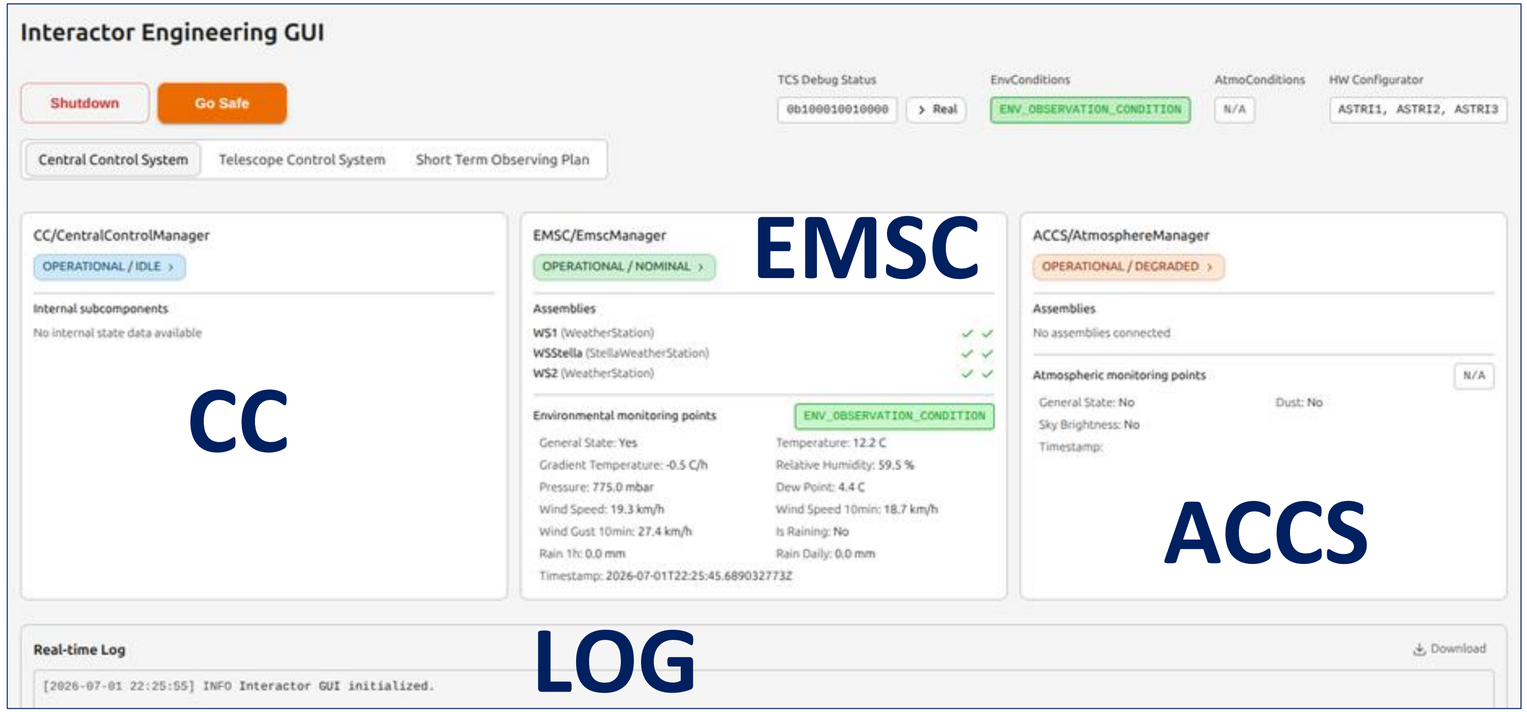
Supervised by an Operator with an HMI (Human-Machine Interface)



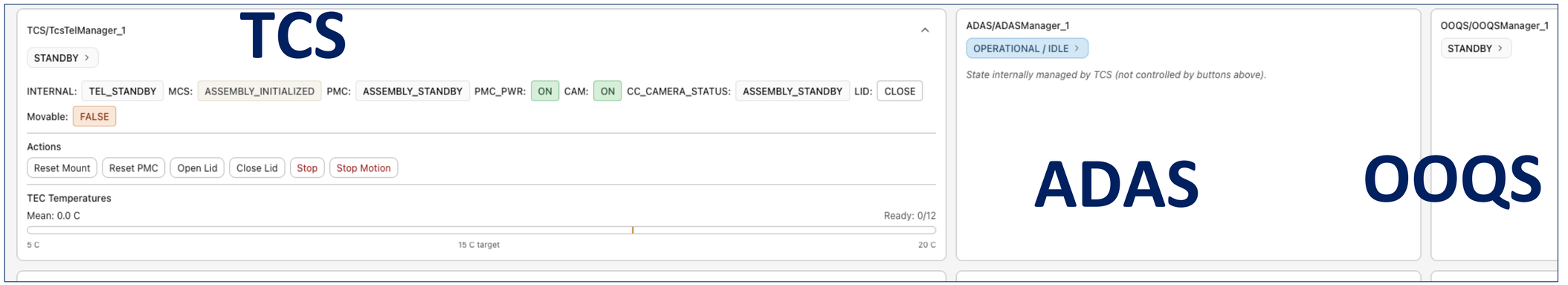
SCADA Components

SCADA software components:

- **CC (Central Control)** coordinates components and operations
- **System Collectors (-SC)** receive info, status and alarms from external devices: Environmental Monitoring (**EMSC**), ICT, Power System, Safe and Security System.
- **Control Systems (-CS)** control and operate devices: Telescopes (**TCS**), Atmospheric Characterisation (**ACCS**), Array Calibration, Telescope Service Cabinets
- Data Acquisition/Quality: Array Data Acquisition System (**ADAS**), Online Observation Quality System (**OOQS**)
- Monitoring/Alarms/Logging systems



SCADA HMI: system components overview



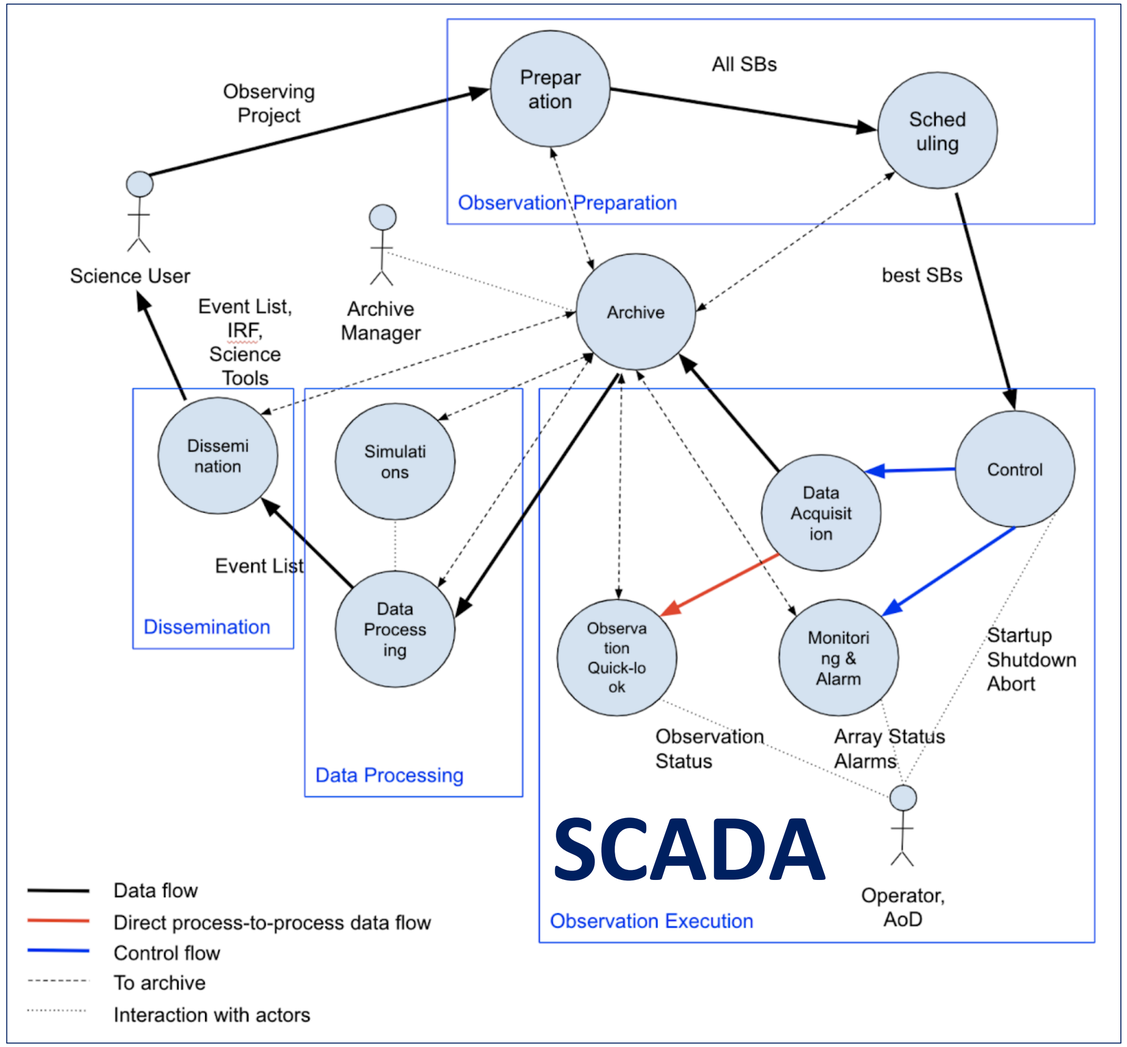
SCADA: a state-machine for the observation cycle

SCADA works as a **State Machine:**

- Subsystems are described by a deterministic state (e.g. **INITIALISED**, **STANDBY**, **IDLE**, **NOMINAL**, **DEGRADED**, **FAULT**)
- State Transitions are strictly regulated
- State Machines create predictable and robust control frameworks
- States and Transitions implement the **Observing Cycle**

ASTRI **Observing Cycle**:

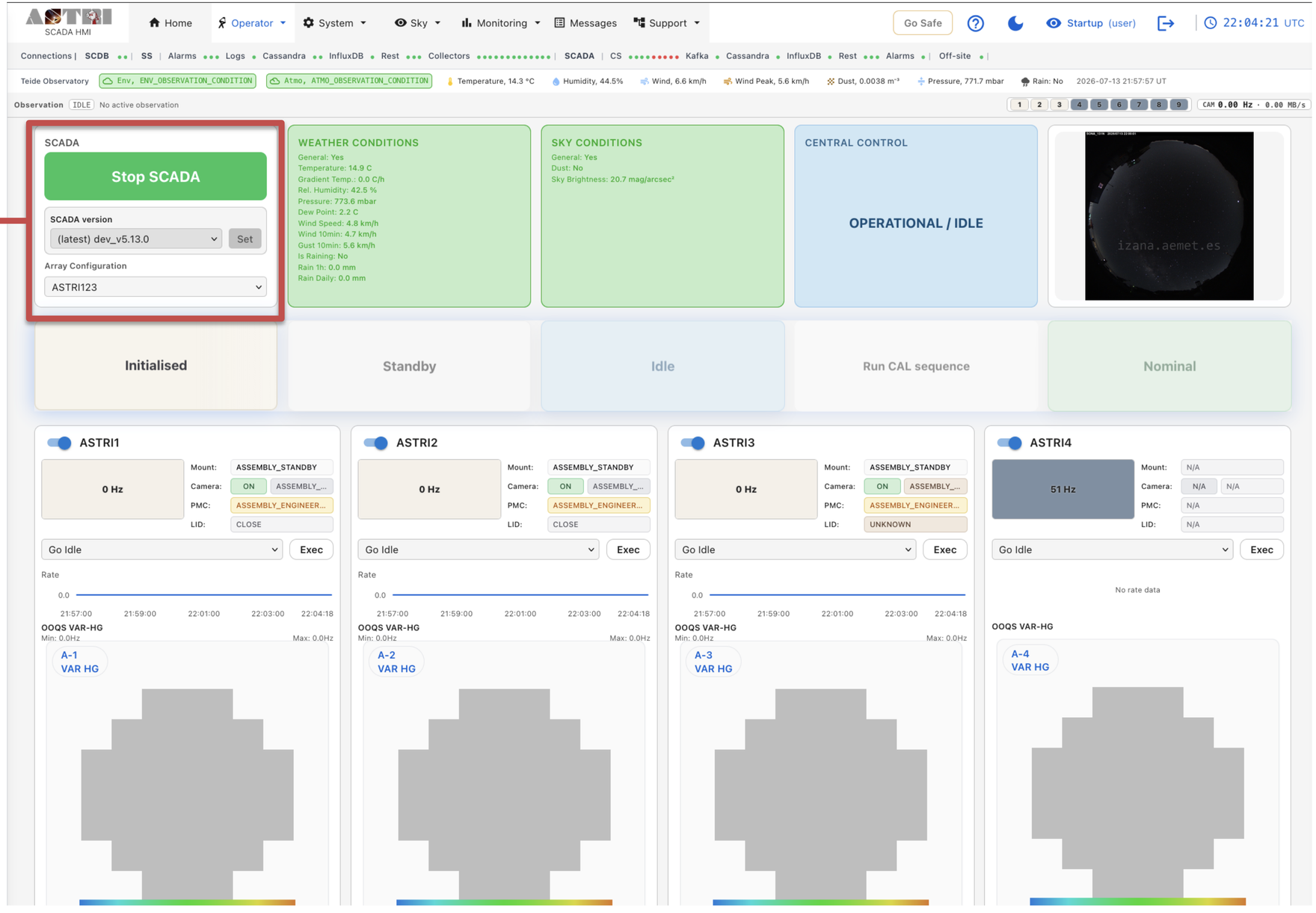
1. Convert an Observing Project into **Scheduling Blocks** (SBs) of **Observation Blocks** (OBs)
2. **SCADA** executes OBs
3. Data Processing produces calibrated and reconstructed data
4. Dissemination: Data and Science Tools are distributed for a scientific analysis of the Observing Project



ASTRI Observing Cycle

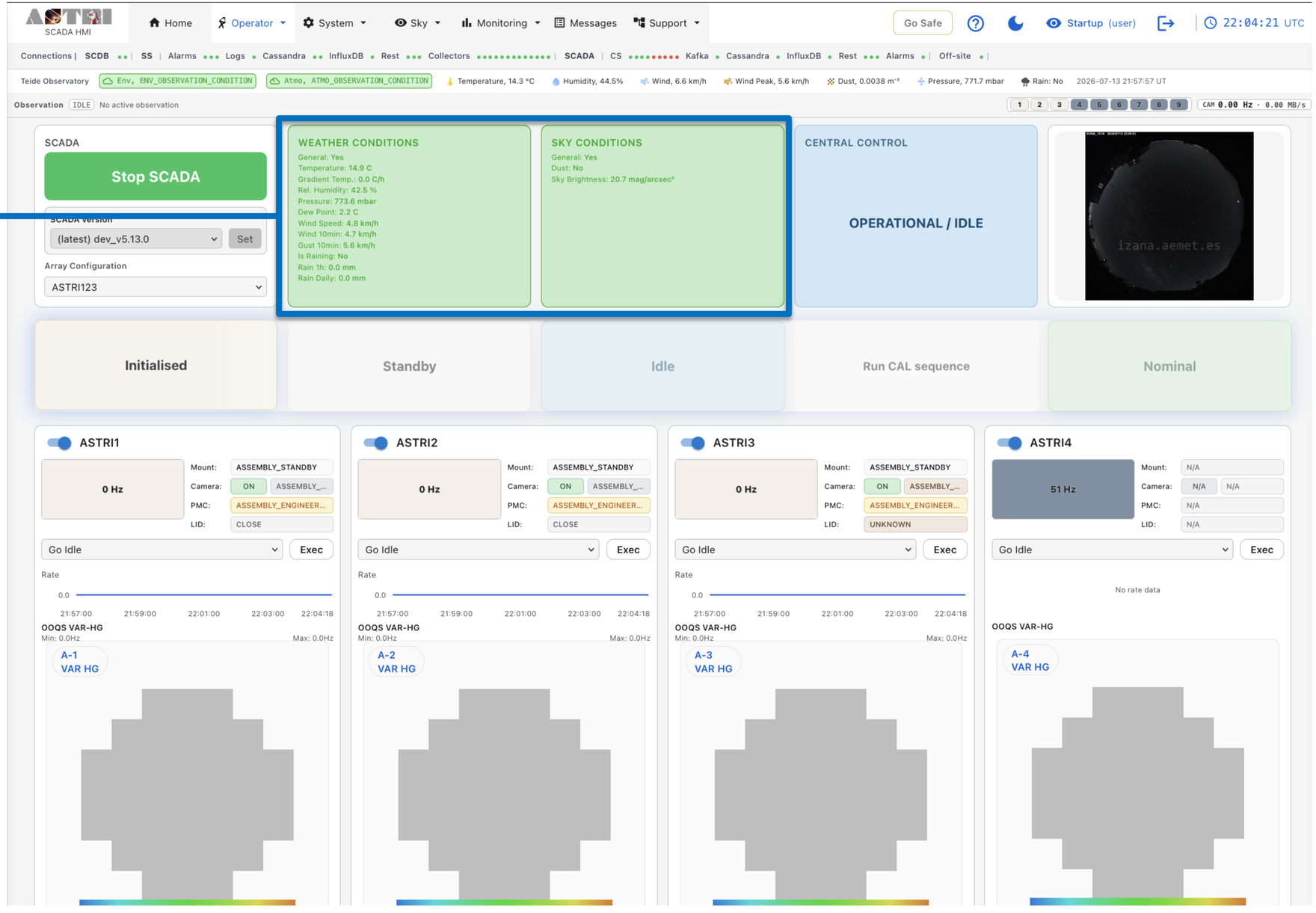
SCADA Operating ASTRI

Turn ON/OFF SCADA



SCADA Operating ASTRI

CHECK ENV AND SKY CONDITIONS!

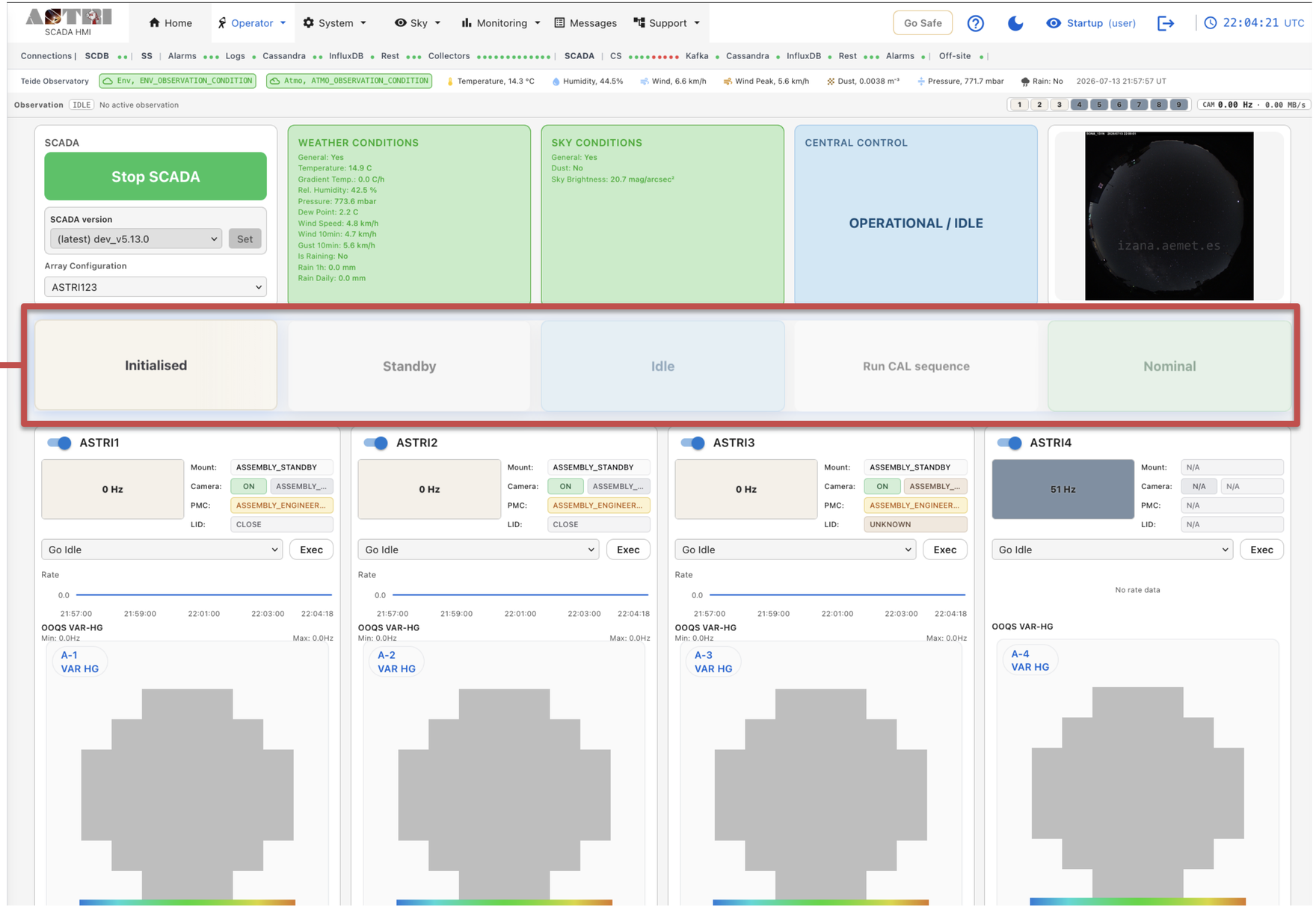


SCADA Operating ASTRI

STATE TRANSITION BUTTONS
Press to Change Array Status

Main **TCS** Array States:

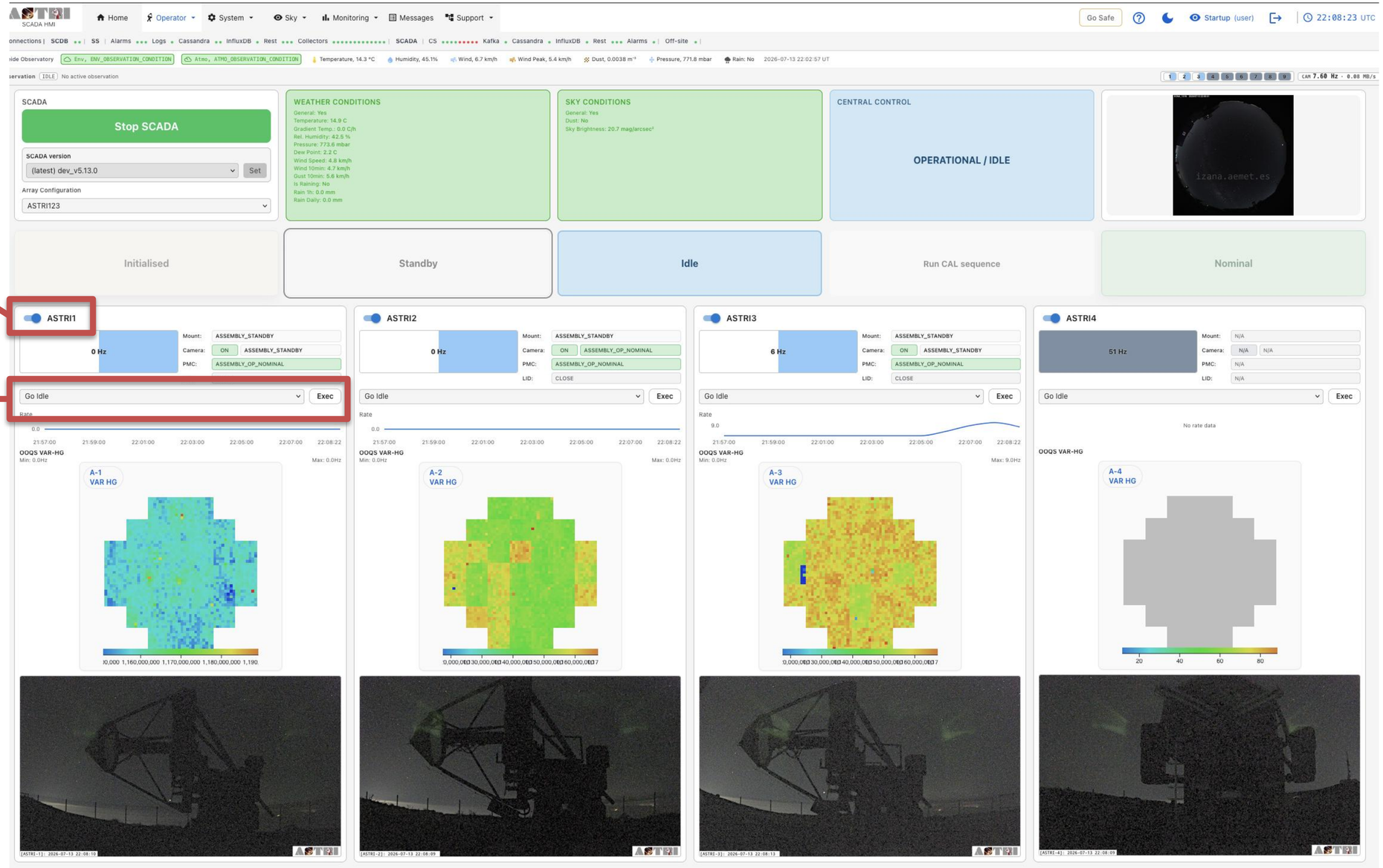
- **INITIALISED:** Camera OFF
- **STANDBY:** Camera ON, LID Closed
- **IDLE:** Camera Thermalised and **Ready for Calibrations!**
- **NOMINAL:** Open LID, Mount Movable and **Ready for Observations!**
- **FAULT:** Main Subsystem Error



SCADA Operating ASTRI

Dis/Connect individual TCS

Individual TCS Commands



SCADA Operating ASTRI

States: | TCS | ADAS |

Main **ADAS** States:

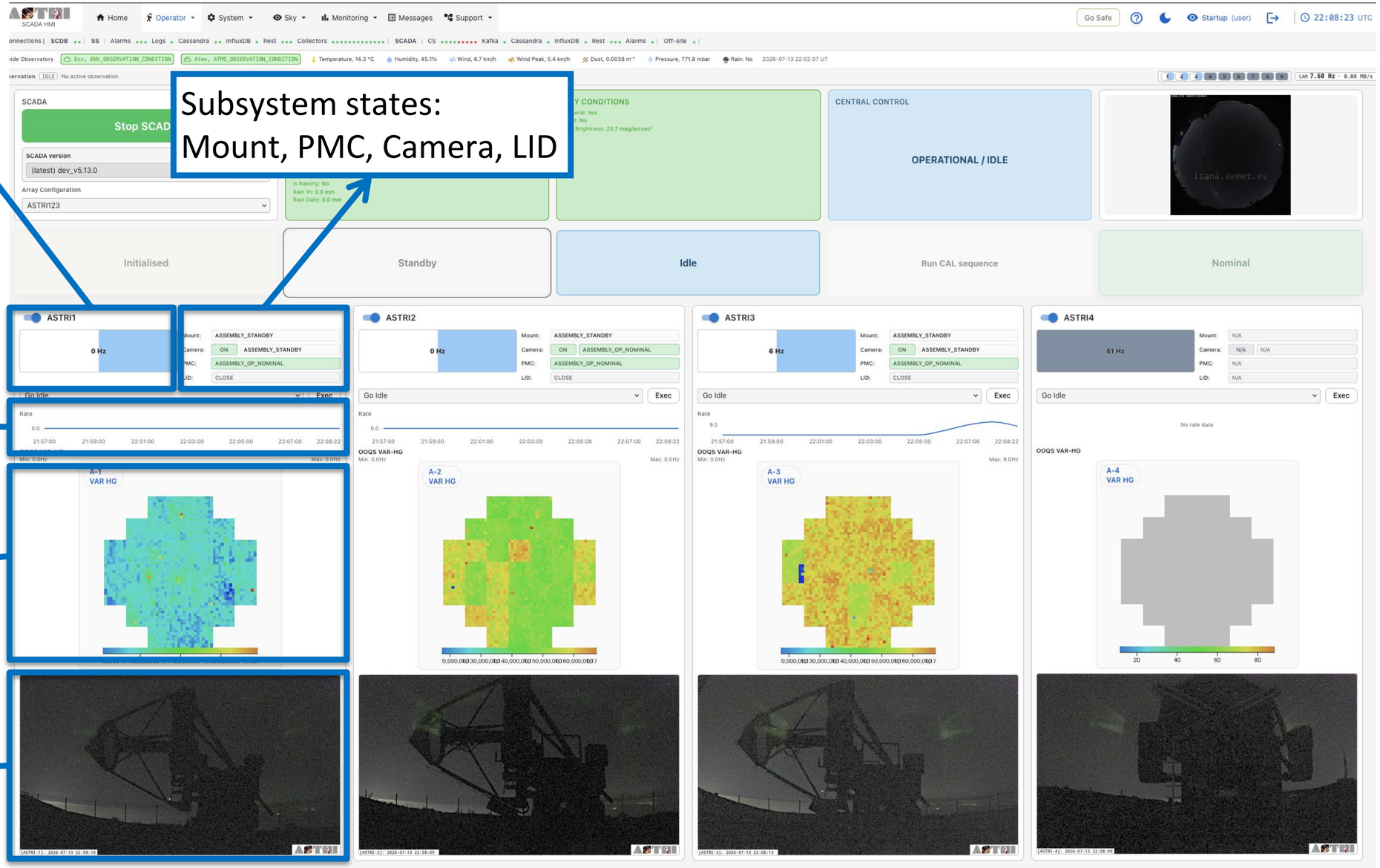
- **INITIALISED:** Off.
- **IDLE:** On and ready.
- **NOMINAL:** Taking Data!

Subsystem states:
Mount, PMC, Camera, LID

Camera Rate

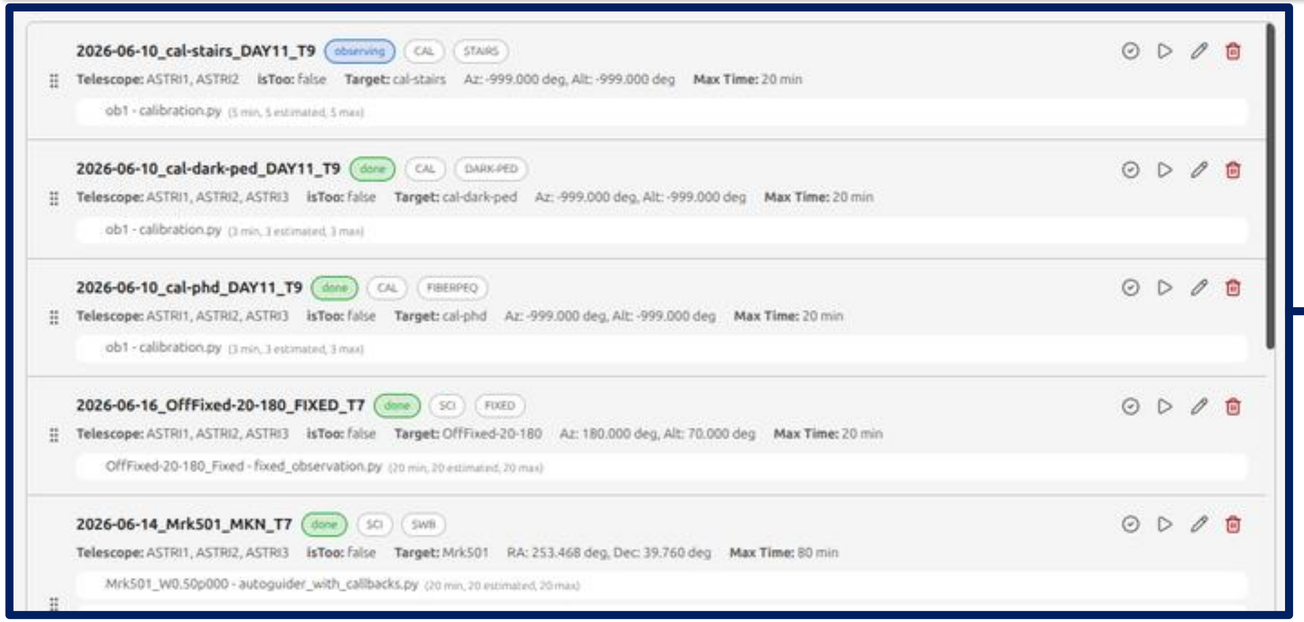
OOQS
Camera Images

Check CCTV



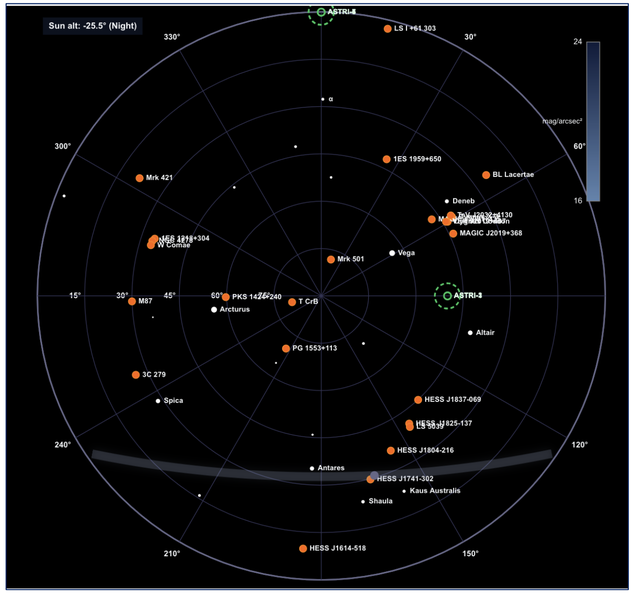
SCADA Operating ASTRI

Mini-Array



Select SB from the **Short-Term Schedule:**

- **Update** (if needed): list of telescopes, OB duration and number
- **Execute** observations!

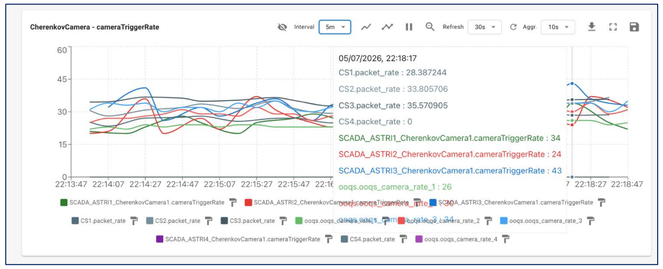


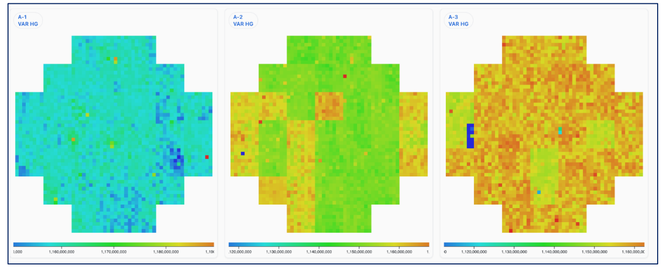
Source Visibility Charts

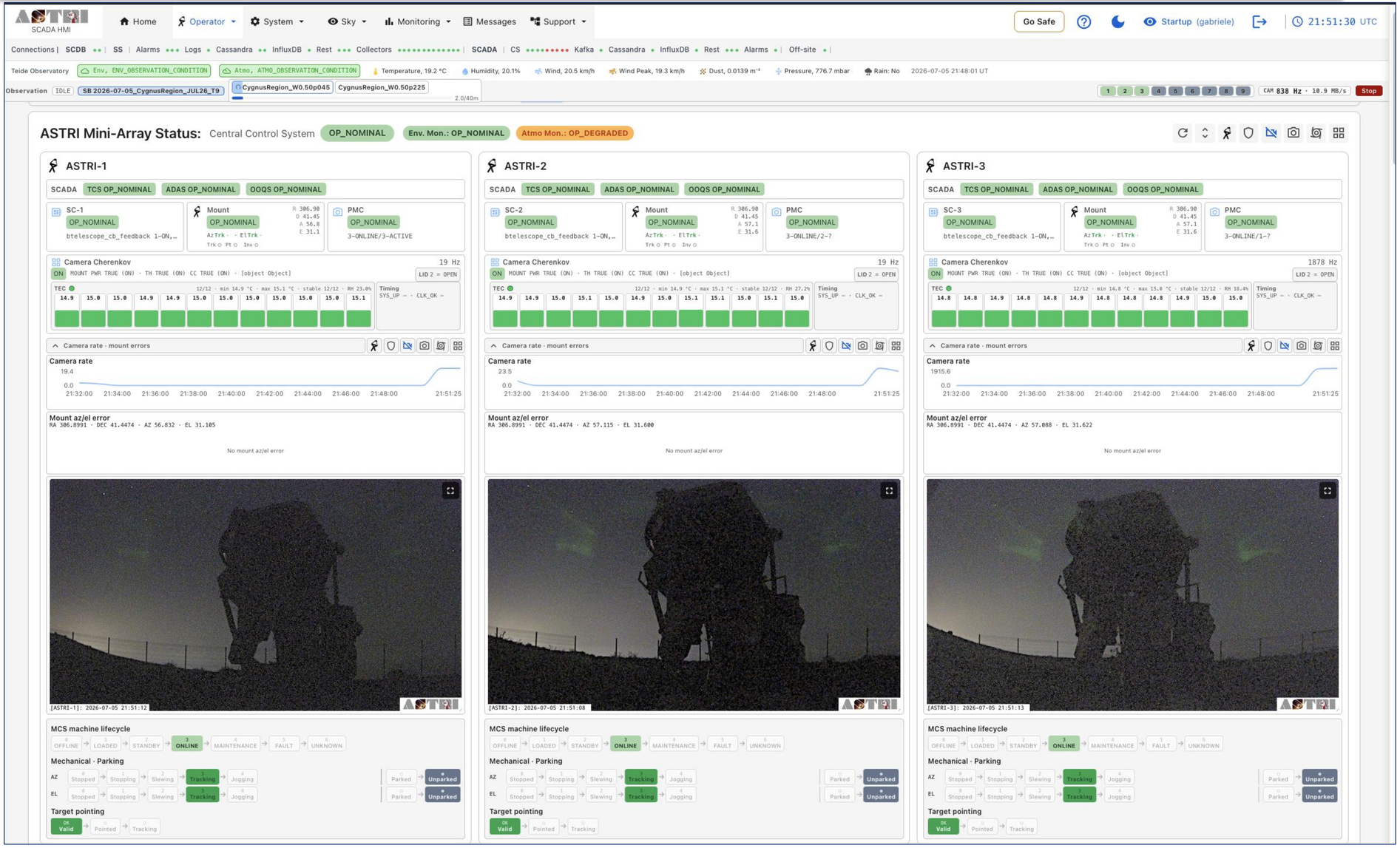
… Enjoy your observations…

Mini-Array

Several additional plots are available in the HMI STATUS page: Rates, pointing, full OOQS products, Safety Chains, Mount Tracking…



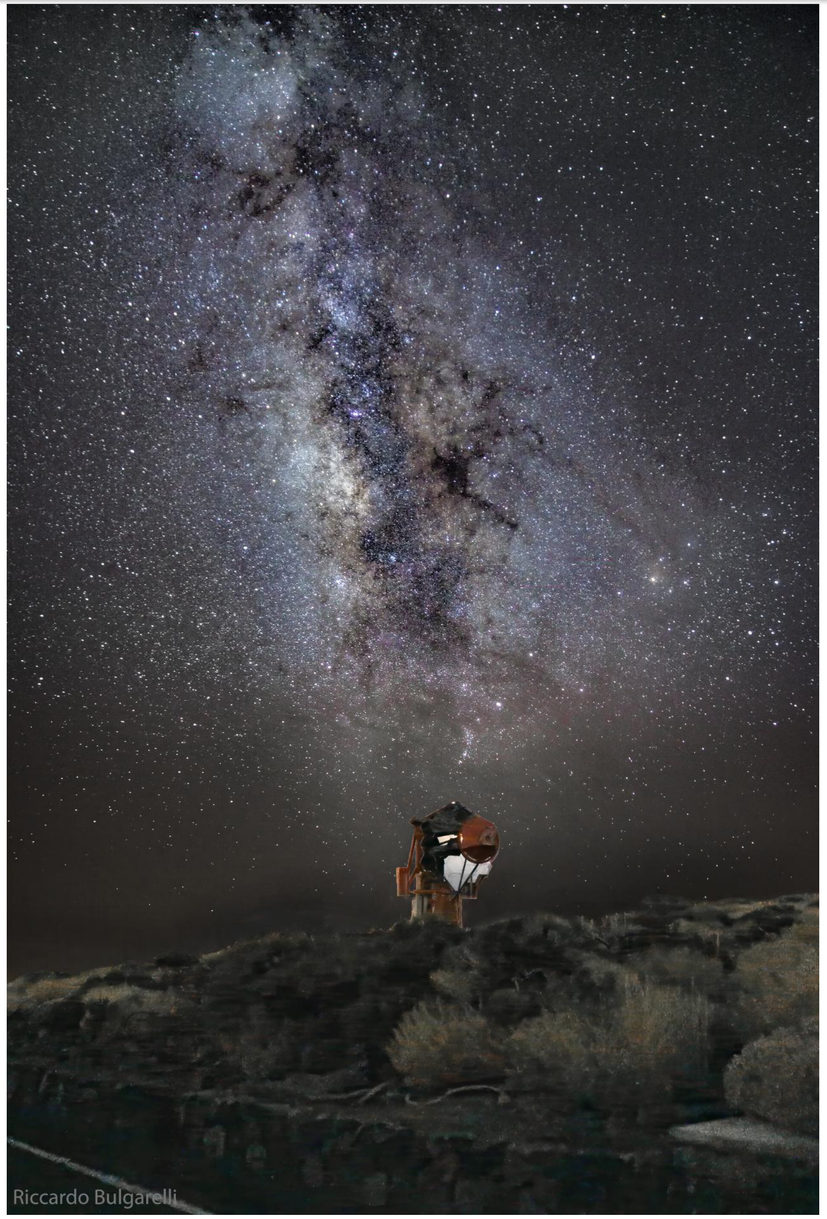




.. And don’t forget to park at dawn!

Results and Conclusions

- SCADA is a core component of the ASTRI-MA Software, bringing observations to life
- Operations proceed through State Machine implementation
- **SCADA Observation Campaign with (up to) ASTRI 1, 2, 3 (June, 18 – July, 21): Cygnus Region (≈39h), Mrk 501 (≈19h), Off-fixed (≈13h background study)**
- Constant Improvement: from SCADA v5.6 to v5.13 in 40 days!
- ASTRI 4: Integration in August
- Preparing for Autumn 2026 observation campaign with more telescopes…


Riccardo Bulgarelli

Extra

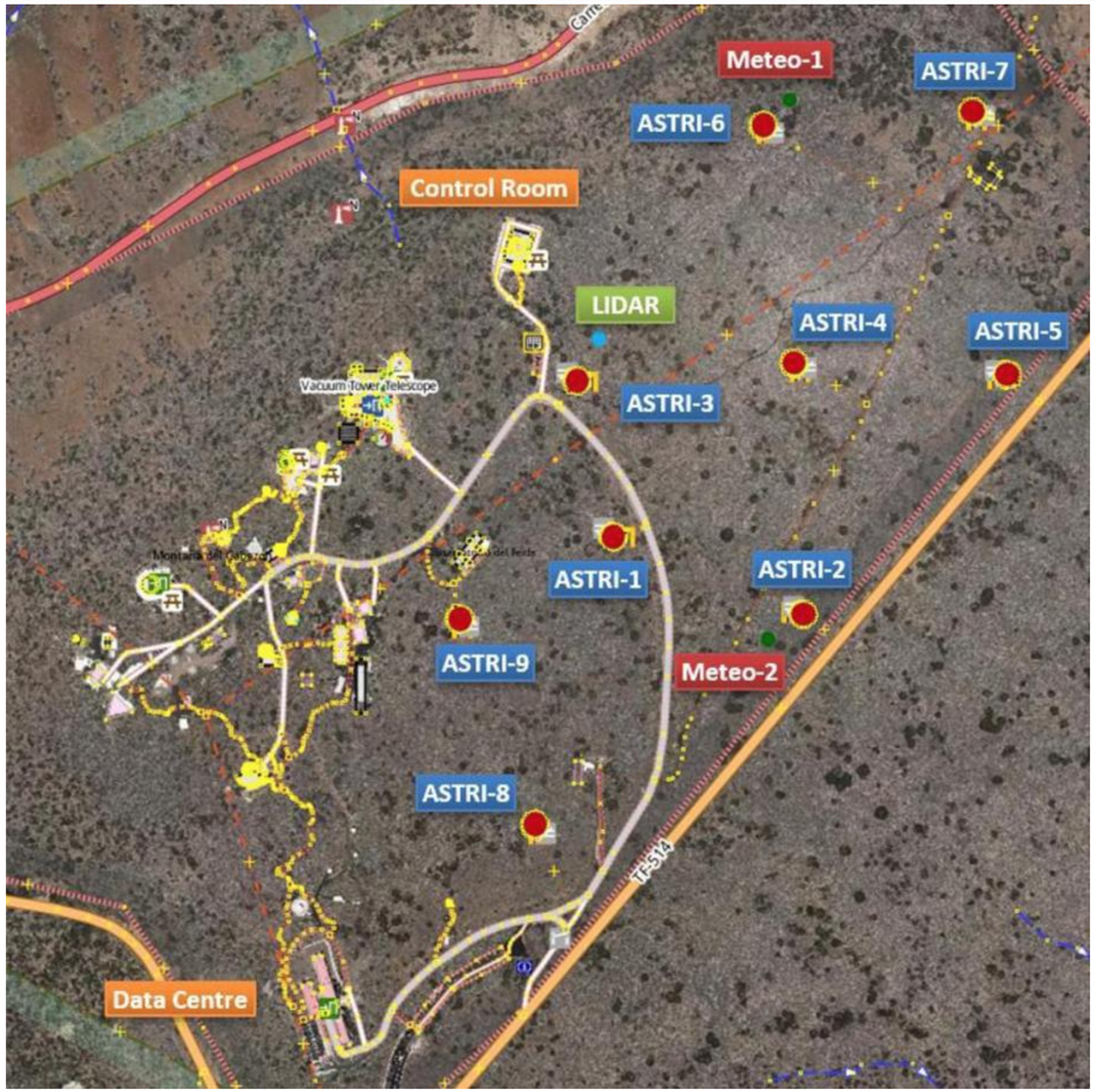
The ASTRI Mini-Array System

Array System, nine Telescopes with their hardware assemblies, including **Cherenkov Camera** and **Stellar Intensity Interferometry Instrument**.

- **ASTRI-1, ASTRI-2, ASTRI-3; ASTRI-4, ASTRI-5, ASTRI-6, ASTRI-7, ASTRI-8, ASTRI-9**

Atmosphere Characterisation System

- **1 LIDAR** (LIght Detection And Ranging) atmospheric composition, structure, clouds and aerosols
- **3 SQM** (Sky Quality Meter): brightness of the night sky.
- **1 UVSiPM**: diffuse night sky background.



The ASTRI Mini-Array at the Teide Observatory

Telescope Power Management System

- **Transformer Station**

Information Communication Technology

- **On-site Data Centre**
- **Control Room**

Safety and Security system

Environmental Monitoring System

- Weather Stations
  - Meteo-1
  - Meteo-2
  - Stella
- Humidity and rain sensors;
- All-sky camera: cloud coverage

ASTRI Mini-Array

End to end approach from design/implementation of all HW/SW components to dissemination of final scientific products.

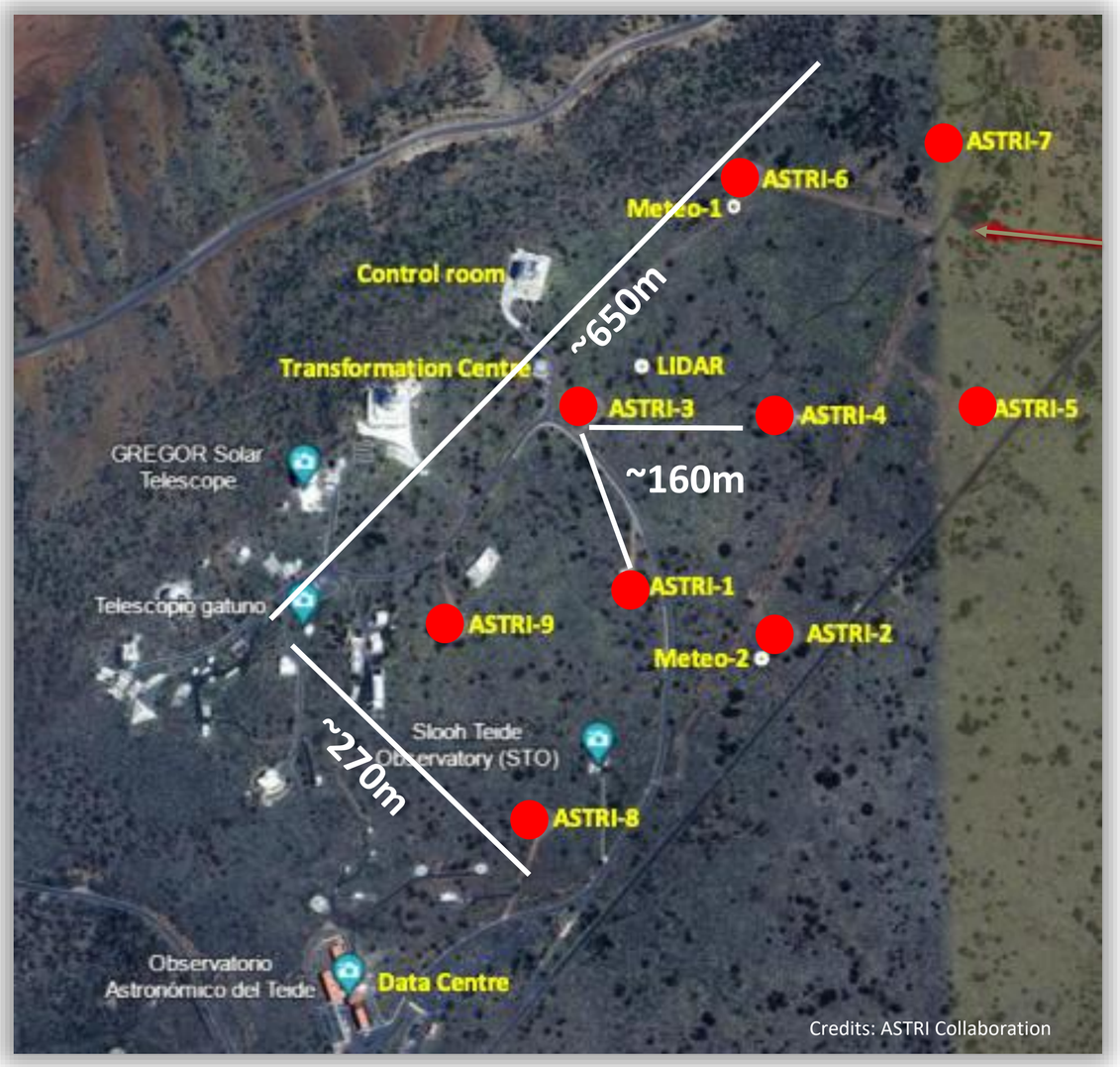
Science Program : 4 year (Core Science Program) + 4 year (Observatory)

Important **synergies** with other Northern ground-based gamma-ray facilities (LHAASO, HAWC, MAGIC, VERITAS, CTAO-N)

ASTRI Mini-Array will be operated remotely.

Unprecedented performance and **wide FoV (~10°) with excellent off-axis performance** for observations at **multi-TeV energies (1-200 TeV)**

- Angular resolution: ~3' (E~10 TeV)
- Energy resolution: ~10% (E~10TeV)



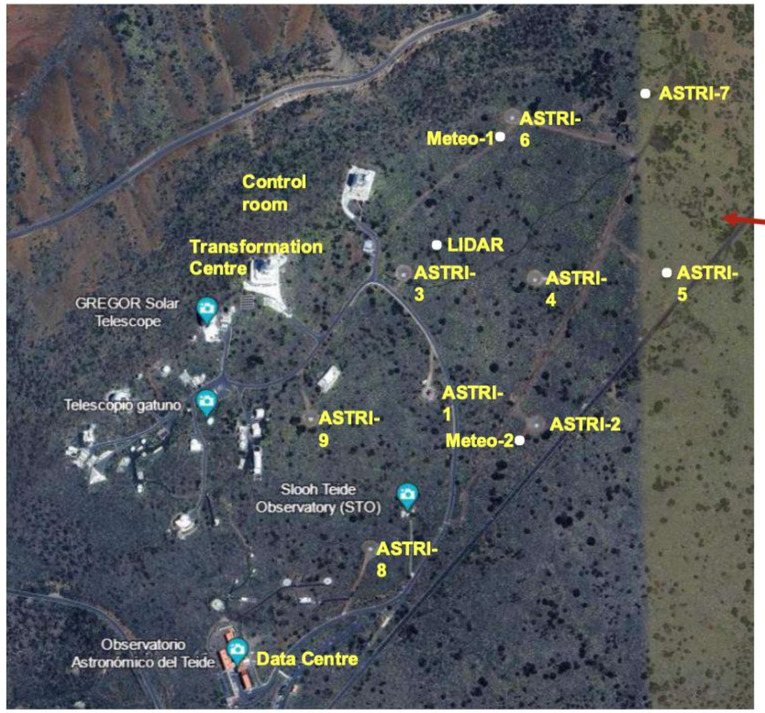
End-to-end approach

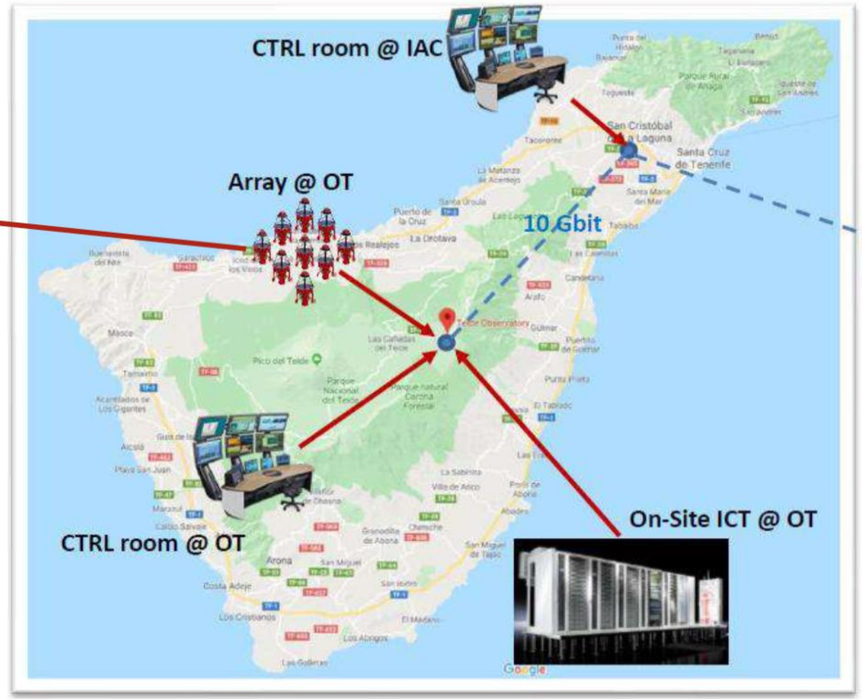
The ASTRI Mini-Array in Tenerife

- Telescope Array & auxiliaries (Observatorio del Teide - OT)
- Local Control Room @THEMIS building (OT)
- On site Data Centre @IAC Residencia (OT)
- Array operation center @IACTEC in La Laguna

The ASTRI Mini-Array in Italy

- Data Centre in Rome
- Remote Array operation centers

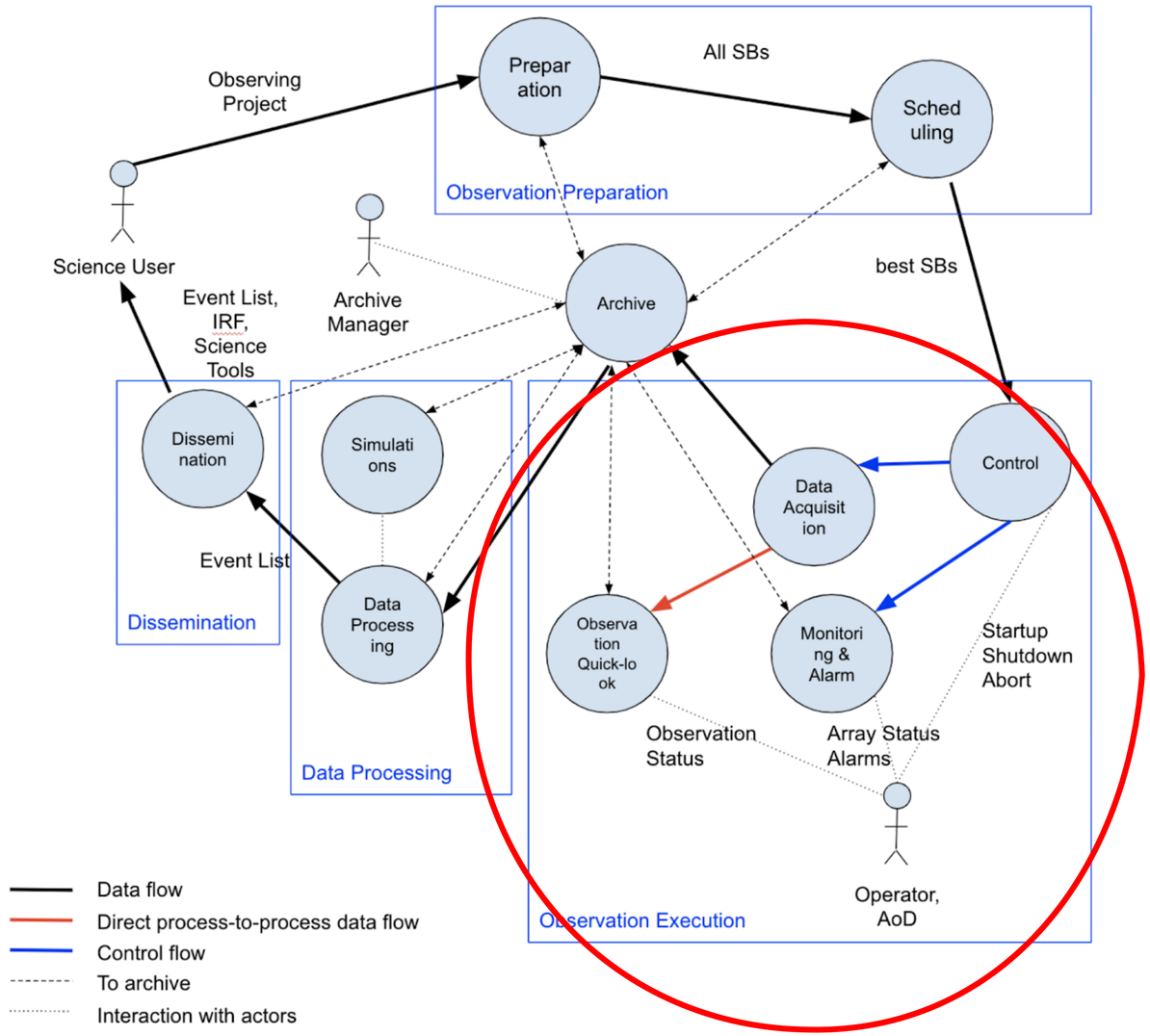




10 Gbit

ASTRI Mini-Array

Observing cycle

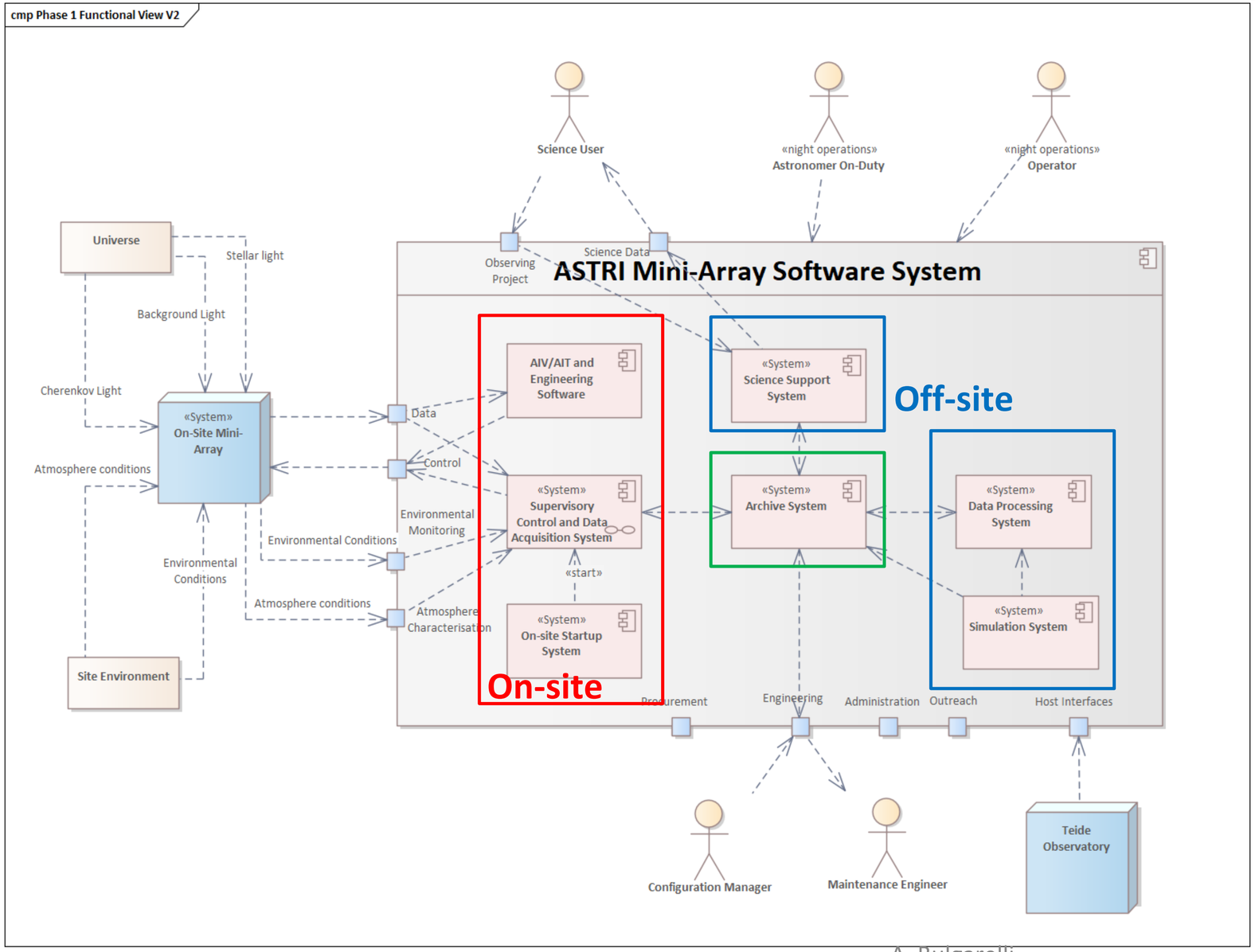


The ASTRI Mini-Array software is envisioned to handle an observing cycle, i.e. the end-to-end control and data flow system. The observing cycle can be divided into the following main phases:

1. Observation preparation: submitting an Observing Project that is turned into Scheduling Blocks (SBs) and Observing Blocks (OBs)
2. Observation execution: execution of Observing Blocks
3. Data Processing: produces calibrated and reconstructed data
4. Dissemination: Data and Science Tools are distributed for a scientific analysis of the Observing Projects.

ASTRI software support the full observing cycle

General software architecture

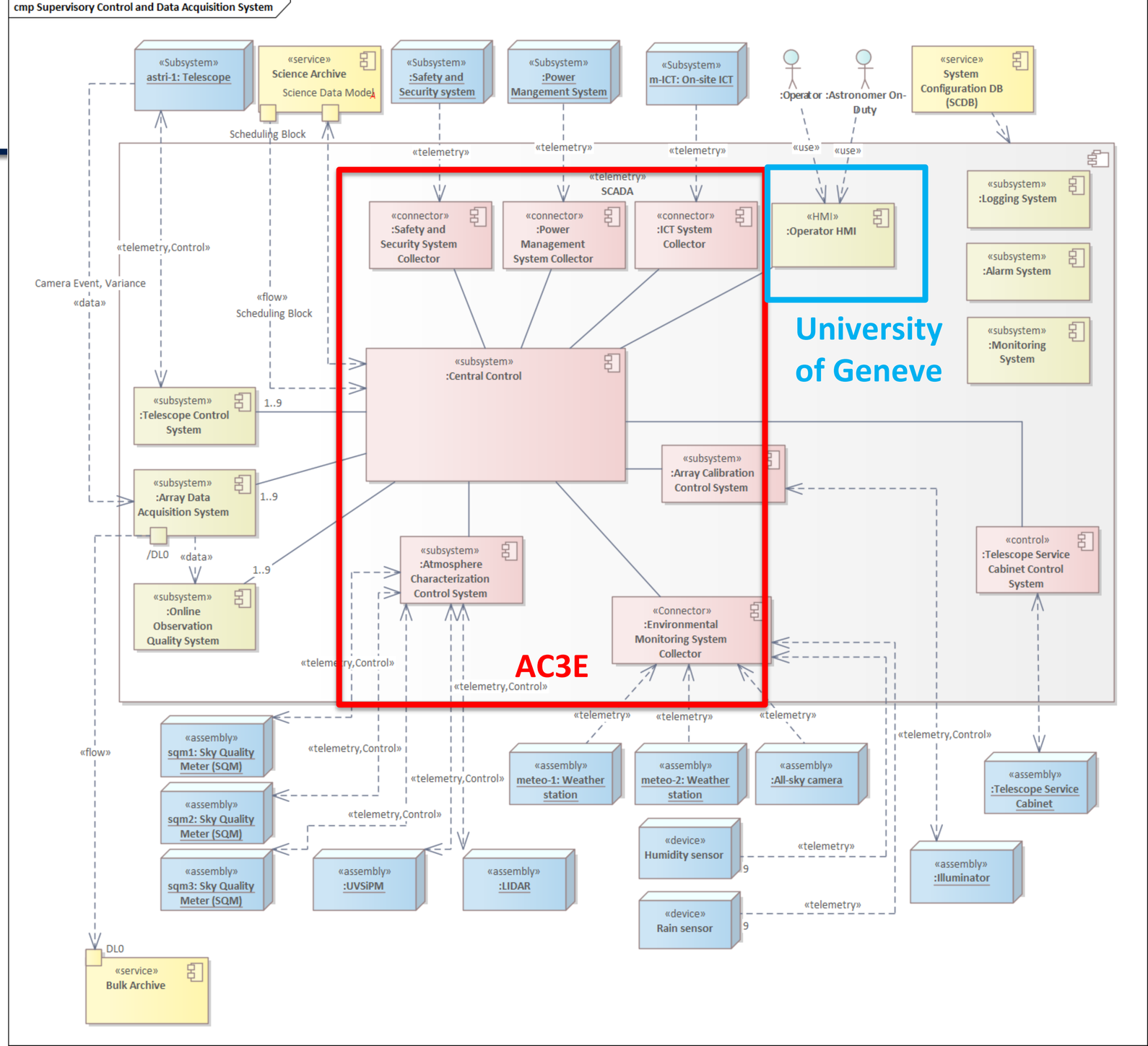


- **Supervisory Control And Data Acquisition (SCADA) System**: *interfaces, controls, monitors, acquires data, manage alarms of all software subsystems and assemblies of the Mini-Array*
- **On-site Startup System**
- **AIV/AIT and Engineering Software**
- **Archive System**
- **Data Processing System**
- **Science Support System**
- **Simulations System**

Supervisory Control and Data Acquisition System (SCADA)

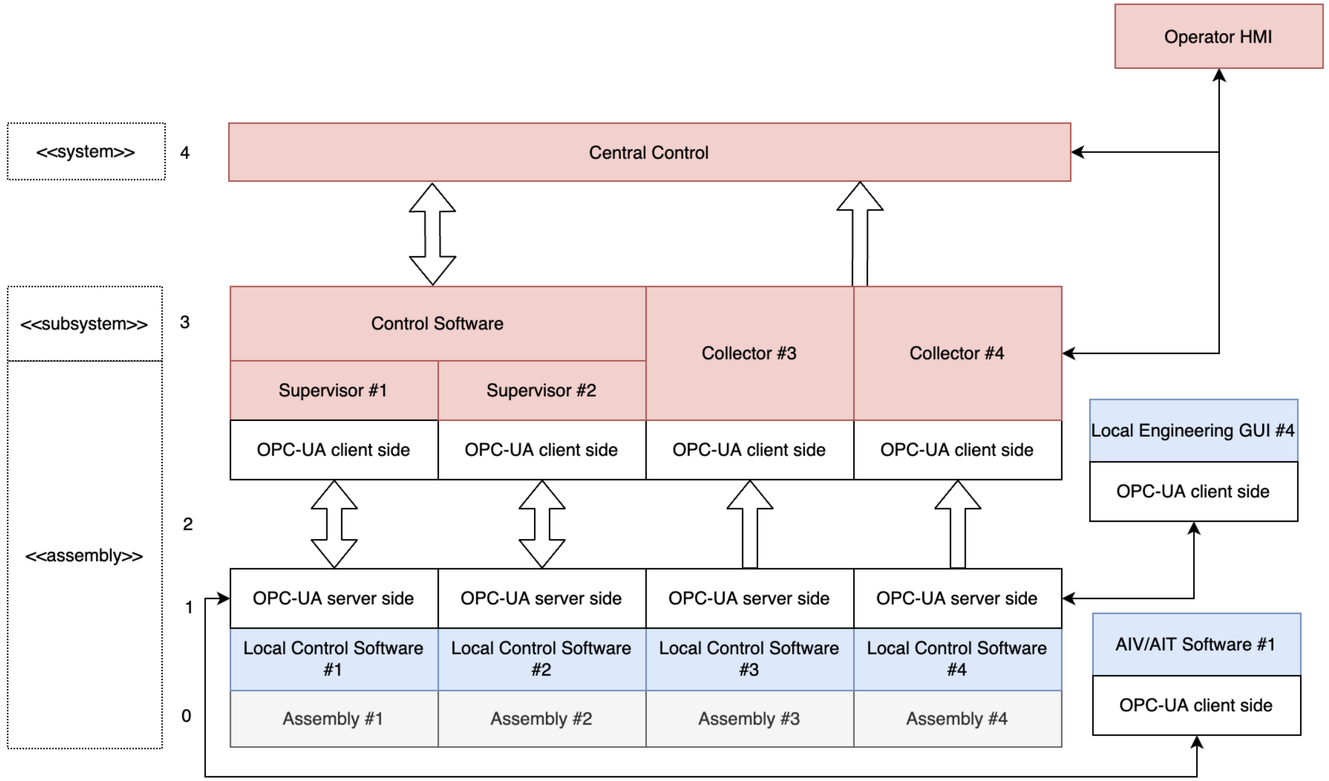
- **SCADA interfaces, controls, monitors, acquires data, manage alarms of all software subsystems and assemblies of the Mini-Array:**
  - automatically execute the whole sequence of operations needed to perform an observation;
  - react to critical conditions in an automatic way to put the array system in a safe state.
- **Software subsystems:**
  - Central Control;
  - Control systems and Collector;
  - Monitoring/Alarm/Logging systems;
  - Data Acquisition and Quality systems;
- Supervised by an Operator with an HMI

Red and green are SCADA subsystem; blue boxes are the ASTRI Mini-Array assemblies; yellow boxes are part of the Archive System.
The << telemetry >> stereotype represents monitoring points, alarms, errors, logs, and status information, << data >> stereotype represents the data flow. The << control >> stereotype represents the control flow.



Supervisory Control and Data Acquisition System (SCADA)/2

- **Central Control System** coordinates the sequence of operations, all software components and hardware assemblies, the sequences of the startup, shutdown, configuration and the status.
- Control systems, to control, monitor, and manage alarms and the status of the telescopes (**Telescope Control System**, developed by INAF based on the ASTRI-Horn experience), the assemblies used to characterise the atmosphere (**Atmosphere Characterisation Control System**), the calibration system (**Array Calibration Control System**), the telescope service cabinets **(Telescope Service Cabinet Control System);**
- Collectors, to monitor and determine alarms and the status of environmental devices (**Environmental Monitoring System Collecto**r), of the Information and Communication Technology (ICT) system (**On- site ICT System Collector**), the power system (**Power Management System Collector**), the Safe and Security System (**Safety and Security System Collector**);
- **Operator Human Machine Interface (HMI),** the user interface for the Operator, including an Operator Logbook to save logs of the observations during the night.



Interfaces between hardware assemblies and SCADA: IEC 62541 standard OPC Unified Architecture protocol, plus

- SNMP for the ICT system
- Modbus for Power Management System

Supervisory Control and Data Acquisition System (SCADA)/3

- **Logging System, Monitoring System and Alarm System**, developed by INAF, monitor the overall performance of the systems through the acquisition of environmental, monitoring and logging points and alarms from instruments and generates status reports or notifications to the Operator.
- **Telescope Control System**, to control a single telescope, developed by INAF
- **Array Data Acquisition System**, developed by INAF, acquires Cherenkov Cameras and Stellar Intensity Interferometry Instruments data
- **Online Observation Quality System**, developed by INAF, focuses on ongoing problems and the status of the observations

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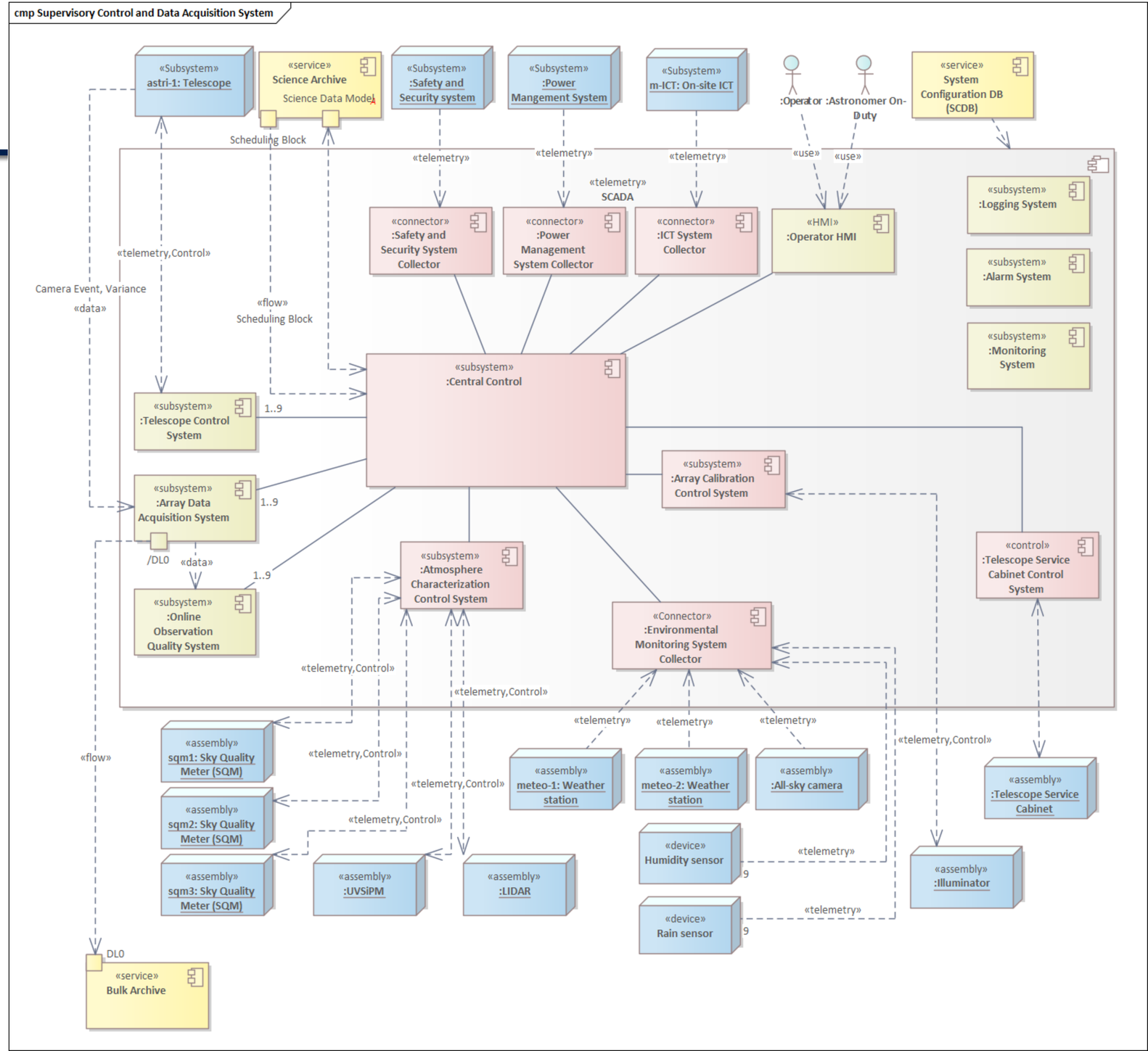
The << telemetry >> stereotype represents monitoring points, alarms, errors, logs, and status information, << data >> stereotype represents the data flow. The << control >> stereotype represents the control flow.



SCADA and software frameworks

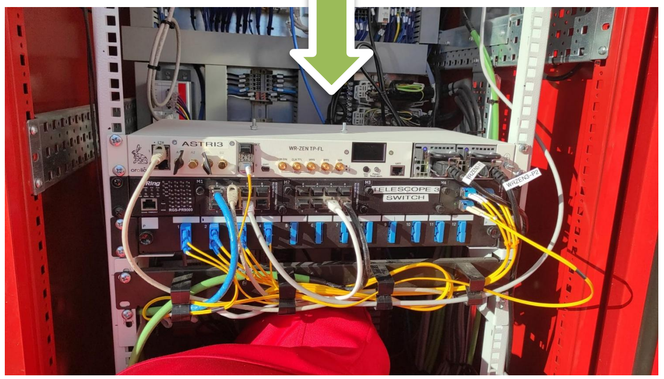
- SCADA is developed using ALMA Common Software (ACS)†, Kafka, Cassandra, MongoDB.
  - ALMA Common Software (ACS): a container component framework, designed for distributed systems, with standardized paradigms for logging, alarms, location transparency, and support for multiple programming languages: Java, C++ and Python.
    - ACS has been used successfully for ALMA, which manages an array of 66 antennas on the Chajnantor plateau in Chile.
    - ACS is used for ASTRI-Horn, Sardinia Radio Telescope, CTAO.
  - Kafka is used as a data backbone for all SCADA subsystems, except for data acquisition that uses TCP/IP.
  - Cassandra is used for the permanent storage of monitoring and data quality information, synchronized with off-site data center
  - MongoDB for observing plans and system configuration

†https://confluence.alma.cl/display/ICTACS/ACS+Documentation

ICT

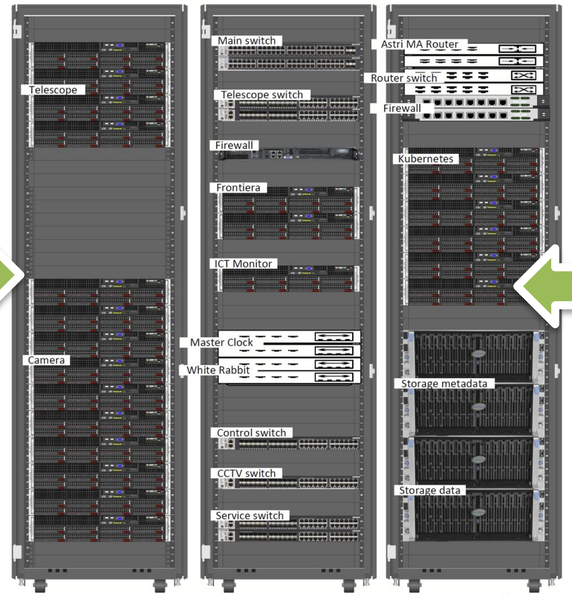
Mini-Array

Service cabinet



Telescopes

On site ICT



- Onsite data center
- Fiber-Optic network backbone
- Service cabinets ICT equipment
- Telescope ICT Equipment
- Control room (@Themis)
- White Rabbit timing system
- Offsite data center

Control room @ Themis

Offsite ICT

ICT

- Fully operational 24/7
- 26 Servers, 10 switches, 2 WRs, 2 Master Clocks, 2 Firewalls, 2 Routers, 200TB of storage.
- Array control and monitoring, data acquisition, storage (temporary) and transfer to offsite data center.
- Designed with high reliability and redundancy, to operate without interruption for at least 10 years.

Conclusions

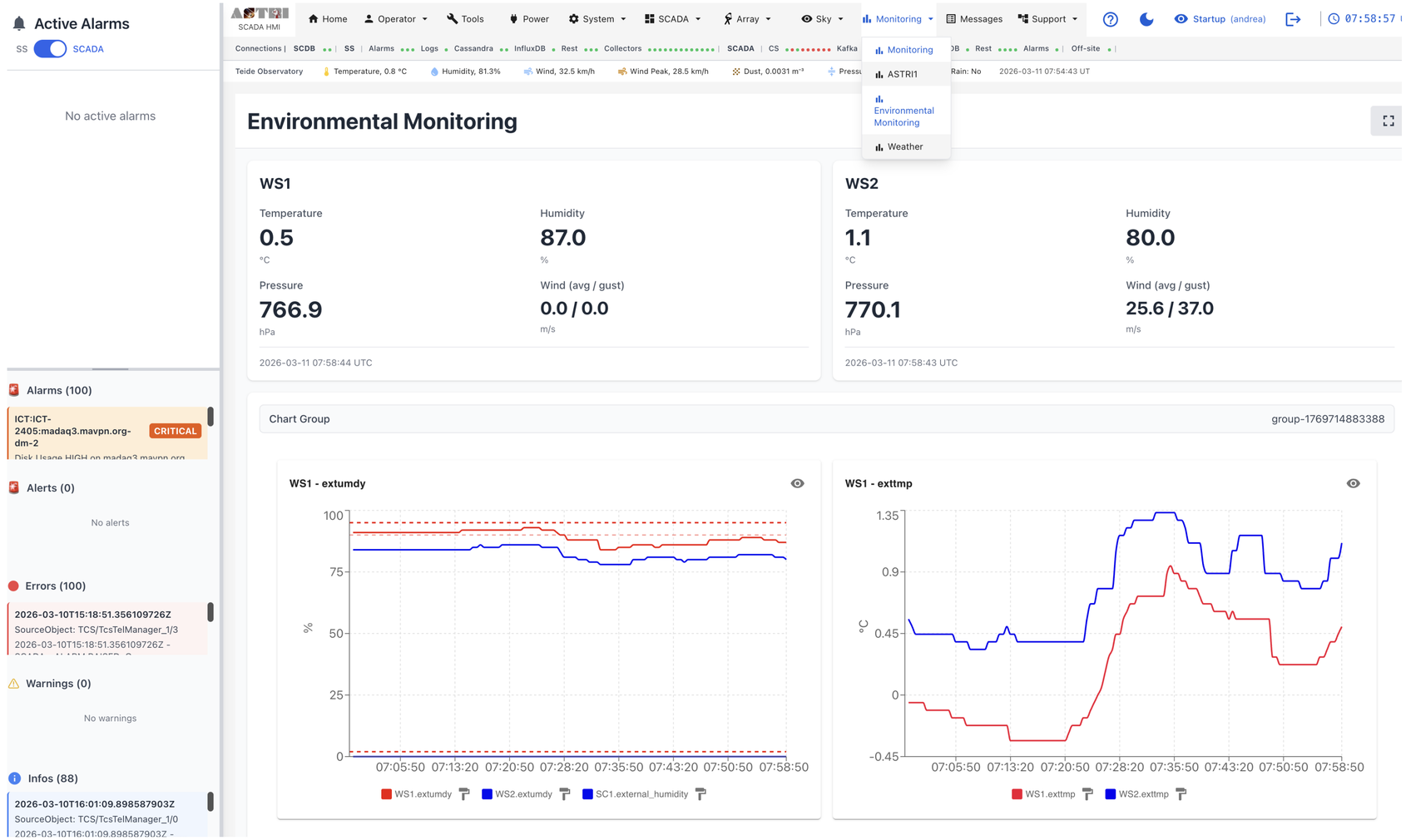
- For the first 4 years the ASTRI Mini-Array will be run as an experiment dedicated to the Core Science Topics but with followup of some transients.
- Detection of Crab, Mrk 501 and Mrk 421.
- The Early Science phase will begin next summer.
- The ASTRI Mini-Array will start scientific observations in Fall 2026 with at least 7 telescopes

- **Transition towards an Observatory period to open to observational proposals from the scientific community**

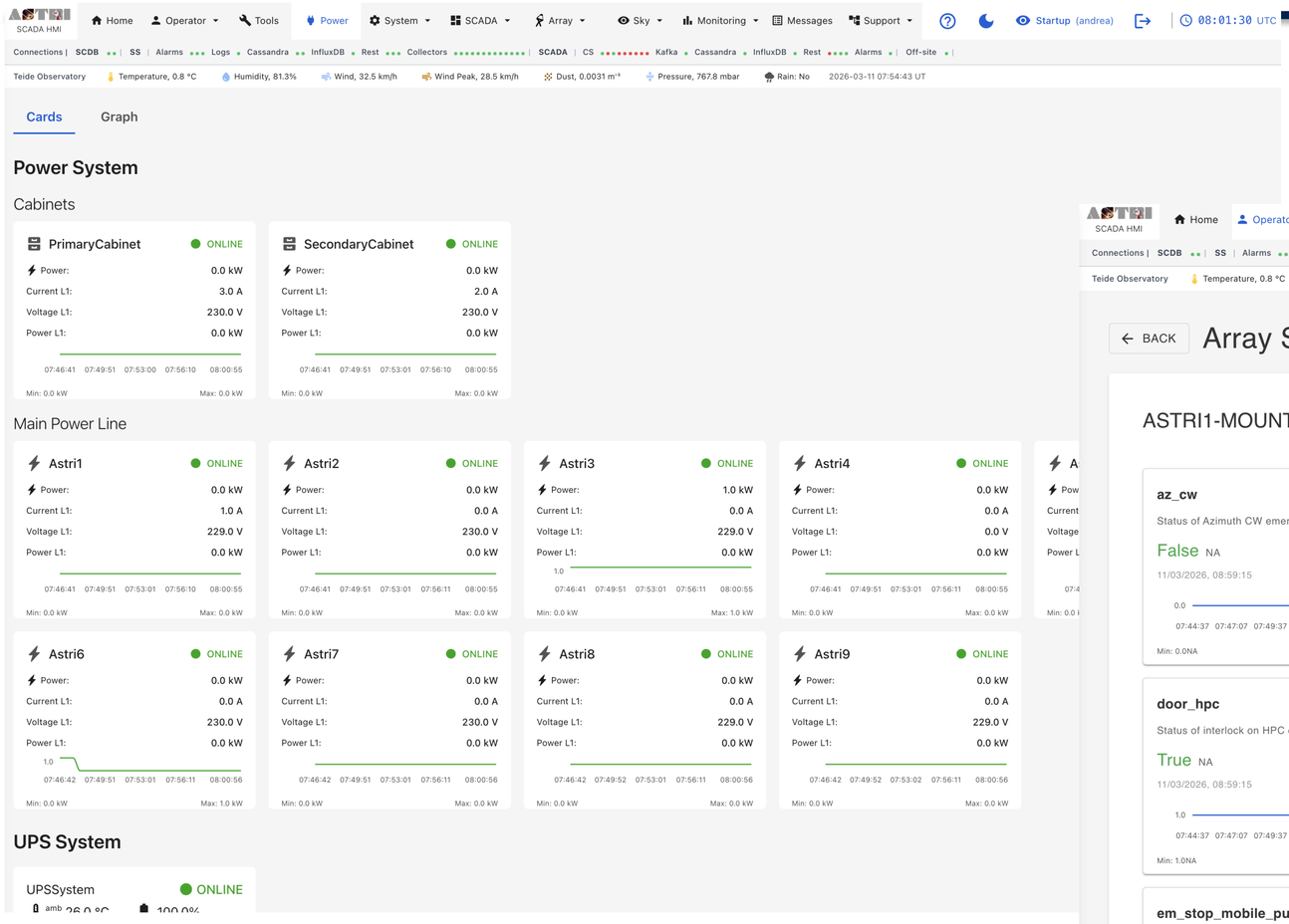
More at :

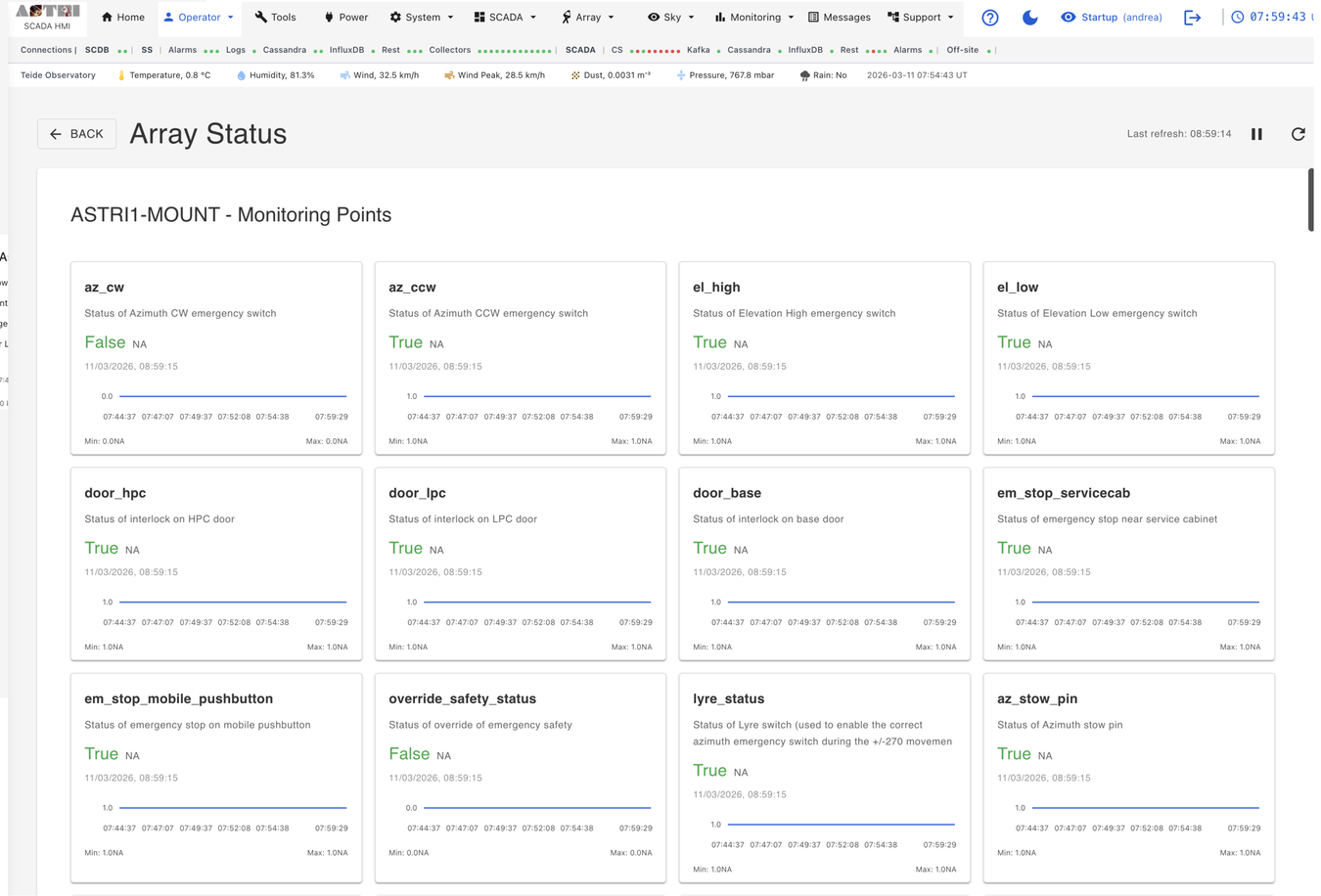
- Astri web site : http://www.astri.inaf.it/
- On socials, search for ASTRIgamma (FB and Instagram)


Riccardo Bulgarelli


Active Alarms
SS SCADA
No active alarms
SCADA HMI
Home
Operator
Tools
Power
System
SCADA
Array
Sky
Monitoring
Messages
Support
Startup (andrea)
07:58:57
Connections | SCDB | SS | Alarms | Logs | Cassandra | InfluxDB | Rest | Collectors | SCADA | CS | Kafka
Alarms | Rest | Alarms | Off-site
Teide Observatory
Temperature, 0.8 °C
Humidity, 81.3%
Wind, 32.5 km/h
Wind Peak, 28.5 km/h
Dust, 0.0031 m⁻³
Rain: No
2026-03-11 07:54:43 UT
Monitoring
ASTRI1
Environmental Monitoring
Weather
Environmental Monitoring
WS1
Temperature
0.5
°C
Humidity
87.0
%
Pressure
766.9
hPa
Wind (avg / gust)
0.0 / 0.0
m/s
2026-03-11 07:58:44 UTC
WS2
Temperature
1.1
°C
Humidity
80.0
%
Pressure
770.1
hPa
Wind (avg / gust)
25.6 / 37.0
m/s
2026-03-11 07:58:43 UTC
Alarms (100)
ICT:ICT-2405:madaq3.mavpn.org-dm-2
CRITICAL
Alerts (0)
No alerts
Errors (100)
2026-03-10T15:18:51.356109726Z
SourceObject: TCS/TcsTelManager_1/3
Warnings (0)
No warnings
Infos (88)
2026-03-10T16:01:09.898587903Z
SourceObject: TCS/TcsTelManager_1/0
Chart Group
group-1769714883388
WS1 - extumdy
100
75
50
25
0
%
07:05:50 07:13:20 07:20:50 07:28:20 07:35:50 07:43:20 07:50:50 07:58:50
WS1.extumdy
WS2.extumdy
SC1.external_humidity
WS1 - exttmp
1.35
0.9
0.45
0
-0.45
°C
07:05:50 07:13:20 07:20:50 07:28:20 07:35:50 07:43:20 07:50:50 07:58:50
WS1.exttmp
WS2.exttmp

ASTRI Mini-Array





SCADA HMI | Home | Operator | Tools | Power | System | SCADA | Array | Sky | Monitoring | Messages | Support | Startup (andrea) | 08:00:4

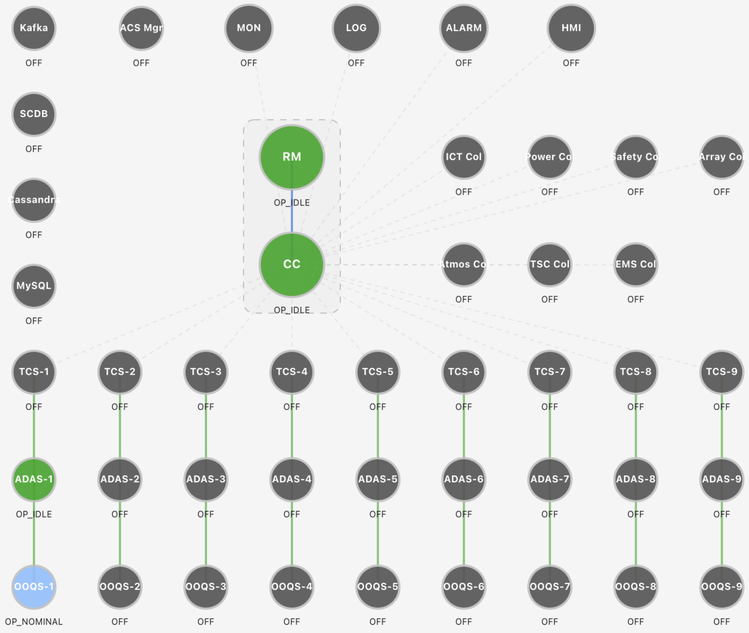
Connections | SCDB | SS | Alarms | Logs | Cassandra | InfluxDB | Rest | Collectors | SCADA | CS | Kafka | Cassandra | InfluxDB | Rest | Alarms | Off-site |

Teide Observatory | Temperature, 0.8 °C | Humidity, 81.3% | Wind, 32.5 km/h | Wind Peak, 28.5 km/h | Dust, 0.0031 m⁻³ | Pressure, 767.8 mbar | Rain: No | 2026-03-11 07:54:43 UT

SCADA System Status

Live

SCADA Status	AMC Components	TCS Systems	Faults
OP_IDLE	4 / 45	0 / 9	0

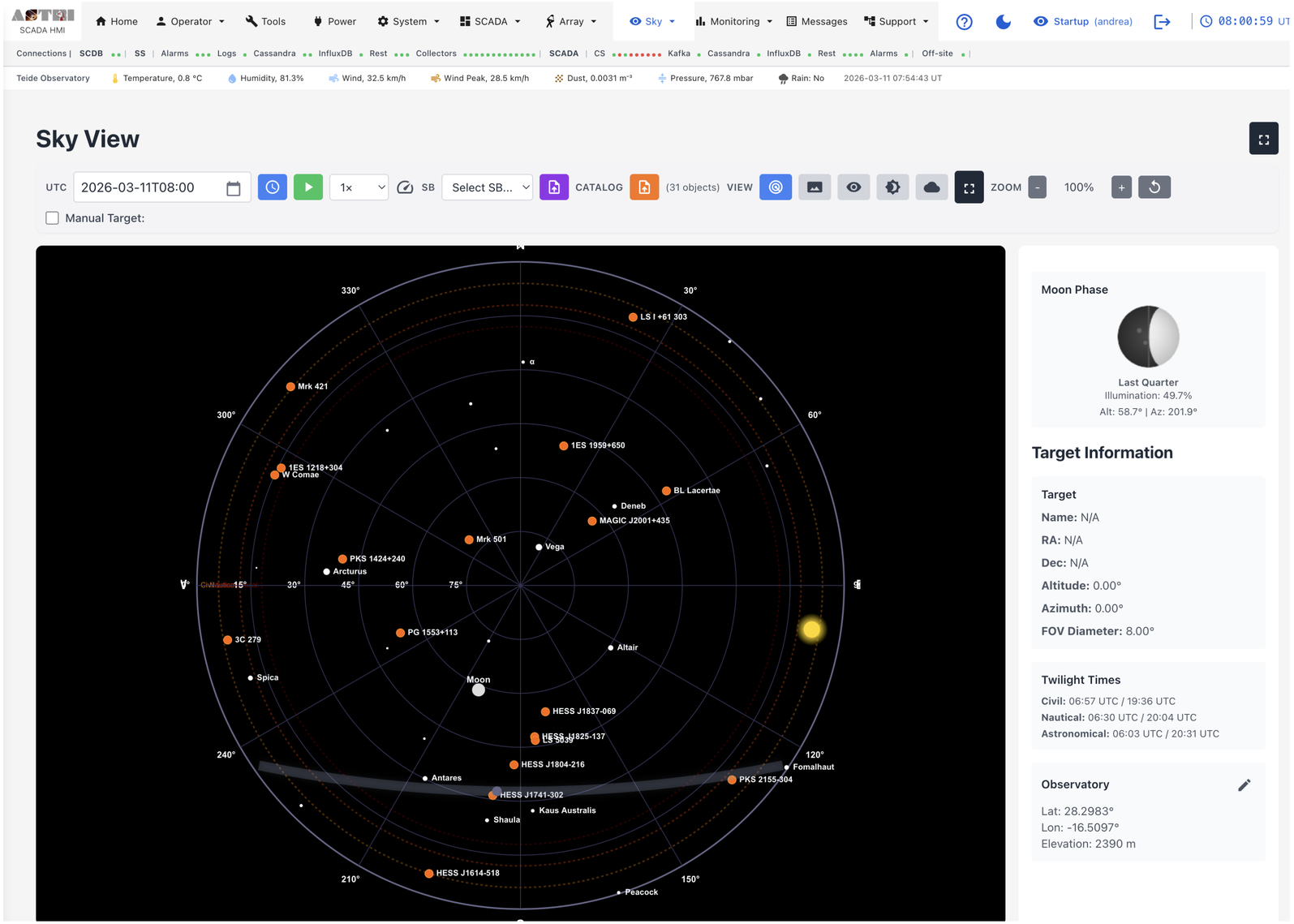


Components

CC — Central Control
RM — Resource Manager
TCS — Telescope Control System
ADAS — Array Data Acquisition System
OOQS — Online Observation Quality System

State Legend

- OFF
- INITIALIZED
- STANDBY
- OP_IDLE
- OP_DEGRADED
- OP_NOMINAL
- SAFE
- ENGINEERING
- FAULT
- UNKNOWN


SCADA HMI
Home
Operator
Tools
Power
System
SCADA
Array
Sky
Monitoring
Messages
Support
Startup (andrea)
08:00:59 UT
Connections | SCDB | SS | Alarms | Logs | Cassandra | InfluxDB | Rest | Collectors | SCADA | CS | Kafka | Cassandra | InfluxDB | Rest | Alarms | Off-site |
Teide Observatory
Temperature, 0.8 °C
Humidity, 81.3%
Wind, 32.5 km/h
Wind Peak, 28.5 km/h
Dust, 0.0031 m⁻³
Pressure, 767.8 mbar
Rain: No
2026-03-11 07:54:43 UT
Sky View
UTC
2026-03-11T08:00
1×
SB
Select SB...
CATALOG
(31 objects)
VIEW
ZOOM
100%
Manual Target:
330°
30°
300°
60°
240°
120°
210°
150°
LS I +61 303
α
Mrk 421
1ES 1959+650
1ES 1218+304
W Comae
BL Lacertae
Deneb
MAGIC J2001+435
Mrk 501
Vega
PKS 1424+240
Arcturus
15°
30°
45°
60°
75°
PG 1553+113
3C 279
Altair
Spica
Moon
HESS J1837-069
LS 5039
HESS J1825-137
HESS J1804-216
Fomalhaut
Antares
PKS 2155-304
HESS J1741-302
Kaus Australis
Shaula
HESS J1614-518
Peacock
Moon Phase
Last Quarter
Illumination: 49.7%
Alt: 58.7° | Az: 201.9°
Target Information
Target
Name: N/A
RA: N/A
Dec: N/A
Altitude: 0.00°
Azimuth: 0.00°
FOV Diameter: 8.00°
Twilight Times
Civil: 06:57 UTC / 19:36 UTC
Nautical: 06:30 UTC / 20:04 UTC
Astronomical: 06:03 UTC / 20:31 UTC
Observatory
Lat: 28.2983°
Lon: -16.5097°
Elevation: 2390 m