The ASTRI Mini-Array Supervisory Control and Data Acquisition software system

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for the ASTRI Project

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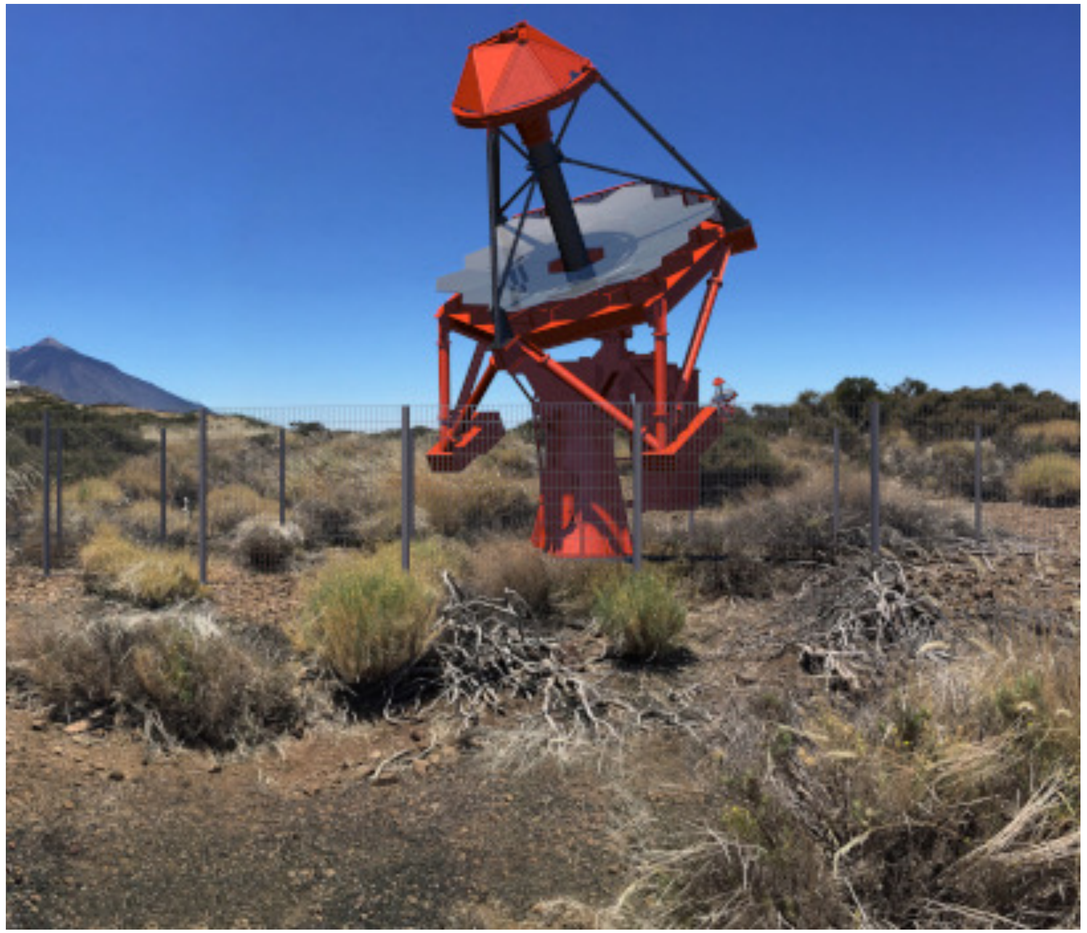
Outline

- The ASTRI Mini-Array Project
- The ASTRI Mini-Array System
- Software Architecture
- Software development approach



The ASTRI Mini-Array Project

- **ASTRI** (Astrofisica con Specchi a Tecnologia Replicante Italiana).
- **First stage**: realization of **ASTRI Horn,** an innovative end-to-end dual-mirror 4 meters prototype Imagining Atmospheric Cherenkov Telescopes (IACT).
- **Current stage**: **ASTRI Mini-Array,** an array of 9 telescopes at the Teide Observatory in Tenerife (Spain) in collaboration with the Instituto de Astrofísica de Canarias.
  - the largest IACT array until the Cherenkov Telescope Array Observatory starts to operate.
- Project led by the **Italian National Institute for Astrophysics (INAF)**, in collaboration with Italian universities, international institutions and private companies.
- The **ASTRI Mini-Array** is devoted to
  - imaging of atmospheric Cherenkov light for very-high-energy gamma-ray astronomy. Wide-field stereoscopic observations in the 1 – 300 TeV energy band;
  - stellar Hambury-Brown intensity interferometry;
  - measurements of cosmic rays, possible because 99% of the observable component of the Cherenkov light is hadronic in nature.

ASTRI Horn telescope at installed and operational on Mount Etna volcano (Sicily, Italy). First detection of a gamma-ray source (Crab Nebula) above 5 sigma with a dual-mirror, Schwarzschild-Couder Cherenkov telescope (Lombardi et al., 2020)

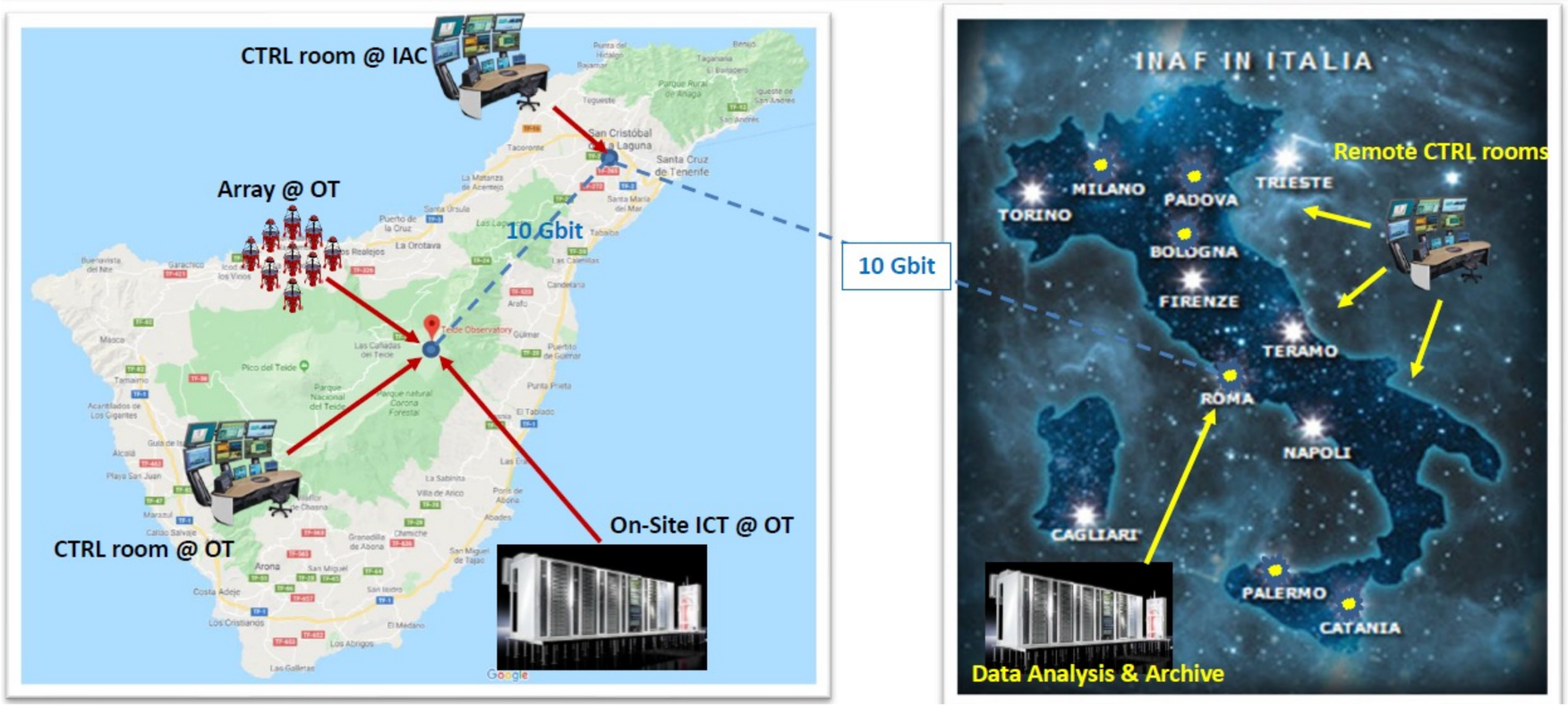
The ASTRI Mini-Array Locations

ASTRI Mini-Array Observing Site (AOS)

- Teide Observatory: ASTRI Mini-Array system.
- IACTEC in La Laguna: Array Operation Center.

ASTRI Mini-Array in Italy

- Data Center in Rome.
- Remote Array Operation Centers.



- ASTRI software allows the Mini-Array to be **operated remotely from the Array Operation Centers (AOCs)**
- **Off-site** at the Data Center in Rome
  - **stereo trigger;**
  - **data processing.**
- **On-site** is foreseen a **quick-look** of data at telescope level

The ASTRI Mini-Array System

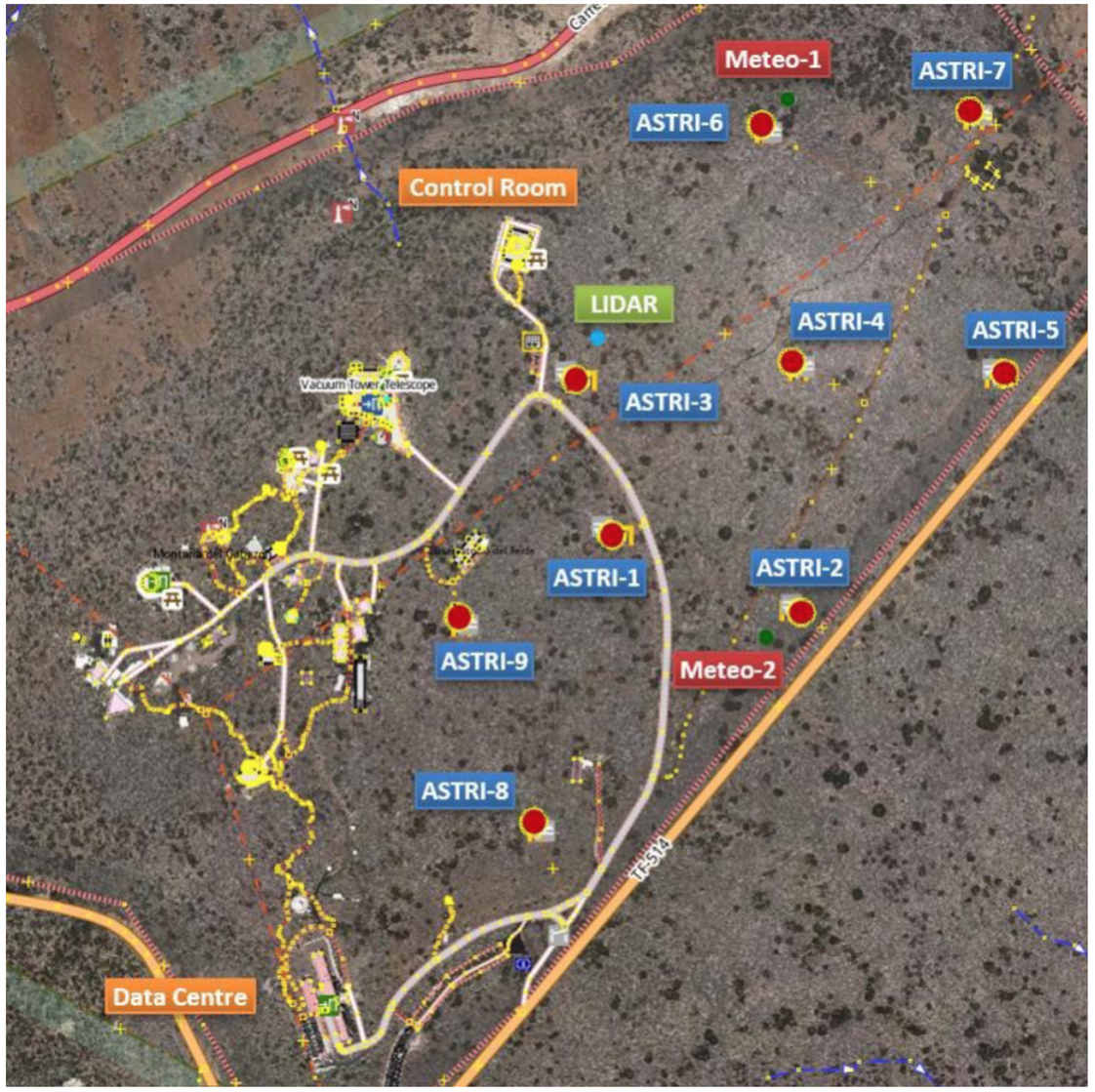
Array System, nine Telescopes with their hardware assemblies, including **Cherenkov Camera** and **Stellar Intensity Interferometry Instrument**.

- **ASTRI-1 to 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.

ASTRI software monitors and control all hardware **assemblies** of the ASTRI Mini-Array.



The ASTRI Mini-Array at the Teide Observatory

Telescope Power Management System

- **Transformer Station**

Information Communication Technology

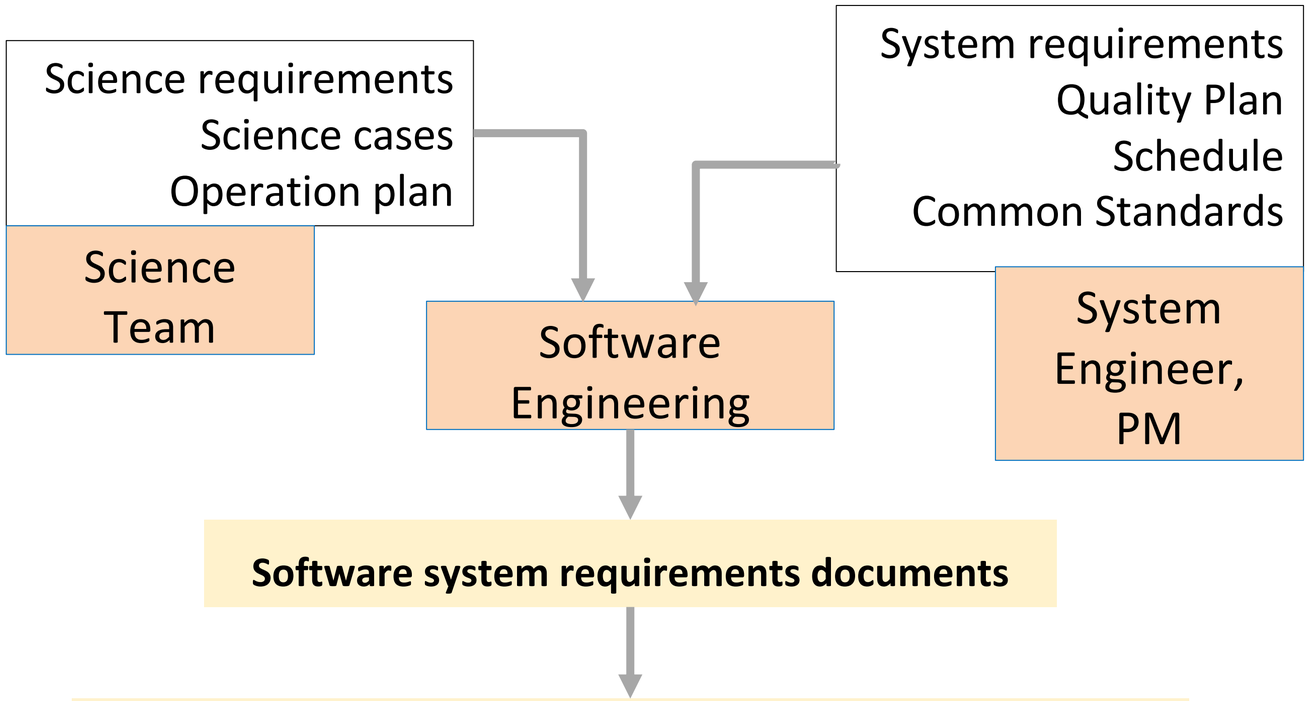
- **On-site Data Centre**
- **Control Room**

Safety and Security system

Environmental Monitoring System

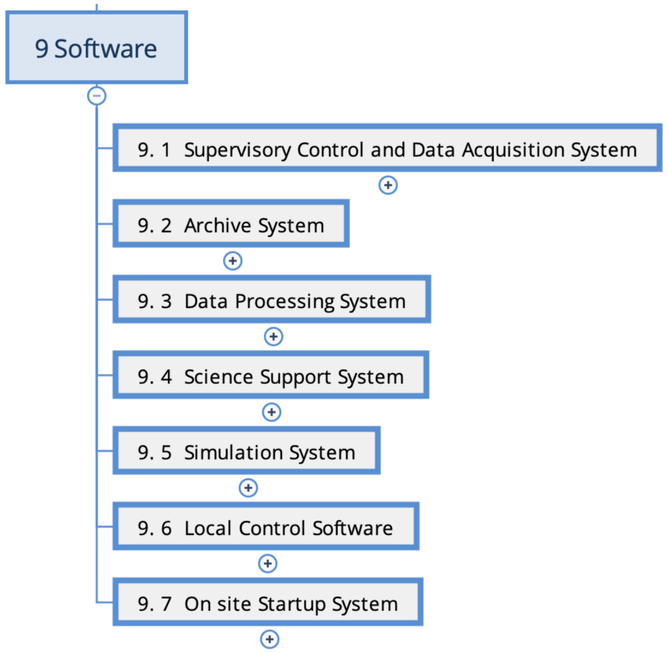
- Weather Stations
  - Meteo-1
  - Meteo-2
- Humidity and rain sensors;
- All-sky camera: cloud coverage

Software system requirement documents

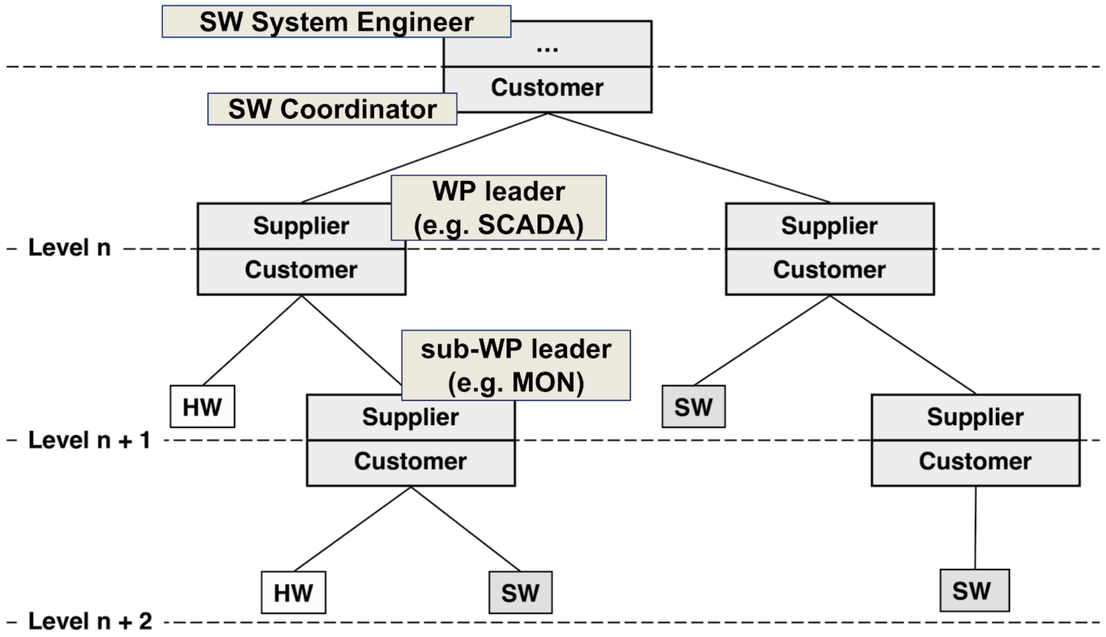


- ASTRI-MA Top Level **Functional Software Architecture**
  - functional architecture and quality requirements
- ASTRI-MA Top Level **Use Cases**
- ASTRI-MA **Data Model**
  - to support functional and behavioural views and support for logical external/internal interfaces
- Derived documents:
  - ASTRI-MA Software **Product Breakdown Structure**
  - ASTRI-MA **Glossary**

Product Breakdown Structure and customer-supplier relationship



First level of the ASTRI Mini-Array software Product Breakdown Structure

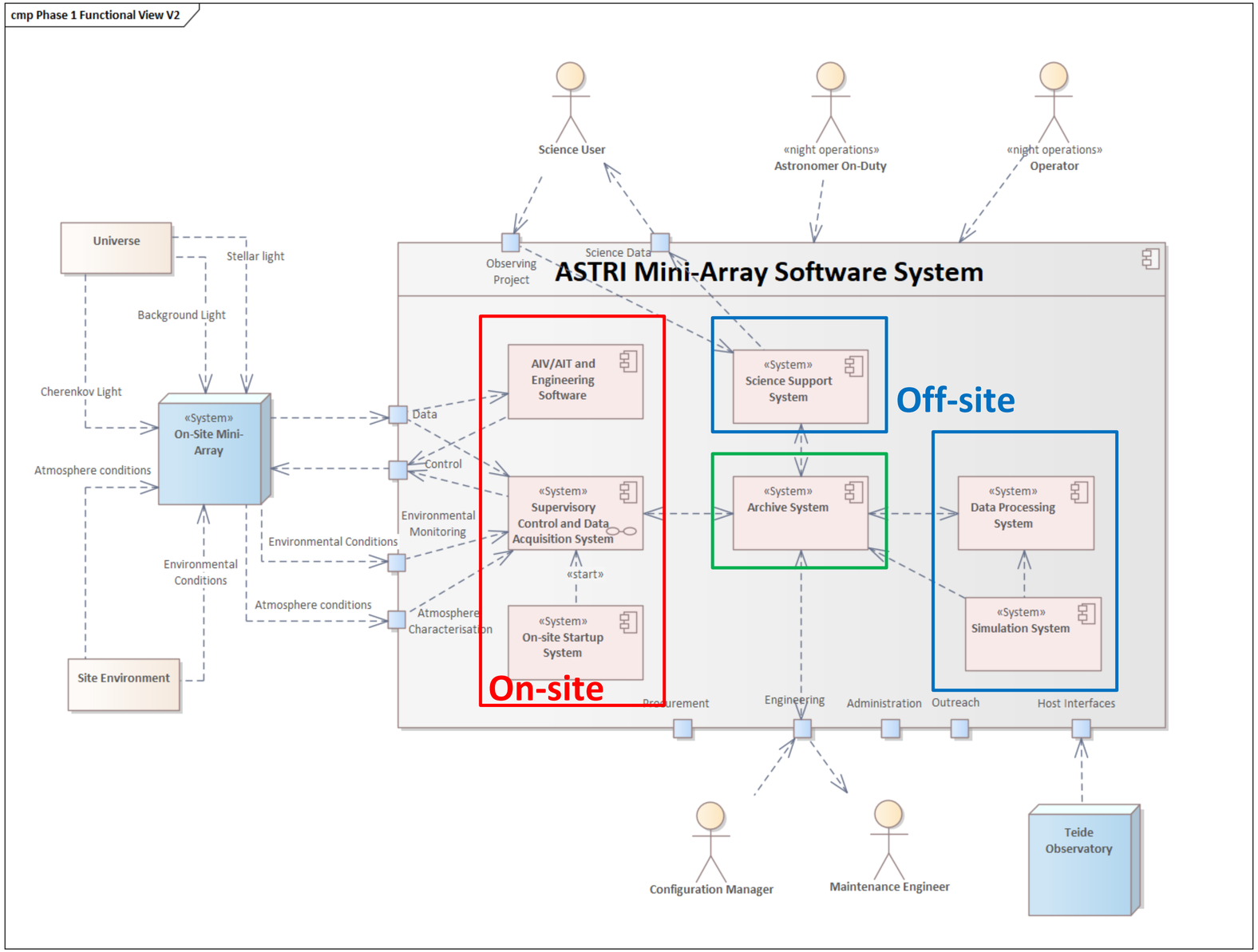


Software suppliers: software development by INAF and external companies/research institutions:

- Central Control System and on-site deployment of SCADA by AC3E (SCADA)
- Operator Human Machine Interface by the University of Geneve (SCADA)

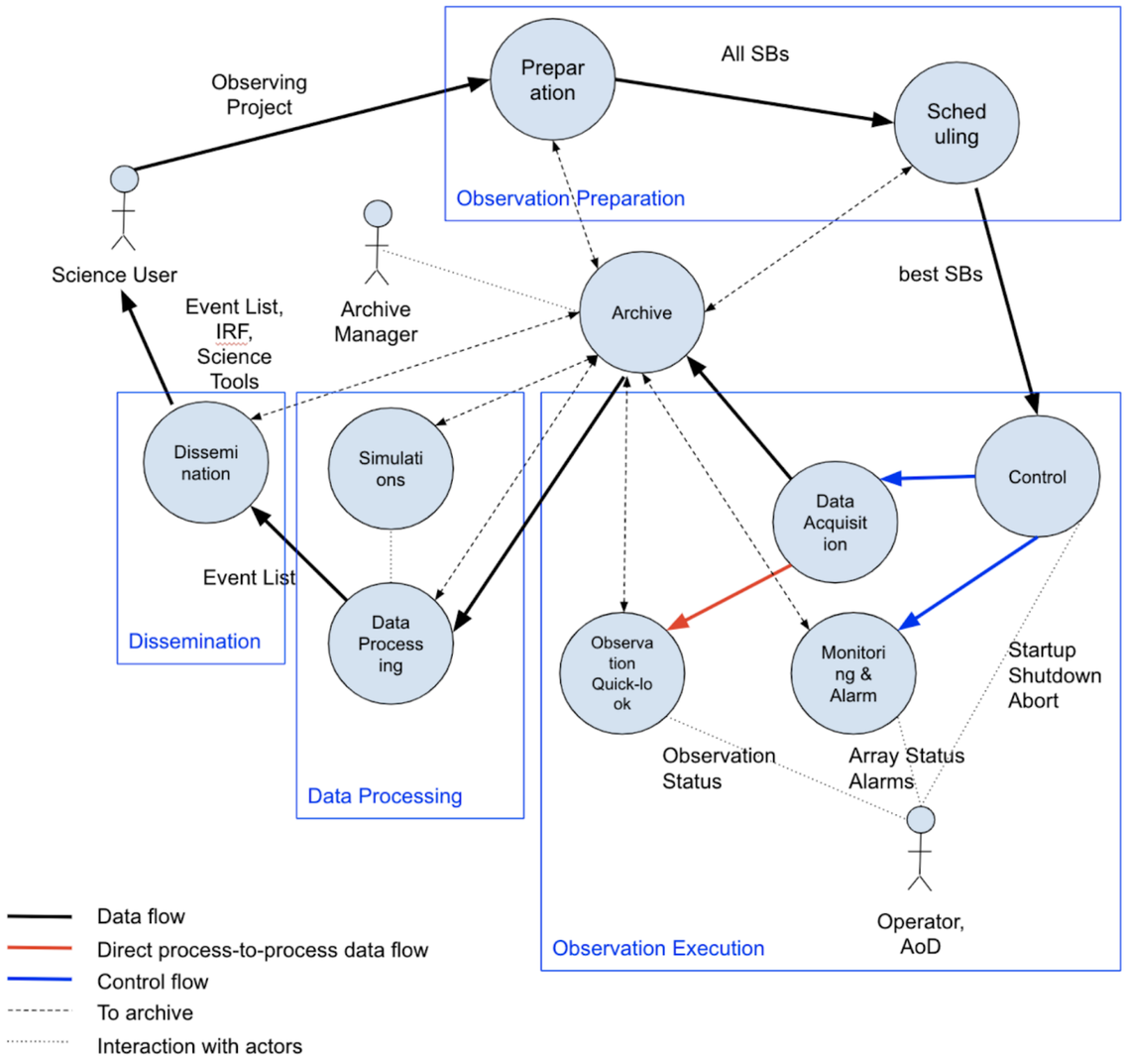
- **The customer-supplier relationship of the ASTRI Mini-Array software.**
- INAF has in charge of **software management and coordination** and development of many software subsystems**.**

Functional 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**

Observing cycle



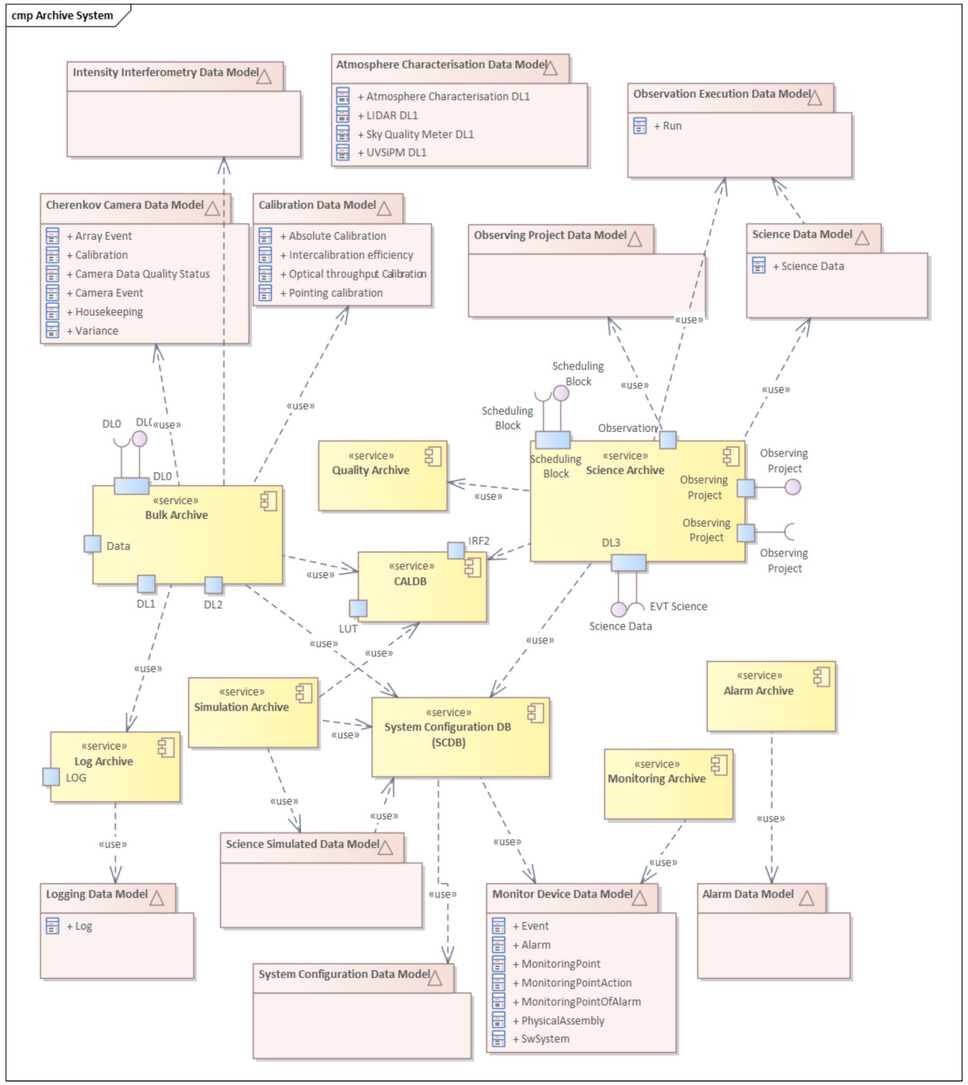
The ASTRI Mini-Array software is envisioned to handle an observing cycle, i.e. the end-to-end control and data flow system. The observing cycle can be divided into the following main phases:

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

Archive System

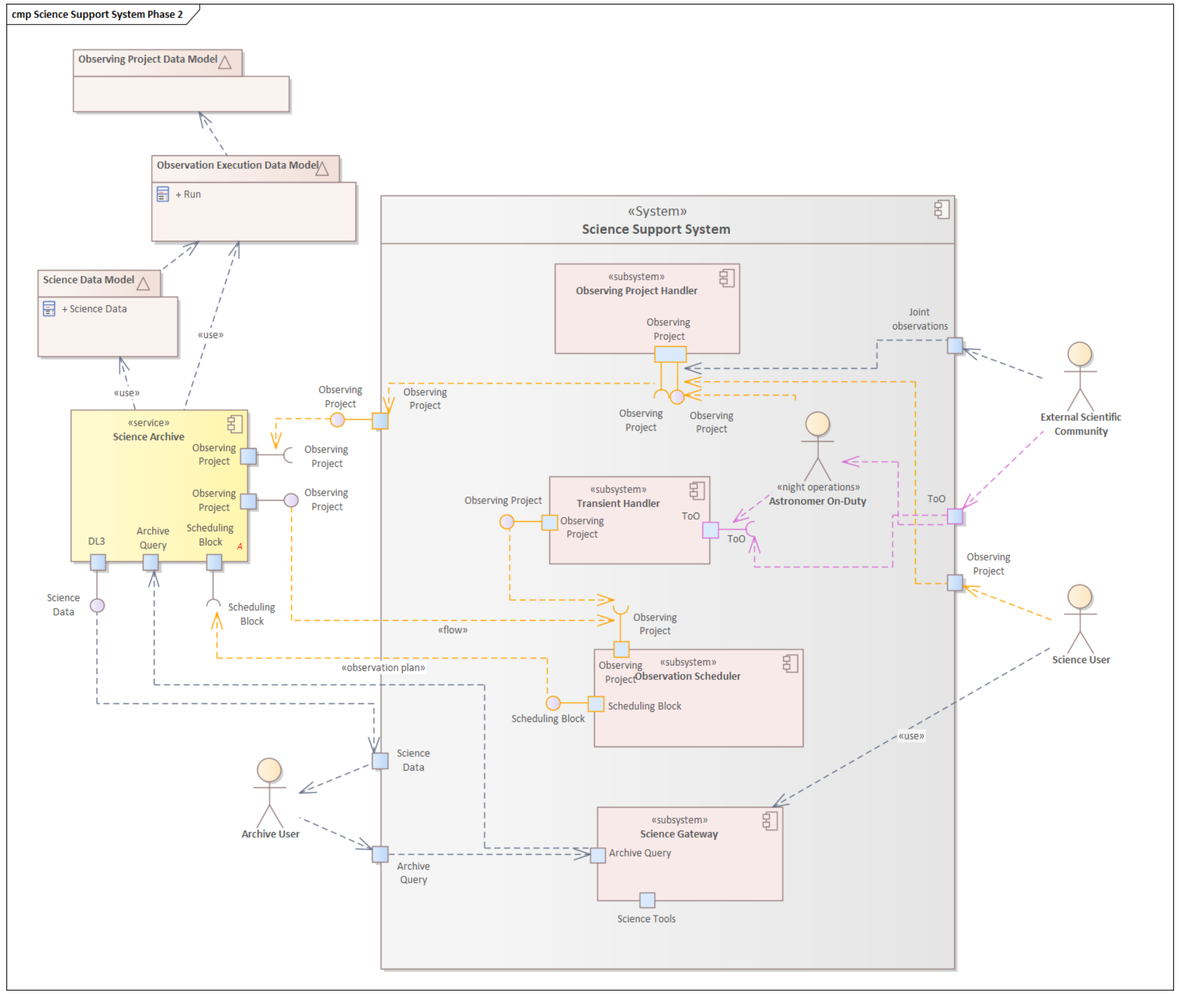
- The central repository and the core of the ASTRI workflow.
- Distributed between on-site (temporary) and off-site.
- Management of
  - Observation plans;
  - Scientific data;
  - Monitoring/alarm/logging data;
  - system configuration.
- **The main interface for the SCADA system**



Logical view of the Archive System and the relationship of each archive with the data models

Science Support System

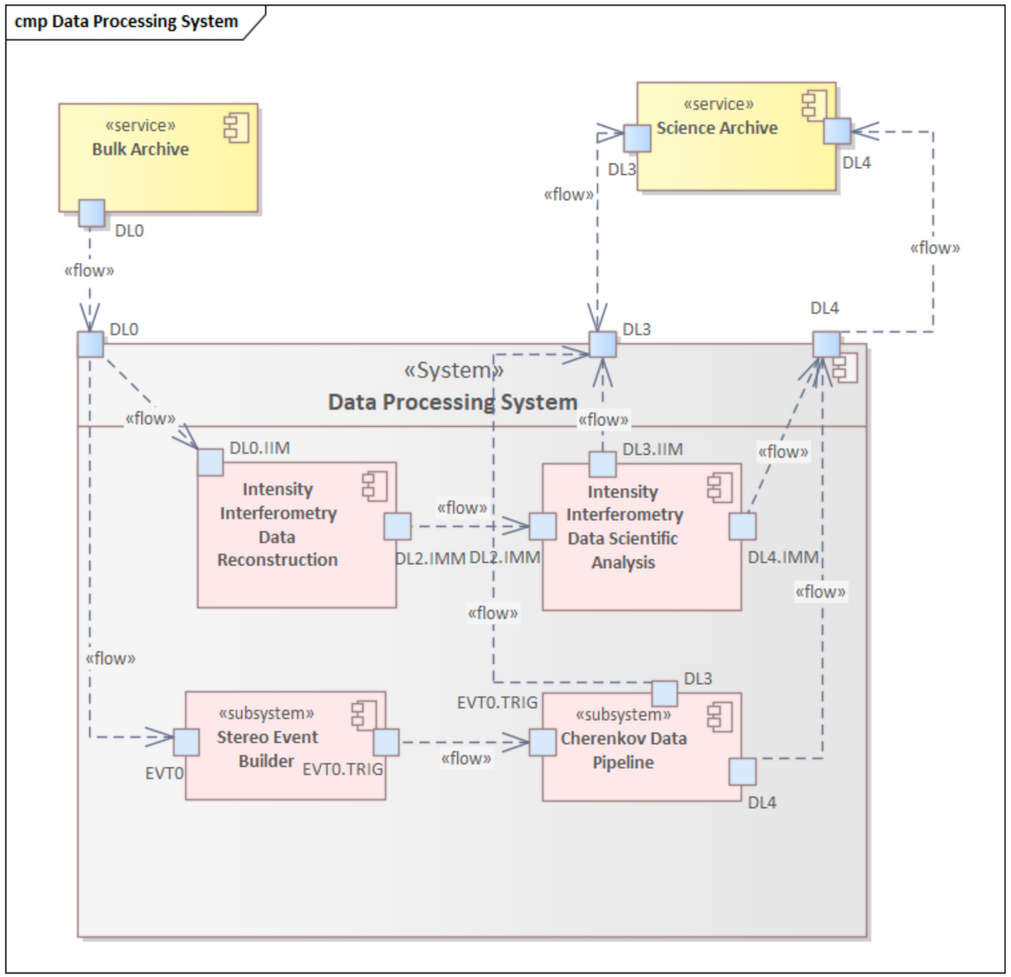
- The Science Support System is the main interface to the Science User.
- It manages observation plans, dissemination of scientific data and science tools.
- **Prepare the observation plan for the SCADA system**
- Main components:
  - **Observing Project Handler**: to submit Observing Projects;
  - **Transient Handler**: to manage ToO observations
  - **Observation Scheduler**: preparation of long-term and short-term observation plans;
  - **Science Gateway**: to retrieve science-ready data, science tools and tools to support the Observing Project preparation.



Science Support System component diagram with the Science Archive and related data models.

Data Processing System

- The Data Processing System (DPS)
  - performs data reduction and analyses;
  - checks the quality of the final data products.
- Main functions:
  - Stereo Event Builder: perform the off-line software stereo array trigger of Cherenkov data;
  - Cherenkov Data Pipeline;
  - Intensity Interferometry Data Reconstruction and Scientific Analysis;

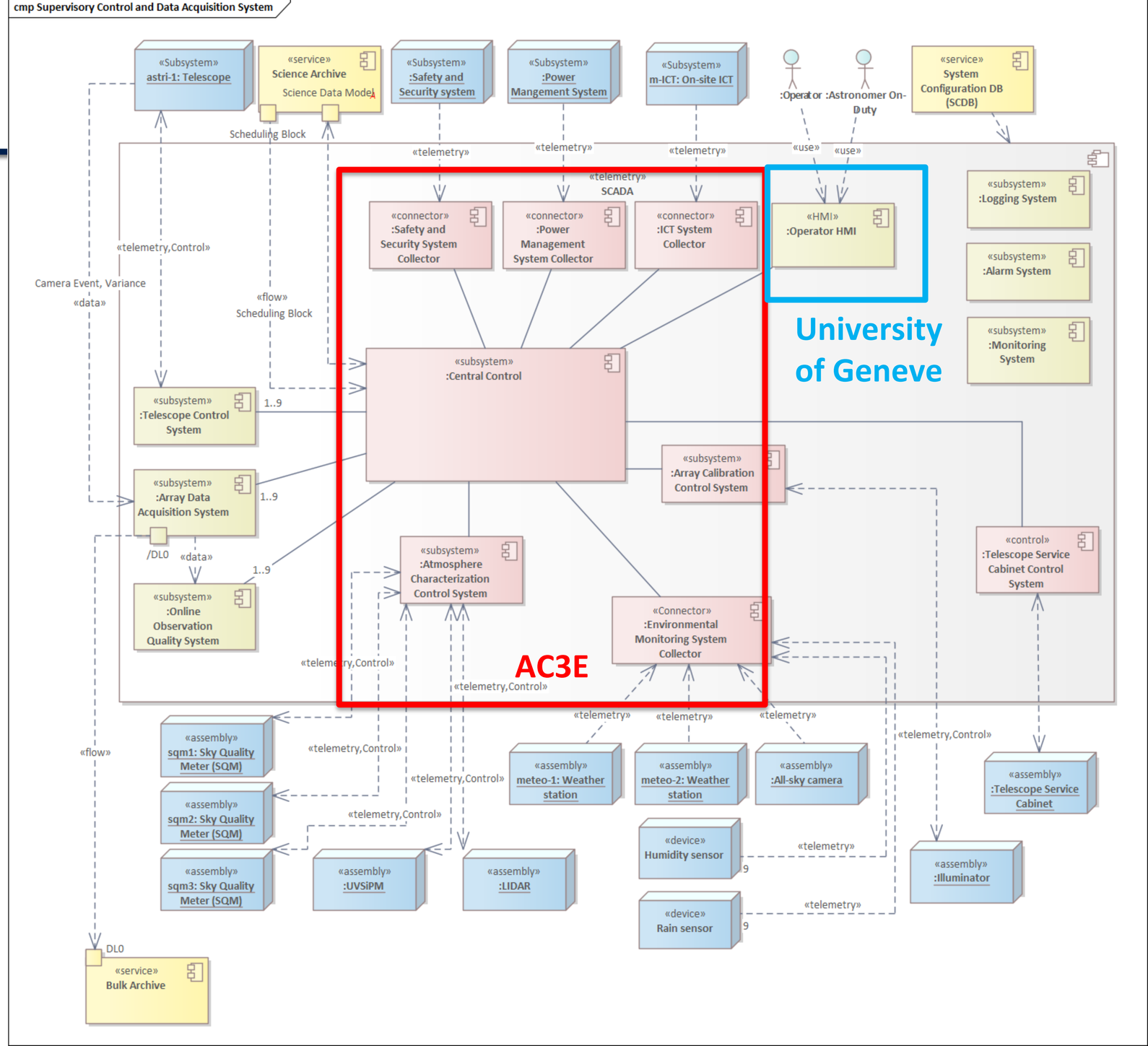


Data Processing System component diagram. DL0 is the raw data generated by scientific instruments, where IMM is the Intensity Interferometry data and EVT is the Cherenkov data. EVT0.TRIG is the Cherenkov data after the stereo array trigger. DL3 and DL4 are scientific products.

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

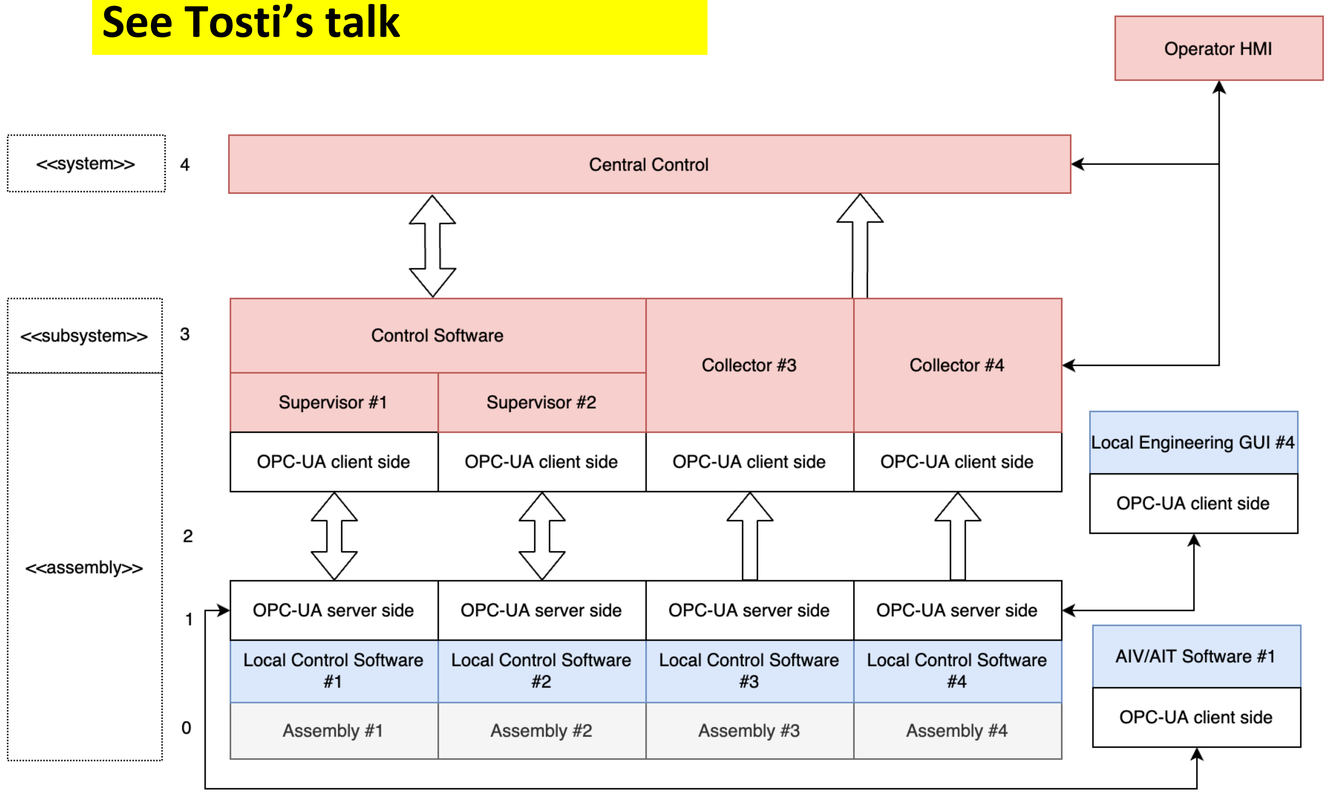
Red and green are SCADA subsystem; blue boxes are the ASTRI Mini-Array assemblies; yellow boxes are part of the Archive System.
The << telemetry >> stereotype represents monitoring points, alarms, errors, logs, and status information, << data >> stereotype represents the data flow. The << control >>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

See Tosti's talk



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

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

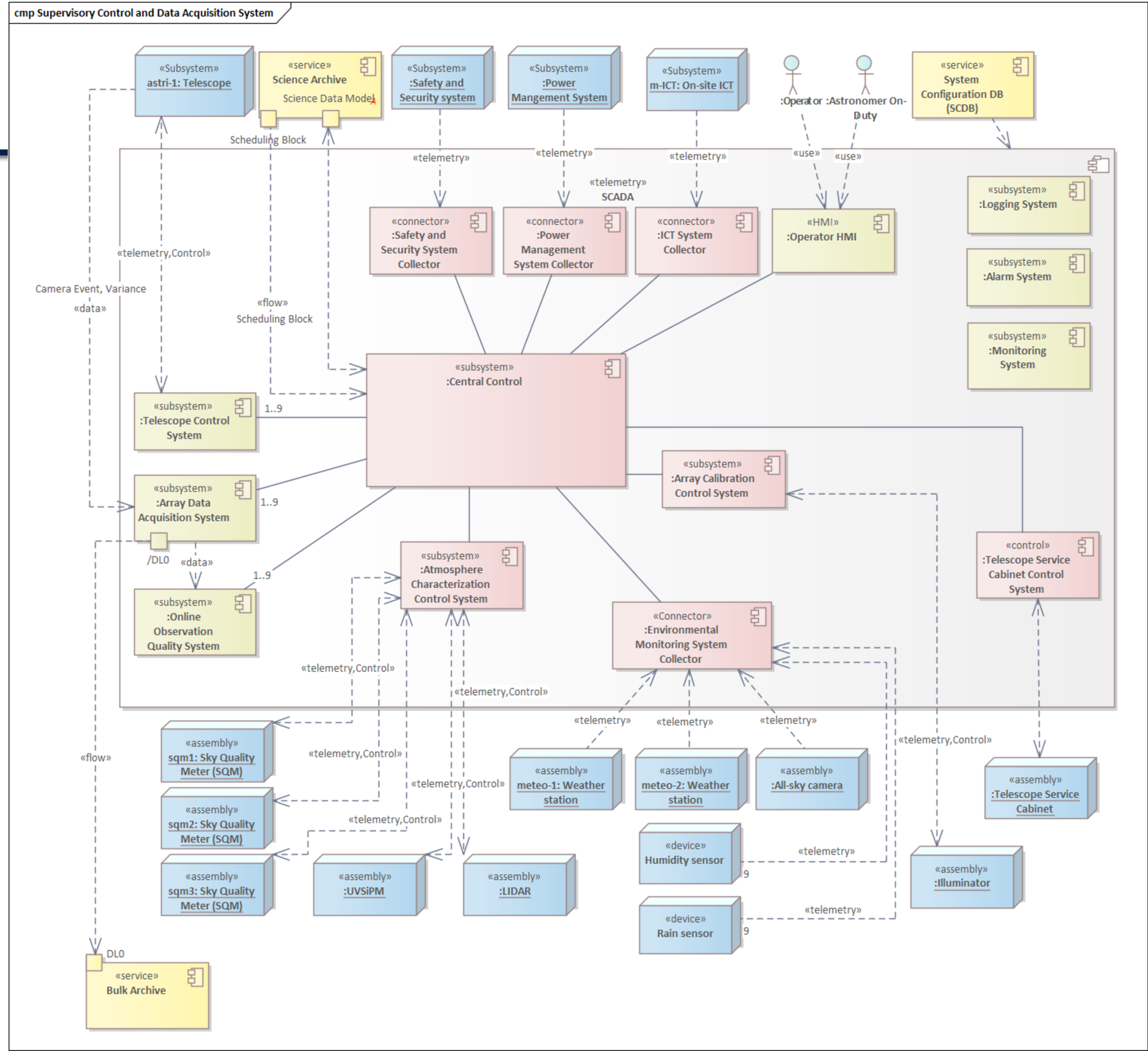
Supervisory Control and Data Acquisition System (SCADA)/3

- **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.

See A. Costa's talk

- **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

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.

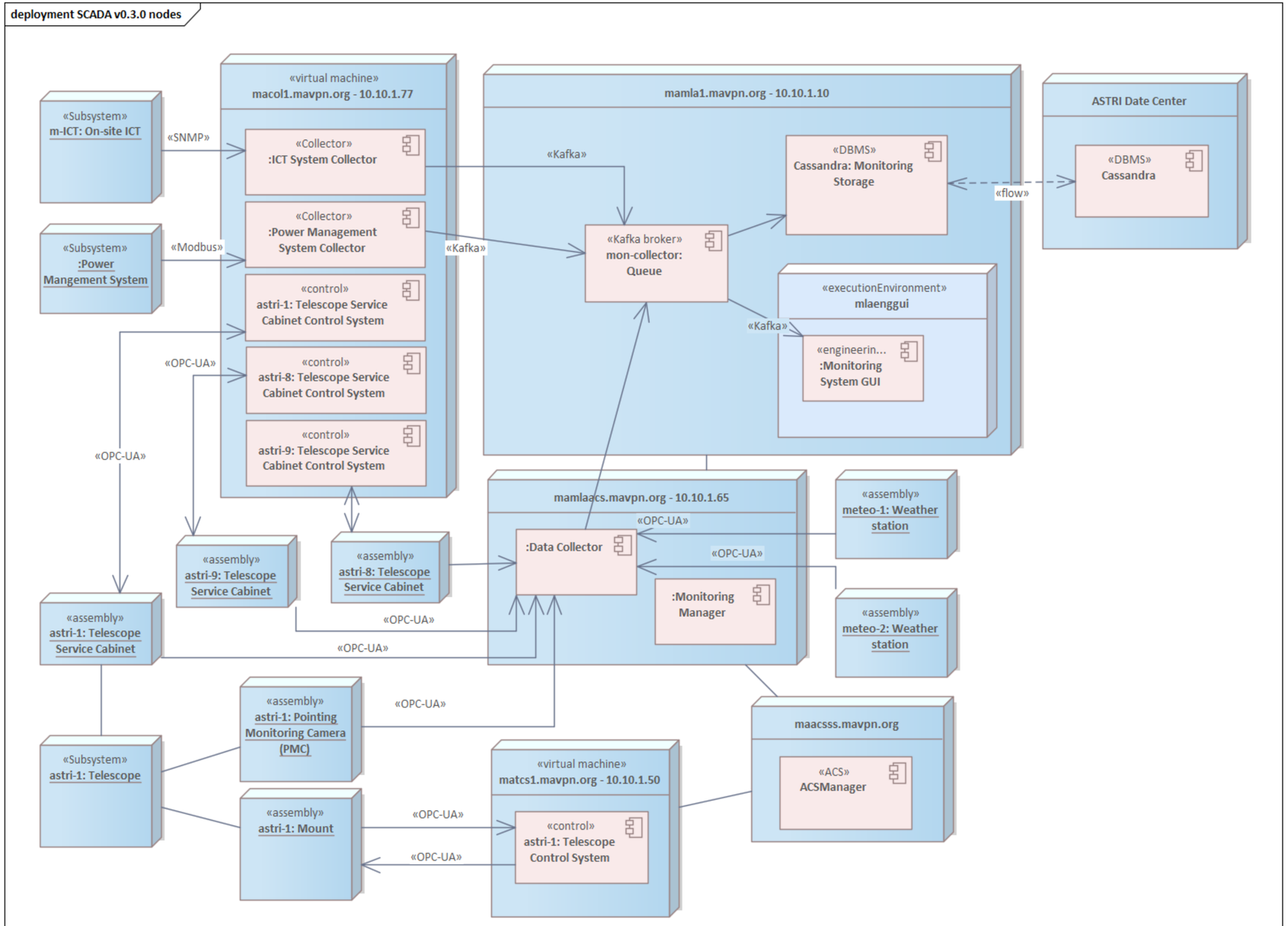


SCADA and software frameworks

- SCADA is developed using ALMA Common Software (ACS)†, Kafka and Cassandra.
  - 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, except for data acquisition that uses TCP/IP.
  - Cassandra is used for the permanent storage of monitoring and data quality information.

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

SCADA deployment

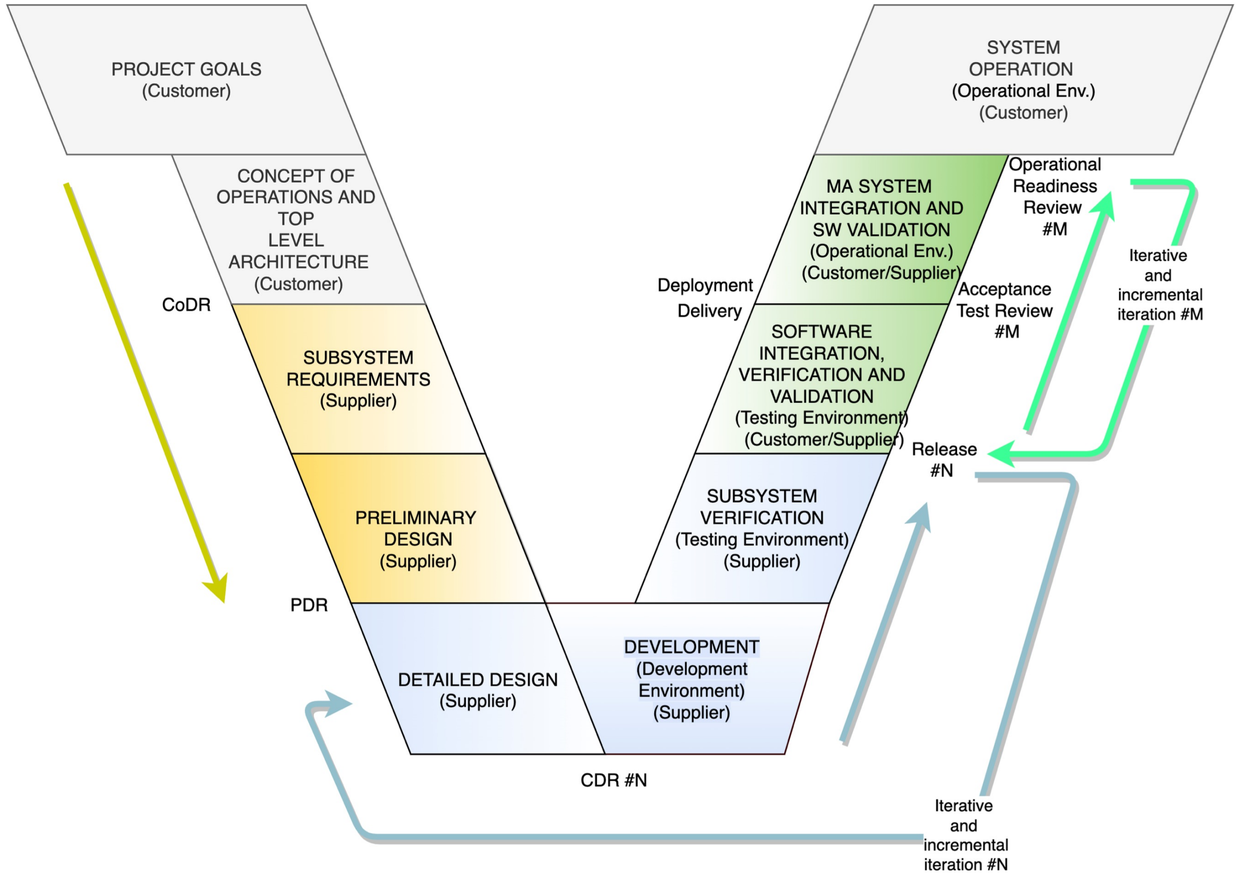


Systems:

- m-ICT **See Gianotti's talk**
- Power Management
- ASTRI-1 telescope
- 3x Telescope Service Cabinets
- 2x Weather Station
- Pointing Monitoring Camerta

Software development approach

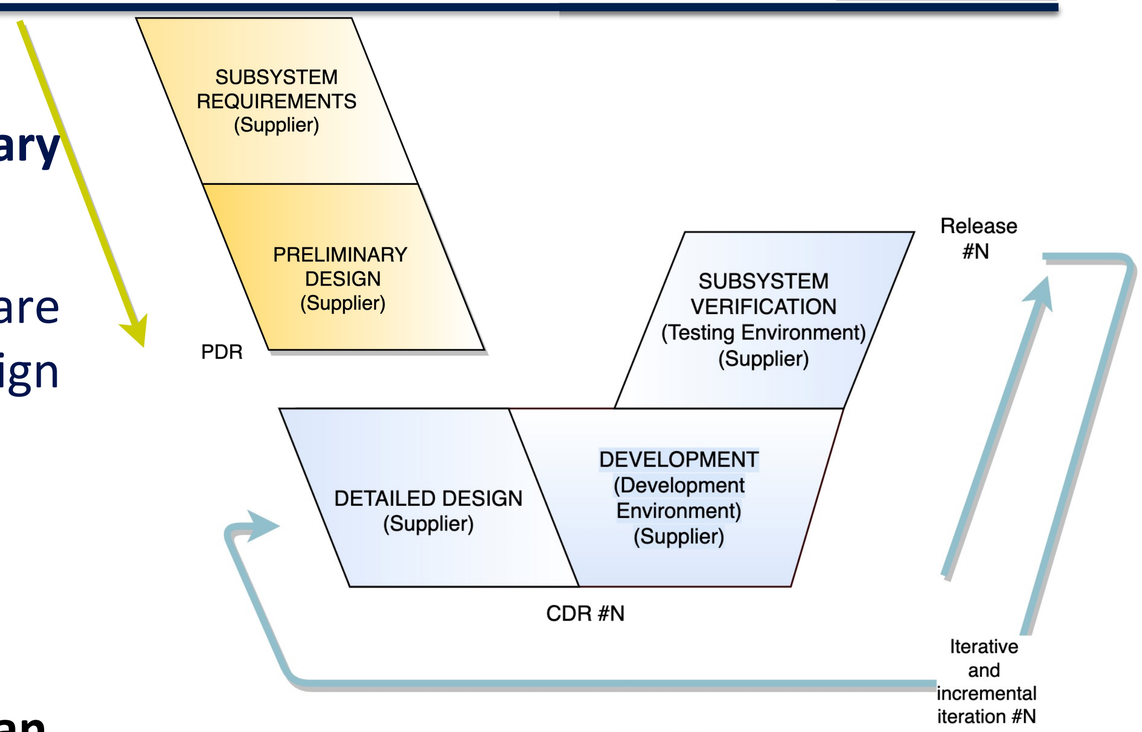
- The high complexity of the software management is due to:
  - the high number of hardware assemblies;
  - the high number of software subsystems;
  - developers from research institutes or private companies working at different locations.
- **Software Development Plan:** **agile development methodologies**, including:
  - **frequent iterations and releases**;
  - **use case-driven development approach**;
  - automated testing and continuous integration;
  - formal reviews when necessary.
- Integrated with **Verification and Validation Test plans** and **Quality Assurance Plan.**



ASTRI Mini-Array Software life-cycle and reviews

Software development approach/2

- **At the subsystem level (e.g. SCADA Monitoring system).**
- **First iteration. Subsystem requirement and preliminary design phase:**
  - **main output: use cases,** a drafts of the software requirement document, and of the detailed design document;
  - closed by a Preliminary Design Review (PDR).
- **Iterations on subsystem development:**
  - **selection of a use case to develop + Verification Test Plan**, then
    - **detailed design:** Critical Design Review for some iterations;
    - **development;**
    - **verification: i**f all automated tests pass, the software is released with the updated documentation + **Verification Test Report**.

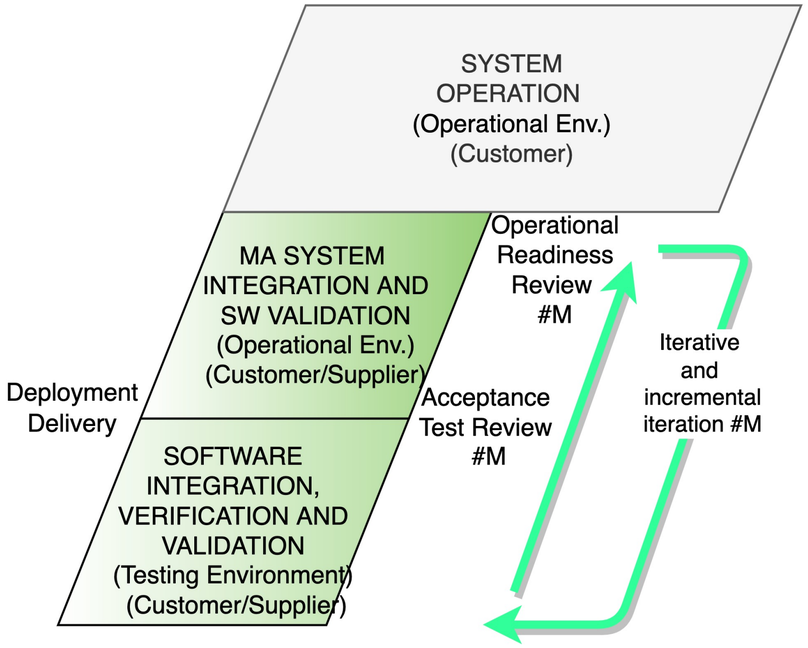


- **INAF GitLab**
- **Enterprise Architect**
- Continuous Integration (CI): GitLab CI environment for automated subsystem verification, dockers.
- SonarQube for quality reports.
- Hardware simulators.

Software development approach/3

- **At the system level (e.g. SCADA, Data Processing System).**
- **Iterations on integration:**
  - **Software integration, verification and validation:**
    - Integration of the subsystems in a **testing environment**;
    - Acceptance Test Review, to verify the completeness of the developed software, documentation, test and analysis reports + preliminary **Validation Test Report**;
  - **Software deployment and system integration (with hardware and other sw systems) in the operational environment:**
    - deployment at the Array Observing Site, or in the off-site Data Center
    - operational Readiness Review (ORR): the software system is ready for operations + final **Validation Test Report**.

Testing environment and **operational environment:** **see F. Gianotti talk**



- Deployment
  - Kubernetes
  - ACS Virtual Machines

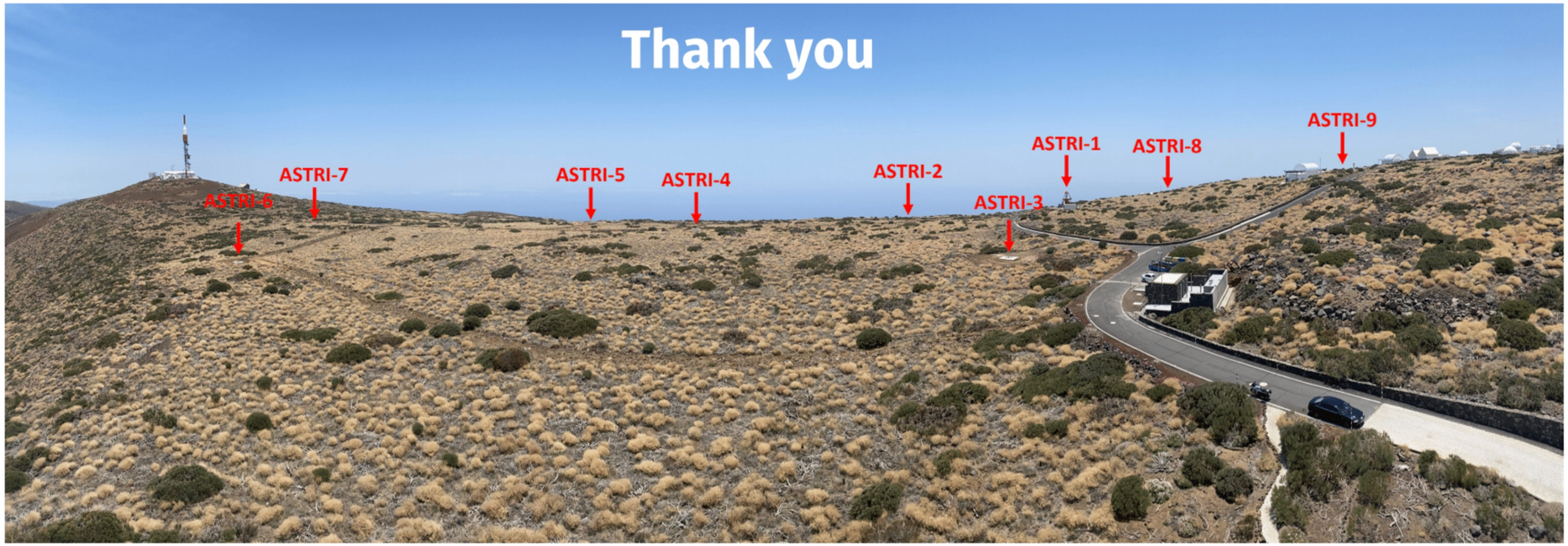
Conclusions

- The ASTRI Mini-Array software development approach allows the ASTRI team to release, integrate and deploy software in an iterative and incremental way:
  - to follow the different phases of the project, from construction to operations;
  - to integrate different geographically distributed teams from national and international research institutes and private companies.

- Talk on ASTRI Mini-Array software at this workshop
  - F. Gianotti: ASTRI Mini-Array On-Site Information and Communication Technology infrastructure
  - G. Tosti: The ASTRI Mini-Array on-site infrastructure startup system, monitoring collectors and the Telescope AIV software
  - A. Costa: The monitoring, logging and alarm system of the ASTRI Mini-Array

ASTRI Mini-Array

View from Vacuum Tower Telescope



View from Themis Telescope

Backup slides

Supervisory Control and Data Acquisition System (SCADA)/1

- **SCADA controls, monitor, and acquire data for all the assemblies and operations carried out at Array Observing Site in an automated way.**
- Supervised by an Operator.