The ASTRI Mini-Array

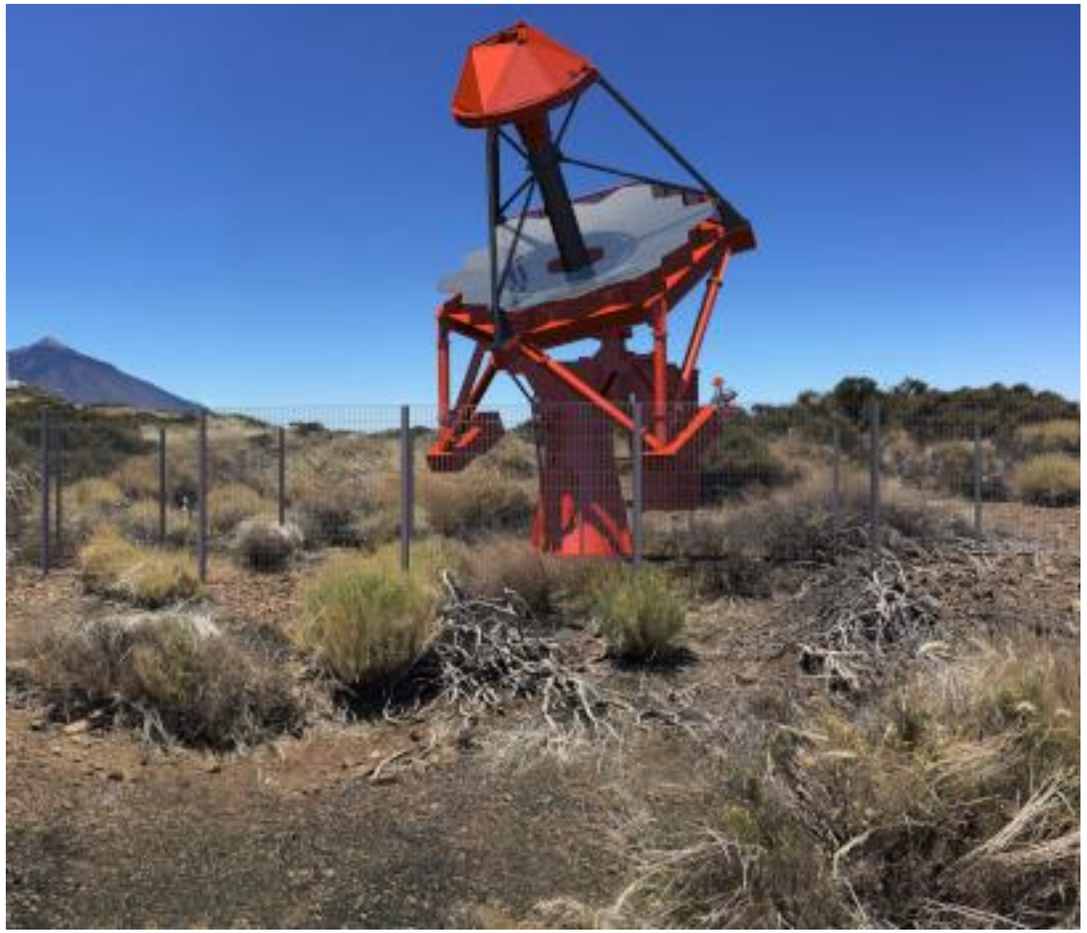
S. Scuderi – IASF Milano

for the ASTRI Project

11th International Workshop on Ring Imaging Cherenkov Detectors. Edinburgh 12-16 Sept 2022

Layout of the presentation

- The ASTRI Mini-Array project
- Performance
- Science & Operation concept
- ASTRI Mini-Array technical description
- ASTRI Mini-Array implementation



The ASTRI Mini-Array Project

ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) was born as “Progetto Bandiera” funded by Italian Ministry for Research with the initial aim to design and realize an innovative end-to-end prototype of the 4 meter class telescopes in the framework of the CTA observatory

The ASTRI Mini-Array is the second step of project whose purpose is to construct, deploy and operate an array of 9 Cherenkov telescopes at the Observatorio del Teide in Tenerife (Spain) in collaboration with Instituto de Astrofísica de Canarias.

More than 150 researchers belonging to

- INAF institutes (IASF-MI, IASF-PA, OAS, OACT, OAB, OAPD, OAR)
- Italian Universities (Uni-PG, Uni-PD, Uni-CT, Uni-GE, PoliMi)
- International institutions (University of Sao Paulo – Brazil, North-West University – South Africa, Instituto de Astrofísica de Canarias – Spain, University of Geneva – Switzerland).

Italian and foreign industrial companies are involved in the ASTRI Mini-Array project with important industrial return.

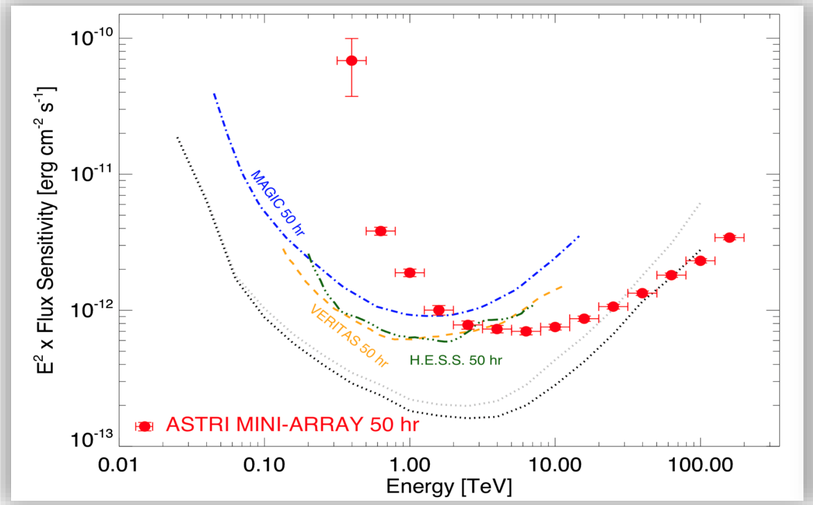
The ASTRI Mini-Array Project

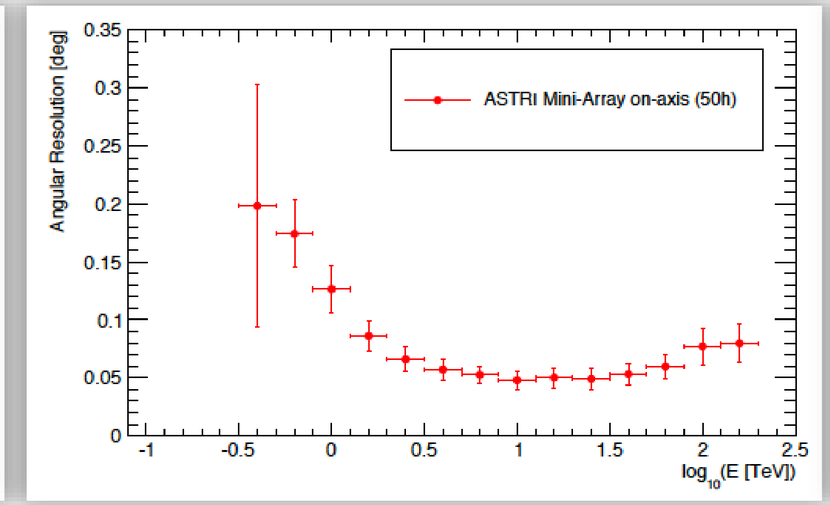
- The ASTRI Mini-Array can be considered a new pathfinder of the arrays of Cherenkov telescopes
- Hosting agreement with IAC foresees 4 + 4 years of operations for the ASTRI Mini-Array starting from beginning of operations
- During the first 3 years of operations the array will be run as an experiment
- The ASTRI Science team is developing a strategy to concentrate the observational time on a limited number of programs with clearly identified objectives
- After this initial period the project will gradually move towards an observatory model in which a fraction of the time will be assigned to scientific proposals through a Time Allocation Committee procedure

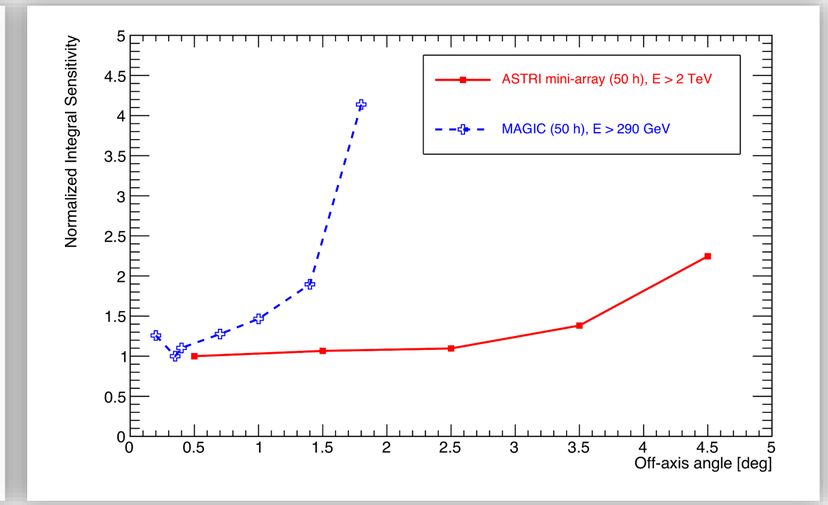
Mini but not small…

Largest Imaging Atmospheric Cherenkov Telescopes facility until CTAO will start to operate

ASTRI Mini-Array expected performance







Sensitivity: better than current IACTs (E ≳ 3 TeV):
Extended spectrum and cut-off constraints

Energy/Angular resolution: ~ 10% / ~ 0.05° (E > a few TeV)
Characterize extended sources morphology

Wide FoV (≥ 10°), with almost homogeneous off-axis acceptance
Multi-target fields and extended sources
Enhanced chance for serendipity discoveries

Mini but not small…

- **Wide-field stereoscopic observations in the 1 – 300 TeV energy band**
  - Restricted number of targets/deep exposures (≥ 200 h)
  - Galactic sources: wide FoV → multi-target fields
  - Extragalactic sources: survey of a few promising targets at > ~10 TeV scale
  - Fundamental physics: studies on LIV, EBL, Axion-Like Particles, …
- **Stellar Hambury-Brown intensity interferometry in the visible band**
- **Direct measurements of cosmic rays**

The ASTRI science team is developing a core science program

ASTRI Mini-Array papers

Journal of High Energy Astrophysics
Volume 35, August 2022, Pages 52-68
Go to table of contents for this volume/issue

The ASTRI Mini-Array of Cherenkov telescopes at the Observatorio del Teide

S. Scuderi [a] ✉, A. Giuliani [a], G. Pareschi [b], G. Tosti [c], O. Catalano [f], E. Amato [p], L.A. Antonelli [h], J. Becerra Gonzàles [m], G. Bellassai [d], C. Bigongiari [h, u], B. Biondo [f], M. Böttcher [n], G. Bonanno [d], G. Bonnoli [b], P. Bruno [d], A. Bulgarelli [e], R. Canestrari [f], M. Capalbi [f] ... R. Zanmar Sanchez [d]

Journal of High Energy Astrophysics
Volume 35, August 2022, Pages 1-42

ASTRI Mini-Array core science at the *Observatorio del Teide*

S. Vercellone [a] ✉, C. Bigongiari [b], A. Burtovoi [c], M. Cardillo [d], O. Catalano [e], A. Franceschini [f], S. Lombardi [b, g], L. Nava [a], F. Pintore [e], A. Stamerra [b], F. Tavecchio [a], L. Zampieri [h], R. Alves Batista [i], E. Amato [c, j], L.A. Antonelli [b, g], C. Arcaro [h, k], J. Becerra González [l, m], G. Bonnoli [a] ... G. Pareschi [a]

Journal of High Energy Astrophysics
Volume 35, August 2022, Pages 91-111

Extragalactic observatory science with the ASTRI mini-array at the *Observatorio del Teide*

F.G. Saturni [a, b] ✉, C.H.E. Arcaro [c, d, e, f], B. Balmaverde [g], J. Becerra González [h, i], A. Caccianiga [j], M. Capalbi [k], A. Lamastra [a], S. Lombardi [a, b], F. Lucarelli [a, b], R. Alves Batista [l], L.A. Antonelli [a, b], E.M. de Gouveia Dal Pino [m], R. Della Ceca [j], J.G. Green [a, b, n], A. Pagliaro [k], C. Righi [o], F. Tavecchio [o], S. Vercellone [o] ... G. Pareschi [o]

Journal of High Energy Astrophysics
Volume 35, August 2022, Pages 139-175

Galactic observatory science with the ASTRI Mini-Array at the *Observatorio del Teide*

A. D'Aì [a] ✉, E. Amato [b], A. Burtovoi [b], A.A. Compagnino [a], M. Fiori [c], A. Giuliani [d], N. La Palombara [d], A. Paizis [d], G. Piano [e], F.G. Saturni [f, g], A. Tutone [a, h], A. Belfiore [d], M. Cardillo [e], S. Crestan [d], G. Cusumano [a], M. Della Valle [i, j], M. Del Santo [a], A. La Barbera [a] ... G. Pareschi [k]

Operation modes

- **Normal (science) observation mode**: this is used to observe the targets as defined by the Science Operation Plan. Usually science observations require dark time, although it is also possible operate also during moderate moonlight conditions. Calibration activities are included in the normal operation mode.

- **ToO Mode**: the science operation plan will identify some astrophysical targets that, giving raises to transient phenomena, will require a response from the night operator and a change in the night schedule. This means that no dedicated automatic software procedure to react to these transient phenomena is foreseen. Depending on the type of transient object the reaction time will vary from 1 hour to 1 day.

- **Coordinated Mode**: Synergies with the current VHE arrays (MAGIC, LST, VERITAS) in the northern hemisphere are foreseen in the science operation plan. This means that simultaneous observations will be possible. Usually, those observations, will be scheduled well in advance.

- **Maintenance mode**: this mode deals with all activities necessary for the maintenance of the telescopes, the on-line control software, the monitoring, characterization and calibration devices, and the infrastructures (e.g. network, data center, etc). This is the only daytime operation mode.

Science Operations

- No real time analysis of the data is foreseen but only a data quality check. Data analysis policy adopted will then be next day processing.

- No array trigger (stereo trigger) will be implemented at the site. Any search for Cherenkov events detected in coincidence by more than one telescope will be performed via software off-line at the Rome Data Centre.

- No subarray operation is foreseen.

- Night science operations will be controlled remotely from La Laguna @ IAC or, eventually, from control rooms located in Italy $\rightarrow$ no people required at the site during the night.

- The local control room at the Themis Observatory will be used during commissioning and science verification phase, during maintenance activities or in case of other special activities.

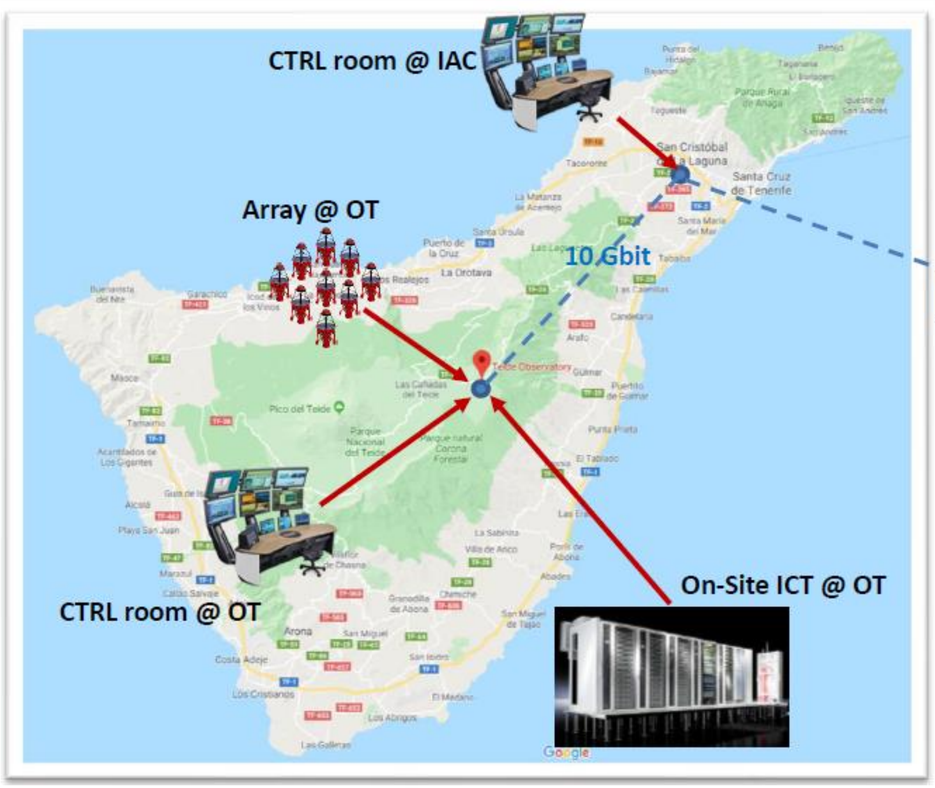
The ASTRI Mini-Array locations

The ASTRI Mini-Array in Tenerife

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

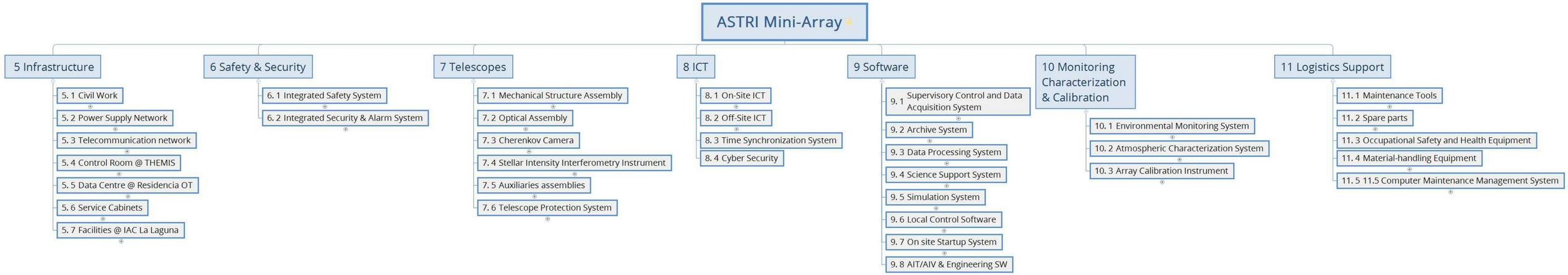
The ASTRI Mini-Array in Italy

- Data Centre in Rome
- Remote Array operation centers



10 Gbit

The ASTRI Mini-Array architecture: Product Tree



Infrastructure: composed by all those parts needed to make the observational site suitable to host the telescopes of the ASTRI Mini-Array.

Safety & Security: an independent system for the protection of people and site assets

Telescopes: include mainly the hardware used to collect and image Cherenkov light from air showers and the auxiliary assemblies needed to support this function.

ICT: includes all computing/storage hardware, the overall networking infrastructure (including cabling and switches) and all system services (operating system, networking services, name services, etc.) necessary on site and off site to control and monitor the array and to archive and analyse the scientific and engineering data.

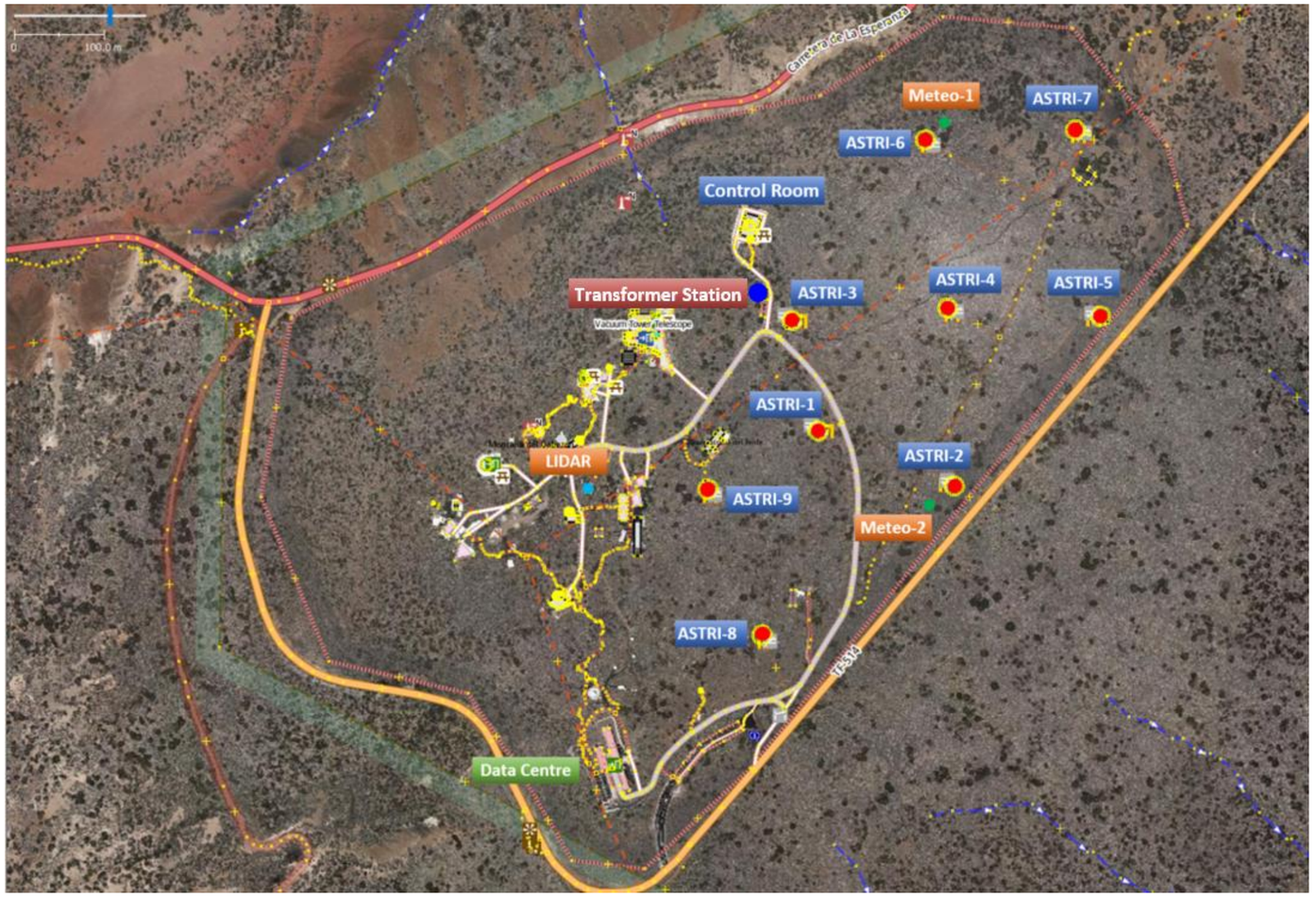
Software: The Mini-Array software will provide to the user a set of tools from the preparation of an observing proposal to the execution of the observations, the analysis of the acquired data online and the retrieval of all the data products from the archive.

Monitoring, Characterization and Calibration: the set of devices that allows the environmental monitoring the atmospheric characterization and the array calibration.

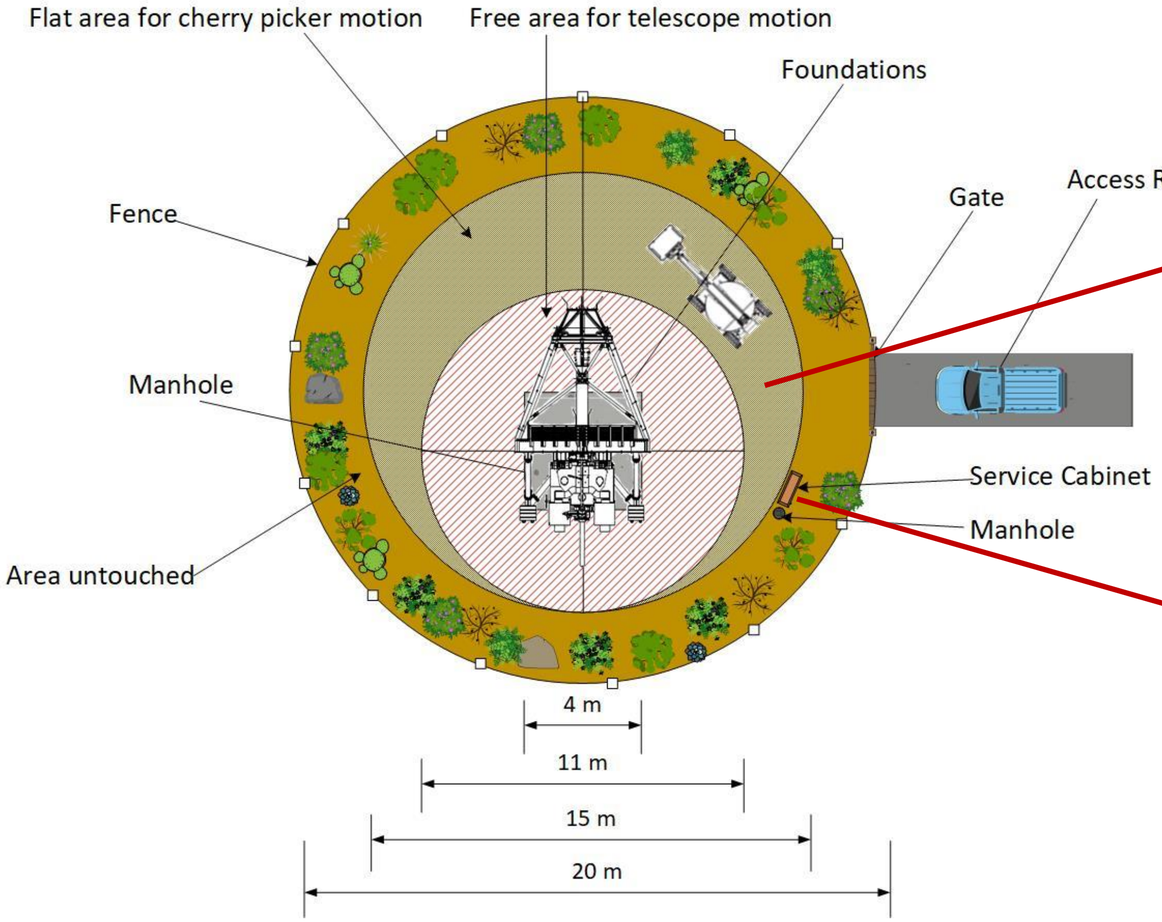
Logistics Support: includes all the hardware & software necessary for the preventive and corrective maintenance of the ASTRI Mini-Array.

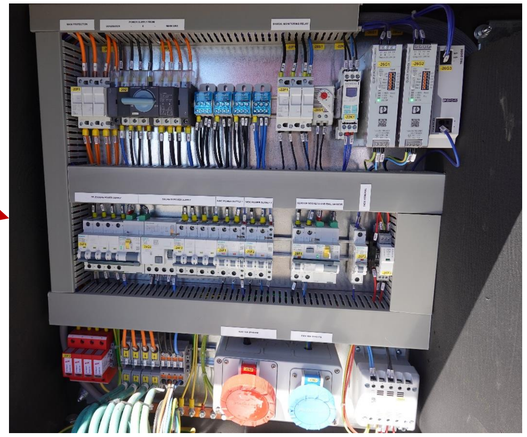
The Teide Infrastructure

- Civil Work (including foundations for telescope and auxiliaries, roads, trenches)
- Power supply network (including transformer station, UPS and emergency power generator)
- Telecommunication network
- Control room @ Themis observatory
- Onsite Data Centre @ Teide Residencia
- Service cabinets



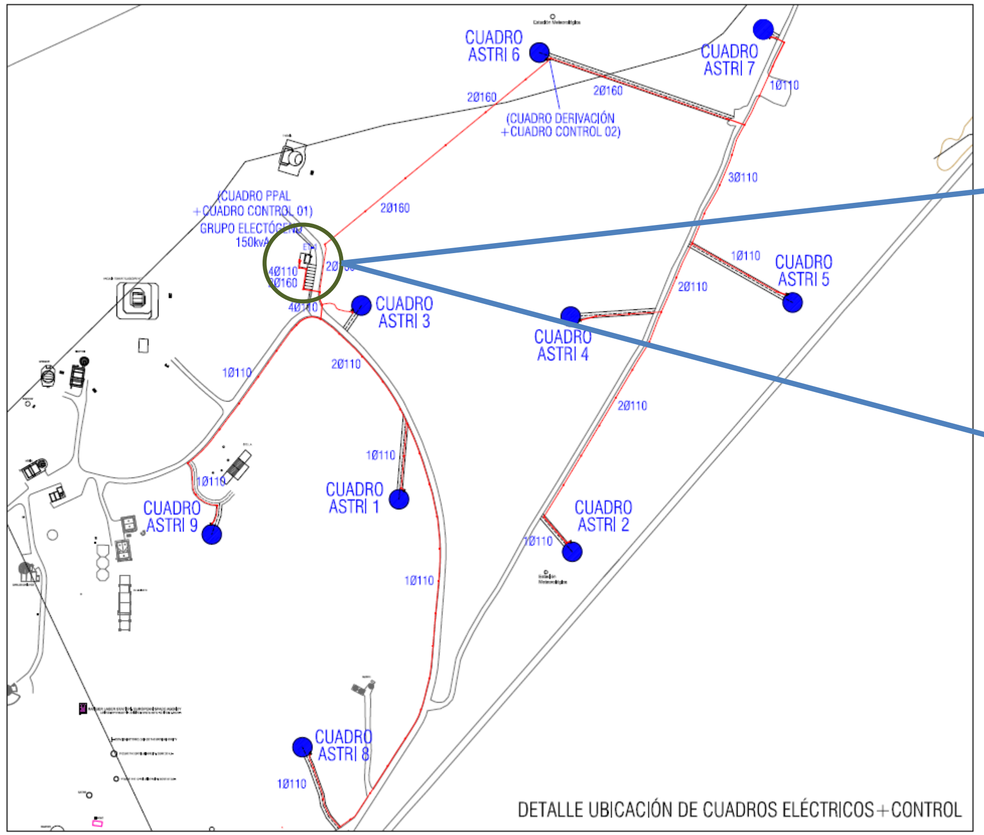
Infrastructure: Telescope's area

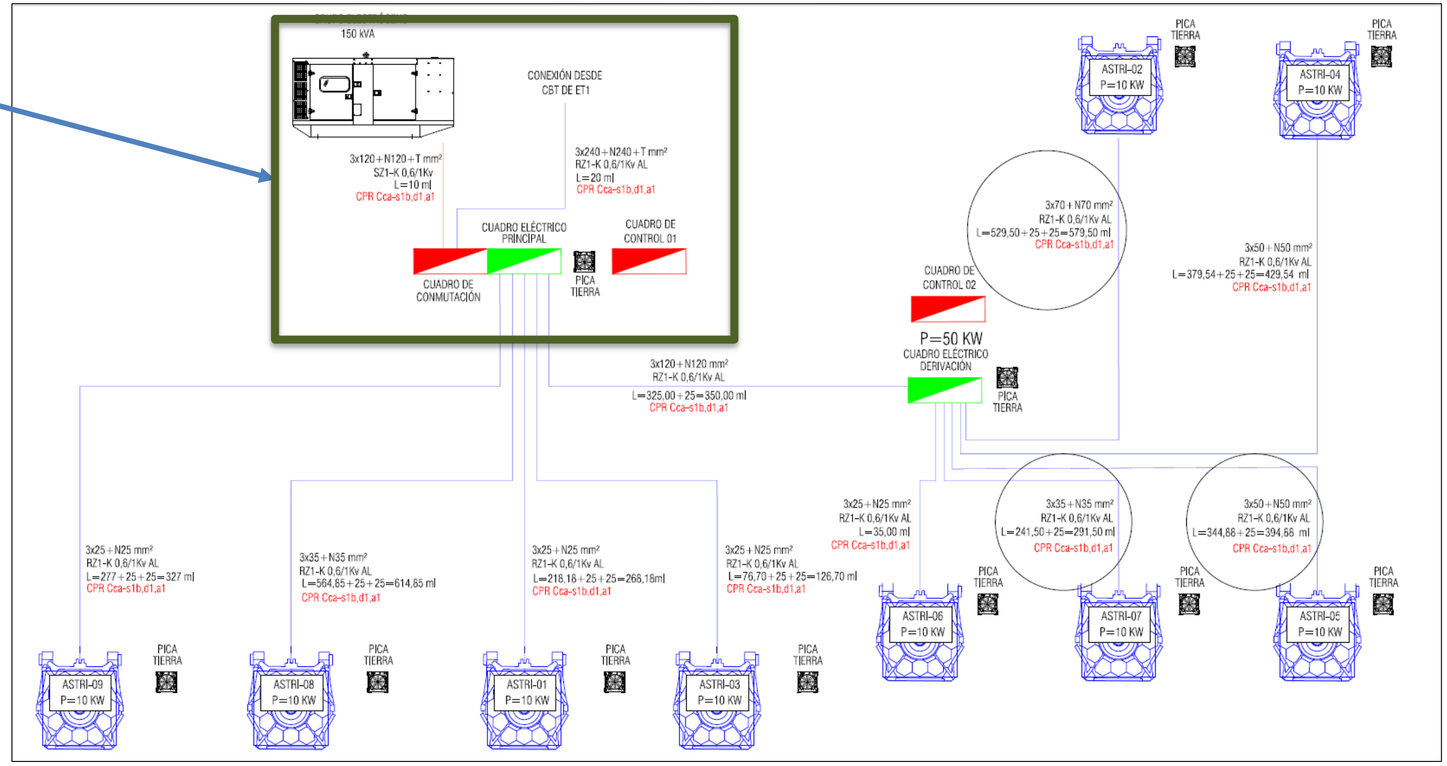




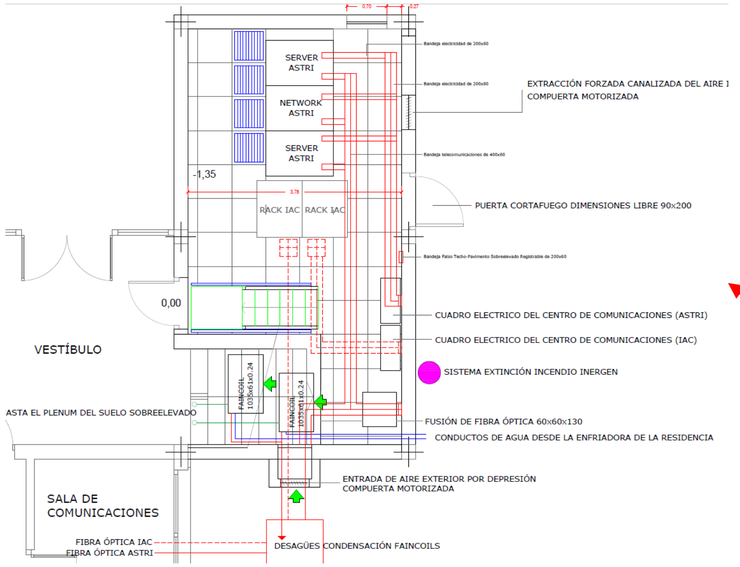
Service cabinet

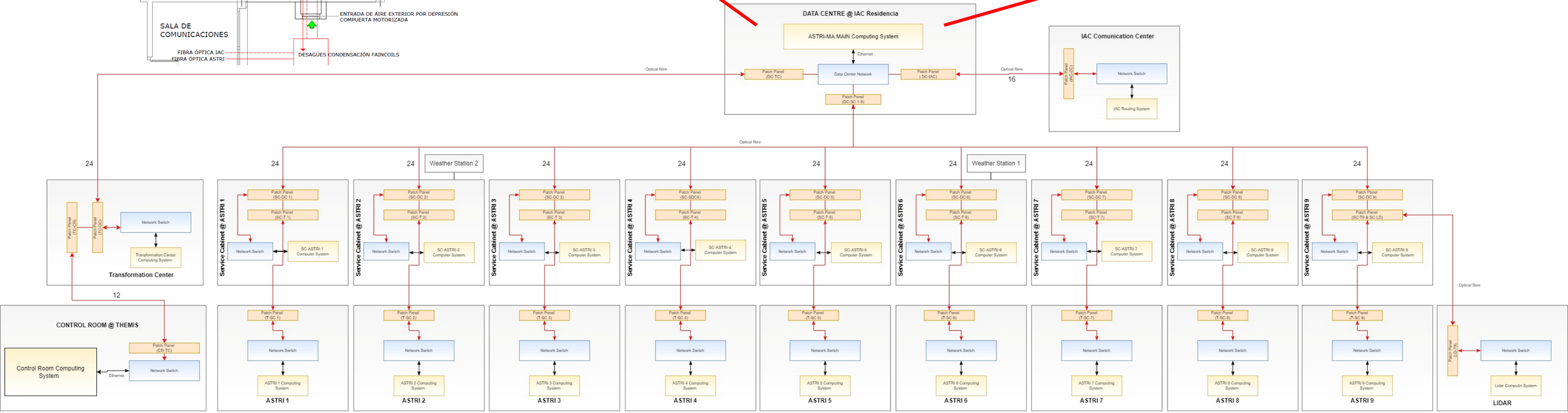
Infrastructure: Power network



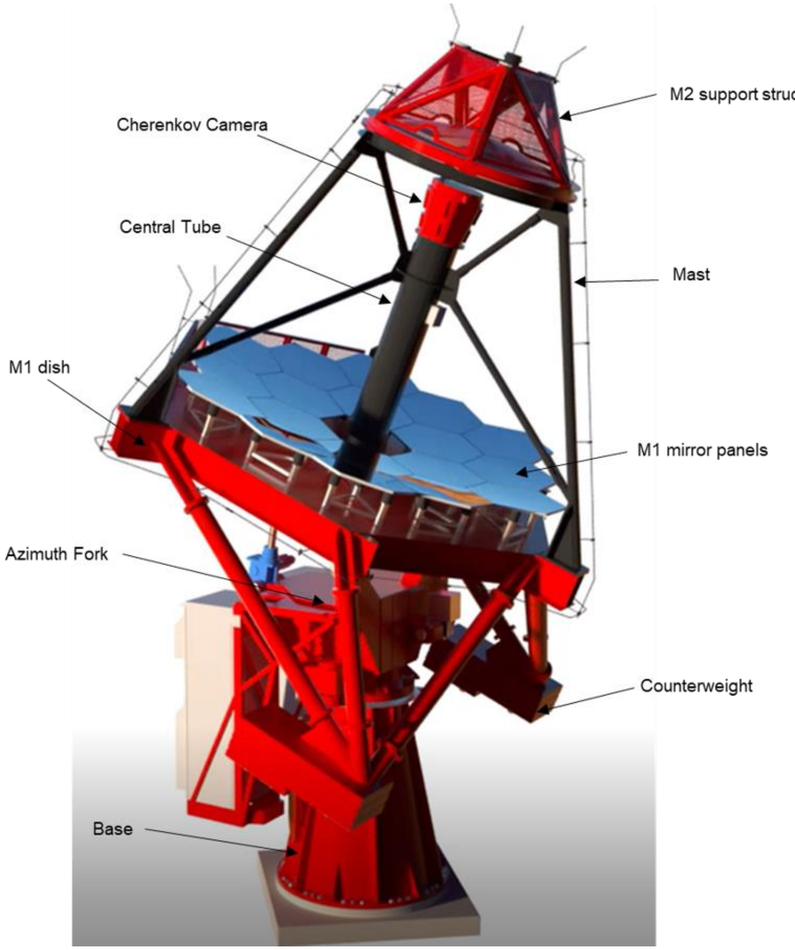


Infrastructure: Telecommunication network

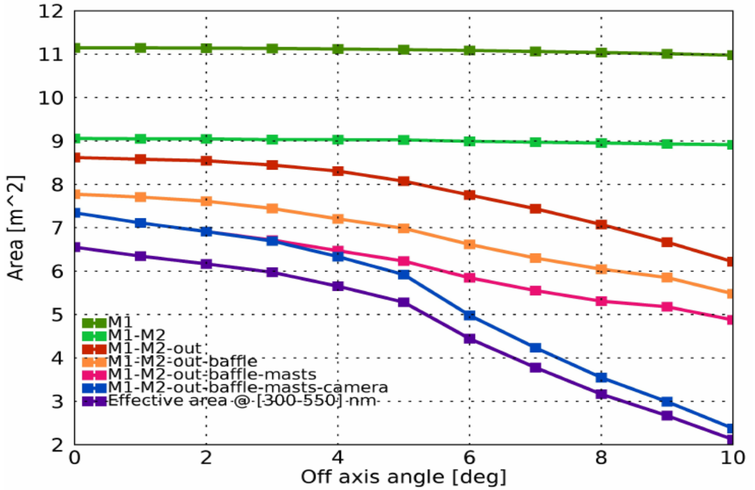




ASTRI Mini-Array telescopes in a nutshell



- **Opto-mechanics (EIE, MLT, Flabeg, ZAOT)**
  - Alt-azimuthal mount
  - Modified Schwarzschild-Couder configuration
  - Primary Mirror: 4.3 m (18 segments)
  - Secondary Mirror: 1.8 m (monolithic)
  - F-number: 0.5
  - Average effective area > 5.0 m^2
  - Optical PSF $\leq$ 0.19 deg
  - Post calibration pointing precision $\leq$ 7 arcsec
- **Cherenkov Camera (CAEN, EIE, NI, Hamamatsu, Weeroc)**
  - Front-end electronics based on CITIROC-1A ASIC
  - SiPM sensors: 7x7 mm (series LV3 – 75 μm pixel size)
  - 2368 pixels (37 matrices of 8x8 pixels)
  - Filter Window with dielectric coating
  - Angular pixel size: 0.19 deg
  - Field of View: 10.5 deg

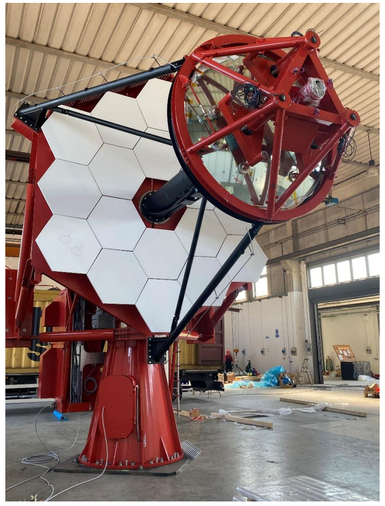


ASTRI-1 integration @ EIE labs

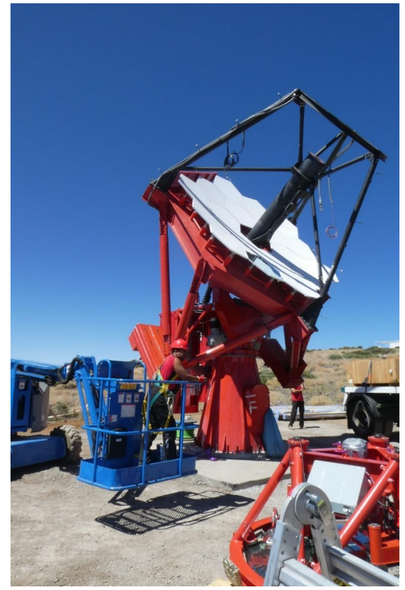






ASTRI-1 on site integration



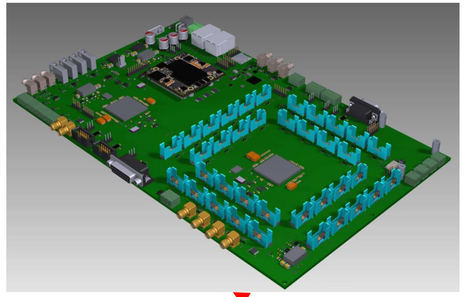
Telescope integration takes 2-3 weeks (working days) including:

- Base grouting 2-3 days
- M1 panels integration 2 days
- M2 mirror integration 2 days

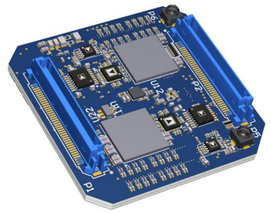
Cherenkov Cameras

Mini-Array

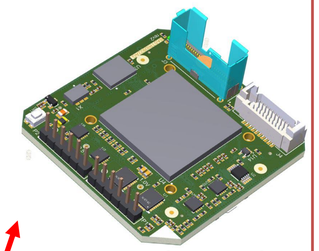
Back End Electronics



Front End Electronics

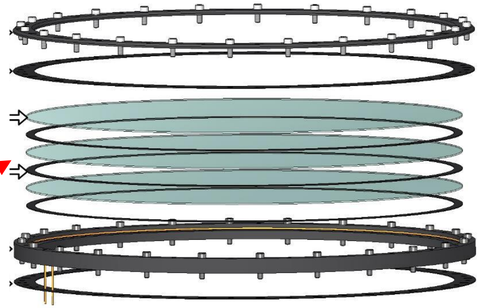


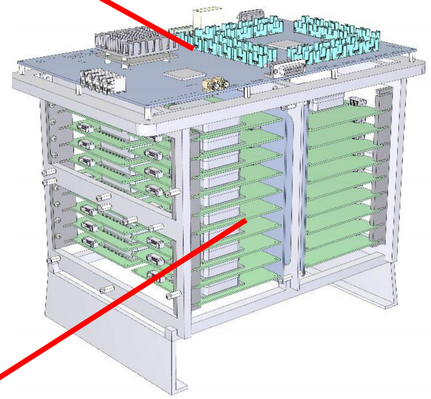
ASIC board

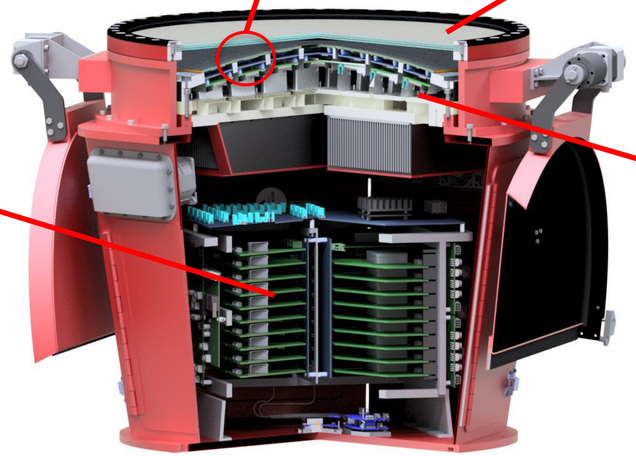


FPGA board

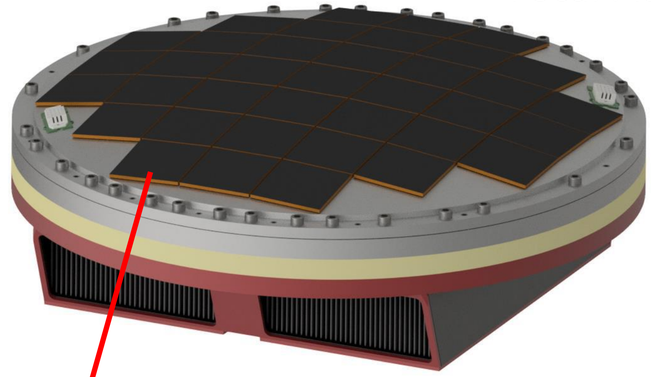
Filter Window







Focal Plane



Voltage Distribution Board

EIE GROUP

CAEN Tools for Discovery

SiPM matrix

HAMAMATSU PHOTON IS OUR BUSINESS

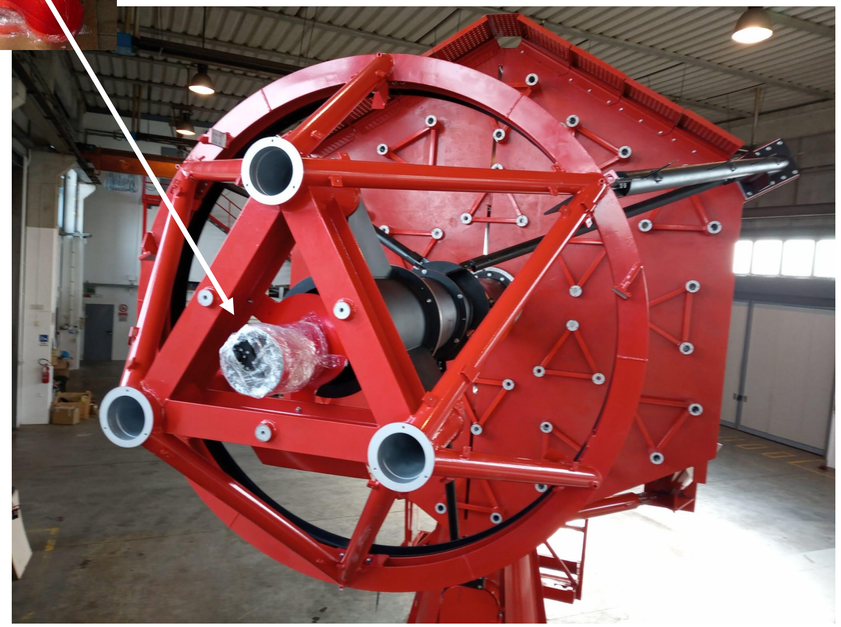
Cherenkov Cameras: status of production

- On going contract for the production of 11 cameras
  - 1 engineering camera for qualification
  - 9 cameras
  - 1 spare camera

- ASIC (CITIROC-1A) production completed
- SiPM production (450 matrices) completed
- Procurement of long lead items ongoing
- Prototyping activities for electronics boards completed
- Electronics and thermo-mechanical design will be frozen @ CDR
- Production of well consolidated subsystems (e.g. ASIC boards) started for the engineering camera
- Engineering camera ready for lab tests by the end of the year

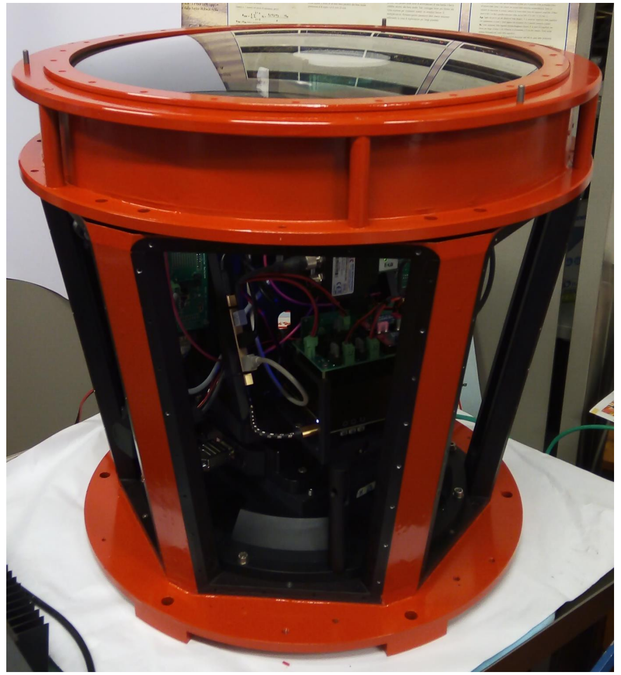
Telescope's auxiliaries

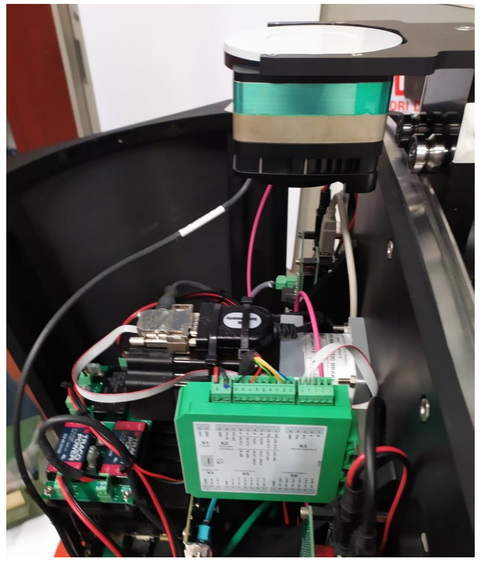
Pointing Monitoring Cameras (Uni-PG)
CCD camera placed on the M2 support structure used to monitor pointing and tracking performances of the telescope



→ First three delivered at Italy integration site
→ PMC of ASTRI-1 mounted on the telescope

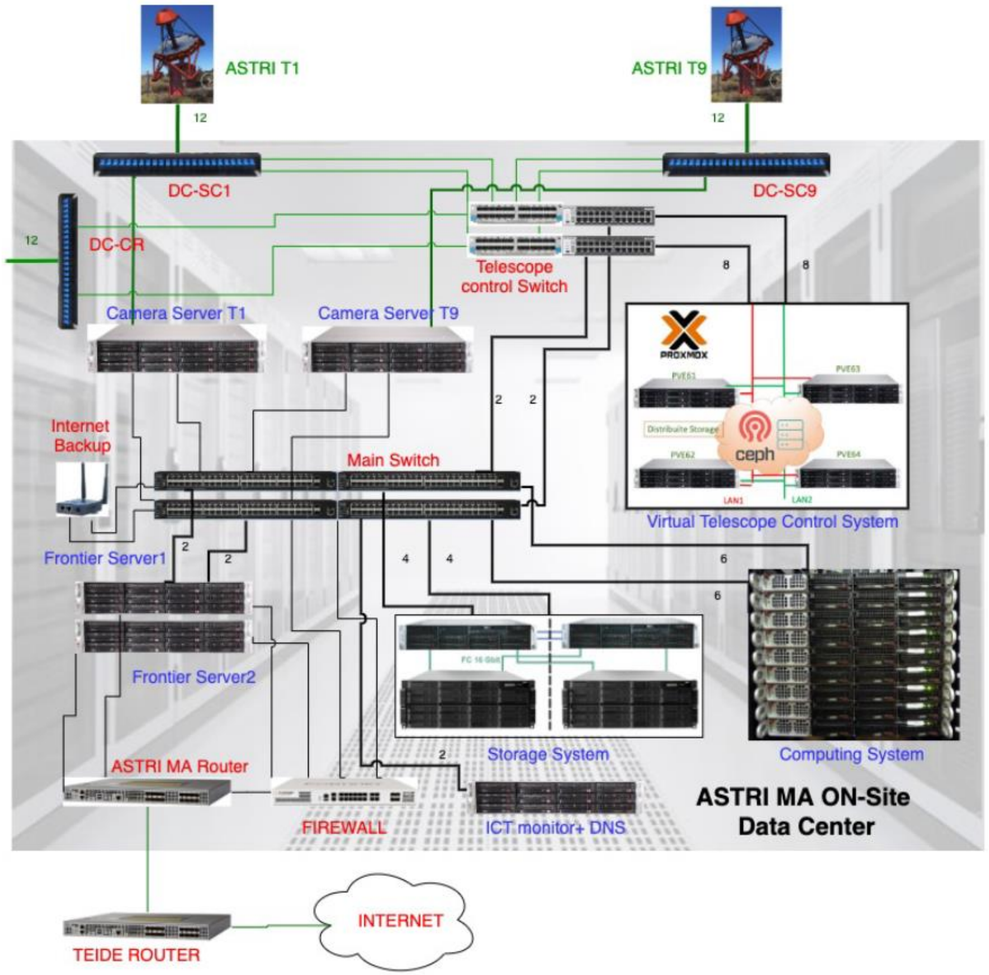
Optical Camera (IASF-MI, OAPD, OACT, OA Brera)
CCD camera placed on the telescope focal plane to align the panels of M1





→ Ready to ship to Tenerife

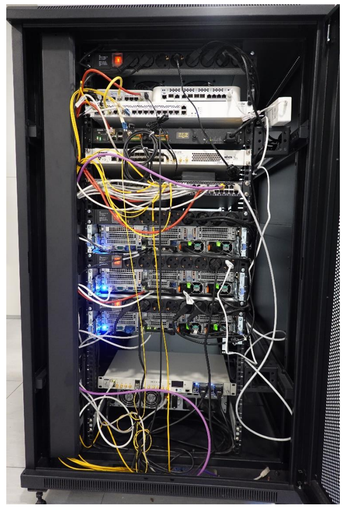
ICT – On site Data centre

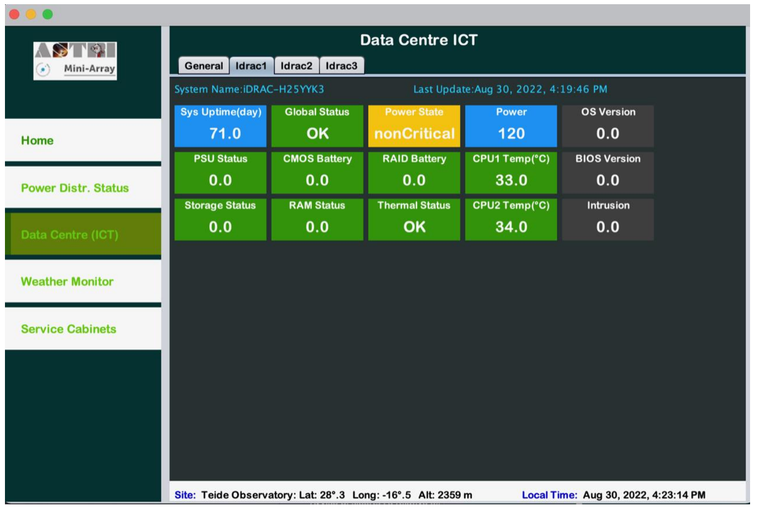


- ***Virtual Telescope Control System***: the system hosting the virtual machines that will be used for the telescopes control.
- ***Camera Servers***: are the physical servers, one for each telescope, for the Cherenkov camera and stellar intensity interferometry data acquisition.
- ***Computing System***: is the set of physical servers dedicated to the on-line analysis of scientific data for quality check and of monitoring data for the alarm management.
- ***Storage System***: is the collection point of the raw scientific data, of the monitoring and of the alarm data. It also the location from where all these data are accessible for remote transfer and for all on-site uses.
- ***Network System***: is the set of devices responsible for internal and external network connections.

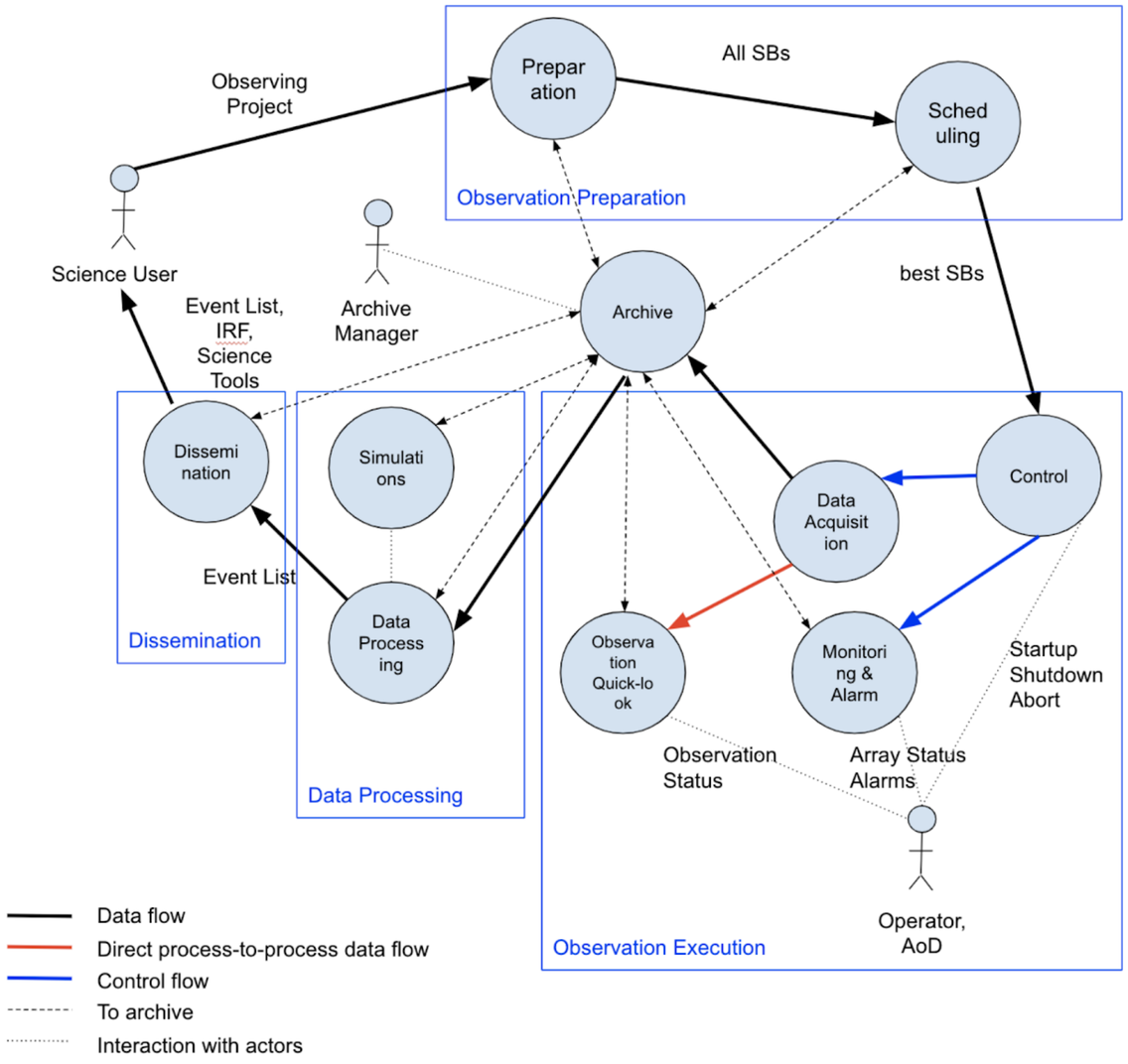
m-ICT

Reduced version of the onsite ICT to run single telescopes installed in the data centre in July





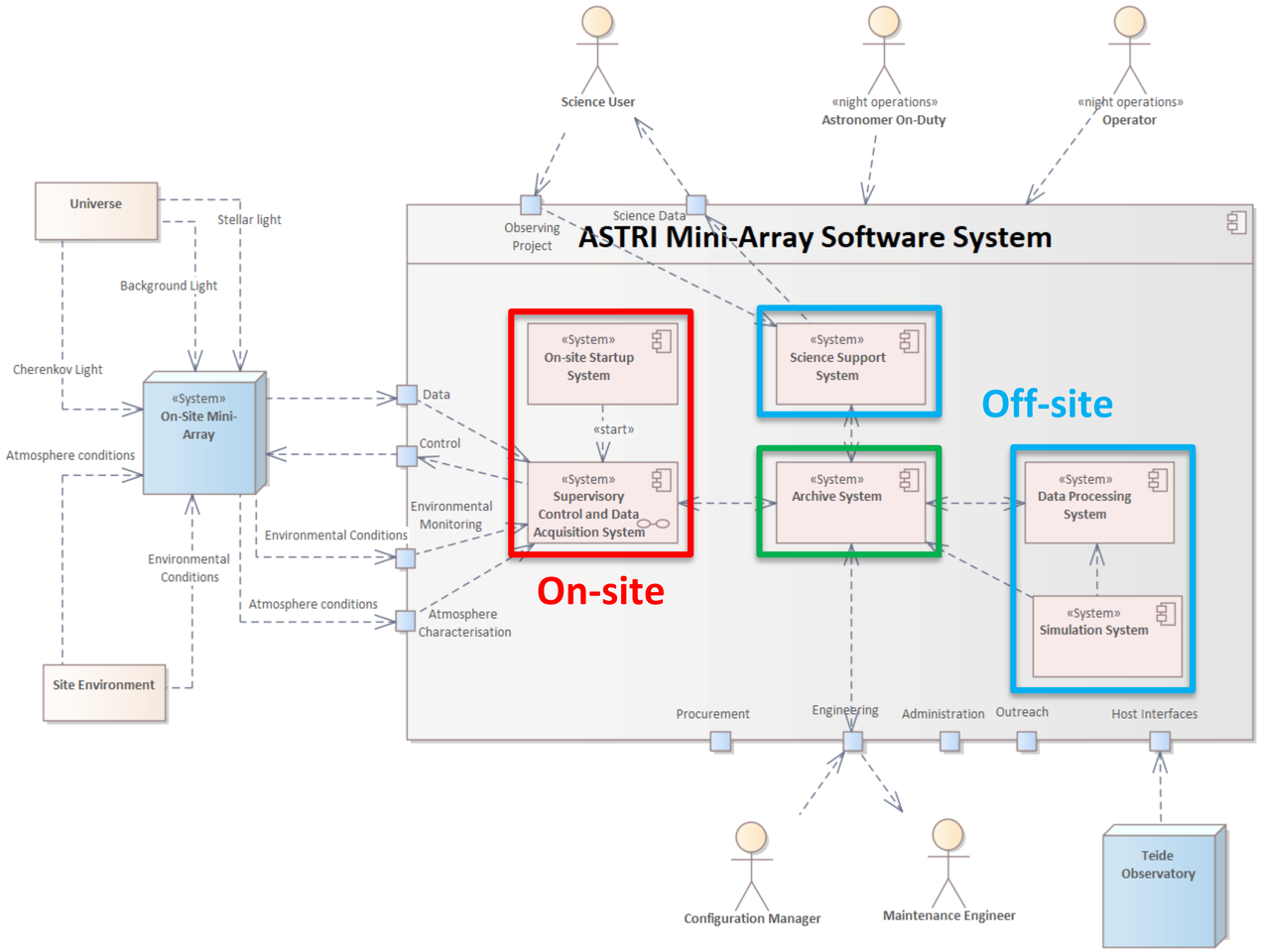
Software: data & information flow



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
2. Observation execution
3. Data Processing
4. Dissemination

Software architecture: context diagram

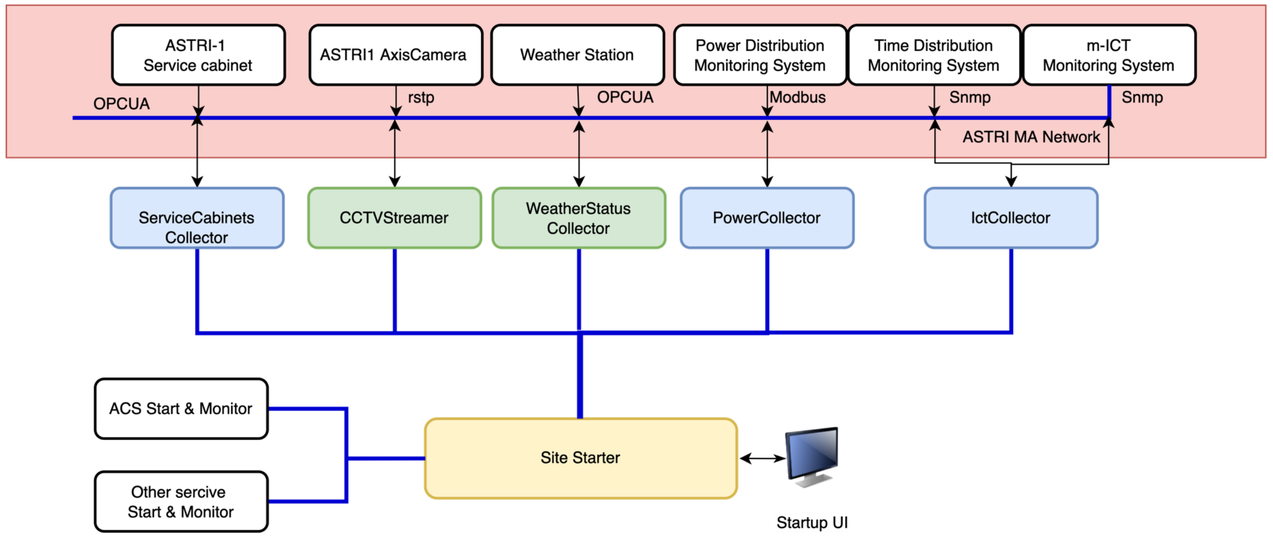


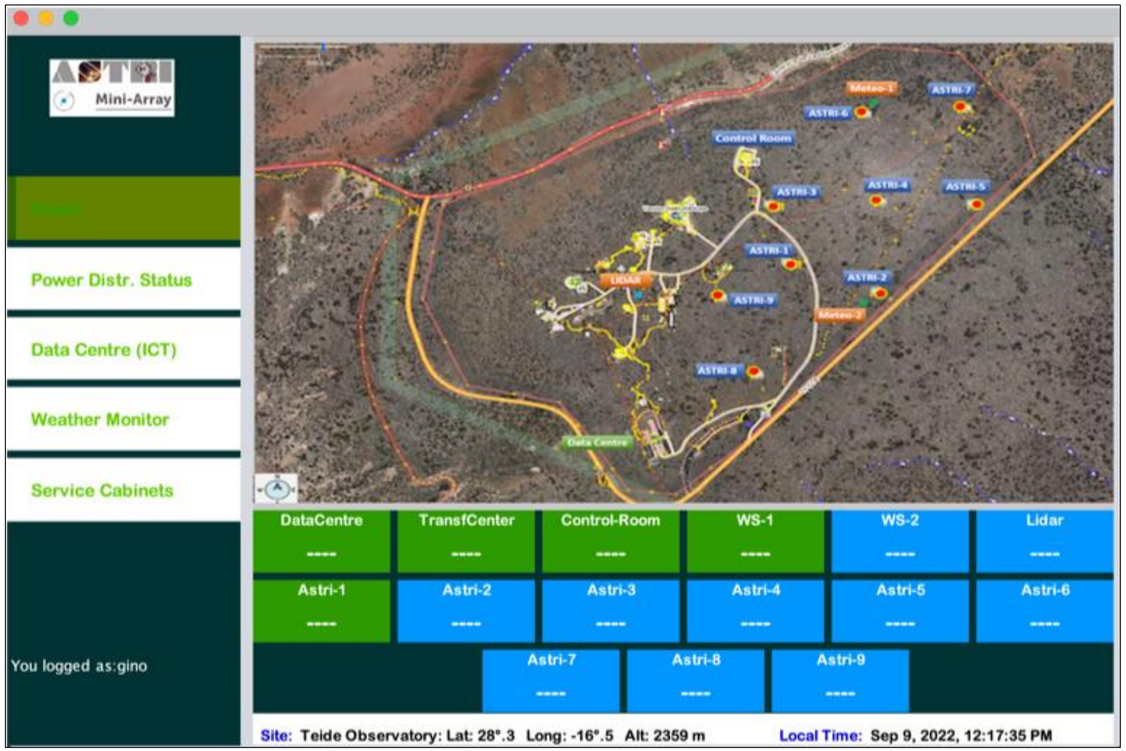
- ***Startup System.*** The software to manage the sequence of the startup and shutdown of the critical on-site systems that have to be available before the start of the Mini-Array.
- ***Supervisory Control And Data Acquisition (SCADA) System.*** The software system devoted to control all the operations carried out at the Mini-Array site, including the startup of the Mini-Array system. SCADA is a central control system which interfaces and communicate with all equipment and dedicated software installed On-Site.
- ***Archive System.*** The software service that provides storage and organization for all data, data products, and metadata generated for and by the Mini-Array, and defined by the Mini-Array Data Models.
- ***Data Processing System.*** The software system used to calibrate and reduce the data acquired. This software is also used to check the quality of the final data products.
- ***Science Support System.*** The software system which provides the main point of access for the exchange of science-related data and information with the ASTRI Science Users, and which supports the whole science-related workflow, from the Observing Project submission to the access to the archived high-level Mini-Array science data products and the corresponding Science Tools to support data analysis.
- ***Simulations System.*** The software system that runs Monte Carlo simulations to provide simulated data for the development of reconstruction algorithms and for the characterization of real observations.

Software: development

Software development mainly by INAF

Startup system

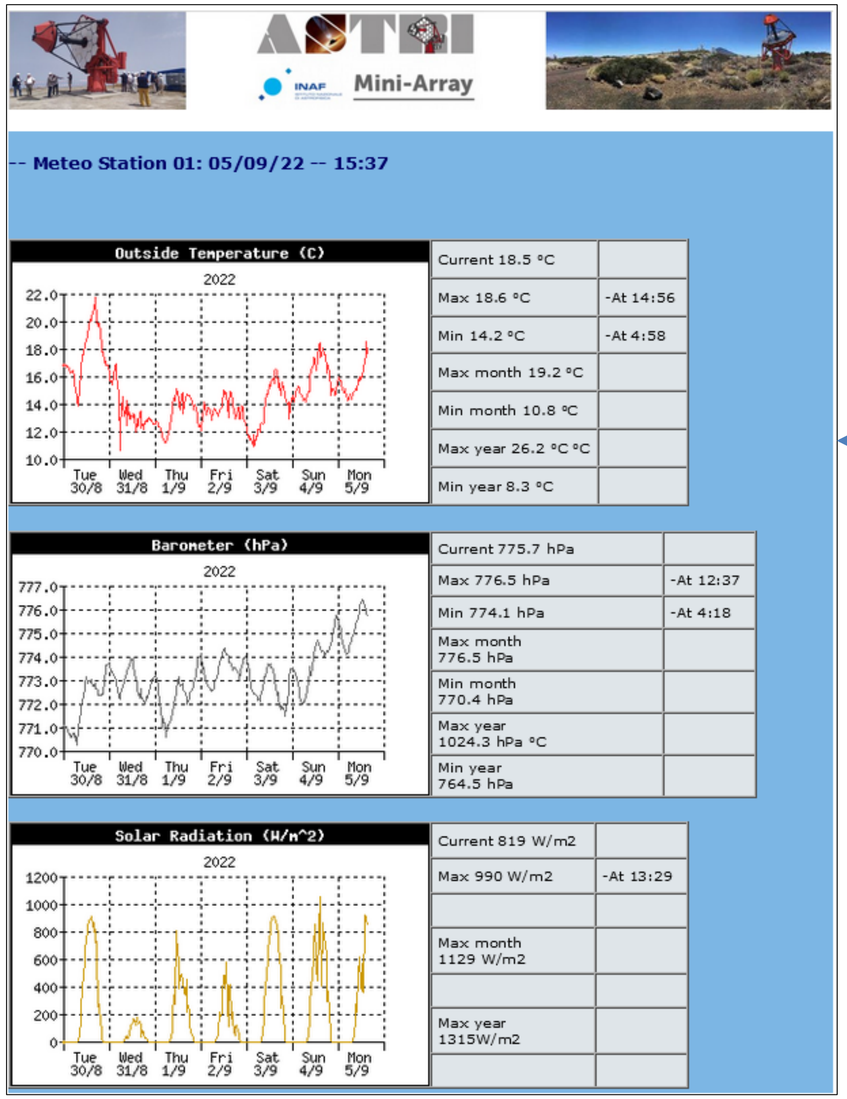




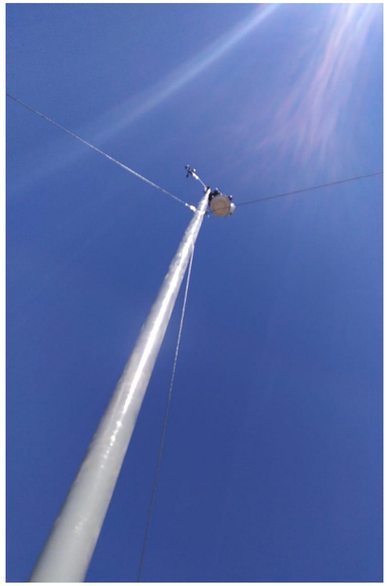
Support by external companies/research institutions on specific aspects:

- Central Control System by Universidad Tecnica Federico Santa Maria (SCADA)
- Operator Human Machine Interface by University of Geneve (SCADA)

Weather Station

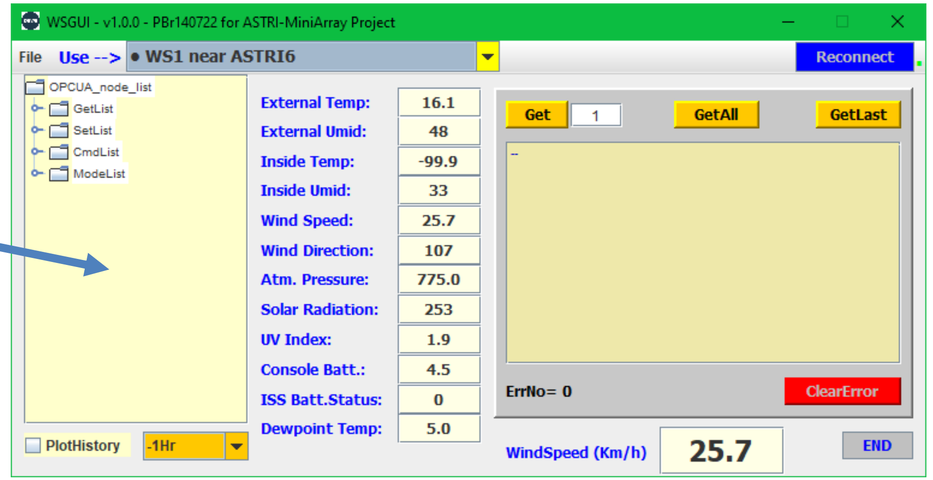


Weather Station 1 installed in July close to ASTRI-6



Example of WEB based GUI

Engineering GUI



ASTRI Mini-Array implementation critical issues

- **All technical issues are under control so far**

- **Programmatic issues due, but not only, to COVID-19 and war**
  - **Raw materials → availability and cost**
  - **Semiconductors/Electronics components → very long lead times**
  - **Increased cost of energy → cost of manufacturing but also survival of suppliers**
  - **Delays related to full scale resumption of activities**

Last practical effects on the project

- **Delays in ASTRI-1 production → commissioning and acceptance shifted to end 2022**
- **Delivery of ASTRI-8 & 9 shifted to early 2023**
- **Cherenkov cameras production → scheduled maintained but costs increased**

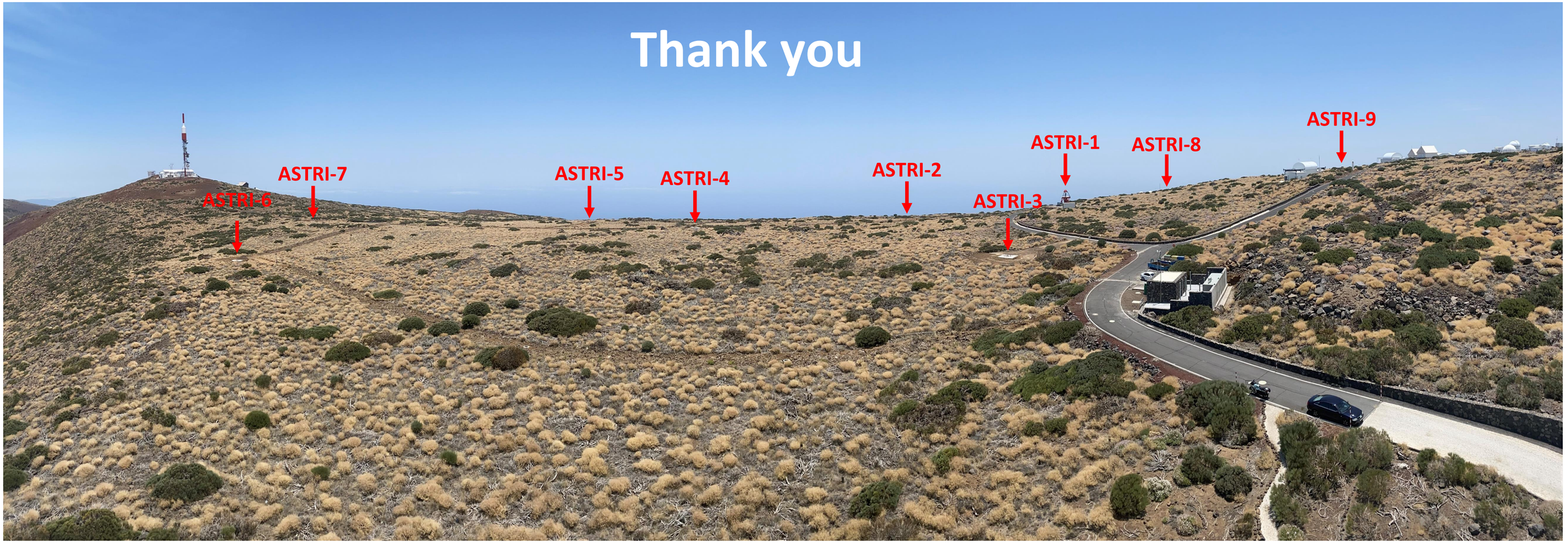
ASTRI Mini-Array implementation timeline

Timeline based on current available information

- Teide infrastructure almost complete -> Contract closed by beginning of October
- ASTRI-1 telescope site acceptance review by the end of 2023
- ASTRI-8 & ASTRI-9 telescopes shipped to Tenerife beginning of 2023 (completion of the first batch of 3 telescopes)
- First camera (engineering camera) ready for lab test at the end of 2022 → @ the site in spring 2023
- First three telescopes (ASTRI-1, 8 and 9) complete in summer 2023
- Early observations start
- Second batch of telescopes (total of six) will start to arrive at the end of summer 2023
- ASTRI Mini-Array ready for commissioning at the end of 2024
- Scientific observations start mid 2025

Photo CREDITS Tommaso Marchiori (EIE group)

ASTRI Mini-Array



View from Themis Telescope

Backup slides

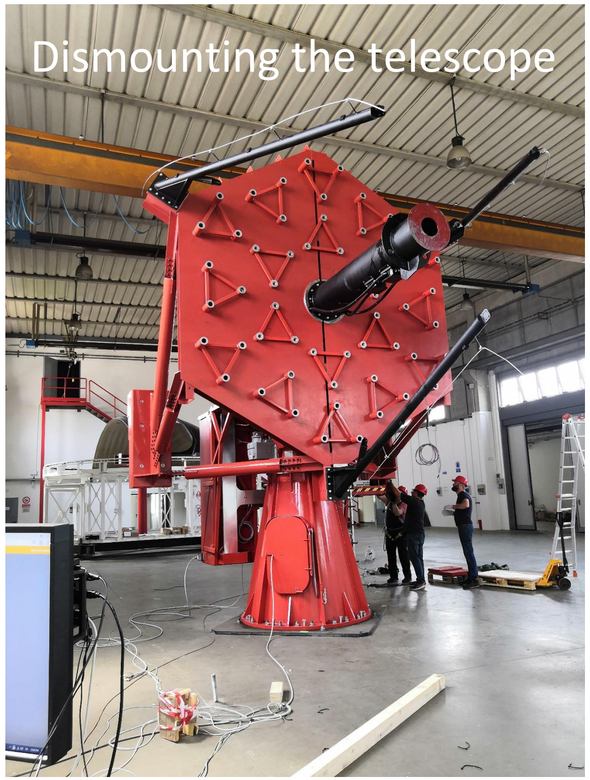
Infrastructure: foundations

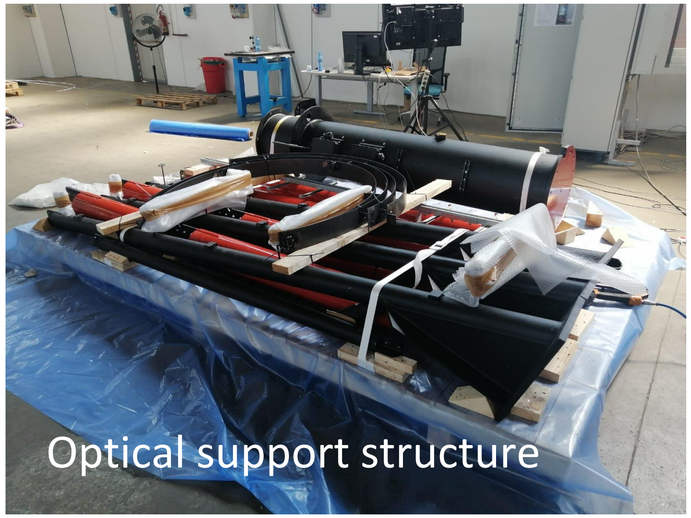







ASTRI-1: disassembling, packing and transportation





ASTRI Mini-Array Optics

- The optical design is based on a polynomial- modified Schwarzschild-Couder aplanatic configuration.
- This configuration allows us to perform a better correction of aberrations at large incident angles even for small focal ratios and hence facilitates the construction of compact telescopes.
- This optical system enables good angular resolution across the entire field of view and allows reducing the focal length and therefore the physical pixel and overall camera size.
- No permanent actuators on M1 panel. Alignment done only during AIV and for maintenance

Mirrors Status

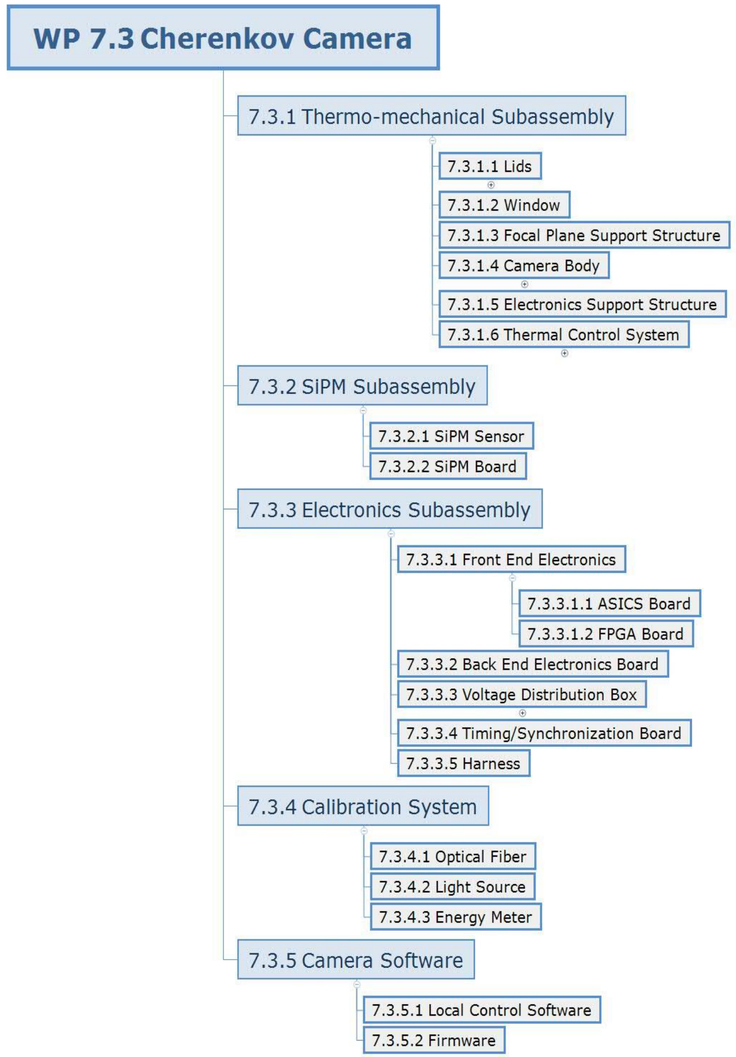
M1 mirrors (Media Lario Srl)

- Segments of primary mirrors ready
- First batch integrated on ASTRI-1

M2 mirrors (Flabeg GmbH, ZAOT, Media Lario)

- 1 mirror integrated on ASTRI-1
- 1 mirror delivered for telescope integration
- 7 mirrors under recoating process

ASTRI Mini-Array Cherenkov Camera



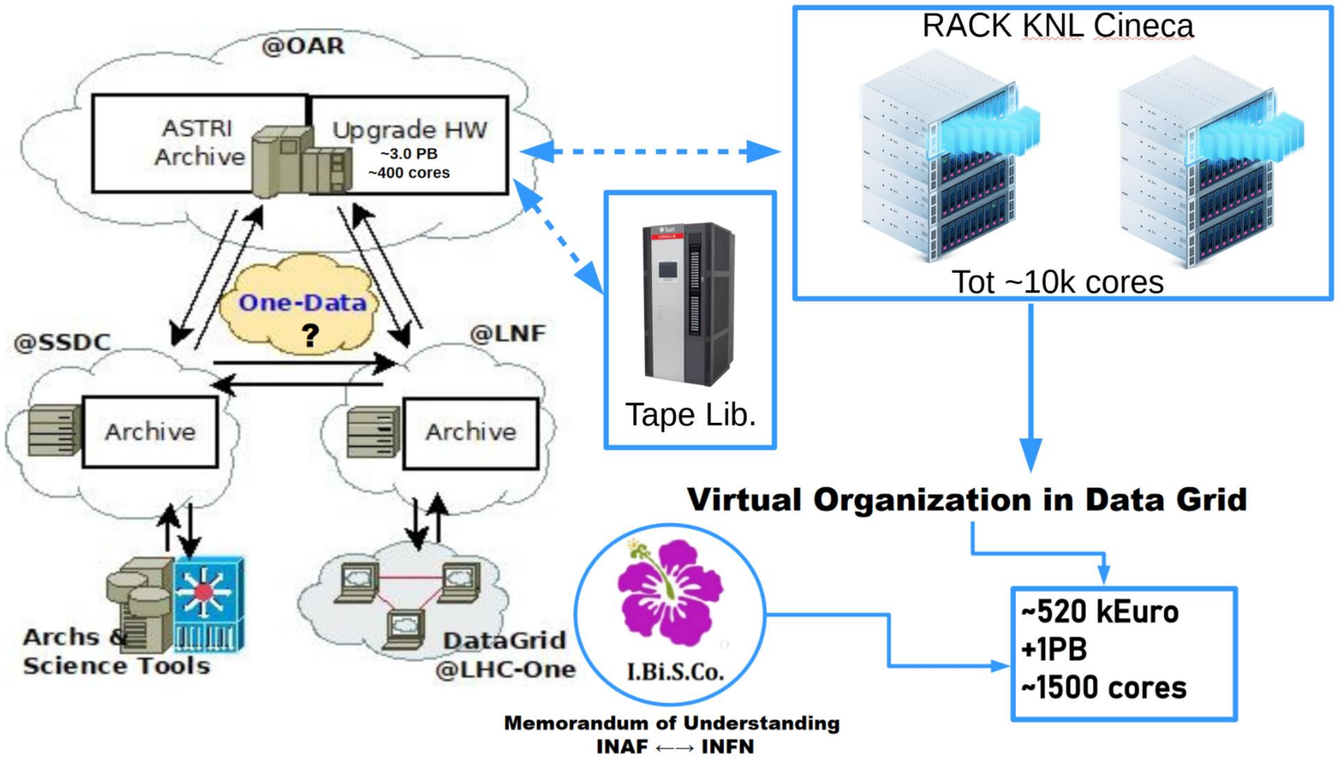
Mechanical Assembly: the mechanical structure assembly is made by the set of structures that host or support the various sub-assemblies and parts of the camera (electronics board and auxiliary devices).

SiPM Assembly: the SiPM assembly is a board composed by the SiPM photodetectors themselves and by a board that interfaces the detectors to the front end electronics.

Electronics assembly: the electronics assembly comprises the Front End electronics (FEE), the Back-End Electronics (BEE) and the Voltage Distribution Board (VDB). The FEE Board is made of the ASIC board and the FPGA Board. The ASIC board is in charge to detect the signals generated by f the SiPM sensors, digitalize them, and send them to the FPGA board. The FPGA board runs the algorithm able to identify a valid trigger on each SiPM sensor. The BEE controls and manages the overall system, including data management formats, lid open-and-close mechanisms and fibre-optic calibration tool. The BEE provides also the needed functions to process and transmit the data-images as processed by the FEE. The VDB is in charge to deliver power to all the subsystems.

Calibration System: The Calibration System embedded in the ASTRI Camera has in charge to perform relative calibration of the Camera's components. It is made by: optic-fibre, laser diode, pulse generator, energy meter.

ICT – Offsite data centre



A distributed archive solution will be adopted for the ASTRI Mini-Array archive with three main nodes

1. INAF – OAR: central storage and computing nodes
2. INFN – LNF: for access to Data Grid infrastructure
3. ASI – SCDC: to interface high level ASTRI Mini-Array science archive with multiwavelength SCDC facilities and science tool services