The ASTRI Mini-Array

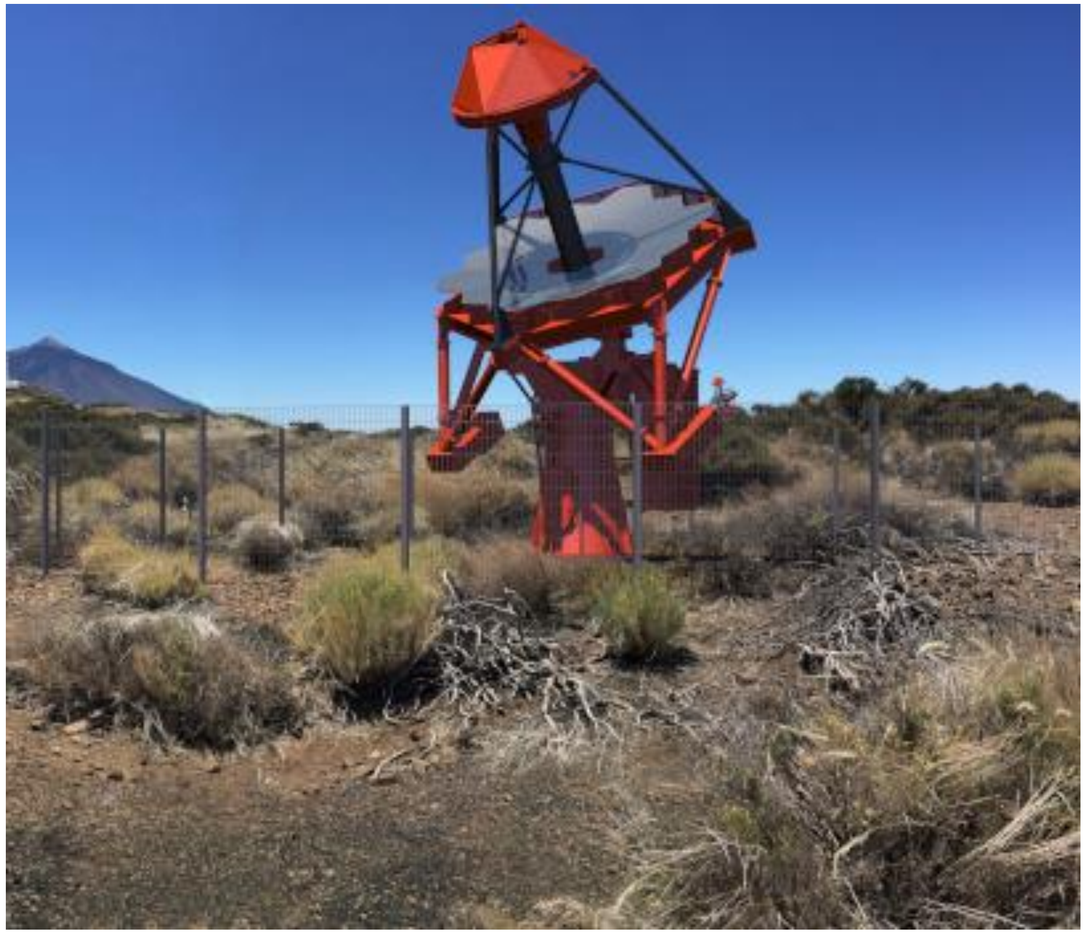
S. Scuderi – IASF Milano

for the ASTRI Project

ASTRI and LHAASO workshop, Milan, 7-8 March 2023

Layout of the presentation

- The ASTRI Mini-Array project
- Operation concepts
- Technical description of the system
- ASTRI Mini-Array status



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, IAPS-Roma, 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 for Cherenkov telescopes arrays
- Hosting agreement with IAC foresees 4 + 4 years of operations for the ASTRI Mini-Array starting from beginning of operations
- During the first 3/4 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

ASTRI Mini-Array scientific objectives

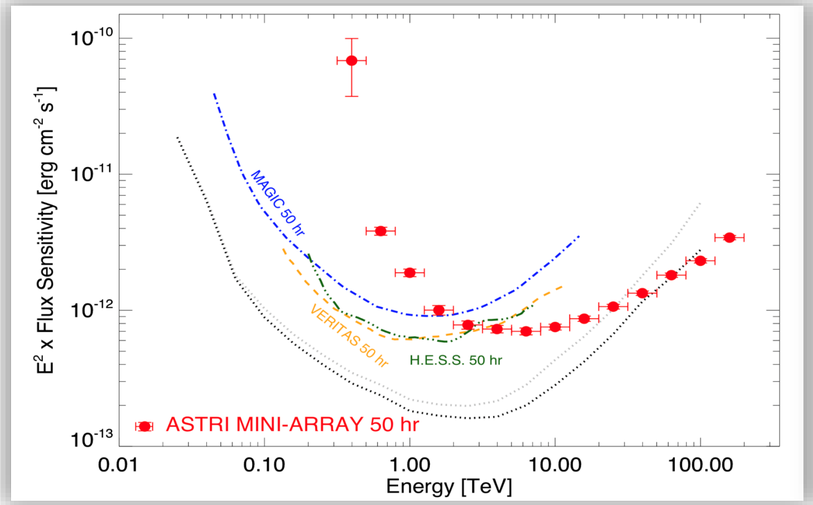
- **Wide-field stereoscopic observations in the 1 – 300 TeV energy band**
  - Restricted number of targets/deep exposures ($\geq$ 200 h)
  - Galactic sources: wide FoV $\rightarrow$ multi-target fields
  - Extragalactic sources: survey of a few promising targets at > ~10 TeV scale
  - Fundamental physics: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

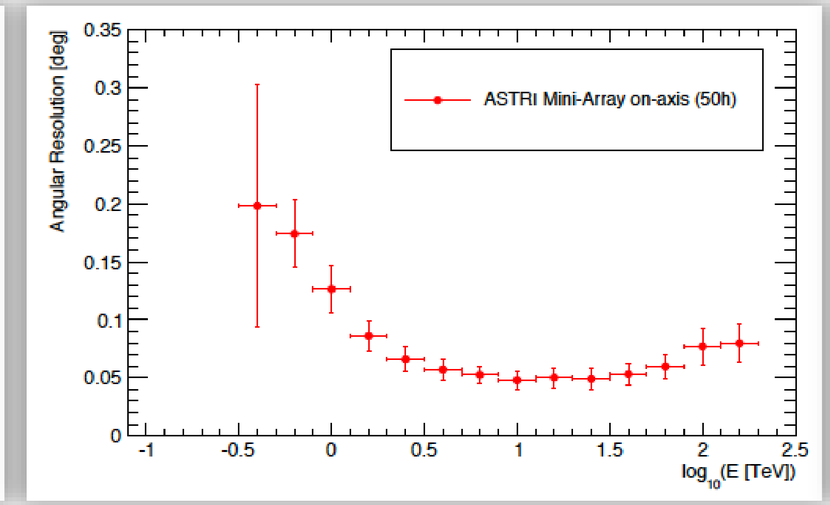
The ASTRI science team has developed a core science program (Vercellone's talk)

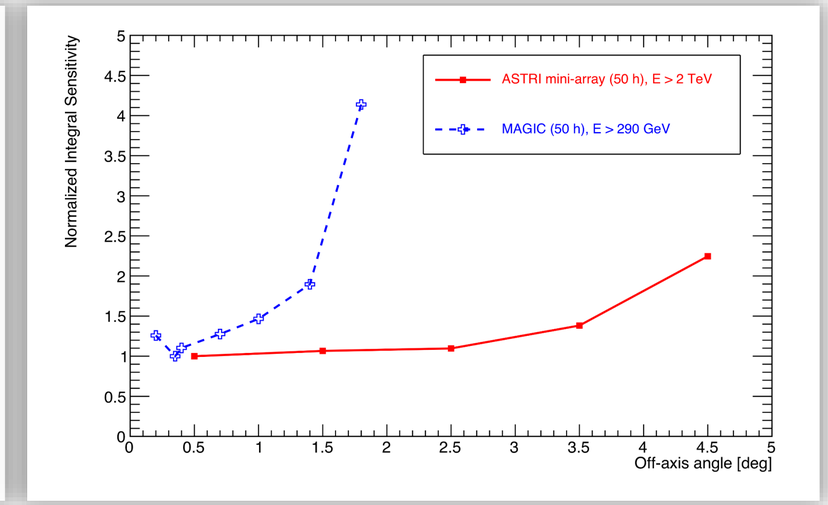
Mini but not small…

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

ASTRI Mini-Array papers

Journal of High Energy Astrophysics
Volume 35, August 2022, Pages 52-68
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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 concept

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 give raise to transient phenomena. No automatic software procedure to react to these transient phenomena is foreseen but a dedicated transient handler will produce a scheduling block and the astronomer on duty will decide if execute it or not. Reaction time will be of the order of minutes.

- **Coordinated Mode**: Synergies with the current (MAGIC, VERITAS) and next generation (CTAO-N) IACT arrays 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.

Array 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 off-line via software at the Rome Data Centre.

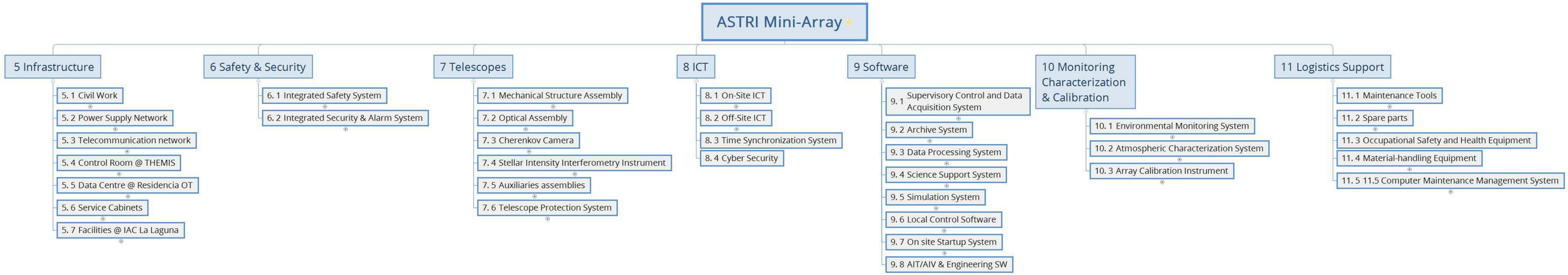
- **No subarray operation** is foreseen.

- 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.

Technical description

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.

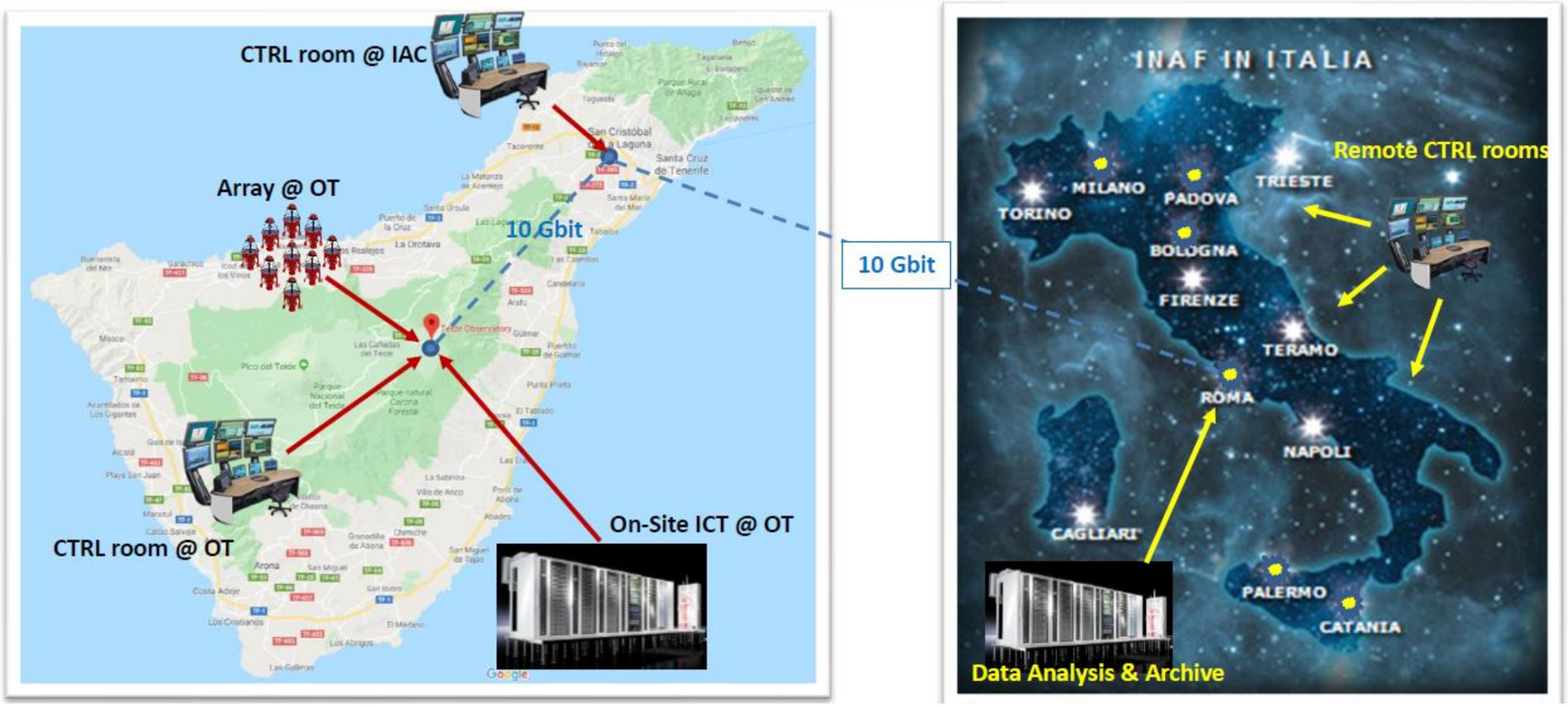
The ASTRI Mini-Array locations

The ASTRI Mini-Array in Tenerife

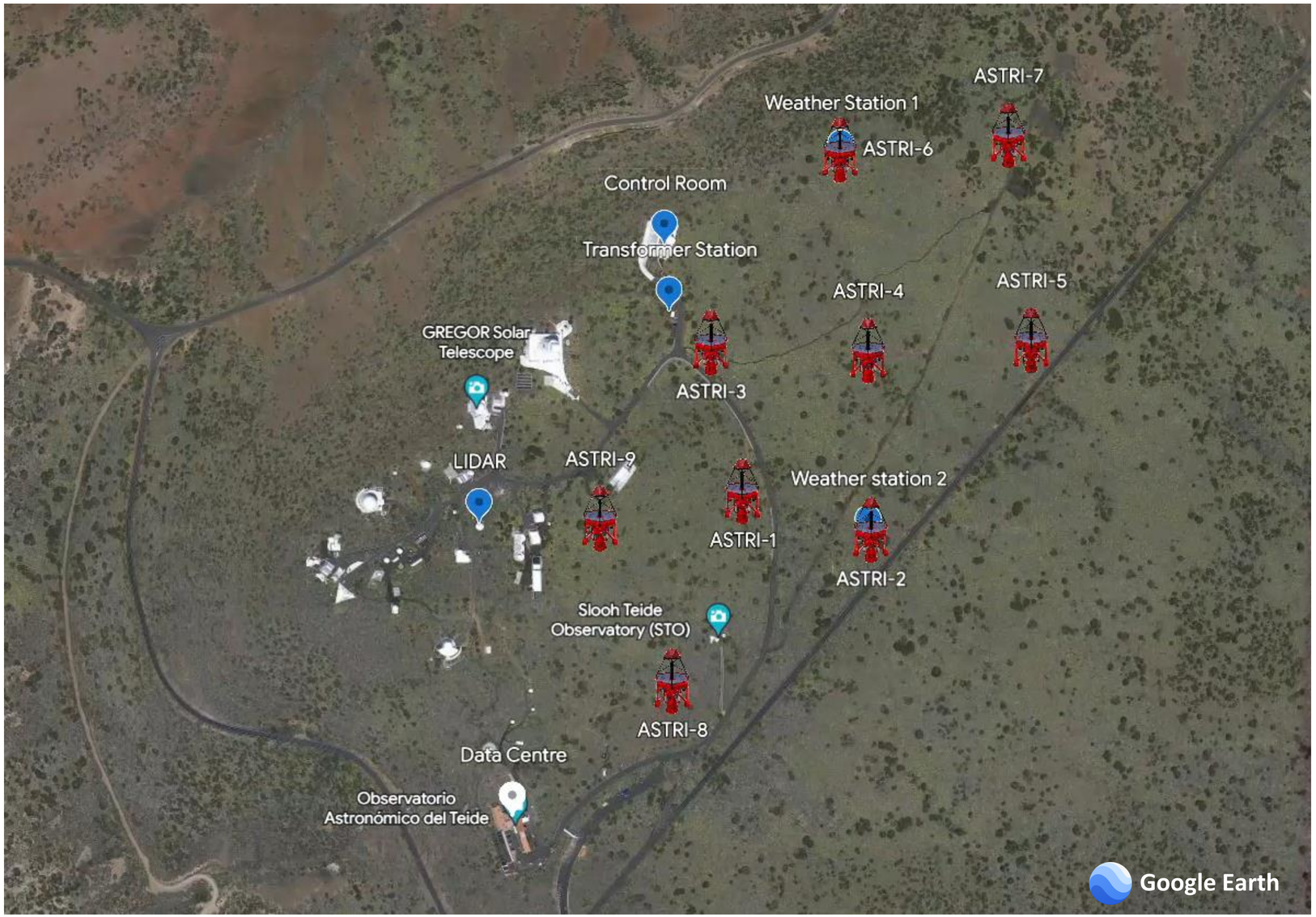
- Telescope Array & auxiliaries (Observatorio del Teide - OT)
- Local Control Room @THEMIS building (OT)
- On site Data Centre @IAC Residencia (OT)
- Array operation center @IACTEC in La Laguna

The ASTRI Mini-Array in Italy

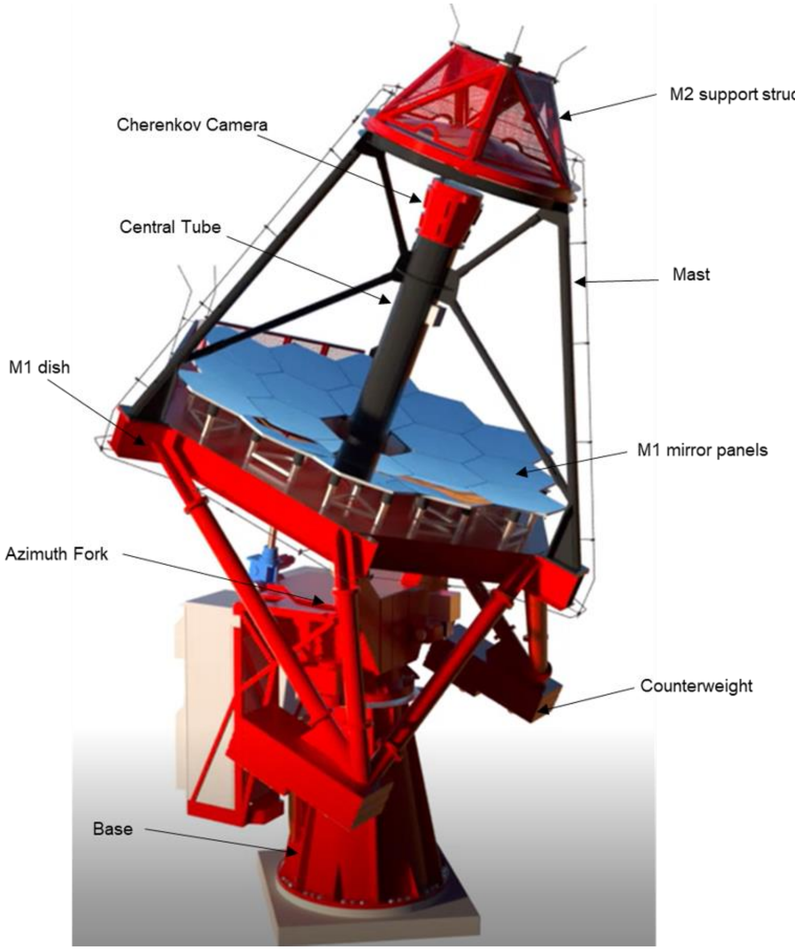
- Data Centre in Rome
- Remote Array operation centers



The ASTRI Mini-Array @ the Teide observatory

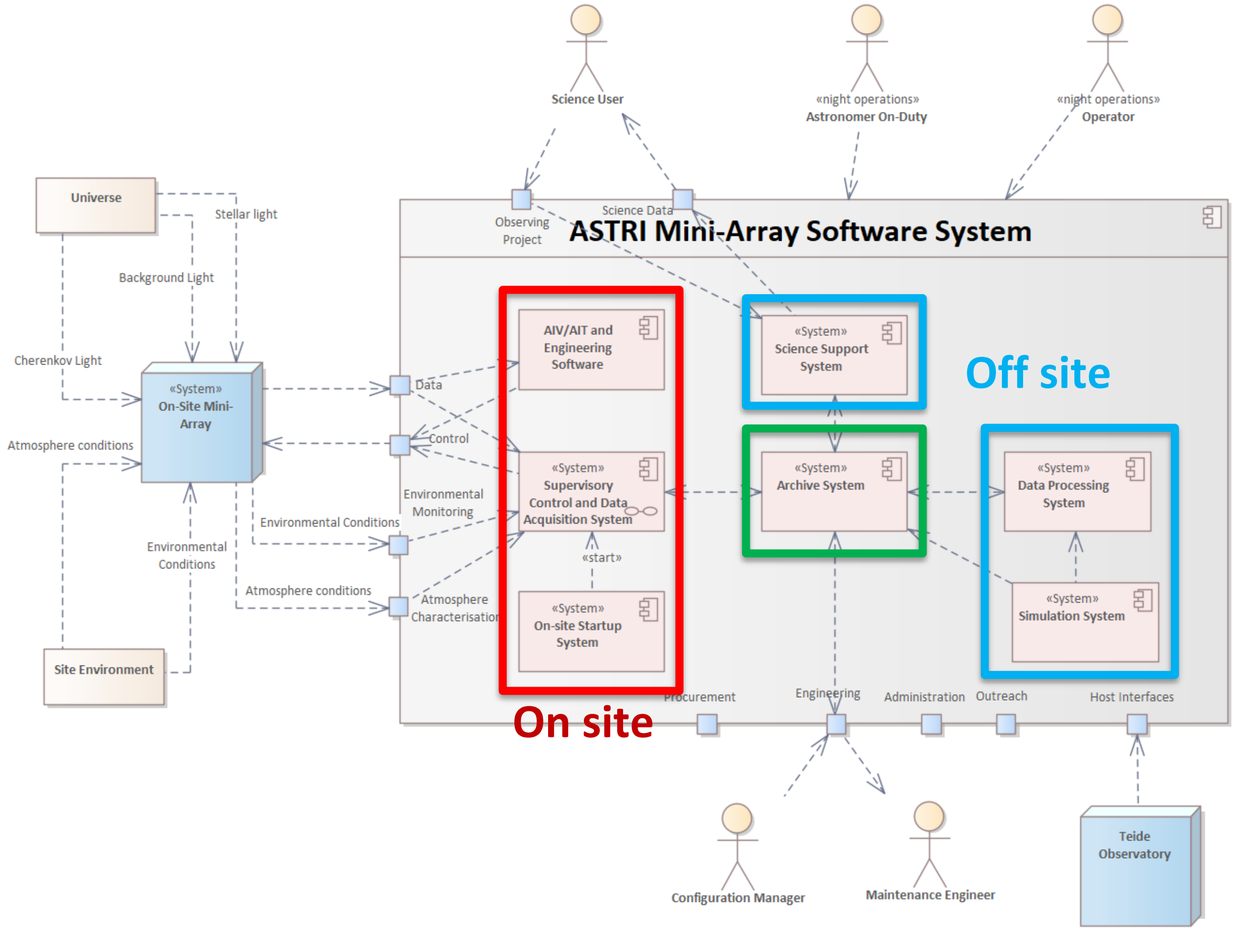


ASTRI Mini-Array telescopes in a nutshell



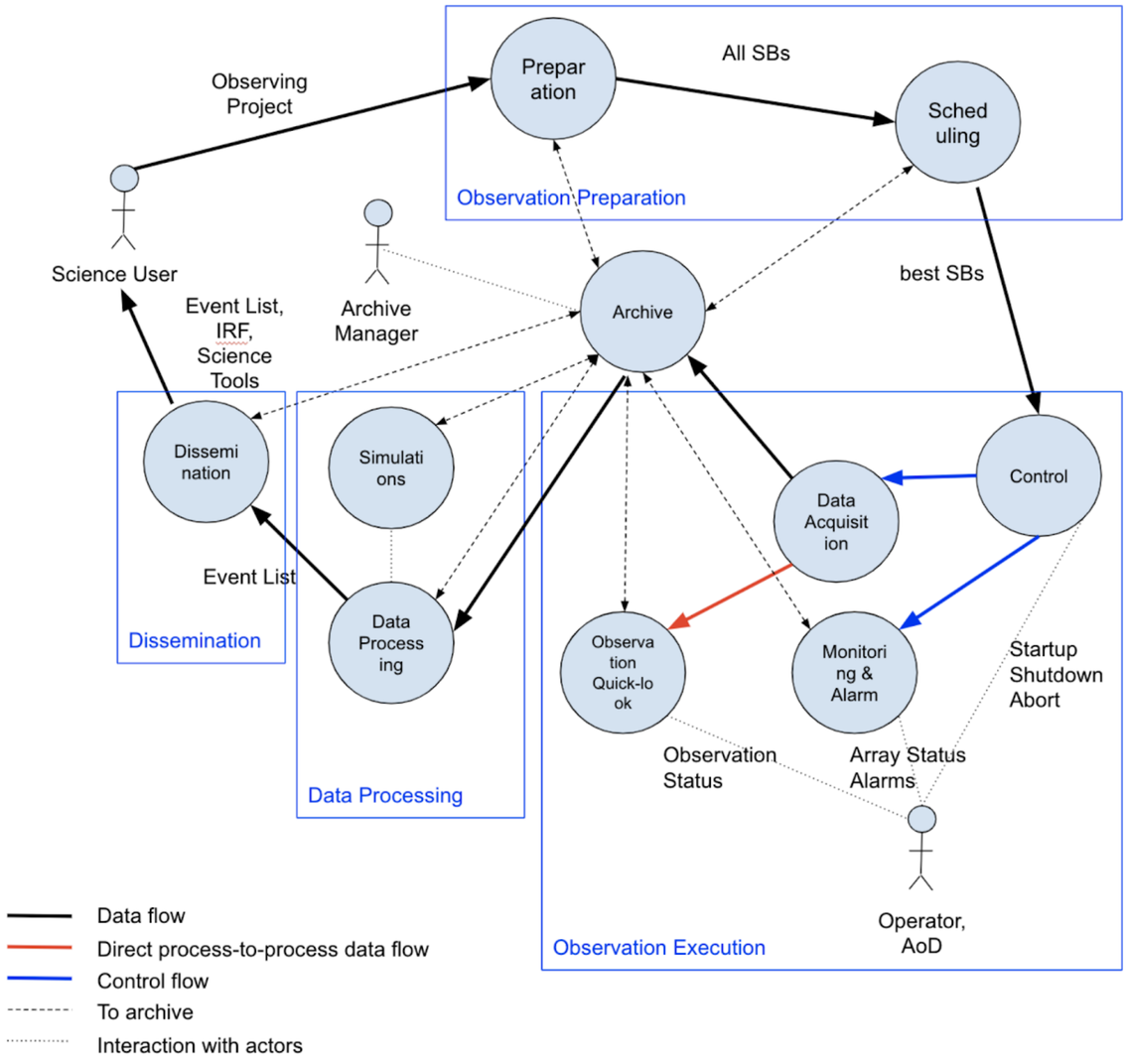
- **Opto-mechanics (EIE, MLT, Flabeg, ZAOT)**
  - Alt-azimuthal mount
  - Modified Schwarzschild-Couder configuration
  - Primary Mirror: 4.3 m (18 segments)
  - Secondary Mirror: 1.8 m (monolithic)
  - F-number: 0.5
  - Average effective area > 5.0 m^2
  - Optical PSF $\leq$ 0.19 deg
  - Post calibration 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

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.
- ***AIV/AIT and engineering software.*** Software to be used during the AIT/AIV phases and during the maintenance activities.
- ***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: data & information flow

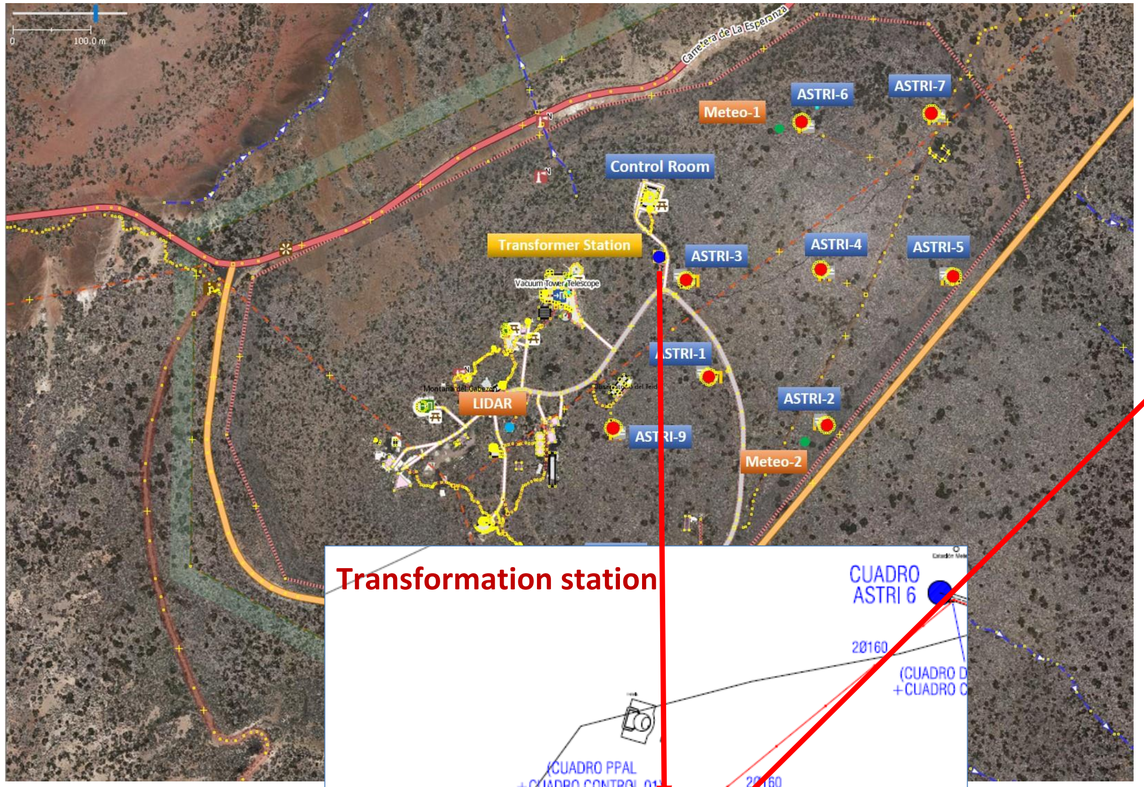


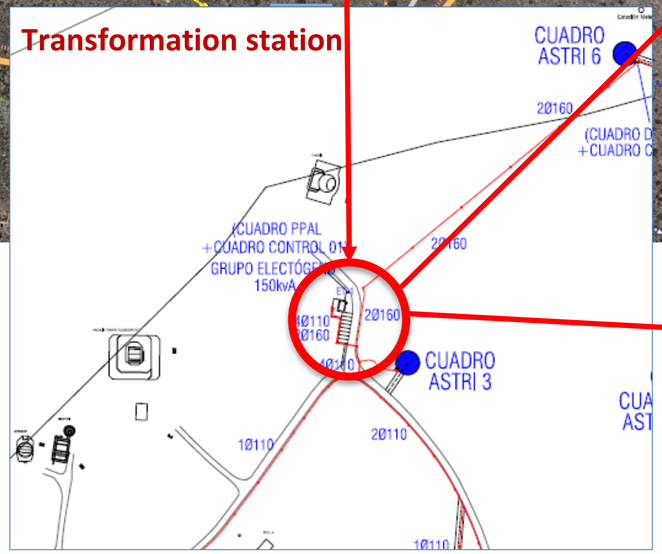
The ASTRI Mini-Array software is envisioned to handle an observing cycle, i.e. the end-to-end control and data flow system. The observing cycle can be divided into the following main phases:

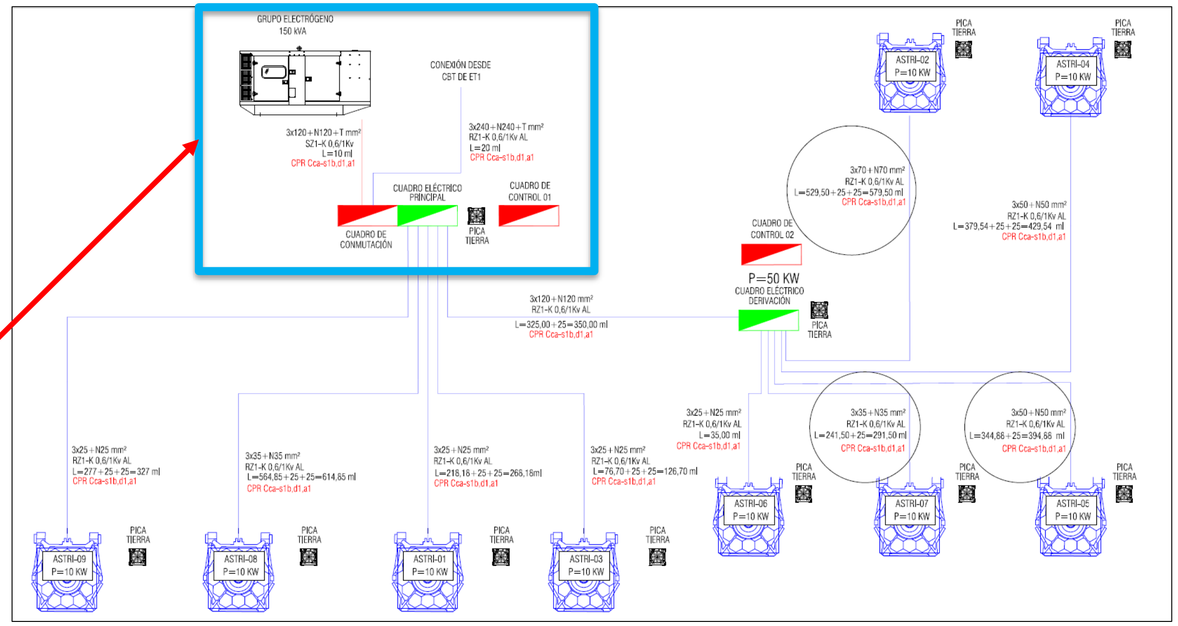
1. Observation preparation
2. Observation execution
3. Data Processing
4. Dissemination

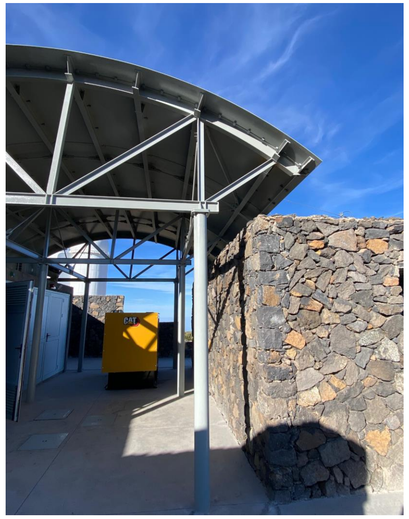
Status of the project

The Teide Infrastructure: power distribution system

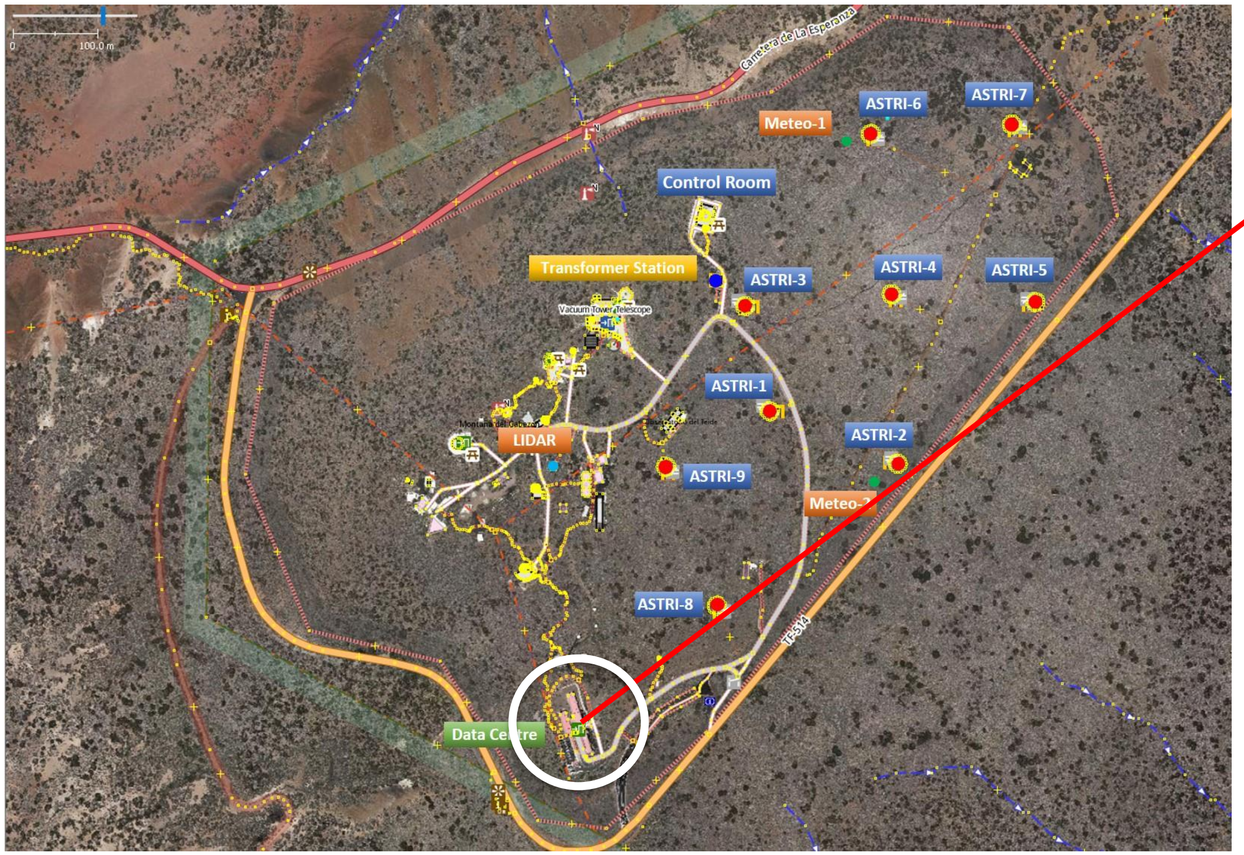






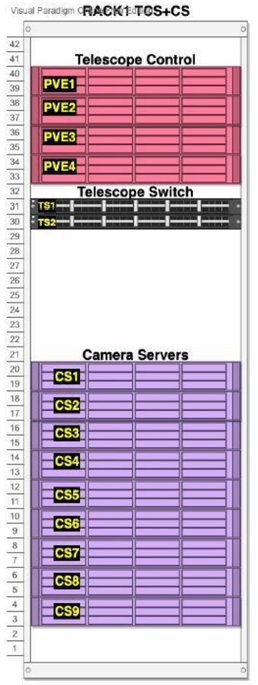


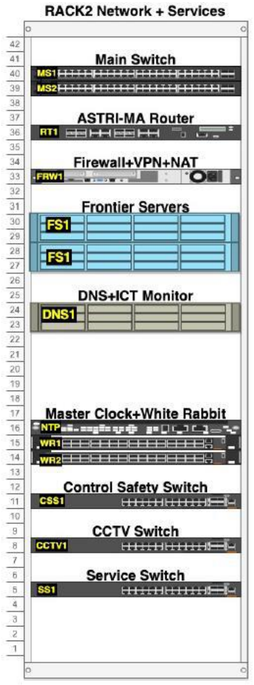
The Teide Infrastructure: data network & ICT

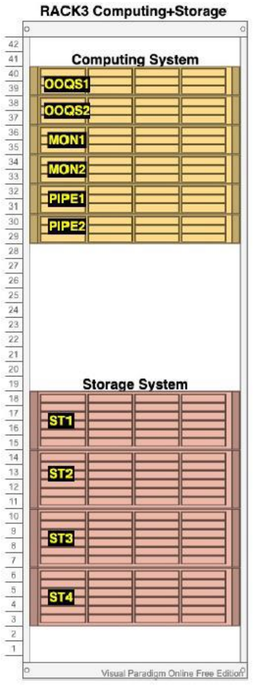


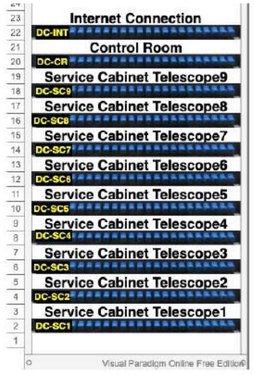
m-ICT

Fibres patch panel rack

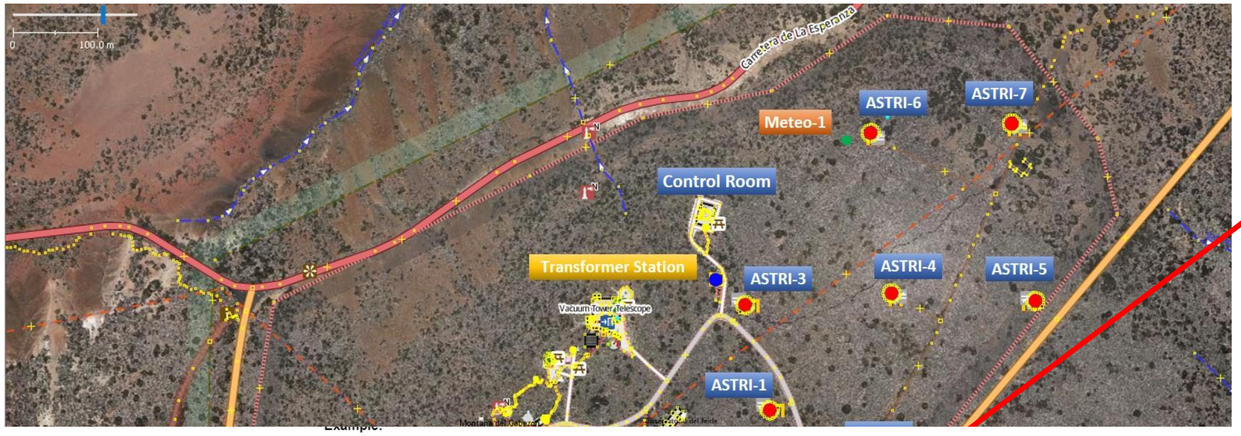








The Teide Infrastructure: data network & ICT

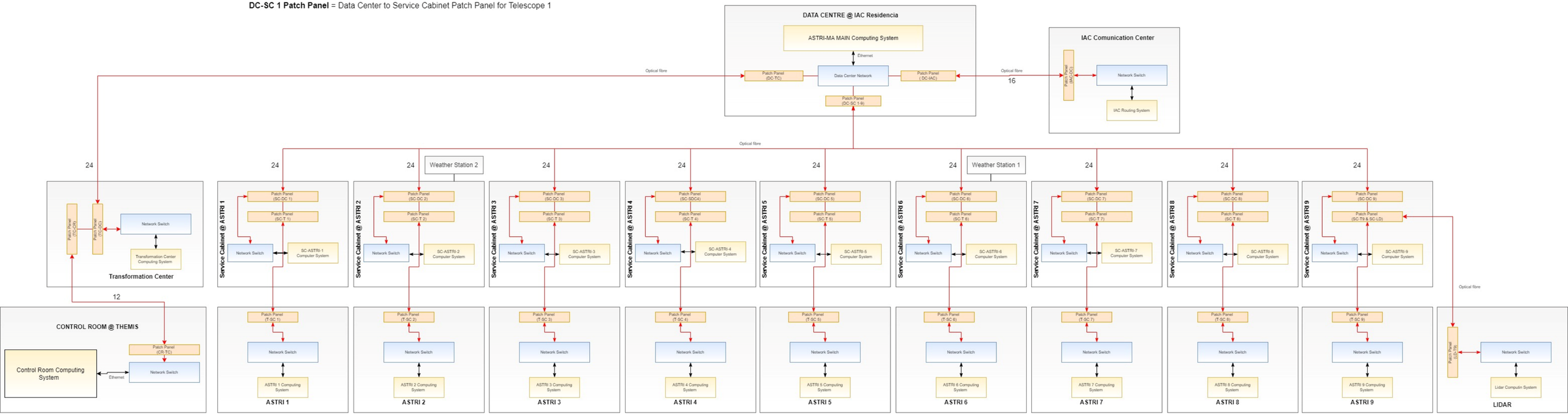


RACK1 TCS+CS

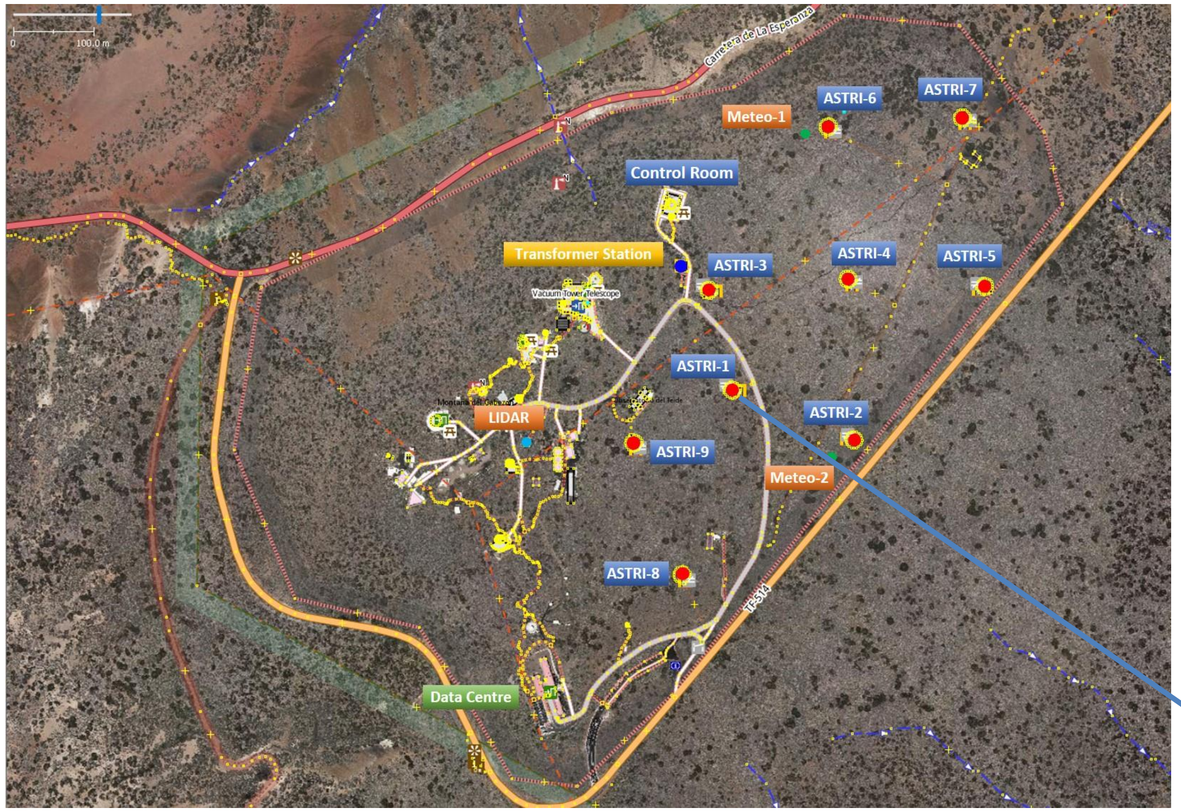
RACK2 Network + Services

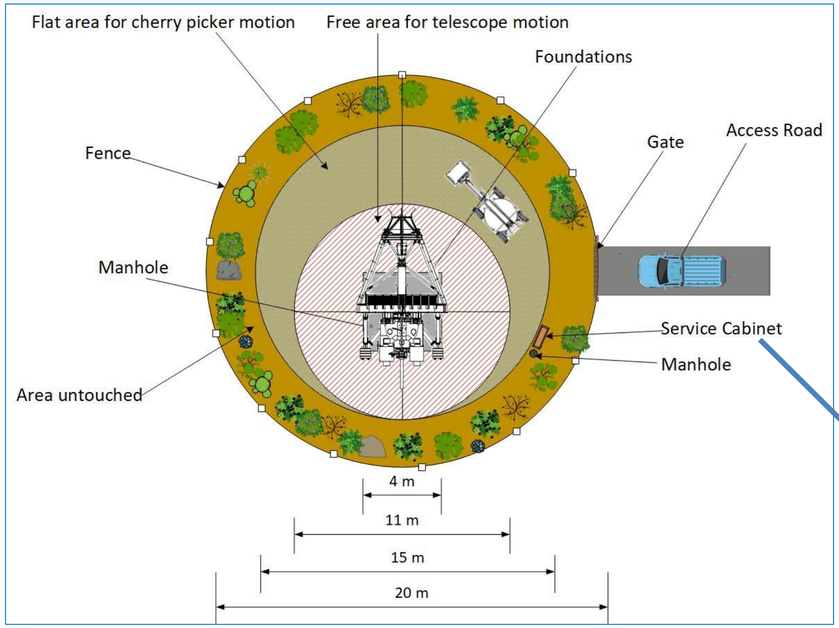
RACK3 Computing+Storage

Example:
DC-SC 1 Patch Panel = Data Center to Service Cabinet Patch Panel for Telescope 1



The Teide infrastructure: telescopes' area



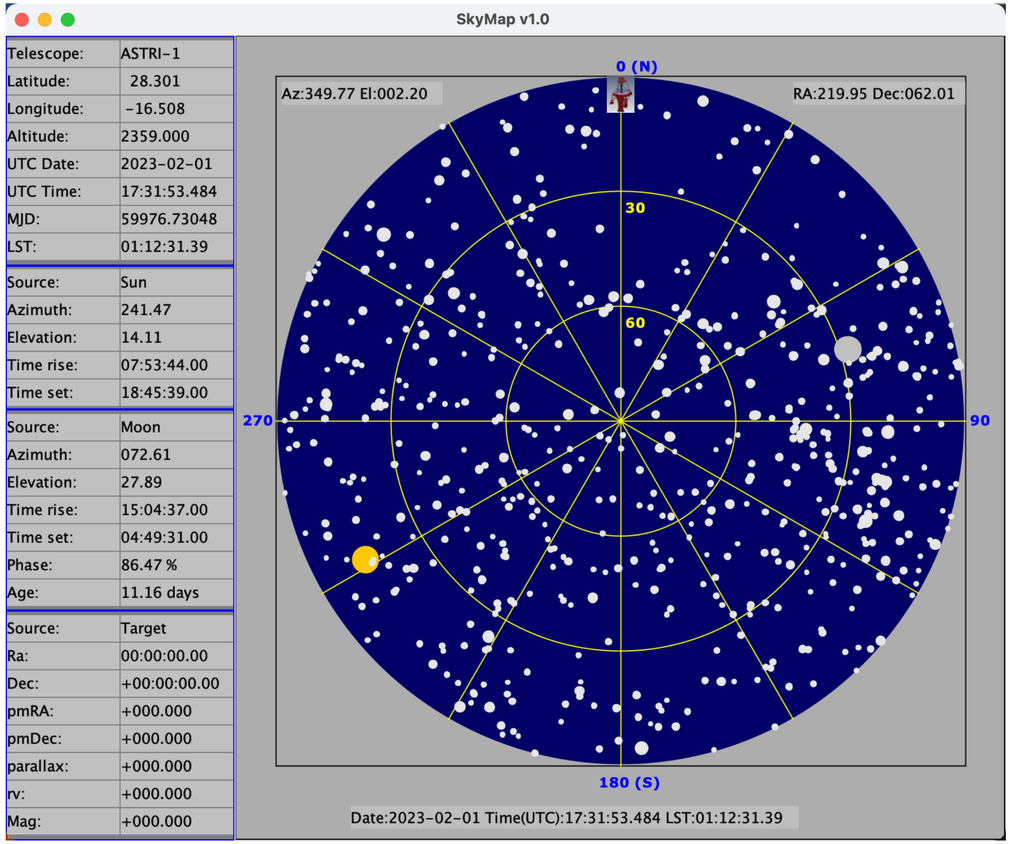


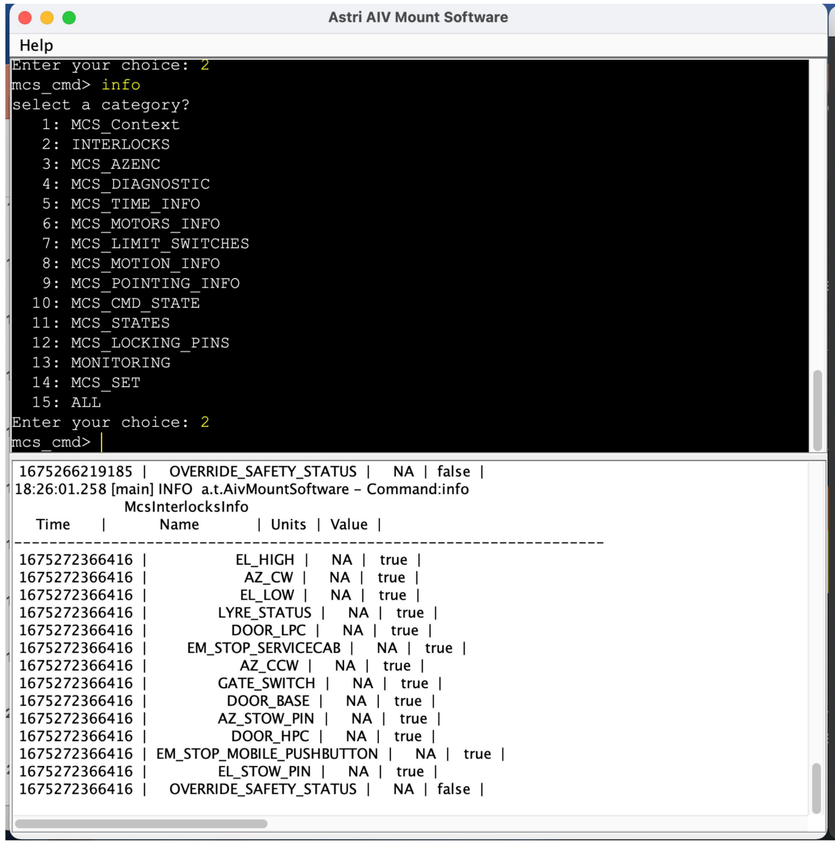
Credits: Johannes Knapp

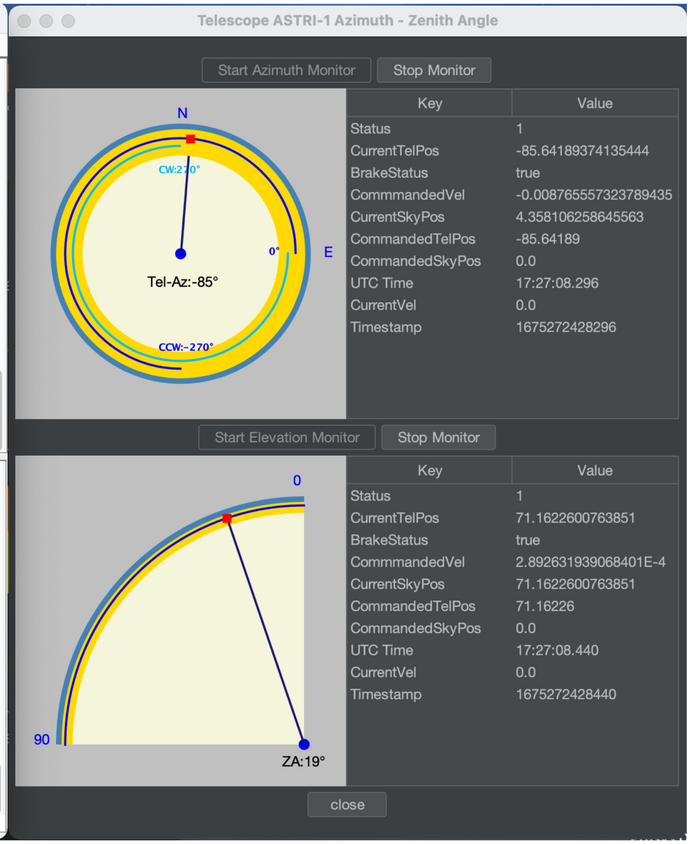
ASTRI-1 onsite integration

EIE GROUP

ASTRI-1: telescope mount AIV software





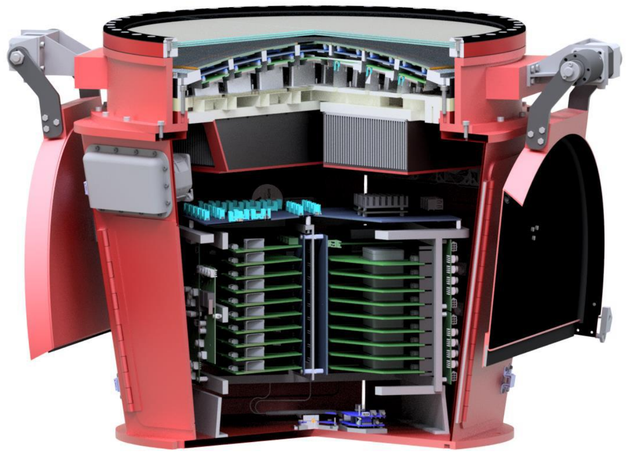


G. Tosti, P. Bruno 2nd TETIS Workshop

Cherenkov Cameras

Contract for the production of 11 cameras

- 1 engineering camera for qualification
- 9 cameras
- 1 spare camera



CAEN Tools for Discovery

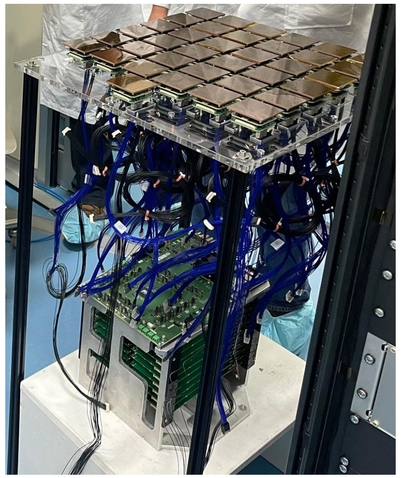
NI Nuclear Instruments

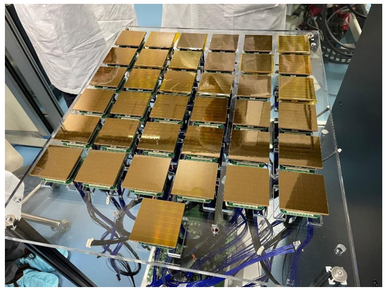
EIE GROUP

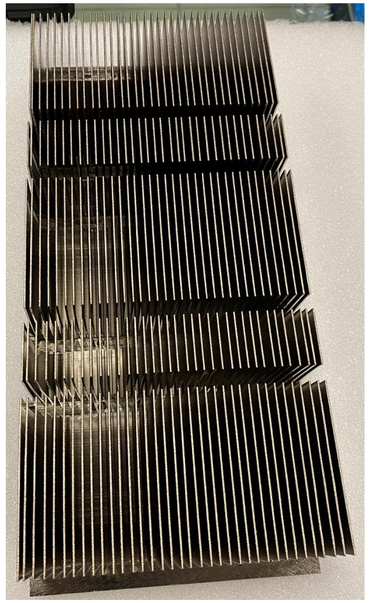
weeroc

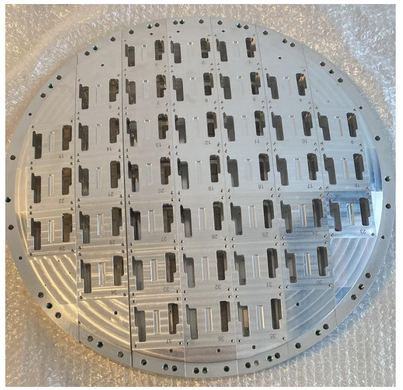
HAMAMATSU PHOTON IS OUR BUSINESS

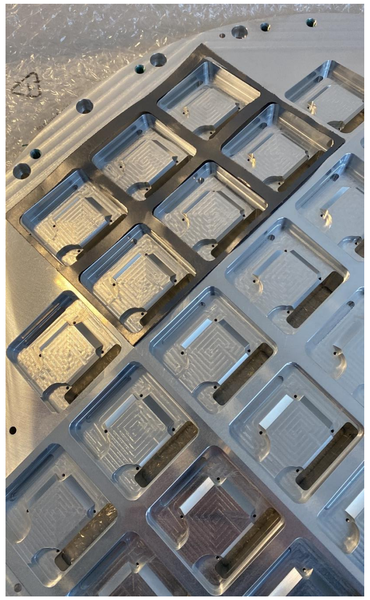
Production and test of engineering camera ongoing



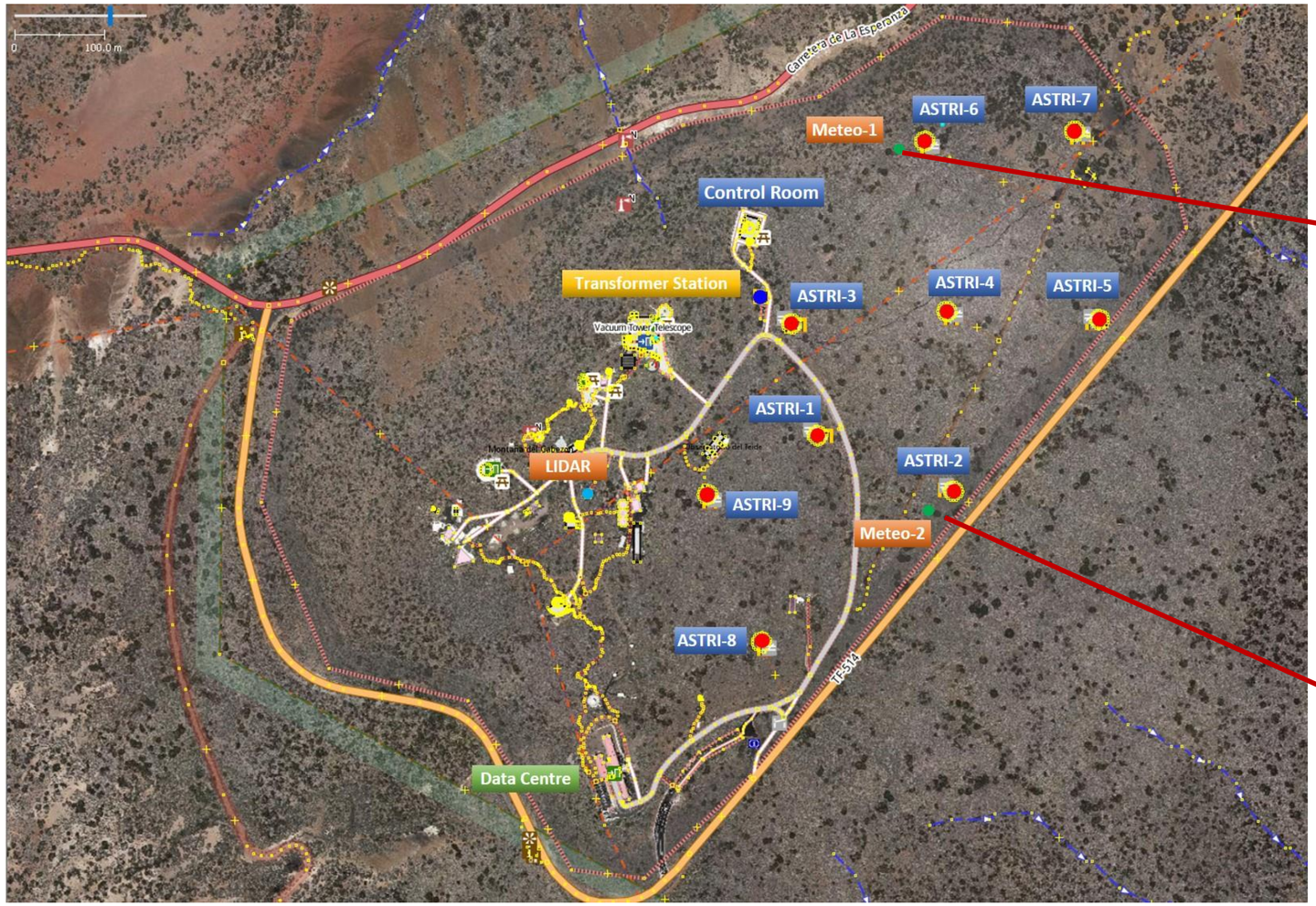


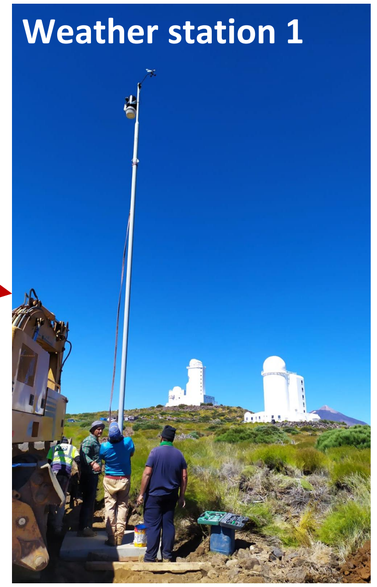


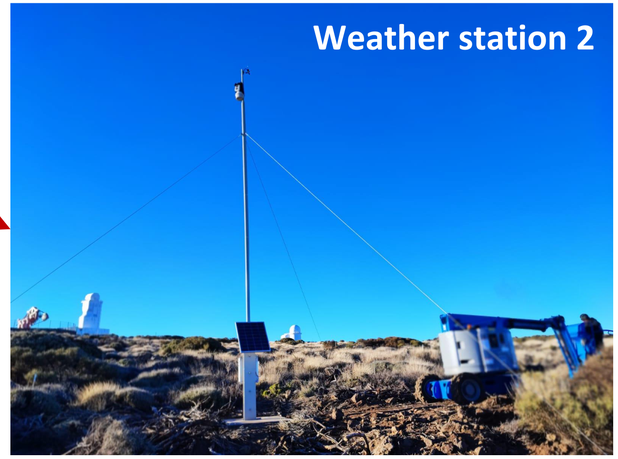




Weather stations







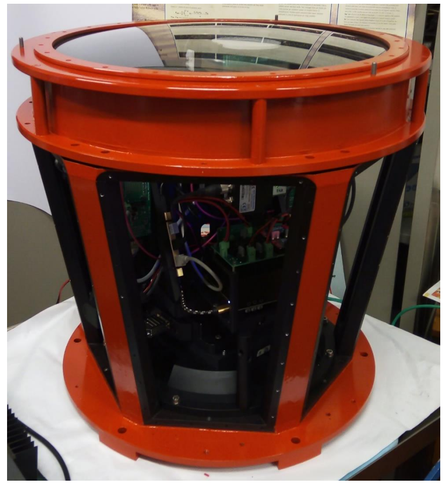
Telescope’s auxiliaries: PMC

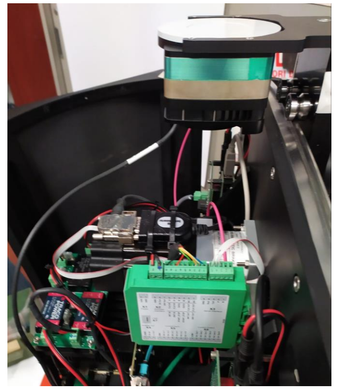
Pointing Monitoring Cameras (Uni-PG)
CCD camera placed on the M2 support structure used to monitor pointing and tracking performances of the telescope

Telescope's auxiliaries: Optical alignment system

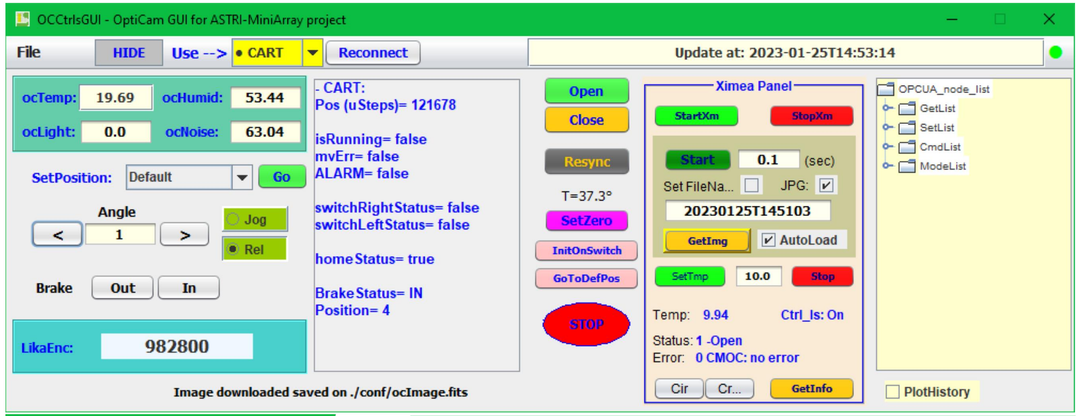
Optical Camera (IASF-MI, OAPD, OACT, OA Brera)

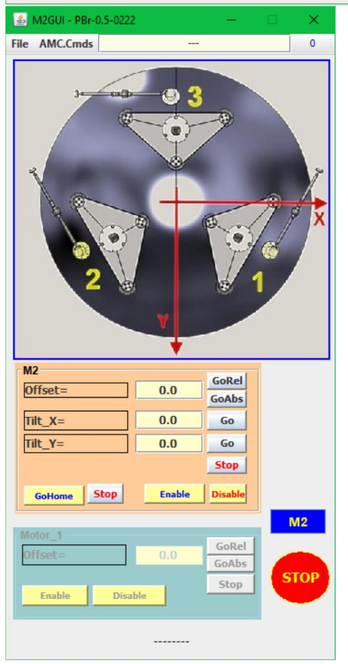
CCD camera placed on the telescope focal plane to align the panels of M1

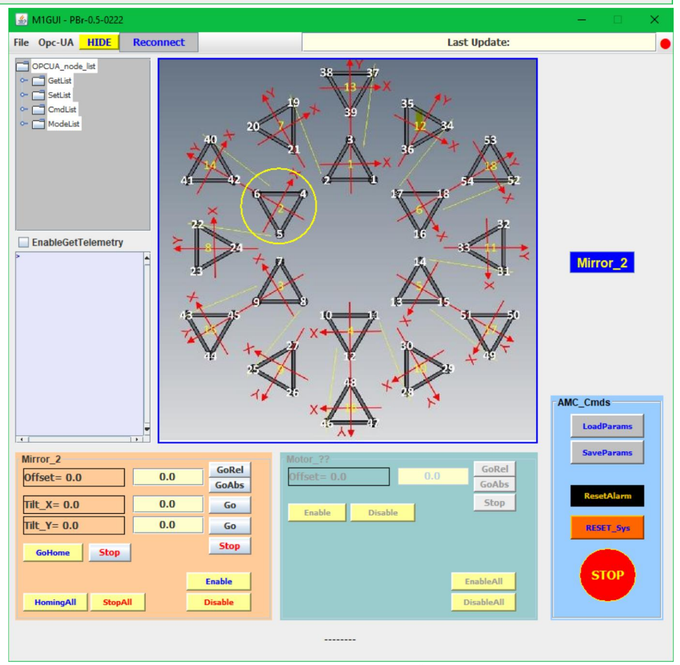




Optical alignment system AIV Software







Summary of the current status @site

- **Power distribution system** → **ready**
- **Data network** → **ready**
- **Telescopes' areas** → **ready**
- **Data centre** → **ready (m-ICT)**
- **Control Room** → **ready**
- **Weather stations** → **ready**
- **Telescopes** → **AIT of ASTRI-1**
- **Service cabinets** → **ready 3 out of 9**

ASTRI Mini-Array next activities @site

March-June 2023

- **ASTRI-1**
  - → **Finalize integration and perform fine tuning**
  - → **Pointing Model**
  - → **Mirrors alignment**
- **Camera #0 → Integration & verification**
- **ASTRI-8 → Integration & verification**
- **ASTRI-9 → Integration & verification**

ASTRI Mini-Array implementation timeline

General timeline based on current available information

- Teide infrastructure completed
- ASTRI-1 telescope site acceptance review April 2023
- ASTRI-8 & ASTRI-9 telescopes delivered May 2023 (first batch of 3 telescopes)
- First camera (engineering camera) on ASTRI-1 end of spring 2023
- First three telescopes (ASTRI-1, 8 and 9) completed early 2024
- Early observations (array of three) start
- Second batch of telescopes (total of six) will start to arrive beginning 2024
- ASTRI Mini-Array ready for commissioning mid 2025
- Scientific observations start end 2025

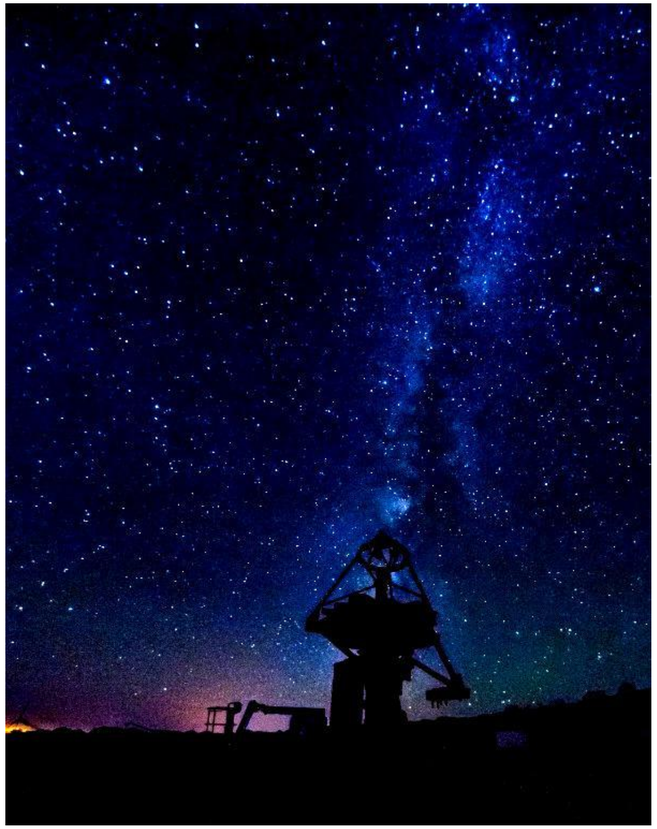
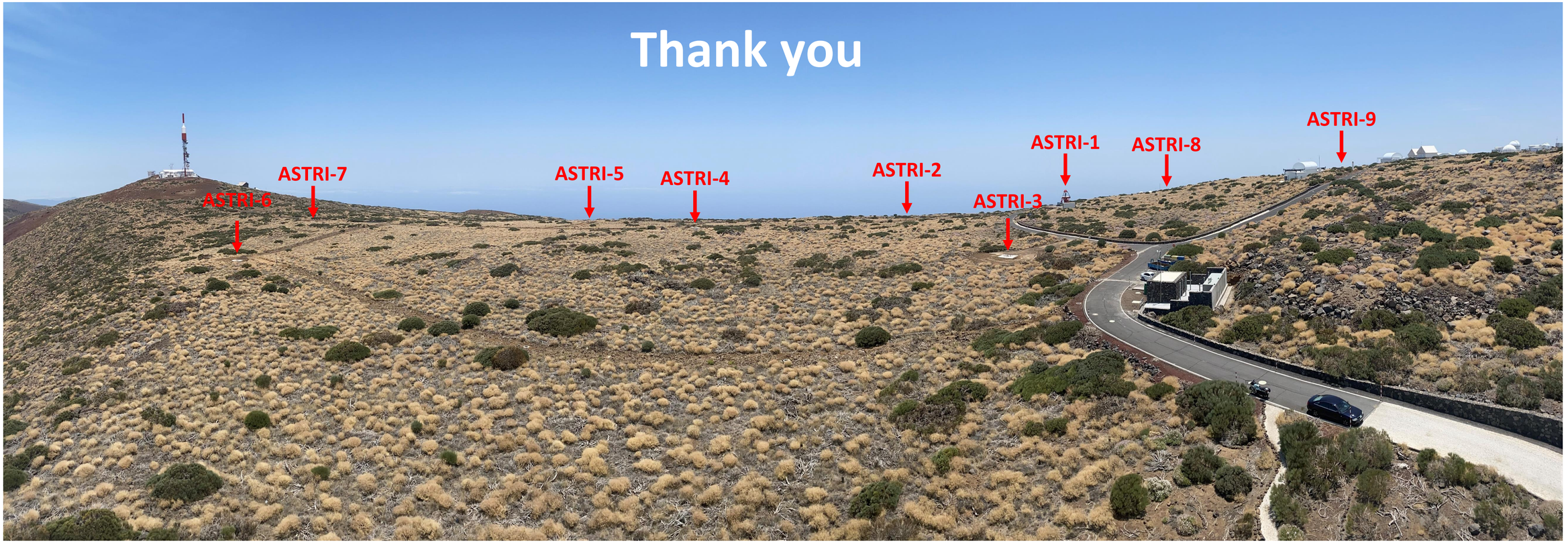


Photo CREDITS Tommaso Marchiori (EIE group)

ASTRI Mini-Array



View from Themis Telescope