The ASTRI Mini-Array and its key performance features

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for the ASTRI Project

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The ASTRI Project in a nutshell

- **ASTRI** (***A****strofisica con* ***S****pecchi a* ***T****ecnologia* ***R****eplicante* ***I****taliana*) was born as "*Progetto Bandiera*" funded by MIUR (now MUR) with the initial aim to design, realize and deploy an innovative end-to-end dual-mirror 4-meters class Cherenkov telescope prototype in the framework of the CTA Observatory
- The prototype, named **ASTRI-Horn**, has been installed at INAF Observatory in Serra La Nave (Mt. Etna, Italy, 1740 m a.s.l.) in fall 2014 and it is currently in operation
- The **ASTRI Mini-Array** is the second step of the project, whose purpose is to construct, deploy and operate an array of 9 dual-mirror 4-meters class Cherenkov telescopes at the *Observatorio del Teide* (Tenerife, Spain, 2390 m a.s.l.), in collaboration with IAC and FGG-INAF
- The project is involving **more than 150 researchers** belonging to:
  - INAF Institutes (IASF-MI, IASF-PA, OAS-BO, OACT, OAB, OAPD, OAR)
  - Italian Universities (Uni-PG, Uni-PD)
  - Italian Research Institutes (INFN – RM2, ASI – SSDC)
  - International Institutions (University of Sao Paulo – Brazil, North-West University – South Africa, IAC – Spain)
- Italian and foreign industrial companies are and will be involved in the ASTRI Mini-Array project with **important industrial return**

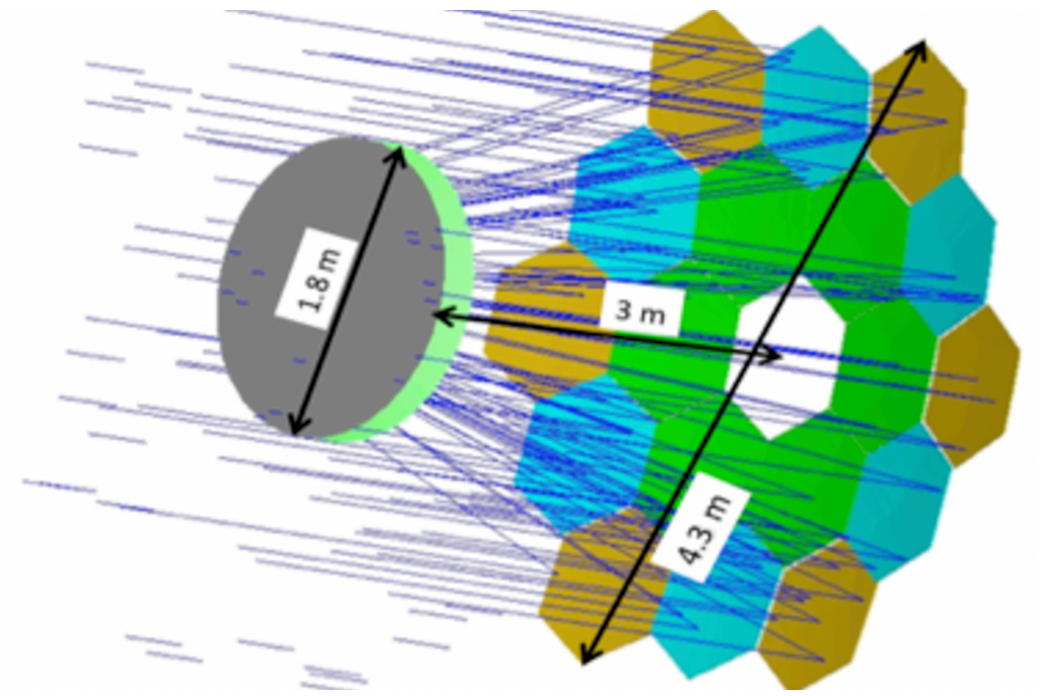
ASTRI-Horn telescope

Installed @ INAF Observatory in Serra La Nave (Mt. Etna, Italy, 1740 m a.s.l.)

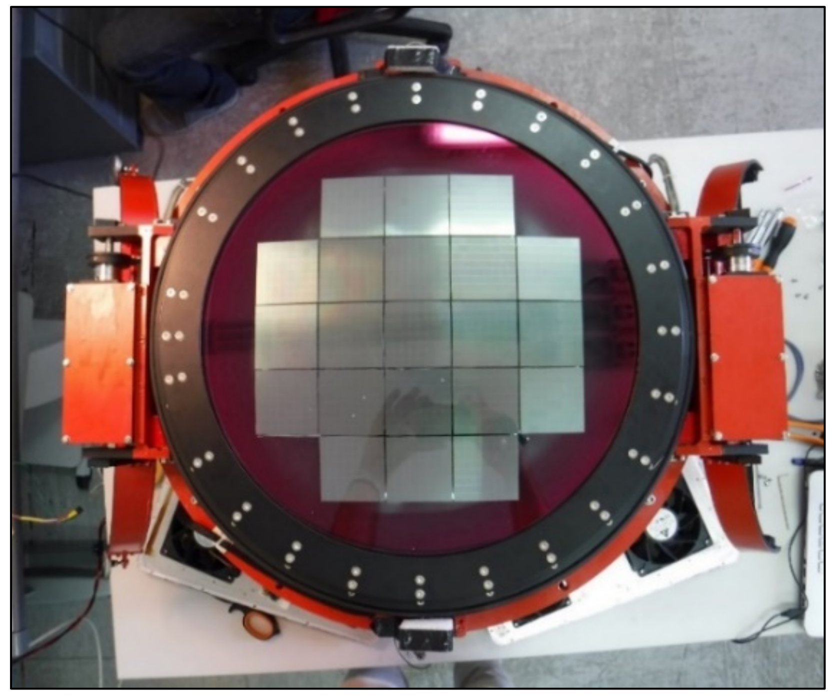
Dedicated to **Guido Horn D'Arturo**, precursor of the segmented astronomical mirrors technique

- **Technological demonstrator with an end-to-end approach** (HW and SW validation through actual Cherenkov observations)

- **Dual-mirror Schwarzschild-Couder design**:
  - ➢ Primary Mirror (M1): ⌀ 4.3 m (18 segments)
  - ➢ Secondary Mirror (M2): ⌀ 1.8 m (monolithic)
  - ➢ Optimal PSF (≤ 0.19°) across entire FoV
  - ➢ Post calibration pointing precision ≤ 7 arcsec
  - ➢ Reduced plate scale (37.5 mm/°) ➔ use of SiPMs



- **SiPM Cherenkov camera**:
  - ➢ Fast front-end electronics based on CITIROC ASICs
  - ➢ 7×7 mm SiPM sensors (Hamamatsu Photonics)
  - ➢ 1344 pixels (21 modules of 8×8 pixels)
  - ➢ Angular pixel size: 0.19° (≥ optical PSF)
  - ➢ Field of View: ~8°



- **Performance**:
  - ➢ Energy threshold: ~1 TeV
  - ➢ Energy/Angular resolution: ≤ 25% / ≤ 0.15°
  - ➢ Sensitivity: 1 Crab @ 5σ in few hours

ASTRI-Horn telescope – results

ASTRI Mini-Array

A&A 608, A86 (2017)
DOI: 10.1051/0004-6361/201731602

Astronomy & Astrophysics

First optical validation of a Schwarzschild Couder telescope: the ASTRI SST-2M Cherenkov telescope

E. Giro[1,2], R. Canestrari[2], G. Sironi[2], E. Antolini[3], P. Conconi[2], C. E. Fermino[4], C. Gargano[5], G. Rodeghiero[1,6], F. Russo[7], S. Scuderi[8], G. Tosti[3], V. Vassiliev[9], and G. Pareschi[2]

A&A 634, A22 (2020)
https://doi.org/10.1051/0004-6361/201936791

Astronomy & Astrophysics

First detection of the Crab Nebula at TeV energies with a Cherenkov telescope in a dual-mirror Schwarzschild-Couder configuration: the ASTRI-Horn telescope

S. Lombardi[1,2,⋆], O. Catalano[3,⋆], S. Scuderi[4,⋆], L. A. Antonelli[1,2], G. Pareschi[5], E. Antolini[6], L. Arrabito[7], G. Bellassai[8], K. Bernlöhr[9], C. Bigongiari[1], B. Biondo[3], G. Bonanno[8], G. Bonnoli[5], G. M. Böttcher[10], J. Bregeon[11], P. Bruno[8], R. Canestrari[3], M. Capalbi[3], P. Caraveo[4], P. Conconi[5], V. Conforti[12], G. Contino[3], G. Cusumano[3], E. M. de Gouveia Dal Pino[13], A. Distefano[4], G. Farisato[14], C. Fermino[13], M. Fiorini[4], A. Frigo[14], S. Gallozzi[1], C. Gargano[3], S. Garozzo[8], F. Gianotti[12], S. Giarrusso[3], R. Gimenes[13], E. Giro[14], A. Grillo[8], D. Impiombato[3], S. Incorvaia[4], N. La Palombara[4], V. La Parola[3], G. La Rosa[3], G. Leto[8], F. Lucarelli[1,2], M. C. Maccarone[3], D. Marano[8], E. Martinetti[8], A. Micciché[8], R. Millul[5], T. Mineo[3], G. Nicotra[15], G. Occhipinti[8], I. Pagano[8], M. Perri[1,2], G. Romeo[8], F. Russo[3], F. Russo[12], B. Sacco[3], P. Sangiorgi[3], F. G. Saturni[1], A. Segreto[3], G. Sironi[5], G. Sottile[3], A. Stamerra[1], L. Stringhetti[4], G. Tagliaferri[5], M. Tavani[16], V. Testa[1], M. C. Timpanaro[8], G. Toso[4], G. Tosti[17], M. Trifoglio[12], G. Umana[8], S. Vercellone[5], R. Zanmar Sanchez[8], C. Arcaro[14], A. Bulgarelli[12], M. Cardillo[16], E. Cascone[18], A. Costa[8], A. D'Aì[3], F. D'Ammando[12], M. Del Santo[3], V. Fioretti[12], A. Lamastra[1], S. Mereghetti[4], F. Pintore[4], G. Rodeghiero[14], P. Romano[5], J. Schwarz[5], E. Sciacca[8], F. R. Vitello[8], and A. Wolter[5]

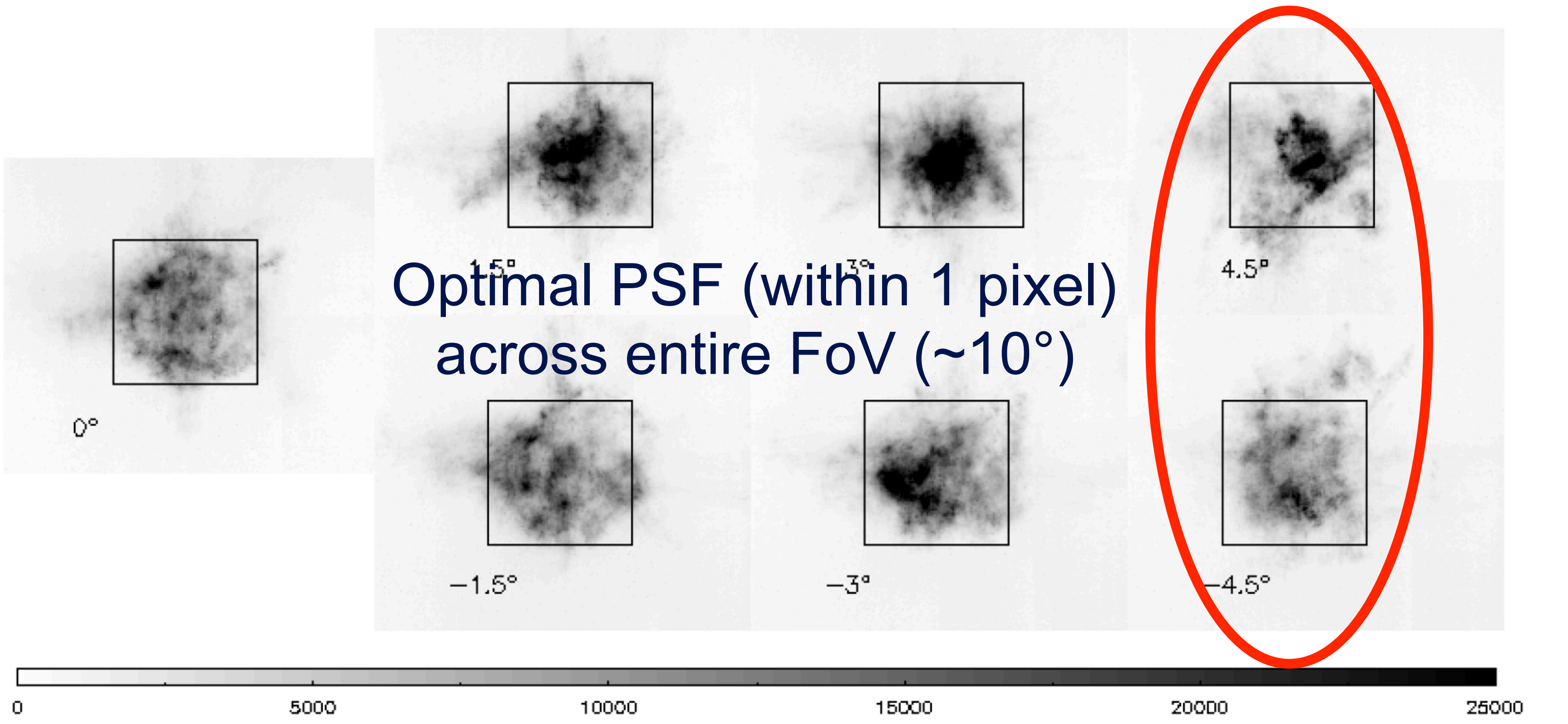


Fig. 5. PSF of the ASTRI SST-2M telescope across the focal plane. Alignment and optical performance have been optimized at 3°. The Cherenkov camera pixel size is overplotted for each PSF.

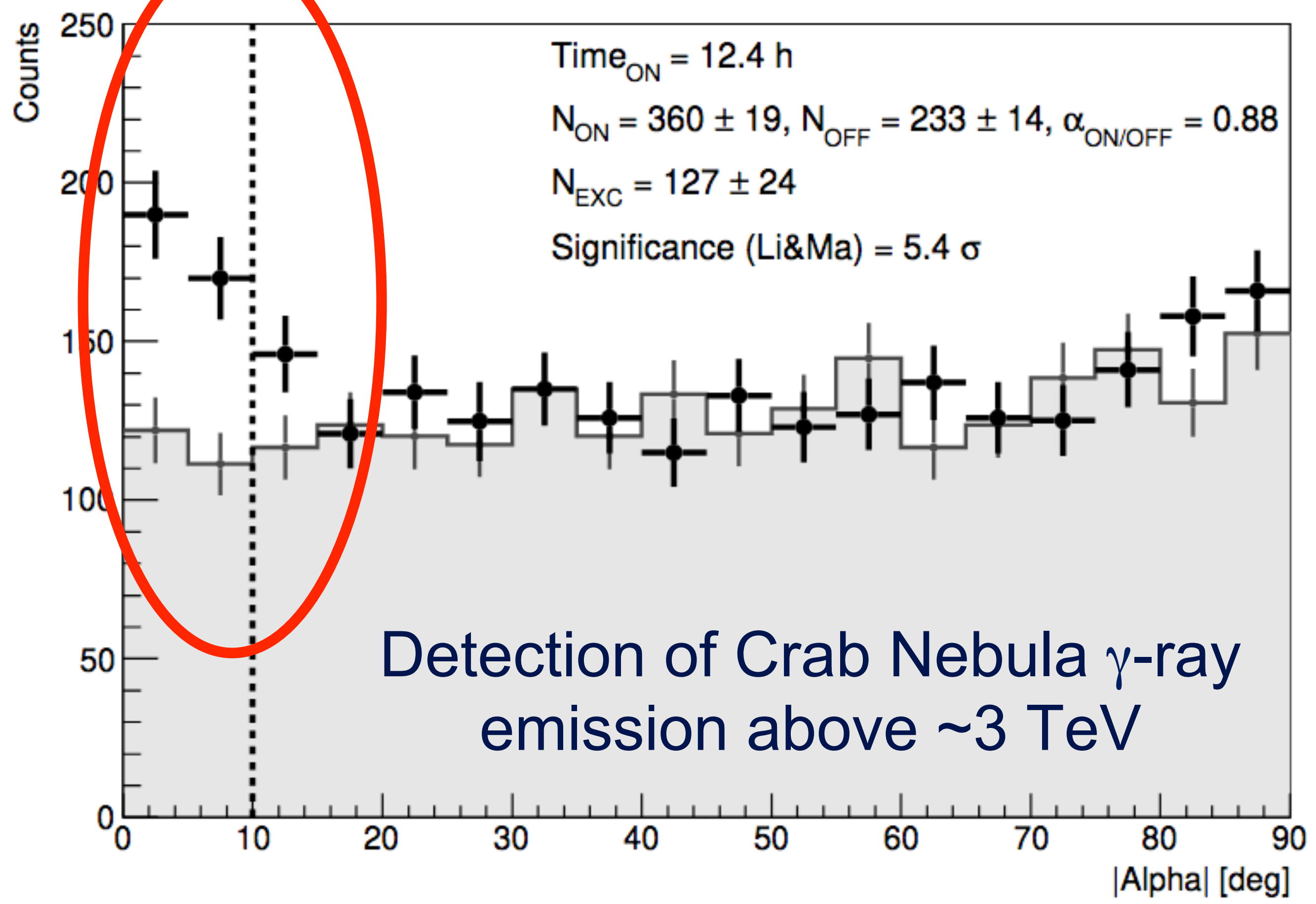
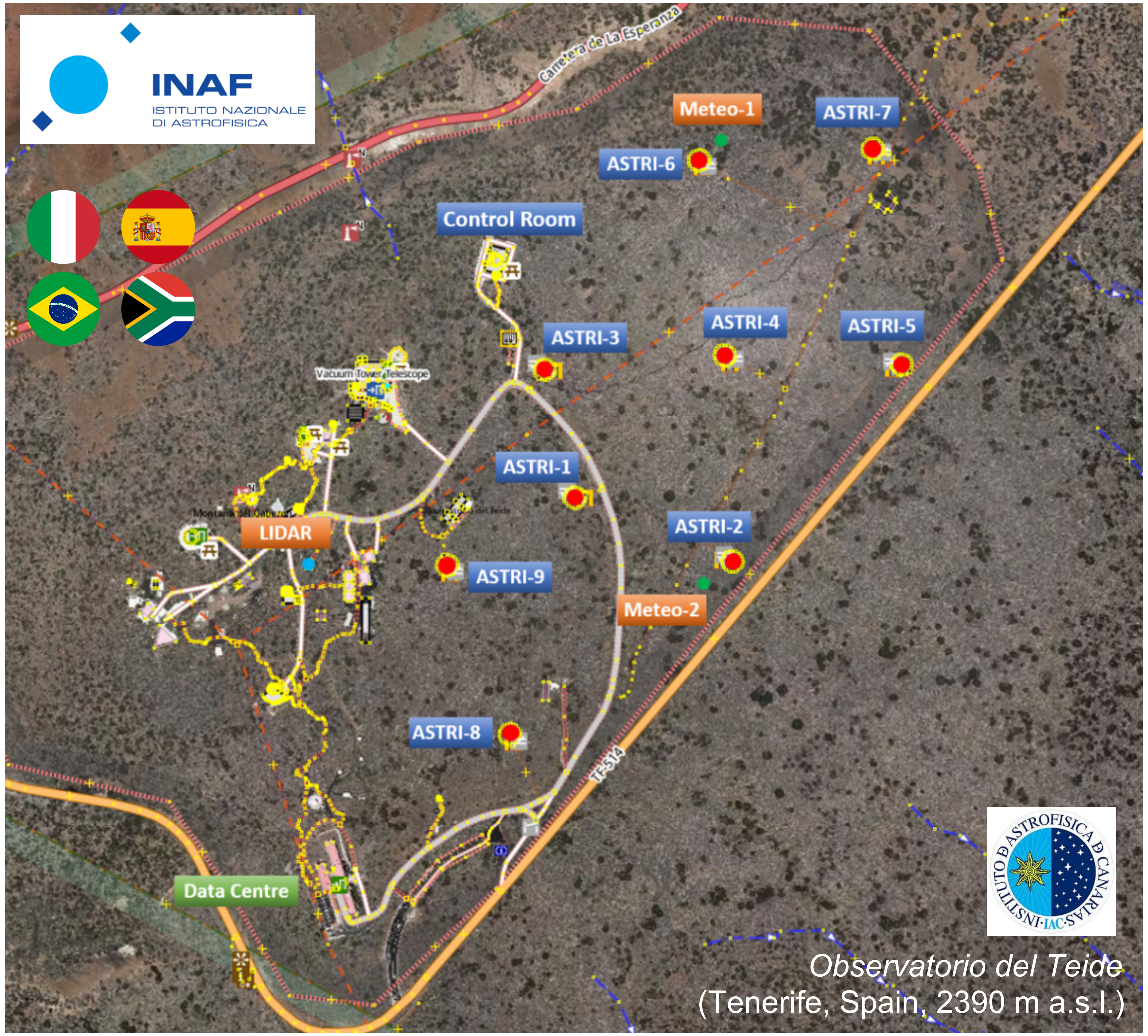


Fig. 2. |*Alpha*|-distributions of the Crab Nebula (ON, black) and the background (OFF, grey) data from ASTRI-Horn observations taken between 5 and 11 December 2018 above an energy threshold of ~3 TeV. The region between zero and the vertical dashed line (at 10°) represents the fiducial signal region.

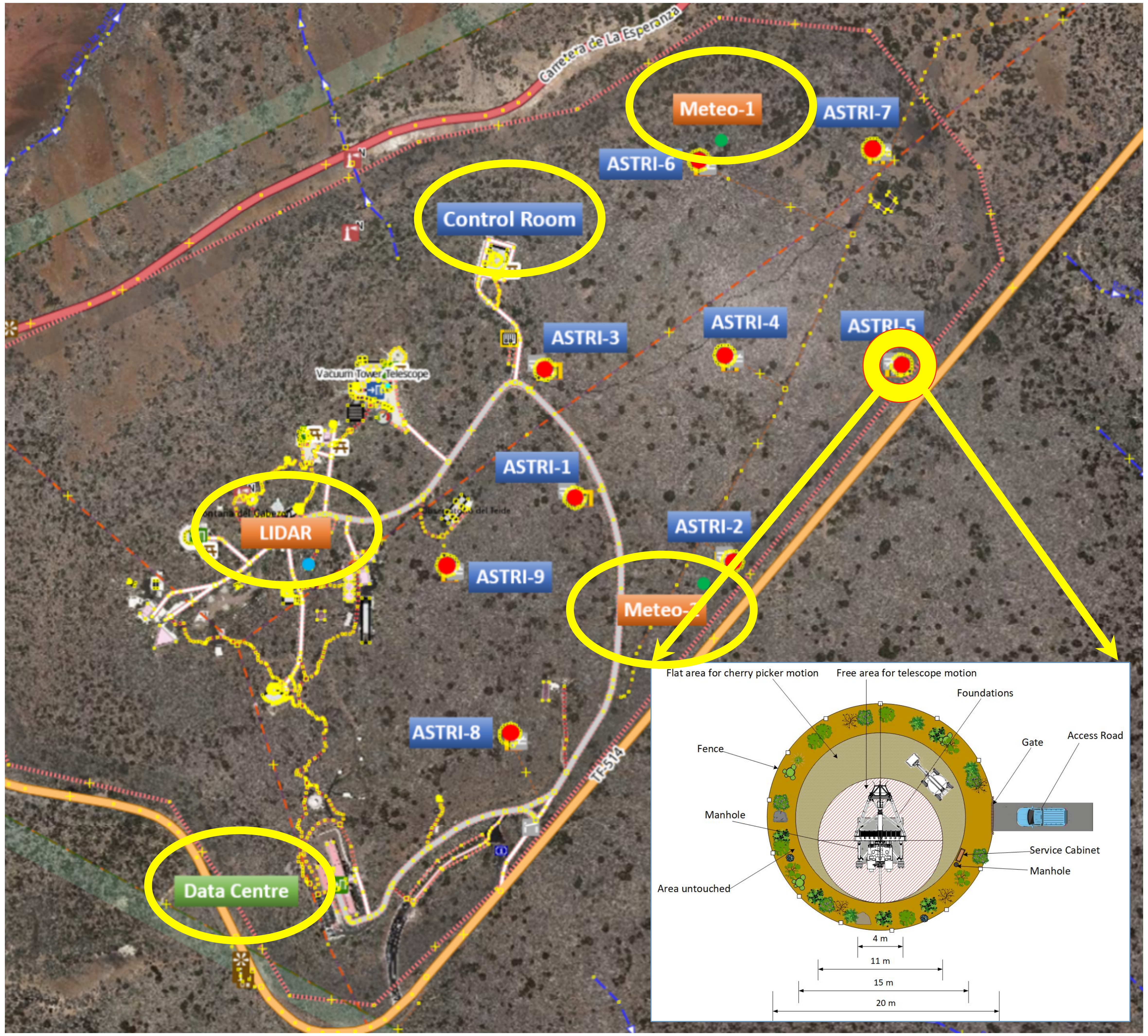
ASTRI Mini-Array

- **Project lead by INAF** in collaboration with Italian and International Institutes and Universities
- **Under construction** at the *Observatorio del Teide* (Tenerife, Spain, 2390 m a.s.l.), with the participation of IAC and FGG-INAF
- **9 dual-mirror 4-meters class Cherenkov telescopes**
- **Largest IACT facility until CTAO** will start operations
- Being developed in all HW/SW aspects
- Telescope technology: evolution of ASTRI-Horn
- INAF – IAC hosting agreement (**~10 years operations**)
- First 4 years: the array will be run as an experiment (**Core Science**), moving gradually to an observatory model (**Observatory Science**)
- Unprecedented **wide-field observations** of the gamma-ray sky **in the 1 – 200 TeV energy band**
- **Synergies** with present- and next-generation gamma-ray observatories in the Northern Hemisphere



ASTRI Mini-Array @ Teide Observatory

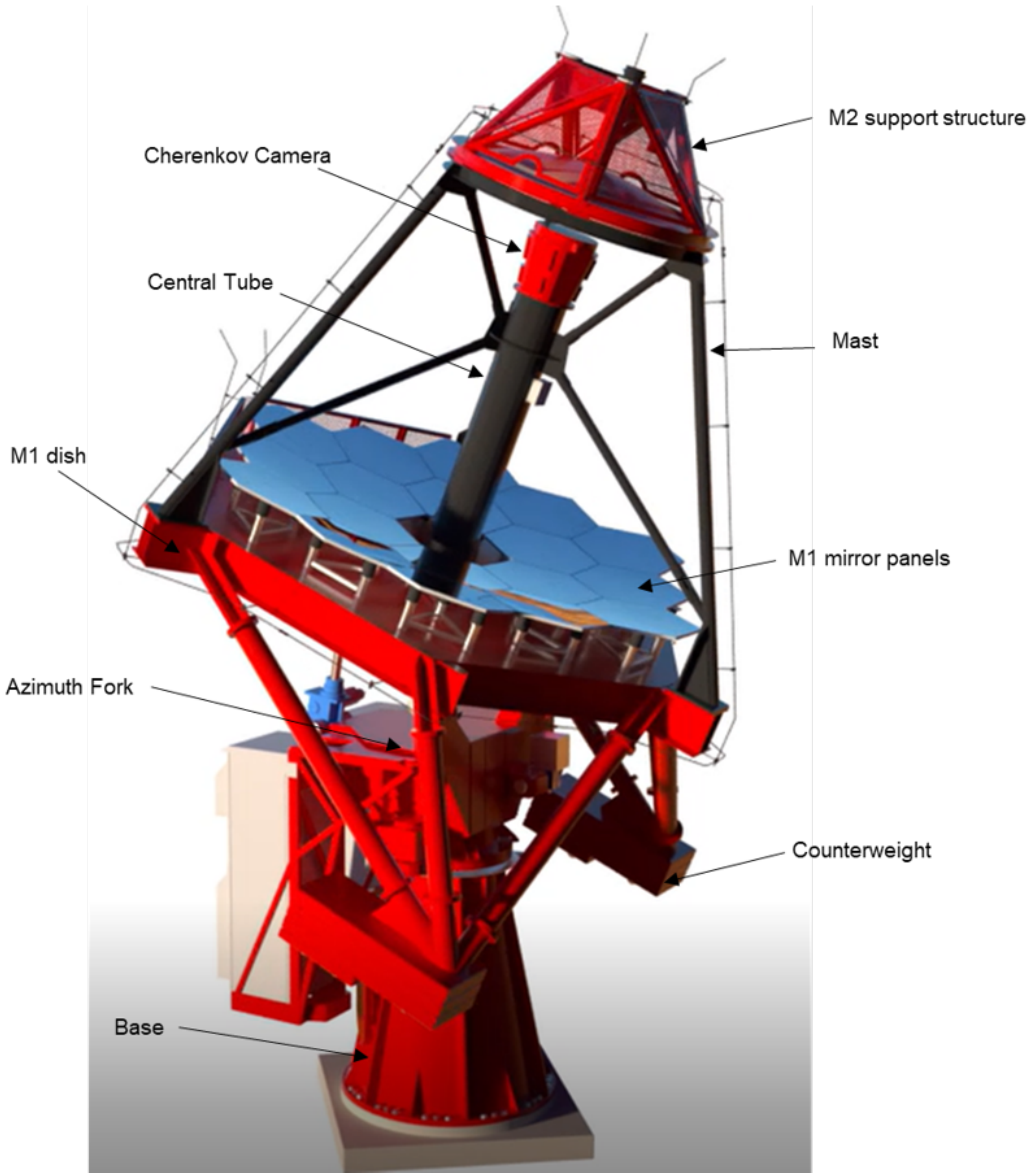
- Each telescope placed in a **dedicated hosting area**
- A **Control Room** hosted in THEMIS building
- A **Data Center** hosted at the OT Residencia building
- A **LIDAR** placed in a dome made available by IAC
- **2 Meteo Stations**
- **Access roads** to telescopes
- **Trenches, cable ducts, cable pits** for power, data, timing and safety and security networks including electrical cables and optical fibers
- Medium to low voltage **transformer station**
- **UPS and diesel generator** for power backup placed close to transformer station
- **Illuminator**: a device to calibrate the telescopes but that will not be permanently mounted at the site (the position(s) of the device is under definition as should allow the view of all of the telescopes)



ASTRI Mini-Array – Components

- **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 analyze 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

ASTRI Mini-Array – Telescopes

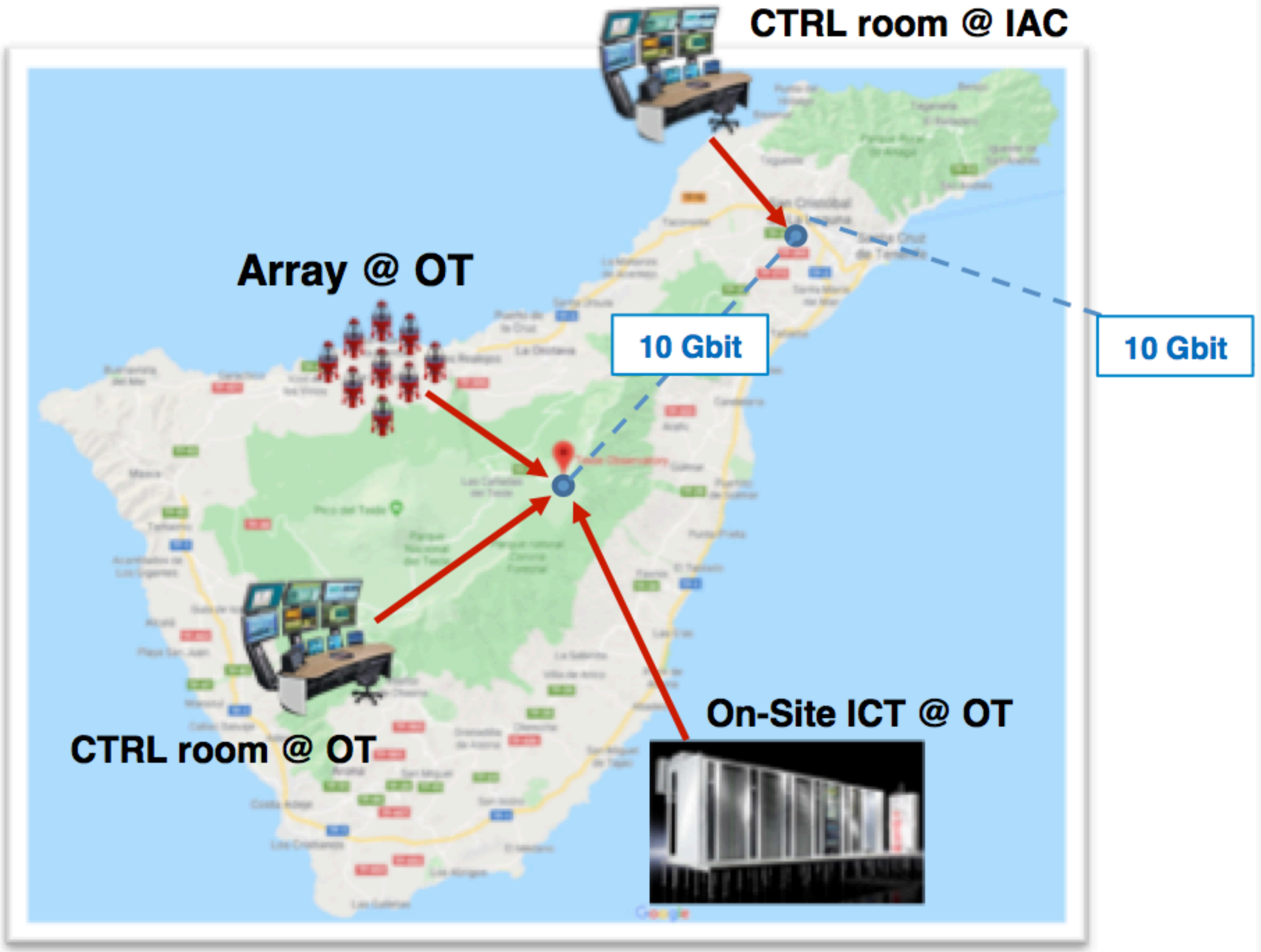


- **Key Features**:
  - ➢ Dual mirror Schwarzschild-Couder design
  - ➢ SiPM Cherenkov camera
- **Evolution of the ASTRI-Horn telescope**
- **Main improvements:**
  - ➢ New M2 support structure (less obscuration)
  - ➢ Optimized M1 dish structure (better loads distribution)
  - ➢ Active mirror control (AMC) system removable
  - ➢ Simplified integration
  - ➢ Improved accessibility for easier maintenance
  - ➢ Mass reduction: 25 t ➔ 17.5 t
  - ➢ Camera with more pixels: 1344 ➔ 2368 (21➔37 modules)
  - ➢ Camera with larger FoV: ~8° ➔ ~10°
  - ➢ Extended range of operability in moonlight conditions

ASTRI Mini-Array – Operation Sites

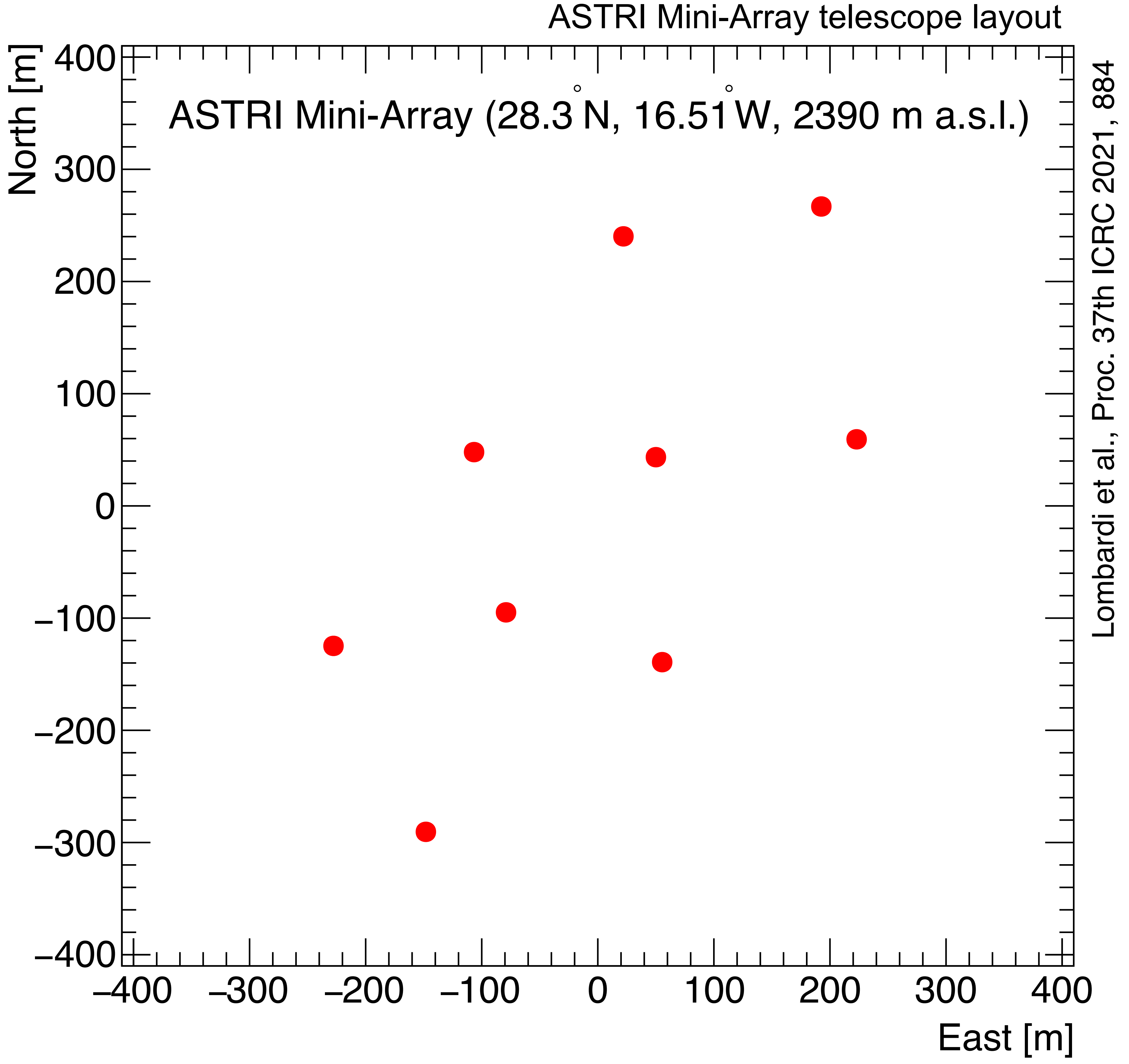
The ASTRI Mini-Array at Tenerife:
- Telescope Array & auxiliaries (Observatorio del Teide - OT)
- Local Control Room @ THEMIS building (OT)
- On-site Data Centre @ IAC Teide Residencia (OT)
- Array Operation Center @IAC in La Laguna

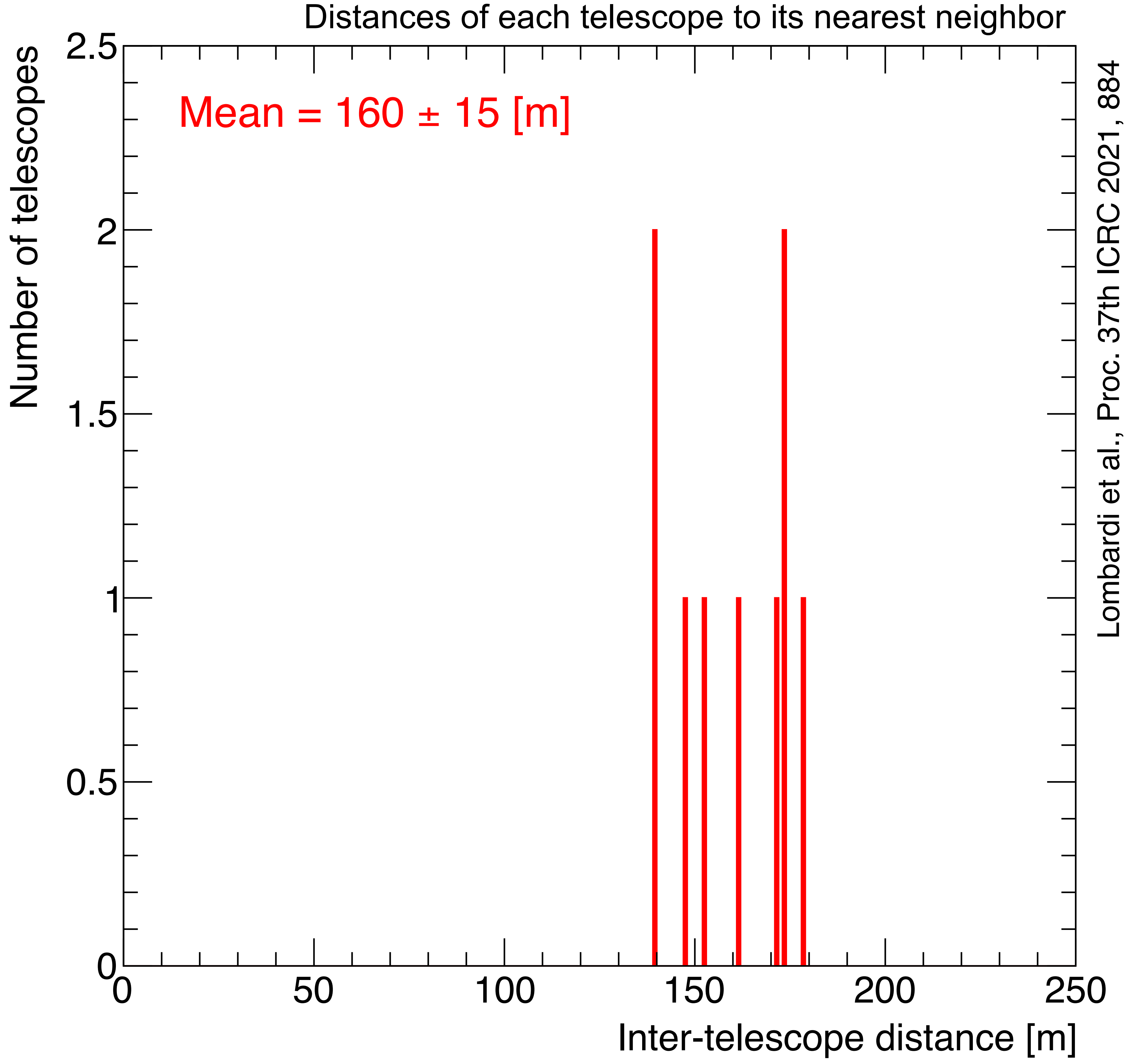
The ASTRI Mini-Array in Italy:
- Data Center @INAF in Rome
- Remote Array Operation Center (any INAF Institute involved)



ASTRI Mini-Array – Key Performance Features

- ASTRI Mini-Array performance evaluated with detailed Monte Carlo simulations and suitable analysis tools
- Telescope positions ➔ trade-off between performance and site constraints
- Telescope next-neighbor distance: ~160 m ➔ enhanced sensitivity at TeV / multi-TeV energy scales





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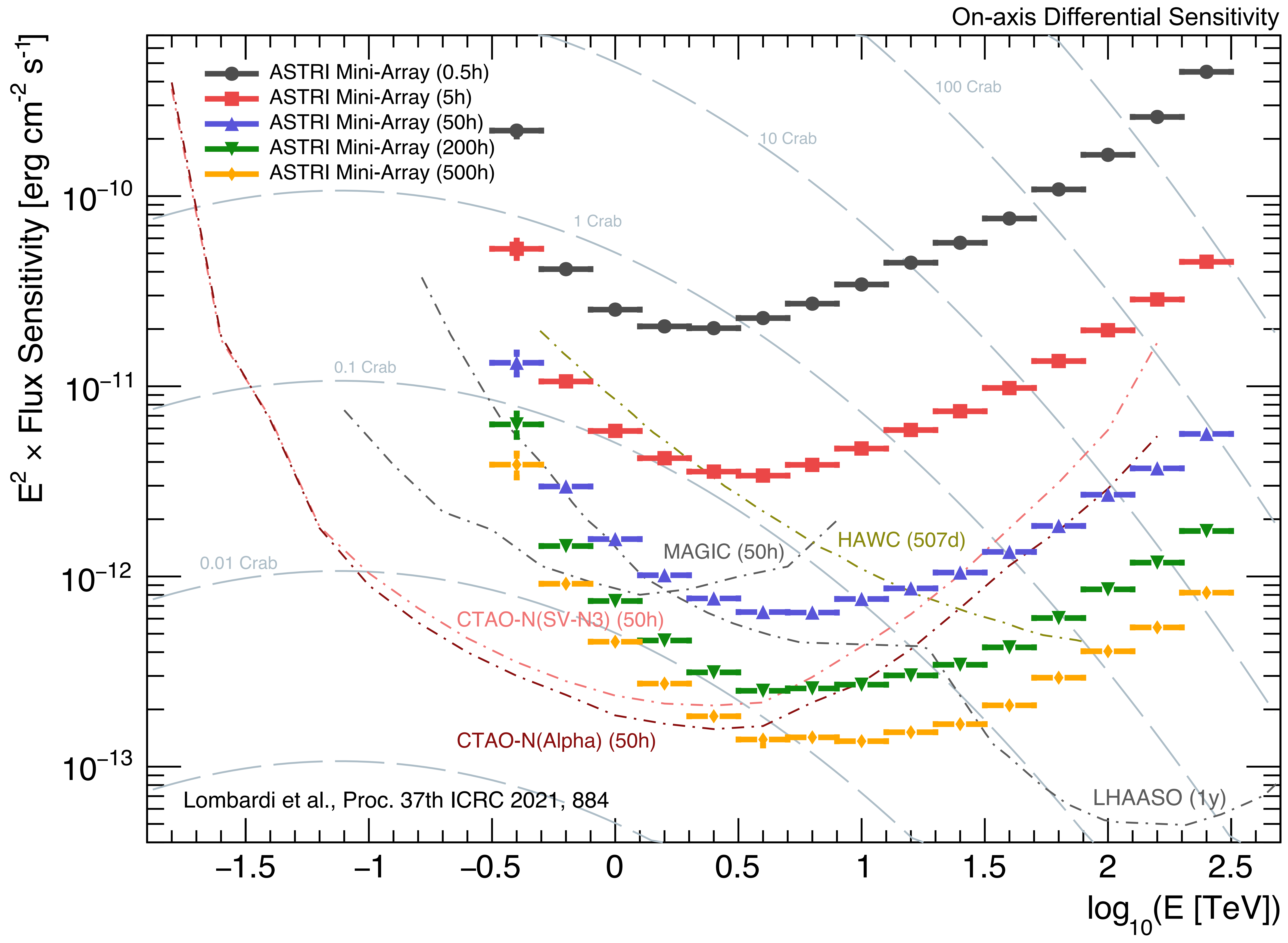


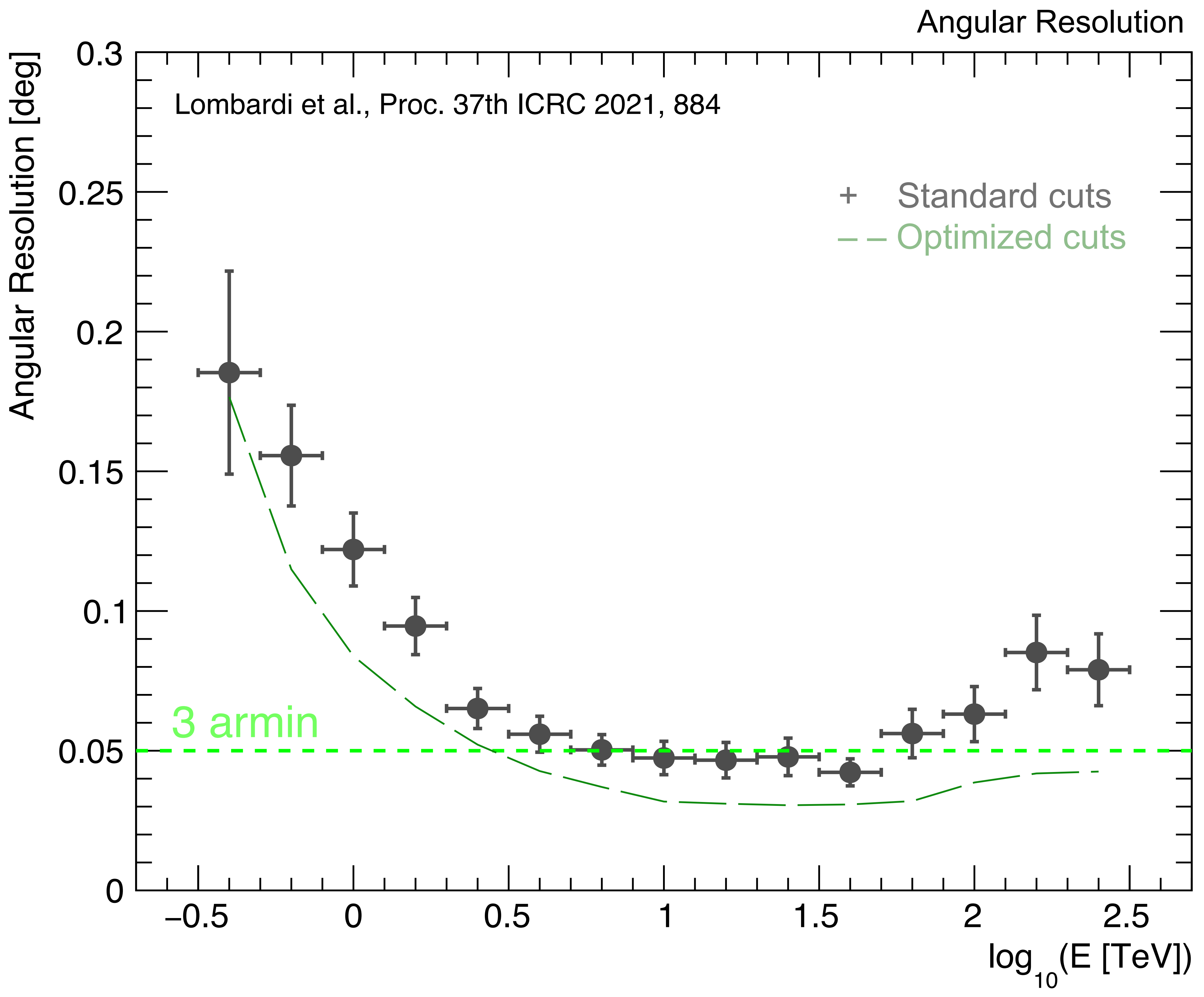
ASTRI Mini-Array Differential Sensitivity:

- Better than present-generation IACTs above a few TeV
- Comparable to CTAO-N above a few tens of TeV
- Surpassed by HAWC (507 days) and LHAASO (1 year) sensitivity above a few tens of TeV, BUT substantially better angular/energy resolution at those energies

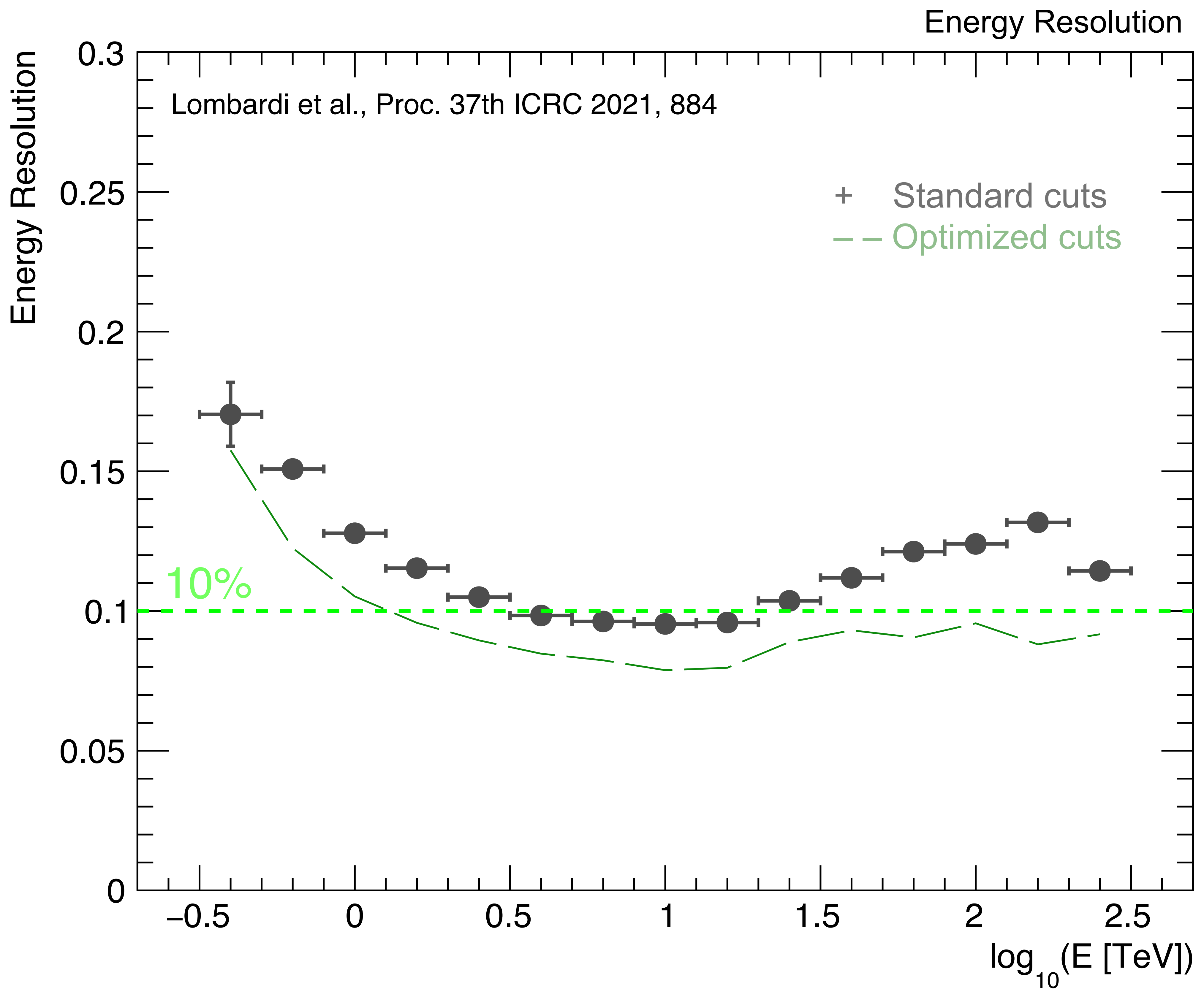
➔ *ASTRI Mini-Array fully functional complement at the TeV / multi-TeV energies to present- and next-generation gamma-ray observatories in the Northern Hemisphere*

ASTRI Mini-Array – Key Performance Features

Angular resolution: ~0.05° above a few TeV ➔ *important for morphological studies of sources detected by HAWC and LHAASO in the multi-TeV regime*

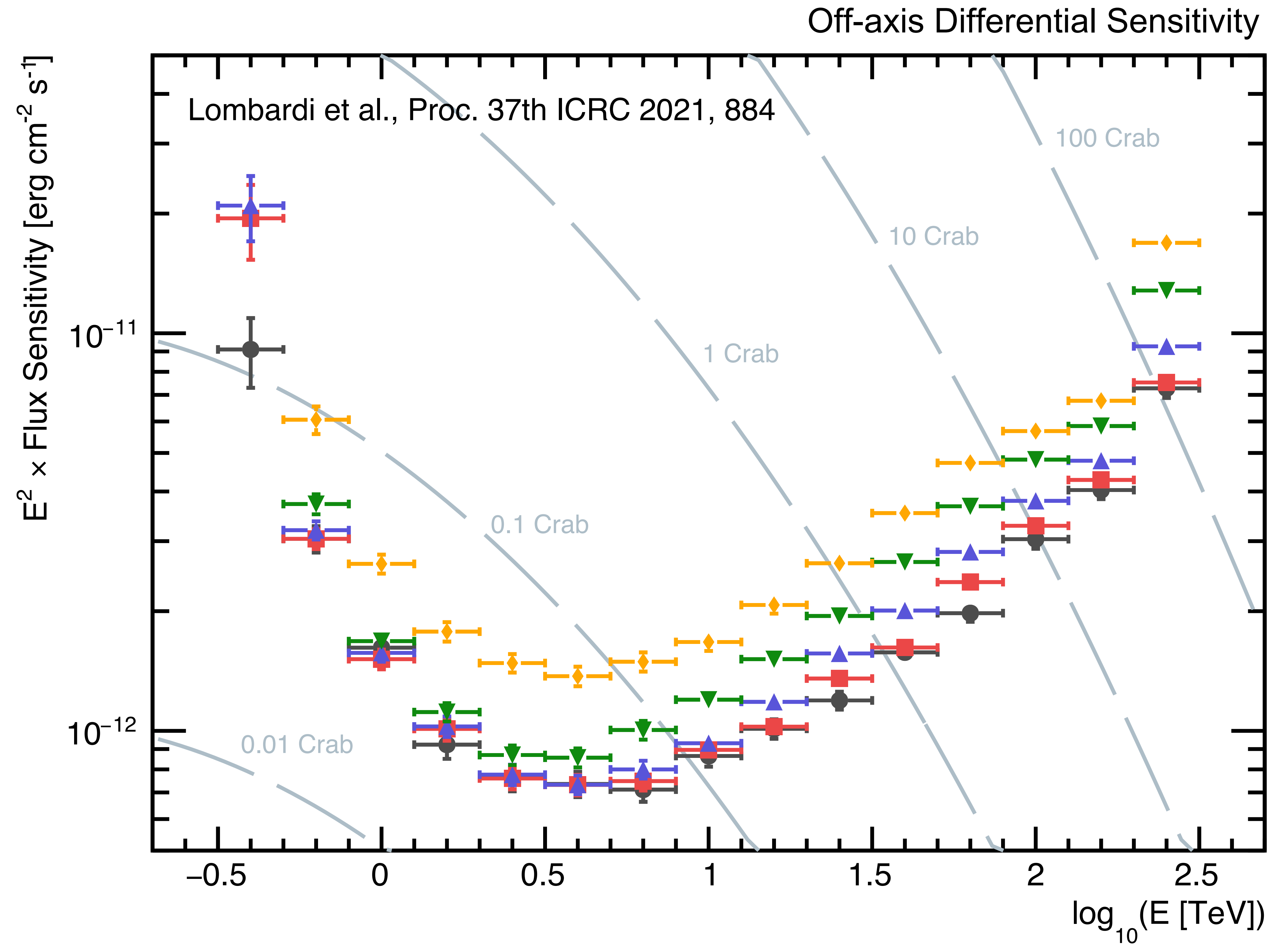


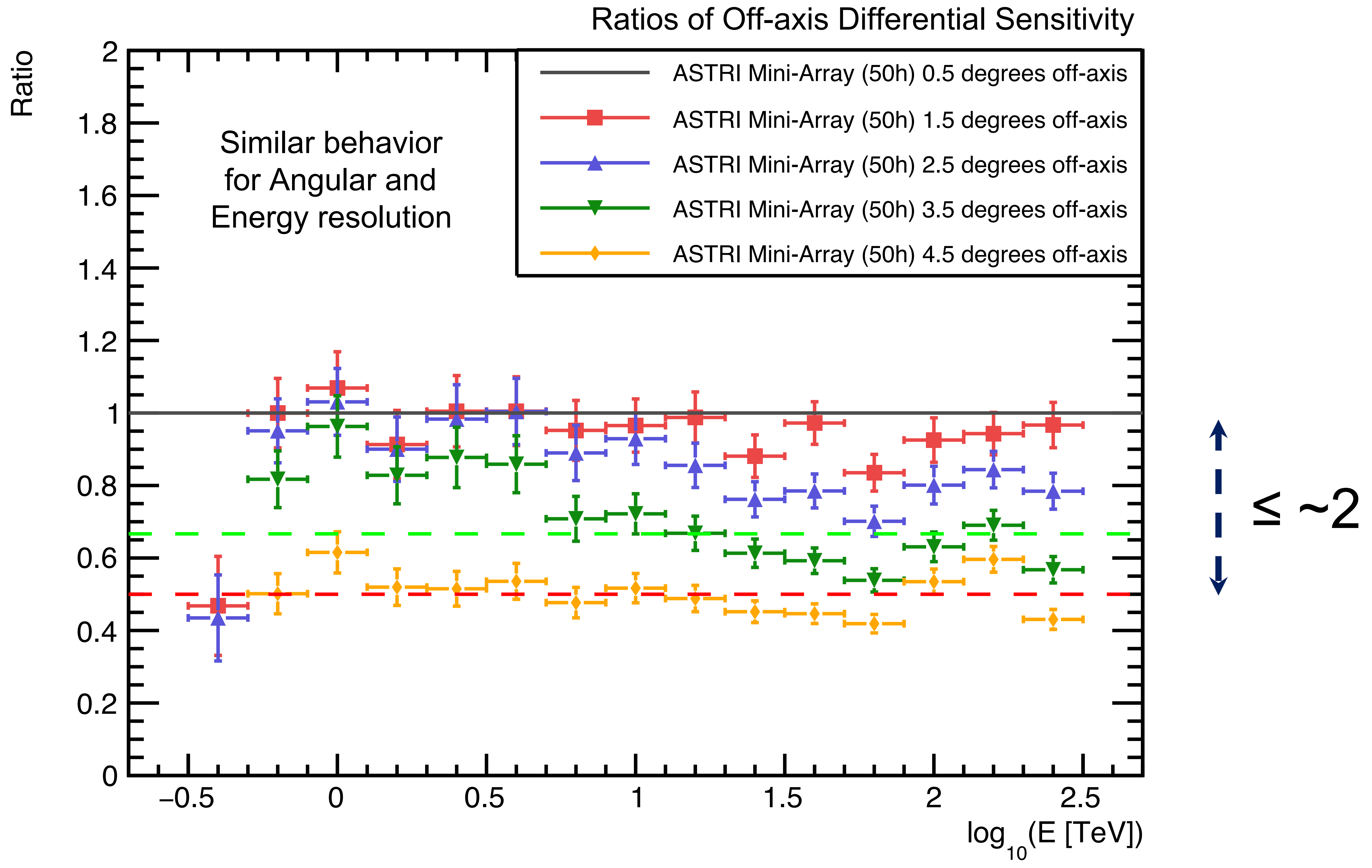
Energy resolution: ~10% above a few TeV ➔ *important for spectral studies (e.g. cut-off, bumps, …) in the TeV / multi-TeV regime*



ASTRI Mini-Array – Key Performance Features

Off-axis Performance: almost homogeneous acceptance (within a factor ~2) over ~10° FoV
➔ *important for simultaneous multi-target observations / extended sources / large surveys of the sky / enhanced chance for serendipitous discoveries*





ASTRI Mini-Array – Key Performance Features

Mini-Array

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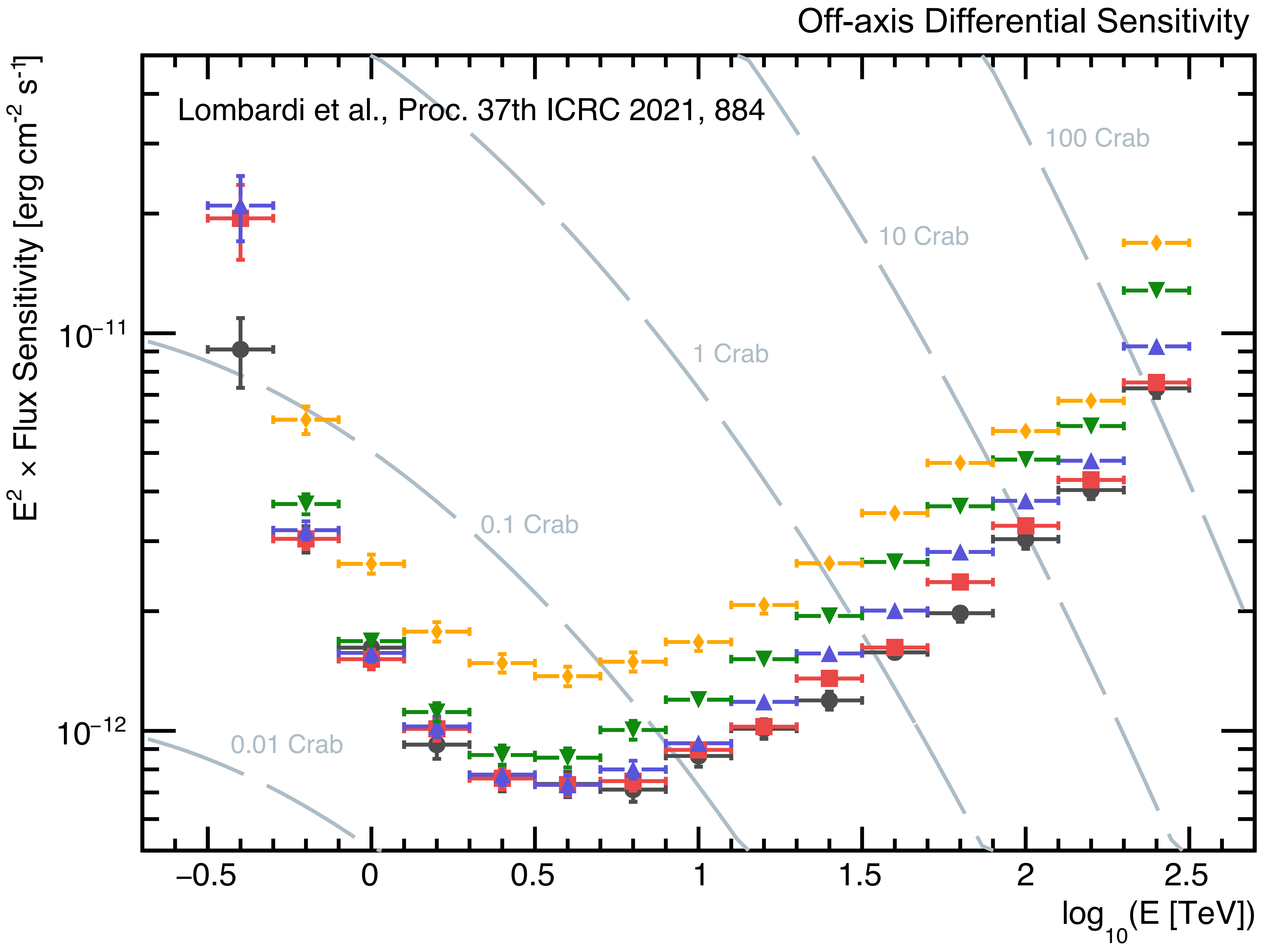
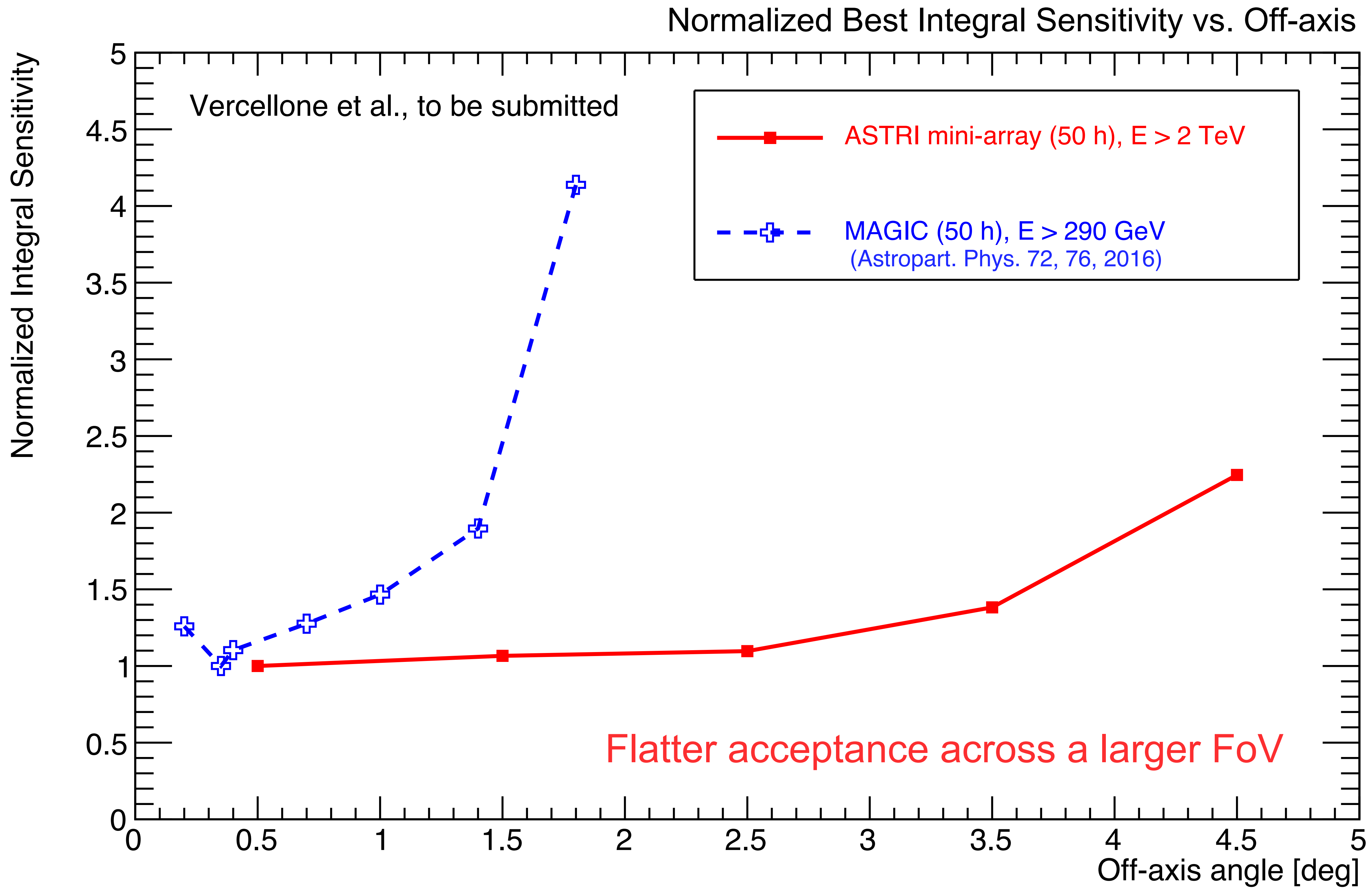




ASTRI Mini-Array – Science Operations

ASTRI Mini-Array

See Talk by S. Vercellone

- **First 4 years ➔ Core Science:**
  - Array operated as an experiment (not as an observatory)
  - Core Science Program developed by ASTRI Science Team
  - Pillar Topics: Origin of Cosmic Rays and Fundamental Physics
  - Few selected targets / Deep exposures (~200 hr)
  - Science beyond VHE astronomy ➔ Stellar Intensity Interferometry
  - Possibility of MoUs with other γ-ray facilities for joint observations

- **Afterwards ➔ Observatory Science:**
  - Observing proposals from a wider scientific community
  - Broader scientific cases, with main focus on the multi-TeV domain:
    - Galactic sources: wide FoV ➔ multi-target fields
    - Extragalactic sources: survey of a few promising targets at > ~10 TeV
    - Fundamental physics: studies on LIV, EBL, Axion-Like Particles, …
    - Direct Measurement of Cosmic Rays
    - Time Domain and Multimessenger Astrophysics

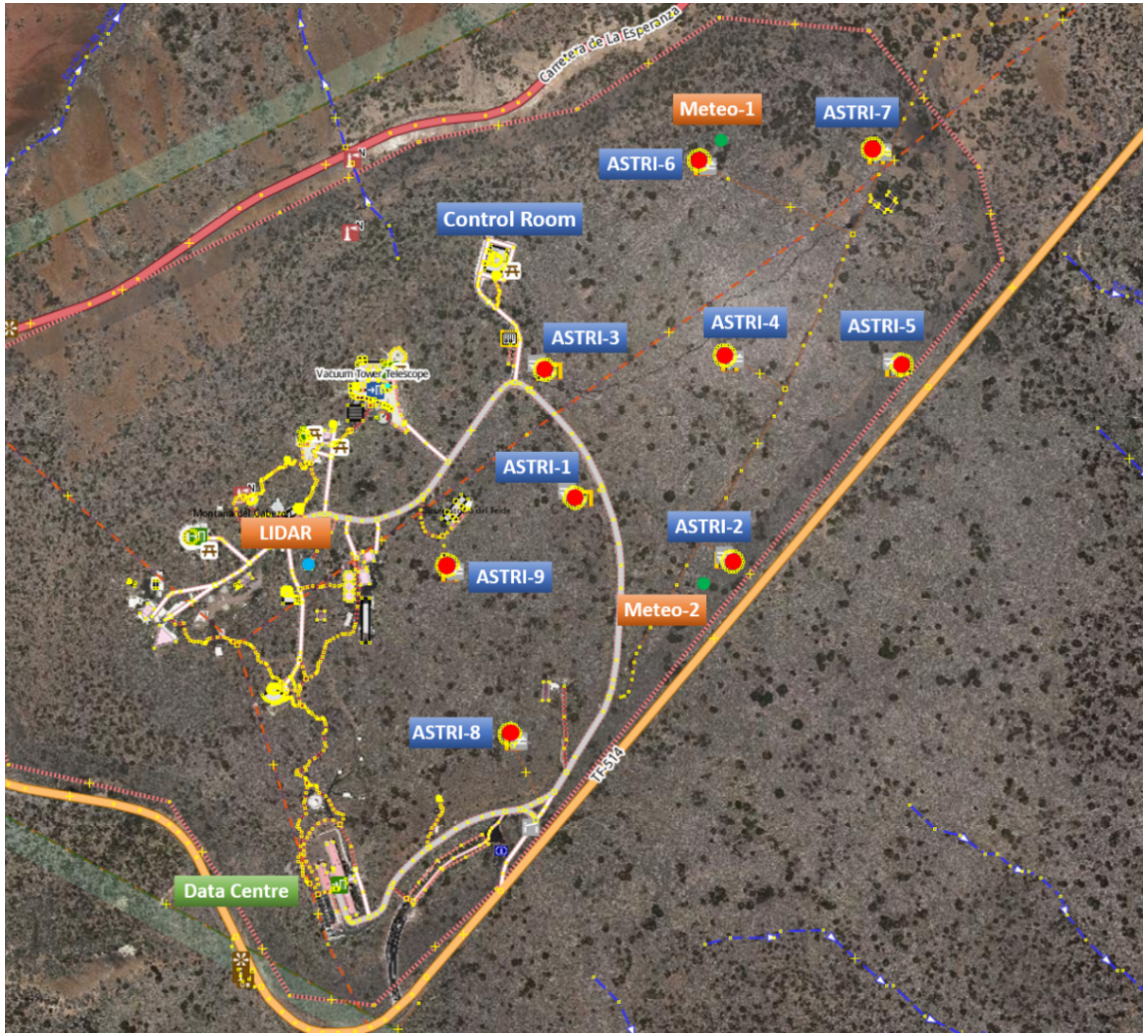
Galactic targets:
- SNRs / PeVatrons / SNRs interacting with MCs
- PWNe / TeV Halos
- Gamma-ray binaries

Extragalactic targets:
- Extreme BL Lacs
- Radio galaxies
- Starburst galaxies

Fundamental physics:
- Lorentz invariance violation / Axion-like particles / Hadron beams in AGN jets
- EBL
- Dark Matter

ASTRI Mini-Array – Schedule

- **Beginning of 2022:**
  - Site infrastructures ready
  - First telescope structure at Teide Observatory



ASTRI Mini-Array – Schedule

- **Beginning of 2022:**
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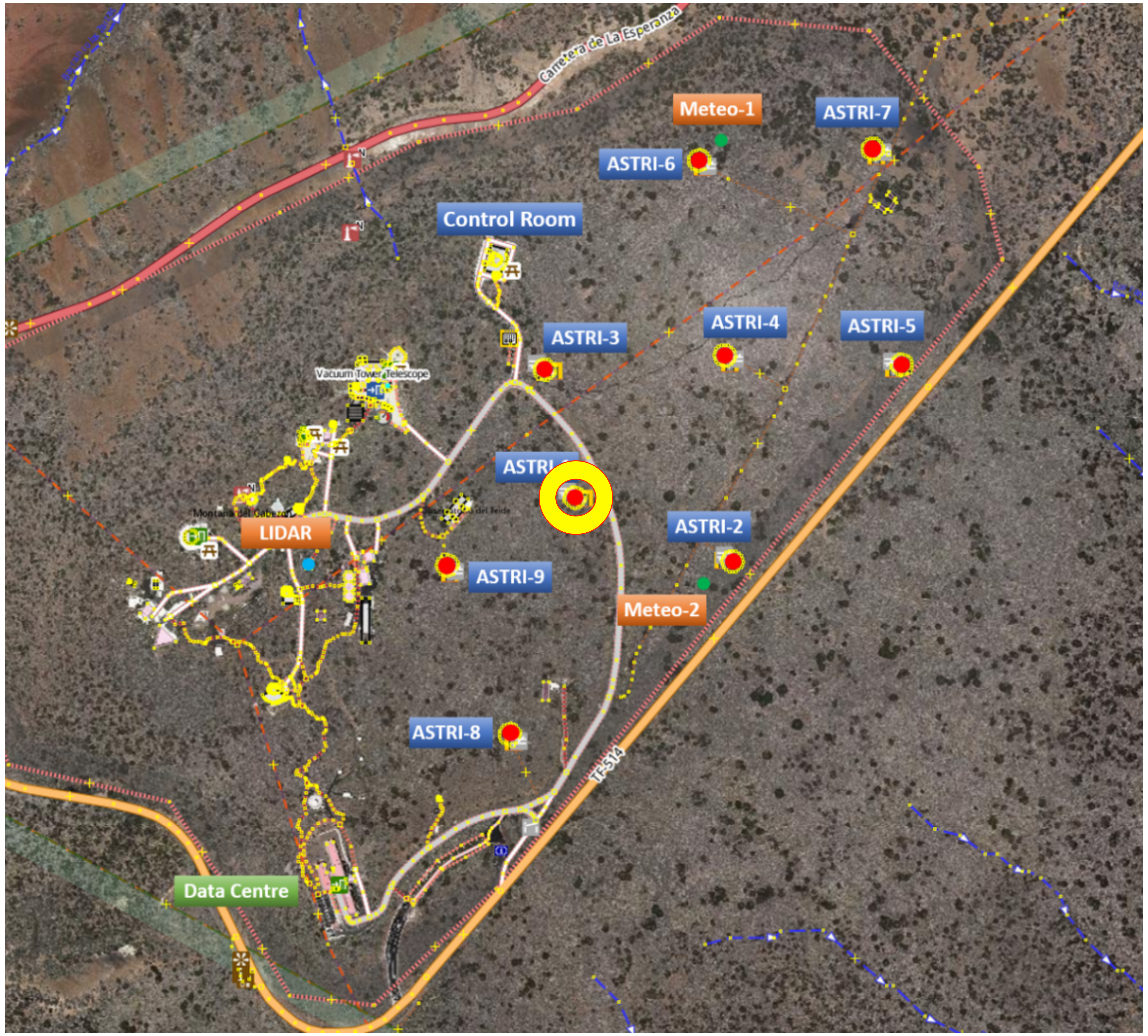
- **End of 2022:**
  - On-site / Off-site ICT deployed
  - First complete telescope at Teide Observatory:
    - Verification of single-telescope system



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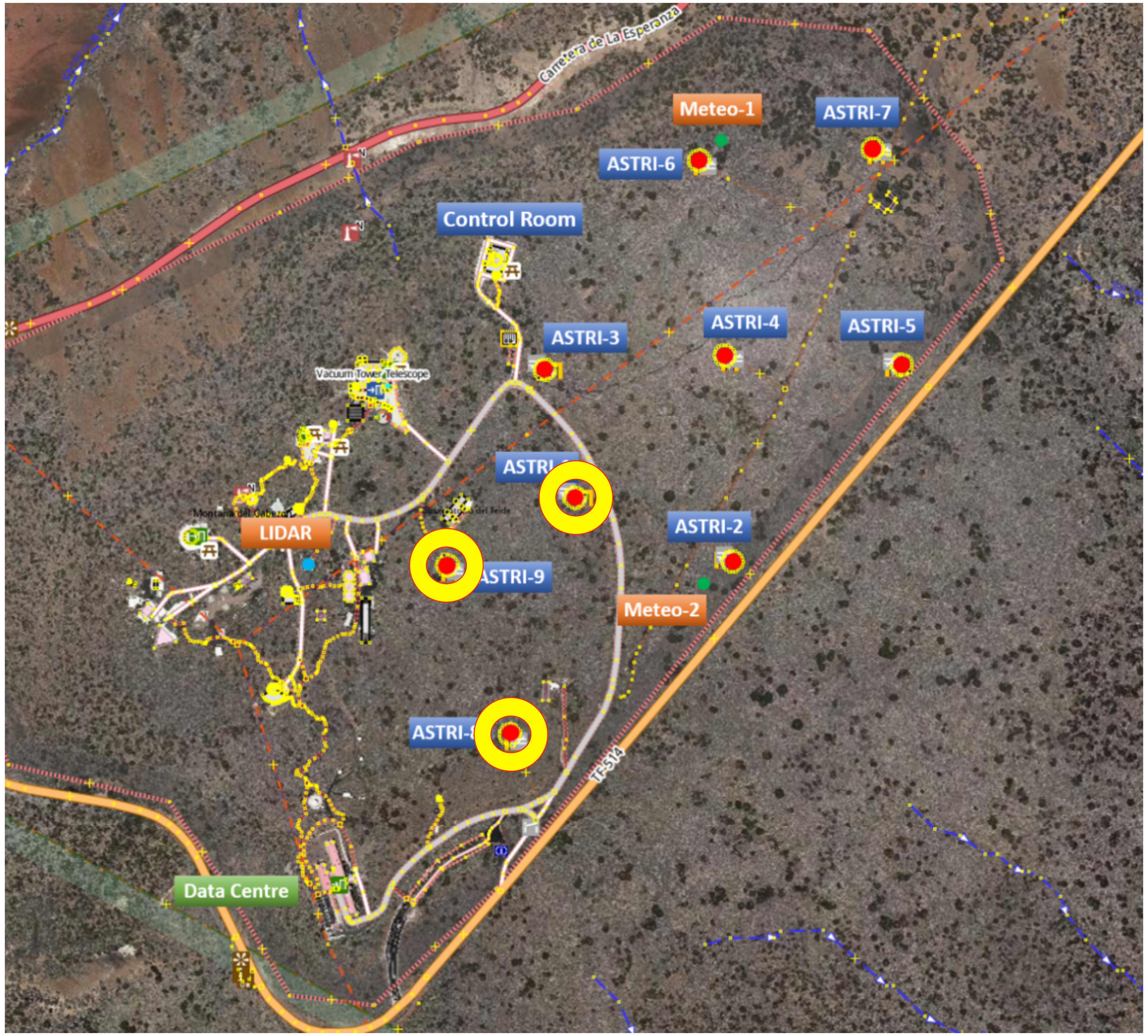
- **Beginning of 2023:**
  - 3 complete telescopes at Teide Observatory:
    - Commissioning of stereo system
    - First stereo observations



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- **Beginning of 2023:**
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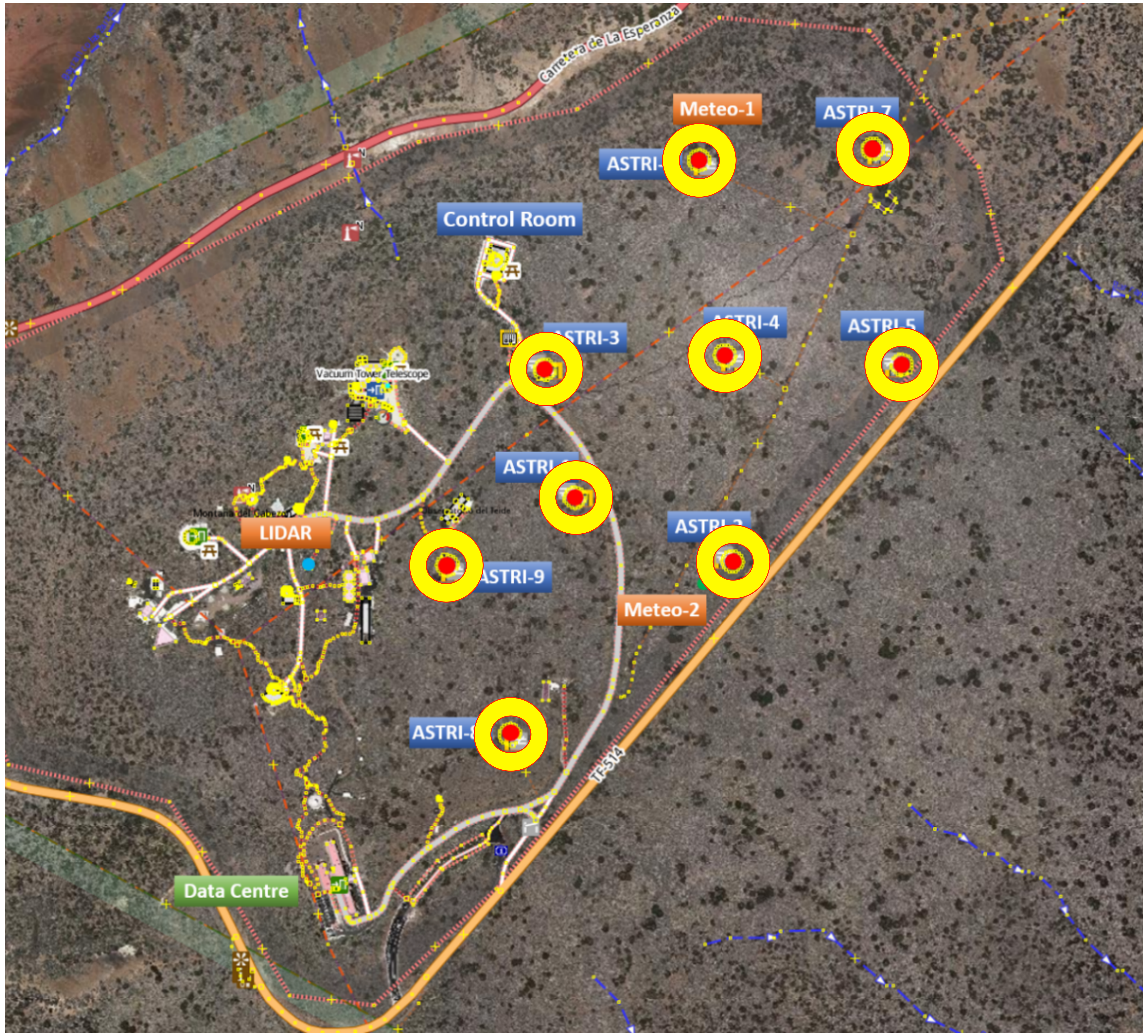
    - First stereo observations
- **End of 2024:**
  - ➢ Array of 9 Cherenkov telescopes:
    - Start of Core Science Program observations



Summary

- **ASTRI Mini-Array** is an **international project led by INAF** aimed to observe the Northern gamma-ray sky in the 1 – 200 TeV energy range
- ASTRI Mini-Array is composed by **9 dual-mirror 4-meters class Cherenkov telescopes** to be deployed at *Observatorio del Teide* (Tenerife, Spain) starting from 2022
- ASTRI Mini-Array Project includes **all systems and sub-systems** (hardware, software and infrastructures) needed for operating the telescopes, acquiring, archiving, analyzing and distributing scientific data
- Thanks to its **key performance features** above a few TeV (Sensitivity: better than current IACTs; Energy/Angular resolution: ~10% / ~0.05°; Wide FoV: ~10°, with almost homogeneous off-axis acceptance), ASTRI Mini-Array is going to be a prominent facility for the observation of the gamma-ray sky at the TeV / multi-TeV energy band, extending IACTs precision measurements up to 200 TeV
- ASTRI Mini-Array will start **scientific observations in 2024** with a 4 (Core Science) + 4 (Observatory Science) years program
- **Important synergies** are expected with other Northern gamma-ray facilities, such as **LHAASO, HAWC, MAGIC, VERITAS, and CTAO-N**