The ASTRI project, status, technology and science prospects

C. Bigongiari (INAF-OAR & ASI-SSDC)

for the ASTRI Project

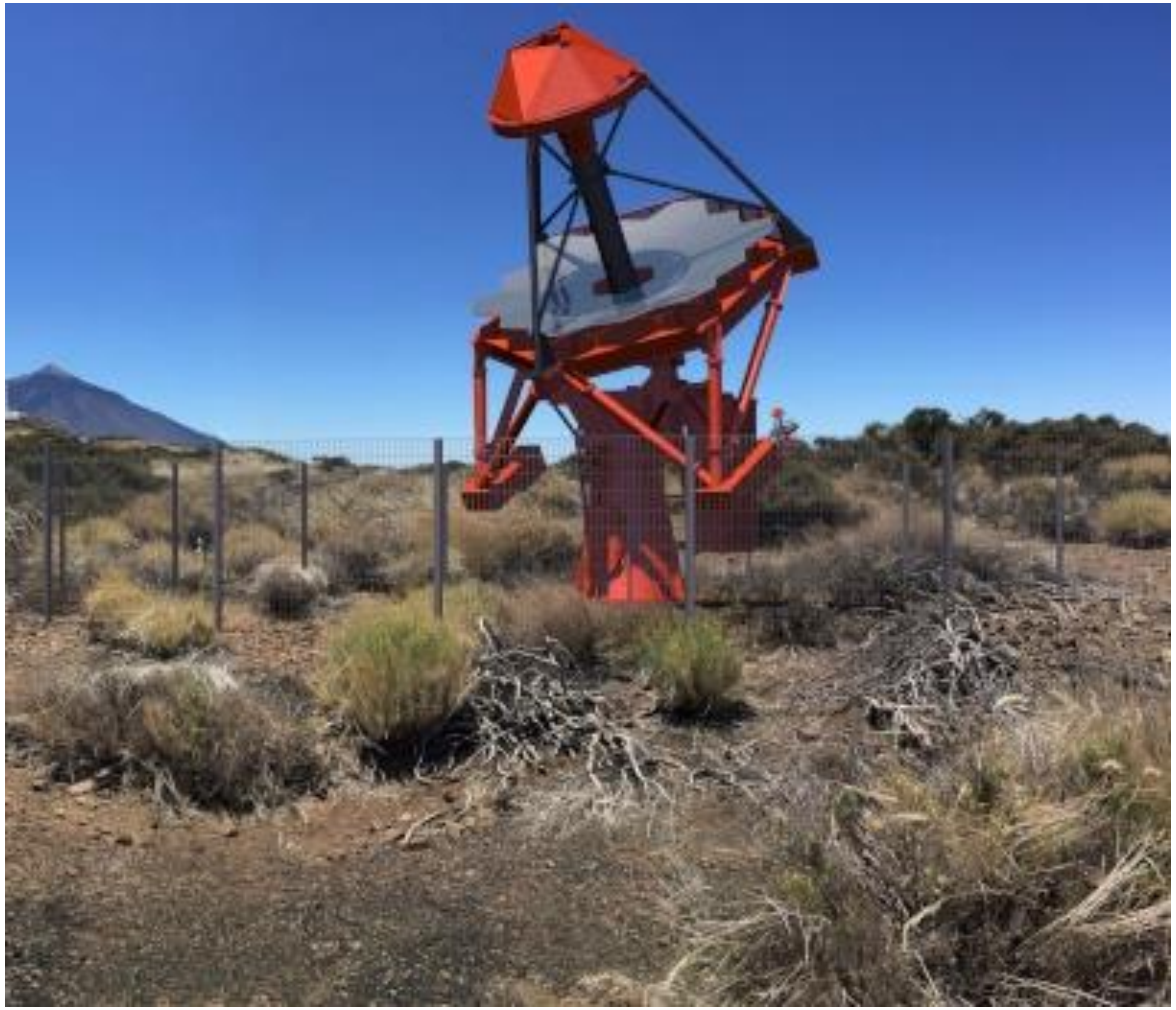
ɣ - 2024

8th Heidelberg International Symposium on High-Energy Gamma-Ray Astronomy

Milan, 2-6 September 2024

Outline

- The ASTRI project:
  - from the ASTRI-Horn prototype to the Mini-Array
- ASTRI innovative technologies
- The ASTRI Mini-Array
- ASTRI Mini-Array expected performance
- ASTRI Mini-Array scientific strategy
- ASTRI Mini-Array status & timeline



ASTRI Project

ASTRI: AStrofisica con Tecnologia Replicante Italiana -> Astrophysics with Italian Replicating Technology

Nanni Bignami

ASTRI-Horn Prototype

INAF Project funded by Italian Ministry of Research

End-to-end prototype installed and operational on Mount Etna (Sicily, Italy)

First detection of a gamma-ray source (Crab Nebula) **with a dual-mirror, Schwarzschild-Couder Cherenkov telescope** (Lombardi et al., 2020)

Array Mini-Array

INAF-led Project with several partners:

Univ. of Sao Paulo/FPESP (Brazil), North-West Univ. (S. Africa), IAC (Spain), FGG, ASI/SSDC, Univ. Geneva, Univ. of Padova, Perugia

Array of 9 ASTRI telescopes being deployed at the *Observatorio del Teide* (Tenerife, Spain) in collaboration with IAC and FGG-INAF.

First 4 years → *Core Science*, following 4 years of *Observatory Science.* **Full Science operation → 2026**

Mirror production with replicant technology

Mini-Array

Primary mirror: facets -> cold slumping

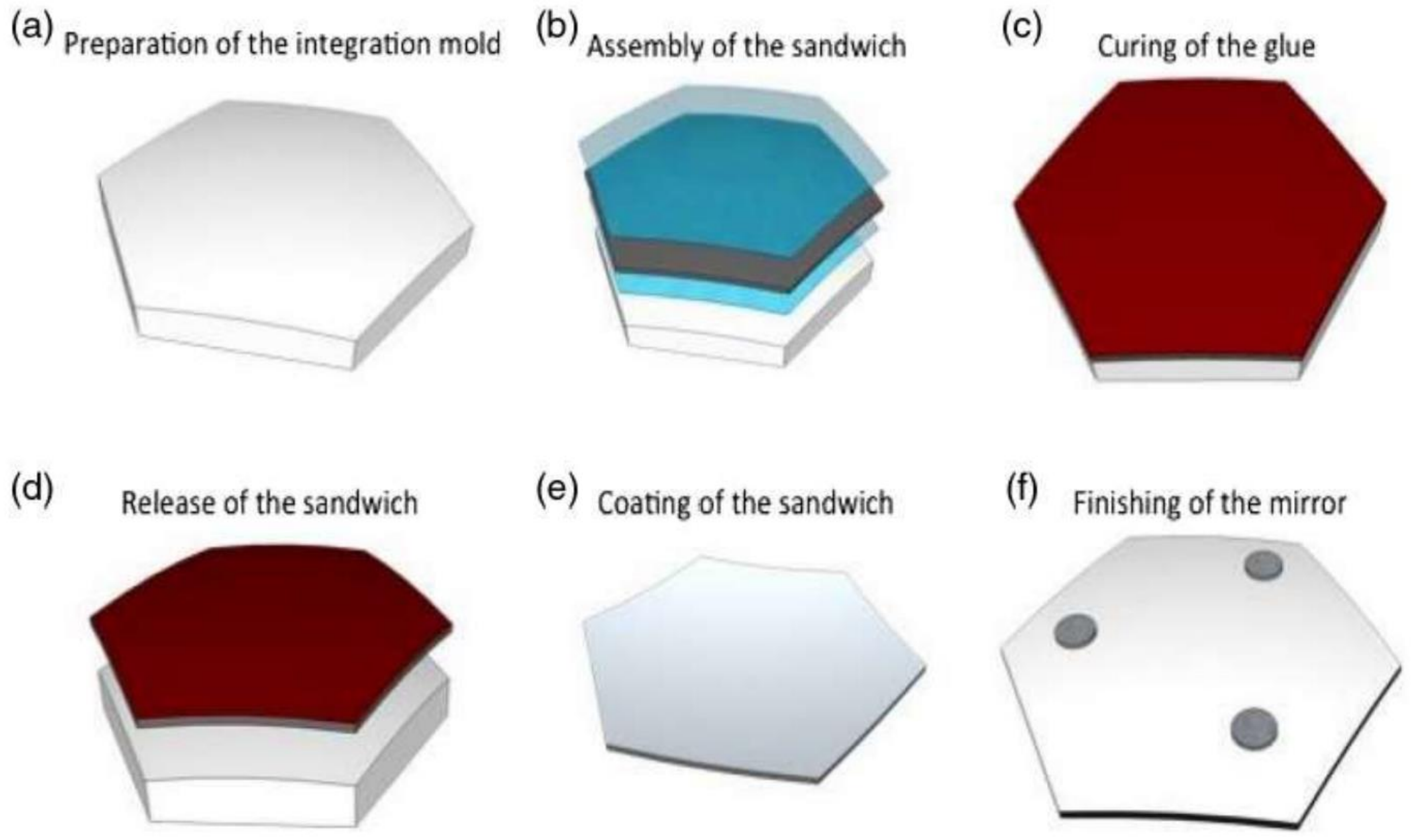


Fig. 1 Conceptual description of the (a)–(f) main steps of the cold-slumping technology.

J. Astron. Telesc. Instrum. Syst. 014005-4 Jan–Mar 2022 • Vol. 8(1)

- Dimensions and radius of curvature not a problem for cold slumping
- Lightweight (~ 8.5 kg) thanks to the sandwich structure
- Cheap (few k€/m^2) thanks to the replica technology

Secondary mirror: monolithic -> hot slumping

- The secondary mirror is 180 cm in diameter, too large for slabs as thin as those used in cold slumping.
- Being 19 mm in thickness, even the M2 mirror produced with the hot slumping technique

In collaboration with Media Lario S.R.L. and VETROLAMP S.R.L.

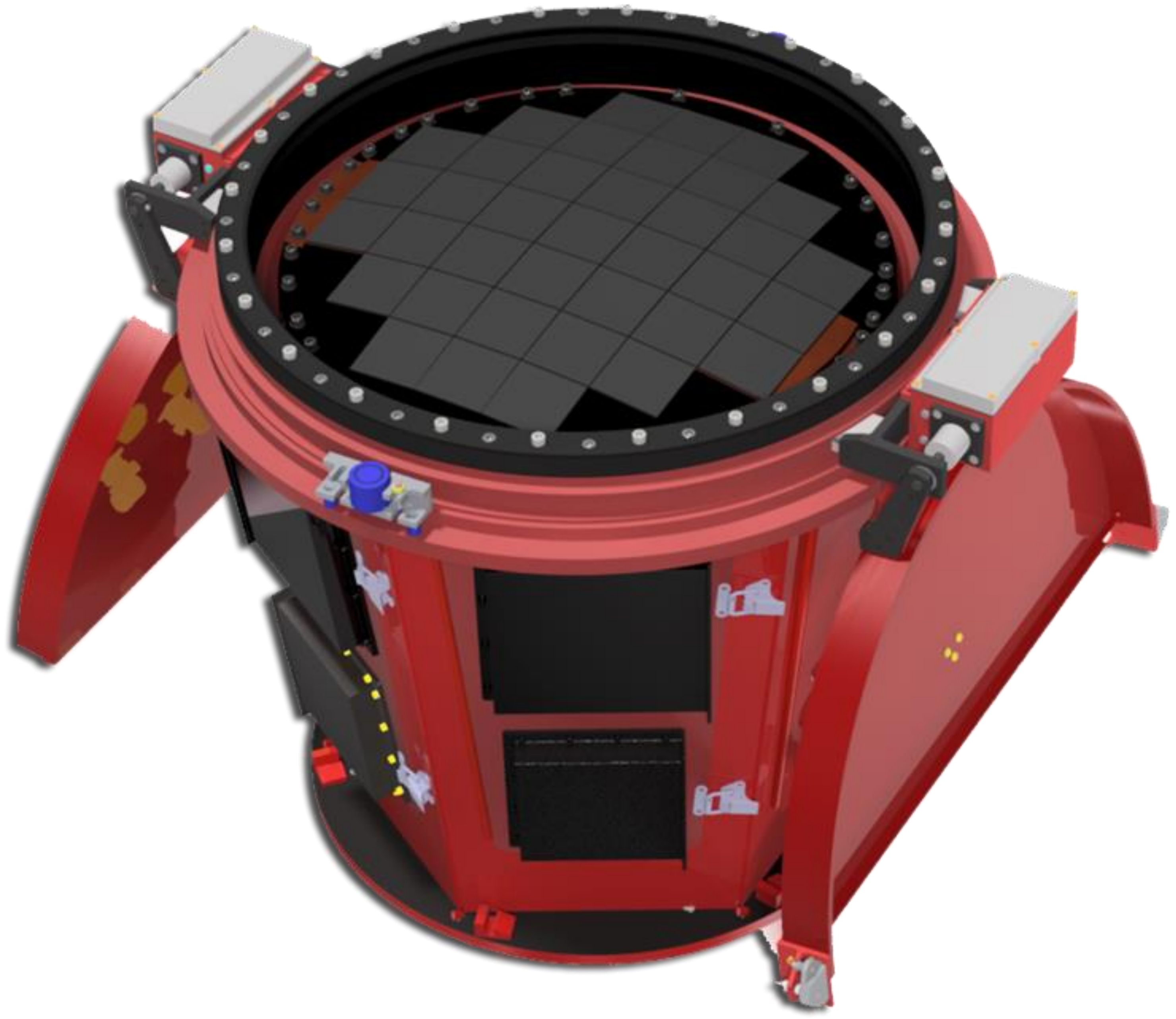
ASTRI SiPM-based Camera

- The SiPM produced by Hamamatsu photonics ($7x7\ mm^2$) grouped in matrices of 8x8 pixels
- 37 matrices are arranged to adapt to the curved focal plane of the telescope.
- innovative electronics for peak detection (CITIROC ASICS , WEEROC-INAF) ⇒ small amount of data
- Interference filter as front window (Romeo et al. (2018) and Catalano et al. (2018)) that allows to reduce the contribution from the night sky background at wavelengths greater than 550 nm where the sensitivity of SiPM detector is still high.

SiPM matrices

ASIC board

FIELD OF VIEW OF 10.5° IN DIAMETER



In collaboration with CAEN S.p.A. and EIE Group S.R.L..

ASTRI-Horn results

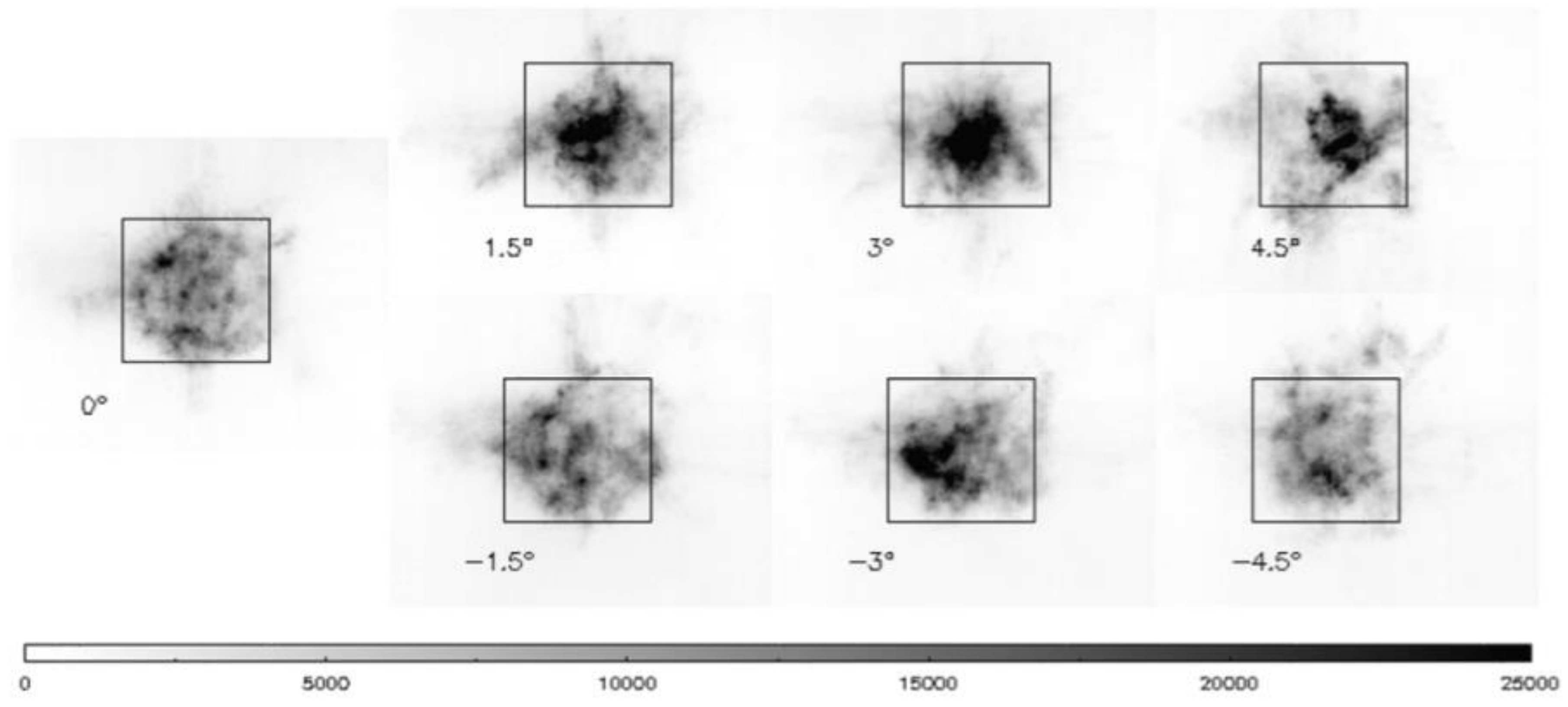
ASTRI Mini-Array

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]

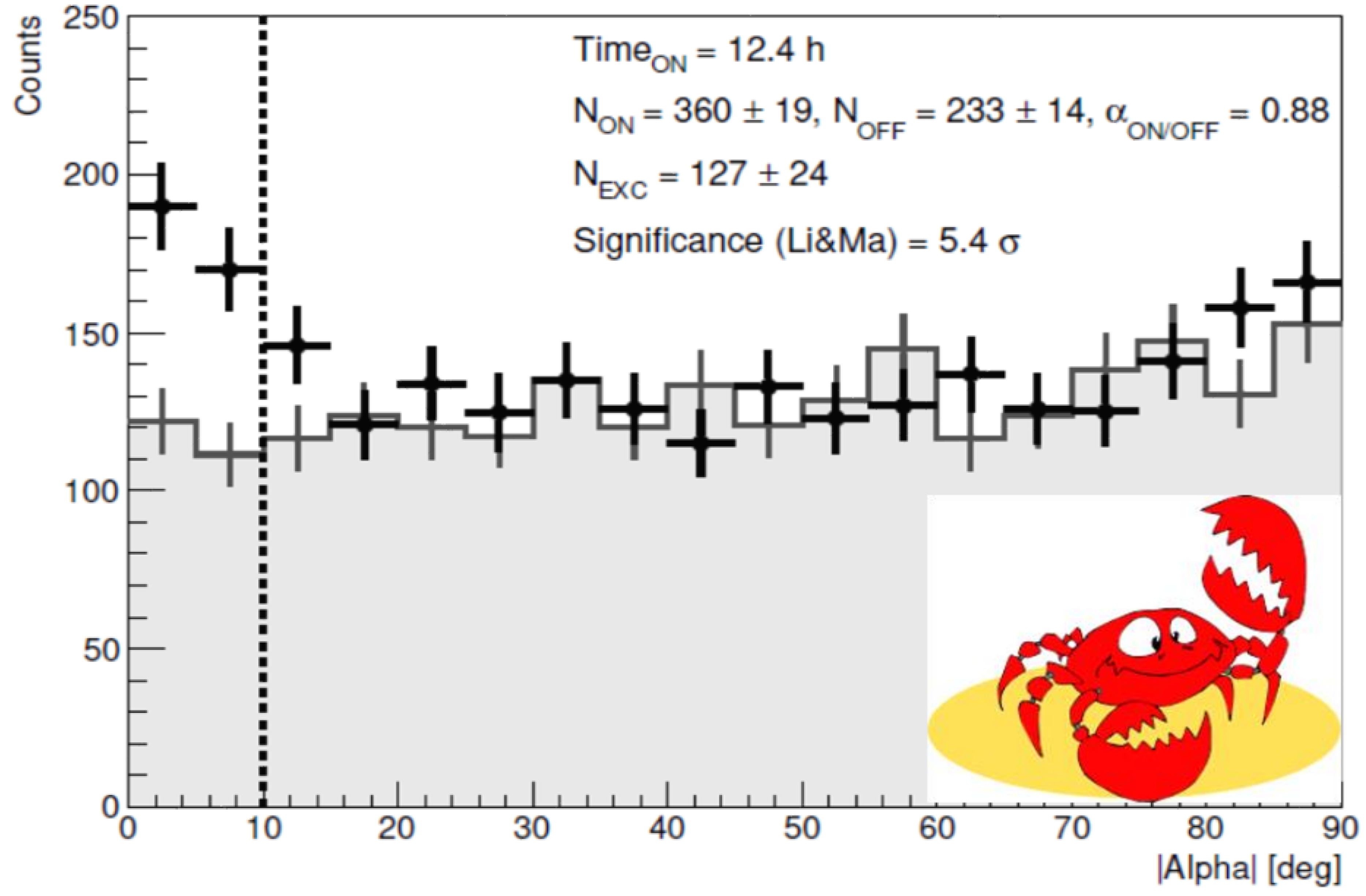


A&A 634, A22 (2020)
https://doi.org/10.1051/0004-6361/201936791

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. Miccichè[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'Ai[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]



See G.Sironi, G.Contino, S.Crestan and S.Iovenitti poster/talks for recent results

The ASTRI Mini-Array in a nutshell

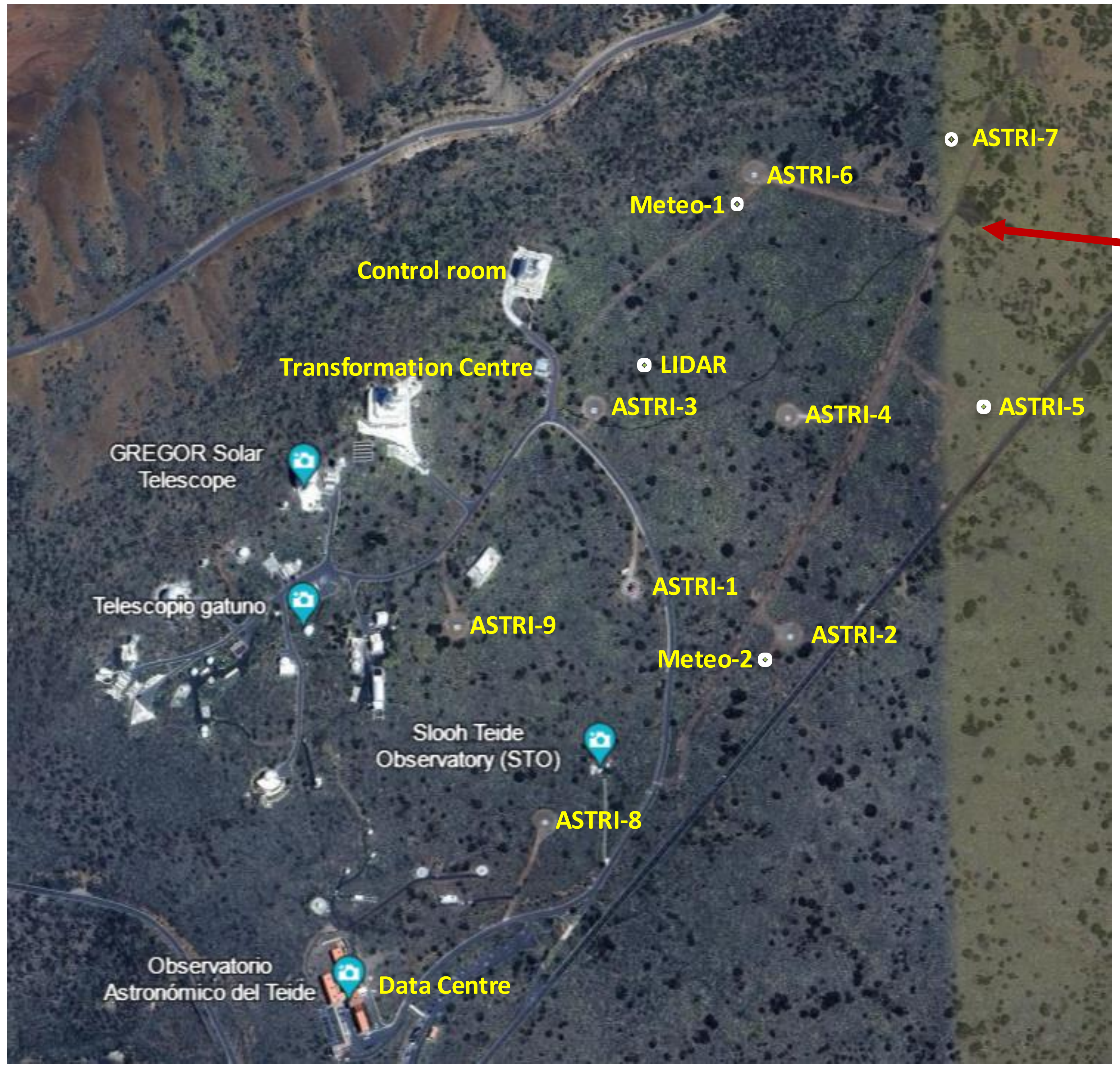
Mini-Array

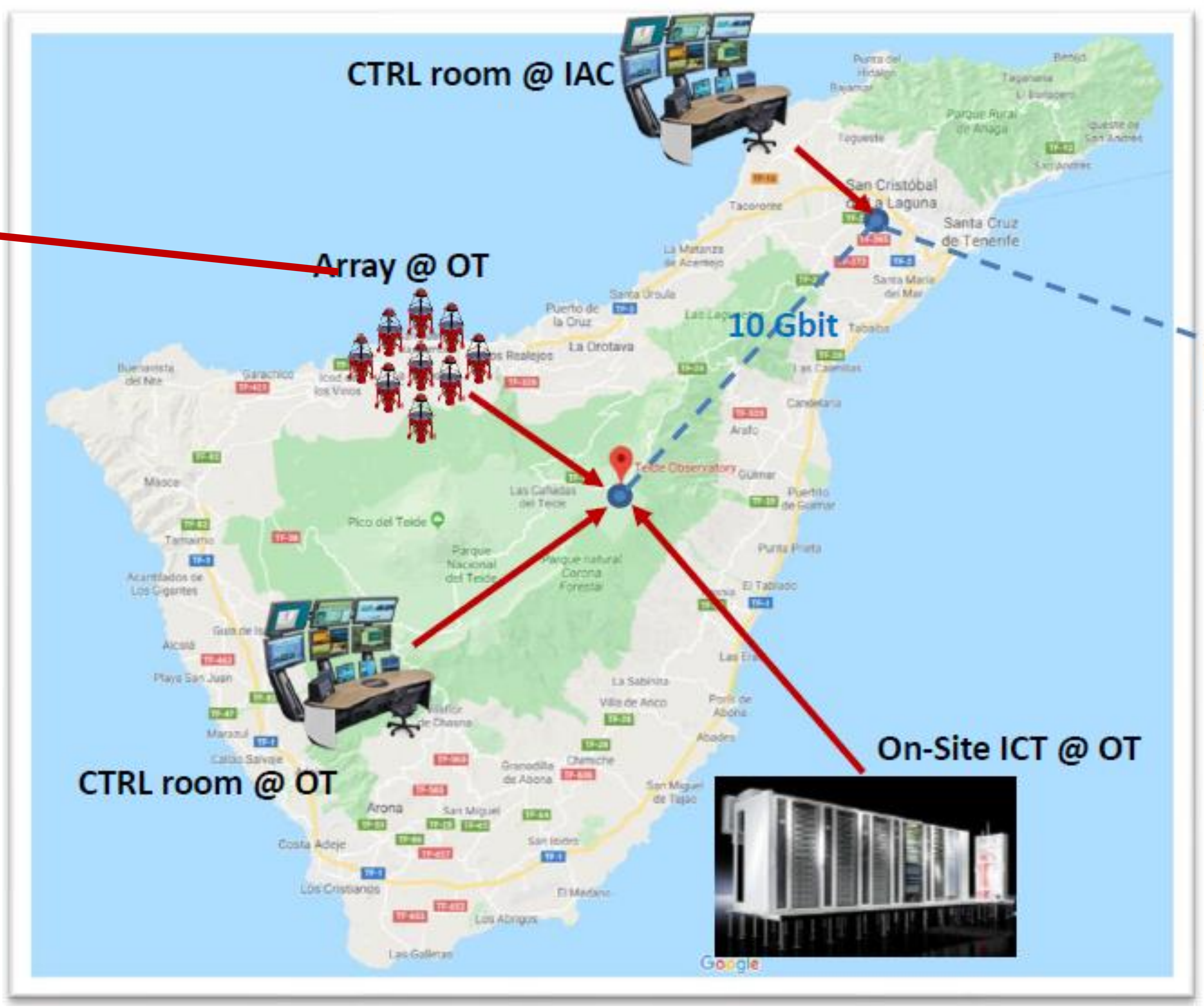
The ASTRI Mini-Array in Tenerife

- Telescope Array & auxiliaries @ Observatorio del Teide (OT henceforth)
- 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

- Off site Data Centre in Rome
- Several Remote Array operation centers





The ASTRI Mini-Array Science Papers

ASTRI Mini-Array

Journal of High Energy Astrophysics 35 (2022) 52–68

Contents lists available at ScienceDirect

Journal of High Energy Astrophysics

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

Check for updates

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], P. Caraveo[a], M. Cardillo[k], V. Conforti[e], G. Contino[f], M. Corpora[f], A. Costa[d], G. Cusumano[f], A. D'Aì[f], E. de Gouveia Dal Pino[l], R. Della Ceca[b], E. Escribano Rodriguez[o], D. Falceta-Gonçalves[s], C. Fermino[l], M. Fiori[j,g], V. Fioretti[e], M. Fiorini[a], S. Gallozzi[h], C. Gargano[f], S. Garozzo[d], S. Germani[c], A. Ghedina[o], F. Gianotti[e], S. Giarrusso[f], R. Gimenes[f,l], V. Giordano[d], A. Grillo[d], C. Grivel Gelly[o], D. Impiombato[f], F. Incardona[d], S. Incorvaia[a], S. Iovenitti[b], A. La Barbera[f], N. La Palombara[a], V. La Parola[f], A. Lamastra[h], L. Lessio[g], G. Leto[d], F. Lo Gerfo[f], M. Lodi[o], S. Lombardi[h,u], F. Longo[r], F. Lucarelli[h,u], M.C. Maccarone[f], D. Marano[d], E. Martinetti[d], S. Mereghetti[a], A. Micciché[d], R. Millul[b], T. Mineo[f], D. Mollica[f], G. Morlino[q], A. Morselli[i], G. Naletto[j,g], G. Nicotra[t], A. Pagliaro[f], N. Parmiggiani[e], G. Piano[k], F. Pintore[f], E. Poretti[o], B. Olmi[q], G. Rodeghiero[e], G. Rodriguez Fernandez[i], P. Romano[b], G. Romeo[d], F. Russo[e], P. Sangiorgi[f], F.G. Saturni[h], J.H. Schwarz[b], E. Sciacca[d], G. Sironi[b], G. Sottile[f], A. Stamerra[h], G. Tagliaferri[b], V. Testa[h], G. Umana[d], M. Uslenghi[a], S. Vercellone[b], L. Zampieri[g], R. Zanmar Sanchez[d]

Journal of High Energy Astrophysics 35 (2022) 1–42

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

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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], M. Böttcher[k], G. Brunetti[n], A.A. Compagnino[e], S. Crestan[o,p], A. D'Aì[e], M. Fiori[h,f], G. Galanti[o], A. Giuliani[o], E.M. de Gouveia Dal Pino[q], J.G. Green[b], A. Lamastra[b,g], M. Landoni[a], F. Lucarelli[b,g], G. Morlino[c], B. Olmi[r,c], E. Peretti[s], G. Piano[d], G. Ponti[a,t], E. Poretti[a,u], P. Romano[a], F.G. Saturni[b,g], S. Scuderi[o], A. Tutone[b], G. Umana[v], J.A. Acosta-Pulido[l,m], P. Barai[q], A. Bonanno[v], G. Bonanno[v], P. Bruno[v], A. Bulgarelli[w], V. Conforti[w], A. Costa[v], G. Cusumano[e], M. Del Santo[e], M.V. del Valle[q], R. Della Ceca[a], D.A. Falceta-Gonçalves[q], V. Fioretti[w], S. Germani[x,y], R.J. García-López[l,m], A. Ghedina[u], F. Gianotti[w], V. Giordano[v], M. Kreter[k], F. Incardona[v], S. Iovenitti[a], A. La Barbera[e], N. La Palombara[o], V. La Parola[e], G. Leto[v], F. Longo[z,aa], A. López-Oramas[l,m], M.C. Maccarone[e], S. Mereghetti[o], R. Millul[a], G. Naletto[f], A. Pagliaro[e], N. Parmiggiani[w], C. Righi[a], J.C. Rodríguez-Ramírez[q], G. Romeo[v], P. Sangiorgi[e], R. Santos de Lima[q], G. Tagliaferri[a], V. Testa[b], G. Tosti[x,y], M. Vázquez Acosta[l,m], N. Żywucka[k,ab], P.A. Caraveo[o], G. Pareschi[a]

ASTRI IRF on Zenodo

«ASTRI Project. (2022). ASTRI Mini-Array Instrument Response Functions (Prod2, v1.0)»

https://zenodo.org/record/6827882#.YtFCjZNBx60

DoI: 10.5281/zenodo.6827882

Journal of High Energy Astrophysics 35 (2022) 91–111

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

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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], A. Wolter[j], E. Amato[p], C. Bigongiari[a,b], M. Böttcher[d], G. Brunetti[q], P. Bruno[r], A. Bulgarelli[s], M. Cardillo[t], V. Conforti[s], A. Costa[r], G. Cusumano[k], V. Fioretti[s], S. Germani[u], A. Ghedina[v], F. Gianotti[s], V. Giordano[r], A. Giuliani[w], F. Incardona[r], A. La Barbera[k], G. Leto[r], F. Longo[x,y], G. Morlino[p], B. Olmi[z], N. Parmiggiani[s], P. Romano[o], G. Romeo[r], A. Stamerra[a], G. Tagliaferri[o], V. Testa[a], G. Tosti[j,u], P.A. Caraveo[w], G. Pareschi[o]

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Journal of High Energy Astrophysics 35 (2022) 139–175

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

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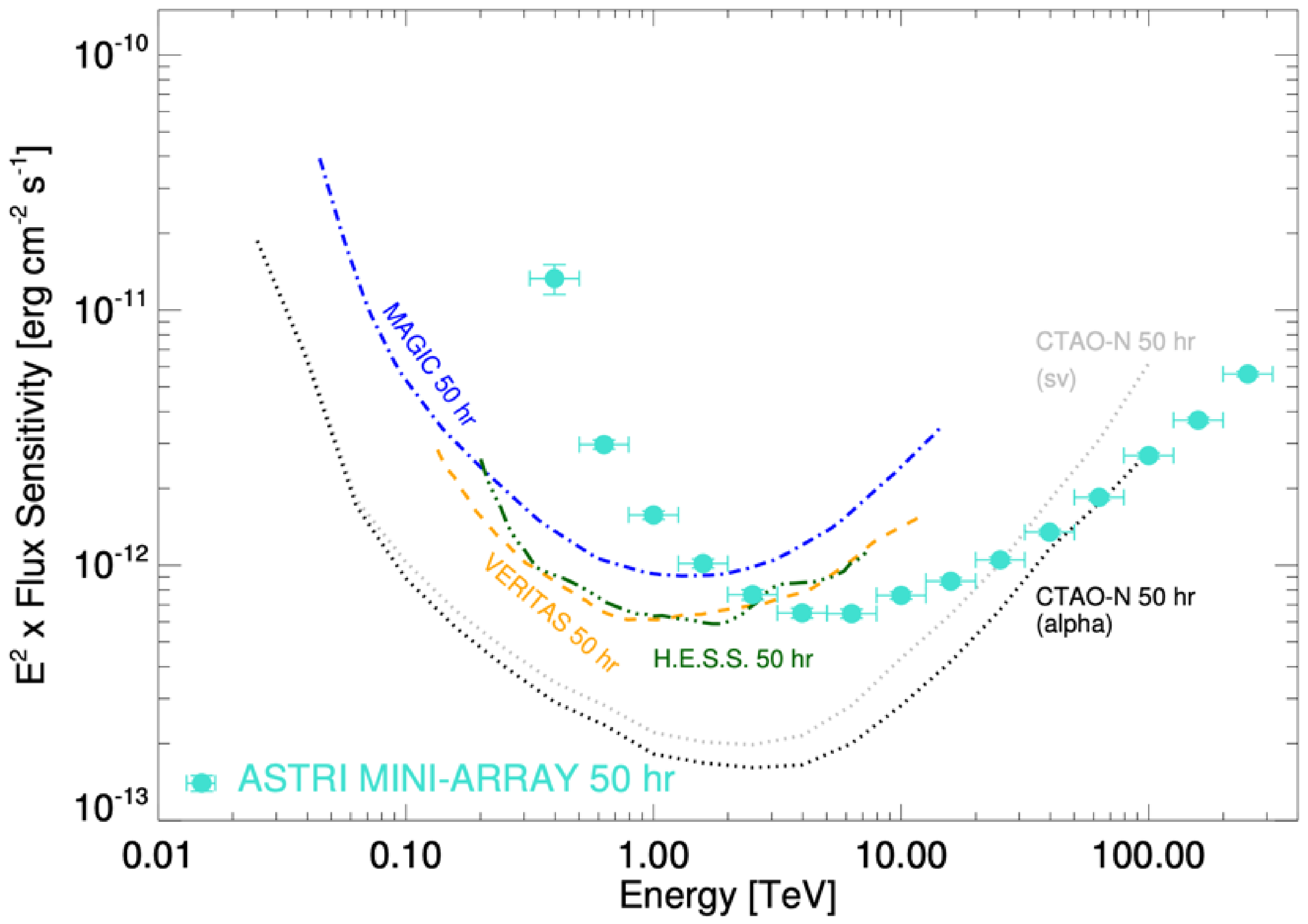
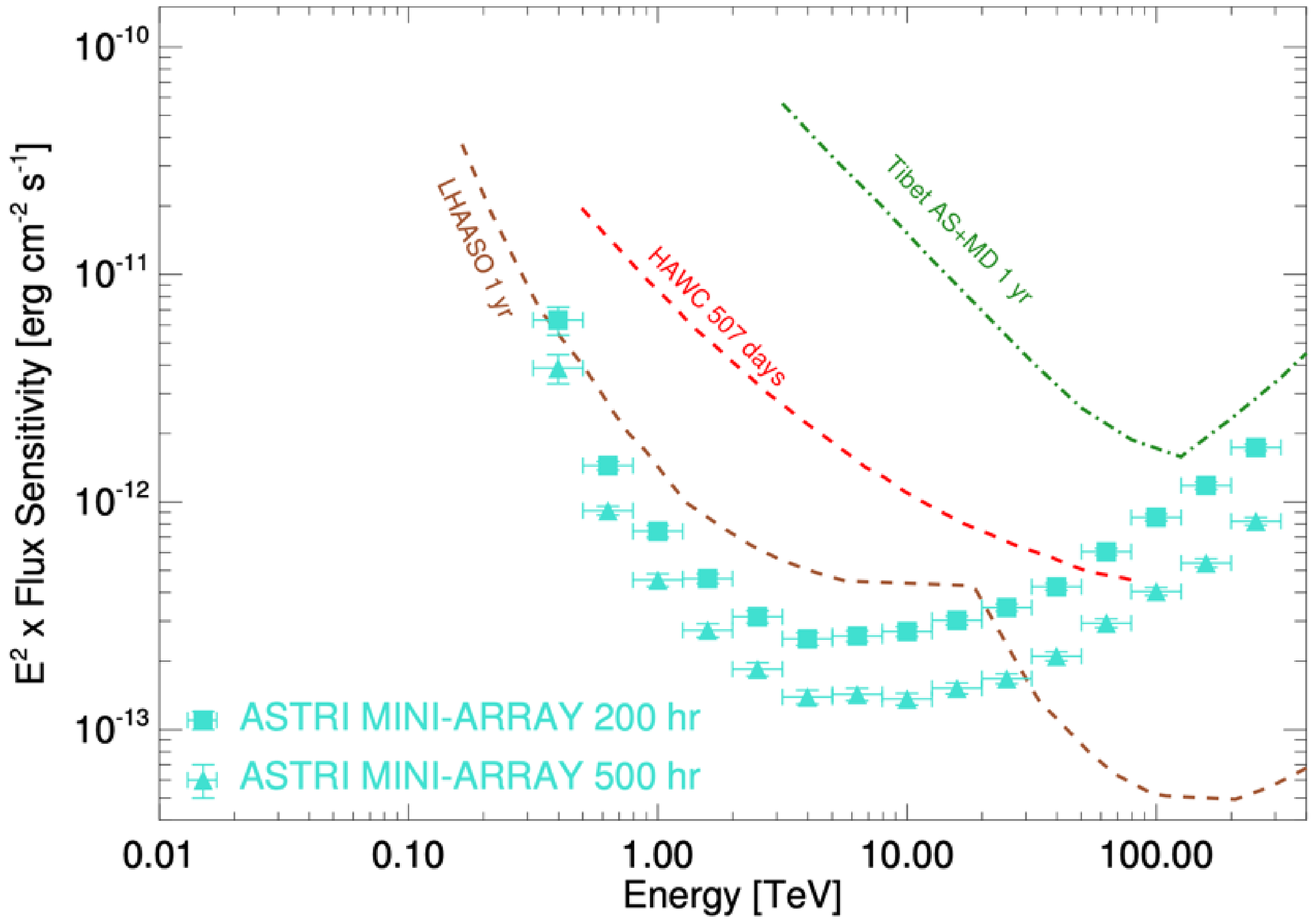
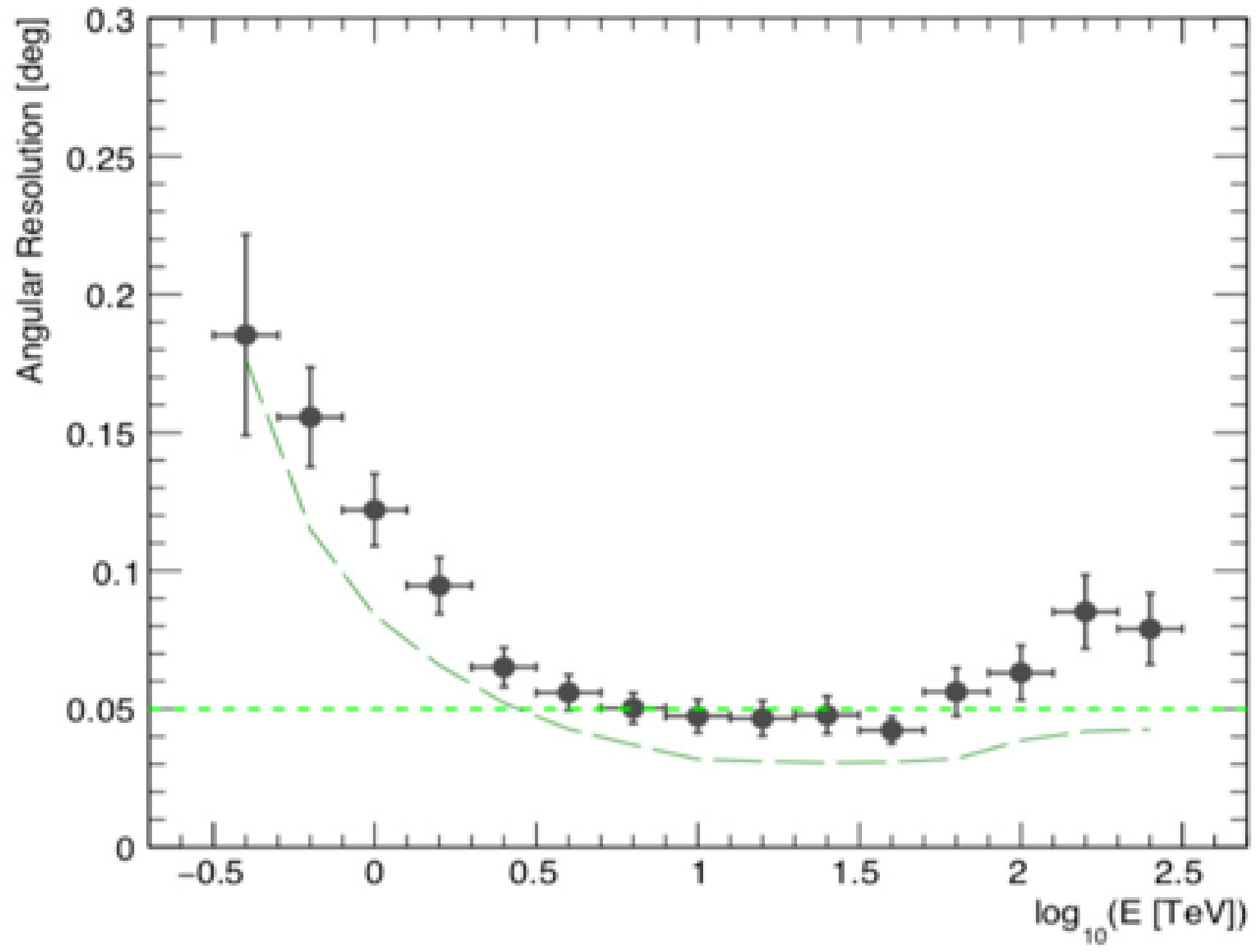
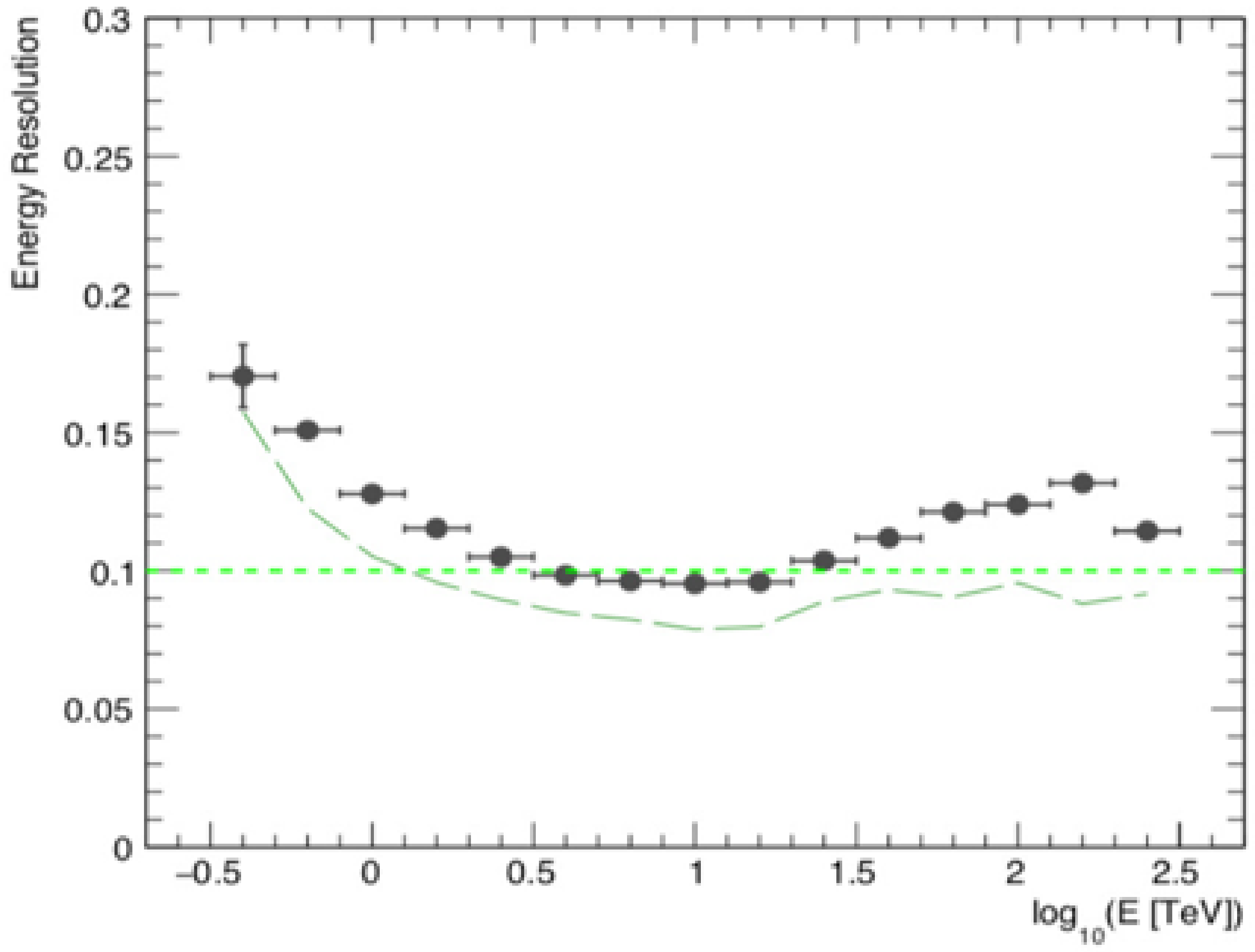
ASTRI Performance









C.Bigongiari, γ-2024, Sep 6th 2024

Largest IACT facility until CTAO MSTs/SSTs will be operational

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

Energy resolution: ~ 10° (E > a few TeV)
Spectral features

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

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

ASTRI Observing Strategy

The ASTRI Mini-Array will focus on gamma-ray sources at E >> 1 TeV

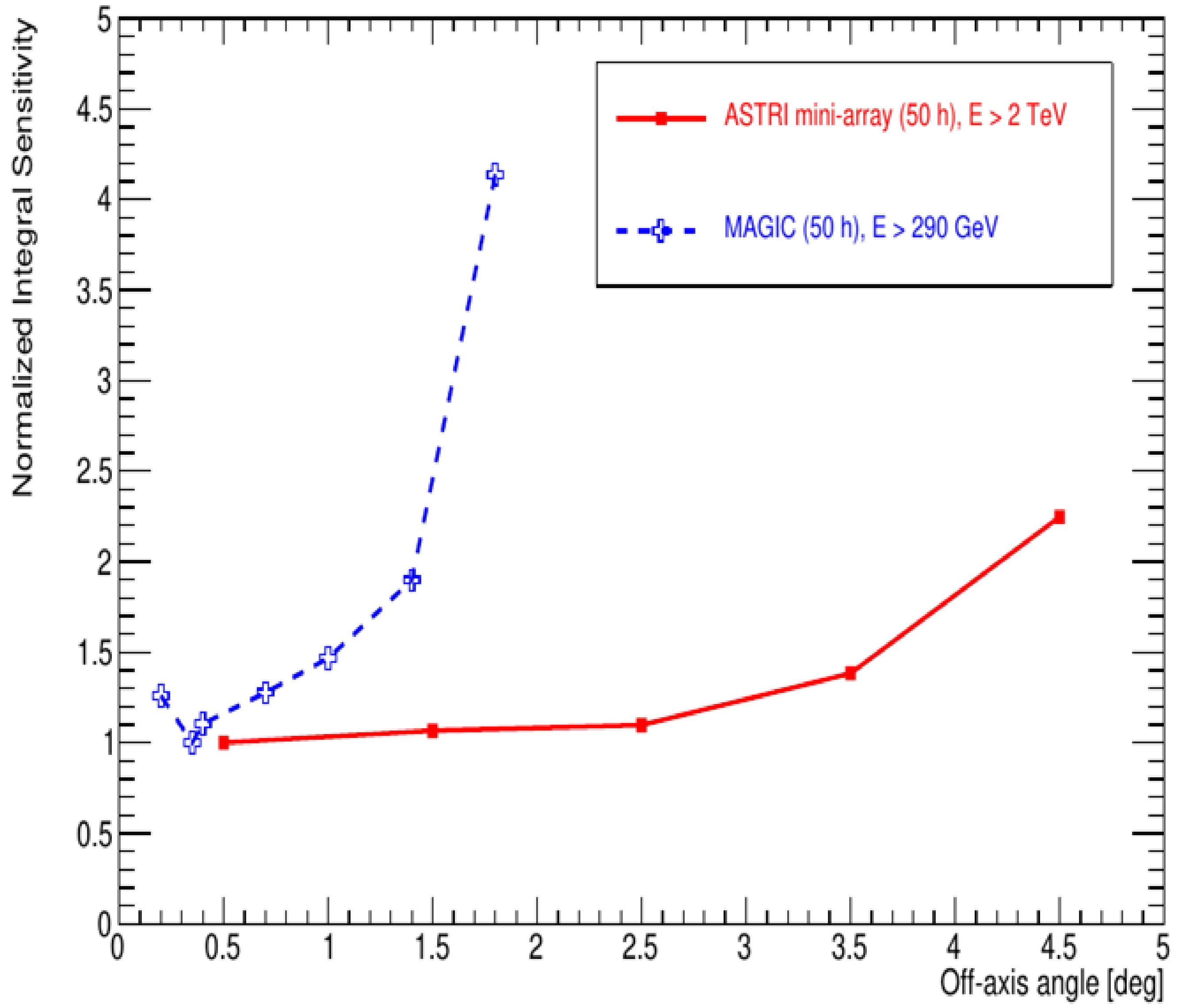
➔ **LOW FLUX** ➔ **Need for deep exposures**

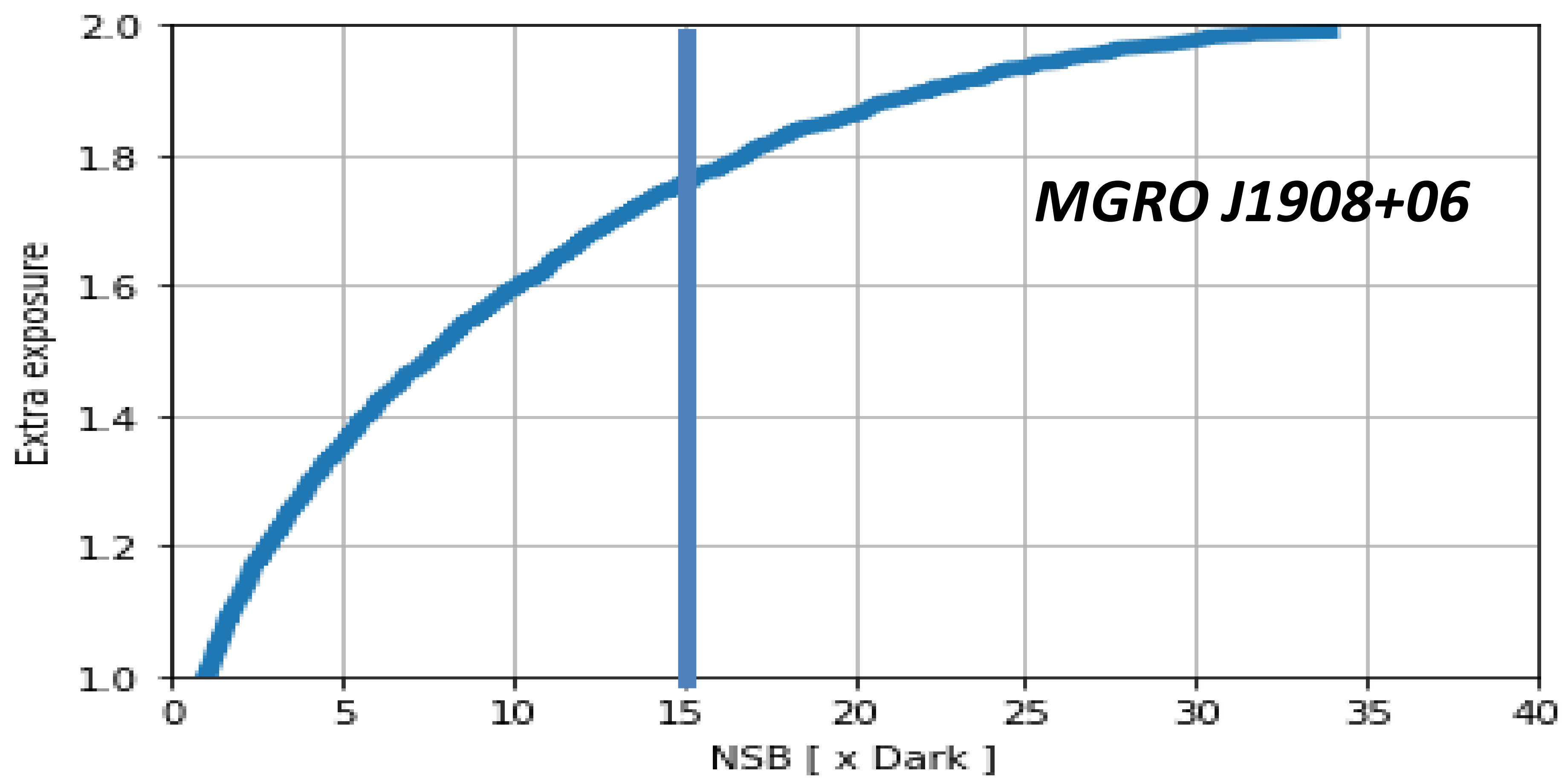
Strategy:

Focus on a few sky fields with long integration times

But with some aces up in our sleeve:

- Large FoV
  → Several sources in the FoV
- Observations with moonlight
  → Increases avail. time ~50-80%
- Large Z.A.
  → Increase A_{Eff} @ high energies





ASTRI Science pillars

ASTRI Mini-Array

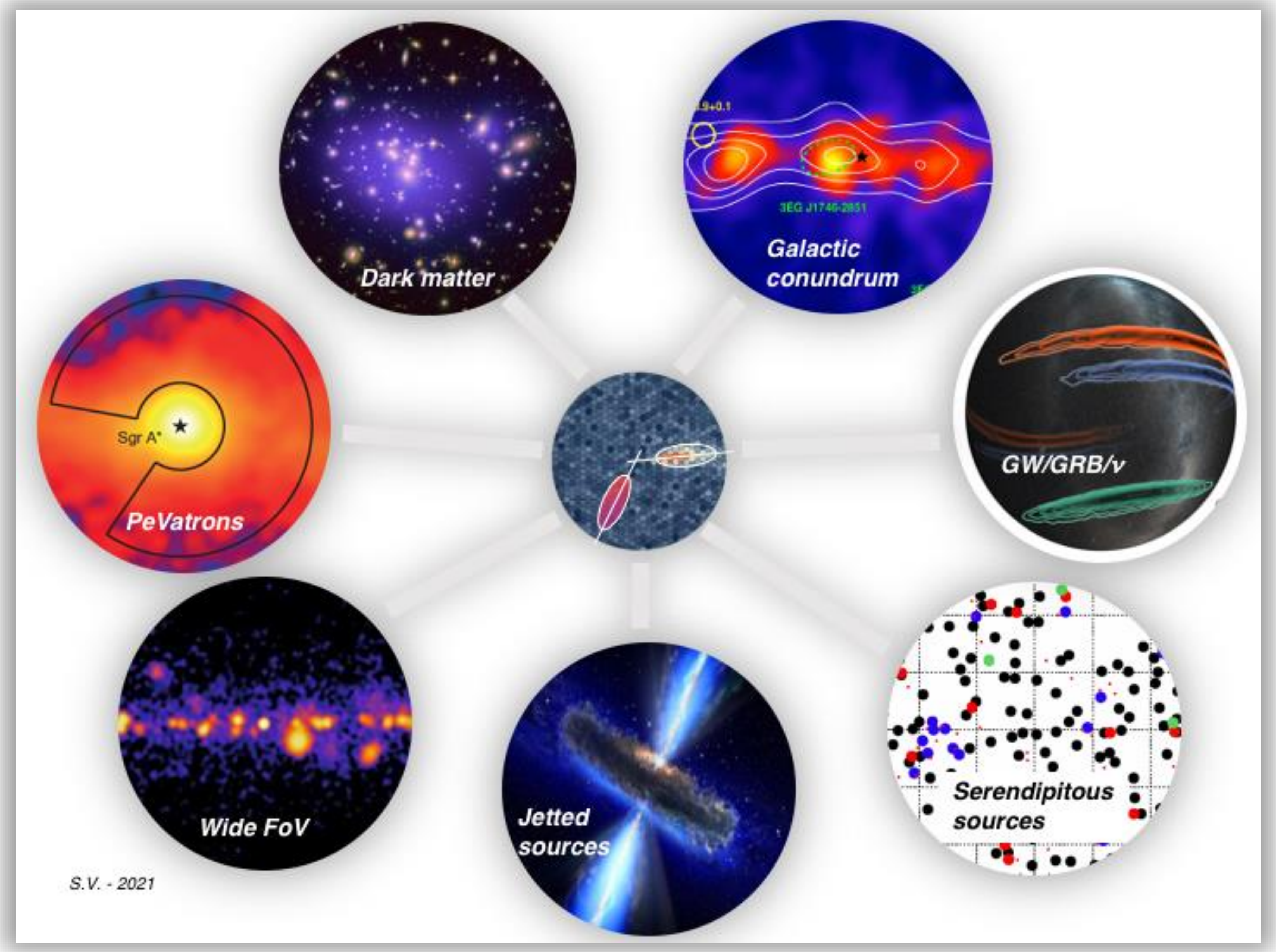
First four years specific science topics → robust answers to a few **well-determined open questions**

Pillar 1 – The origin of cosmic rays

The quest for PeVatrons
Particle escape and propagation
High energy emission from Pulsar Wind Nebulae
Ultra High Energy Cosmic Rays from Starburst Galaxies

Pillar 2 – Cosmology and Fundamental Physics

TeV observations and constraints on the IR EBL
Probing intergalactic magnetic fields
Blazars as probes for hadron beams
Tests on the existence of axion-like particles
Lorentz Invariance violation studies
Indirect dark matter searches



ASTRI first targets

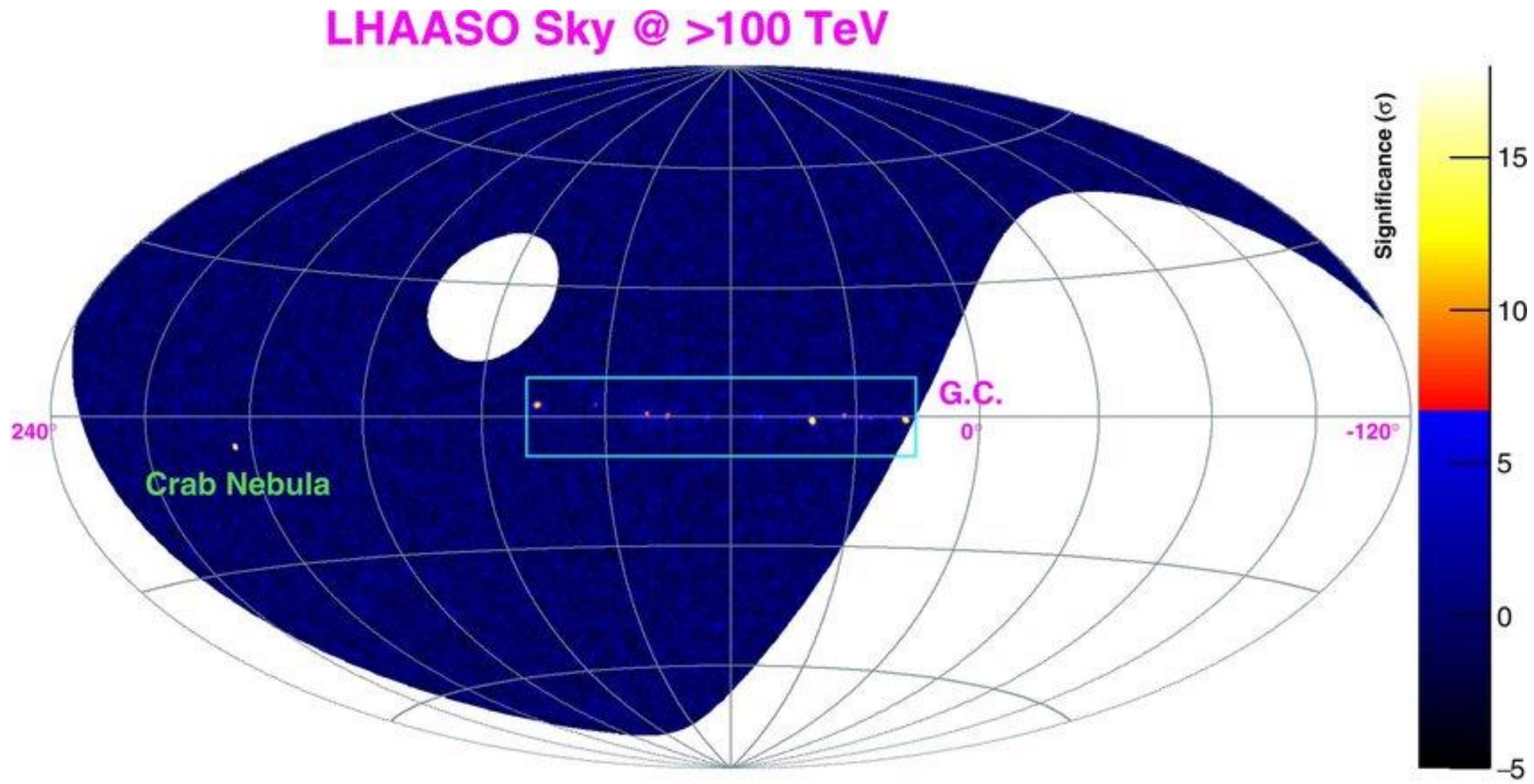
One of the outcomes of the work done for the ASTRI Science Papers shown before is a list of targets that will be observed in the first 4 years of data-taking and the amount of time that we need to dedicate to each of them

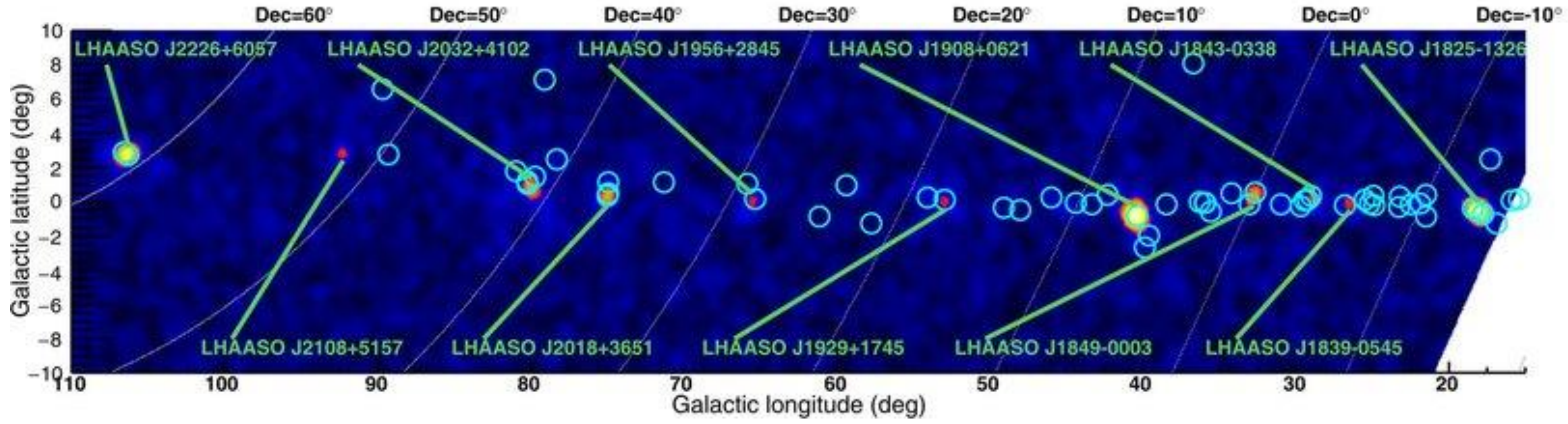
This list is going to be updated considering impressive LHAASO results

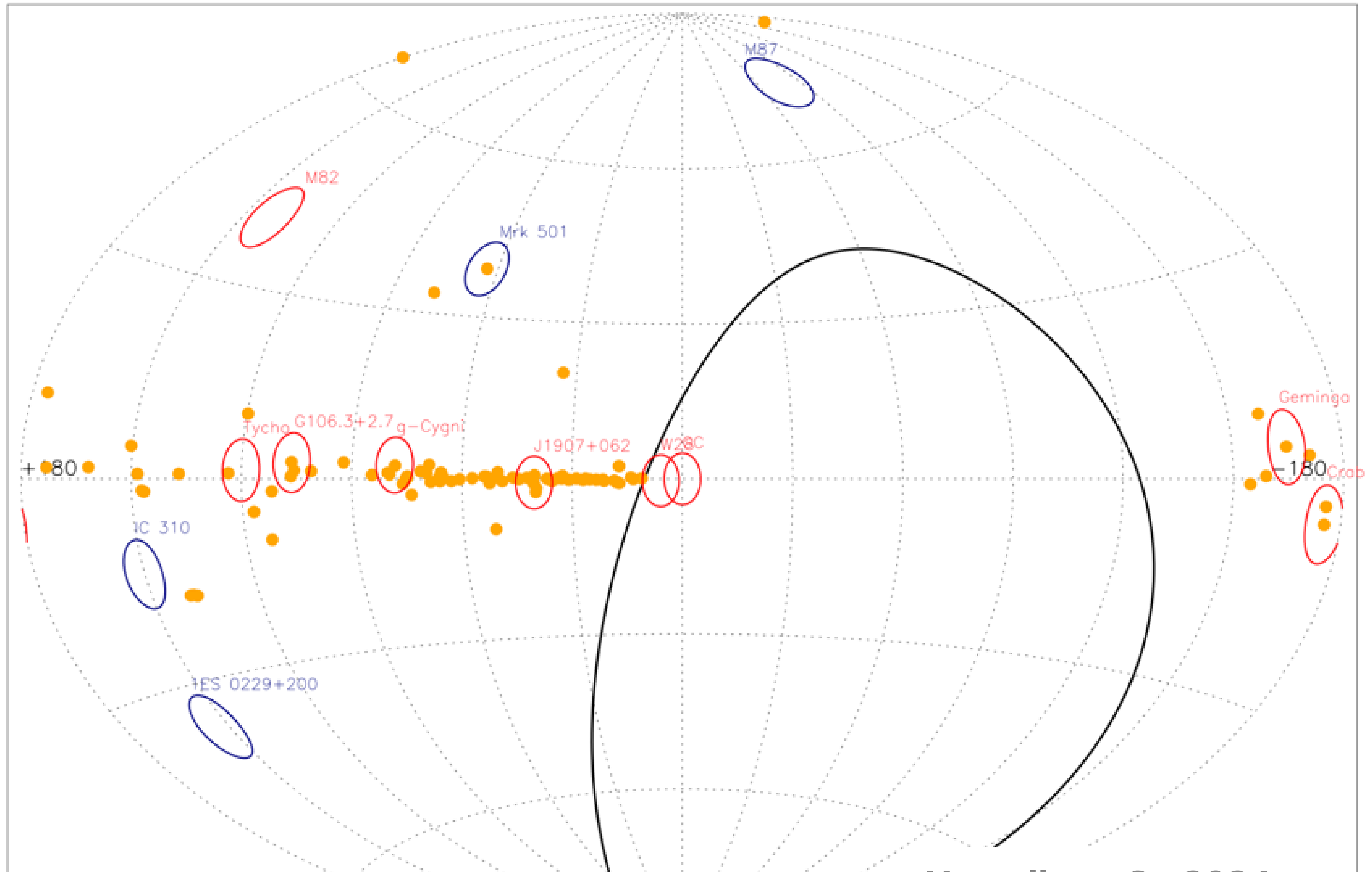
		Source		Type		Needed exposure [hours]
Pillar 1	PeVatrons	Tycho Snr		SNR		400
		Galactic Center		Diffuse		260
		VER J1907		SNR+PWN		500
		G106.3+2.7		SNR		200
	CRs propagation	γ-Cygni		SNR		500
		W28		SNR/MC		500
		M82		Starburst		400
	Pulsar Wind Nebulae	Crab		PWN		300
		Geminga		PWN		500
Pillar 2		IC 310		Radio galalaxy		10-500
		M87		Radio galalaxy		10-500
		Mkn 501		Blazar		5-500
		1ES 0229+200		Blazar		200-500

ASTRI follow up of LHAASO Sources

Mini-Array







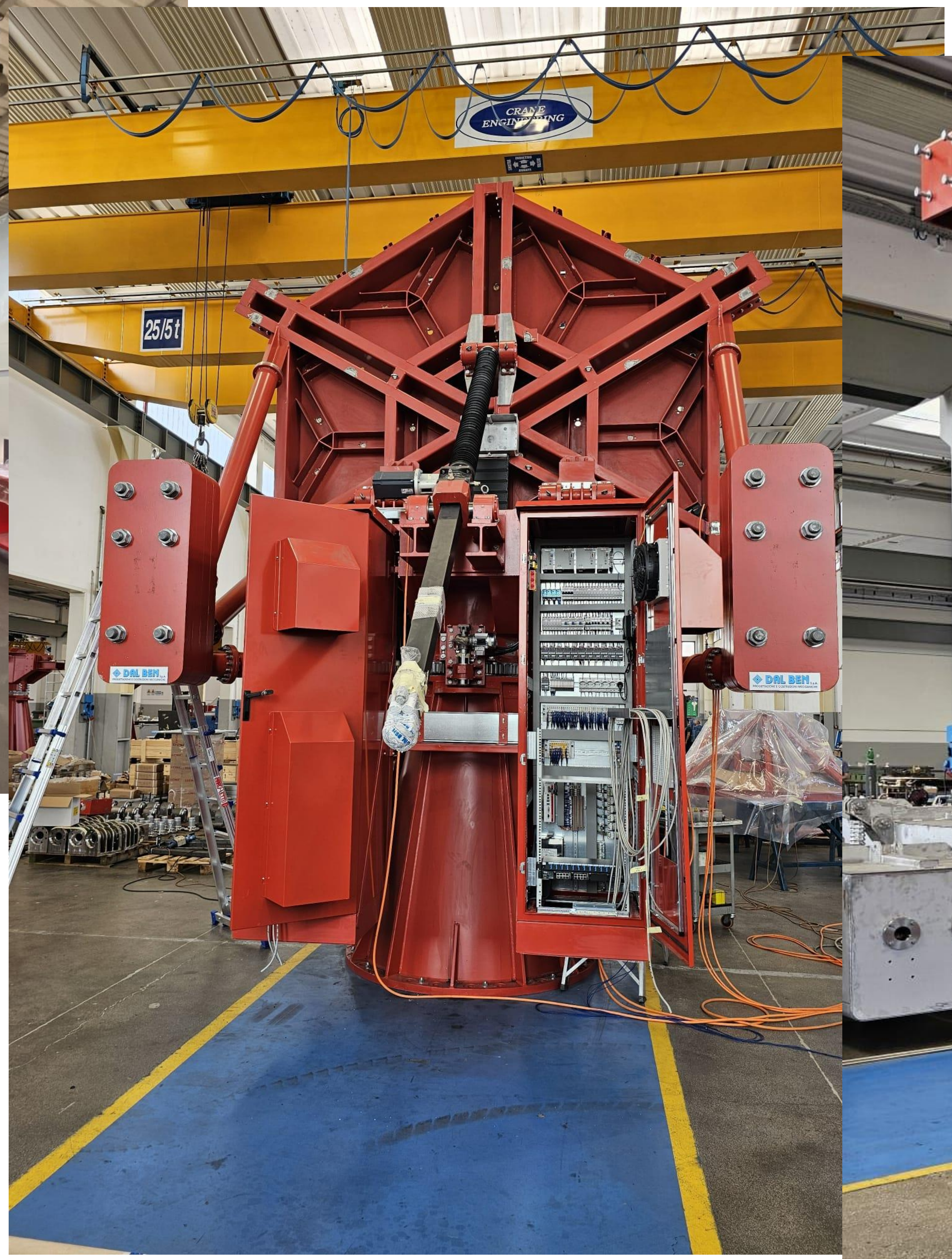
Vercellone S., 2024, Universe 2024, 10(2), 94

Many of the LHAASO sources are still unidentified

ASTRI can play a relevant role due to:

- **its wide field of view**
- **excellent angular resolution**

The remaining 8 telescope structure are on their way

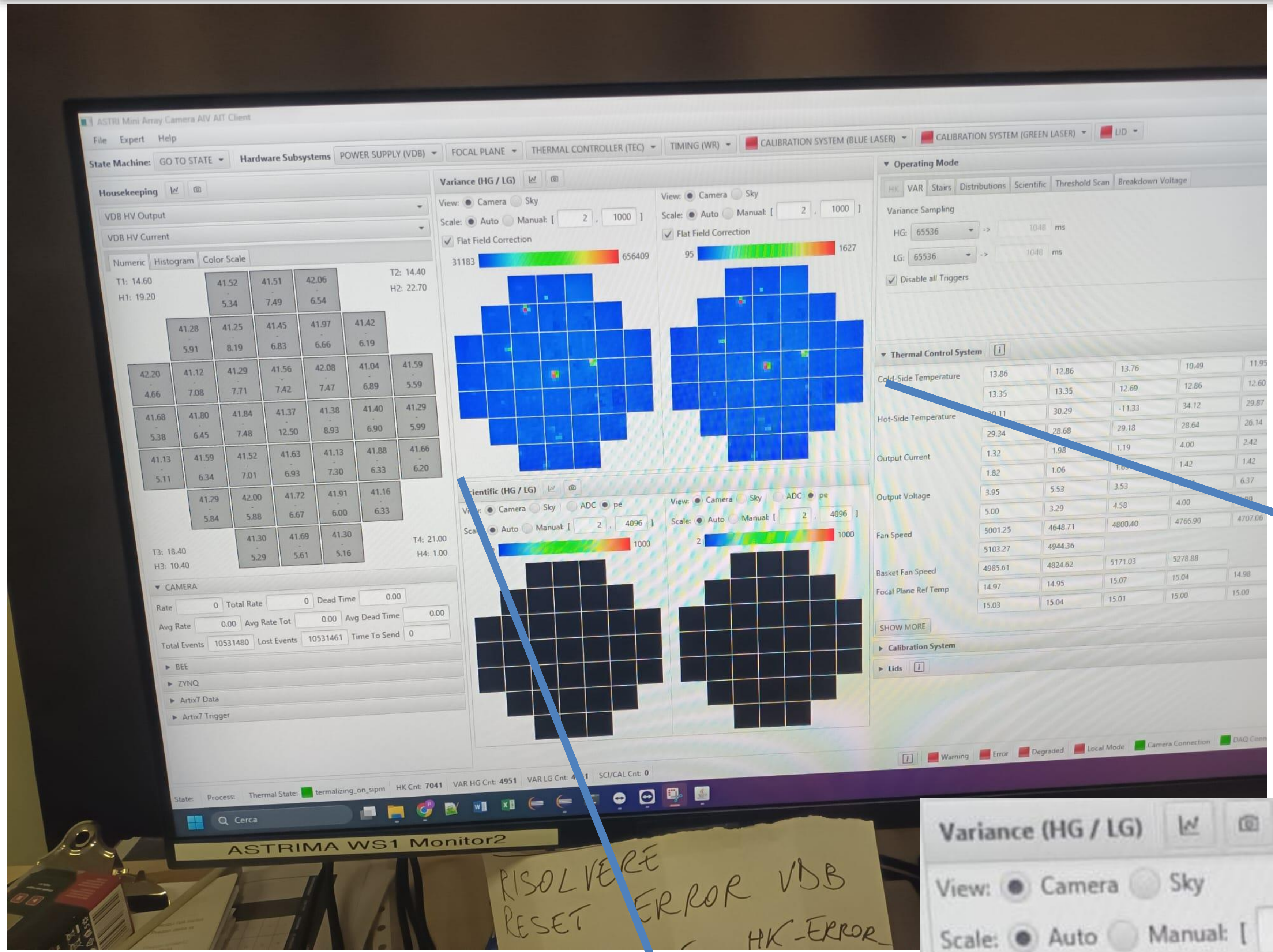


Second telescope structure
to be delivered in Oct 2024

Two cameras in production

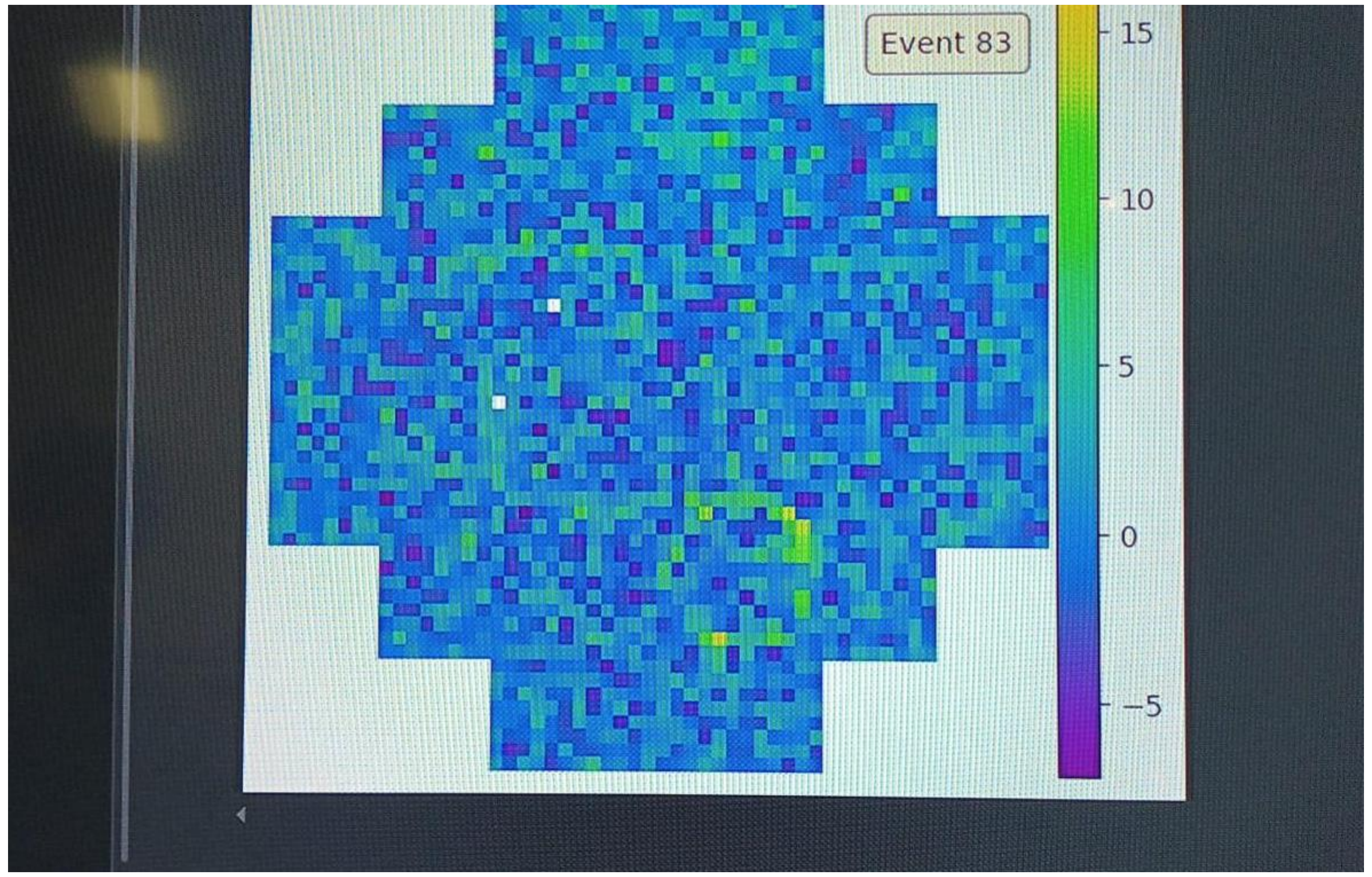
CREDITS: Dal Ben SpA and EIE GROUP SRL

ASTRI latest achievements

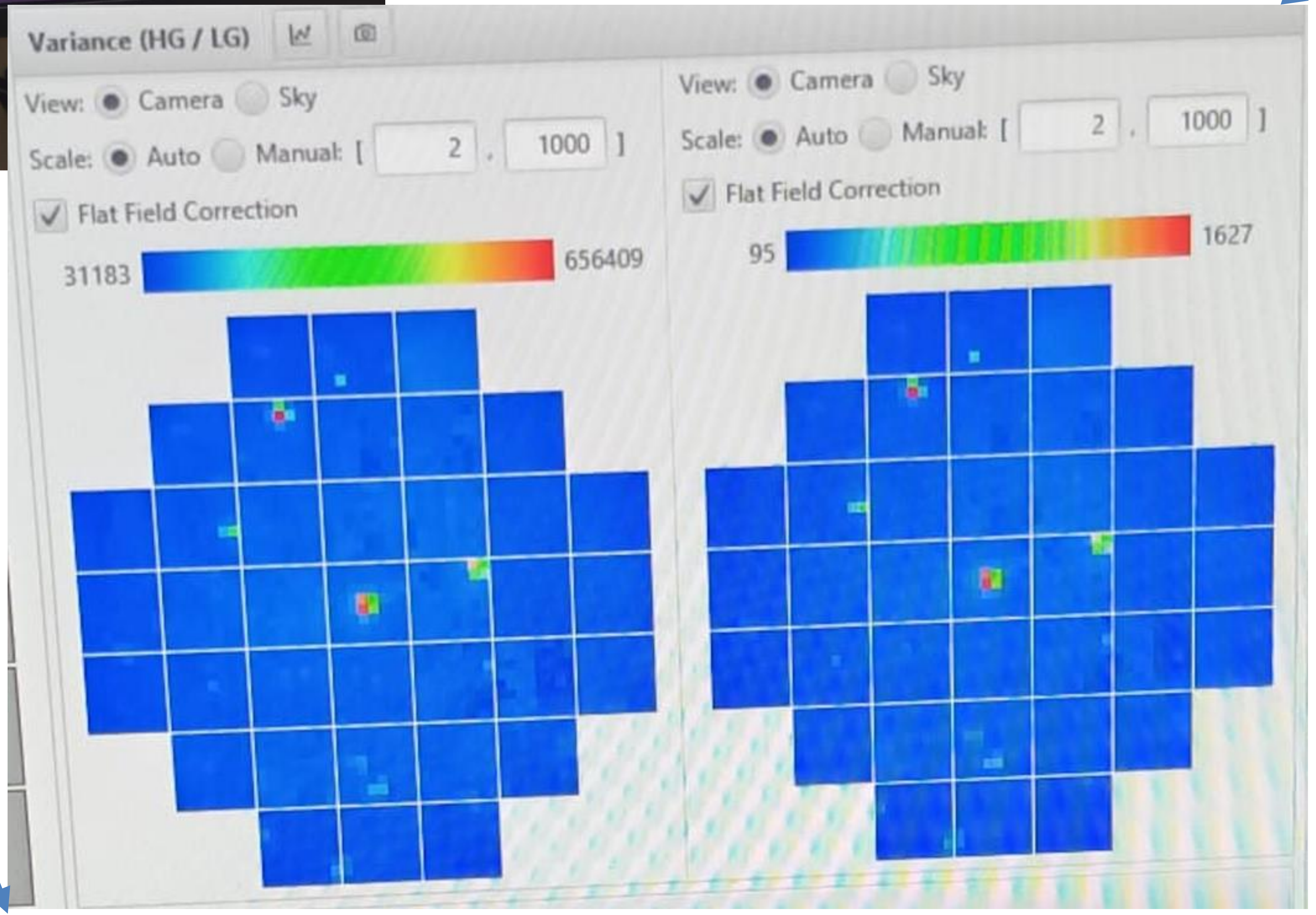


ASTRI-1 first light !

Sep 2nd, 2024

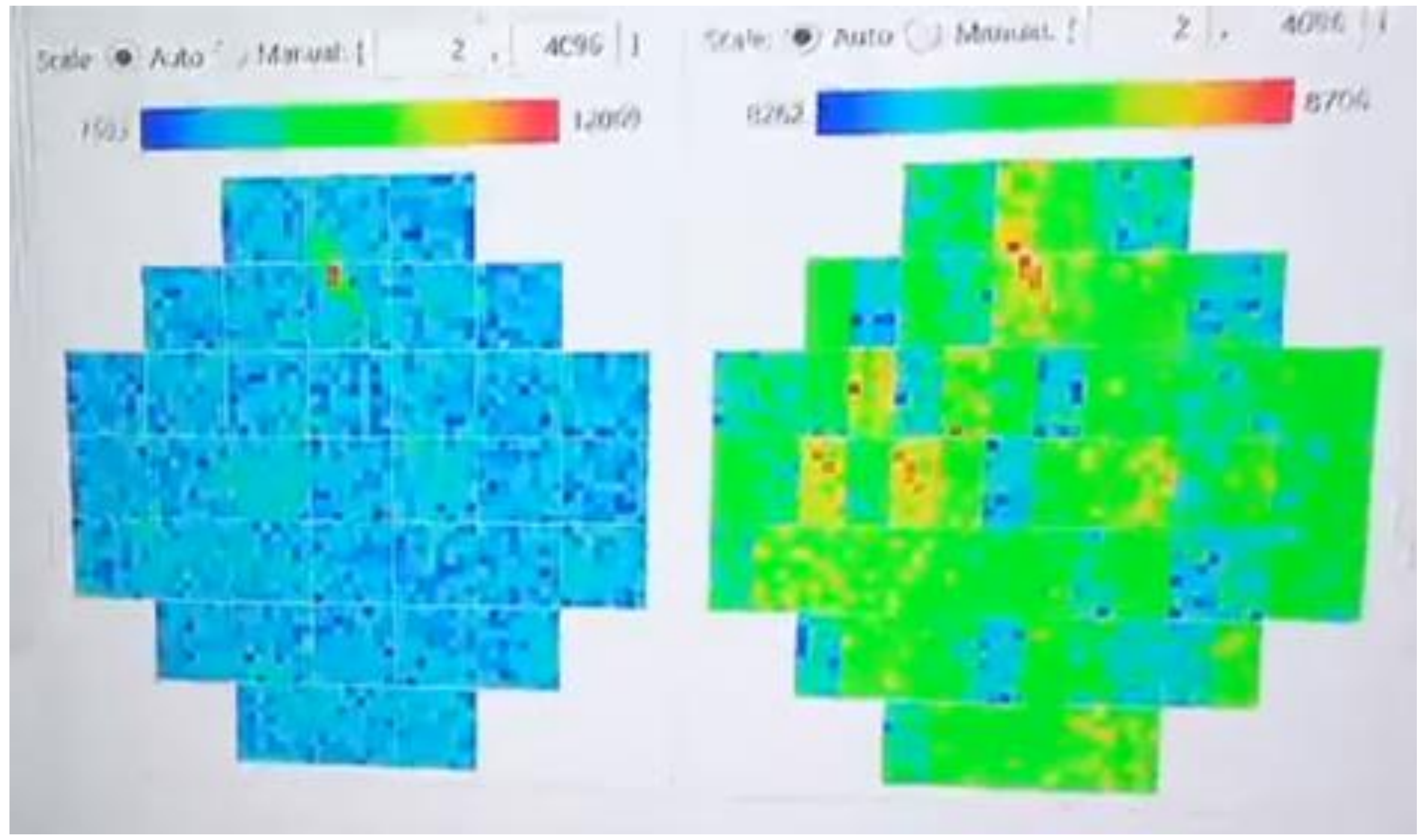


First muon ring



Some stars clearly visible in the variance monitor, both in the High and Low Gain channels

See A.Compagnino, S.Lombardi, A.Pagliaro, A.LaBarbera, P.G.Bruno, D.Mollica, V.LaParola and T.Mineo talks/posters for recent results.

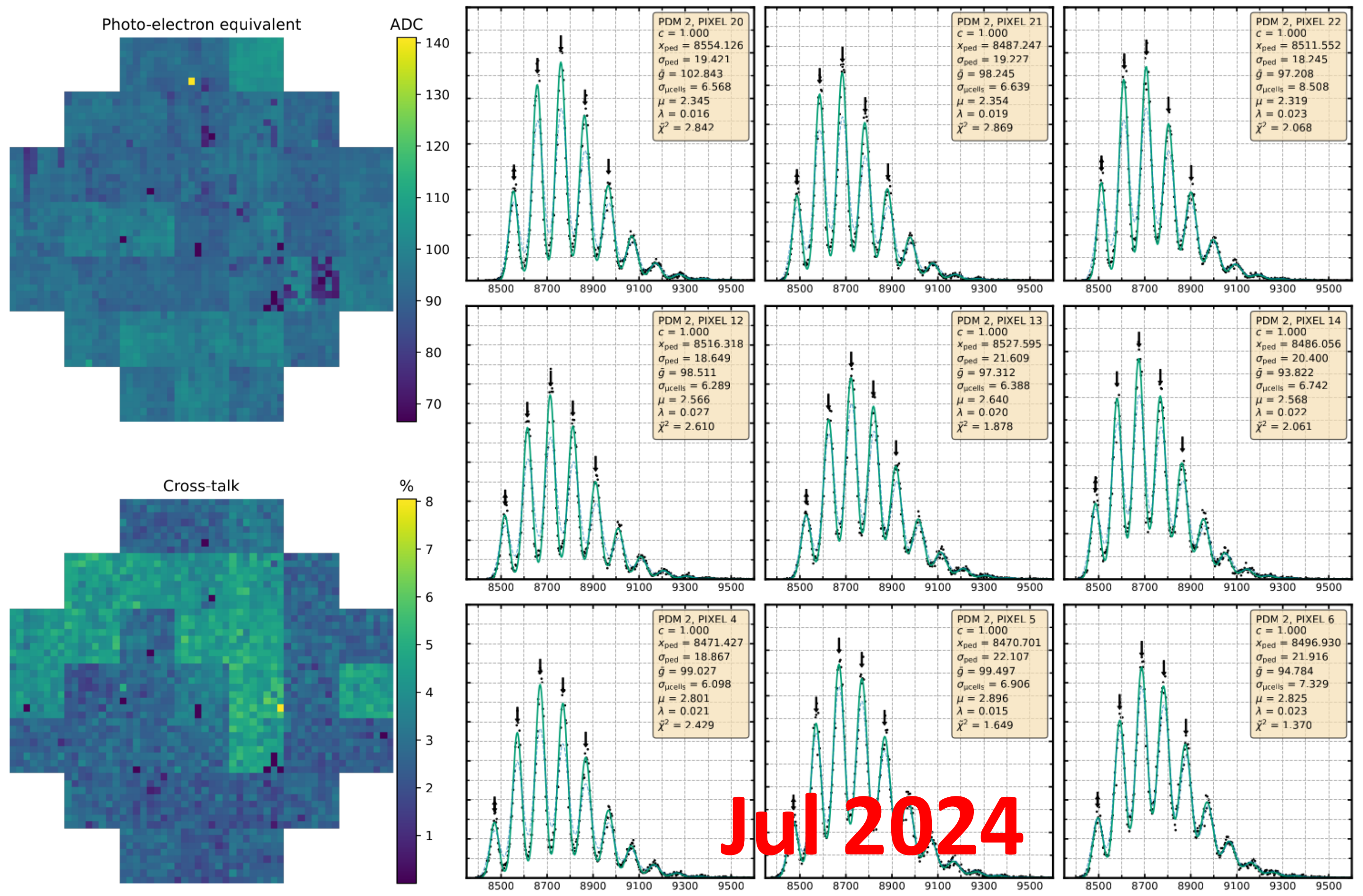


First cosmic-ray event

C.Bigongiari, ɣ-2024, Sep 6th 2024

ASTRI Timeline

- Site infrastructure completed
- First telescope ASTRI-1 accepted
- Engineering camera on ASTRI-1 delivered at end of July 2024
- On site ICT will be delivered mid-October 2024
- Second telescope will be delivered in October 2024
- First scientific/technical observation October 2024
- Two more cameras completed by spring of 2025
- Ready for commissioning late summer 2025
- Scientific operations will start with a partial array in 2025 (3 telescopes)
- All telescopes completed in 2026



Eager to collaborate with existing and future gamma-ray facilities!
(MAGIC, HESS, VERITAS, HAWC, LHAASO/LACT, CTAO, SWGO…)

Nanni's fundamental contribution

ASTRI Mini-Array

Mem. S.A.It. Vol. 75, 70

Memorie della

Ghe minga ASTRI?

The ASTRI mini-array wide-field gamma-ray experiment

G. Pareschi,
on behalf of the ASTRI collaboration

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Received: 9 July 2024; Accepted: Day Month Year

Abstract. Over a decade ago, the ASTRI program was initiated with the main purpose of developing compact wide-field IACT telescopes based on mirrors realized with the cold-shaping glass replication technology invented by INAF. These telescopes were designed to serve as a model for the array of small-sized telescopes (SSTs) that would eventually be deployed at the Cherenkov Telescope Array Observatory (CTAO) southern site in Paranal, Chile. Nanni Bignami was the brain behind the ASTRI program. He not only came up with the idea but also coined its acronym, which stands for *Astrofisica con Specchi a Tecnologia Replicante Italiana* (meaning: Astrophysics with Mirrors via Italian Replication Technology). Later, when he became the INAF President, he provided strong support to the project that is mainly funded by the Italian government and, later on, received further support from various international partners (including the University of São Paulo/FAPESP, North-West University/South Africa, IAC, Fundacion Galileo Galilei, and University of Geneva). The program's initial noteworthy accomplishment was the implementation of the end-to-end ASTRI-Horn prototype and its installation at the INAF astronomical site of Serra La Nave (Sicily, on the Etna volcano slope). The prototype included a novel compact camera based on SiPM sensors. It proved the dual-mirror polynomial optical configuration to be an aplanatic telescope system according to the design and successfully detected the Crab Nebula in gamma rays. The next step was the implementation of the ASTRI mini-array that comprises nine telescopes and is being implemented in Tenerife to study the gamma-ray sky in the energy band (1-100) TeV.

Key words. Gamma-ray astronomy – Cherenkov Telescopes – ASTRI mini-array

Thank you for your attention

Back-up

The Schwarzschild Aplanatic Telescope

Mini-Array

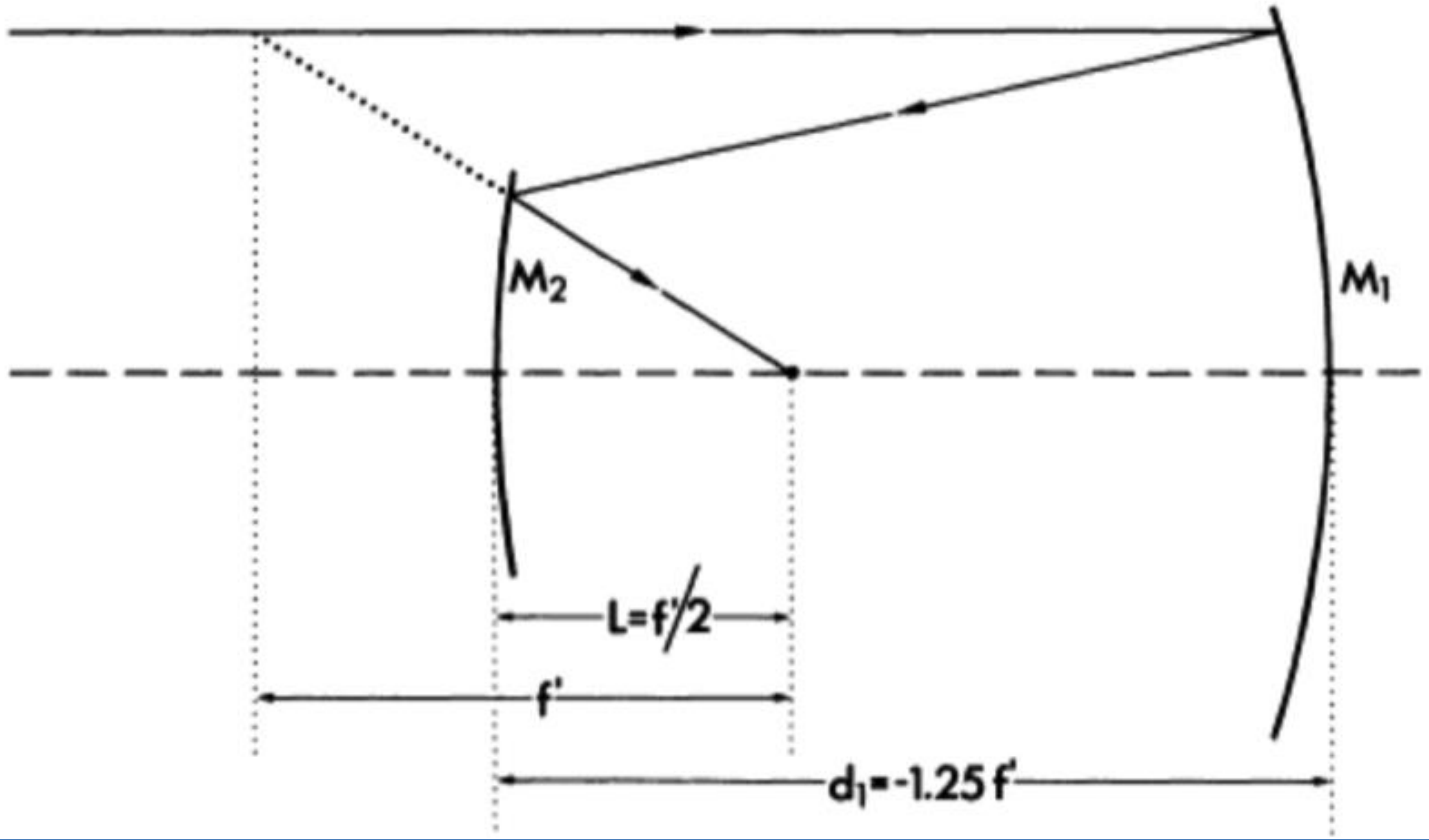
1905: Karl Schwarzschild solved the Seidel 's equations for **spherical** aberration and **coma** finding a relation between parameters capable to make a telescope **aplanatic**. *(Couder 1926 ➔ also correction of **astigmatism** with curved focal plane)*

Vladimir Vassiliev, UCLA

"For any geometry, 2 aspheric mirrors allow the correction of SI and SII to give an aplanatic telescope"

Schwarzschild telescope

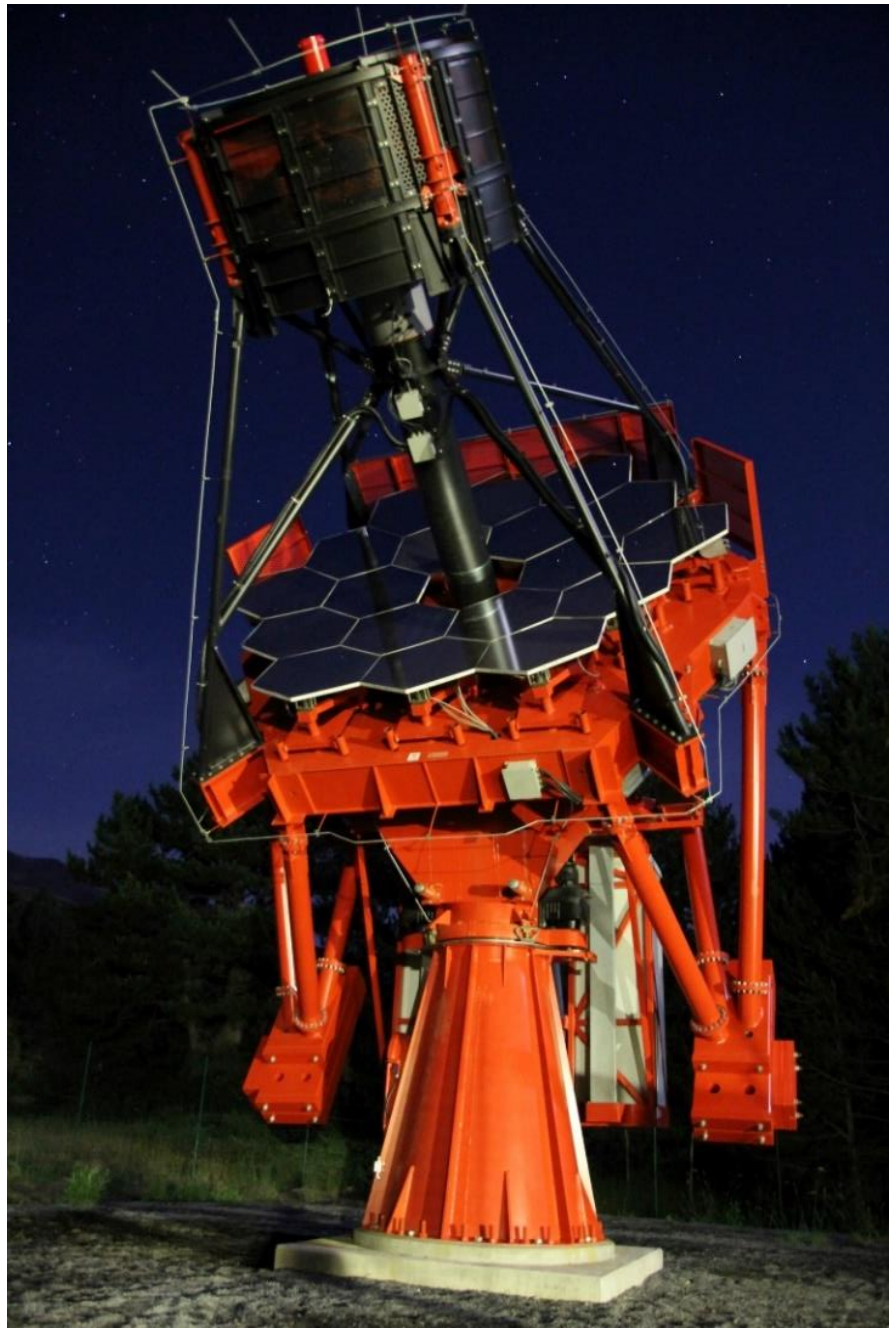
KS: f/3.0
b_{S1}= -13.5 (Hyperbola)
b_{S2}= 1.963 (Spheroid)
FoV:2.8 deg
RMS_{edge}~12''



Technology challenge: Aspherical Optics manufacturing + large secondary mirror

The ASTRI-Horn prototype

Mini-Array



ASTRI-Horn "Mission"

- Demonstrator to validate the novel technology
- Training facility for telescope and maintenance operations.
- Test bench for the implementation of new HW and SW.
- End-to-end approach: telescope validated through astrophysical Cherenkov observations in an astronomical site

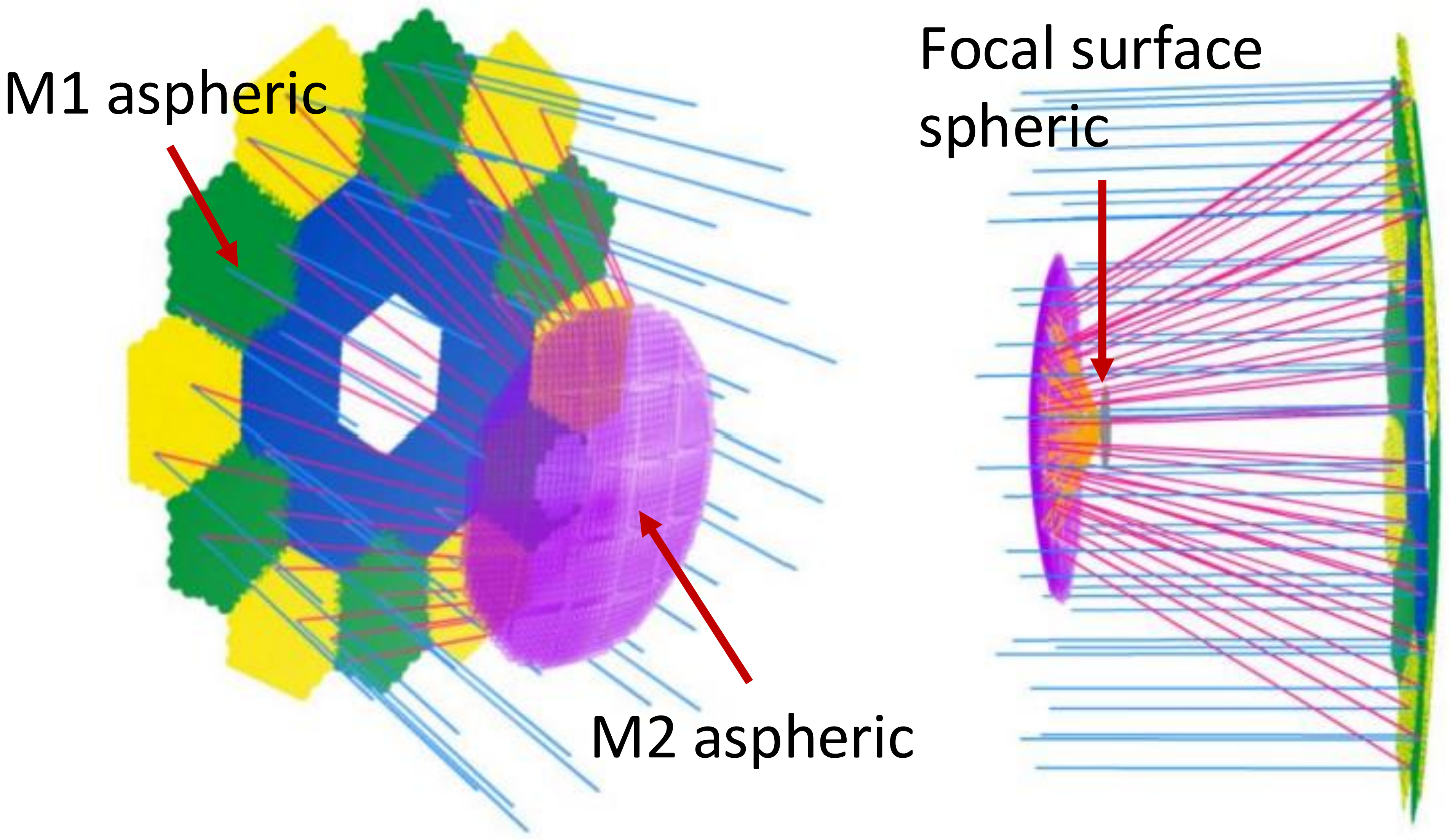
ASTRI-Horn Timeline

- September 2014: Inauguration of the prototype @ INAF-Catania mountain station in Serra La Nave placed at 1725 meters on the Etna volcano (Sicily)
- October 2016: Validation of the Schwarzschild-Couder concept
- May 2017: First Cherenkov light with the ASTRI camera
- November 2018: Dedication of ASTRI prototype telescope to Guido Horn D'Arturo a precursor of the technique of segmented astronomical mirrors
- December 2018: Detection of Crab Nebula

Optical Design

Most of the technological innovations of the ASTRI Mini-Array telescopes derive from the selected optical design. Some have an impact only on the scientific performance, while others simplify the complexity of the system.

The design is based on modified a Schwarzschild–Couder configuration where a polynomial optimization leads to a two-mirror design free of aberrations and characterized by a large FoV, small plate scale, low vignetting, and isochrony.



Parameter	Value
M1(diameter) – segmented – 3 rings of 6 panels	4300 mm
M2 (diameter) – monolithic	1800 mm
Distance M1-M2	3108.4 mm
Distance M2-focal surface	519.6 mm
Effective focal length	2154 mm
F-number	0.5
Plate scale	37.64 mm

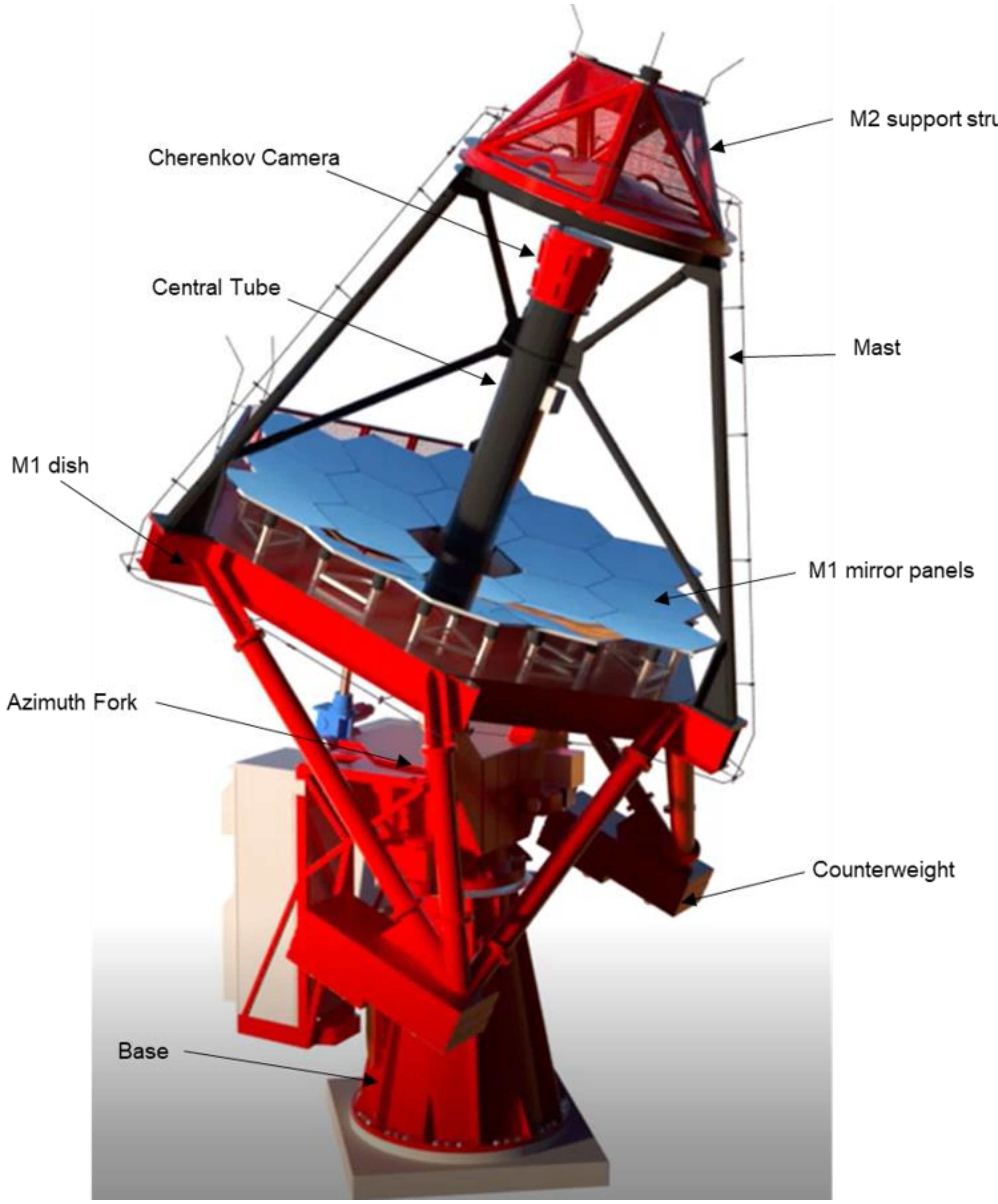
Advantages

- Compact telescope structure
- Compact camera
- Large field of view
- Better resolution on the FoV

Disadvantages

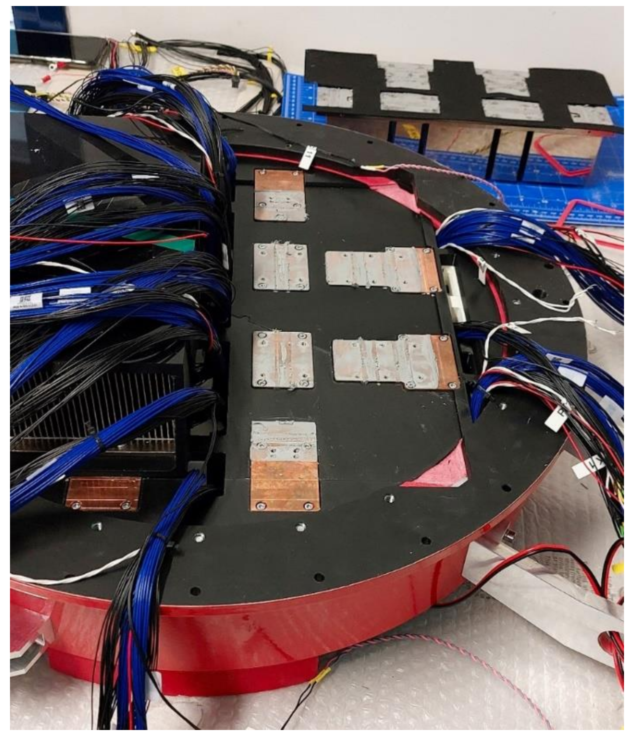
- Double reflection
- M2 vignetting

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

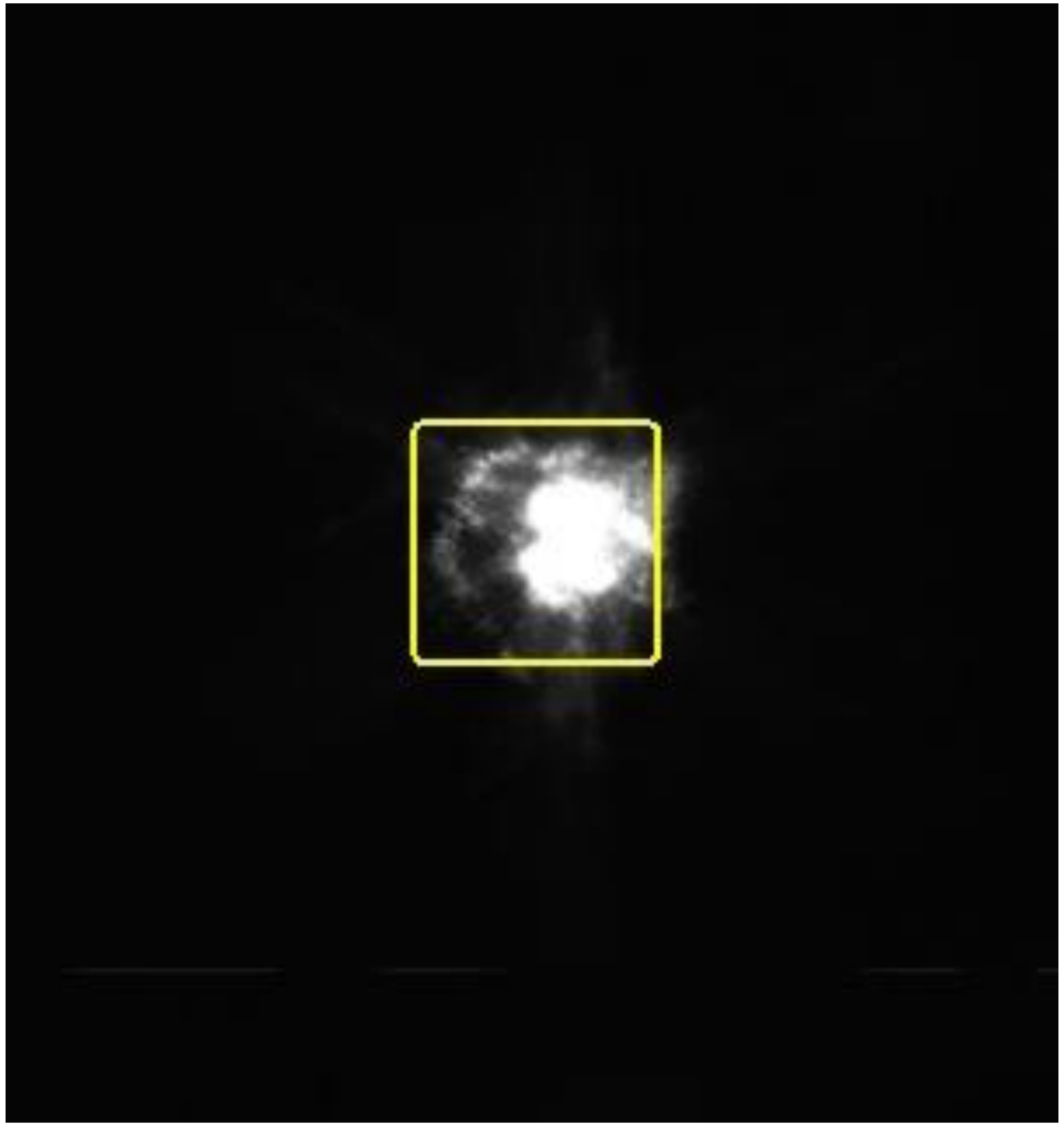
Cherenkov Camera details

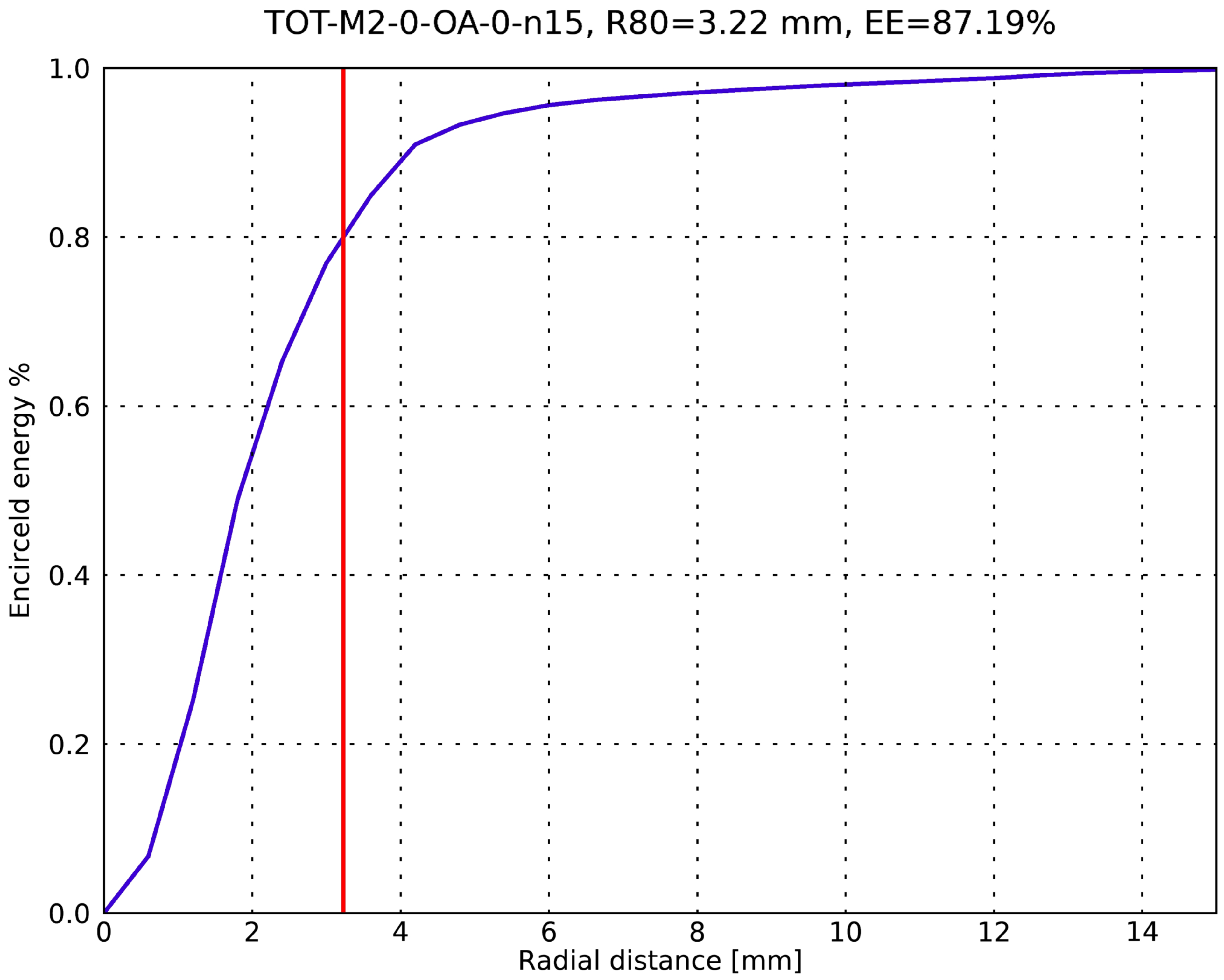


- **SiPM:**
- Linear dimensions of the PSF (D80) are about 7 mm, which fit the size of the Silicon PhotoMultipliers detectors
- Photon Detection Efficiency up to 50%, bias voltage down to 30V, excellent single photon resolution, not sensitive to magnetic fields, not damaged by a high level of light exposure.
- 7×7 mm pixel size and no coating → enhanced PDE, Dark Count Rate and Optical Crosstalk within the requirements
- Improvement of duty cycle of the system allowing safe and effective operation with any level of Moon condition
- **Front End Electronics:**
- Based on CITIROC 1A ASIC developed by Weeroc in collaboration with INAF
- Peak detection technique → store the signal proportional to charge injected in the pixel and time of arrival → low power and low data rate production
- Variance technique → signal proportional to photon flux → NSB measurements & camera astrometric calibration
- **Array Stereo trigger:**
- Data produced by a telescope 50 GByte/hour → all data transfer to offsite data centre in 15 min → No need for onsite pre-processing, data storage and array stereo trigger → simplified onsite ICT and operational software
- **Thermal control system:**
- FEE low power consumption
- Focal plane @ 15±2 C for SiPM gain stabilization
- TCS based on TECs, heat pipes and fun
- Low power and low maintenance (respect to chillers)
- **NSB filter:**
- stack of windows with multilayer coating to cut Night Sky Background (above 600 nm)

Mirrors alignment: preliminary results

Mini-Array

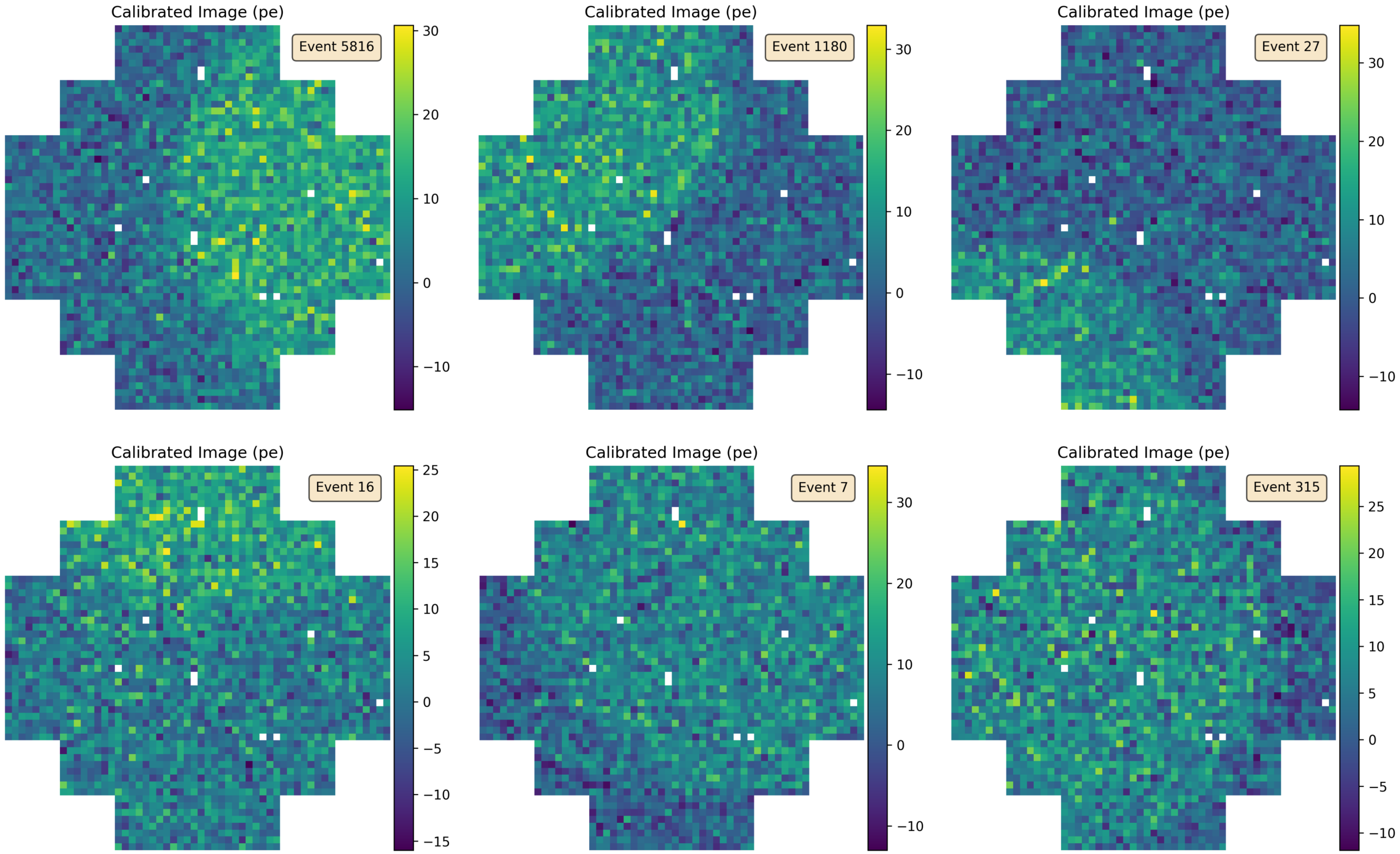




See A. Ghedina, SPIE Astronomical Telescopes + Instrumentation, 18/07/2024

On-ground camera tests

- Detection of on-ground Cherenkov light from extensive air showers



ASTRI Camera window

- Detection of not internally reflected Cherenkov light induced by muons passing through the camera protective window