ASTRI Mini-Array : CTAO Precursor

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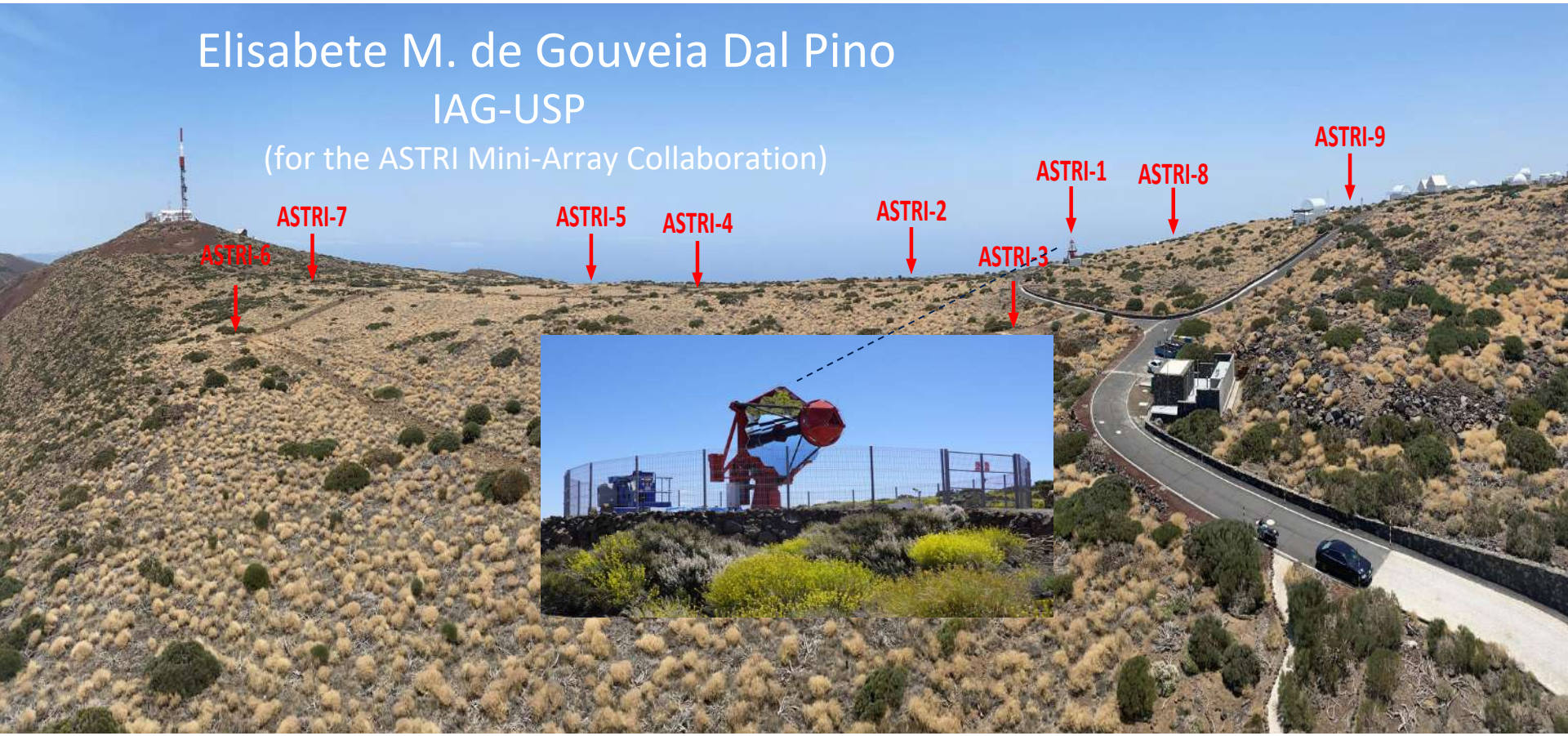
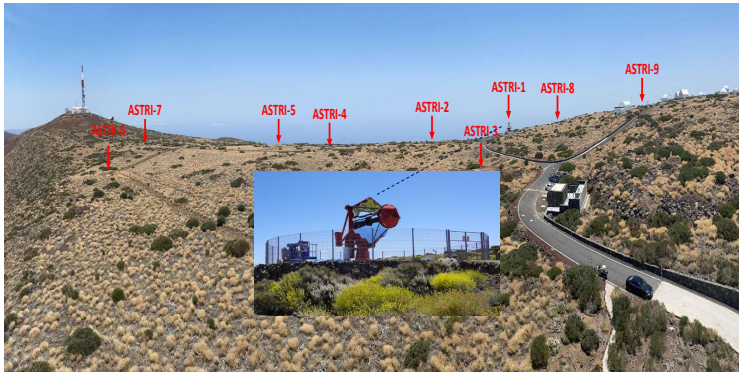
IAG-USP
(for the ASTRI Mini-Array Collaboration)



III LASF4RI for HECAP Symposium, August 29th, 2024

Universidade de São Paulo

Next generation of IACT arrays



ASTRI Mini-Array

- 9 telescopes at the Teide observatory (Canary islands)
- 4.3 m diameter
- Schwarschild-Couder modified design (2 mirrors)
- FoV: 10.5 deg
- 0.19 deg/pixel (SiPM based camera)

CTAO (south site)

- 53 telescopes in the Atacama desert
- 2 LST → 23 m diameter, 1M, FoV > 4.5º, PMT camera (INAF leadership, PNRR funds)
- 14 MST → 12 m diameter, 1M, FoV > 7º, PMT camera
- 37 SST → 4.3 m diameter, 2M, FoV > 9º, SiPM camera, (INAF leadership, PNRR funds)
- CTAO north site → 4 LST and 9 MST

LACT (Large Array of Cherenkov Telescopes)

- 32 telescopes at LHAASO site
- 6m diameter
- Davis-Cotton design (one mirror)
- FoV: 8 deg
- 0.19 deg/pixel (SiPM based camera)

Mini-Array

A CTA Precursor @ Tenerife

9 SST-2M telescopes:
INAF (Italy) + Brazil, South Africa, Spain, Switzerland

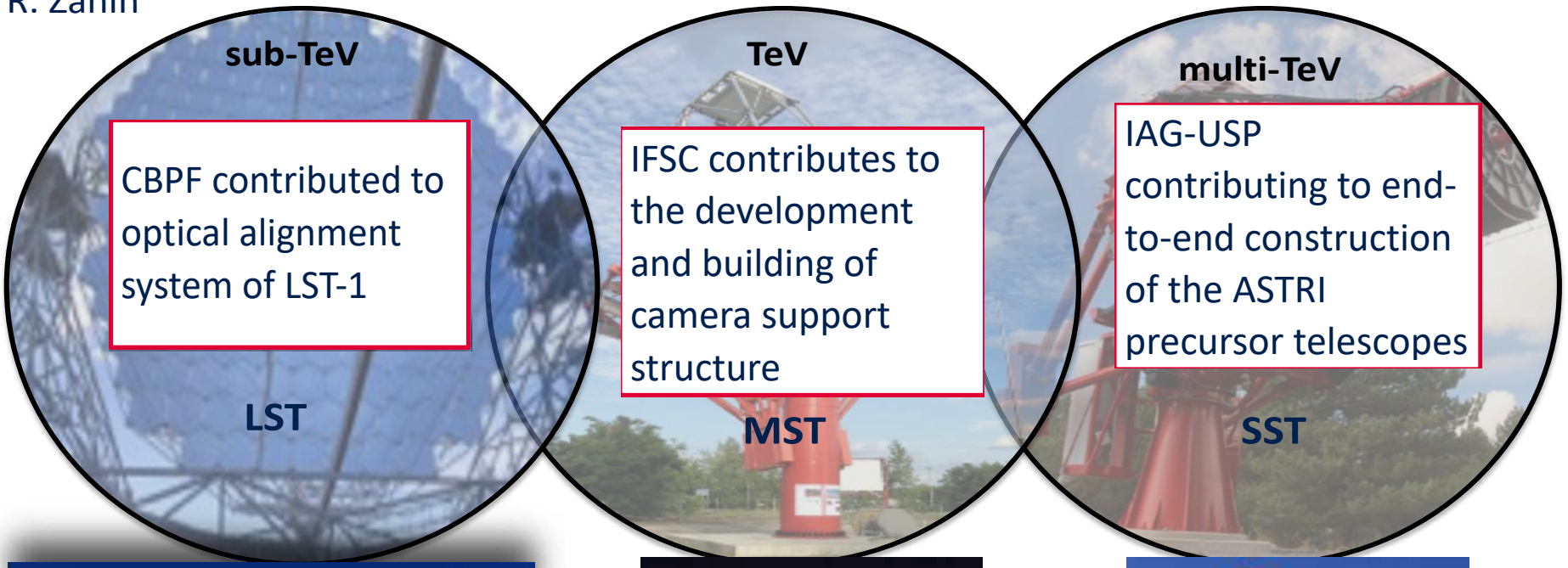
3 structures: Brasil - IAG-USP (FAPESP funding)

Currently in construction
Installation **Teide Observatory (Tenerife, Canary Islands):**
Operation starts : 2025

CTAO – SSTs: build with ASTRI structure

ASTRI Mini-Array

© R. Zanin



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ASTRI Mini-Array in the context of IACT arrays

- ASTRI Mini-Array largest IACT facility until CTAO starts operation
- Technological forerunner for CTAO Small-Sized Telescopes

- SST Consortium will have to deliver 37 complete Cherenkov telescopes
- Optics and the electro-mechanical structures very similar/identical to the ASTRI Mini-Array ones

- ASTRI Mini-Array essential training ground to optimize methods and approaches for production, quality assurance processes and AIT/V activities for the SST telescopes

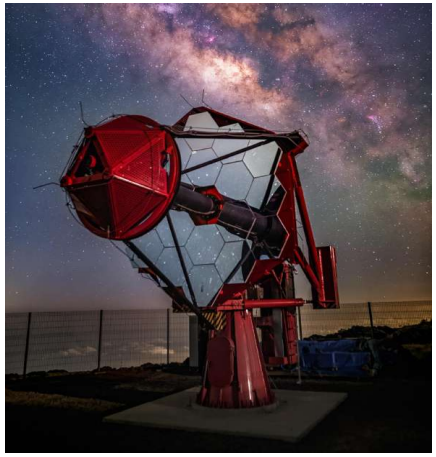
The ASTRI-Horn prototype

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

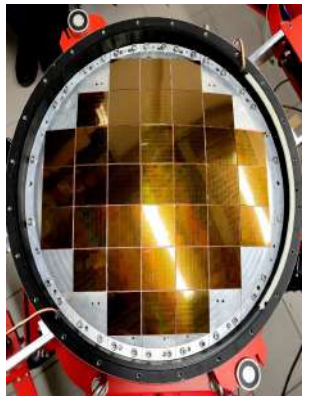


Telescope and camera

ASTRI 1 in Tenerife

- **Opto-mechanics (EIE, DAL BEN, MLT, Flabeg, ZAOT, Cilas, Vetrolamp)**
  - 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

Energy range: 1 to few 100 TeV

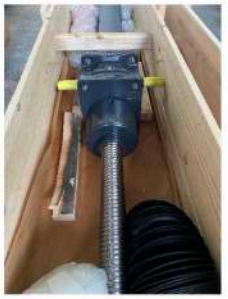


Integration Factories



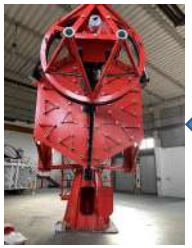
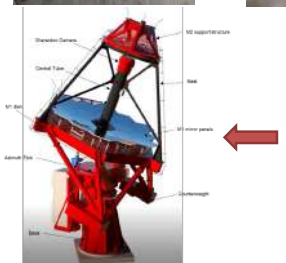








Telescopes: ASTRI-8/9 (EIE GROUP Srl)

Current EIE schedule (updated 16/04/2024)

- Complete integration in Italy of lower part of the telescopes (Azimuth) by beginning of July
- Shipment and integration of Azimuth part at site by end of July
- Elevation part ready to be shipped beginning of September
- Complete integration at site by beginning of November
- Commissioning and acceptance foreseen for 19/12/2024

Telescopes: ASTRI-2/3/4/5/6/7 (DAL BEN SpA)

ASTRI Mini-Array

Current DAL BEN schedule

- All mechanical parts have been produced
- All COTS have been procured
- Electrical cabinets and control software not ready yet
- Complete integration in Italy of first telescope by end of May
- Tests of the first telescope in Italy (including on sky tests) June-July
- Shipment and integration at site in September
- Telescopes 2 to 6 all integrated in parallel in Italy and tested (functional tests only)
- At least two telescopes by the end of the year but the goal is to have all of them

On site ICT

Mini-Array

Rack 42U			
RU		Power (W)	Weight (kg)
42			
41			
40	Telescope	1200	30
39			
38	Telescope	1200	30
37			
36	Telescope	1200	30
35			
34	Telescope	1200	30
33			
32			
31			
30			
29			
28			
27			
26			
25			
24			
23			
22	Camera server	1200	30
21			
20	Camera server	1200	30
19			
18	Camera server	1200	30
17			
16	Camera server	1200	30
15			
14	Camera server	1200	30
13			
12	Camera server	1200	30
11			
10	Camera server	1200	30
9			
8	Camera server	1200	30
7			
6	Camera server	1200	30
5			
4	Camera server	1200	30
3			
2			
1	Total	16800	420

Rack 42U			
RU		Power (W)	Weight (kg)
42			
41			
40	Main switch	240	10
39	Main switch	240	10
38			
37			
36	Telescope switch	160	10
35	Telescope switch	160	10
34			
33			
32	Firewall	300	10
31			
30			
29	Frontiera	1200	30
28			
27	Frontiera	1200	30
26			
25			
24			
23	ICT Monitor	1200	30
22			
21			
20			
19			
18	Master clock	0	10
17	Master clock	60	10
16	White rabbit	60	10
15	White rabbit	60	10
14			
13			
12			
11			
10	Control switch	160	10
9			
8			
7	CCTV switch	160	10
6			
5			
4	Service switch	160	10
3	Service switch	160	10
2			
1	Total	5520	220

Rack 42U			
RU		Power (W)	Weight (kg)
42			
41			
40	Astri MA Router 1	60	10
39	Astri MA Router 2	60	10
38	Router Switch 1	60	10
37	Router Switch 2	60	10
36	Firewall Netgate 1	60	10
35	Firewall Netgate 6100 2	60	10
34			
33			
32	Kubernetes	1200	30
31			
30	Kubernetes	1200	30
29			
28	Kubernetes	1200	30
27			
26	Kubernetes	1200	30
25			
24	Kubernetes	1200	30
23			
22	Kubernetes	1200	30
21			
20			
19			
18	Storage Metadata	2000	75
17			
16			
15			
14	Storage Metadata	2000	75
13			
12			
11			
10	Storage Data	2000	75
9			
8			
7			
6	Storage Data	2000	75
5			
4			
3			
2			
1	Total	15560	540

- HW integration close to completion
- Pre-acceptance test in Italy foreseen in May
- Delivery at the site in the second half of June
- Integration and acceptance by 10th of July
- Issue with the ATLAS rack discussed with OT administrator

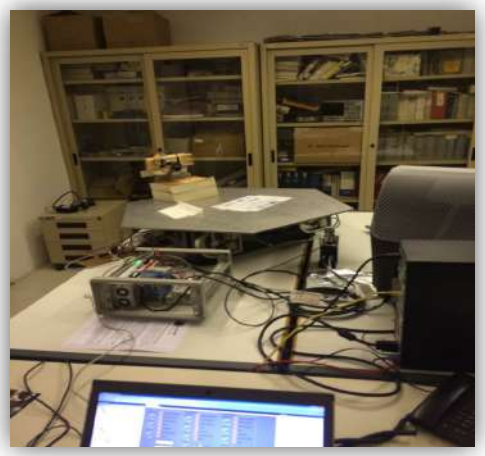
Brazilian Engineers @ ASTRI structure/cam/software development

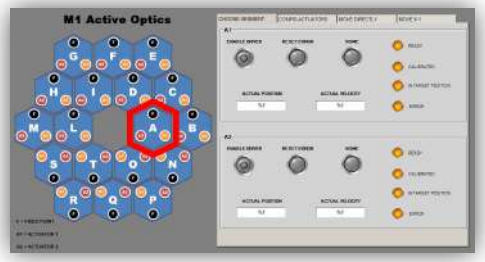
Active optics tests (Torino)
- With Daniele Gardiol & Federico Russo

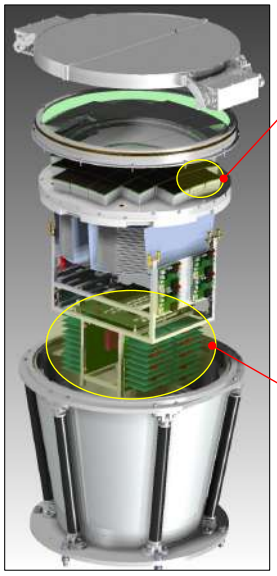
Performed task:
- Segment motion
- Data colection and callibration
- Repeatability verification

M1 Interface elaboration (Catania)
- W/ Matteo Munari, Salvo Scuderi, Enrico Giro, Luca Stringhetti, Elisa Antolini

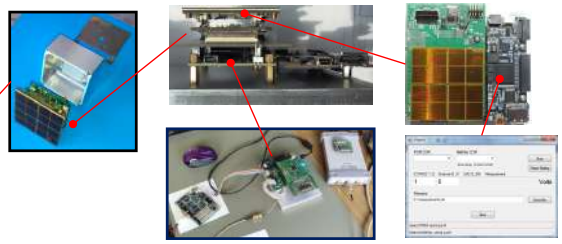
Performed task:
- Actuator configuration as in CANopen
- Screens preparation for driving motors
- interface implementation with users, scheduling tests, etc.
- Teaching on operation of logics for future change and implementation
- Teatching hardware & software Beckhoff



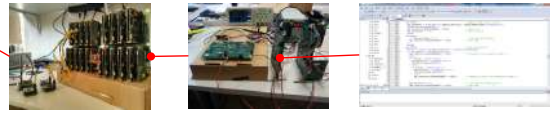




ASTRI Camera



PDMs – Photodetector Modules
- *Hardware Improvements and EMI Countermeasures*
- *Calibrations, Test Set-Ups and PC Applications*



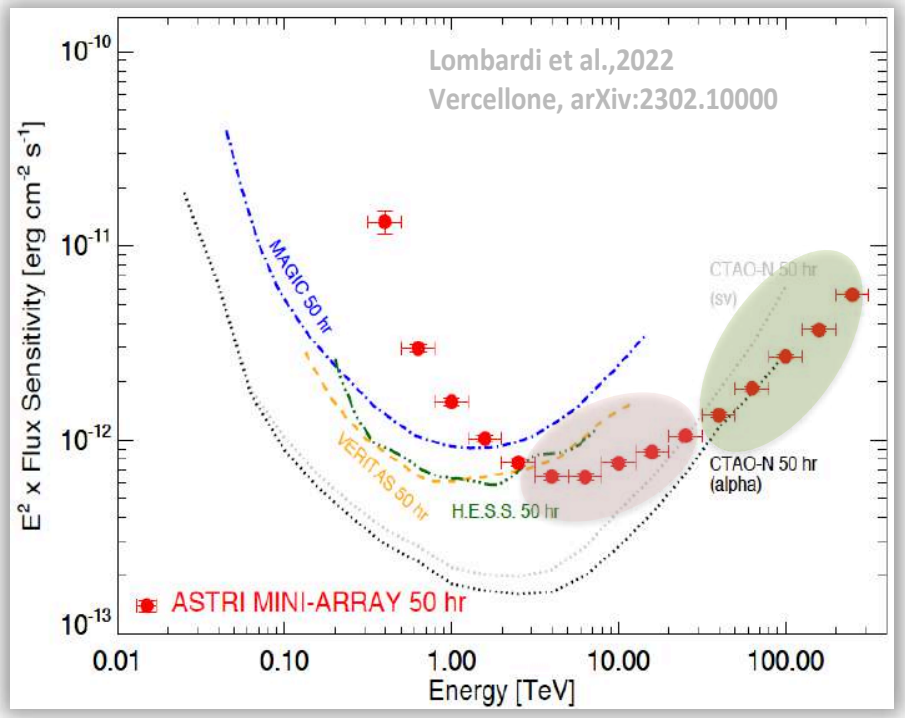
VDB – Voltage Distribution Box
- *Hardware and Firmware Corrections and Improvements*
- *Test Set-Ups, Test Jigs and PC Control Software*
- *Calibration Routines and Climate Tests*
- *DC/DC Converter Design for New SiPMs Biasing*

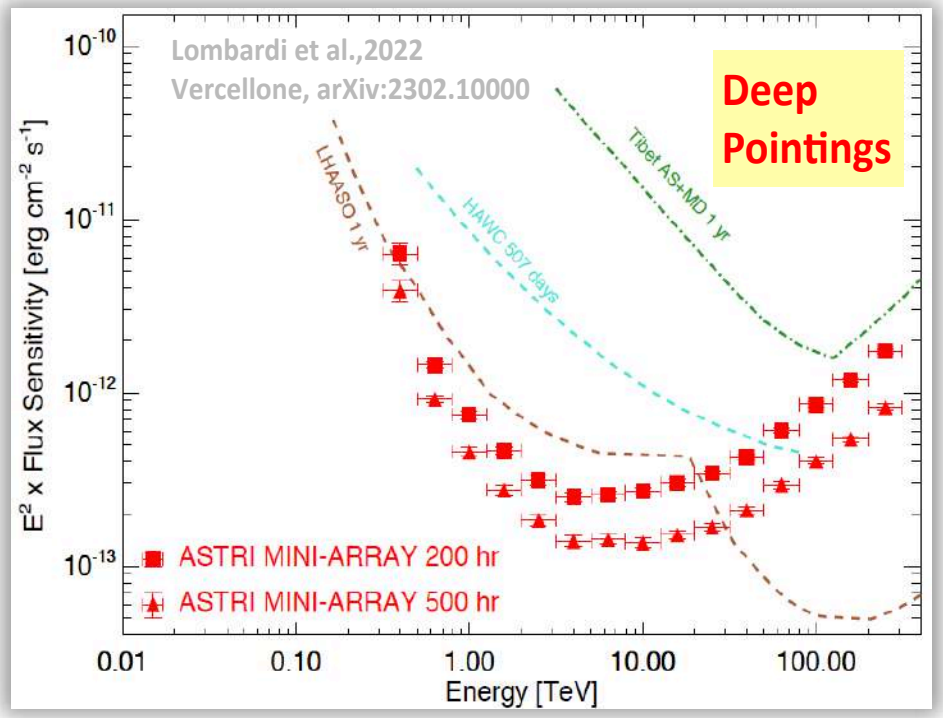
C. Fermino at ASTRI 1 telescope installation, Observatory del Teide, (2022 and 2023)

Mini Array Performance

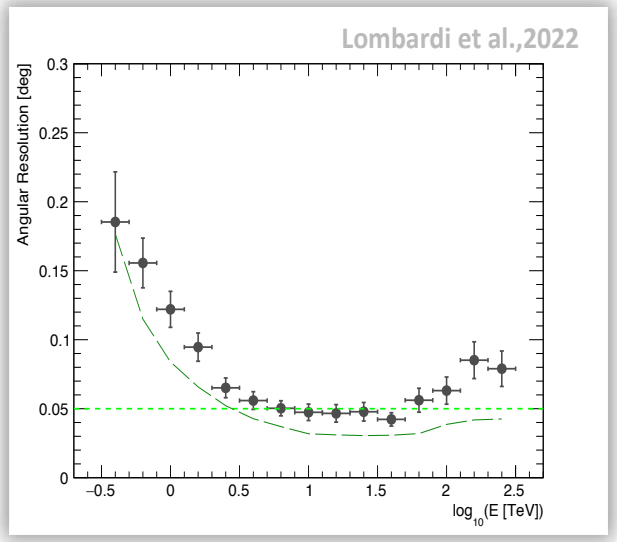
We extend current IACTs **differential sensitivity up to several tens of TeV and beyond**

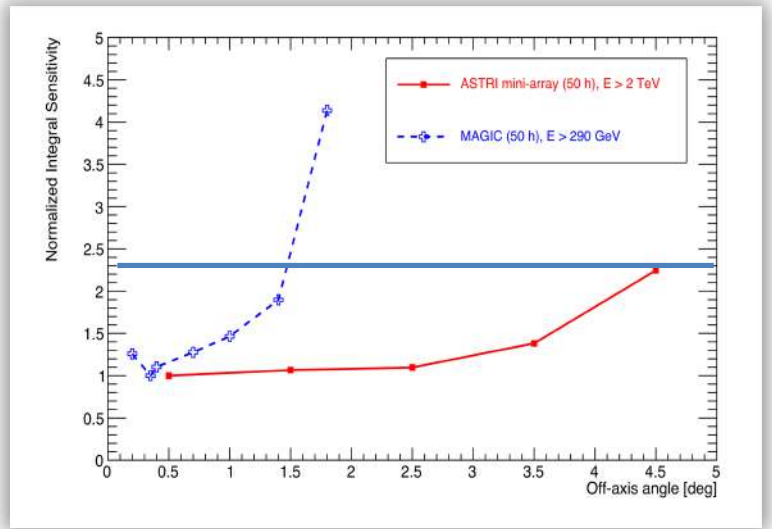
Investigate possible spectral features at VHE, such as the presence of **spectral cut-offs** or the detection of emission at several tens of TeV expected from **Galactic PeV sources**

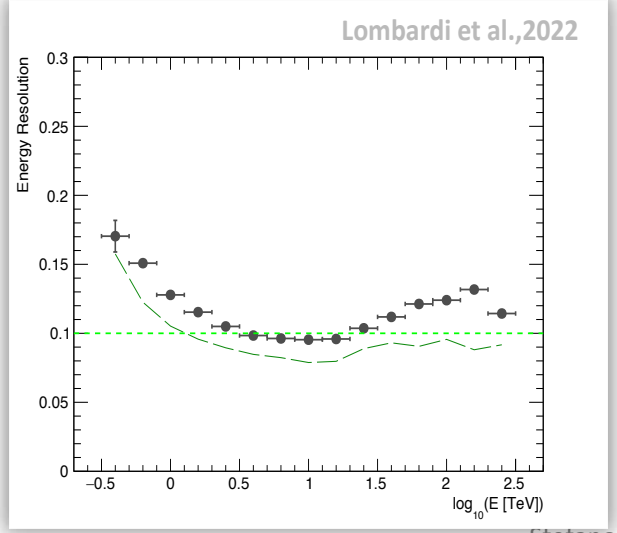




FOV, Angular and Energy Resolution







Sensitivity: better than current IACTs (E ≳ 3 TeV)

- Broad-band spectrum
- Spectral cut-off constraints

Energy/Angular resolution: ~10% / ~0.05° (E ~10 TeV)

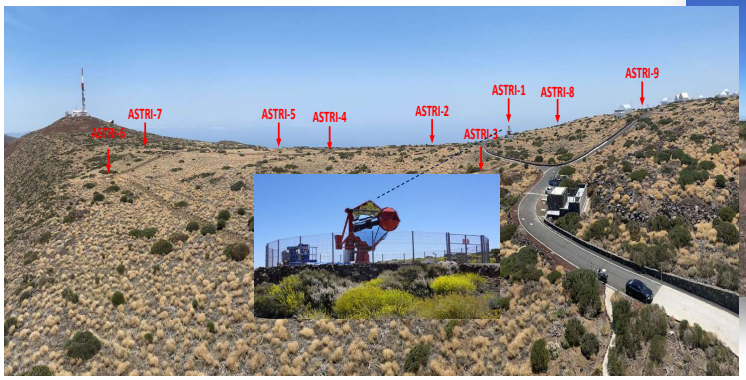
- Extended sources morphology

10° field of view with excellent off-axis performance

- Multi-target fields
- Serendipitous discoveries

Mini-Array

ASTRI mini-array: mini but not small…



Expected performance:

- **Sensitivity: better than current IACTs (E > 10 TeV):**
  - Extend spectra of already detected sources and measure cut-offs
  - Characterize morphology of extended sources at the highest VHE
- **Energy/Angular resolution: < ~10% / < ~ 0.05° (E ~ 10 TeV)**
- **Wide FoV (≥ 10°), with homogeneous off-axis acceptance**
  - Optimal for multi-target fields, surveys, and extended sources
  - Enhanced chance for serendipity discoveries

Science with the ASTRI Mini-Array

Pillar 1
The origin of cosmic rays

Quest for PeVatrons
Particle propagation
PWN HE emission
UHECR from SB galaxies

Transients

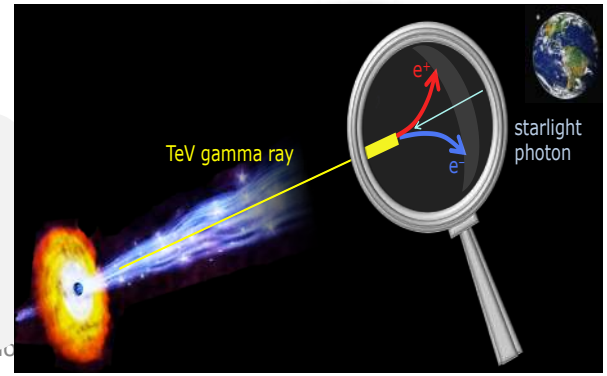
Time-domain

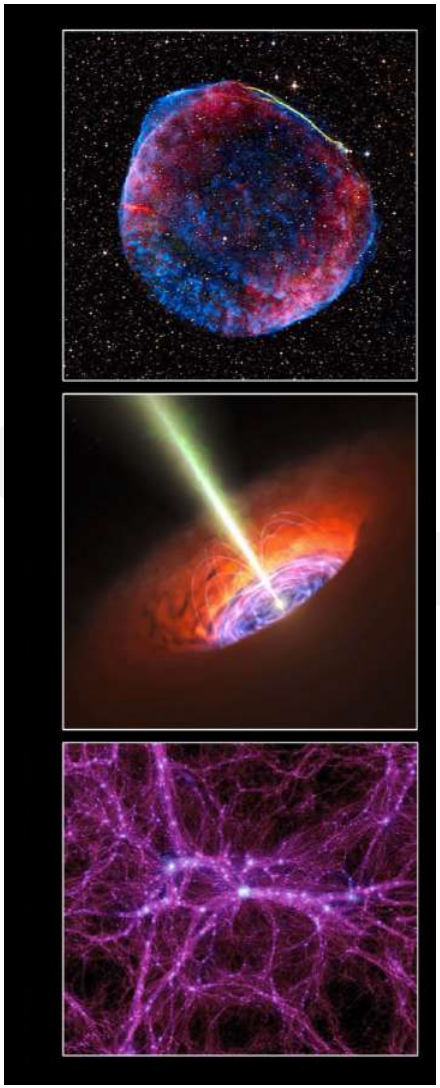
GRB, GW, ν

Pillar 2
Fundamental physics

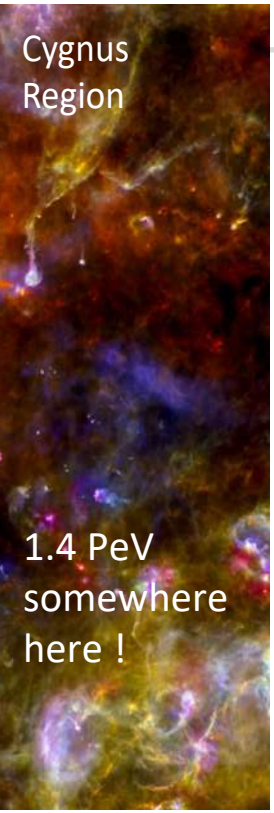
IR EBL constraints
Probing IGMF
Blazars & hadron beams
Test on ALPs & LIV

Dark Matter



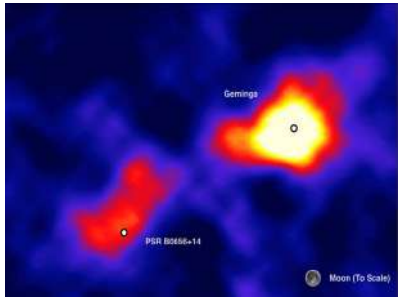


LHAASO discovered PeVatrons @ Galaxy



Cao et al., 2021, Nature

Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	-13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	-5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	-3.65	8.5	$0.26 - 0.10^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	-0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71 - 0.07^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)



Geminga: TeV halo

Discovery of 12 sources emitting at **several hundreds of TeV, up to 1.4 PeV**
Diffuse gamma-ray structures with angular extensions 1°

Sources UNKONWN: SNRs, galactic center, pulsar wind nebulae, young stellar clusters?

ASTRI MA -> can identify, probe morphology and spectra

Gamma-Ray Bursts with Mini-Array

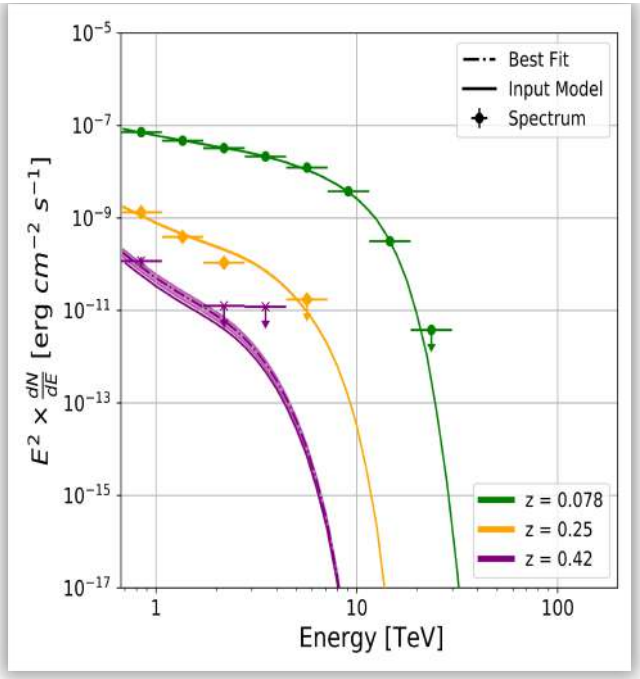
- LHAASO detection of **GRB 221009A (z=0.15) well above 10 TeV challenges the standard physics model**

The ASTRI Mini-Array

emission from GRB 190114C

- is able to confirm afterglow emission at E >1 TeV from close (z < 0.4) GRBs if observations start within the first tens of seconds up to few minutes from the onset of the burst
- can measure the spectral cut-off, either originated by the EBL absorption or intrinsic, if greater than 1 TeV

The expected number of follow-ups on observable GRBs is about 1 per month



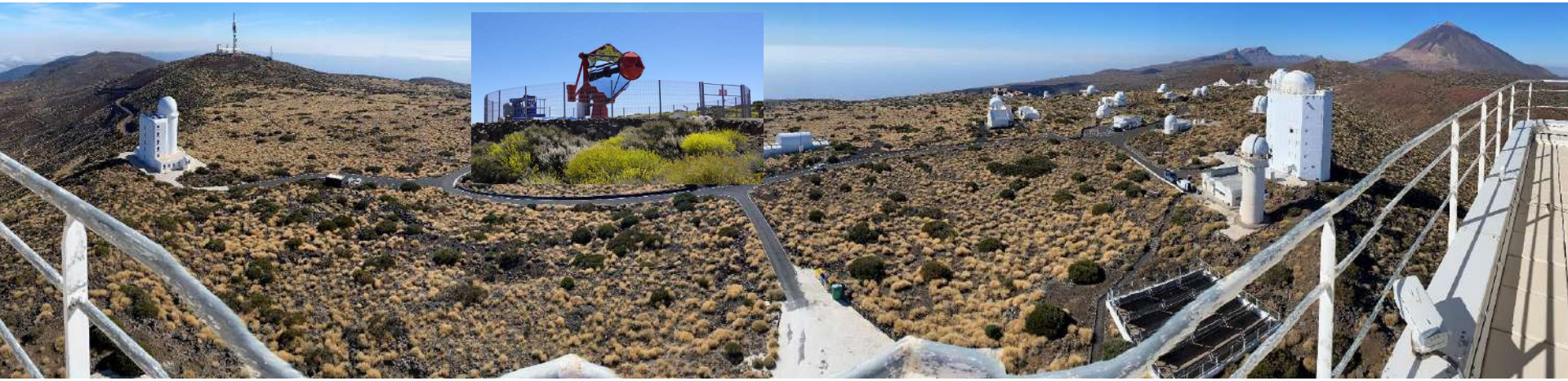
Simulation of the emission from three GRB 190114C-like bursts, at three different redshifts (z = 0.078, z = 0.25 and z = 0.42)

Simulations of GRB 221009A will start very soon

Current Master Schedule

ASTRI Mini-ARRAY will start observations at end of 2025

- Teide infrastructure completed
- ASTRI-1 telescope accepted October 2023
- ASTRI-8 & ASTRI-9 telescopes delivered December 2024
- ASTRI-3 delivered September 2024 others will follow soon after (goal end of 2024)
- First camera (engineering camera) on ASTRI-1 July 2024
- Two more cameras completed by end of 2024 (Goal)
- ASTRI Mini-Array ready for commissioning late summer 2025
- Early observations will start already with three telescopes
- Scientific observations start end 2025



Brazil in the ASTRI Mini-Array and SSTs for CTAO-South

Brasil in the SST-CTAO and ASTRI MA since 2014:

Currently: ~60 members in CTAO-Br (30 in SST-Br from IAG-USP, EACH-USP, Mackenzie, UFABC, IFUSP, CBPF)

Current aims: **ASTRI MA installation (2025) and AIV of 37+3 (ASTRI based) SSTs for CTAO-South array (2025-2030)** (FAPESP: ~5MUSD)

Mini Array - Summary

ASTRI mini-array: mini but not small…

The ASTRI Mini-Array will start **scientific observations in 2025** from the *Observatorio del Teide* with a 4 (core science) + 4 (observatory science) year programme

Its **10° field of view** will allow us to investigate both extended sources (e.g., SNRs) and crowded/rich fields (e.g., the Galactic Center) with a single pointing

Its **3' angular resolution** at 10 TeV will allow us to perform detailed morphological studies of extended sources

Its **sensitivity extending above 100 TeV** will make it the most sensitive IACT in the energy range 5-200 TeV in the Northern hemisphere before CTAO-N