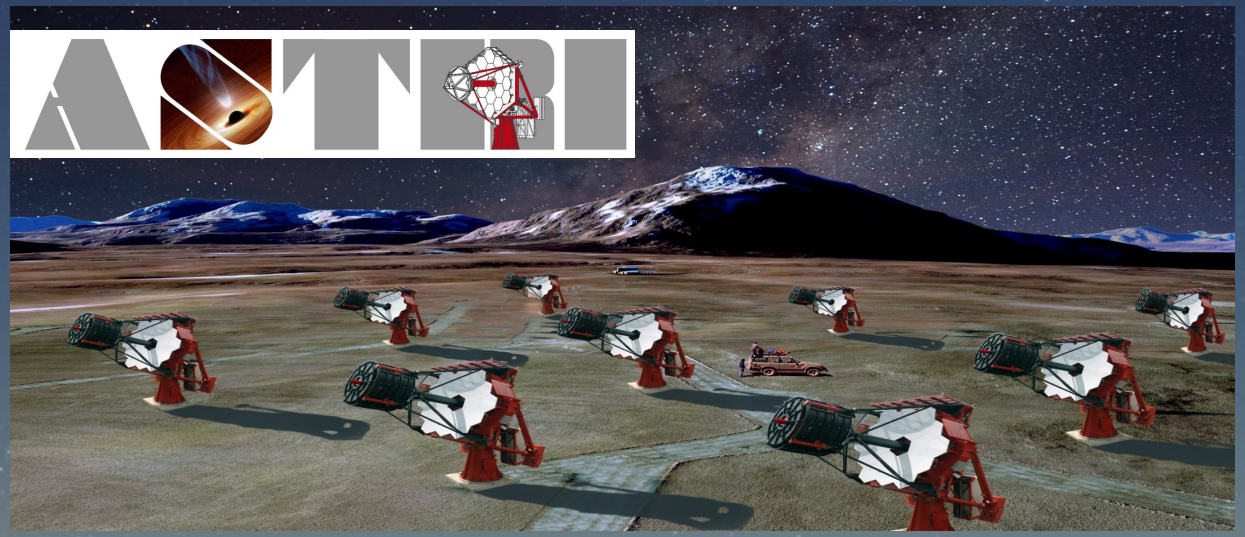
Advances of the ASTRI MINI-ARRAY - the CTA Precursor & the Small Size Telescopes (SSTs) of CTA



Elisabete M. de Gouveia Dal Pino and Maria Victoria del Valle
(On behalf of the CTA and ASTRI Mini-Array Group in Brazil)

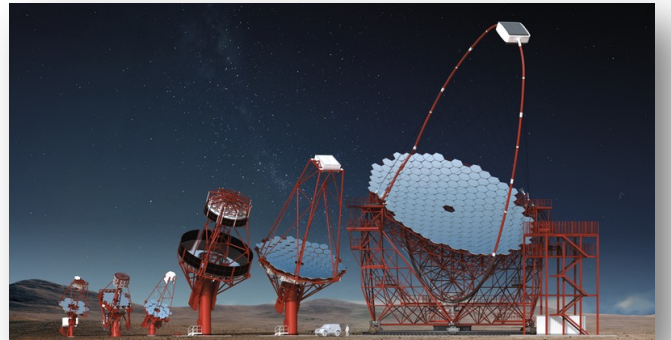
IAG INSTITUTO DE ASTRONOMIA, GEOFÍSICA E CIÊNCIAS ATMOSFÉRICAS
USP Universidade de São Paulo

RENAFAE Workshop, July 2021, ONLINE

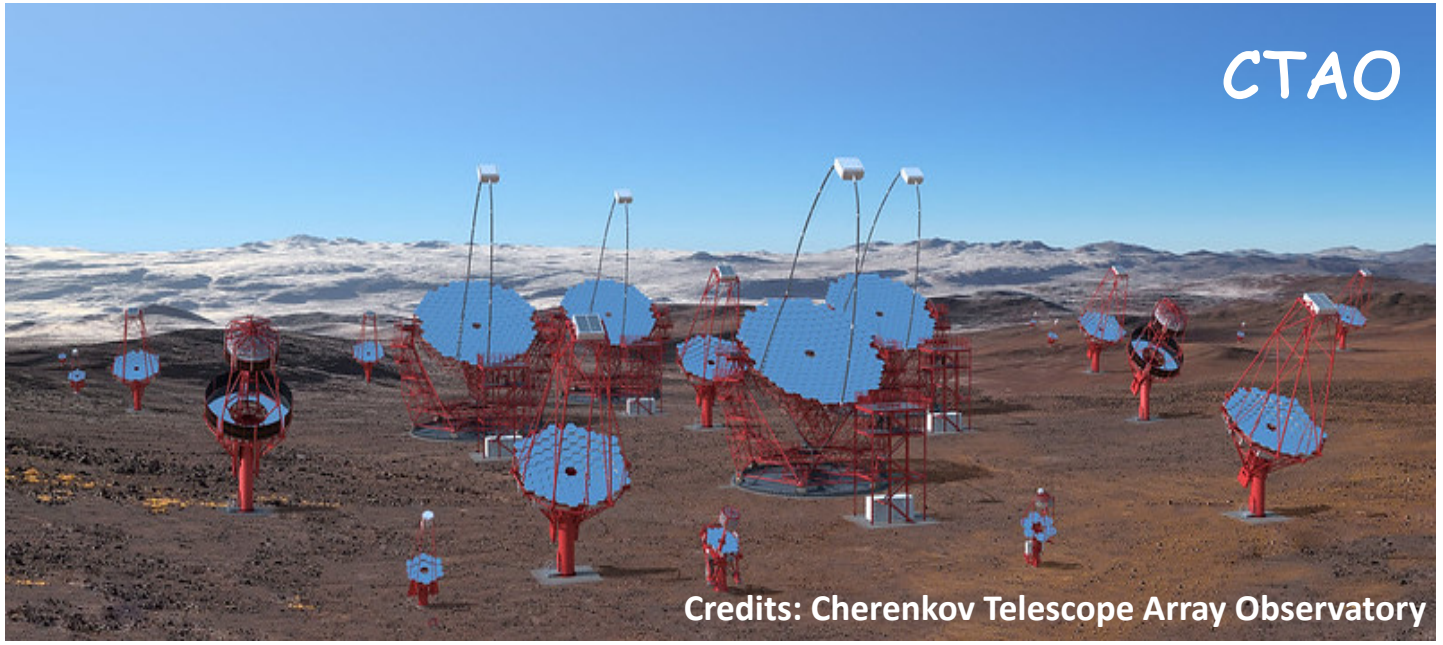
ASTRI Mini-Array with 9 Cherenkov telescopes:

for ground based high-energy gamma-ray astronomy up to few 100 TeV

- **Partners: Italy, Brazil, South Africa, Spain**
  - INAF, INFN, and several Italian Universities - more than 100 hundred researchers
  - Universidade de São Paulo/FAPESP (Brazil): provided 3 of the telescopes (mechanical structures)
  - North-West University (South Africa)
  - Recently: IAC (Spain) for site support in Tenerife

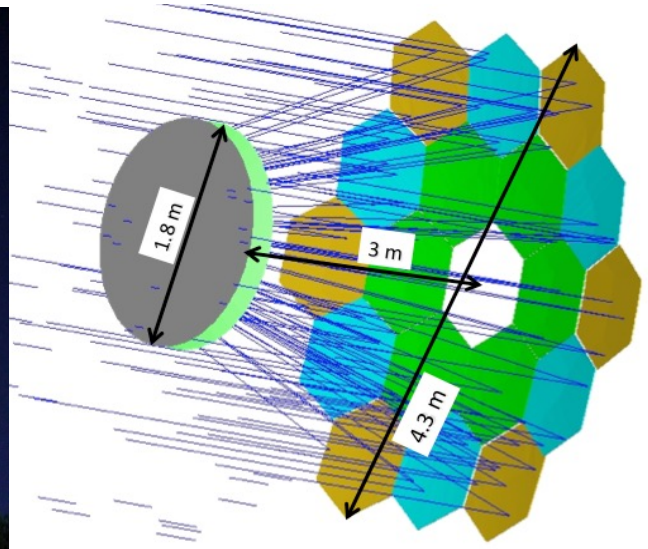


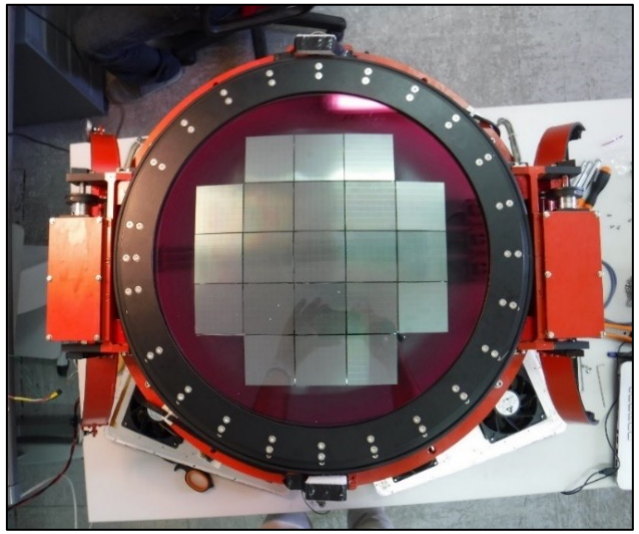
ASTRI: A three-step program



1. Development of an end-to-end technological **PROTOTYPE for CTA**
2. Construction and operation of the **ASTRI mini-array** @ Teide Observatory (Canary Islands)
3. Leading the consortium that will **implement the SST telescopes @ CTAO** southern site

ASTRI Prototype: The prototype in a nutshell





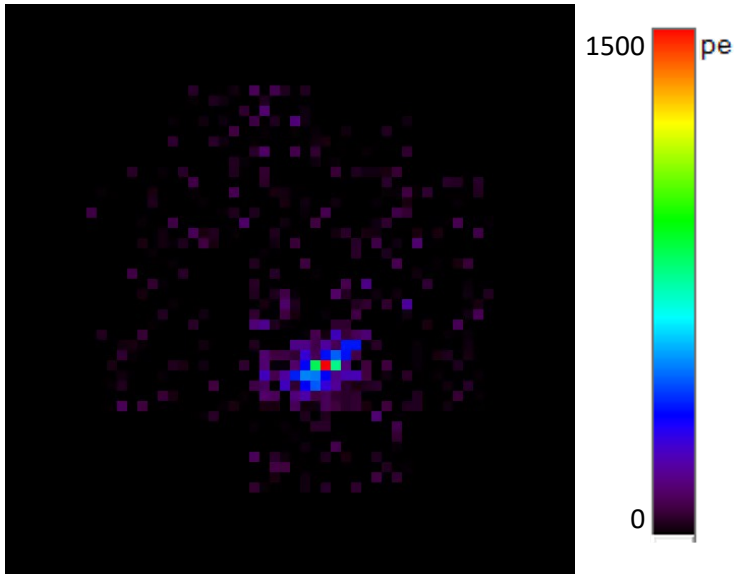
- **Opto-mechanics**
  - Alto-azimuthal mount
  - **Schwarzschild-Couder optical design**
  - Primary Mirror: 4.3 m (segmented)
  - Secondary Mirror: 1.8 m (monolithic)
  - F/#: 0.5 m
  - Average effective area: 5.0 m^2
  - Optical PSF $\leq$ 0.19 deg
  - Post calibration pointing precision $\leq$ 7 arcsec
- **Cherenkov Camera**
  - **Front End electronics based on CITIROC ASICs**
  - **SiPM sensors: 7x7 mm**
  - 1344 pixels (2368 when focal plane fully populated)
  - Field of View: 8.2 deg (10.5 deg)
  - Angular pixel size: 0.19 deg
- **Expected performance**
  - Energy threshold ≈ 1 TeV
  - Energy/Angular resolution < ~25% / < ~0.15°
  - Sensitivity ≈ 1 Crab @ 5 σ in few hours

ASTRI Prototype: Inauguration

24th September 2014

Inauguration of the prototype @ INAF-Catania mountain station in Serra La Nave placed at 1725 meters on the Etna volcano

ASTRI Prototype: ASTRI camera first Cherenkov Light



25th of May 2017

First Cherenkov light with the ASTRI camera

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cta cherenkov telescope array

Press Release

CTA Prototype Telescope, ASTRI, Achieves First Light

Download full release: 2 MB / PDF

During the nights of 25 and 26 May, the camera of the ASTRI telescope prototype (pictured to the left) recorded its first ever Cherenkov light while undergoing testing at the astronomical site of Serra La Nave (Mount Etna) in Sicily managed by INAF-Catania. This comes not long after its optical validation was achieved in November 2016 (read story here). This accomplishment was the first optical demonstration for astronomical telescopes using the novel Schwarzschild Couder dual-mirror design. The ASTRI telescope is a proposed Small-Sized Telescope design for the Cherenkov Telescope Array (CTA).

Although the camera was not fully configured, the ASTRI team was still able to capture its first Cherenkov light and produce beautiful images of the showers generated by cosmic rays in the Earth's atmosphere. The image below shows one of the events captured by the team. This information will allow scientists to reconstruct the direction of gamma-ray photons emitted from celestial sources (indicated by the yellow line on the image on the left). The camera is based on novel SiPM small pixel sensors (7 mm x 7 mm) and CITIROC ASICS peak-finder front-end electronics. The camera was specifically designed to fit on the dual mirror ASTRI telescopes for covering a large field of view of 10^{o} x 10^{o}.

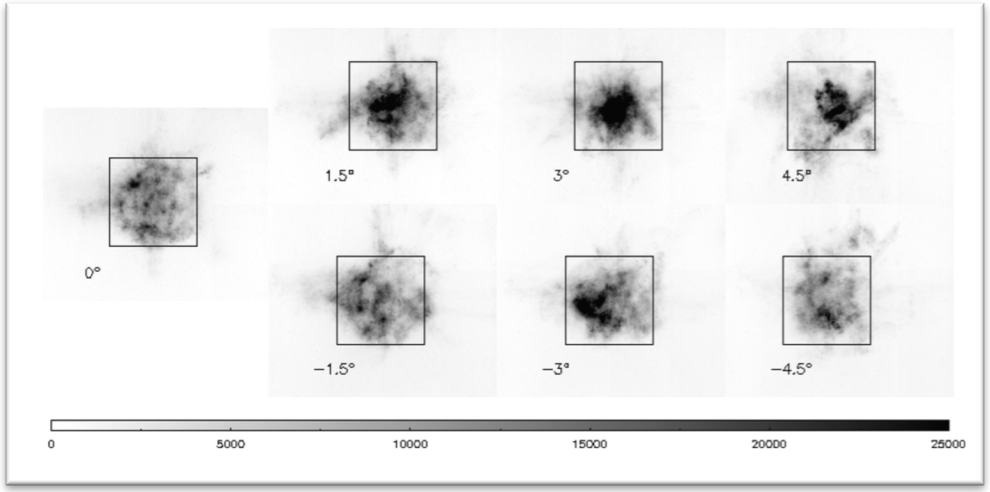
ASTRI Prototype: The results

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]

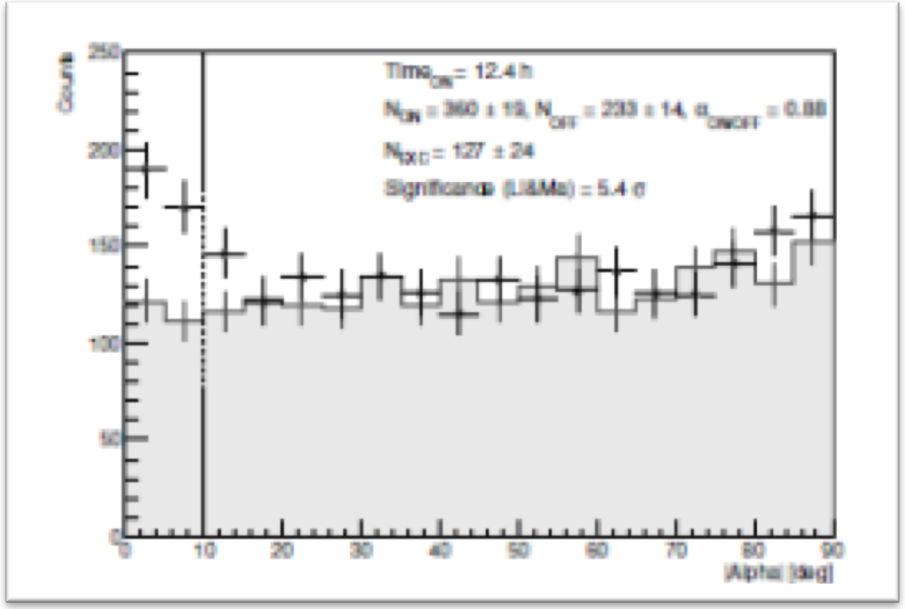


A&A 634, A22 (2020)
https://doi.org/10.1051/0004-6361/201936791

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'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], F. Sciacca[8], E. R. Vitello[8], and A. Wolter[5]



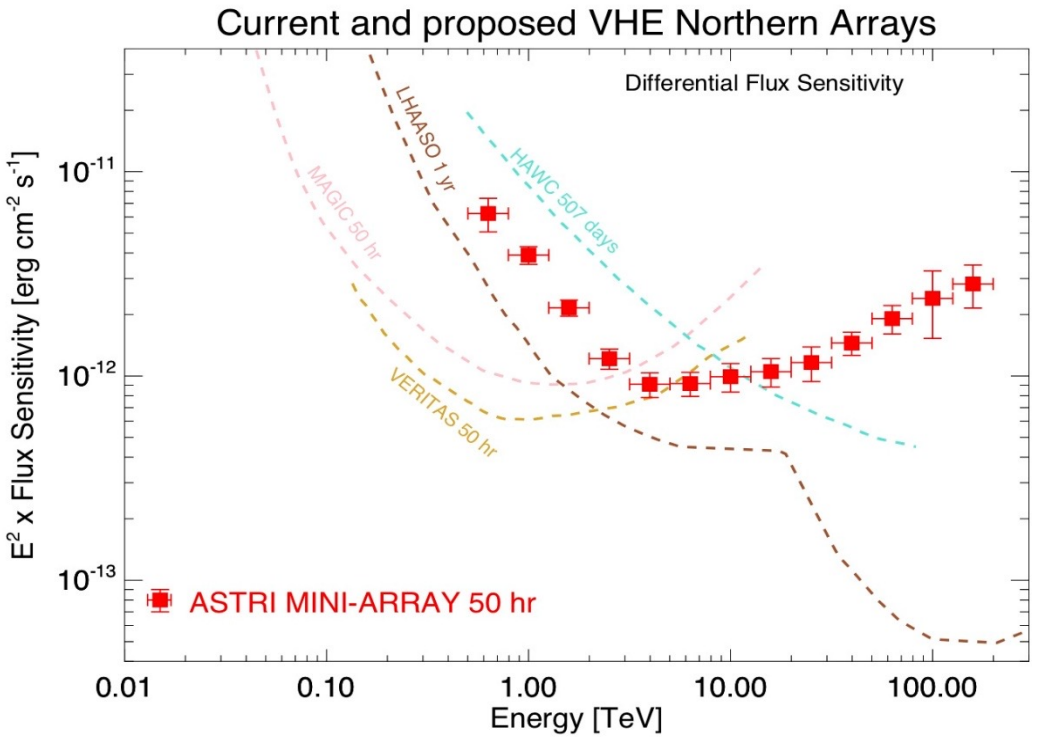
ASTRI mini-array: The next step of the program

The ASTRI mini-array will be a new pathfinder of the arrays of Cherenkov telescopes

- INAF commitment with the Italian government and international partners: Brazil, South Africa, Spain
- Dedicated funding
- It will have 9 ASTRI telescopes: resulting from evolution of the ASTRI-Horn prototype successfully implemented and tested
- It will be deployed at the Teide Observatory (Canary Islands) in collaboration with Spain & Brazil

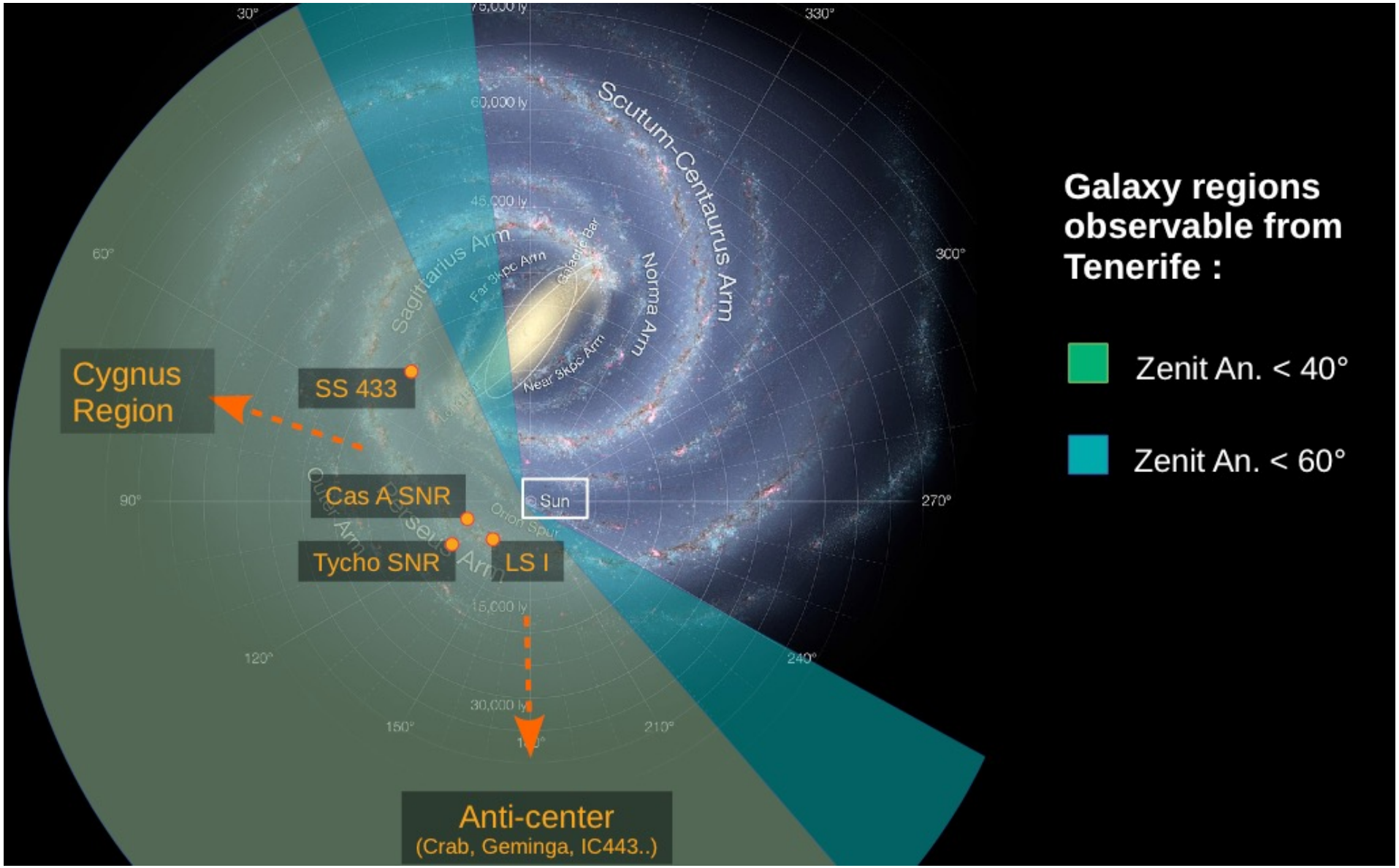
ASTRI mini-array: mini but not small…

Science at very high gamma ray energy in the northern hemisphere!



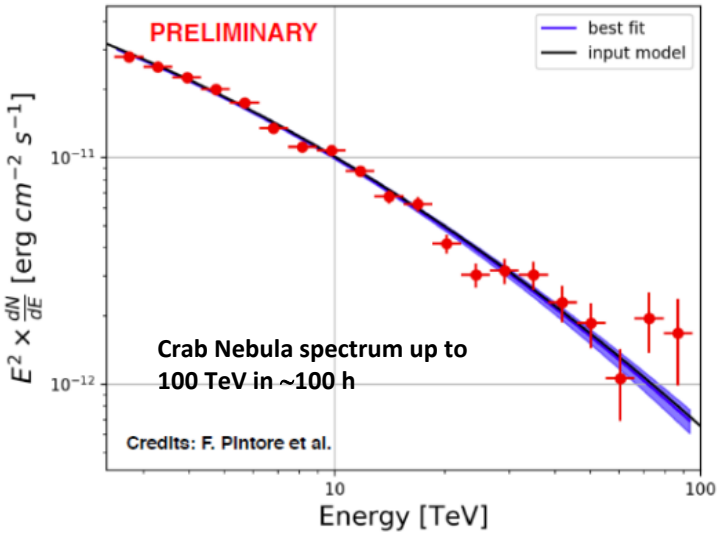
Expected performance:

- **Sensitivity: better than current IACTs (E > 10 TeV):**
  - Possibility to extend the spectra of already detected sources and/or measure cut-offs
  - Possibility to characterize the morphology of extended sources at the highest VHE
- **Energy/Angular resolution: < ~10% / < ~ 0.1° (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


Galaxy regions observable from Tenerife :
Zenit An. < 40°
Zenit An. < 60°
Cygnus Region
SS 433
Cas A SNR
Tycho SNR
LS I
Sun
Anti-center
(Crab, Geminga, IC443..)
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Orion Spur
Outer Arm
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
60,000 ly
45,000 ly
15,000 ly
30,000 ly

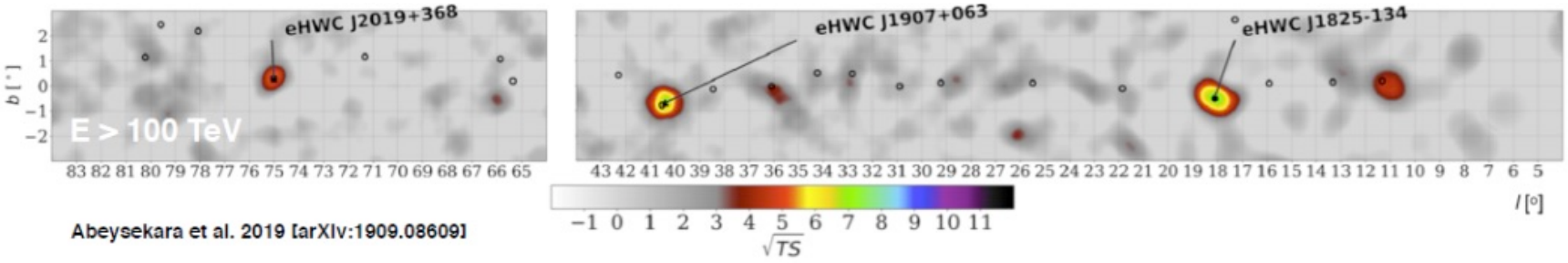
Core science program in the first ~2/3 years (detailed strategy under definition):

- Restricted number of targets/deep exposures (>~ 200 h) → strong scientific cases
- 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, …
- Science beyond VHE astronomy also envisaged → Stellar Intensity Interferometry

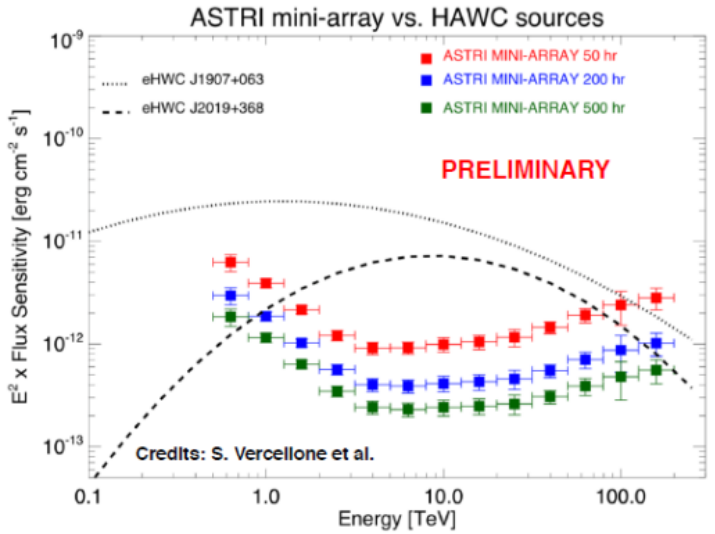


Synergies with current VHE Northern Arrays:

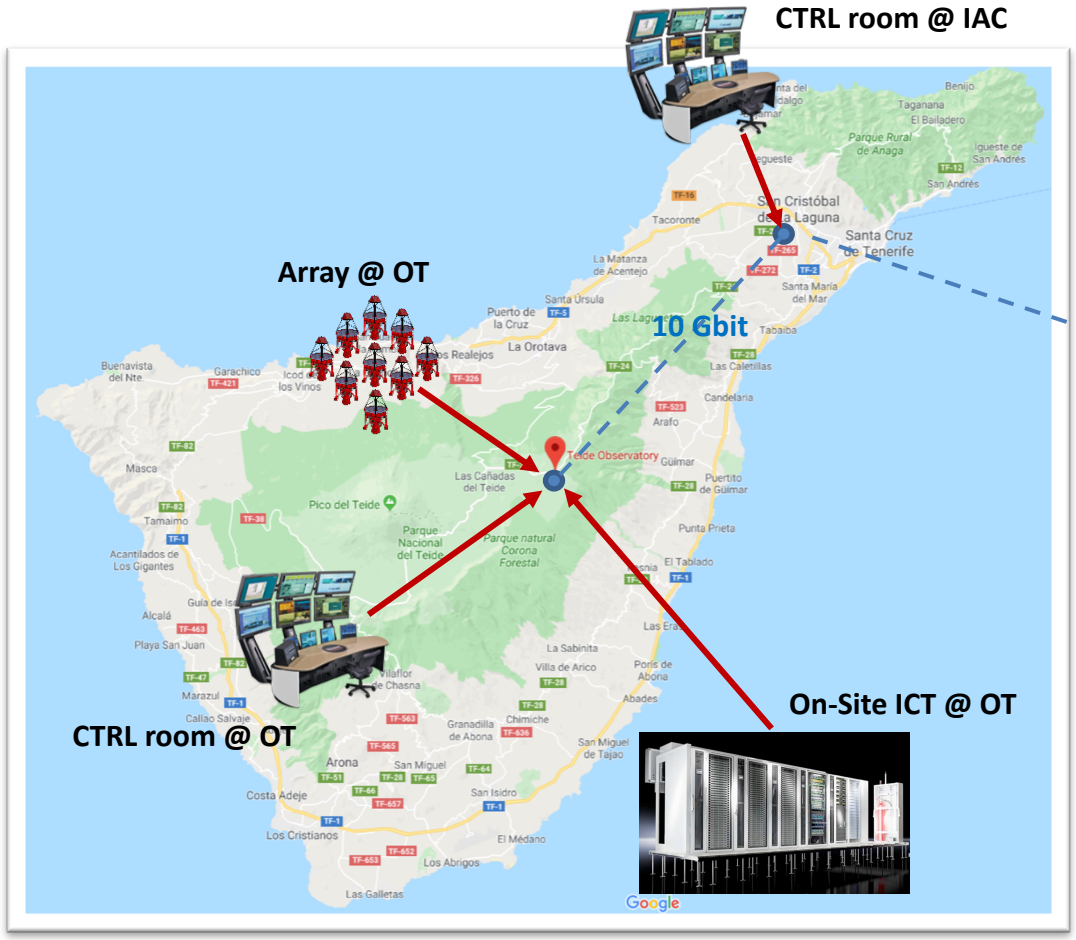
- Observations of HAWC sources with much higher angular/energy resolution
- Simultaneous observations with MAGIC and LSTs will be possible



Abeysekara et al. 2019 [arXiv:1909.08609]



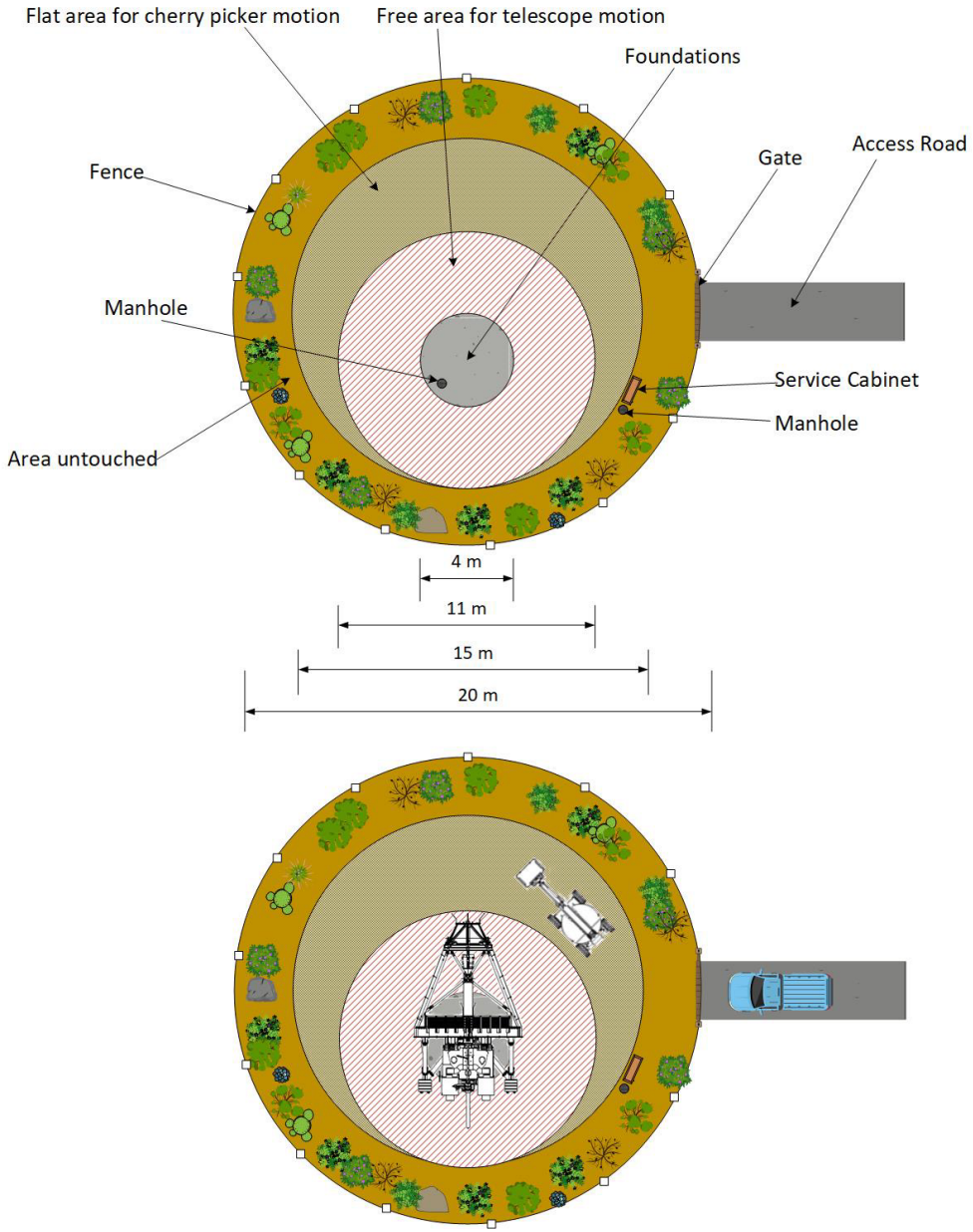
ASTRI mini-array: The physical layout



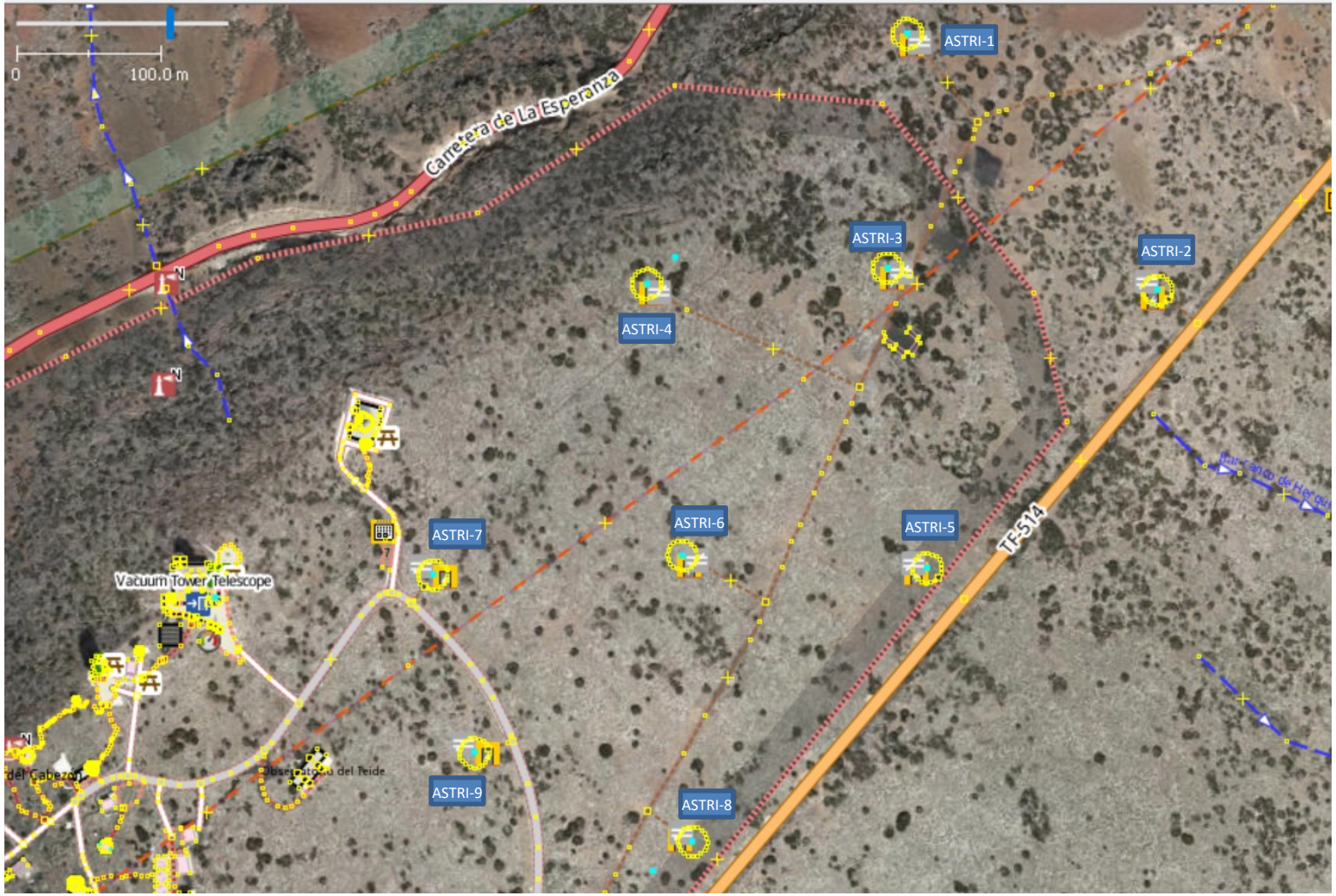
10 Gbit

- It will be developed in order to be operated, after the commissioning phase, remotely.
- Data analysis will be performed off-site

ASTRI mini-array: Site design

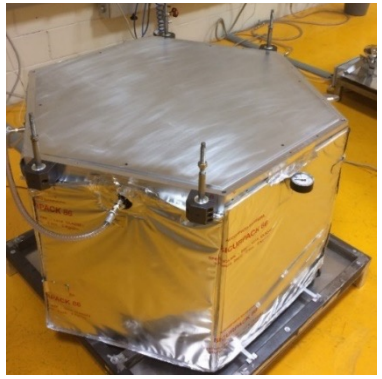


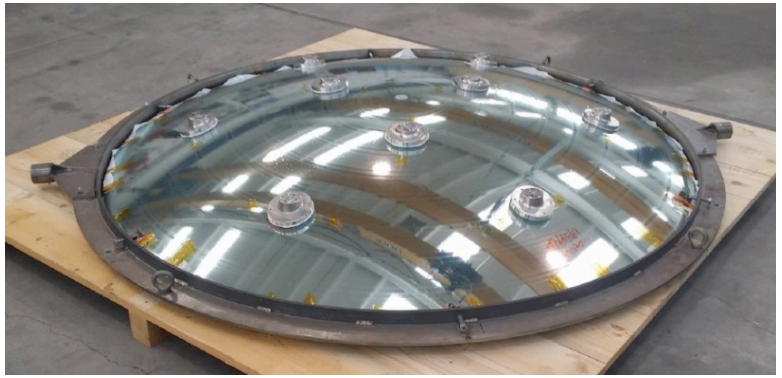
Site ready to host the first telescope in September 2021

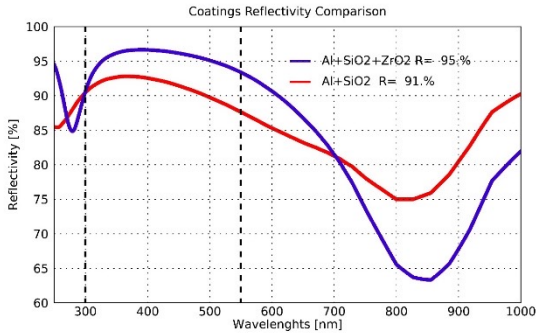


Mirrors & Camera

M1 and M2 production completed and mirrors packed and ready for shipping

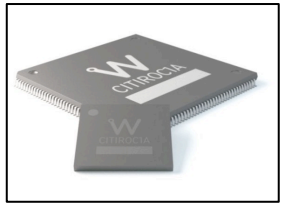


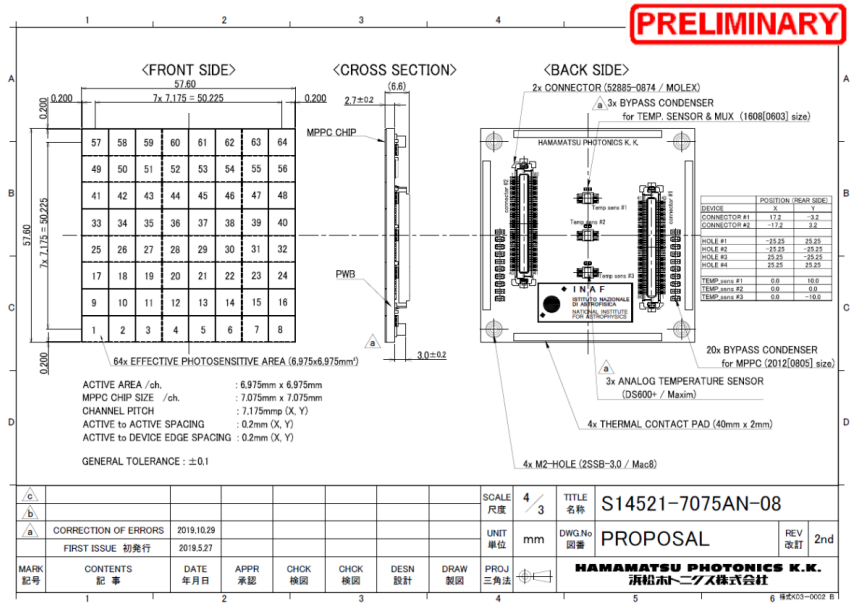




Credits: Media Lario, Flabeg, ZAOT

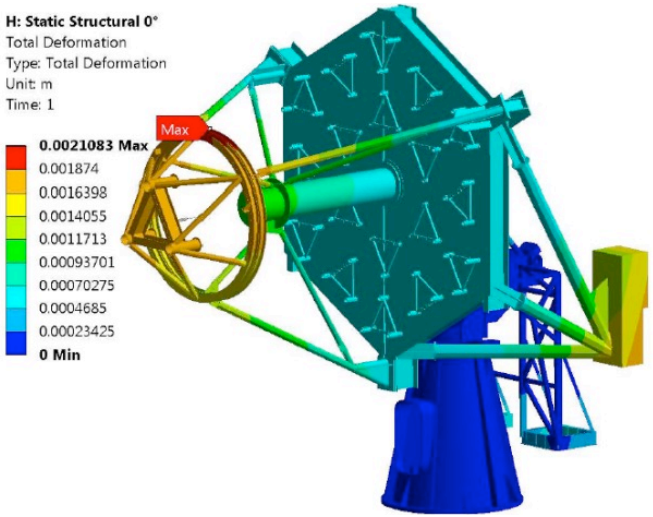
- Procurement of CITIROC-1A completed
- Procurement of SiPM detectors ongoing
  → Hamamtsu LV3, 7x7 mm, uncoated
- Procurement of Cherenkov Camera
  → tender process started

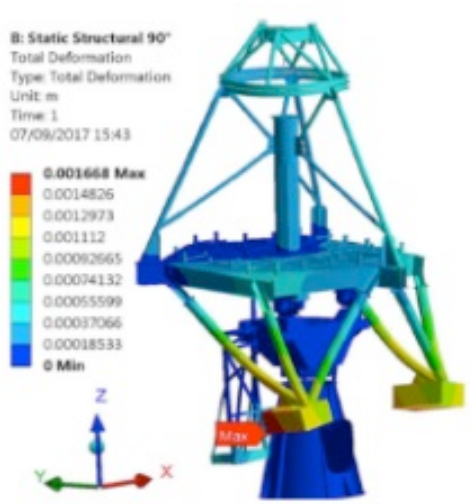




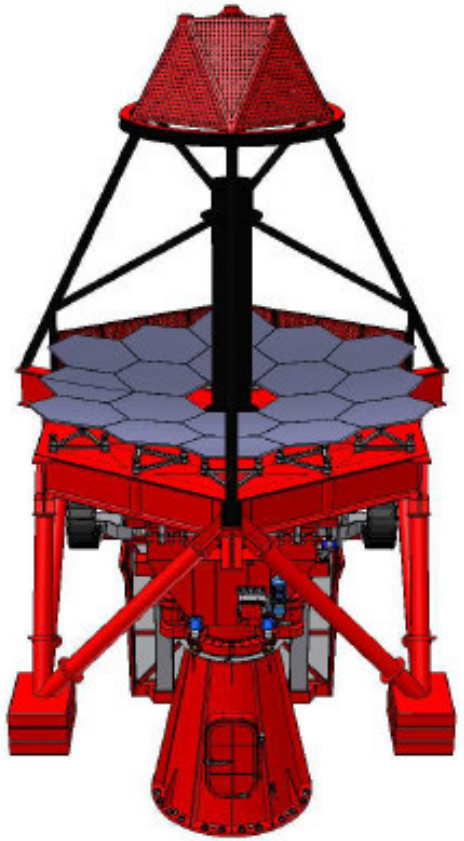
Credits: Hamamatsu Photonics, Weeroc

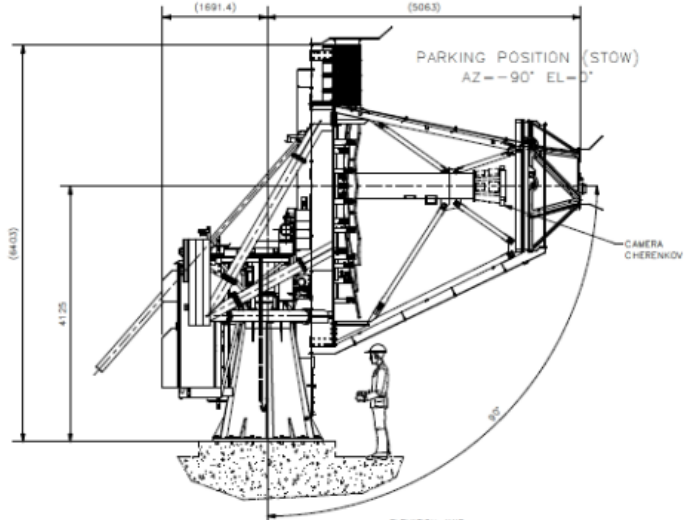
Electro-Mechanical Structure





- Production of first three structures COMPLETED
- Tender for remaining six to be issued





Credits: EIE, Galbiati

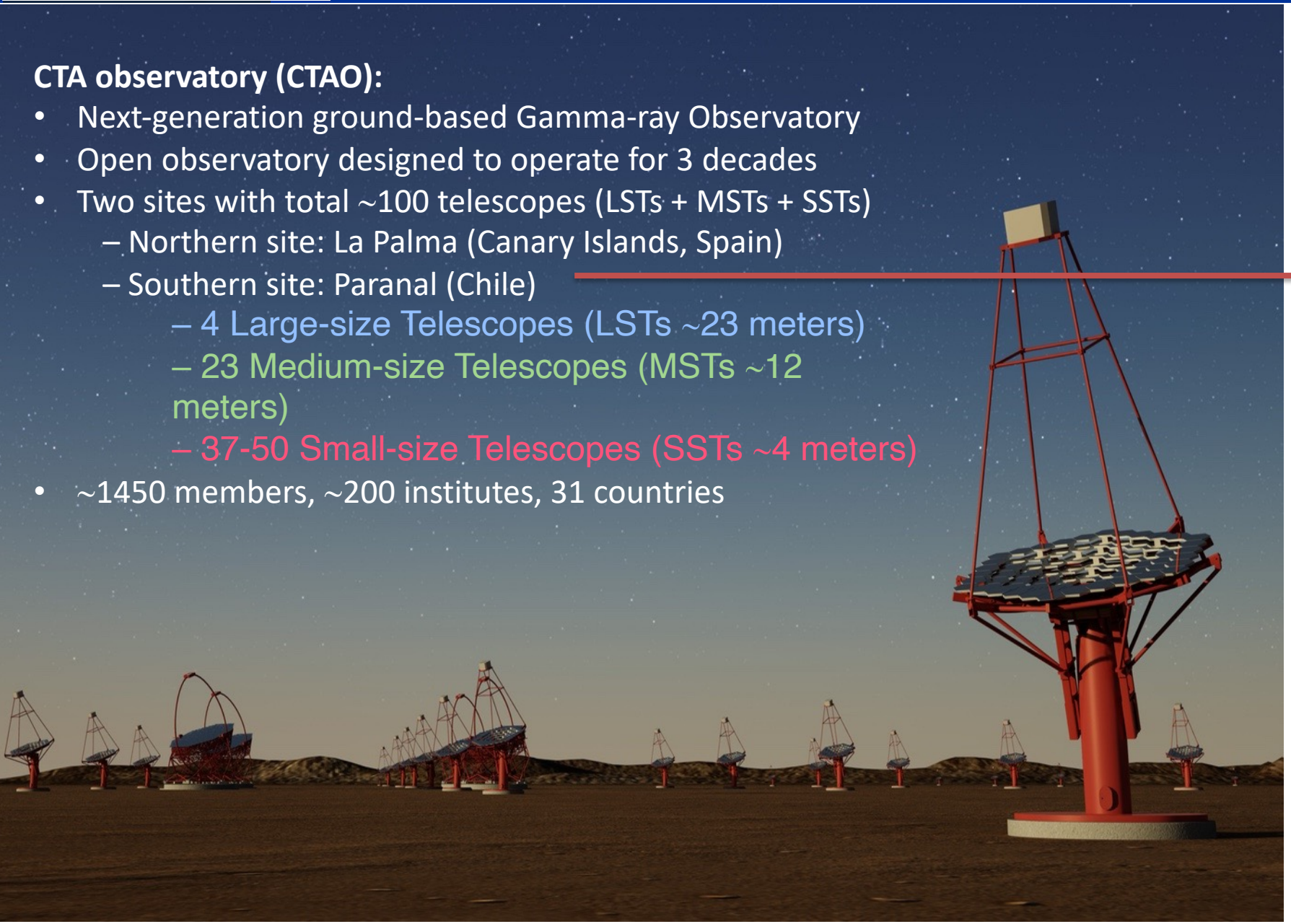
Design Consolidation

- **Mass reduction (25% → 17 Tons)**
  - Design consolidation of the dish and secondary support to maintain same stiffness lowering telescope weight
  - **Finite Element Analysis → The structure is able to support seismic loads without suffering damages that will prevent motion.**
- **Active Mirror Control (AMC) simplification**
  - No need for AMC during operations
  - AMC radially mounted for easier mirrors integration
  - AMC mounted only in integration phase and for maintenance

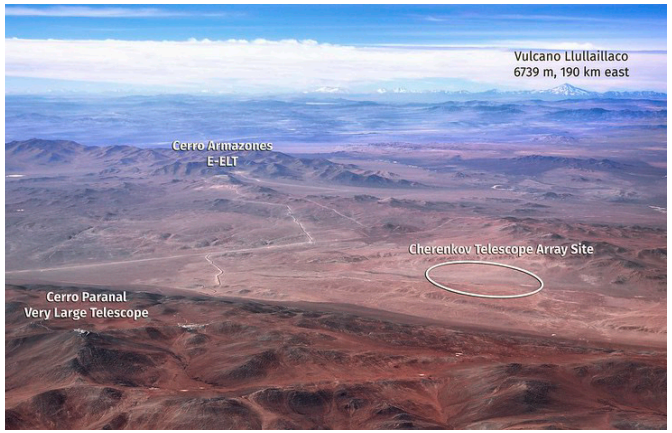
CTAO: The final step of the program

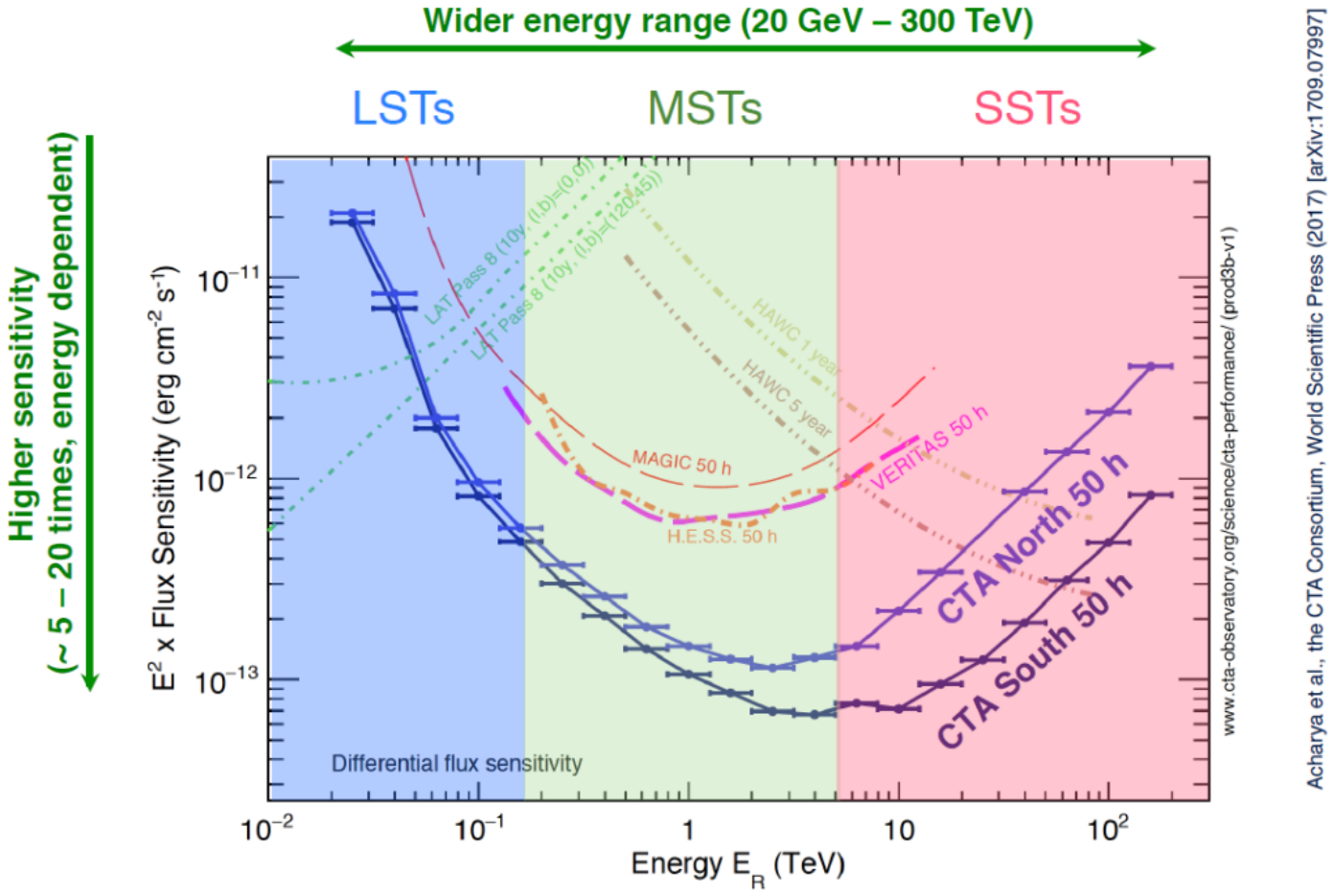
CTA observatory (CTAO):

- Next-generation ground-based Gamma-ray Observatory
- Open observatory designed to operate for 3 decades
- Two sites with total ~100 telescopes (LSTs + MSTs + SSTs)
  - Northern site: La Palma (Canary Islands, Spain)
  - Southern site: Paranal (Chile)
    - 4 Large-size Telescopes (LSTs ~23 meters)
    - 23 Medium-size Telescopes (MSTs ~12 meters)
    - 37-50 Small-size Telescopes (SSTs ~4 meters)
- ~1450 members, ~200 institutes, 31 countries



cherenkov telescope array





Science with the Cherenkov Telescope Array. Edited by CTA Consortium https://www.worldscientific.com/worldscibooks/10.1142/10986

CTA will address three science themes

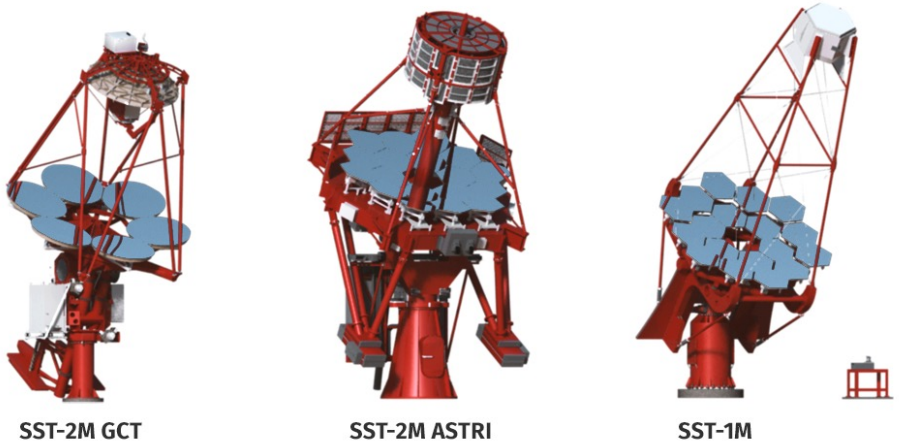
1. Cosmic Particle Acceleration
2. Probing Extreme Environments
3. Physics frontiers – beyond the Standard Model

through several key science programs

- Dark Matter Programme
- Galactic Center Survey
- Galactic Plane Survey
- Large Magellanic Cloud Survey
- Extragalactic Survey
- Transients
- Cosmic-ray PeVatrons
- Star Forming Systems
- Active Galactic Nuclei
- Clusters of Galaxies

CTAO: SSTs very short history

In the beginning…



May 2018 ➔ CTAO Council decision to *"to evolve towards a single design for the SST structure and camera"*

Summer 2018 ➔ Start of the "harmonization" process through a Request for Information.

March 2019 ➔ Three "proposals" submitted (ASTRI/CHEC, GCT/Obs. de Paris, Consortium 1M) and evaluated by an external committee

June 2019 ➔ Council resolution on the SST configuration *"…., the CTAO Management proposes that the CTA-SST design be based on the ASTRI-CHEC dual-mirror scheme taking into account the previous experience gained on all designs."*

November 2019 ➔ A high level management and implementation plan for the SST telescopes presented at the CTAO Council by ASTRI, CHEC and Obs de Paris teams

SST Programme Proposal

A high-level implementation plan for the provision of the SSTs

Version

V2.0 (08-01-2020)

Editorial Board

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OVERALL COST about 50 MEURO

Country	Stakeholders
Italy	INAF
France	Observatoire de Paris / CNRS
Germany	MPIK DESY U. Erlangen (ECAP)
UK	U. Leicester U. Liverpool U. Oxford U. Durham

Country	Stakeholders
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Japan	U. Nagoya
Australia	U. Adelaide[1]
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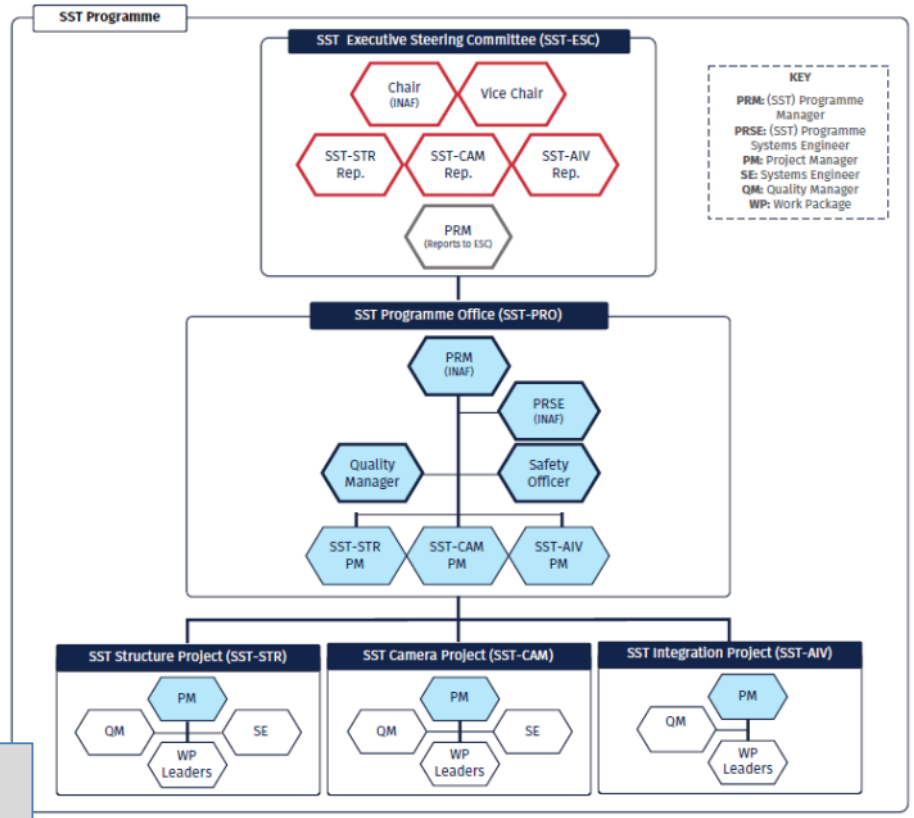
South Africa	North West U.
Switzerland	U. Geneva, Dept. of Astronomy



High Level Organization of the SST Consortium

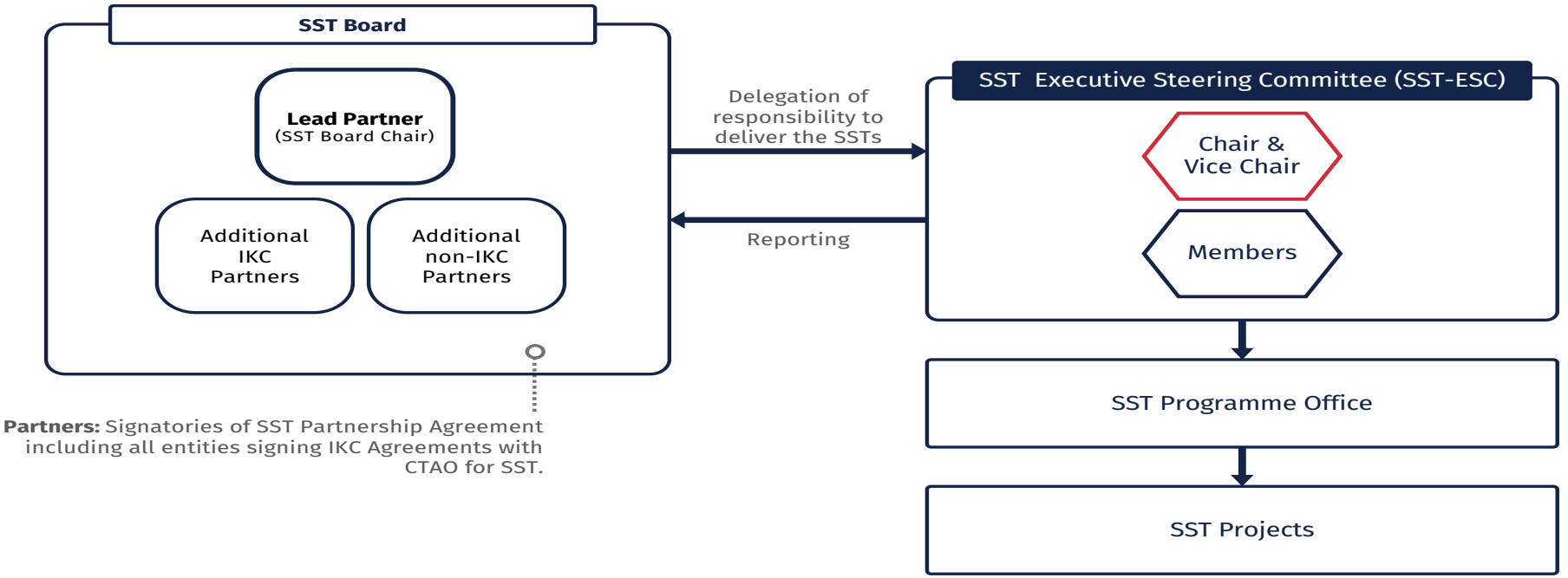


Figure 1: Overview of the SST Governance structure.

E. M. de Gouveia Dal Pino: member of the SST Executive Steering Committee

Interactions with CTAO

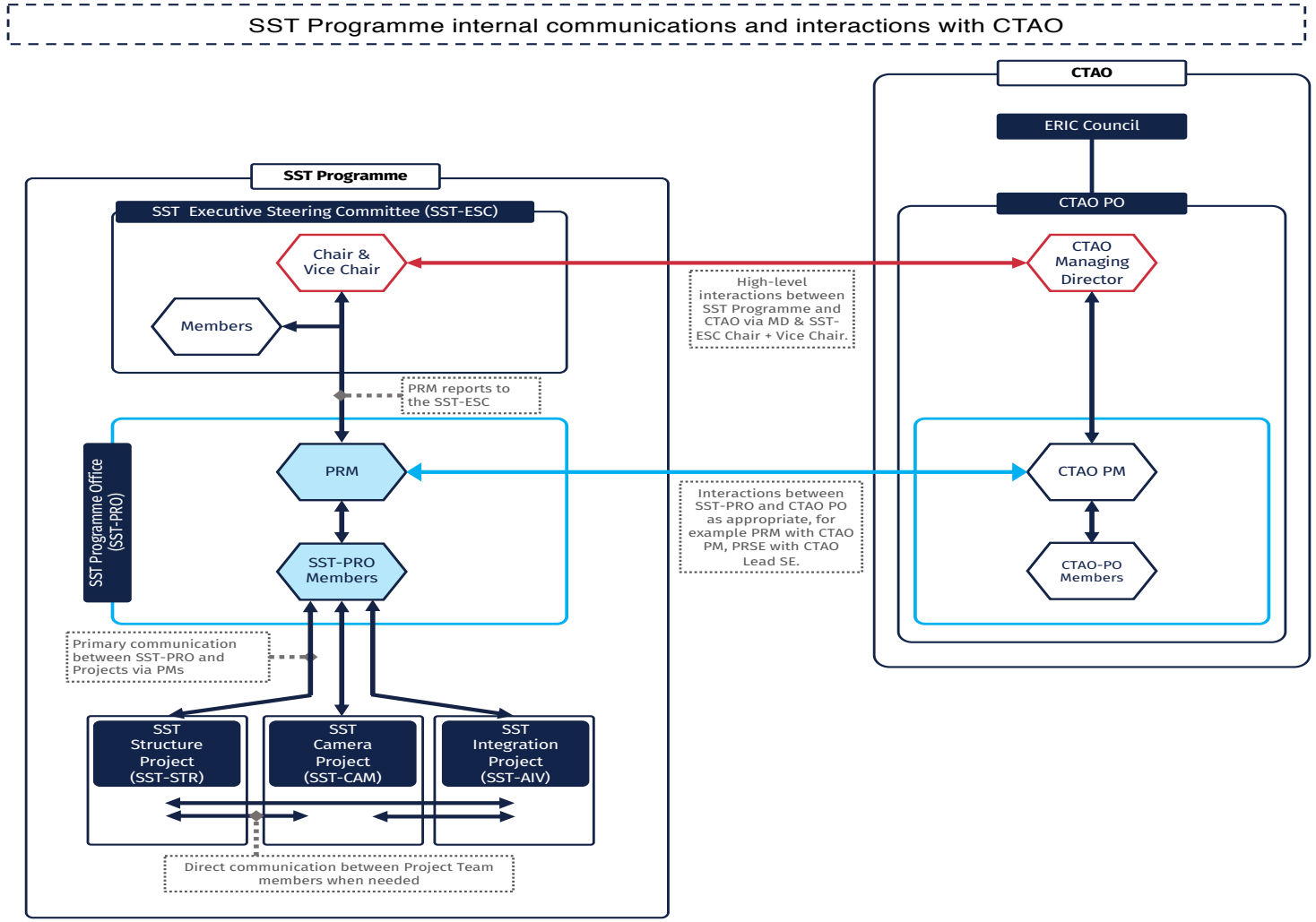
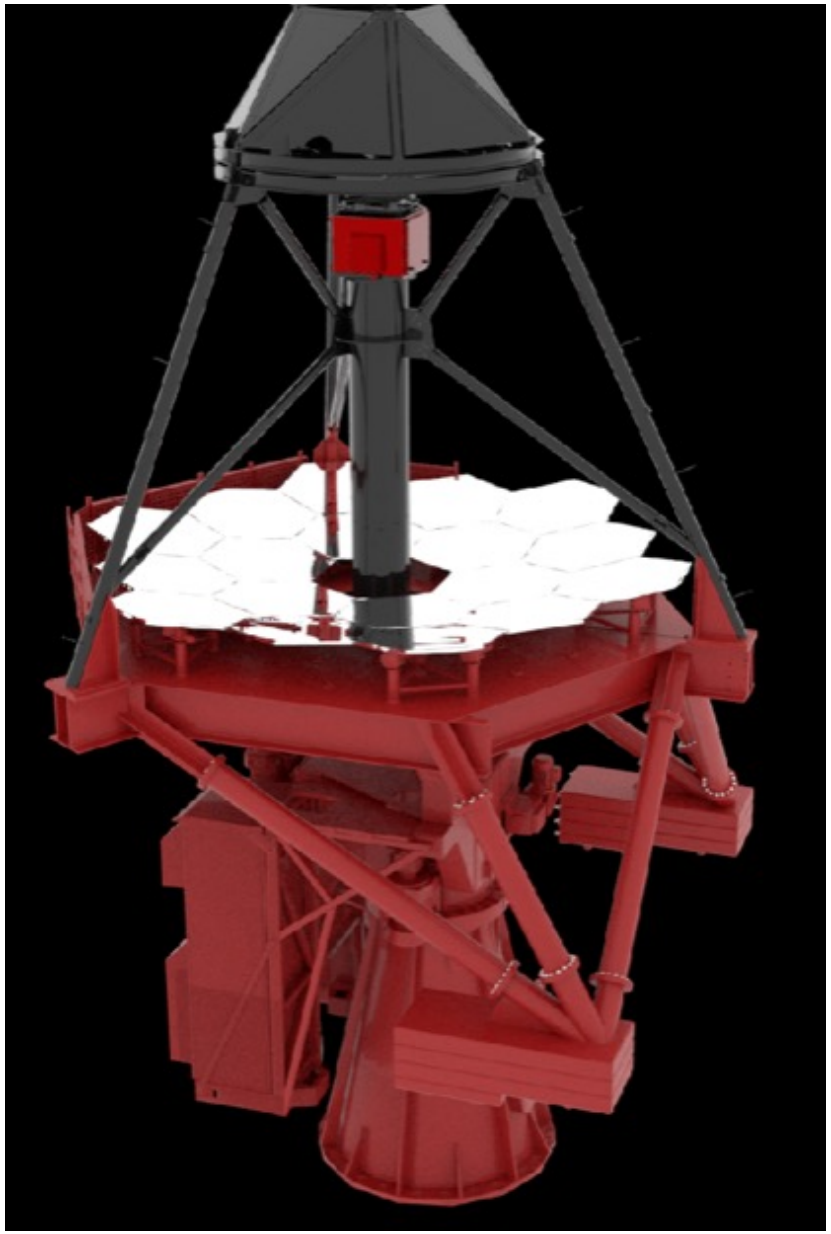


Figure 3: Outline of internal Programme communications and SST Programme interactions with CTAO. Exact scheme to be finalised upon release of CTAO Project Management Plan.



- Design Review of the ASTRI/CHEC design organized by CTAO with external members (also able to consider different solutions for subsystems)
- Optimization of the design for both Structure and Camera and finalization of the design leading to a Critical Design Review and then to production
- Preparation of the Implementation and Managements plans → ad interim (waiting for ERIC and IKC) Program Office (and final Steering Committee will be appointed)
- Verification of the resources and trade off (in close collaboration with CTAO)

BRAZILIANs in the ASTRI & CTA-SSTs *so far*

- About 29: researchers, post-docs, students, engineers
- IAG-USP
- EACH-USP
- IFUSP
- Universidade Mackenzie
- UFABC
- CBPF

BRAZILIAN BUDGET in ASTRI & CTA *so far*

- **FAPESP** : total budget awarded: **R$ 19.3M**

  ✓ **Thematic Project 13/10559-5 (Elisabete de Gouveia Dal Pino, IAG-USP): 14,4 M R$**

  + 2,7 M R$ (postdoc scholarships and international advanced school)

OUR PARTICIPATION *history so far*

- **2016 ASTRI MOU** involving USP, FAPESP and INAF: roles and responsibilities of the parties transfer of technology, intellectual property use, governance and maintenance of the MINI-ARRAY
- **1.6 MEuro** issued to INAF for 3 ASTRI Structures (2017)
- **Several scholarships** (in our Project: 6 postdocs, 2 JPs, 6 PhDs, 1 M, 5 ICs)
- **Training of Human Resources**: SPSAS-HighAstro CTA - **Sao Paulo Advanced Science School on High Energy and Plasma Astrophysics at the CTA Era** (2017)
- **Development of the Science** Working Packages of CTA & ASTRI Mini-Array
- **Editorial board** of ASTRI papers (ASPO)
- **Engineers** Renato Gimenes and Carlos Fermino**: Instrumentation development**

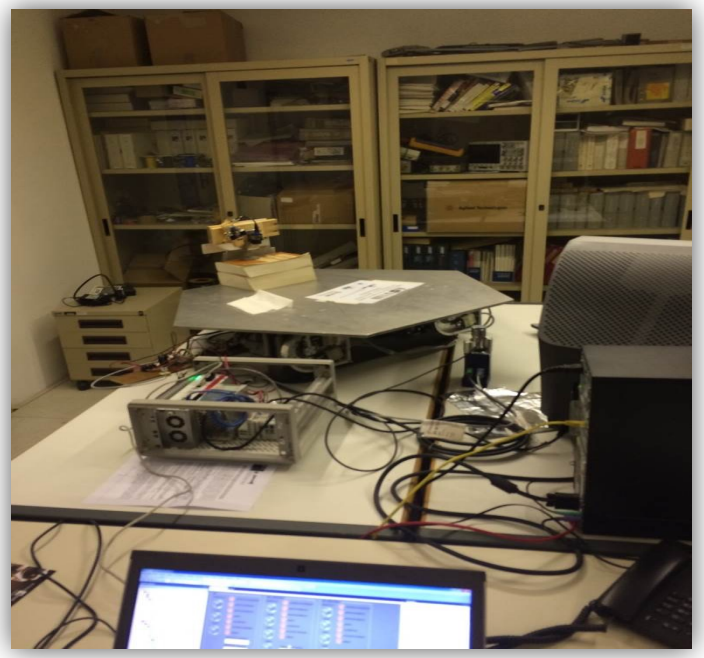
BRAZILIAN ENGINEERS @ ASTRI: structure/cam/software development

Active optics tests (Torino)

- With Daniele Gardiol & Federico Russo

Performed task:

- Segment motion
- Data colection and callibration
- Repeatability verification

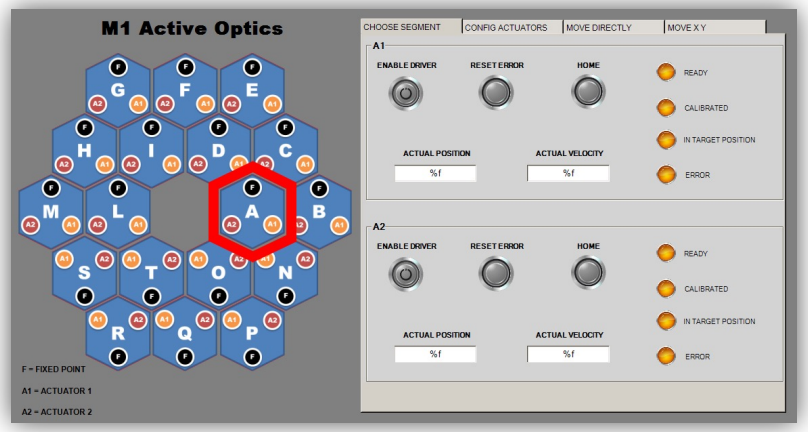


M1 Interface elaboration (Catania)

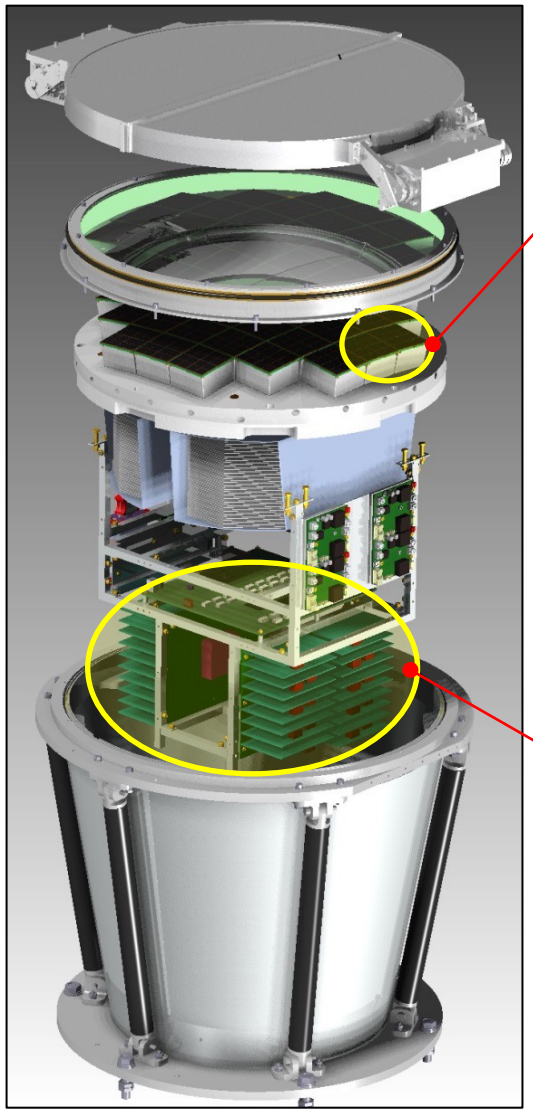
- W/ Matteo Munari, Salvo Scuderi, Enrico Giro, Luca Stringhetti, Elisa Antolini

Performed task:

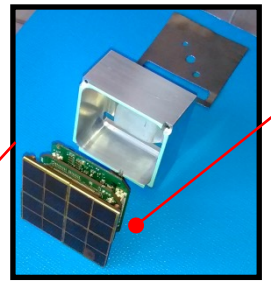
- Actuator configuration as in CANopen
- Screens preparation for driving motors
- interface implementation with users, scheduling tests, etc.
- Teaching on operation of logics for future change and implementation
- Teatching hardware & software Beckhoff

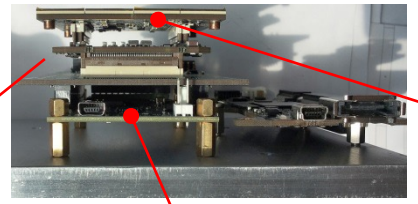


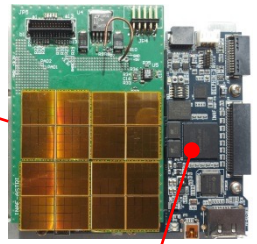
BRAZILIAN ENGINEERS @ IASF Palermo

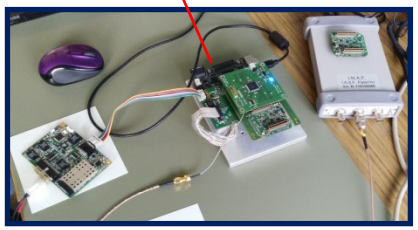


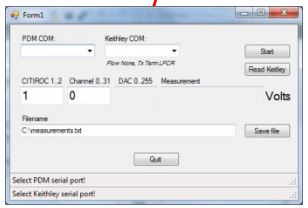
ASTRI Camera





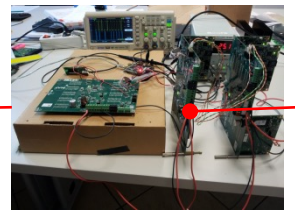


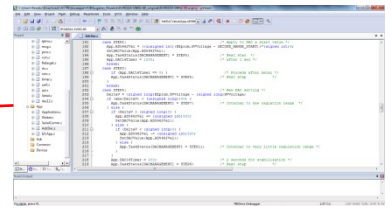




PDMs – Photodetector Modules

- *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*

NEXT STEP PARTICIPATION in SSTs for

- **Brasil in the SST Program**: ASTRI+CHEC (editorial board document)
- Currently: **~60 members in CTA-Br (~29 -> in this Project from IAG-USP, EACH-USP, Mackenzie, UFABC, IFUSP, CBPF)**
- Plans for manufacturing in Brazil **at least 3 of the 37 ASTRI SSTs structure**s of CTA-South array
- Approximate total cost: **~12 MReais**
- Technical Advisory: Eng. Carlos Fermino (eFe – Tecnologia (http://www.incubadora-araraquara.com.br/empresas-incubadas/residentes)
- Potential Companies: ZANINI; IESA; CITROTEC; SERMATEC

CTA Precursor towards CTA