IPARCOS

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Instrumental Contribution to Gamma Ray Astrophysics by IPARCOS-GAE

IPARCOS Scientific Advisory Board: Bi-Annual Review 2026

J.A. Barrio, on behalf of IPARCOS-GAE

Instrumentral Contribution Overview

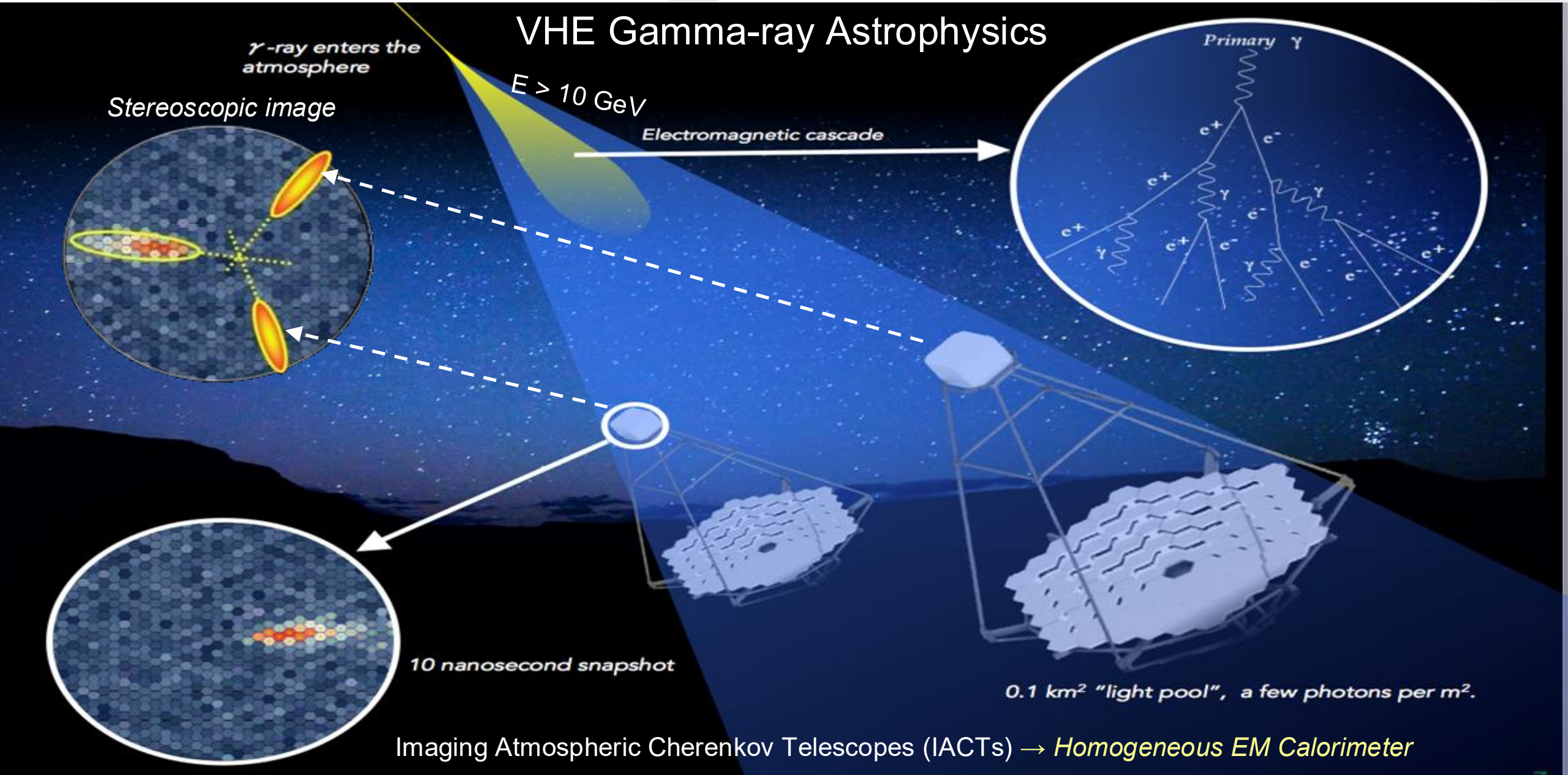
CTAO contribution

- Pipeline Software for On-Site Analysis
- ML-based Event-Reconstruction software
- Trigger for Telescope Cameras
- R&D Trigger & Clock for Advanced Cameras

Other contributions

- **Silicon Photo-Multiplier characterization**

IACT Technique



Imaging Atmospheric Cherenkov Telescopes (IACTs) → *Homogeneous EM Calorimeter*

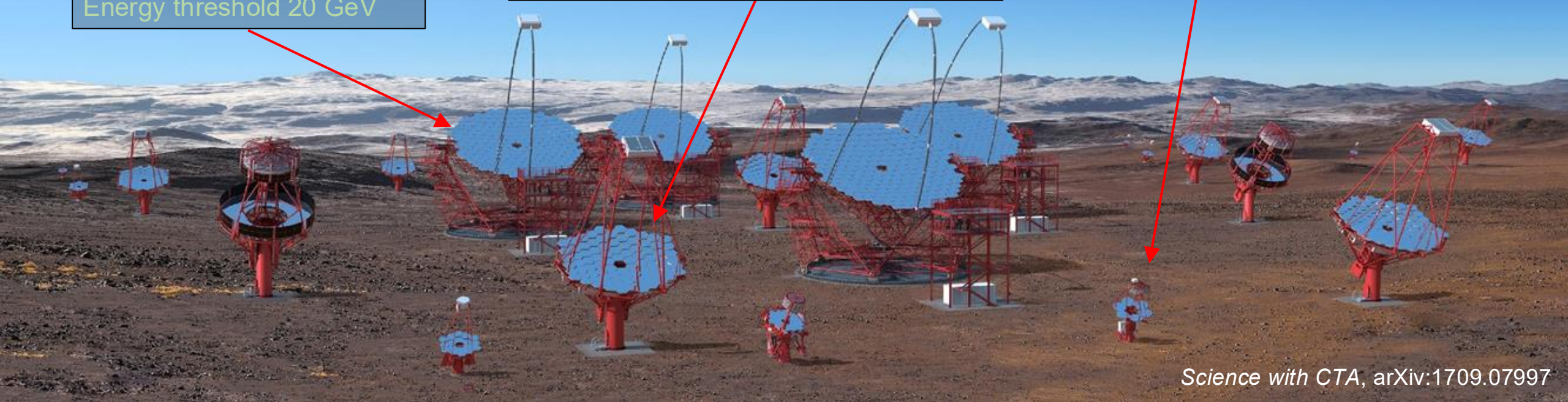
CTAO description

- Cherenkov Telescope Array Observatory
- 5-20 fold better sensitivity w.r.t. current IACTs
- 4 decades of energy coverage: 20 GeV to 300 TeV
- Improved angular and energy resolution
- Two arrays (North – La Palma / South - Paranal)

Low-energy range (LST):
23 m ø Parabolic reflector
4.5° FoV
Energy threshold 20 GeV

Mid energy-range (MST):
12 m ø modified Davies-Cotton reflector
8° FoV
Full system sensitivity 150 GeV – 5 TeV

High-energy range (SST):
4 m ø Schwarzschild-Couder reflector
10° FoV
Several km^2 area at multi-TeV energies



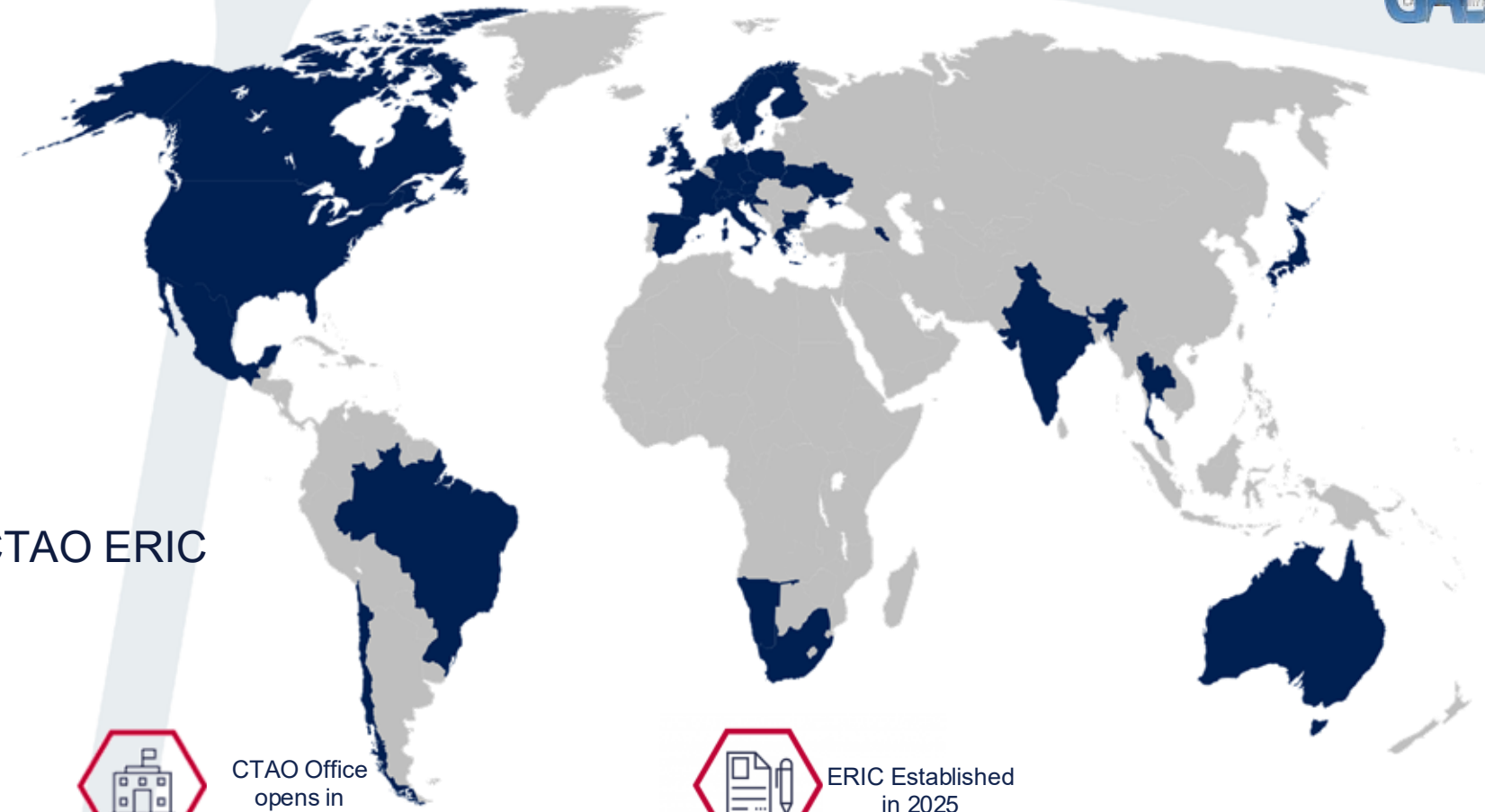
Science with CTA, arXiv:1709.07997

CTAO Project

~15 countries
~200 institutes
~1500 members

CTAO Council

CTAO ERIC



CTAO Office opens in Bologna in 2017

ERIC Established in 2025

Design	Prototyping	Pre-production (2019 – 2026)	Production (2027 – 2030?)
2008 - 2012	2012 - 2018	Early LST Science	Early CTAO Science

First Pre-production LST-1 on Site 2019

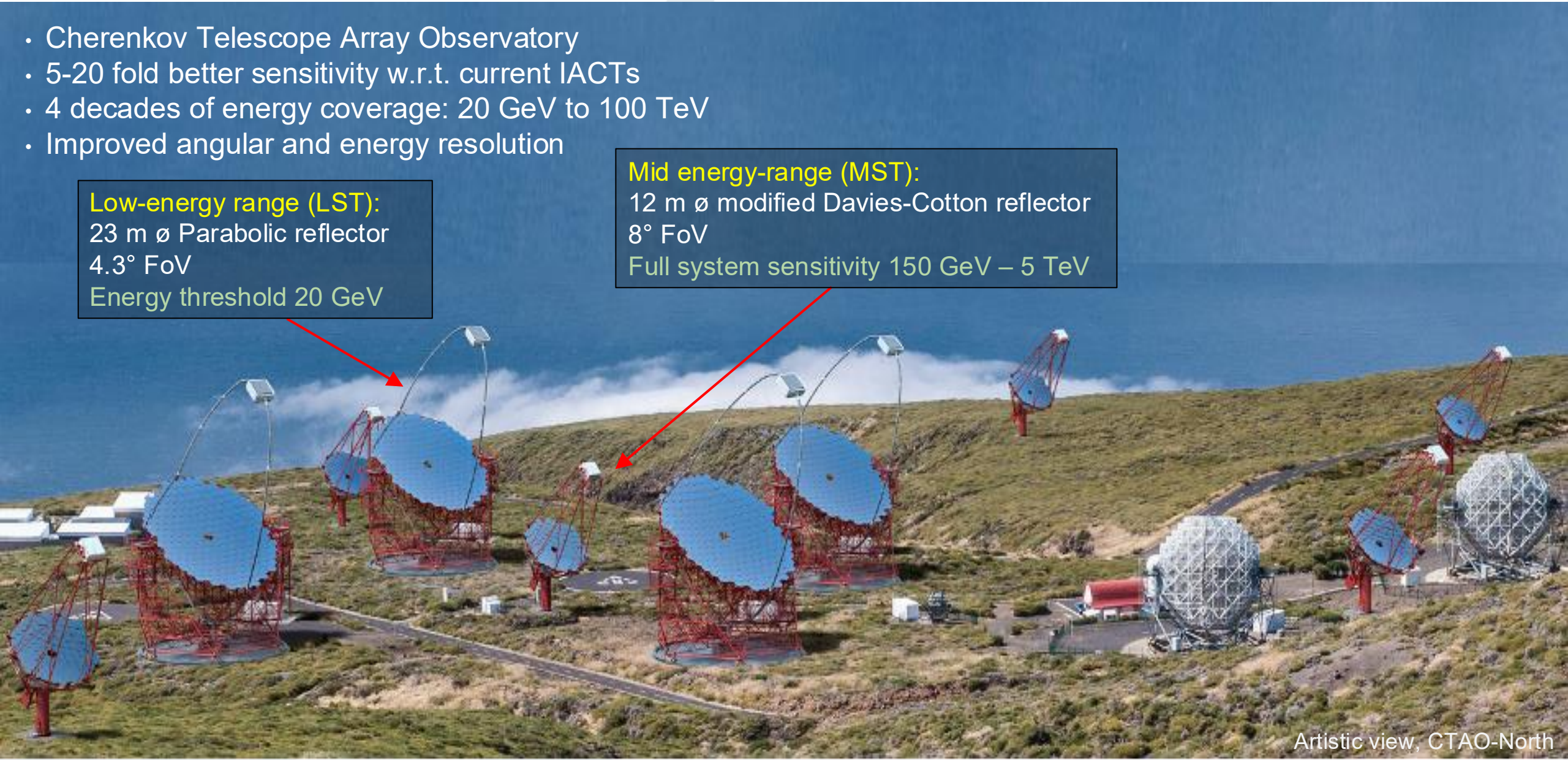
First Pre-production MSTs on Site 2026

IPARCOS-GAE focus on CTAO North

- Cherenkov Telescope Array Observatory
- 5-20 fold better sensitivity w.r.t. current IACTs
- 4 decades of energy coverage: 20 GeV to 100 TeV
- Improved angular and energy resolution

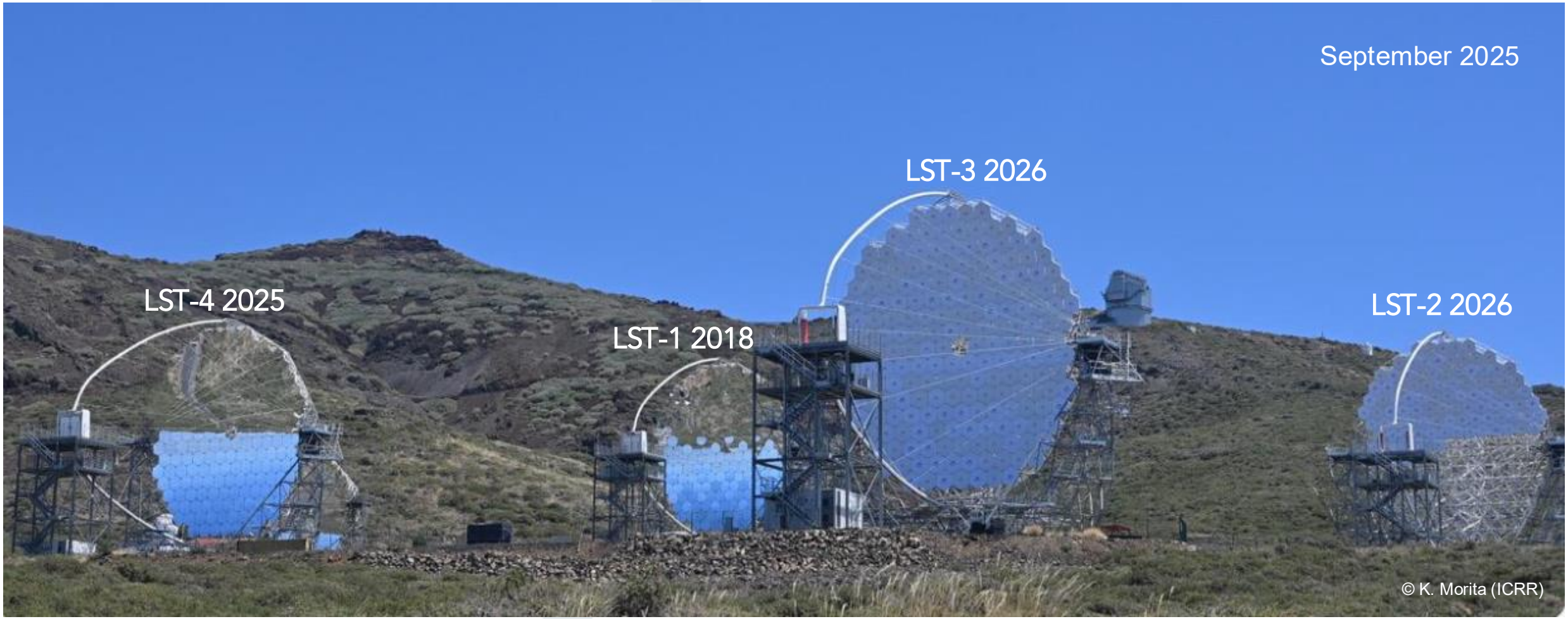
Low-energy range (LST):
23 m ø Parabolic reflector
4.3° FoV
Energy threshold 20 GeV

Mid energy-range (MST):
12 m ø modified Davies-Cotton reflector
8° FoV
Full system sensitivity 150 GeV – 5 TeV

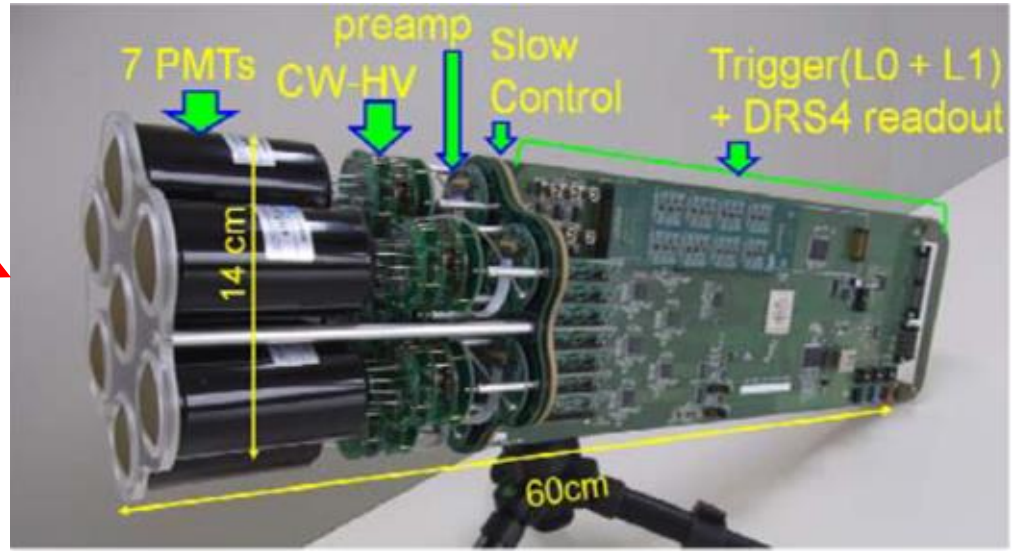


Artistic view, CTAO-North

IPARCOS-GAE focus on CTAO North

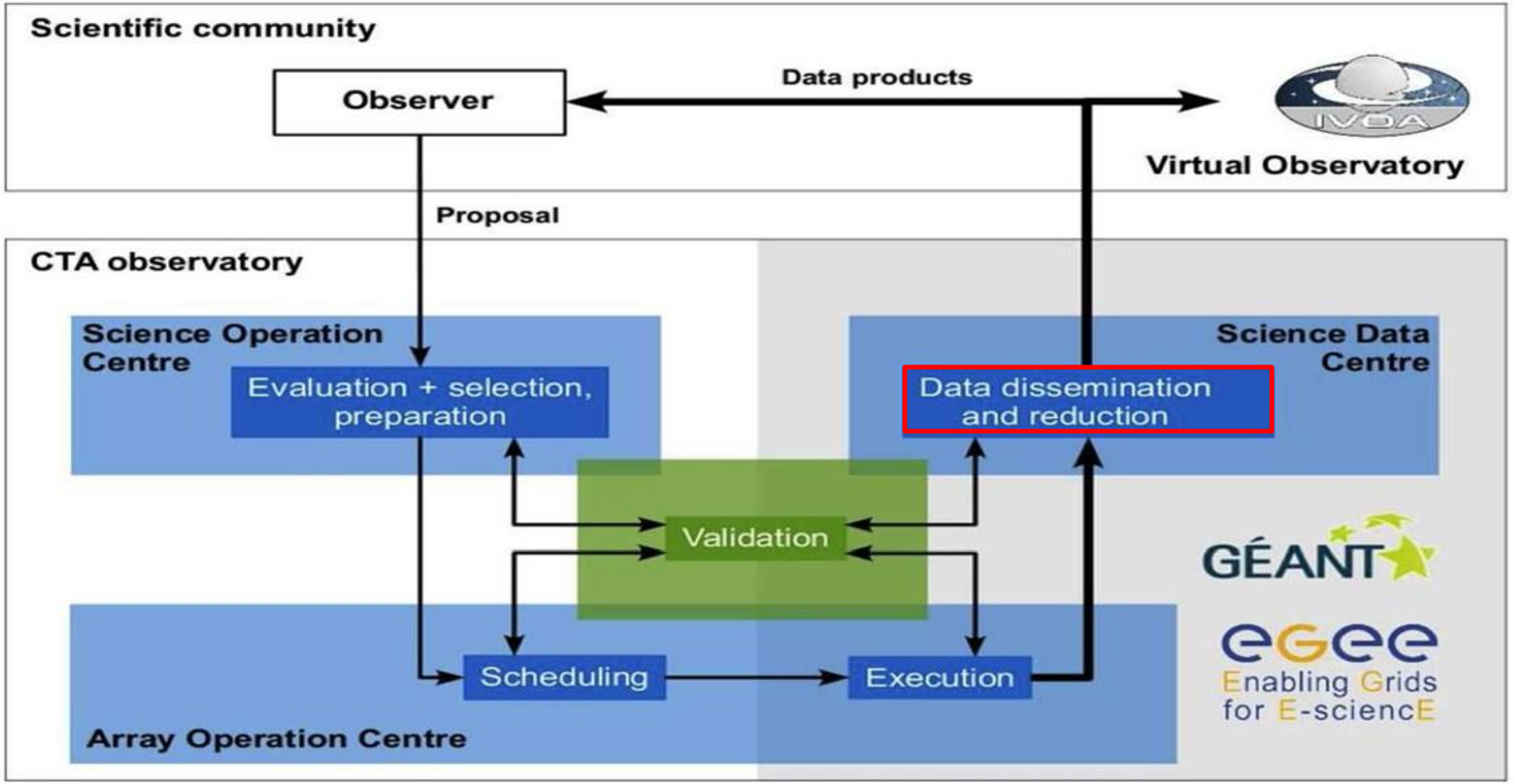


Cherenkov Telescope Array Observatory



~2000-pixel PMT-based camera

Cherenkov Telescope Array Observatory



Pipelines: Onsite Analysis MAGIC & LST

The group is responsible for the onsite analysis of both observatories

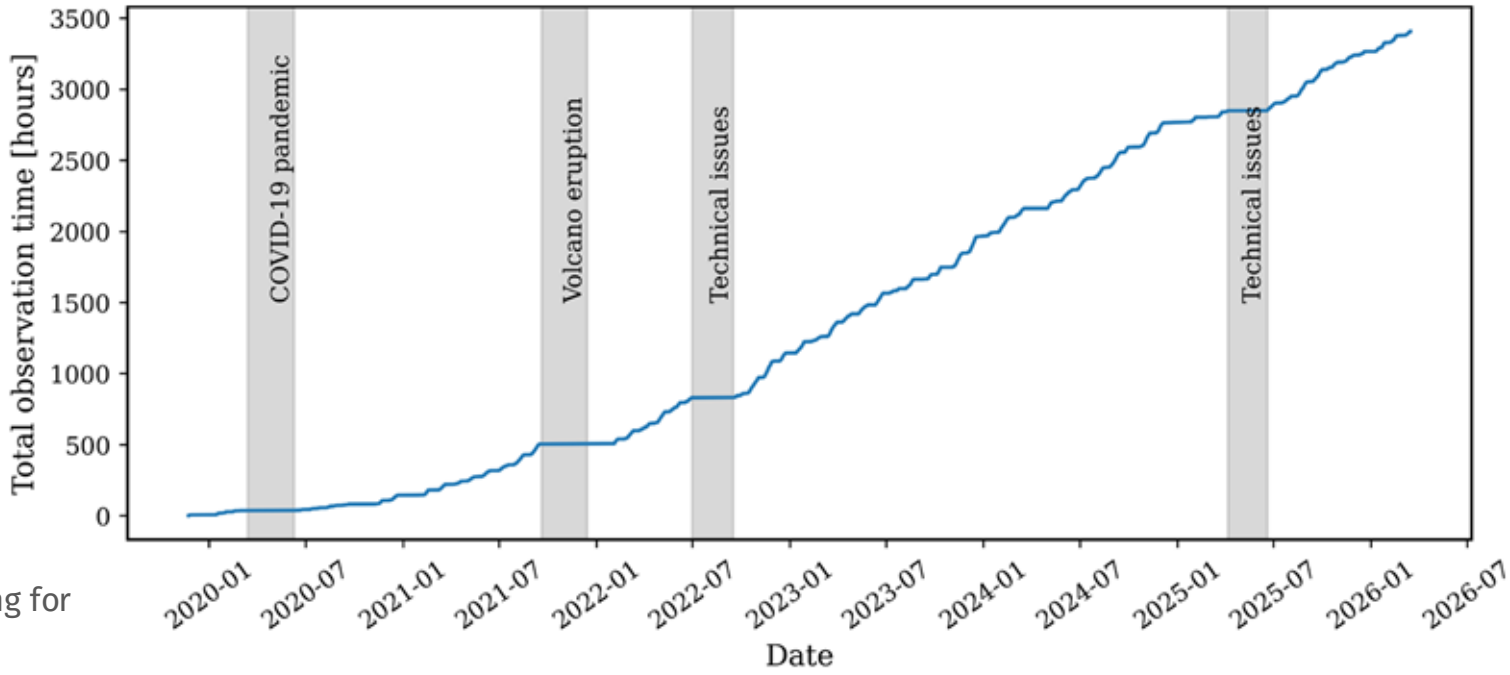
Data produced is the basis for 90% of the papers and the daily data check, and Data Volume Reduction (LST-1)

Both of them work everyday @observatory sites in an nearly automatic mode.

- **MAGIC: (2003→):** Private code. Maintenance and supervision (1-2 TB/day)
- **LST (2020 →):** Public code. Working and growing (40-50 TB/day)
  Massive paralellisation: up to 20k jobs/day

Personnel

2 shared Phd. Students
1 yearly contract
IPARCOS staff: J.L. Contreras



A.Dinesh et al 2025 ICRC 2025 Geneva July 2025
"Next-day observation processing for the LST-1 and MAGIC"

Pipelines: Onsite Analysis MAGIC & LST

A lot of work in the future on the LST side

- **More telescopes coming on line LST-2, LST3, LST-4**

  CPU x 4 , Disk x 4 ? → Now at ~1800 cores + 5.7 PB

- **Onsite IT resources are under tension, both on disk and CPU**

- **Official CTAO software will eventually take over, not sure when**
  We should collaborate with them

  More person-power needed → Integrating AI in the development (as everyone)

- **Resources promised for CTAO software development are late**

CTLearn

High-level Python package for using deep learning for IACT event reconstruction

- **Open source on GitHub:**

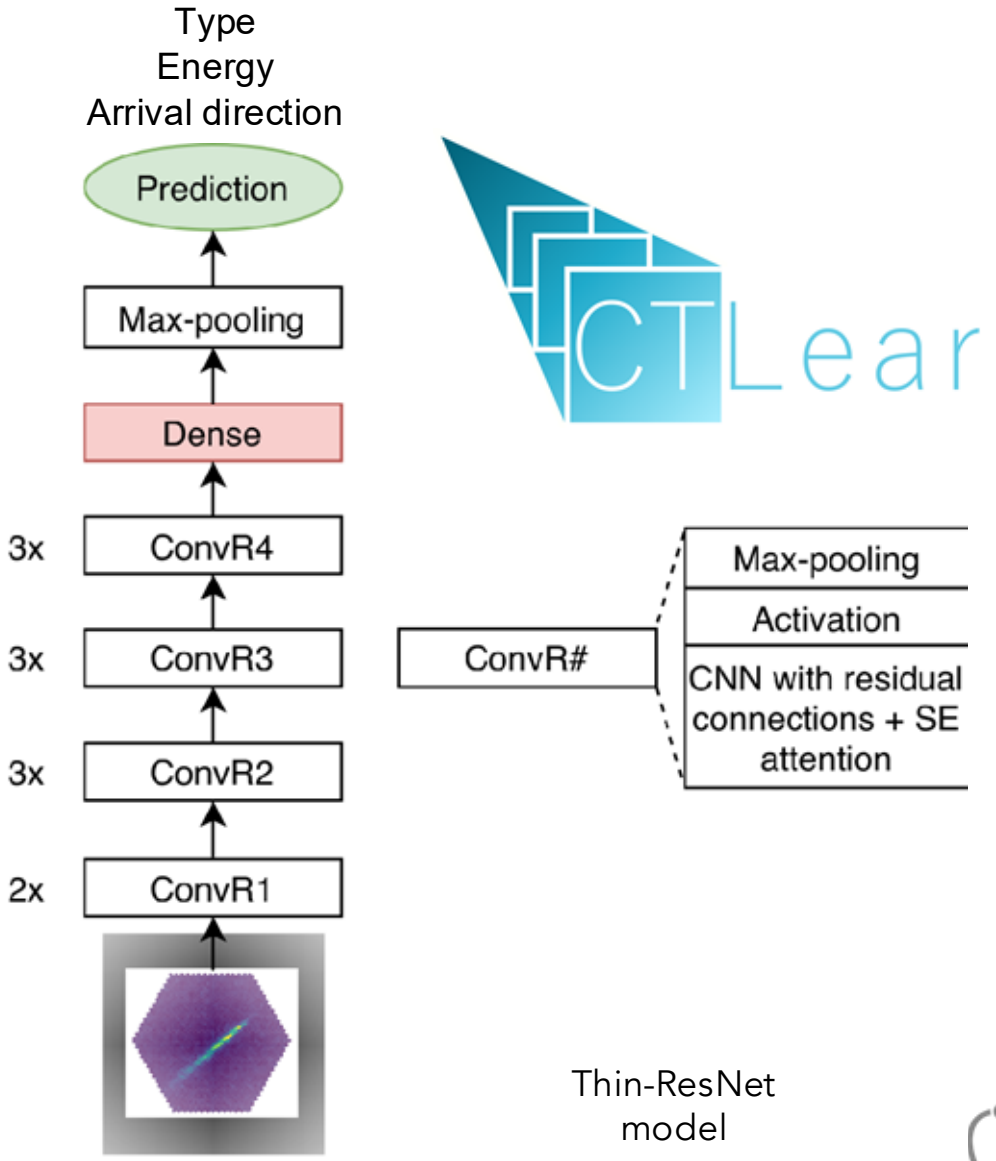
  github.com/ctlearn-project/ctlearn
  10.5281/zenodo.3342952

- **Collaborative effort led by IPARCOS-UCM:**

  IPARCOS staff: D. Nieto
  U. de Geneve, IAA-CSIC, U. Torino

Access to ARTEMISA GPU cluster in 2025

- Bulk of experiments run there now but keep maintaining our local GPU infrastructure
- Trimestral renewal since first allocation



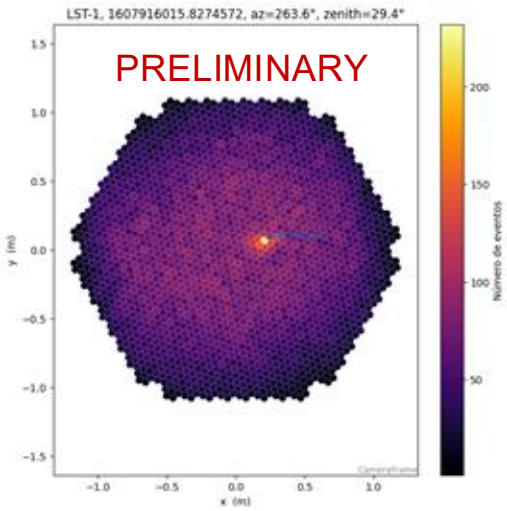
Thin-ResNet model

CTLearn

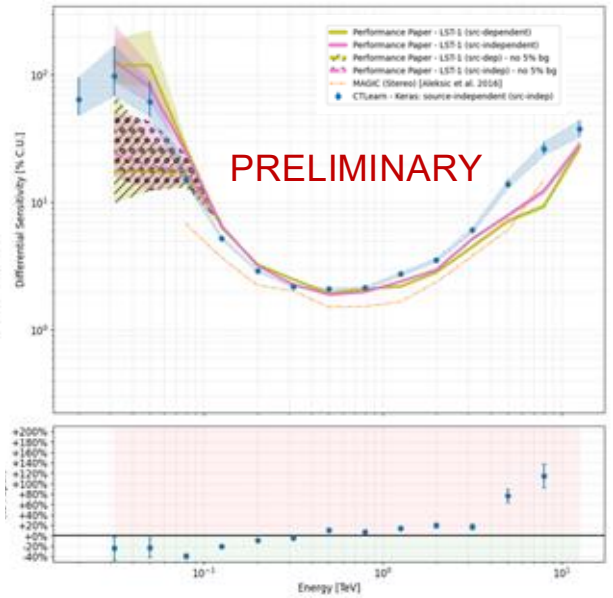
Major milestone achieved in 2025:

- Application to LST-1 REAL DATA from the Crab Nebula and Pulsar

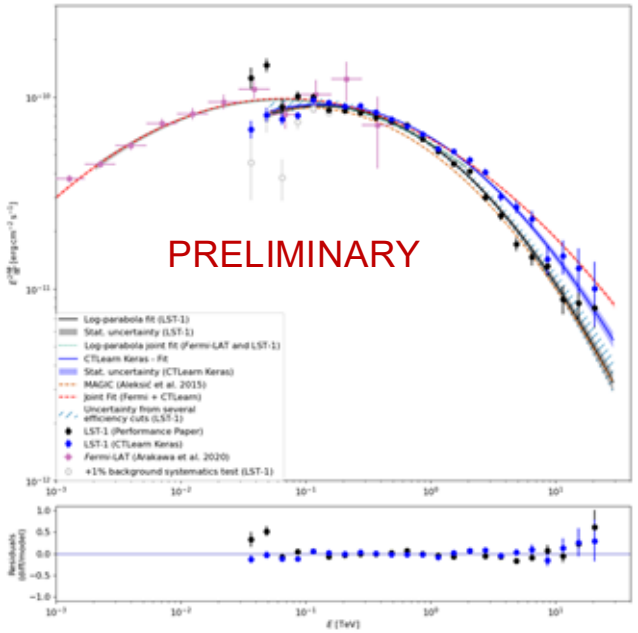
Skymap



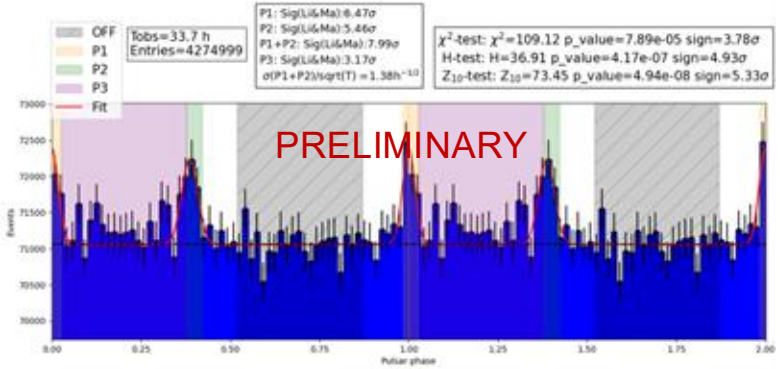
Sensitivity



Spectrum



Phaseogram



A. Cerviño & J. Buces (PhD students)

Trigger Interface Board for Telescopes

TIB functionalities

- Hardware Stereoscopic Triggers among LSTs → Energy threshold reduction
- Trigger management for LSTs and MSTs

CTAO-North LST production

- 4 TIB produced and integrated in cameras by 2023

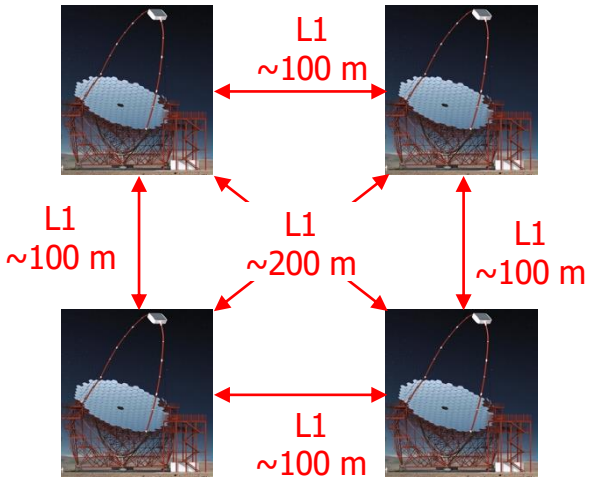
CTAO-North MST production

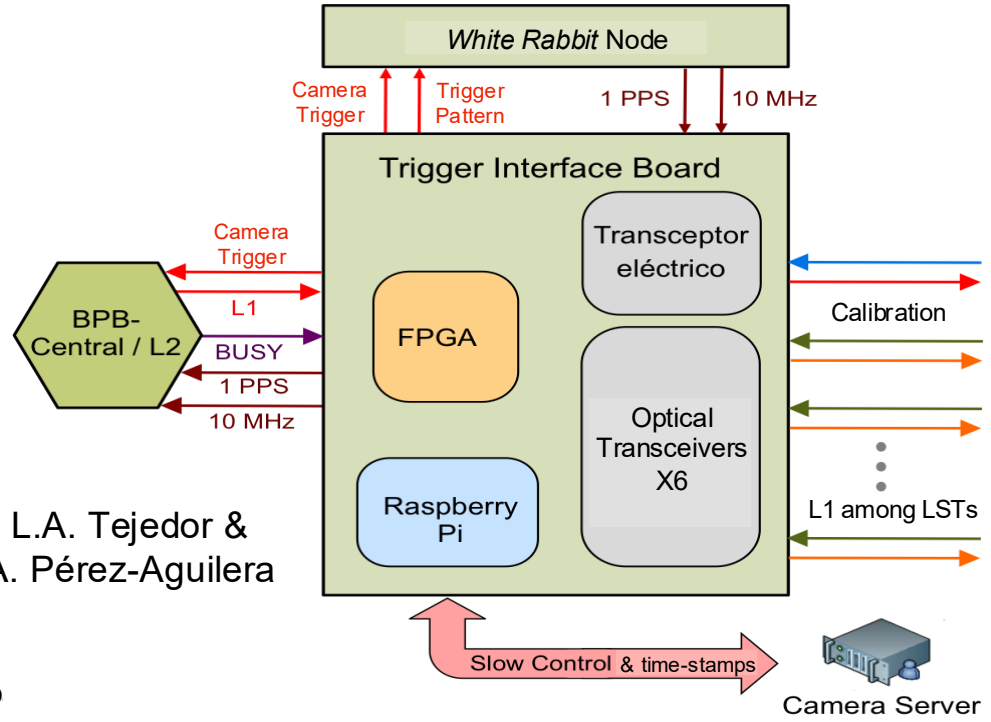
- 9 TIB produced by 2025
- Integration ongoing for ~2025-2028

CTAO-South LST production

- 4 TIB produced by 2025
- Integration ongoing for ~2025-2028

IPARCOS staff: J.A. Barrio, L.A. Tejedor





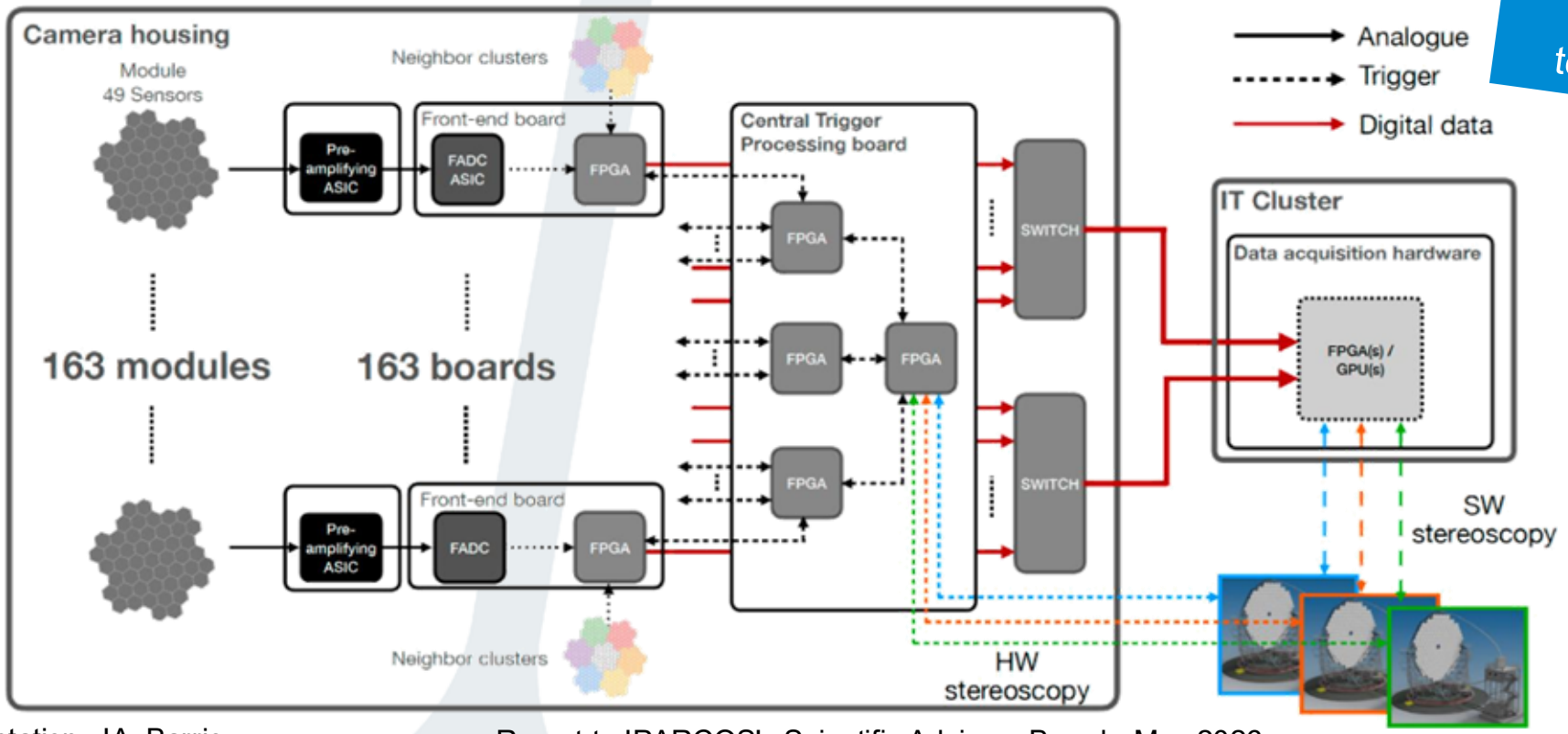
L.A. Tejedor &
A. Pérez-Aguilera

Advanced Camera Trigger

The group contributes to the design of the Advanced Camera for LSTs, based on SiPM

- 7987 pixels, sampled at 1 GHz, grouped in 163 modules with Front-end boards (FEB) implementing the L1 trigger
- IPARCOS-GAE is in charge of the Central Trigger Processor board (CTP), performing the Camera Trigger
  - Receives a 10 Gbps optical link from each FEB with trigger information
  - Runs **CTLearn** Machine Learning algorithm on these information, to accept Cherenkov showers images and reject NSB
  - Over the remaining events, runs a topological stereo trigger
  - Camera Clock via White Rabbit core

Candidate for mid-term upgrade of CTAO telescope cameras



Advanced Camera Trigger

Development, training and assessment of ML algorithms

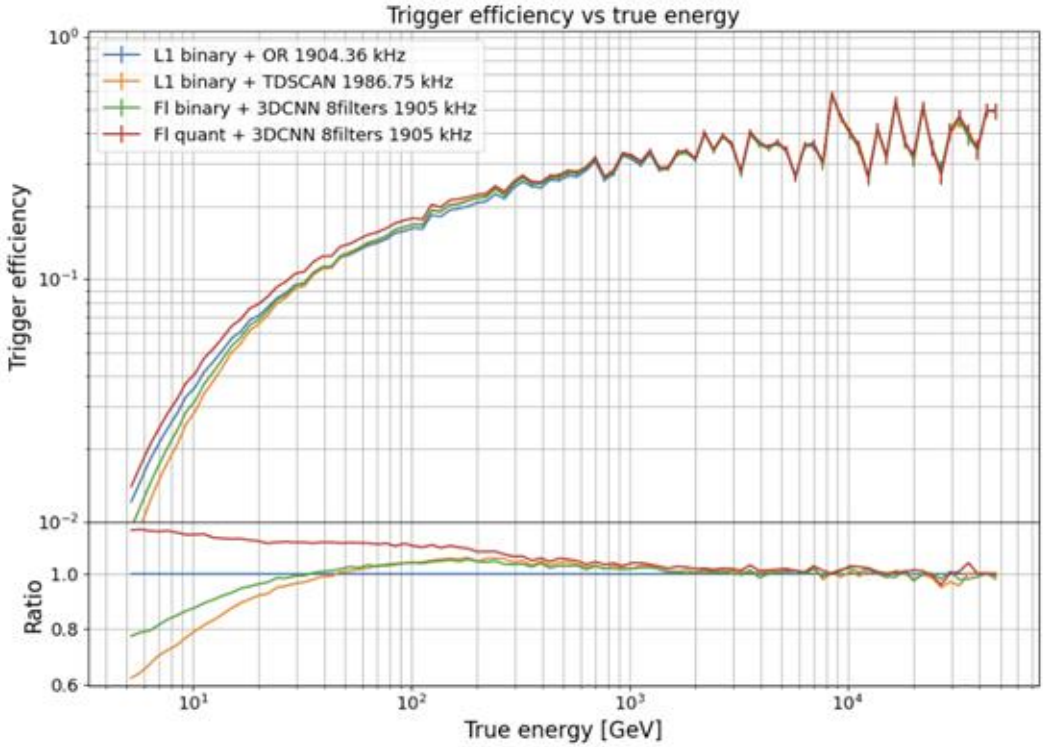
- Using boolean data or amplitude aware data.
- **CTLearn**-CNNs beat the performance of other algorithms

Implementation and test of CNN algorithms in FPGAs

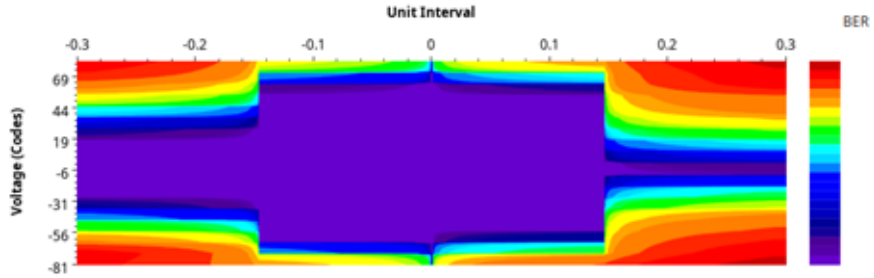
- Porting trained CNN models to Vitis (C++), as alternative to HLS4ML
- HLS optimization techniques: Loop unrolling, dataflow and array optimization, AXI4 interfaces, etc.
- Validation at XCKU040@330 MHz
- 1.94 ·10^6 inferences/s, 1,91 µs fixed latency

Design of the CTP

- Development and test of high frequency PCBs
- Test of high speed optical links: Fireflies and protocols
- Inclusion of a White Rabit node



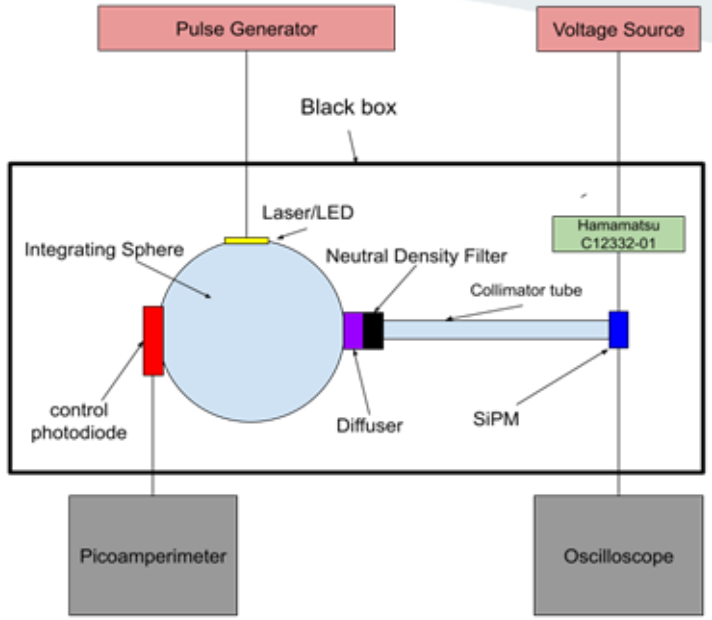
J. Buces, M. Molina, A. Pérez-Aguilera (PhD students)



Silicon PM Characterization

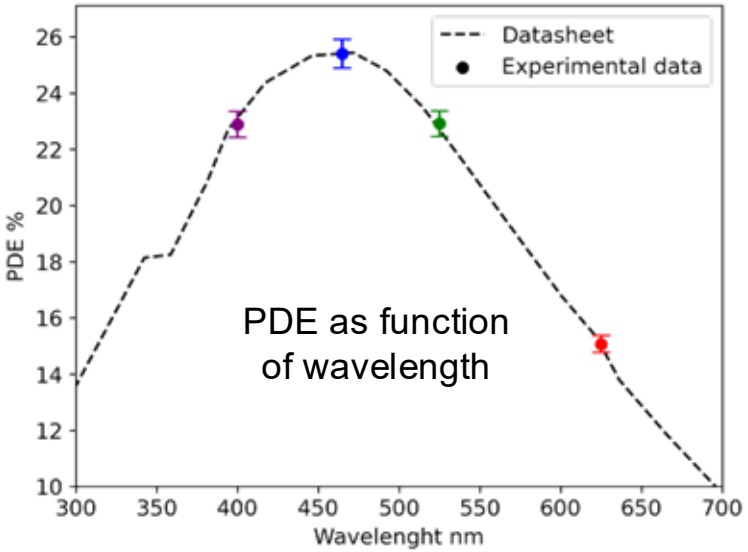
Experimental setup

- Laser and LED light sources + waveform generator
- Integrating sphere
- Calibrated photodiode + picoamperimeter
- Variety of SiPMs + driver circuit
- Diffuser, optical filters, collimator tubes…
- Black box
- Digital oscilloscope
- Detailed waveform analysis



Absolute PDE measurements

- Laser and LED pulses at different wavelengths
- Number of incident photons determined by calibrated photodiode
- SiPM measurements at single photon conditions (Poisson statistics)



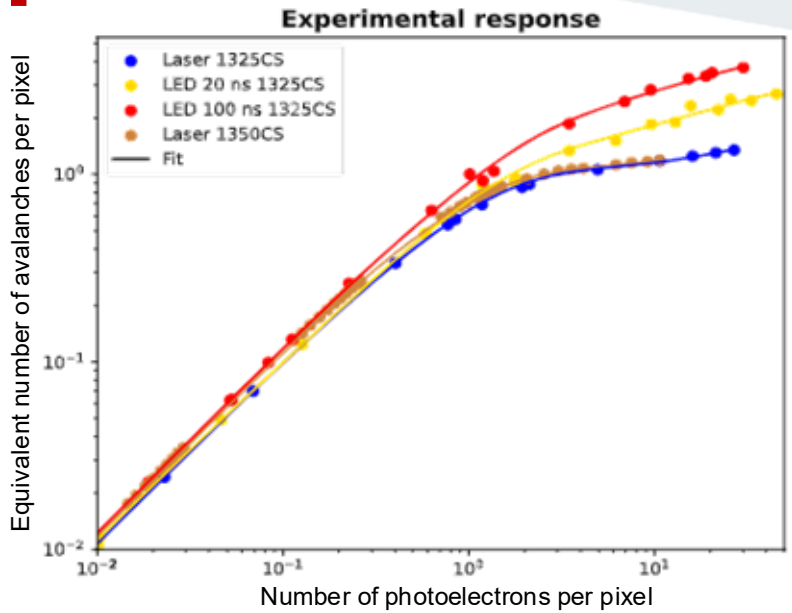
V. Moya (PhD student)

IPARCOS staff: J. Rosado

Silicon PM Characterization

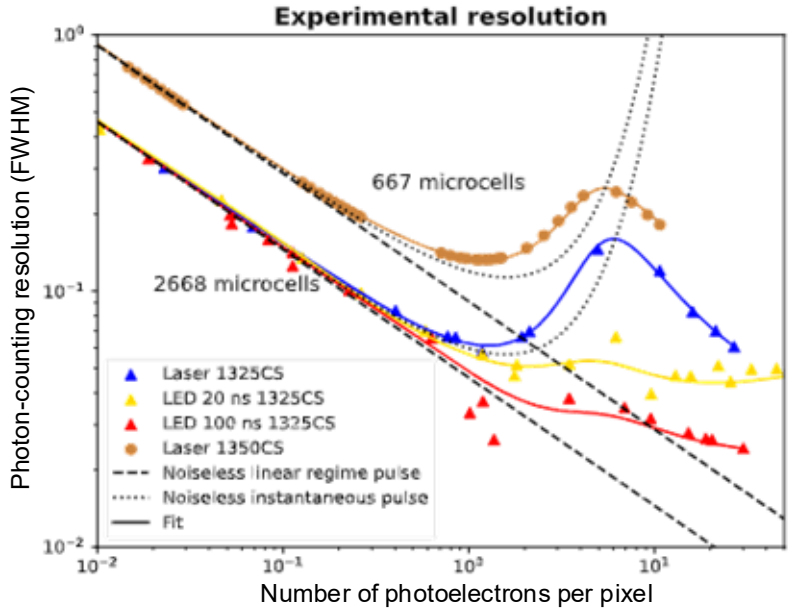
Nonlinear response of SiPM

- Characterization of mean output charge for different light pulse shapes and widths
- Fitting model including pixel recovery, correlated noise and light pulse shape



Photon-counting resolution in the nonlinear regime

- Exact theoretical models for limiting cases: instantaneous or very long light pulses without correlated noise
- Fitting models for general case
- Optimal resolution in the nonlinear regime !!



V. Moya (PhD student)

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Conclusions

- Strong focus on finishing CTAO telescope production
- Contribution to s/w pipelines and ML tools for CTAO
- R&D for CTAO merging Trigger & ML expertise
- Characterization of SiPMs