The Large-Sized Telescope

Project status

Matthieu Heller for CTA LST Project
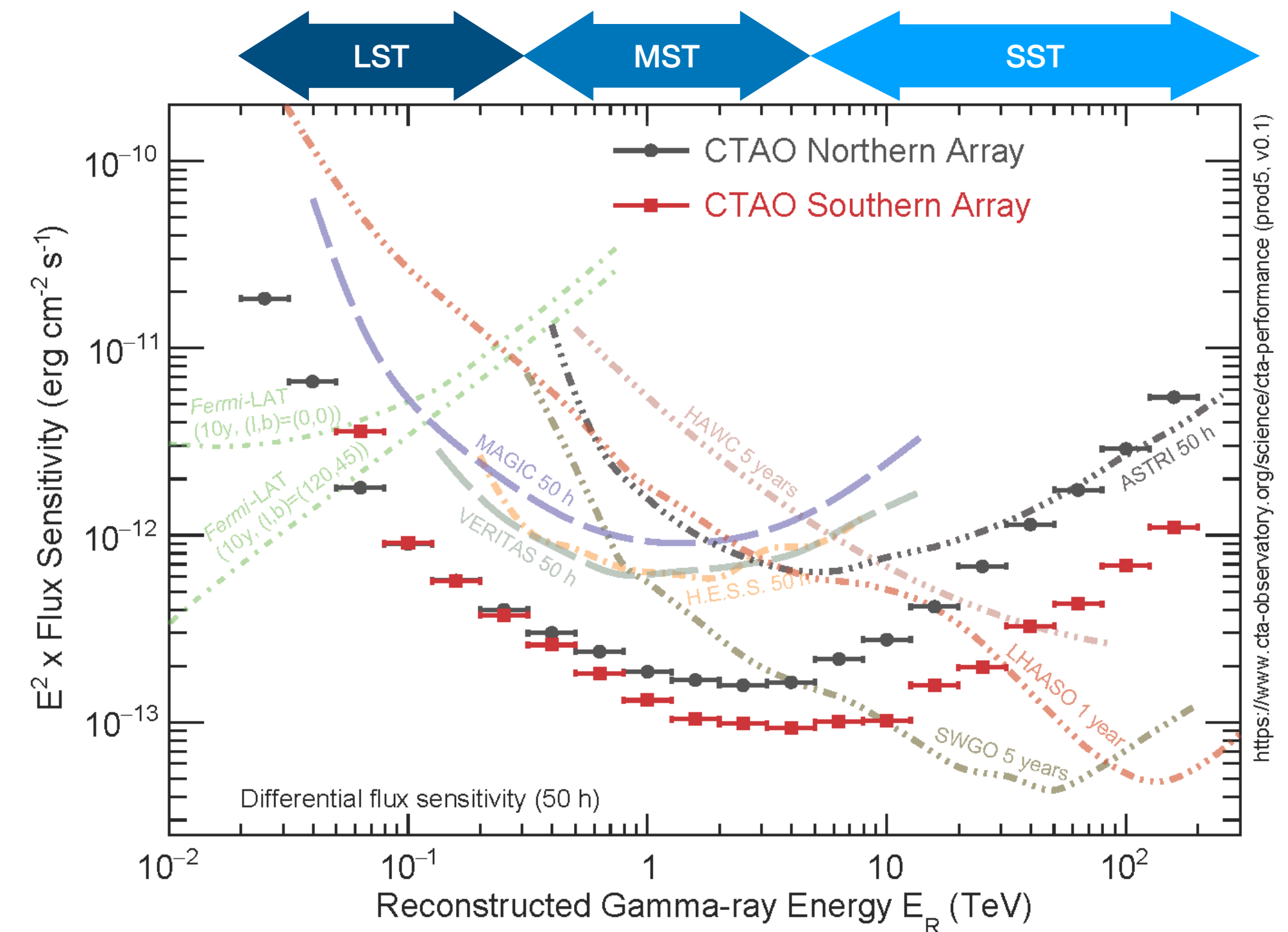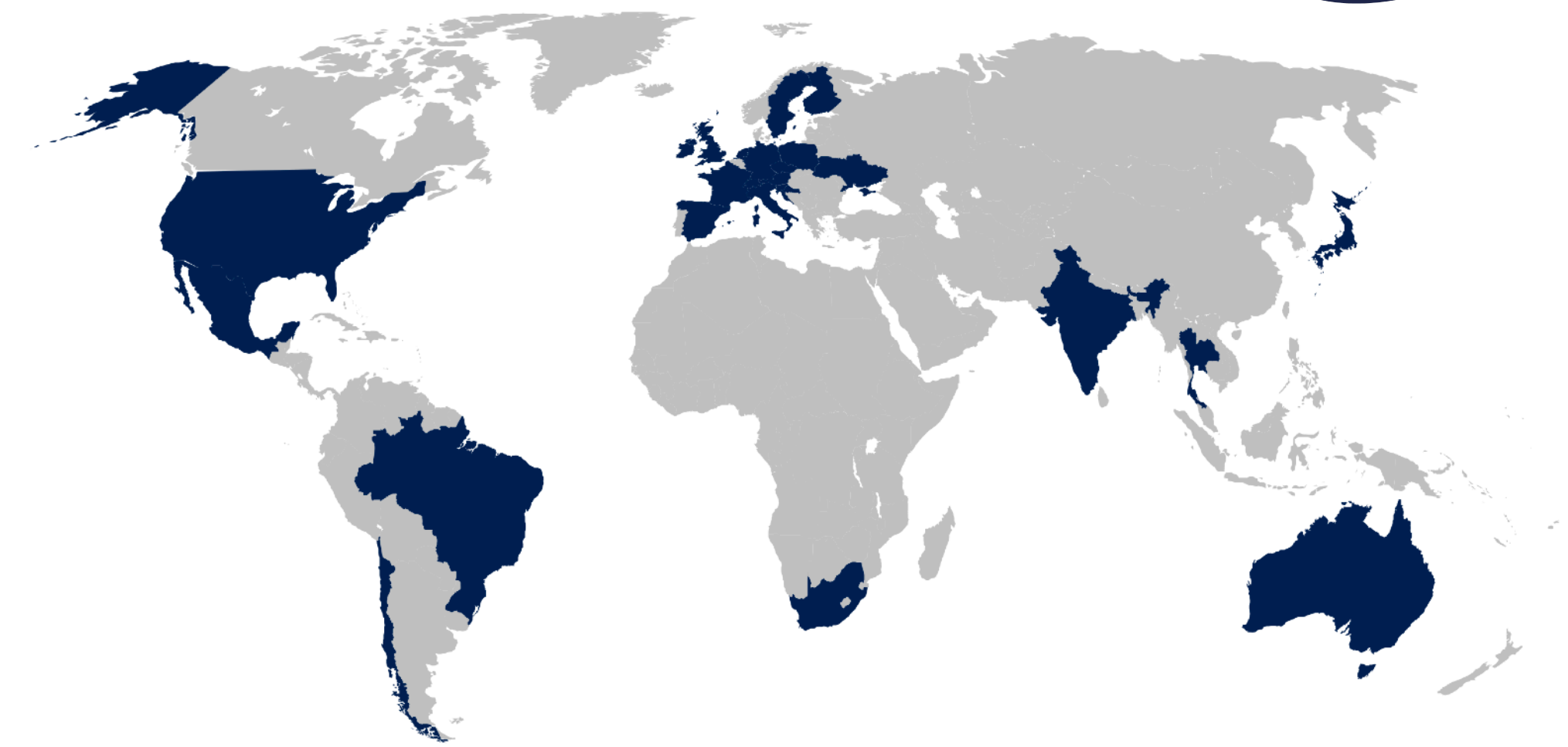
CTA in a nutshell

- Next-generation observatory for gamma-ray astronomy in the **Very-High Energy band (>20 GeV)**

- Consortium gathers more than **1,500 scientists** and engineers from about **150 institutes in 25 countries**

- **June 25th 2021**: design and cost-book of first CTA phase ("Alpha configuration") approved by the Board of governmental representatives $\Longrightarrow$ support for CTA construction at Northern (La Palma, Spain) and Southern (Paranal, Chile) sites

|	**LST**	**MST**	**SST**
Effective mirror area	*370 m²*	88 m²	8m²
Energy range	*20 GeV - 3 TeV*	80 GeV - 50 TeV	1 TeV - 300 TeV
Exclusive energy range	*20 GeV - 150 GeV*	150 GeV - 5 TeV	5 TeV - 300 TeV
#telescopes North	*4*	9	0
#Telescopes South	*0**	14	37*
Photo-sensors	*PMT*	PMT	SiPM

CTA in a nutshell

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Full Sky Coverage

Southern sky   Northern sky
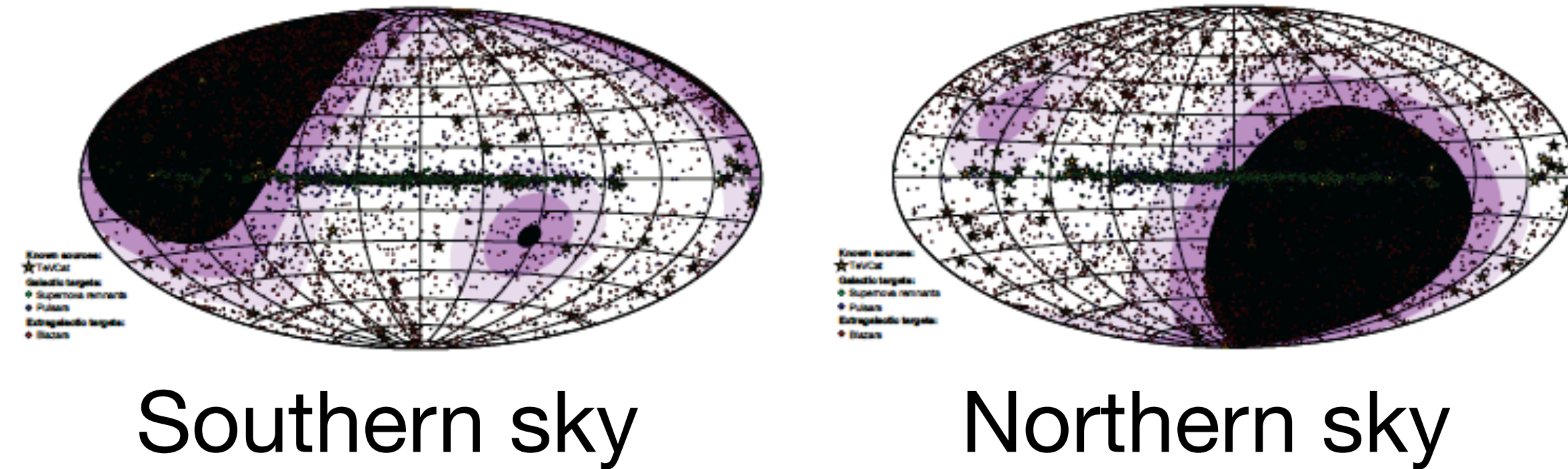
CTA North artistic rendering

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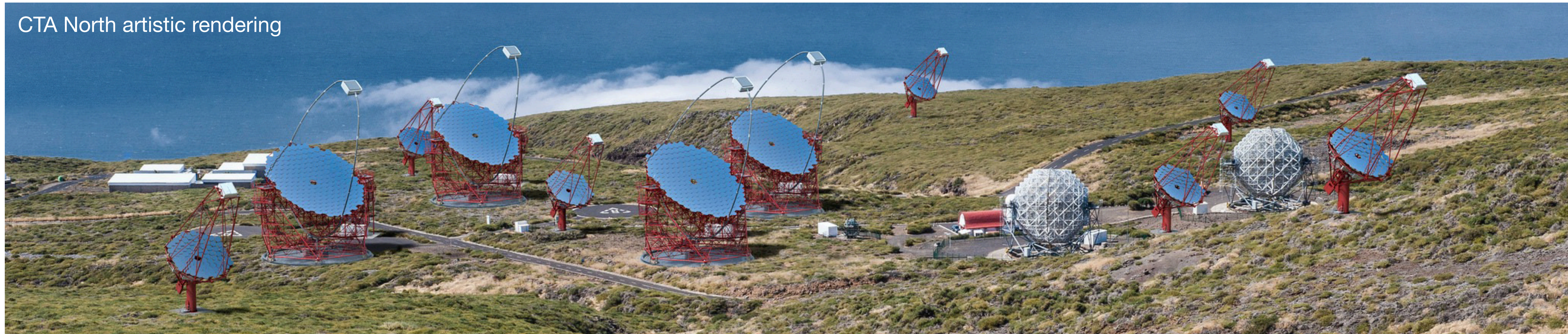
The Large-Sized Telescope

Collaboration

- ~ 300 scientists in 11 countries
- Development and building of the 4 LSTs on the CTA North site

Germany
Switzerland
Poland
France
Czech Republic
Spain
Bulgaria
Italy
Croatia
Japan
Brazil

The Large-Sized Telescope

Design

Stucture	
Alt-Azimuth Mount on a circular rail	
Tubular Structure in CFRP & Steel	
Full Telescope Weight	103 tons
Maximum time for repositioning	30 s
Optics - Parabolic Mirror	
Primary Mirror Diameter	23 m
Focal Length	28 m
Effective area including	370 m²
Camera	
Field of View	4.3°
Number of Pixels	1855
Pixel size	0.1°
Photo Sensor	PMT
Signal sampling rate	1 GHz

LST Project Status

- Construction ahead of CTAO ERIC formation

- LST-1 first telescope at CTA site:
  - ✦ Telescope inaugurated in 2018
  - ✦ Under commissioning: Covid-19, supply-chain crisis, volcano, inflation…
  - ✦ Data-taking efficiency 70% in dark time, not yet reaching 95% requirement, mostly due to development of control software

- LST-2, LST-3, and LST-4: under production
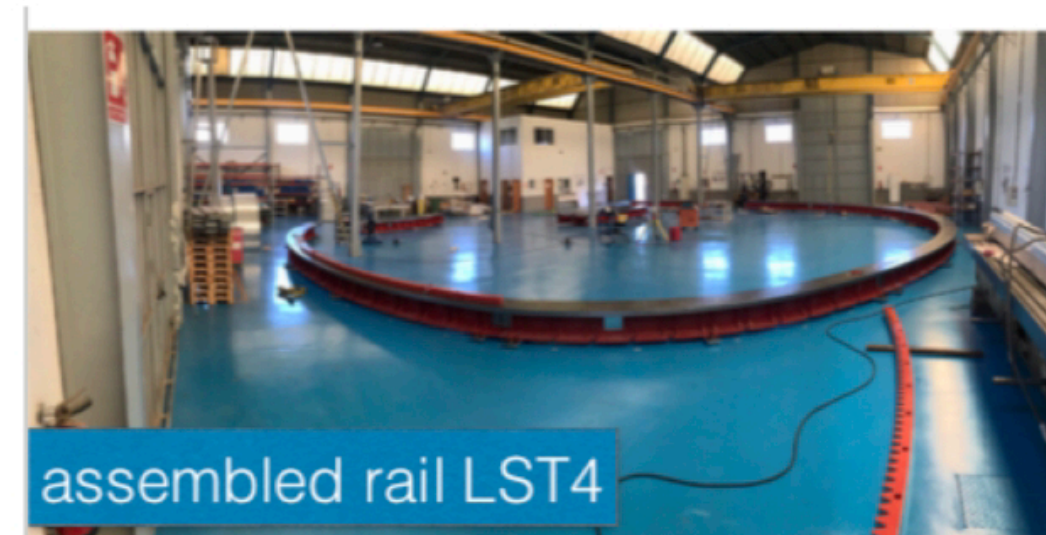
- LST-South: Partially funded

MAGIC

Credit: M. Linhoff

LST-1

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LST Project Status

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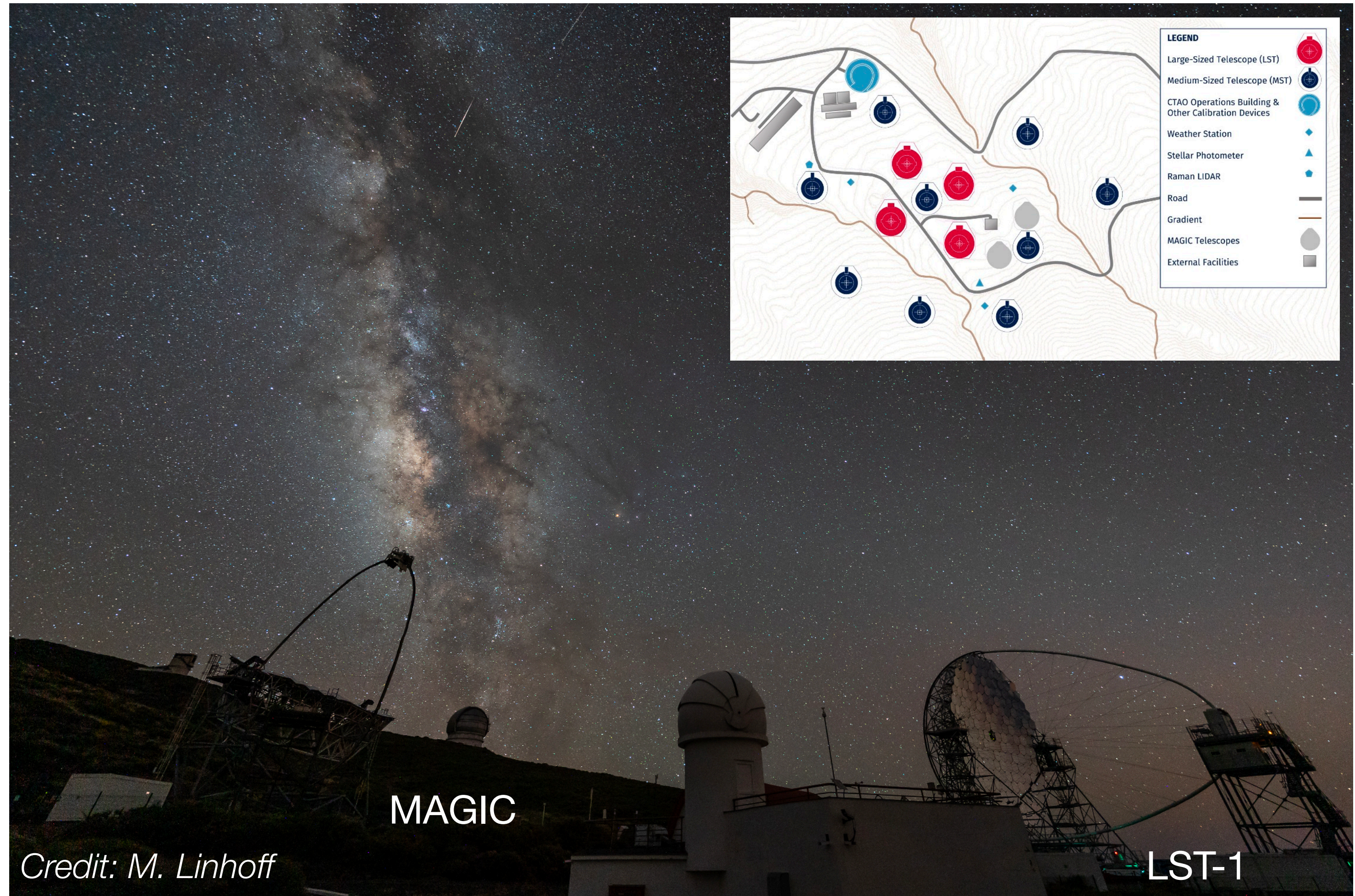
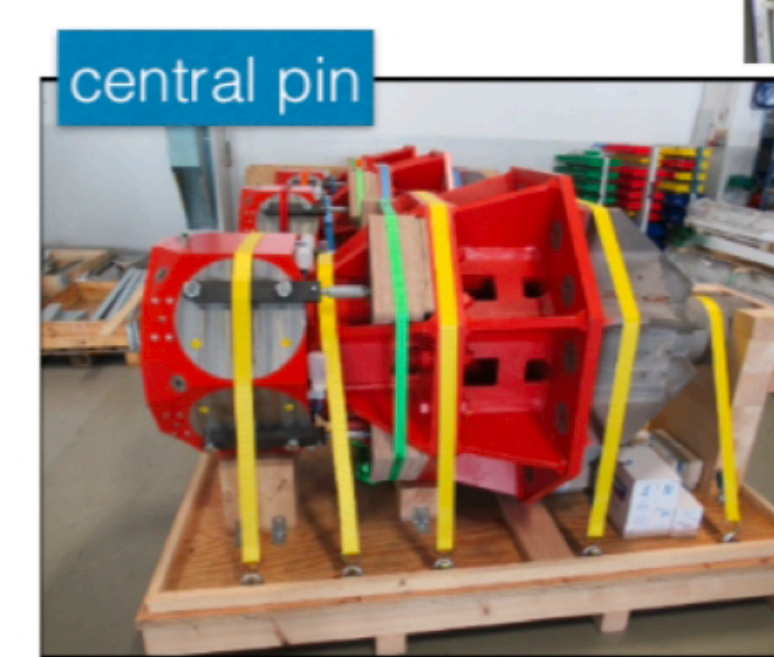- LST-South: Partially funded
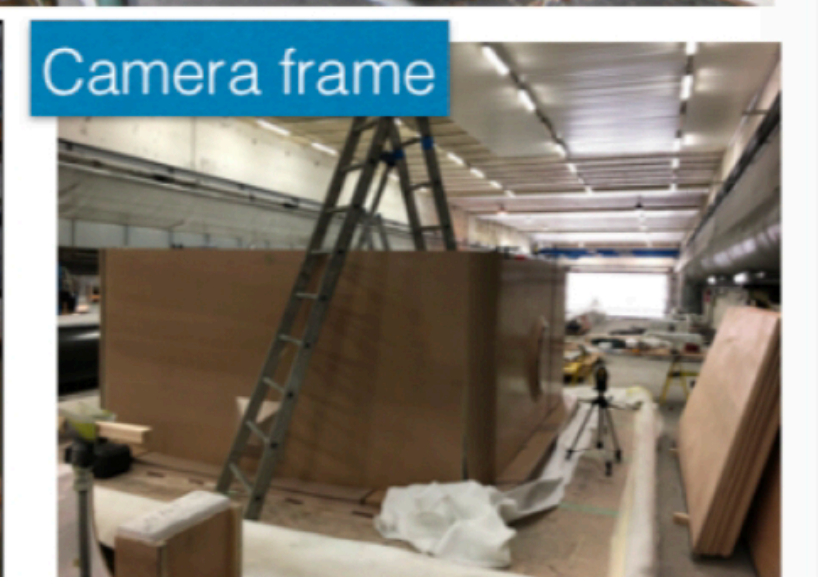

LST-2 Camera at IAC
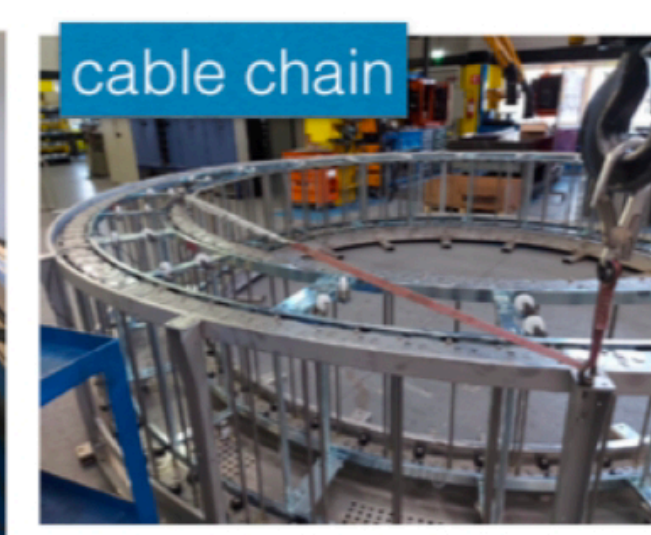
cable chain

Tubes for understructure

assembled rail LST4

backplane

central pin

Camera frame

azimuth lock

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LST commissioning

- As other islands
  of the Canaries,
  La Palma is famous
  for its stunning beaches
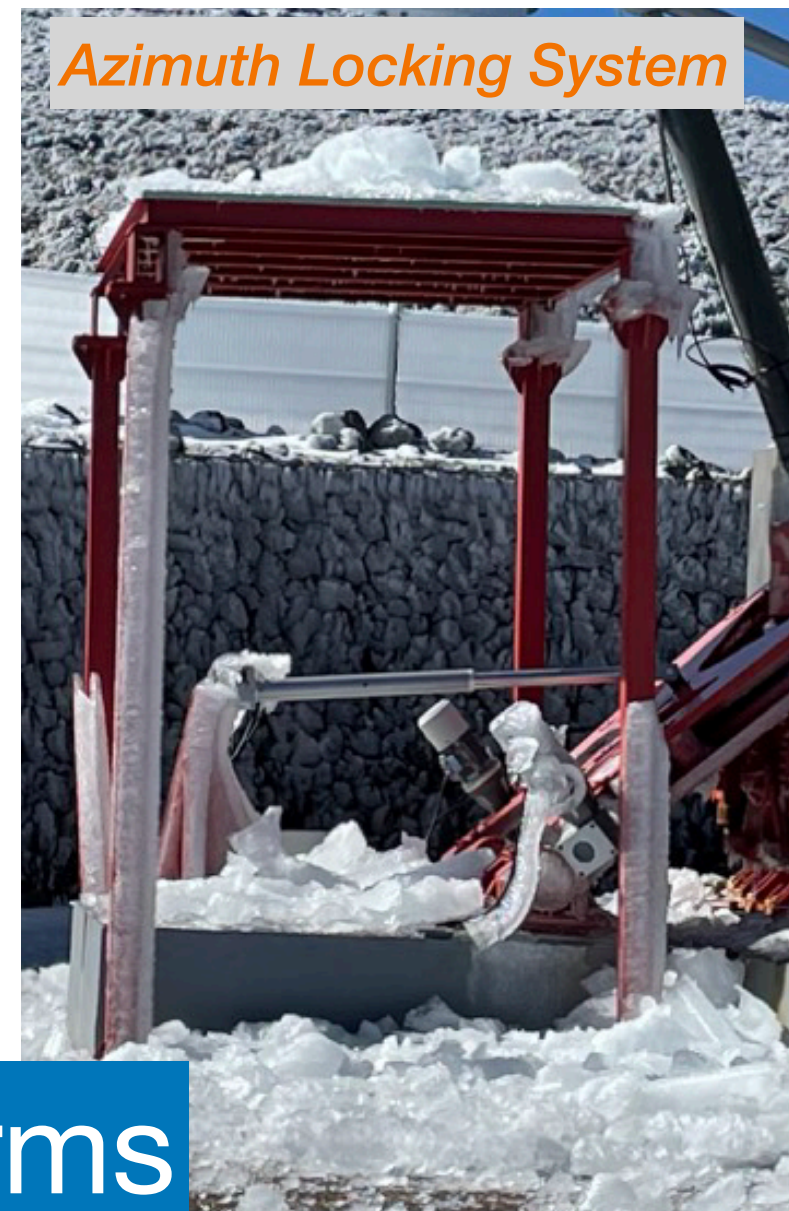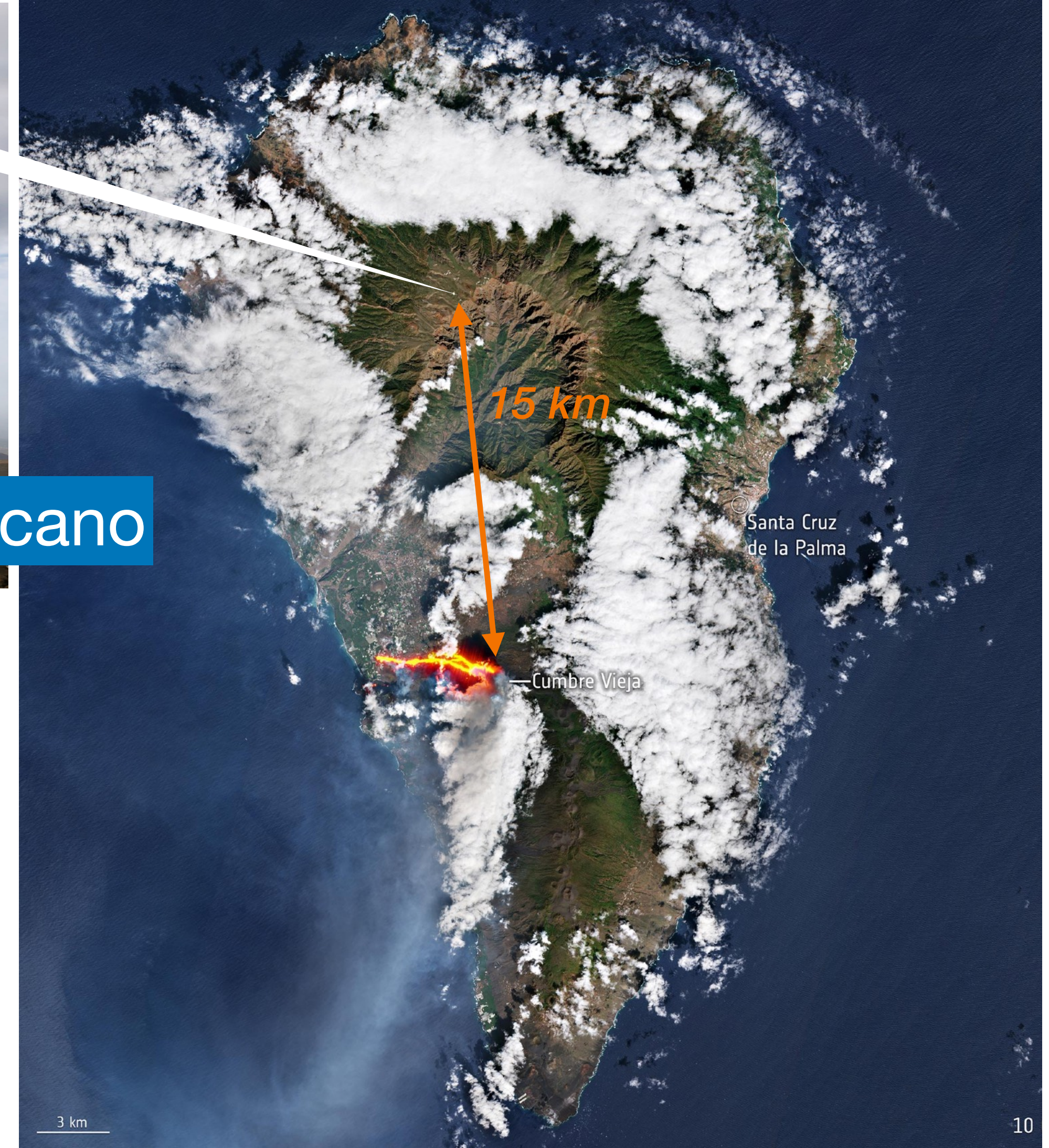 and gorgeous
  landscapes
- But not only …

Playa de Nogales

LST commissioning

- As other islands of the Canaries, La Palma is famous for its stunning beaches and gorgeous landscapes
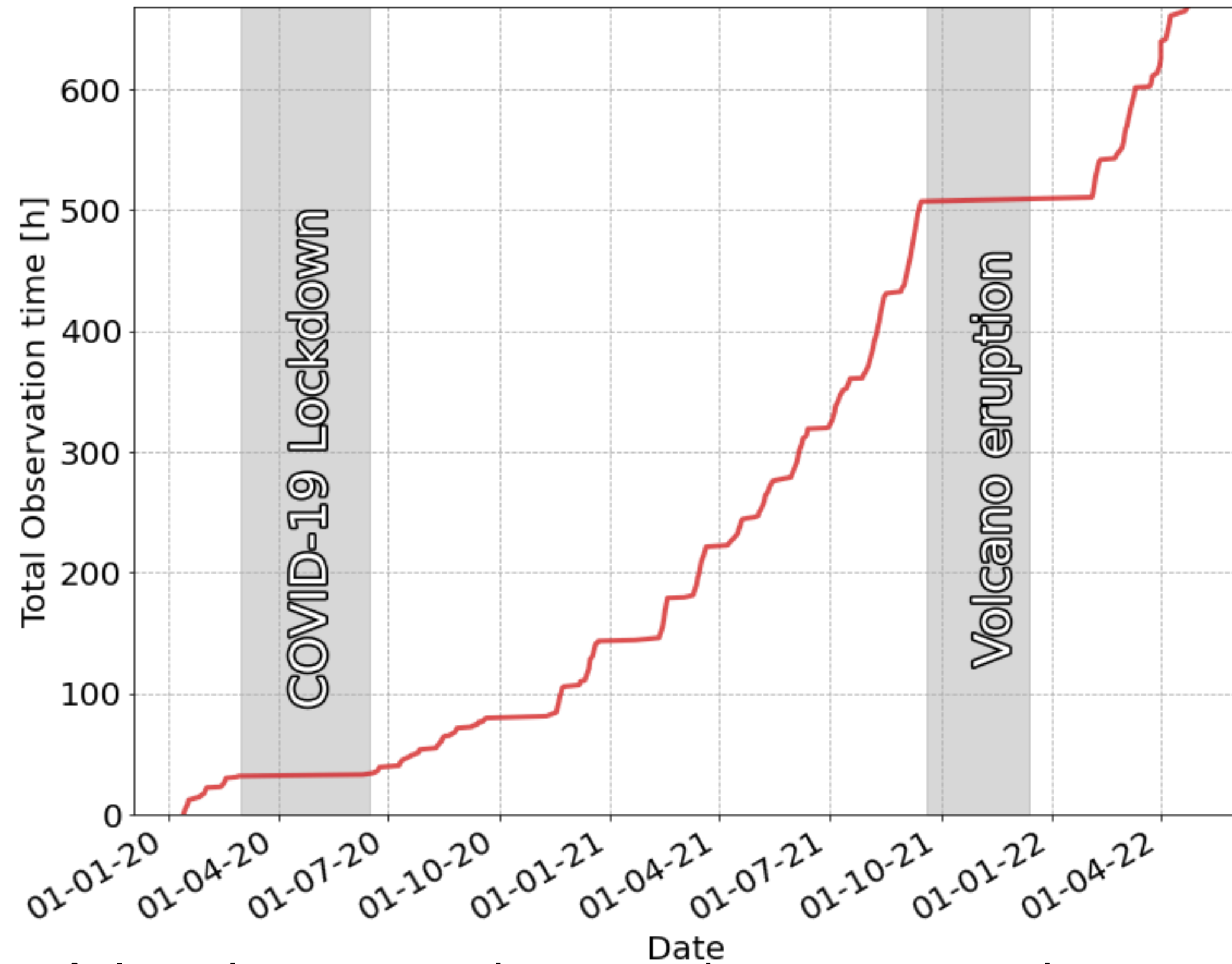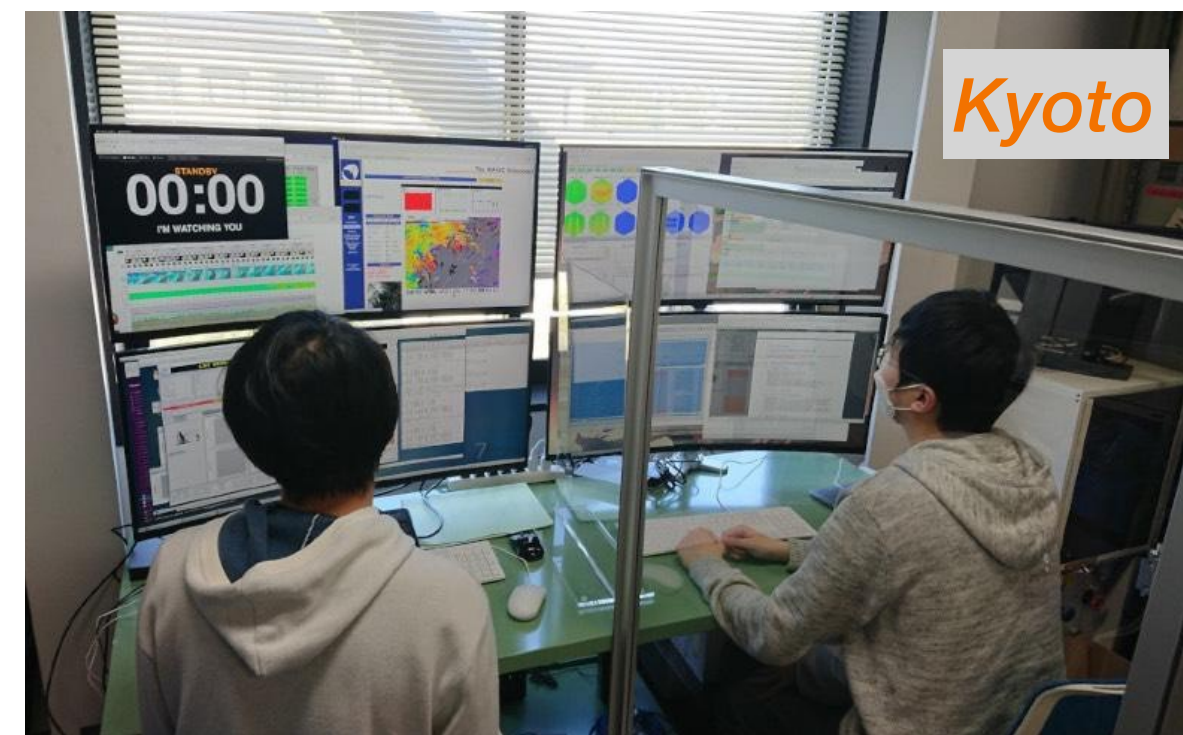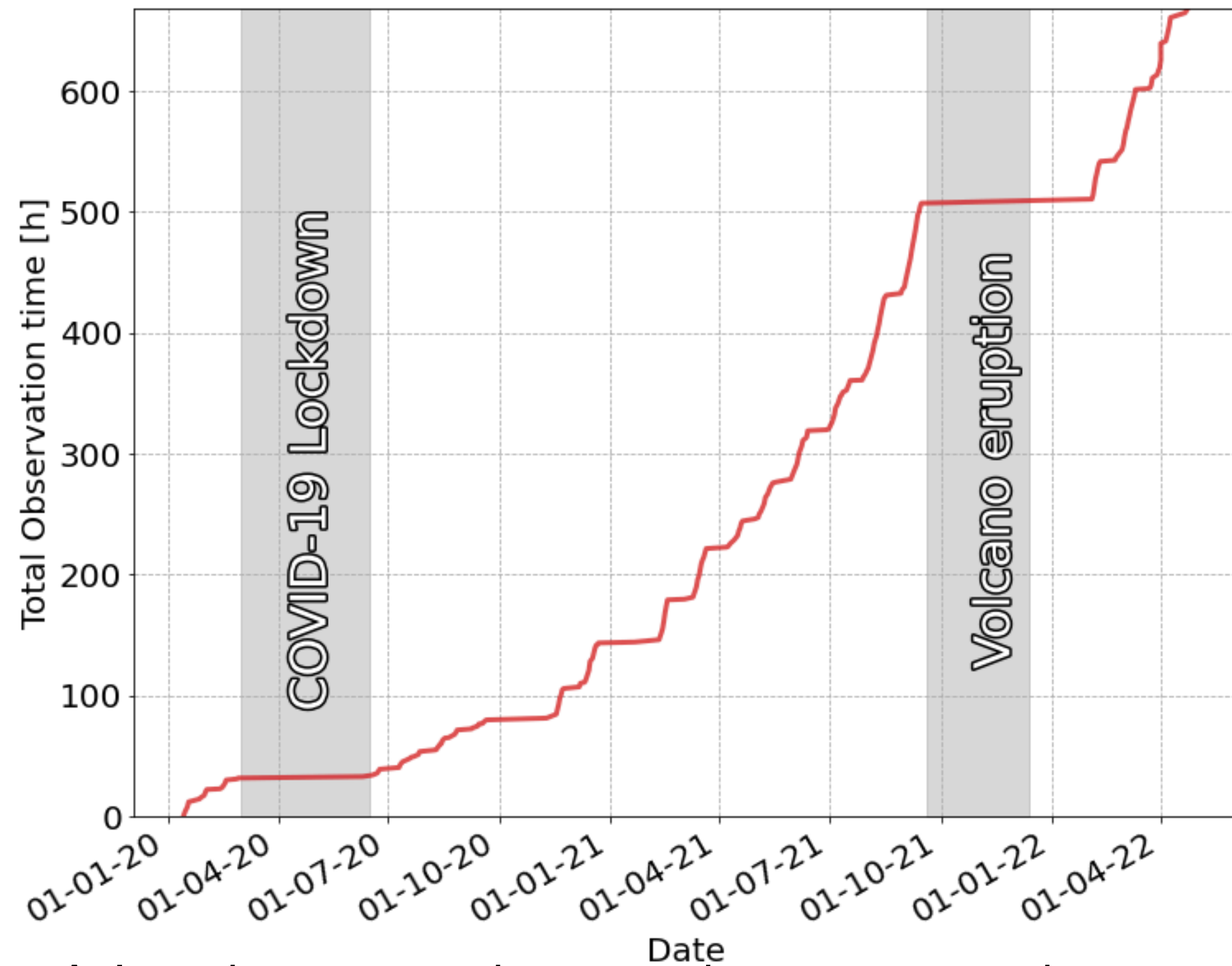- But not only …

Observatorio del Roque de los Muchachos

Volcano

15 km

Santa Cruz de la Palma

Cumbre Vieja

3 km

10

Azimuth Locking System

LST Central Pin

Ice storms

LST-1 commissioning

Data taking

- A lot done on observation automation "thanks" to Covid-19 pandemic
- Shifts shared between local and remote crews

On-site CR

Tokyo

Kyoto

Annecy

Rijeka

Torino

LST-1 commissioning

Data taking

- A lot done on observation automation "thanks" to Covid-19 pandemic
- Shifts shared between local and remote crews

- Telescope Control Unit:
  - ✦ Black box for CTAO to connect and control telescope as part of the future Array
  - ✦ All-in-one interface for telescope operation

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M. Heller, The LST Project Status, RICH 2022

LST-1 commissioning

Data taking

Telescope Control Unit

- AutoOperator: Telescope manager client
  - ✦ State machine control
  - ✦ To be replaced by CTAO control system (ACADA)
- Dynamic/Interactive schedule

LST Analysis pipeline

Classical approach

Raw event → Calibrated event →
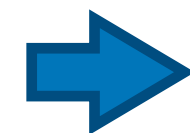
Integrated charge (p.e.)
+
Peak time (ns)
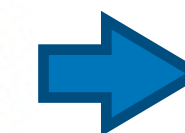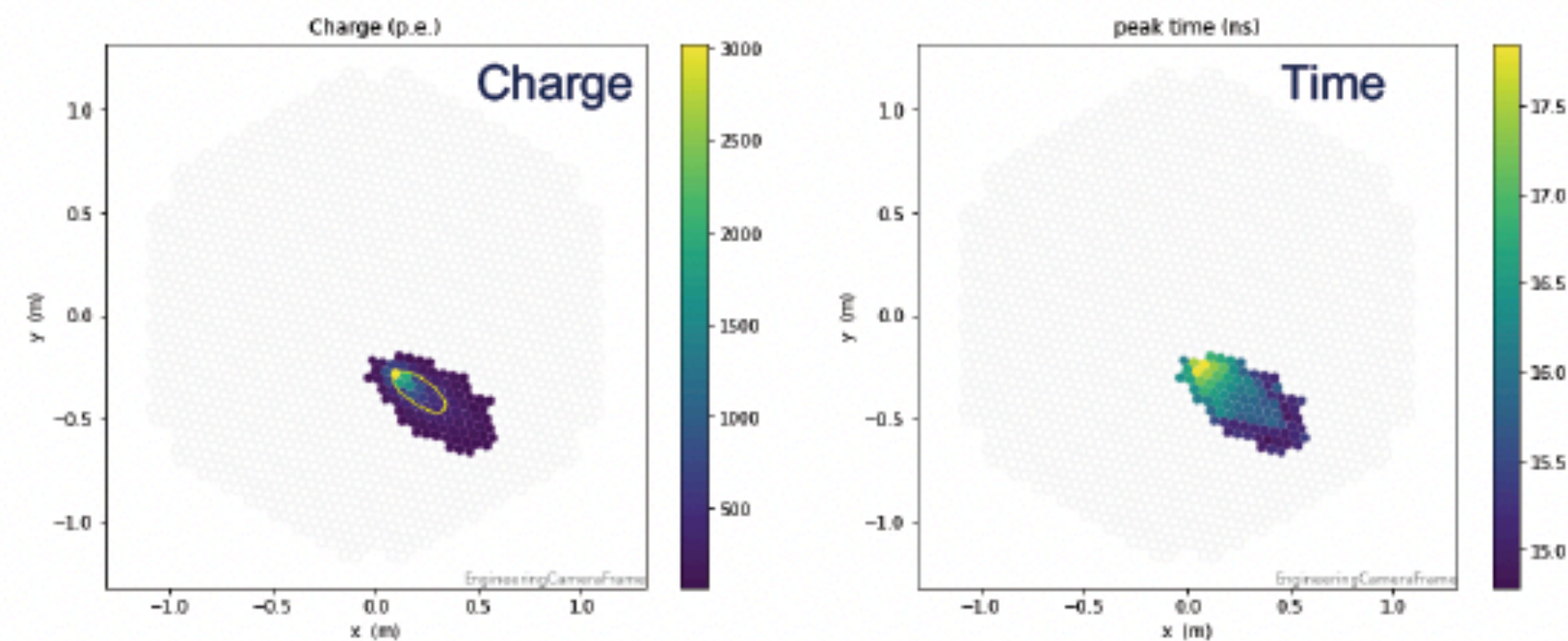
Regression for direction and energy reconstruction, and γ/h classification performed with dedicated random forests

Cleaned image

Parameterised image

LST-1 performance

- Analysis conditions:
  - Zenith angle = 10 deg
  - γ-ray efficiency = 60% (due to gammaness cut)

- Observations are still performed in monoscopic mode:
  - Limited angular or energy resolution
  - However competitive down to 100 GeV with best instruments

- Effective area > 10^3 m^2 down to ~20 GeV.

- *Performance paper to be published soon*
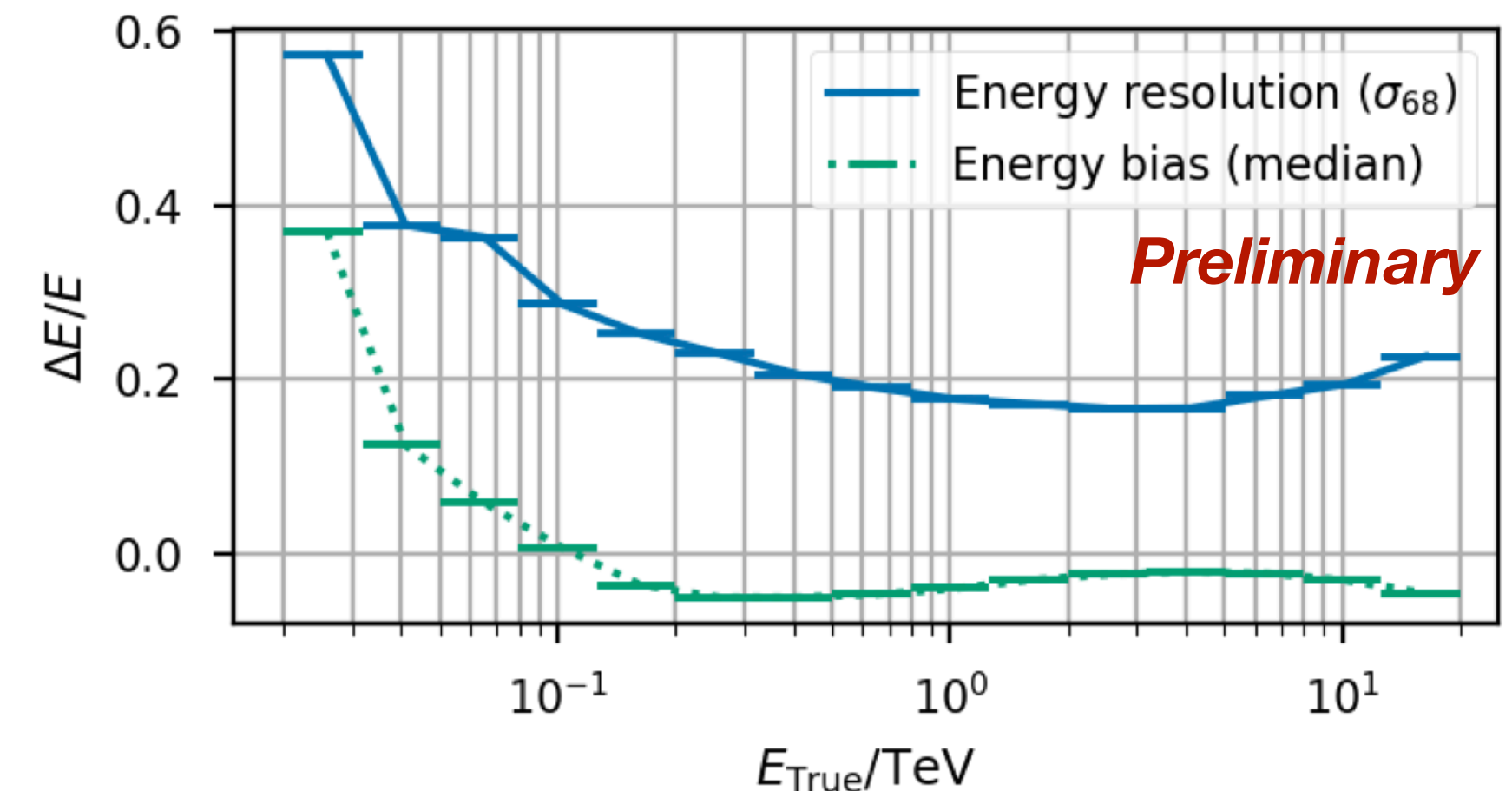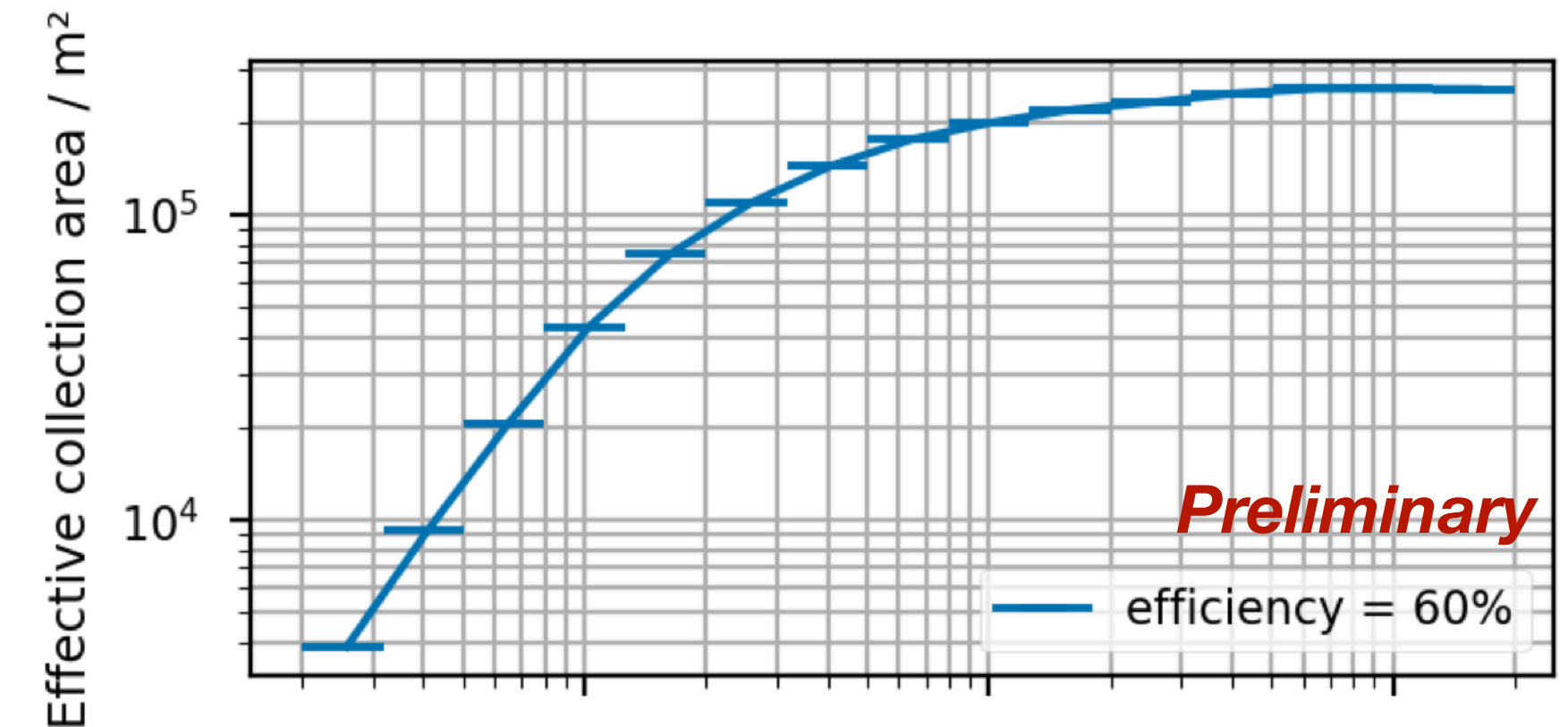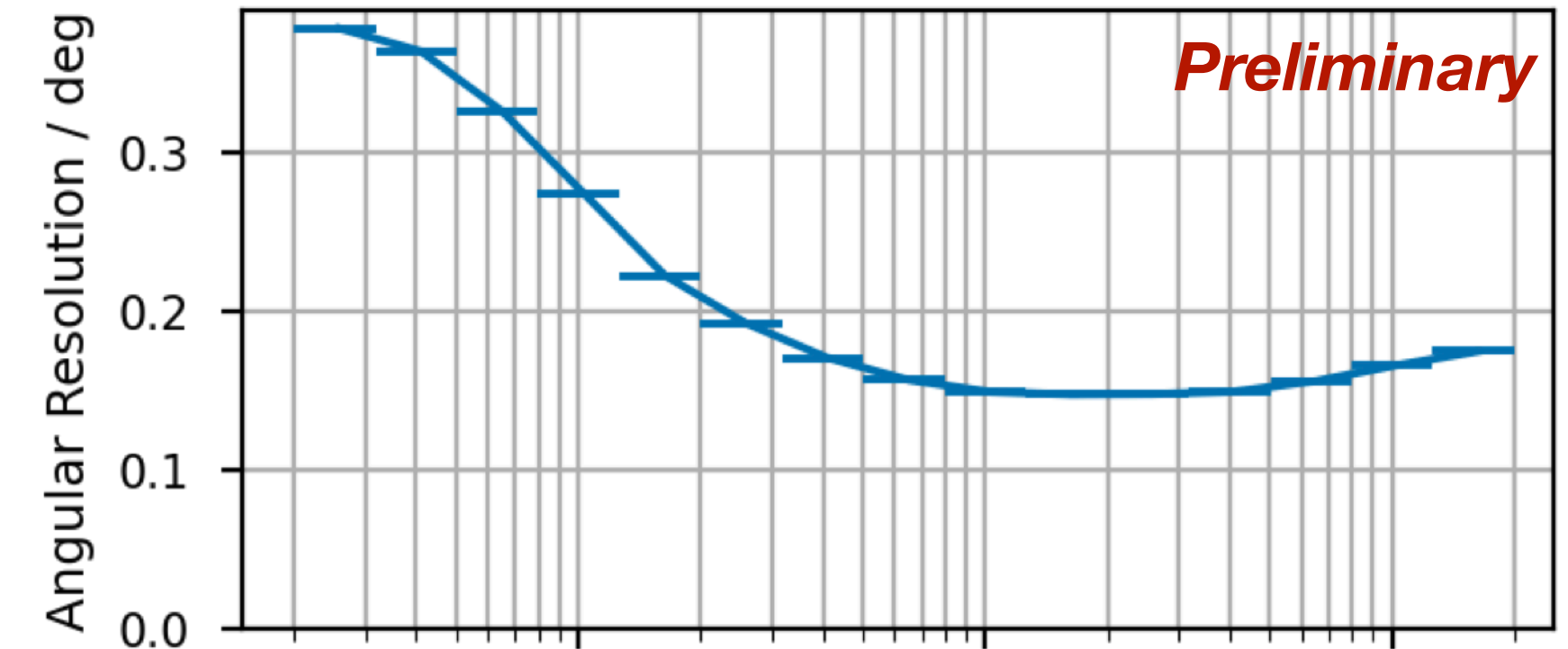
LST-1 performance

Sensitivity

- Able to measure energy down to 50 GeV

- Roughly 1.5 x less sensitive than MAGIC stereoscopic system
  - ✦ Consistent with single telescope performance vs Stereoscopic system
  - ✦ Single telescope system have higher backgrounds

- *Performance paper to be published soon*
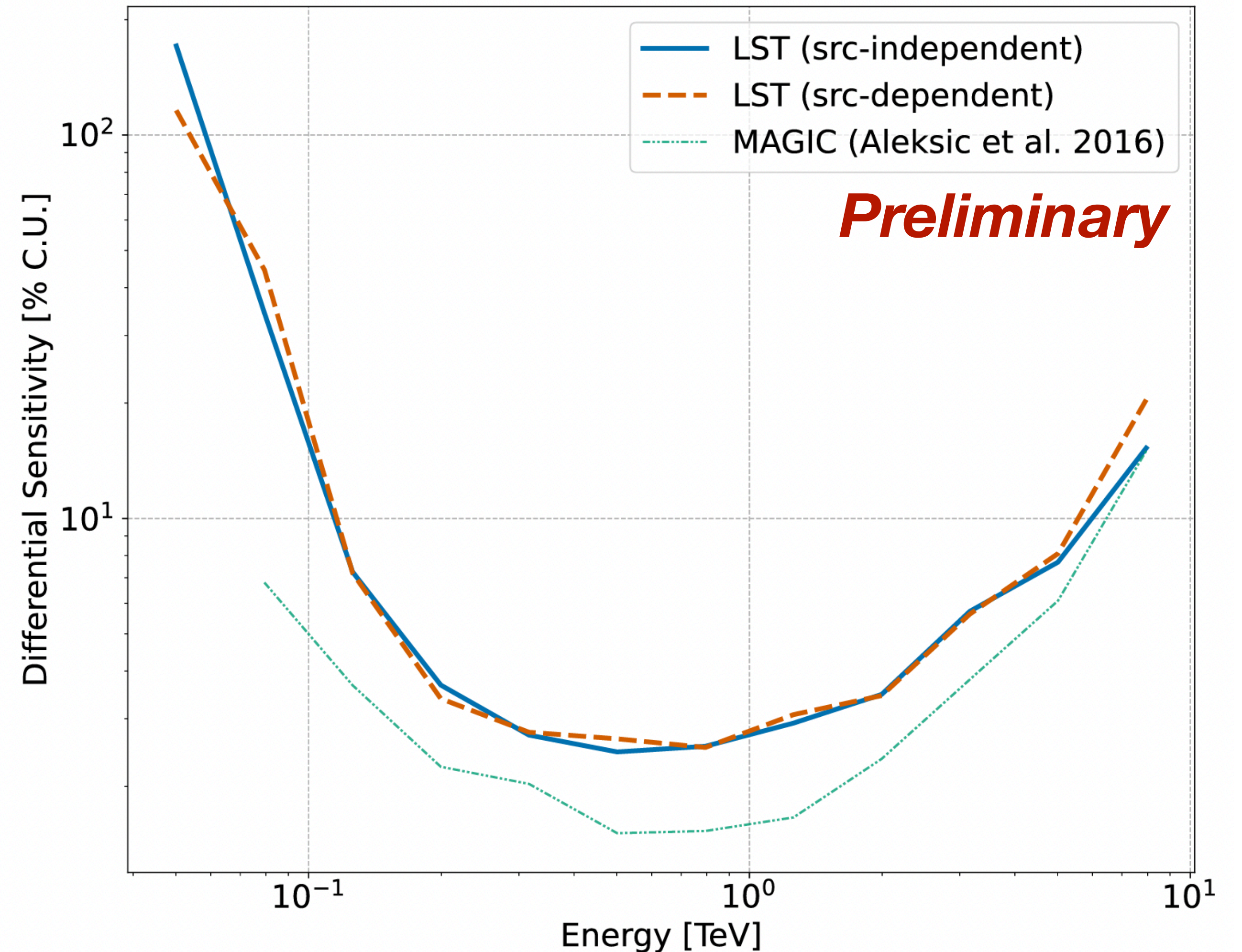
Science with LST-1

- Performance paper to be published soon, including results shown here and more.

- ~800 hours of data taken since 2020 on many sources:
  - RS Ophiuchi
  - LHAASO J2108+5157
  - AGNs: BL Lac (including a strong flare in 2021!), Mrk 421 and 501, 1ES 1959+650, PG 1553+113…
  - Transients

- Several publications in preparation on these observations, few trailers in the next slides

GRB#	Zenith Angle (deg)	$T_{observation} - T_0$ (minutes)
1	40	1320
2	45	970
3	51	119
4	59	39
5	56	1072
6	61	1302
7	6	57
8	41	588
9	65	60
10	62	1138
11	59	33

Some numbers on transients

- Following GRBs with triggers from Swift, GBM, and LAT
  ➡ No detection
- Also following Neutrino triggers, Galactic transients, and FRBs
- *Automatic repositioning expected in second half of 2022*

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Crab Nebula spectrum

- 34.2 hours of effective time
- Gamma-ray efficiency:
  - ✦ 70% from gammaness cut
  - ✦ 70% from θ^2 cut
- Error bars are only statistical
- Systematic errors: blue lines correspond to the effect of ± 1% background
- Consistent with MAGIC and Fermi-LAT
- *Lowest data point at 25 GeV!*
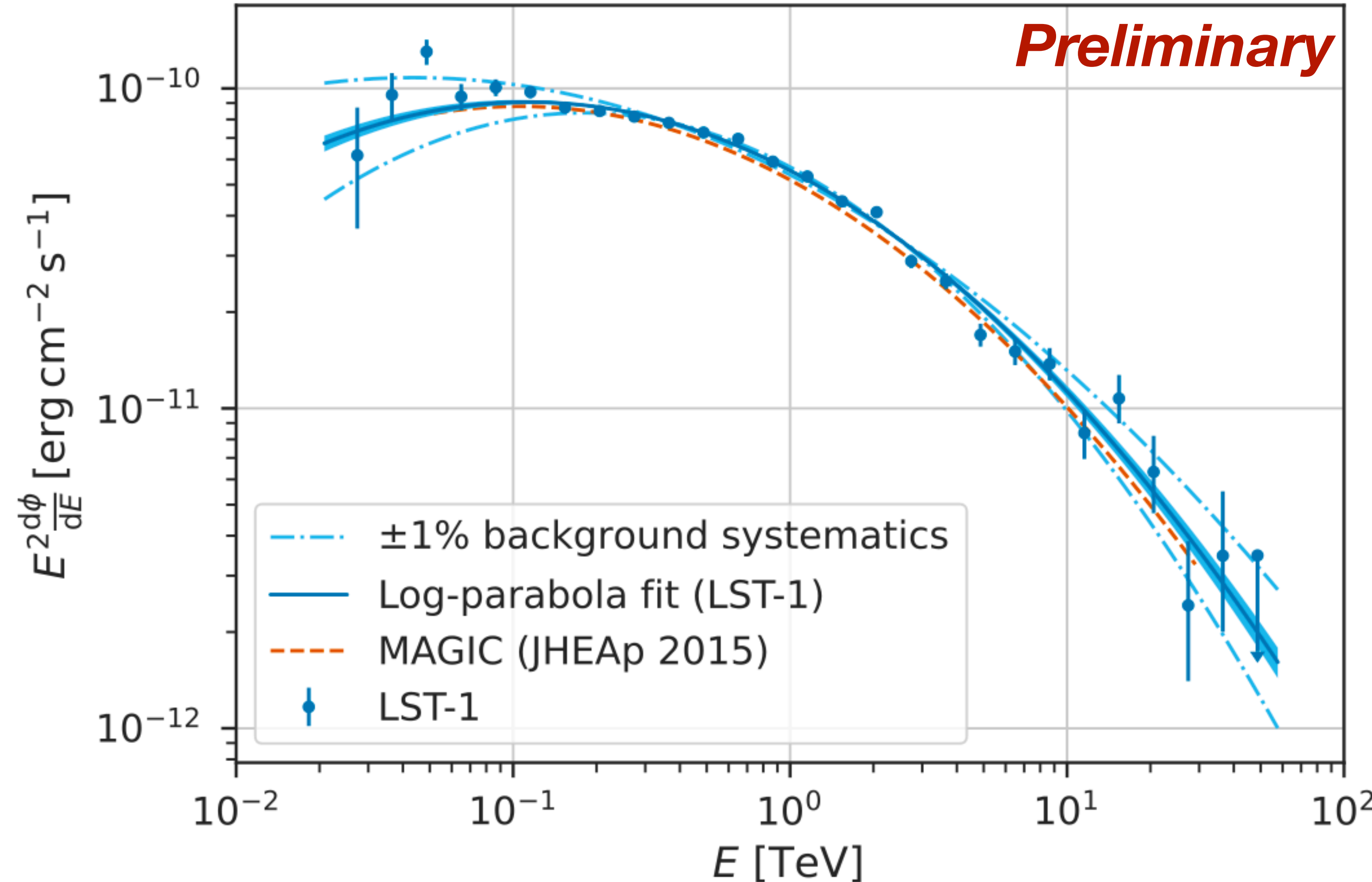
Crab pulsar phasogram

- Data from Nov 2020 to March 2022

- Data selection:
  - ✦ cut in rate + no technical issues (more strict than previous analyses)
- Highly significant detection down to few tens of GeV.

- P1/P2 ratio tends to 1 at low energies

Credit: NASA, ESA, G. Dubner (IAFE, CONICET-University of Buenos Aires) et al.; A. Loll et al.; T. Temim et al.; F. Seward et al.; VLA/NRAO/AUI/NSF; Chandra/CXC; Spitzer/JPL-Caltech; XMM-Newton/ESA; Hubble/STScI

Events = 7696582
Time = 123131 s
N_{ex} (P1) = 4334
Significance (P1) = 7.1 σ
N_{ex} (P2) = 5416
Significance (P2) = 8.6 σ
Significance(Joint) = 10.6σ
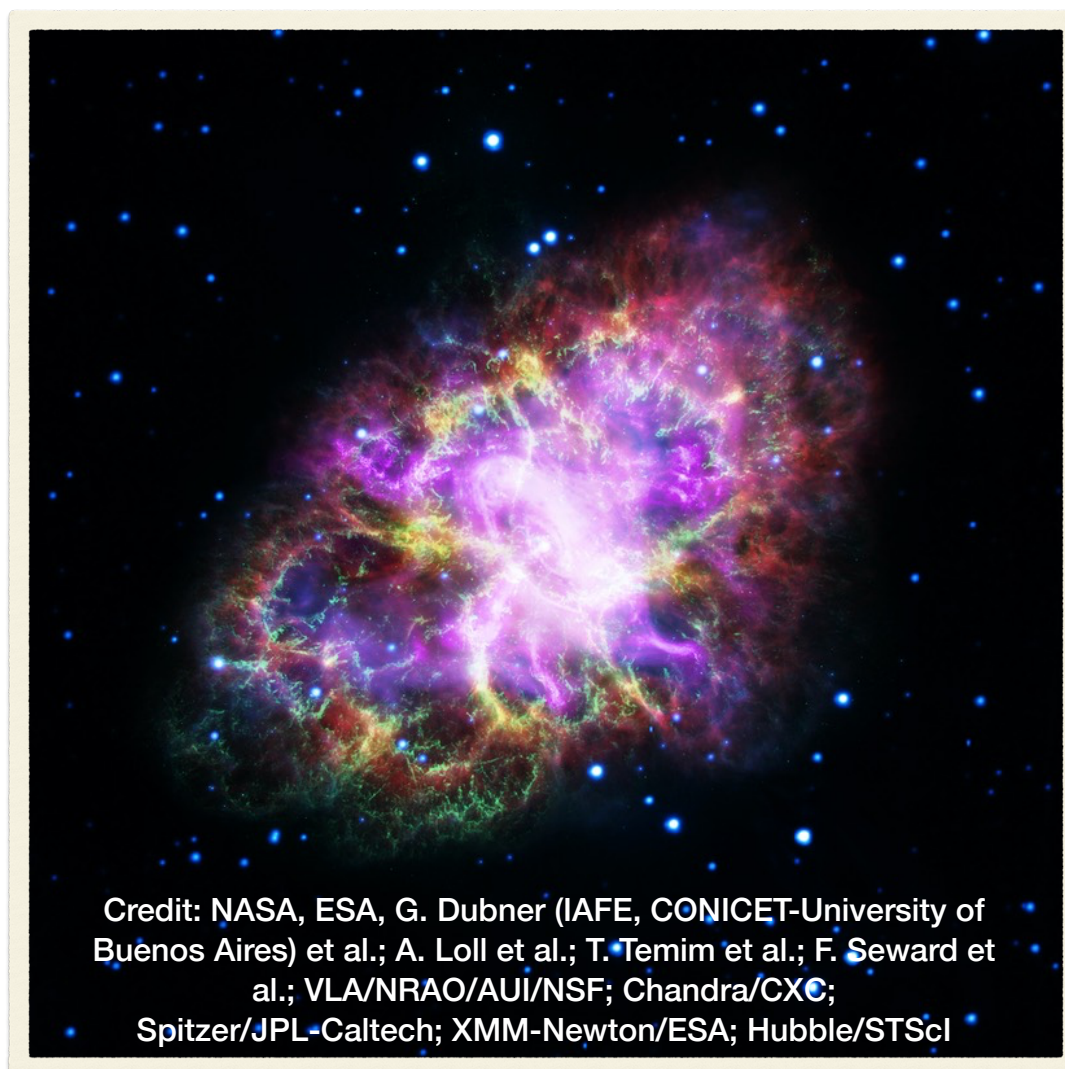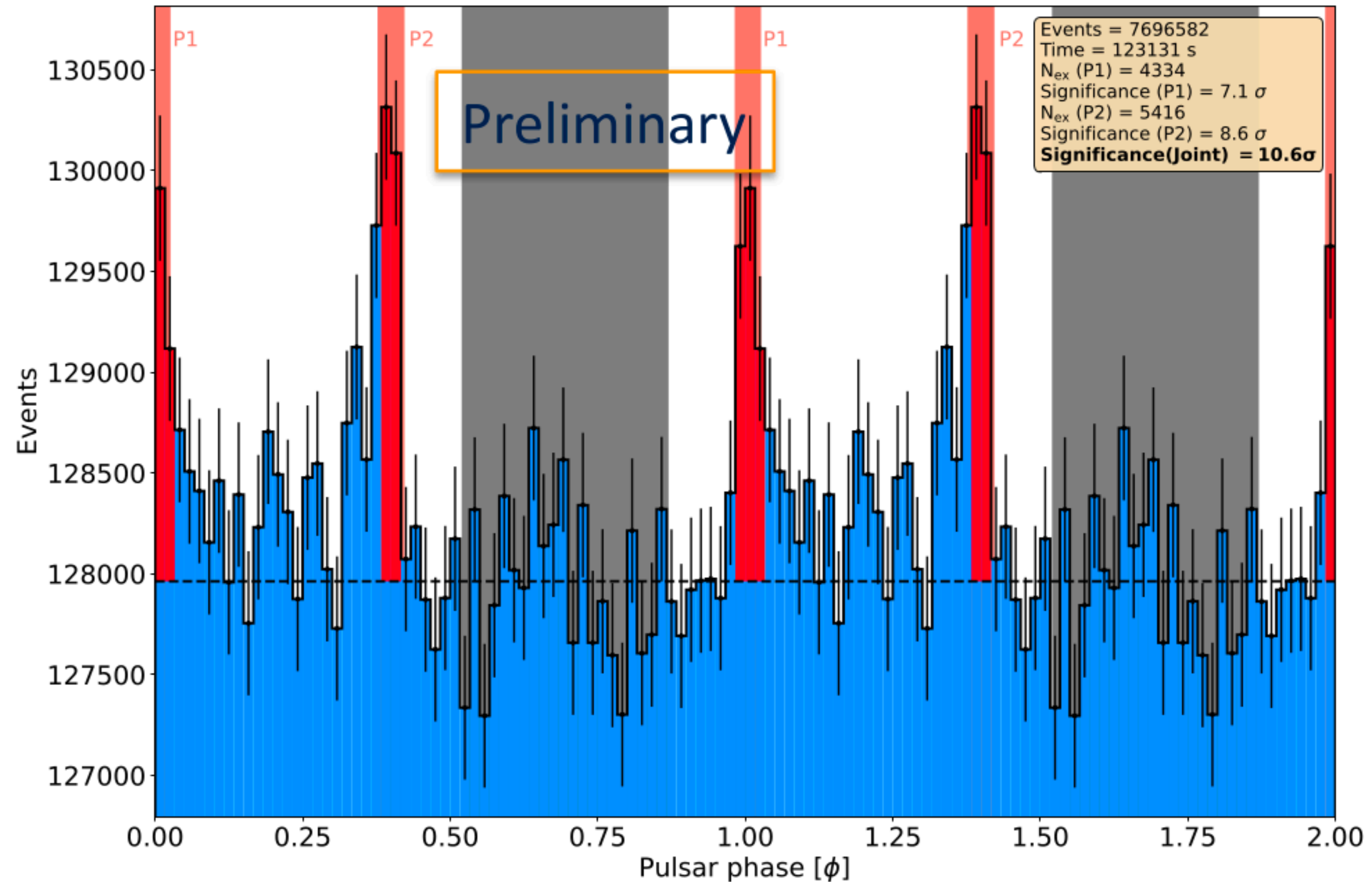
First VHE-detected NOVA: RS Ophiuchi

- LST-1, 4-day average
- MAGIC, 4-day joint data (Acciari 2022)
- H.E.S.S. Aug 9 + 13 SEDs (H.E.S.S. Collab 2022)
- Consistent SEDs

Credit: David A. Hardy

PRELIMINARY

$\Gamma = -3.3 \pm 0.2$
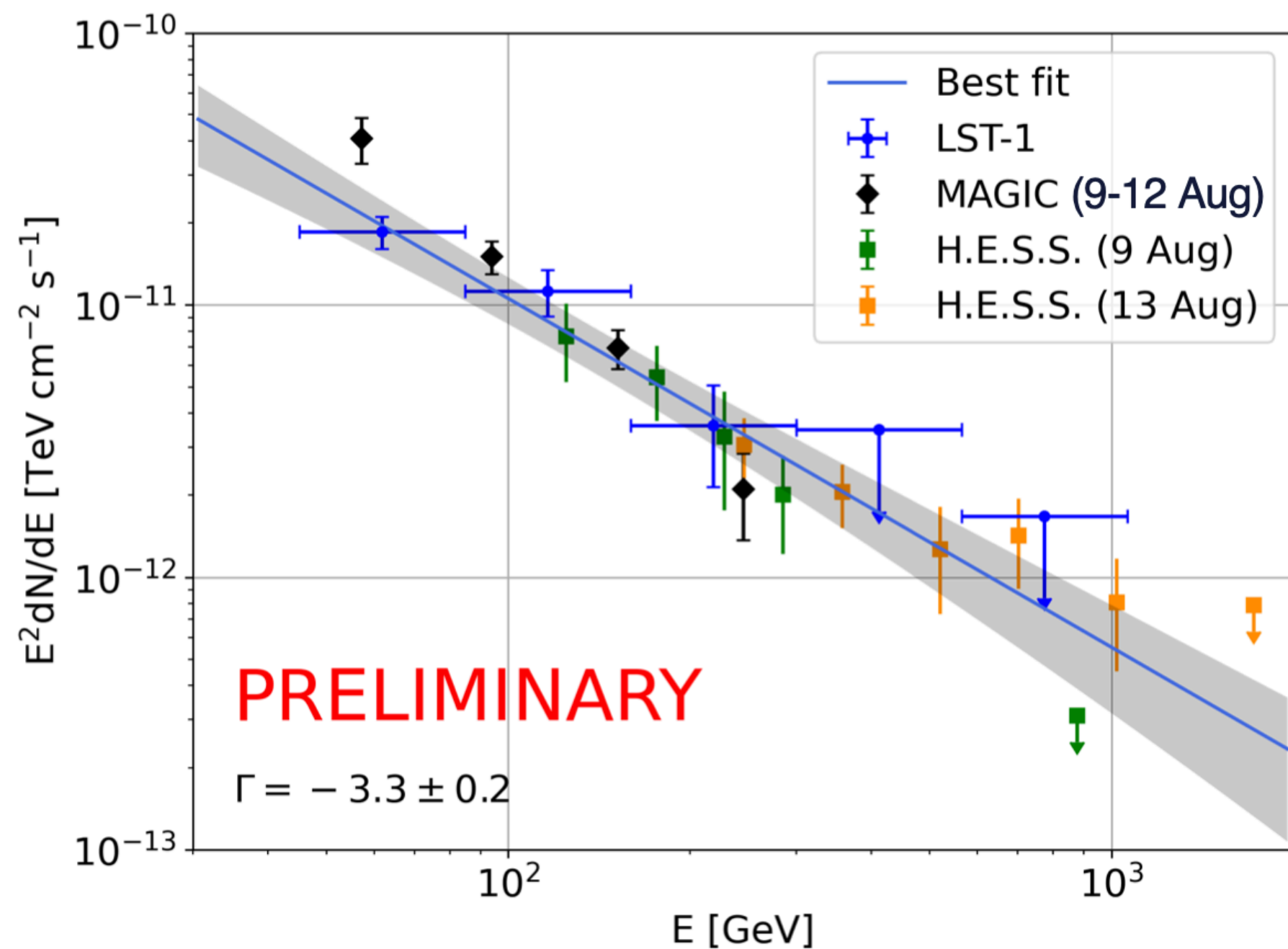
MAGIC results from Acciari et al. 2022
H.E.S.S. results from H.E.S.S. Collaboration 2022.

Fermi-LAT (9-12 Aug)

PRELIMINARY

$\Gamma = -3.3 \pm 0.2$
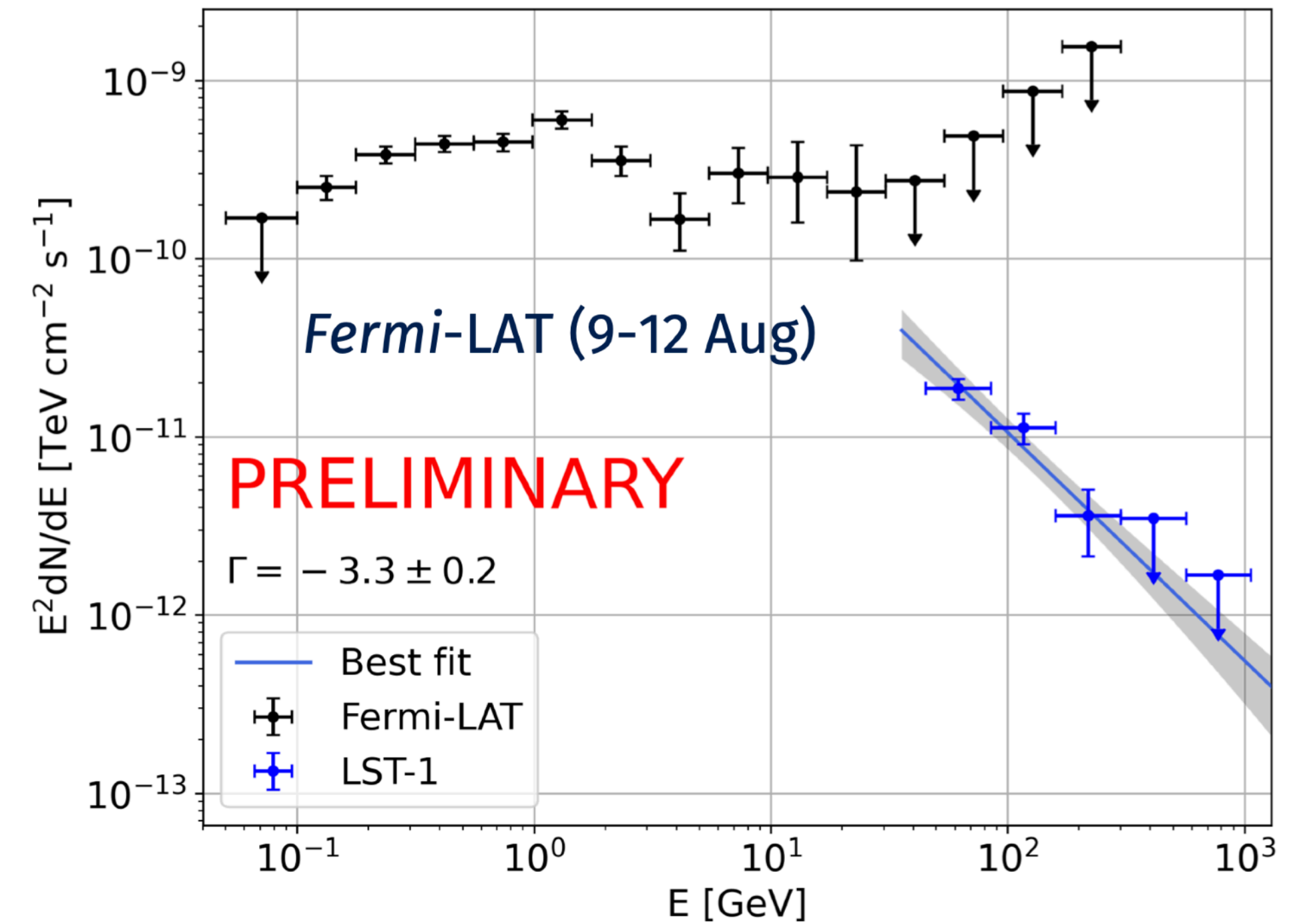
- Nice connection between LST-1 and Fermi-LAT data
- Energy threshold already competitive with MAGIC (~45 GeV)
- *Paper already in progress*

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BL Lac Flare 2021

CTA's first ATEL

[Previous I Next I **ADS**]

Detection of very-high-energy gamma-ray emission from BL Lac with the LST-1

ATel #14783; *Juan Cortina for the CTA LST collaboration*
on *13 Jul 2021; 21:03 UT*
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

Subjects: TeV, VHE, Request for Observations, AGN, Blazar, Transient

Referred to by ATel #: 14820, 14826, 14839

[Tweet]

The LST-1 telescope has observed an increase in the very-high-energy (VHE; >100 GeV) gamma-ray flux from BL Lacertae (RA=22:02:43.3, DEC=+42:16:40, J2000.0). The preliminary offline analysis of the LST-1 data taken on 2021/07/11 (MJD 59406), triggered by an increase of the optical flux (see ATEL #14773 and references therein), has been detected with a significance of 8 sigma with a differential flux of 1.3 +/- 0.2 10^9 cm-2 s-1 TeV-1 (25% of the Crab Nebula) at 100 GeV. Note though that this is the result of a quick-look analysis and the data were taken under non-optimal weather conditions (atmospheric transmission at 9km of ~50-60%), hence this flux measurement is a lower bound on the true flux. The LST-1 observations were performed during commissioning which began in 2018. LST-1 is a prototype of the Large-Sized Telescope for the Cherenkov Telescope Array, and is located on the Canary island of La Palma, Spain. The LST-1 is designed to perform gamma-ray astronomy in the energy range from 20 GeV to 3 TeV. LST-1 observations on BL Lacertae will continue during the next few nights, multi-wavelength observations are encouraged. The preliminary offline analysis has been performed by Daniel Morcuende (dmorcuen@ucm.es) and Ruben Lopez-Coto (ruben.lopezcoto@pd.infn.it). The LST-1 contact persons for these observations are Masahiro Teshima (mteshima@mpp.mpg.de) and Juan Cortina (juan.cortina@ciemat.es).
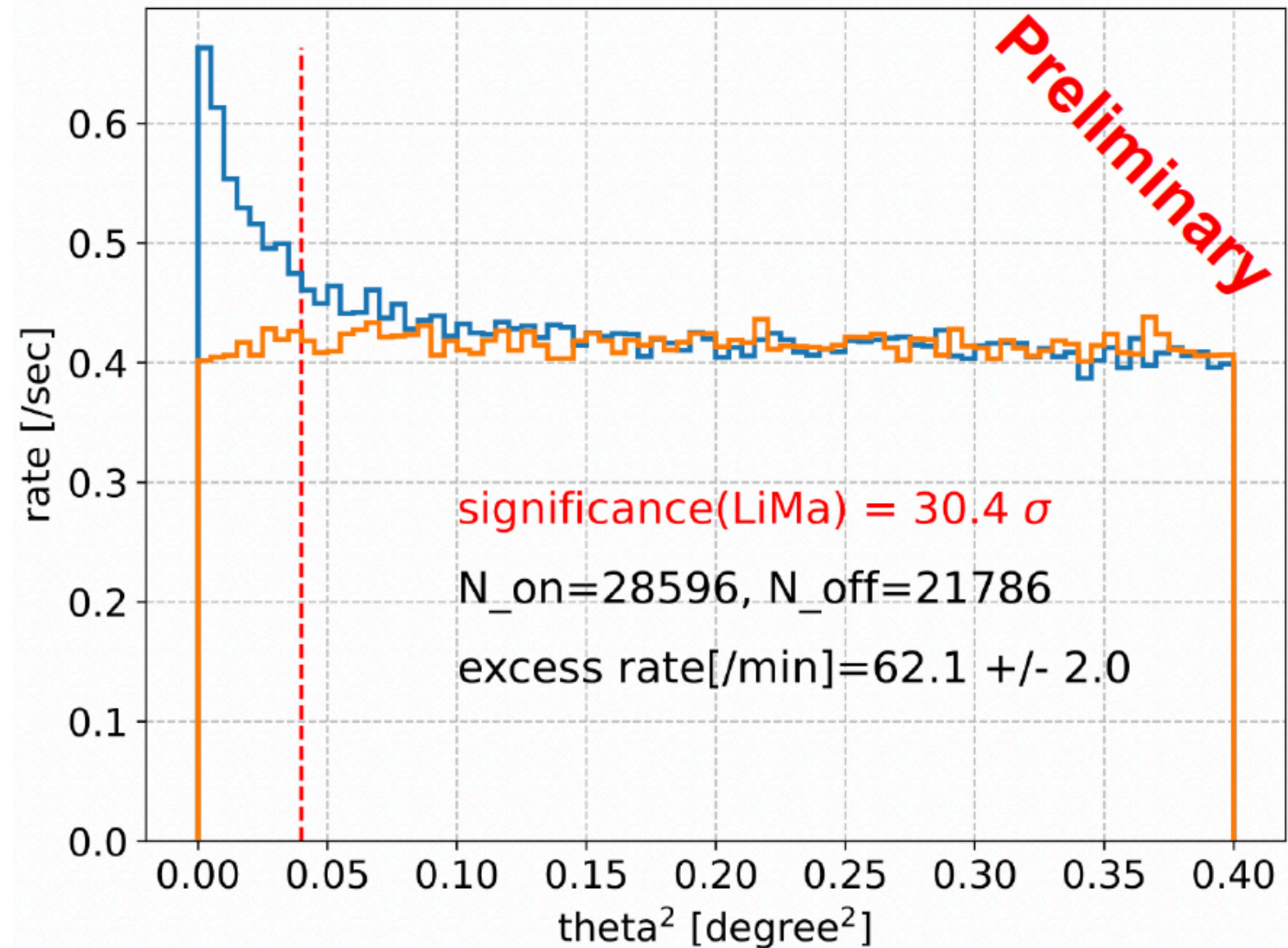
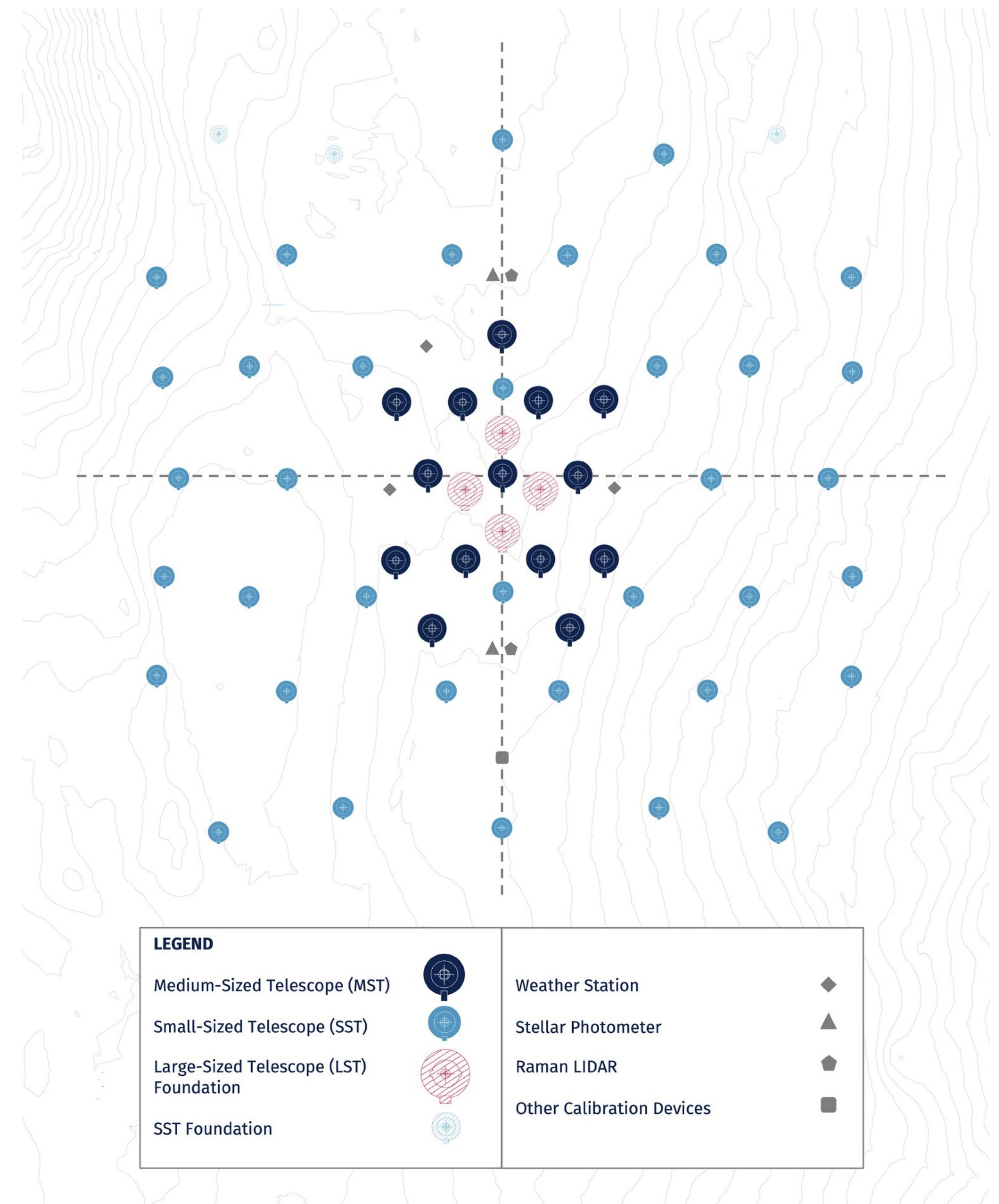- ATEL published within 48 hours after observation with confirmation and cross-check

BL Lac Flare 2021

- IBL at z=0.069

- August 8th 2021:
  High state >1 crab for E < 300 GeV

- Soft spectrum allows to extract
  spectral point at 30 GeV in
  < 2 hours observation

- Two separate analyses are in good
  agreement

- Variability observed on timescales
  ranging from minutes to days
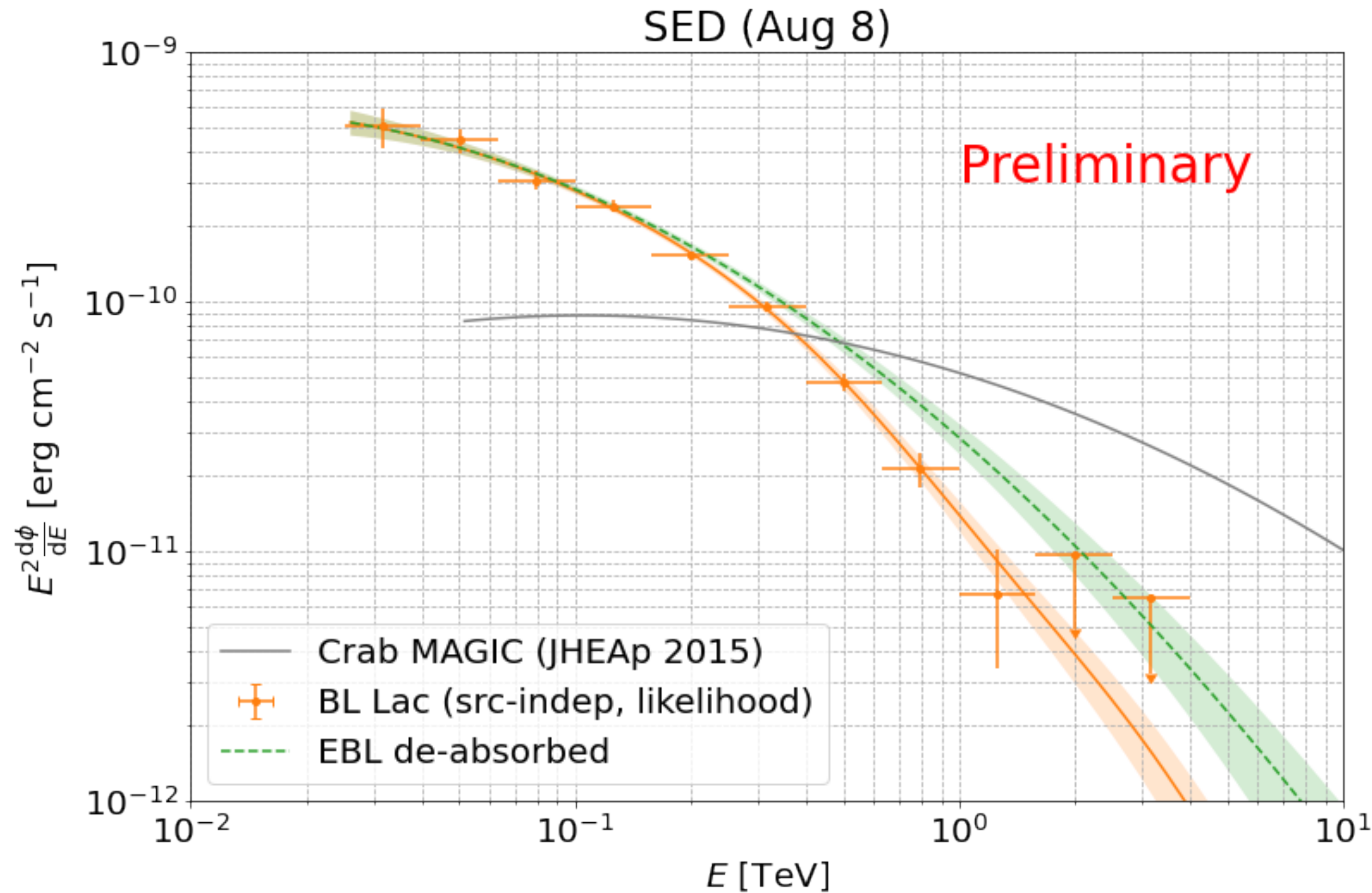
LSTs at the South

- LSTs allow the detection of the lowest energies, in CTA-South especially relevant for:
  - ✦ GRBs, AGN flares, transients.
  - ✦ Dark Matter searches.

- Preparations are being made for building LST telescopes at CTA-South as well, at later CTA construction phases

- Our Italian colleagues (INAF+INFN) have secured fundings for 2 LSTs.
  - ✦ Manufacturing of the telescope parts must happen before the end of 2025.

- *The goal is to build 4 LSTs at South!*

LEGEND

Medium-Sized Telescope (MST)	Weather Station	◆
Small-Sized Telescope (SST)	Stellar Photometer	▲
Large-Sized Telescope (LST) Foundation	Raman LIDAR	⬟
SST Foundation	Other Calibration Devices	■

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LST Advanced SiPM Camera

R&D phase

- Improve duty cycle, robustness, stability using SiPMs
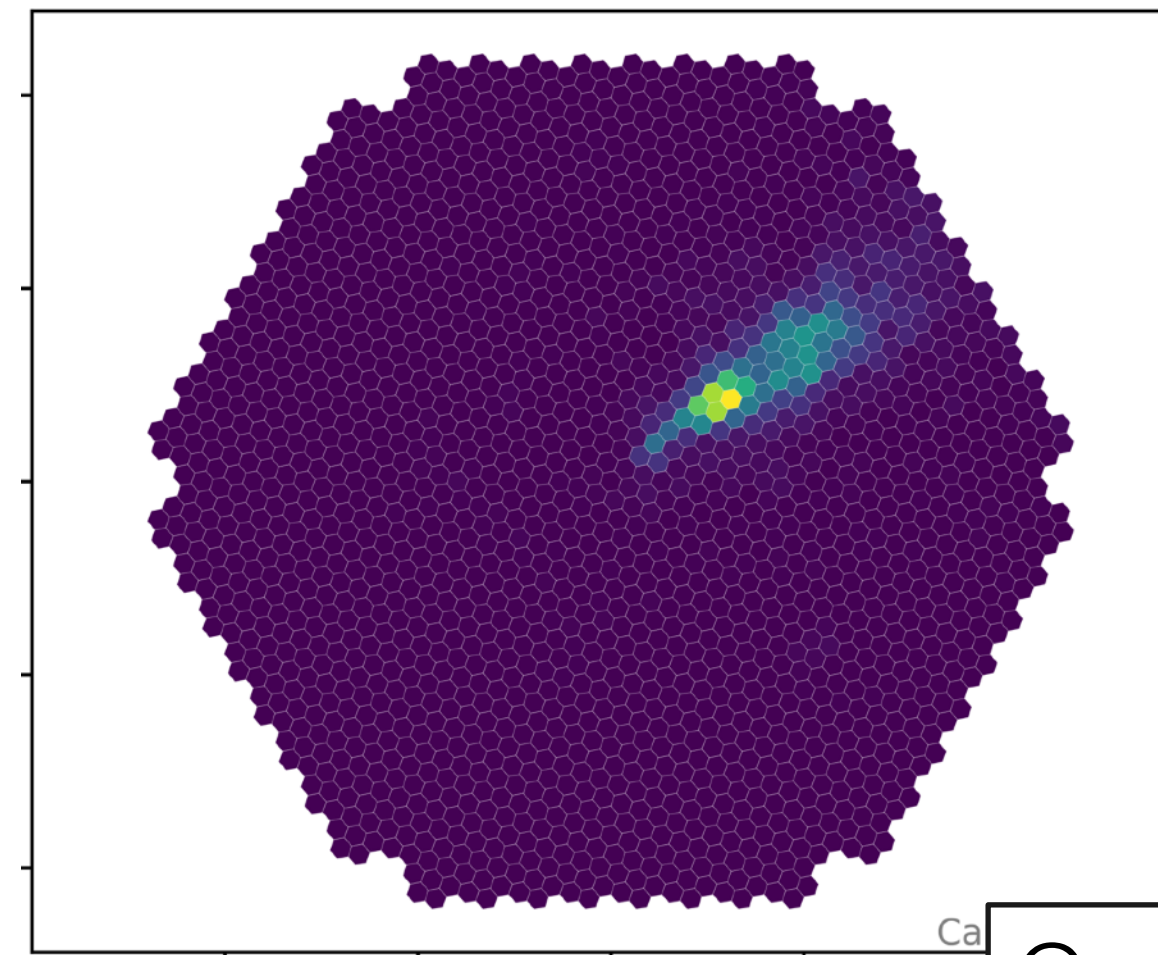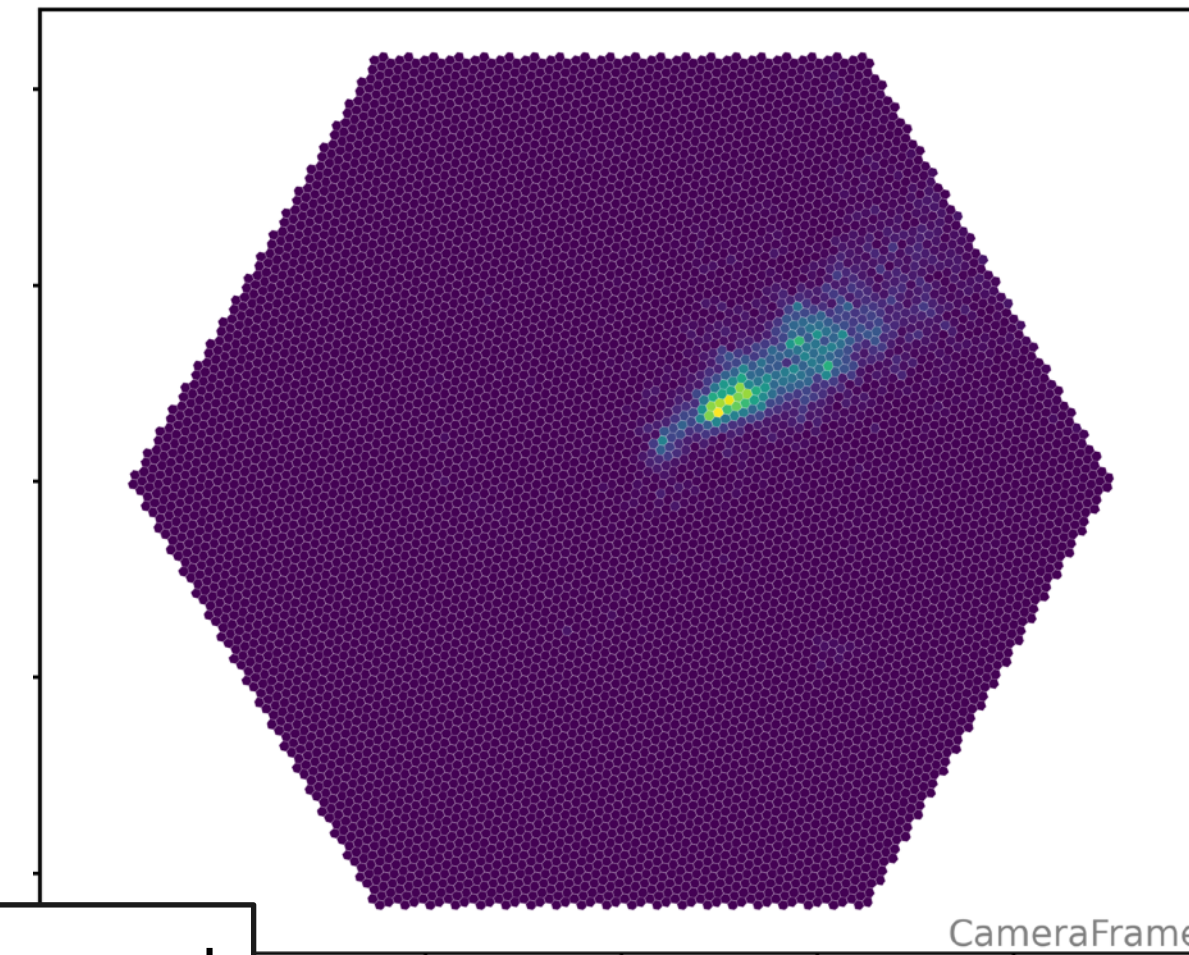- Increase image granularity for better image feature extraction
- Fully digital readout for better upgradability and use of artificial intelligence at earliest stage of the readout chain
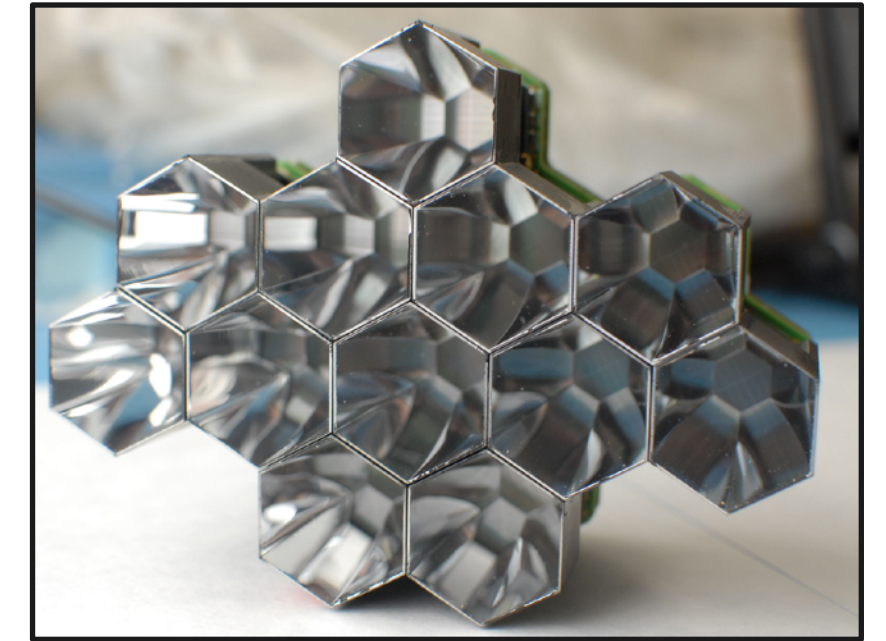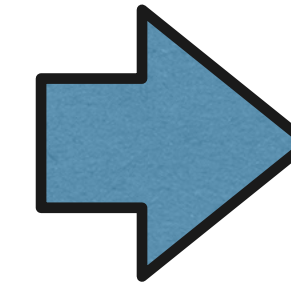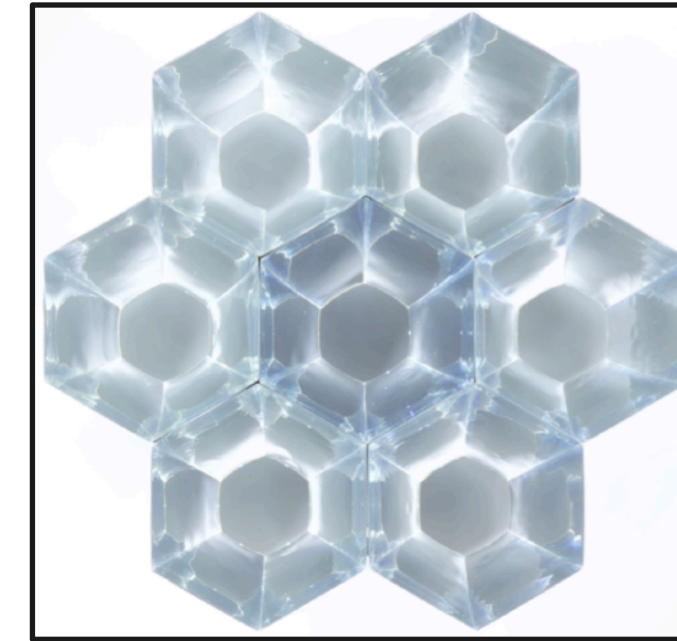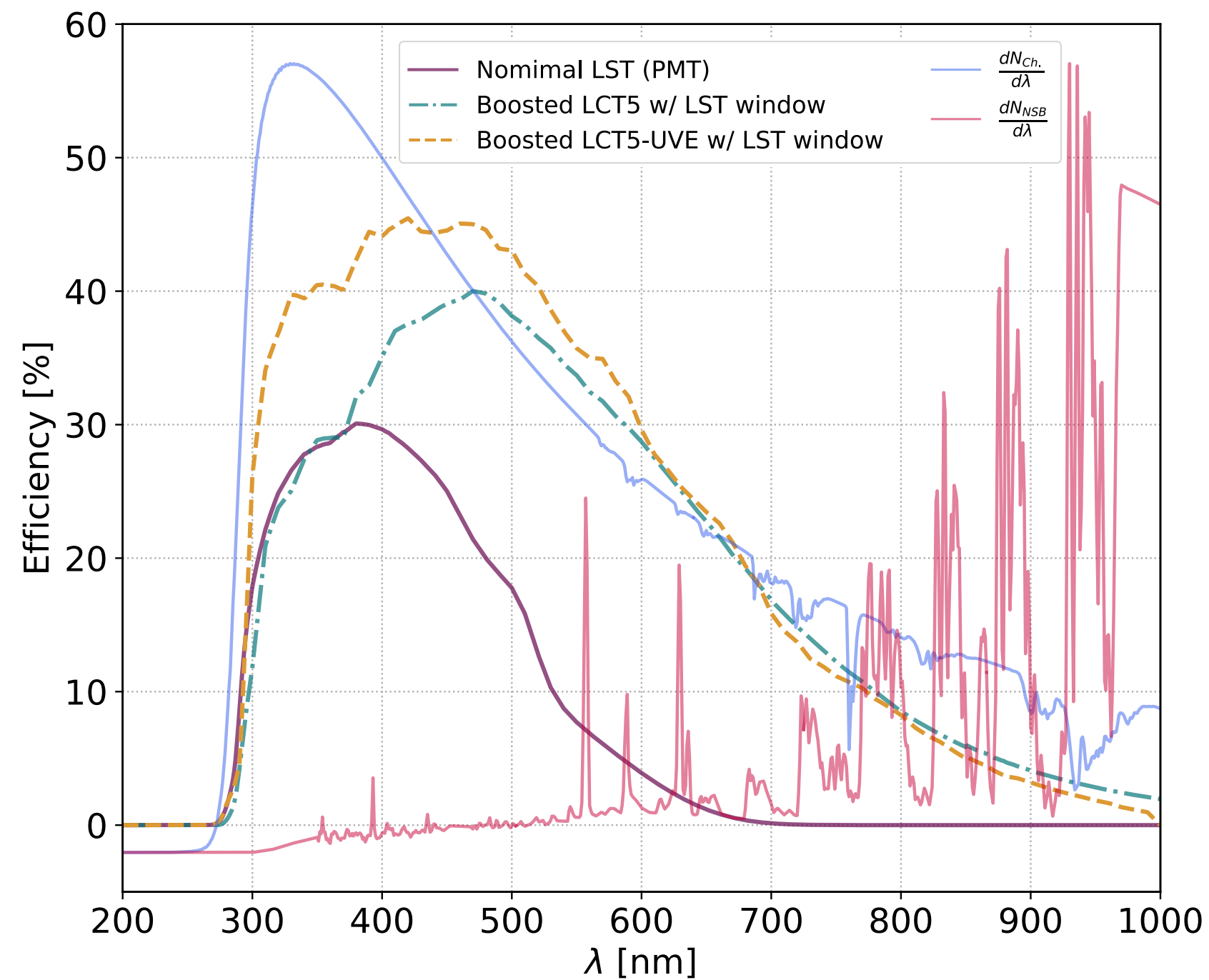

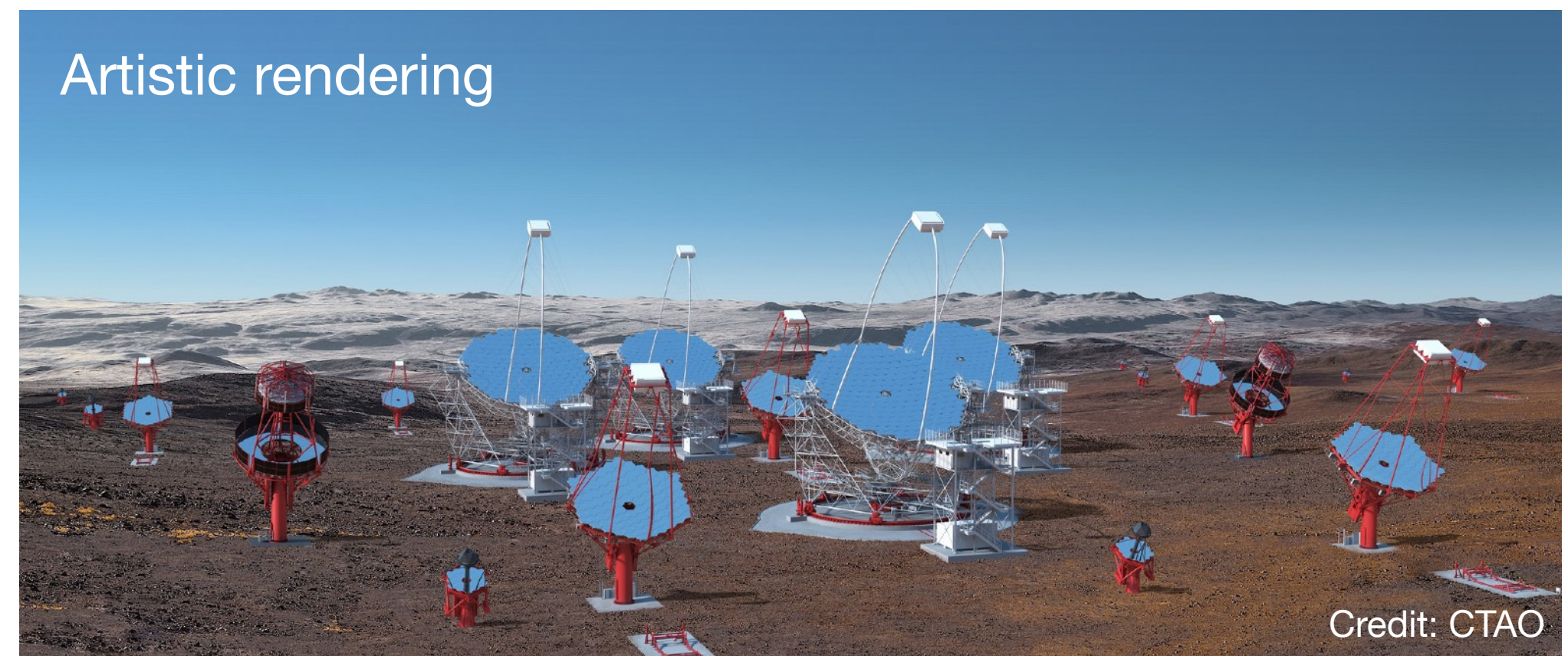LST PMT camera **(0.1°)**

LST SiPM camera **(0.05°)**

Gamma event

Conclusions

- The prototype telescope LST-1 was installed on the CTA-North site (La Palma, Spain) in 2018.
  - ✦ Performances of the telescope within requirements.
  - ✦ Taking engineering data runs since 2020.
  - ✦ First papers, starting with performance paper, to be published soon.
- Performance and data analysis well understood:
  - ✦ Promising observations and results ranging from Galactic:
    - ◉ Crab(s), RS Oph, LHAASO J2108
  - ✦ to Extragalactic:
    - ◉ BL Lac, other TeV Blazars

- Construction and commissioning of remaining LSTs in CTA North (LST-2 to LST-4) should be completed by 2025.

- Funding secured for 2 LSTs in CTA-South.

Credit: Other Ballester

Artistic rendering

Credit: CTAO
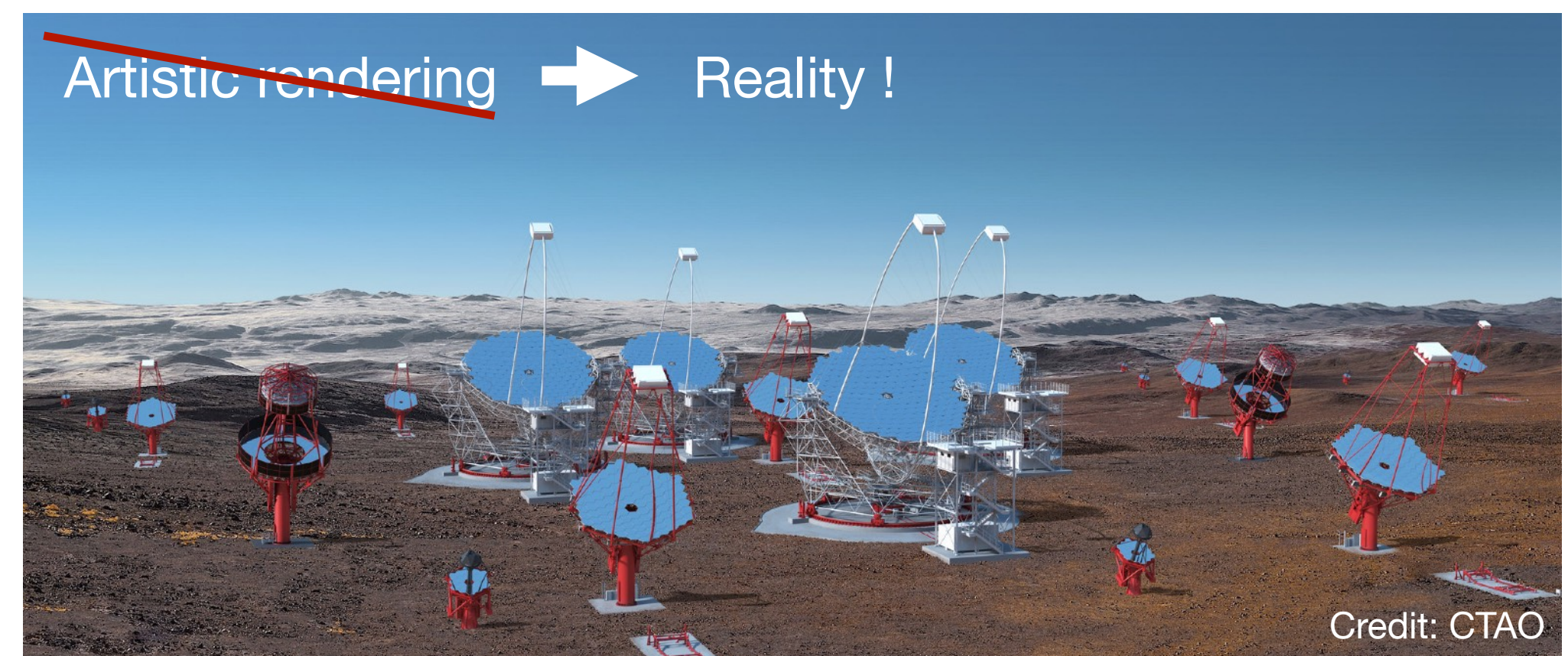
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Credit: Other Ballester

Artistic rendering ➡ Reality !

Credit: CTAO

To Jacques

- I had the unforgettable chance to share time with Jacques working on the AX-PET detector at CERN
- His great expertise and extreme kindness have been an amazing support for this period
- An inspiring person for all