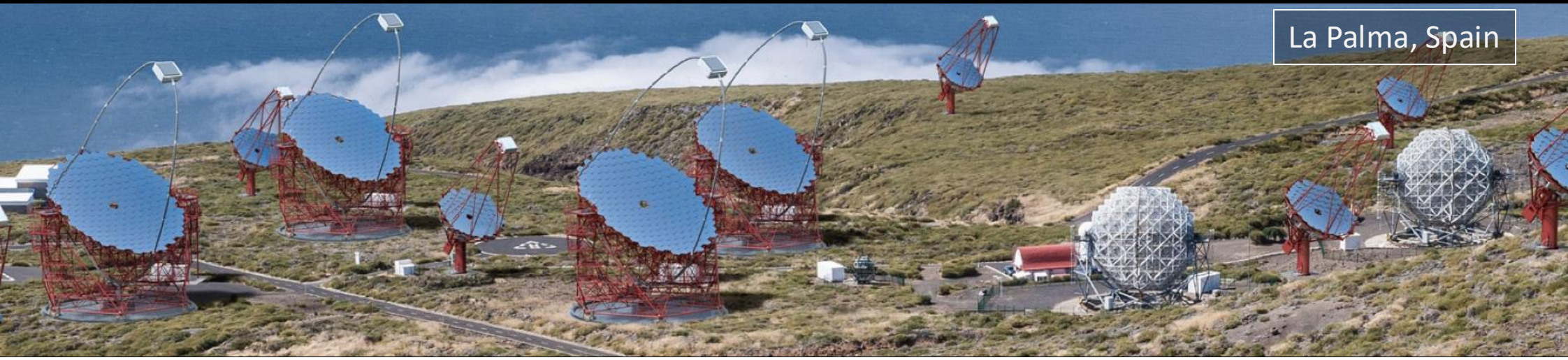
Status of CTA and Highlights

Masahiro Teshima for the CTAO Consortium

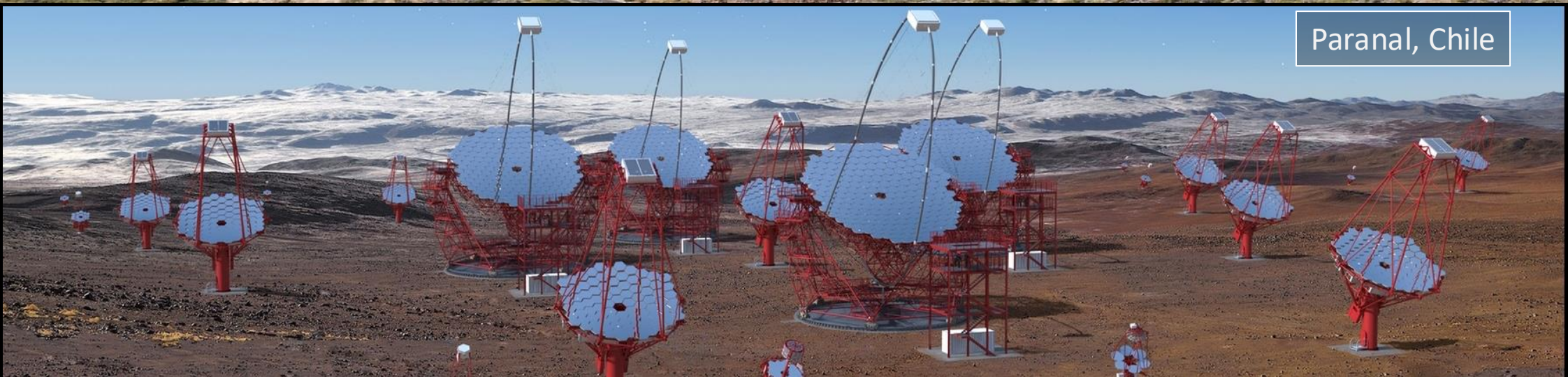
Max Planck Institute for Physics, Munich, Germany
Institute for Cosmic Ray Research, The University of Tokyo, Japan



Status of CTA and Highlights

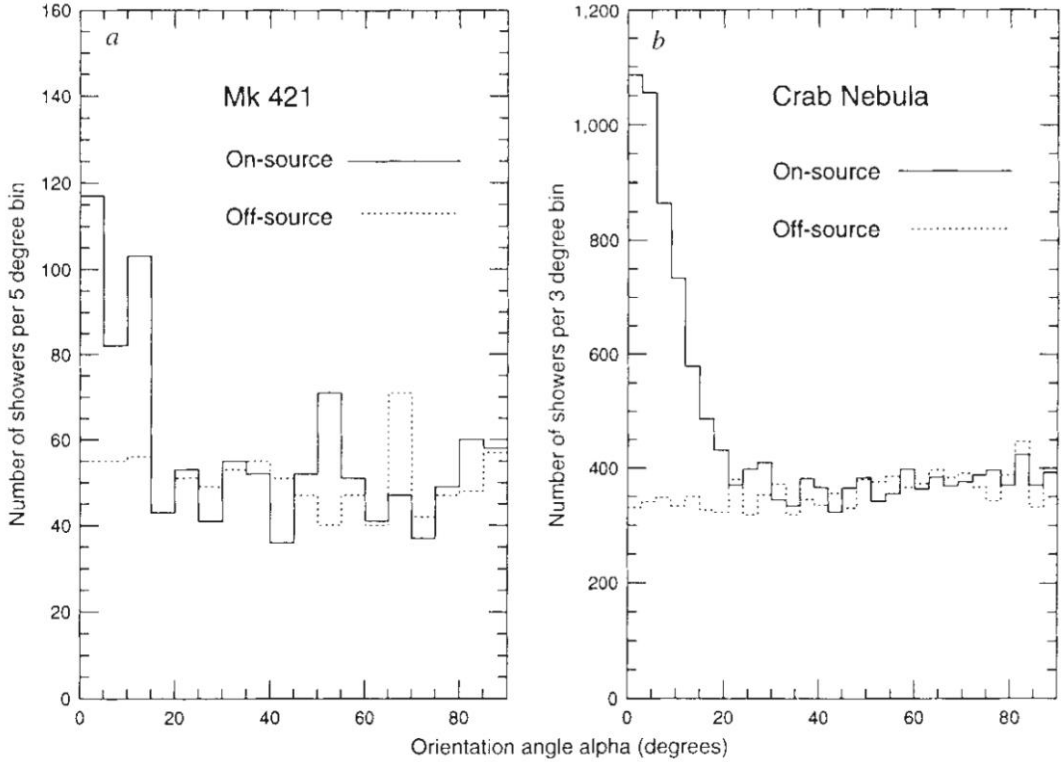
Masahiro Teshima for the CTAO Consortium

Max Planck Institute for Physics, Munich, Germany
Institute for Cosmic Ray Research, The University of Tokyo, Japan



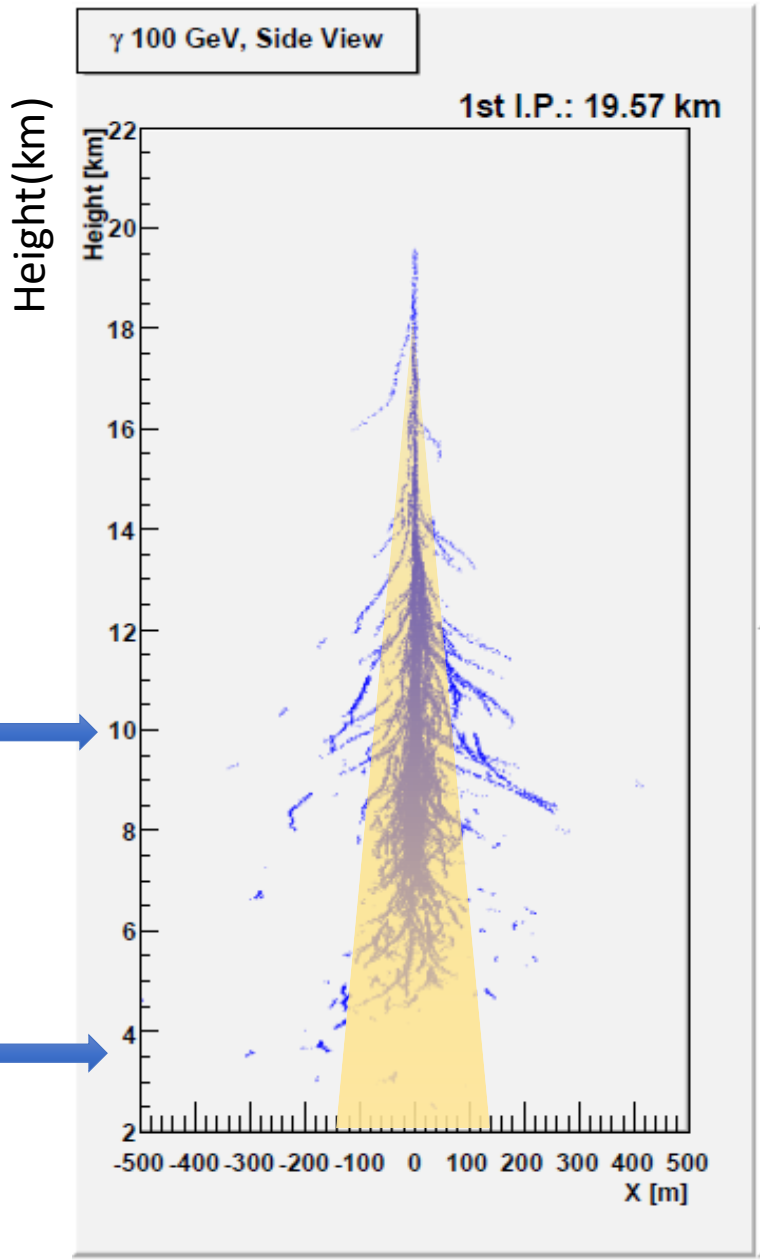
History of VHE gamma-ray astronomy
Imaging Atmospheric Cherenkov Telescope

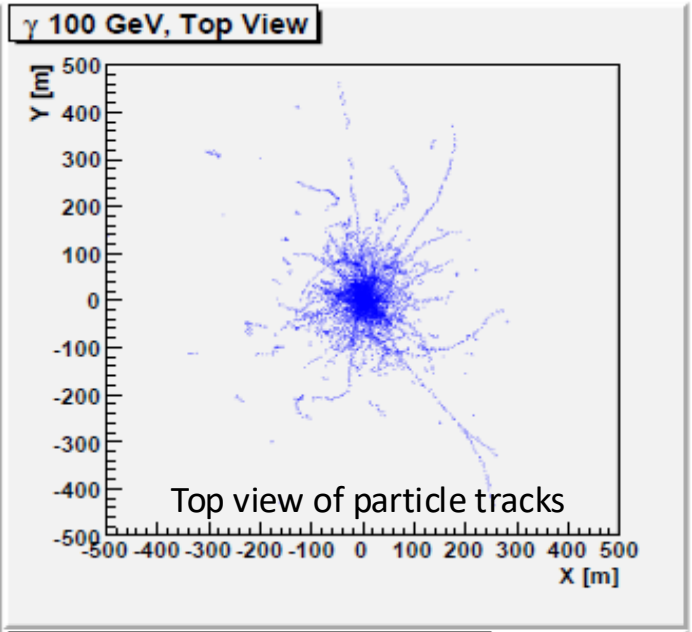
- The first idea of IACT from Michel Hillas in 1985 at ICRC in San Diego, USA
- Dr. Trever Weeks demonstrated the power of IACT with the Whipple telescope. VHE gamma rays from the Crab Nebula is discovered in 1989 (1G)
- ➔ Whipple, HEGRA, CANGAROO-I, II, and TA at DPG (1G)
- ➔ CANGAROO-III, HESS, MAGIC, and VERITAS (2G)
- ➔ CTA (3G)

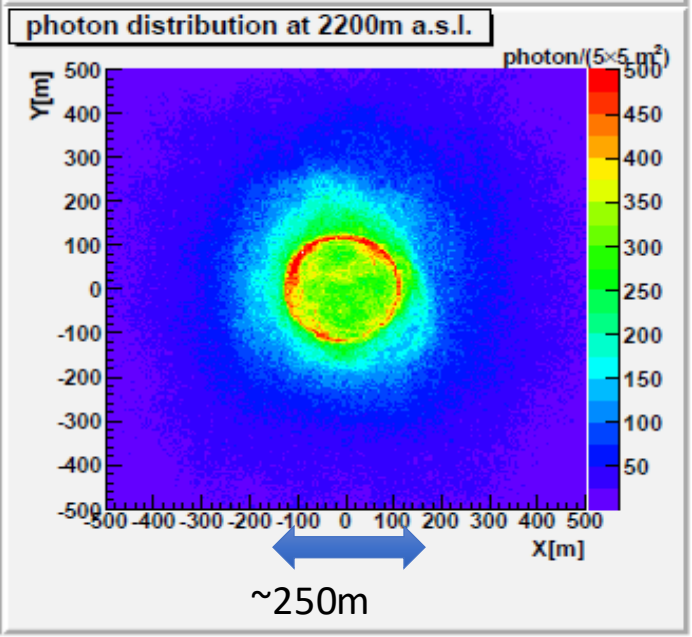


The observation of the first extragalactic source Mrk421
M. Punch et al., Nature 1991

TeV Gamma Rays
➔ EM showers
➔ Cherenkov Light







Refractive Index of Atmosphere
n = 1.000292

Light velocity
c' = c/n
= 0.9997 c

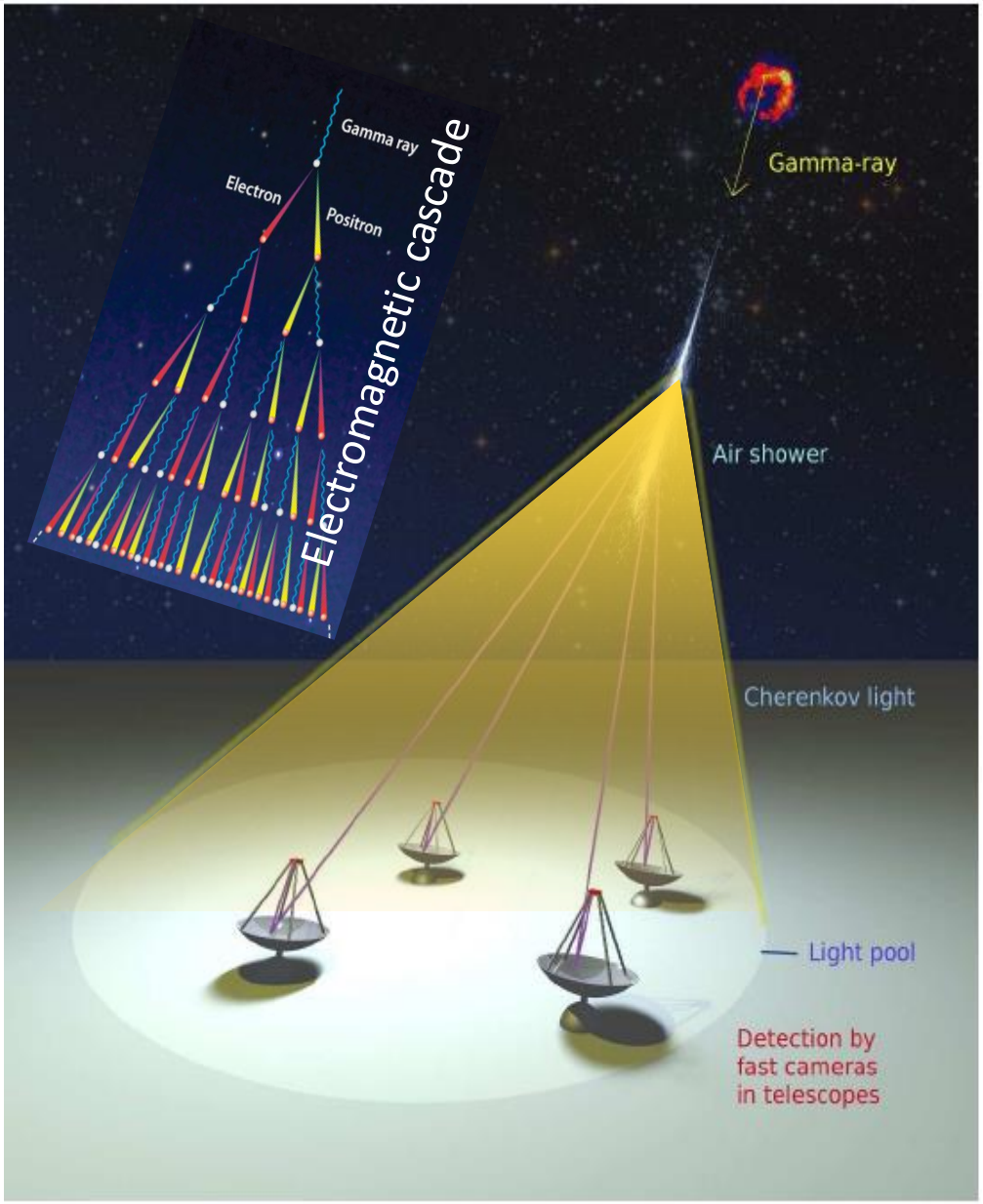
Particle velocity
v ~ c

Airplane

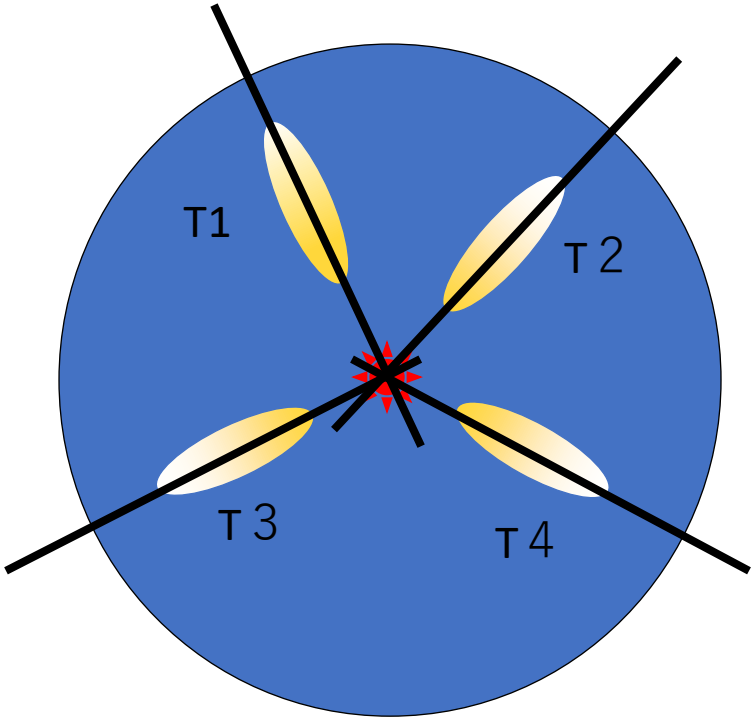
Mt. Fuji

Cherenkov light Footprint

Imaging Atmospheric Cherenkov Telescopes (IACTs)



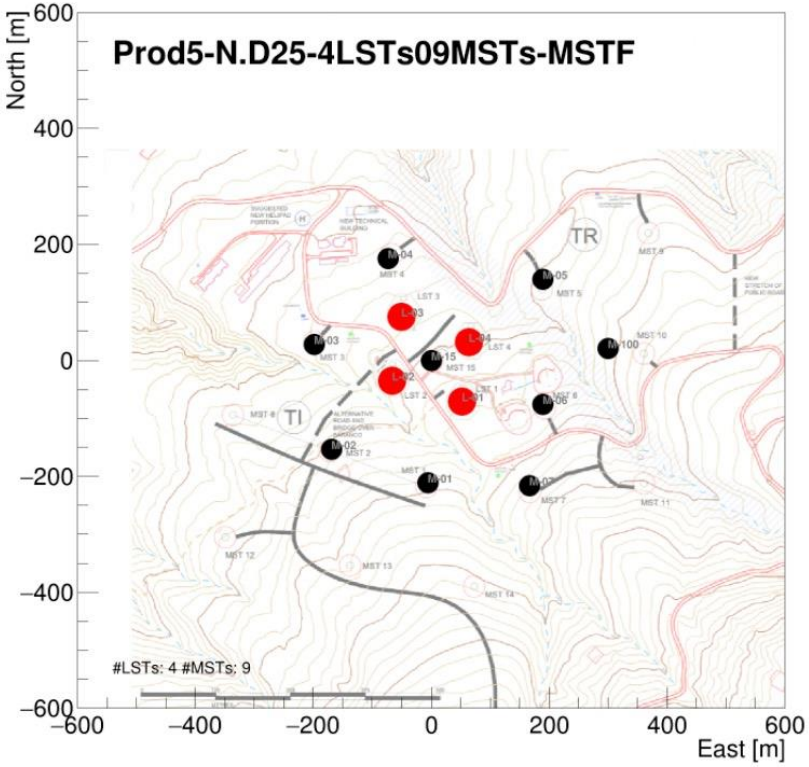
# of Photons: 50photons/m^2 at 1TeV



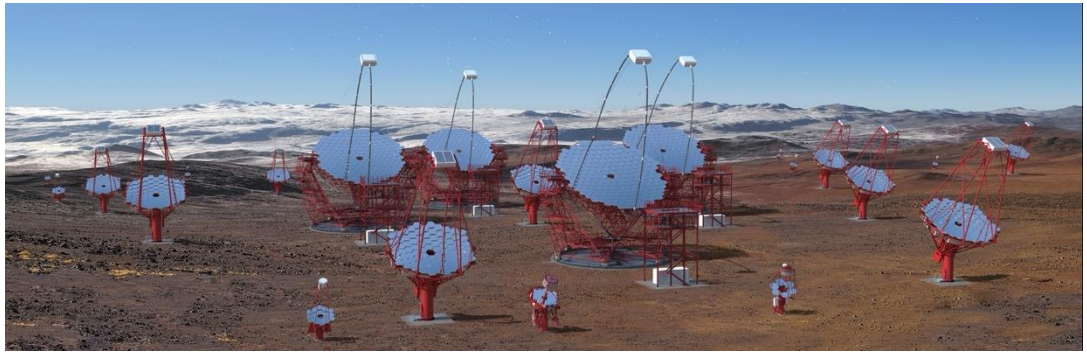
- Energy range 50GeV ~ 100TeV
- Angular Res. ~0.06 degrees
- Energy Res. ~15%
- Effective Area ~$10^5 m^2$
- Sensitivity ~0.6% Crab Flux (10^{-13} erg/cm^2s)

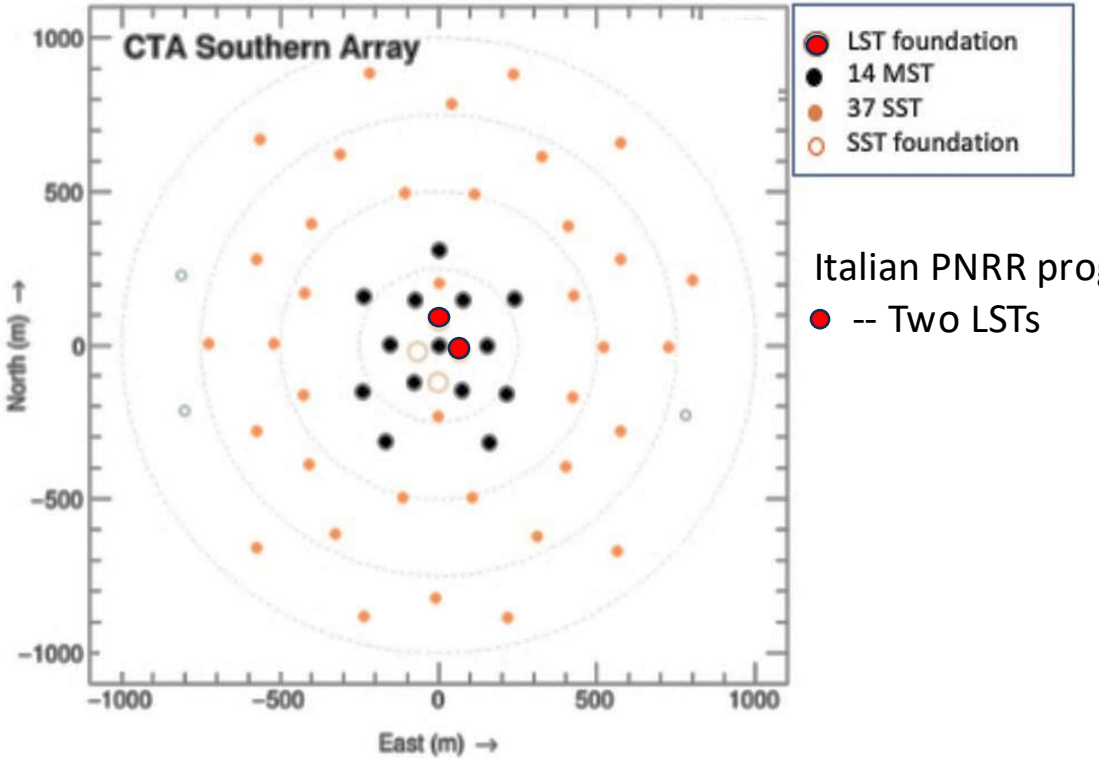
CTAO: Alpha Configuration

Roque de los Muchachos Observatory
La Palma, Spain

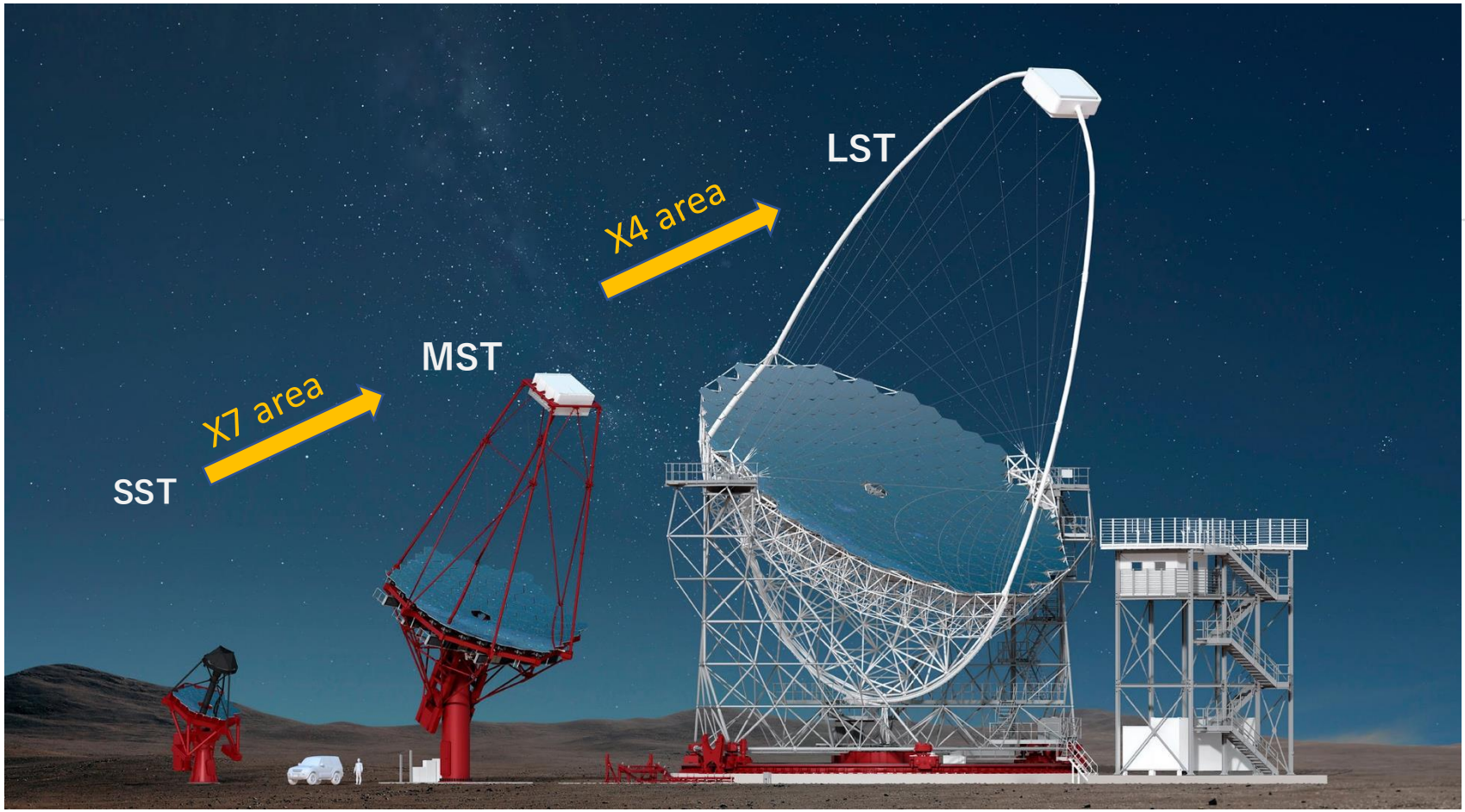


Paranal, Chile





Italian PNRR prog.
-- Two LSTs



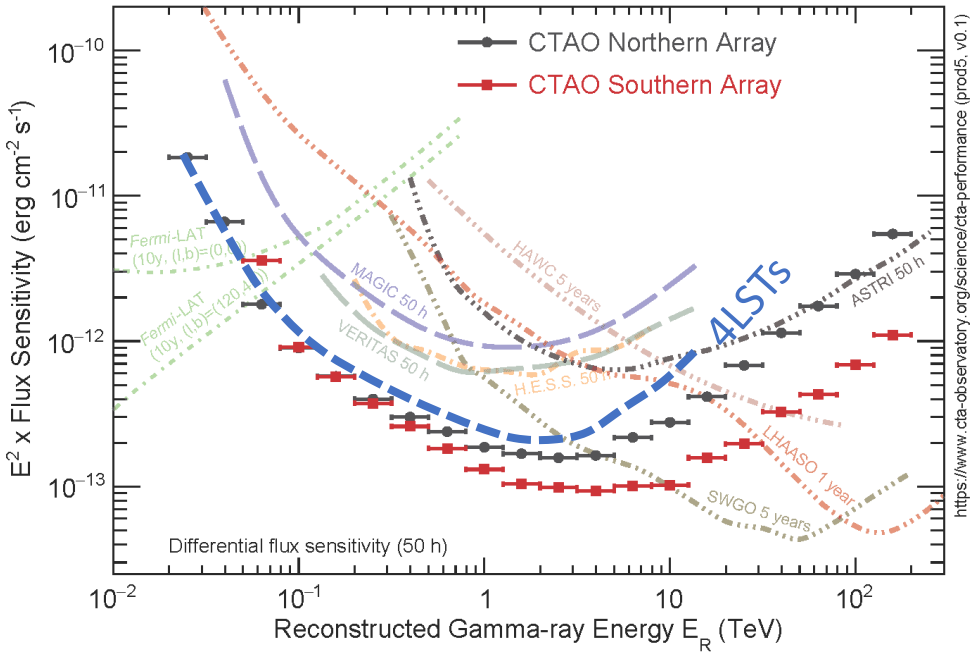
Telescope Types	SST	MST	LST
Optics	Schwarzschild-Couder	Davies-Cotton	Parabolic (Isochronous)
FoV and Camera	10.5 deg SiPM	7.5 deg PMT	4.3 deg PMT
Mirror Diameter	4.3m	11.5m	23m
Energy Range	3 TeV - 200 TeV	100GeV - 10TeV	20GeV – 2TeV
Science Targets	Galactic Sources PeVatron (UHE CR)	Galactic Sources Nearby AGNs (z<0.5) Dark Matter	Transient Sources AGNs(z<2), GRBs(z <4) Dark Matter

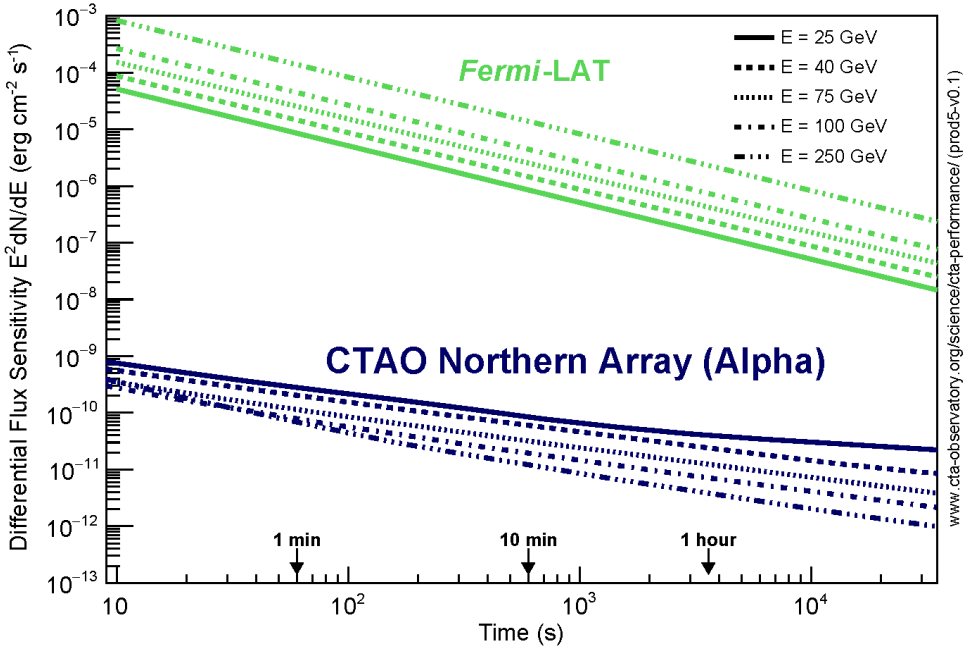
Observatories in Spain La Palma, and Chile Paranal for all sky observatory

CTAO Sensitivities for point sources

- CTA array offers a 10 times better sensitivity
- Energy coverage from 20GeV to 200TeV

- LSTs are designed to do follow-up observations of transients in 20 seconds.

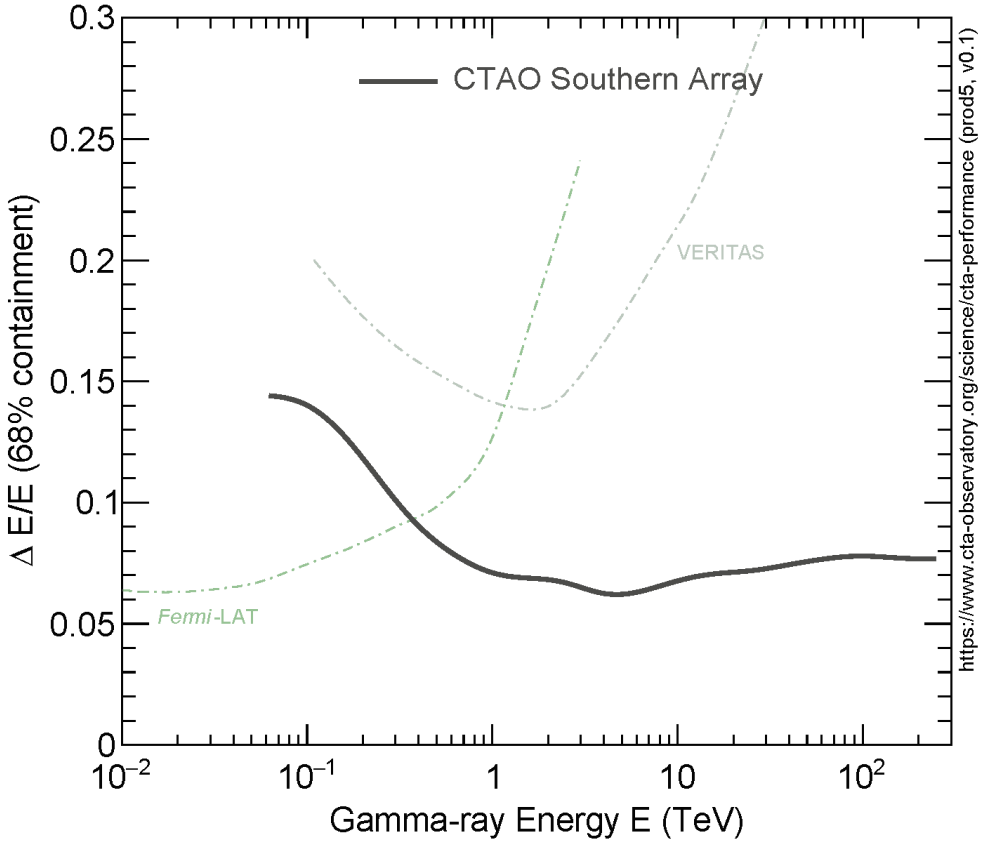


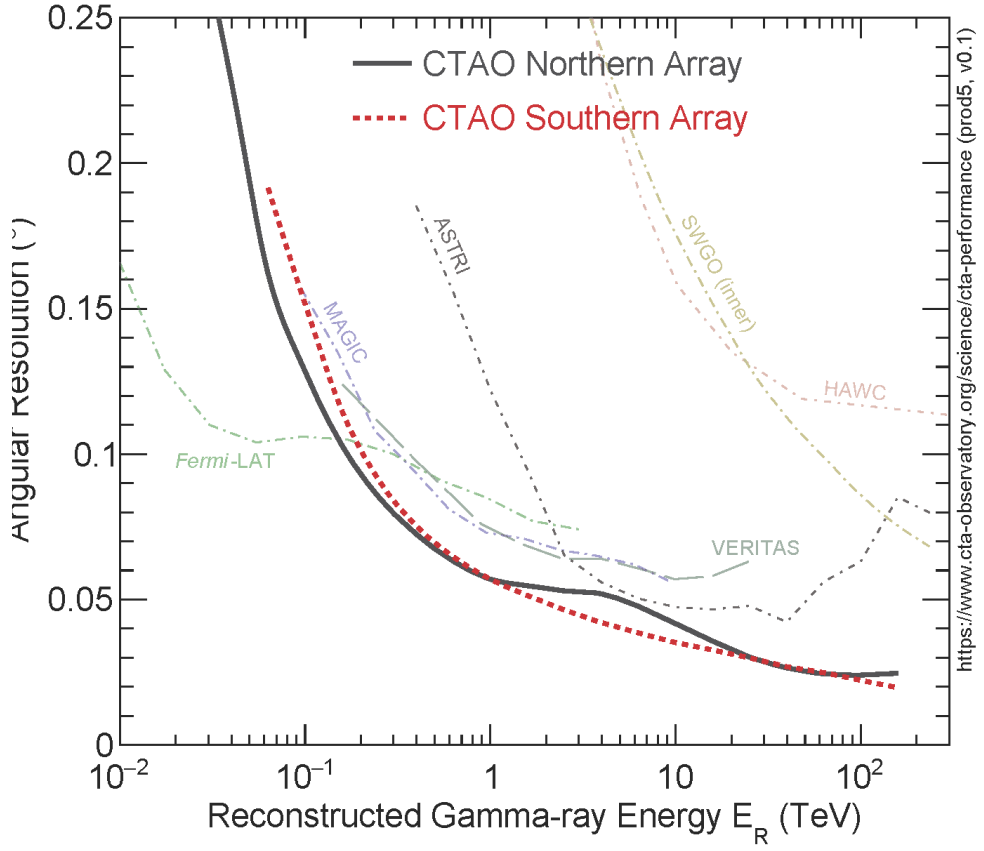


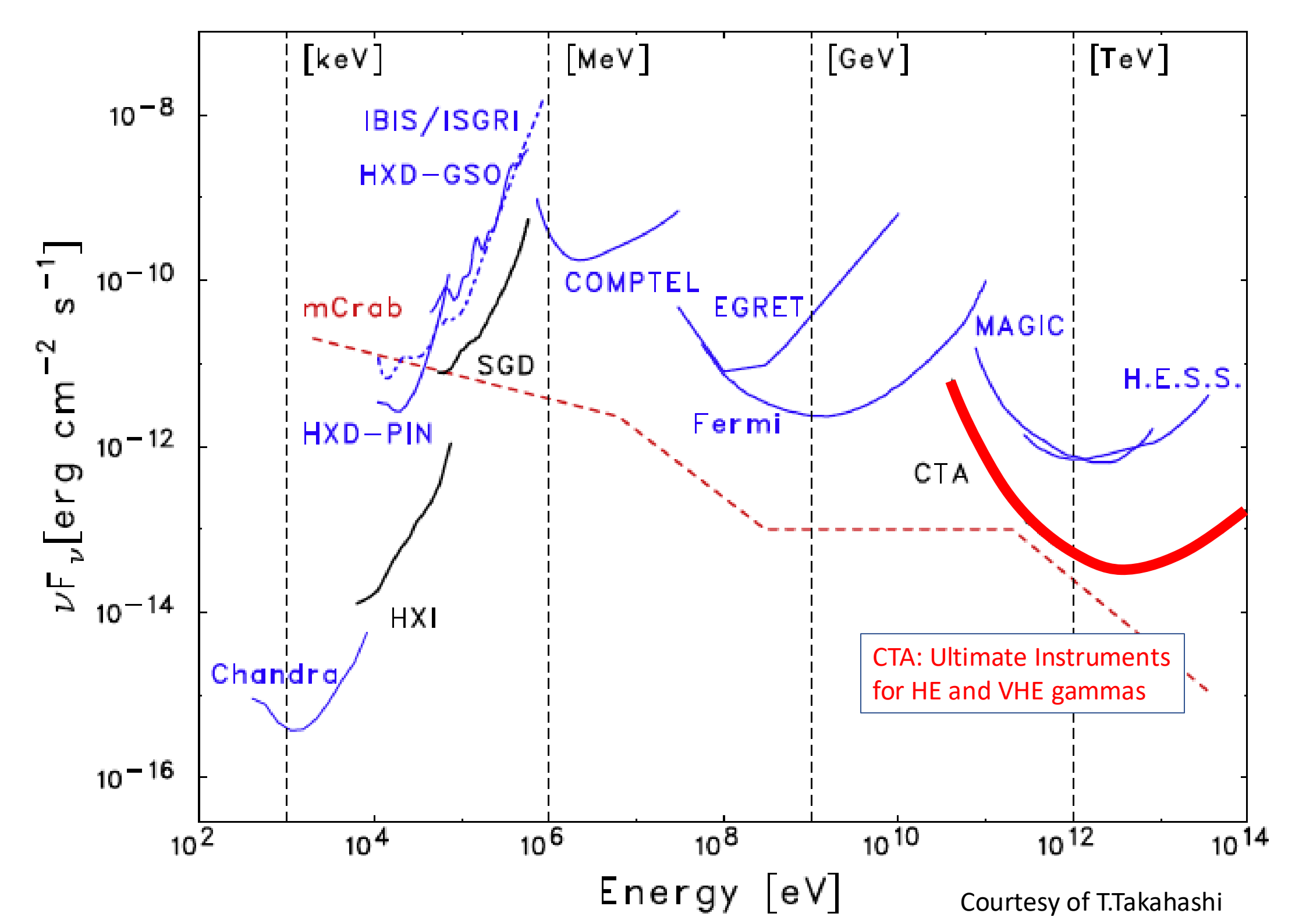
- LSTs will offer
  - Distant AGNs up to z = 2 and GRBs up to z = 4 are observable with LSTs
  - X10000 sensitivity for GRBs and AGN flares than Fermi
  - The fast rotation (20 sec) offers the observation of GRBs even in the prompt phase

CTAO Energy Resolution and Angular Resolution

- ❑ **Energy Resolution**
  - ❑ 7% above 1TeV
  - ❑ 15% below 1TeV
- ❑ **Angular Resolution**
  - ❑ 0.06 degrees above 1TeV
  - ❑ 0.12 degree at 100GeV% at 100GeV





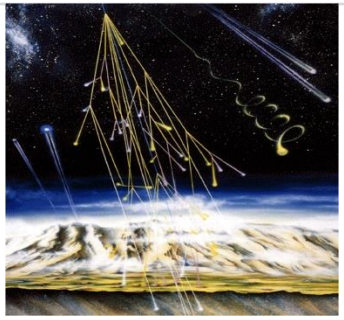


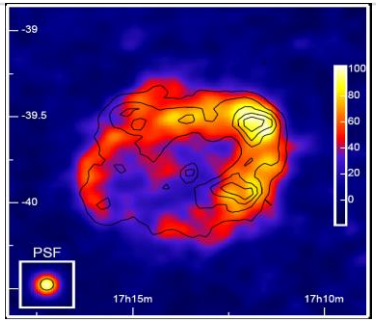
Courtesy of T.Takahashi

CTAO | LST COLLABORATION

Science of CTAO is very wide

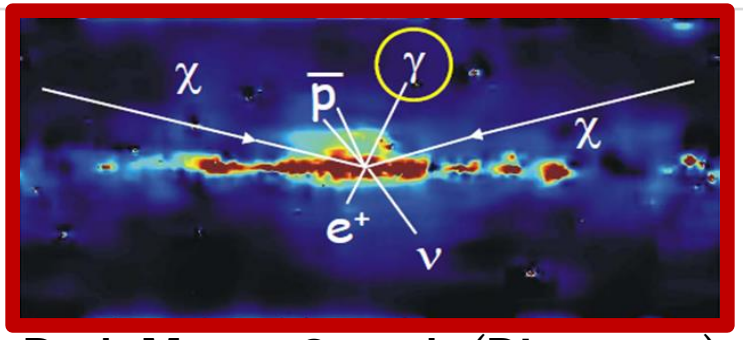
CTA-LST will cover S.M.B.H., Dark Matter, AGNs, GRBs, etc.





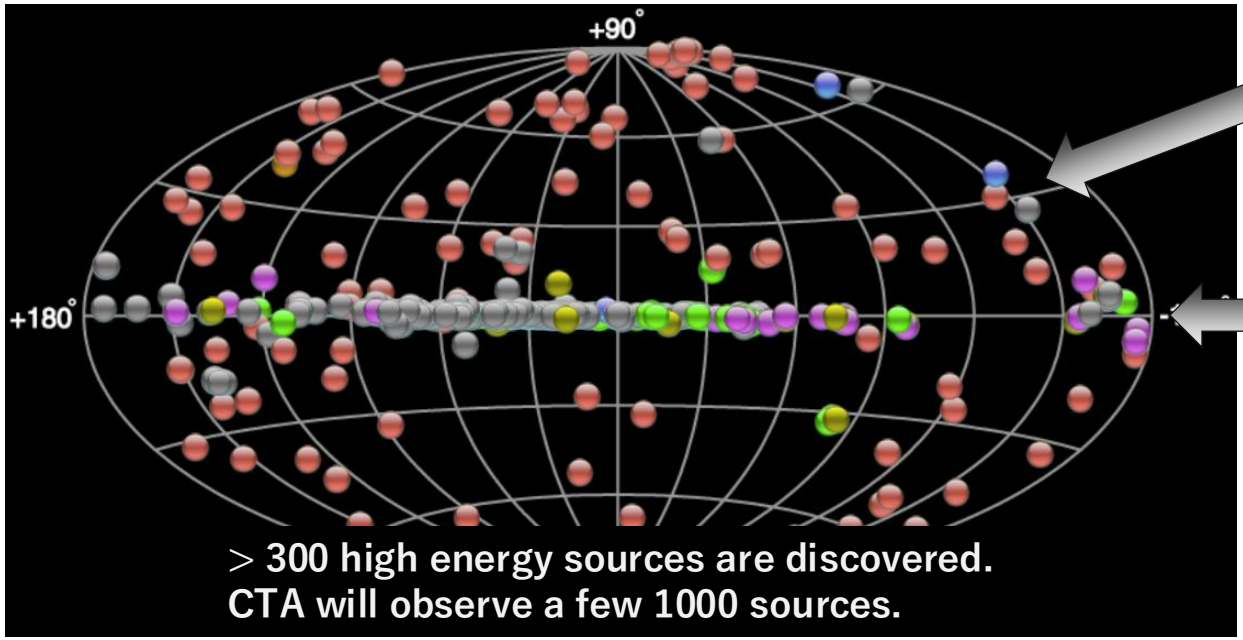
Cosmic Ray Origin

Super Massive Black Holes



Dark Matter Search (Discovery)

- Origin of Cosmic Rays (Big accelerators)
- Black Hole and S.M.B.H.
- Dark Matter Search



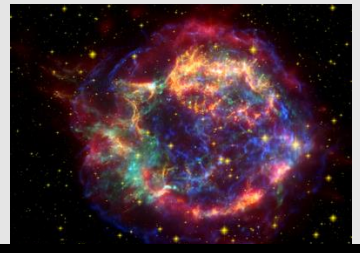
> 300 high energy sources are discovered.
CTA will observe a few 1000 sources.

Extragalactic Sources

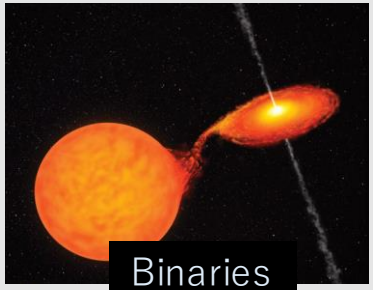
Active Galactic Nuclei

Gamma Ray Bursts

Galactic Sources



Super Nova Remnants



Binaries

Timeline of the project

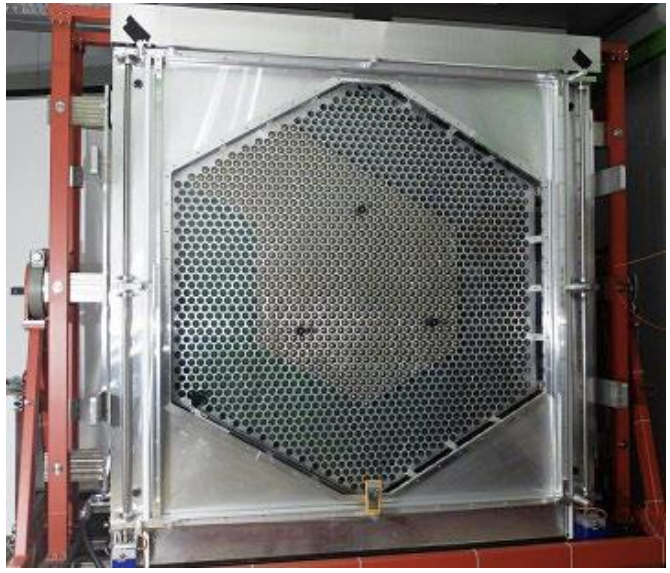
- CTAO ERIC was approved on January 7, 2025

- CTA South
  - The construction of CTA South officially starts in 2025.
  - Infrastructure construction will be done in 2025-2027
  - 2 MSTs and 5 SSTs will be shipped and assembled in 2026.
  - 2 LSTs will also be coming in the South.
  - The south array will be completed in 2029 or 2030.

- CTA North
  - LST1 was completed in 2018 and started commissioning in 2019.
  - The construction of LST2-4 in CTA North will be completed in 2026, and commissioning will be completed in 2028
  - MST1 will come in 2026
  - MST2-9 will come around 2028 or later.
  - The north array will be completed around 2028.

MST prototype

MST Prototype in Berlin (2012-2020)



MST Camera (1800ch PMTs)

SST Prototype Telescope
ASTRI Telescope

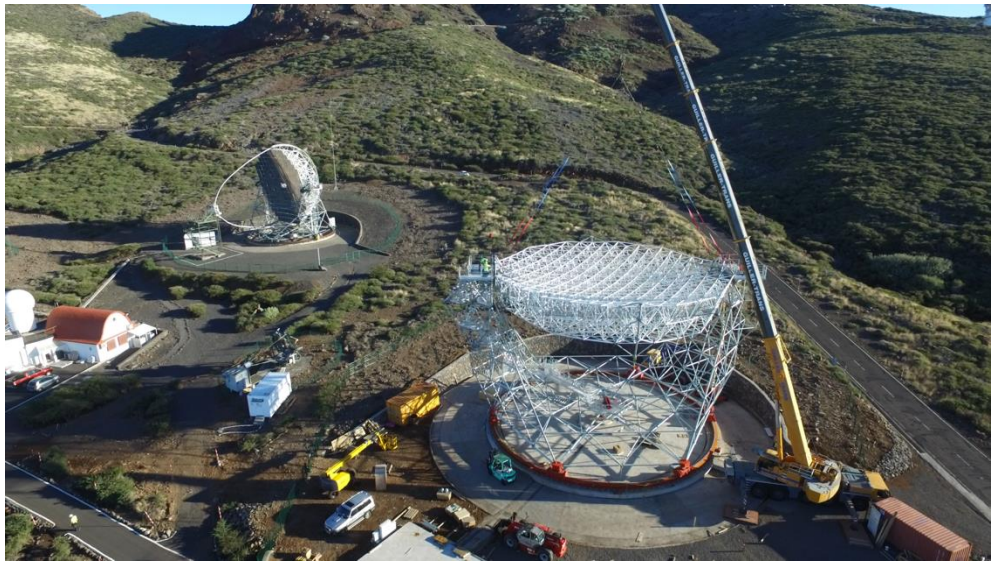
SST Prototype in Catania (2014)

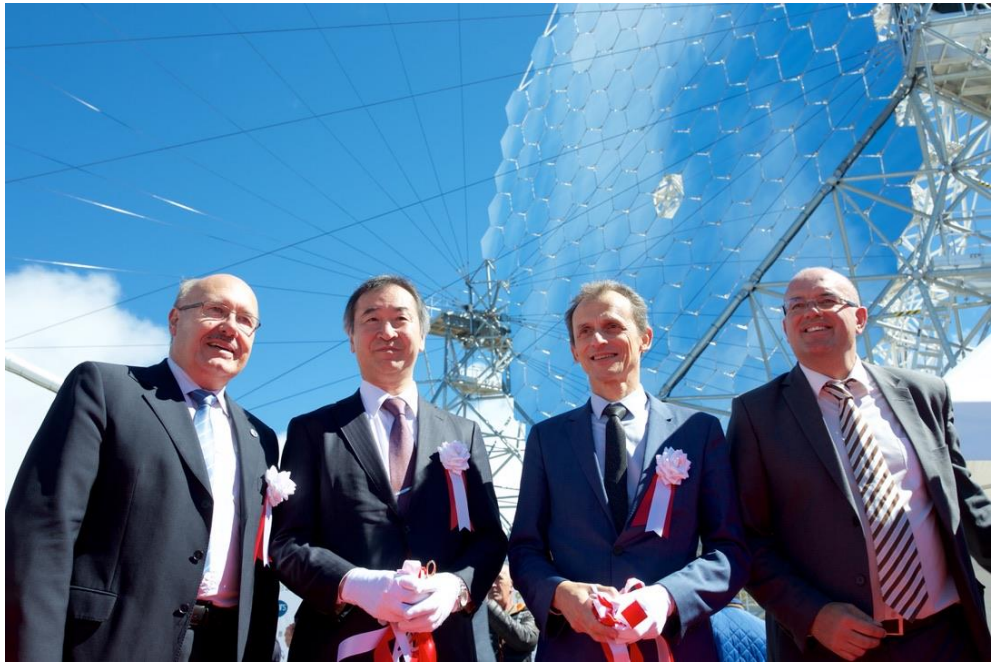
First ASTRI Telescope in Tenerife (2024-)
8 more telescopes will come soon

SST Camera

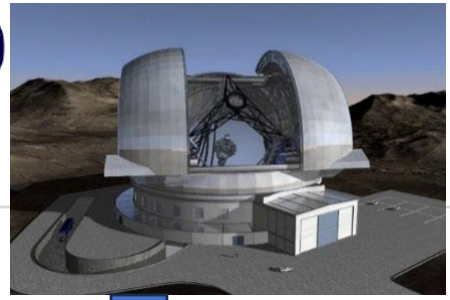
CTAO | LST COLLABORATION

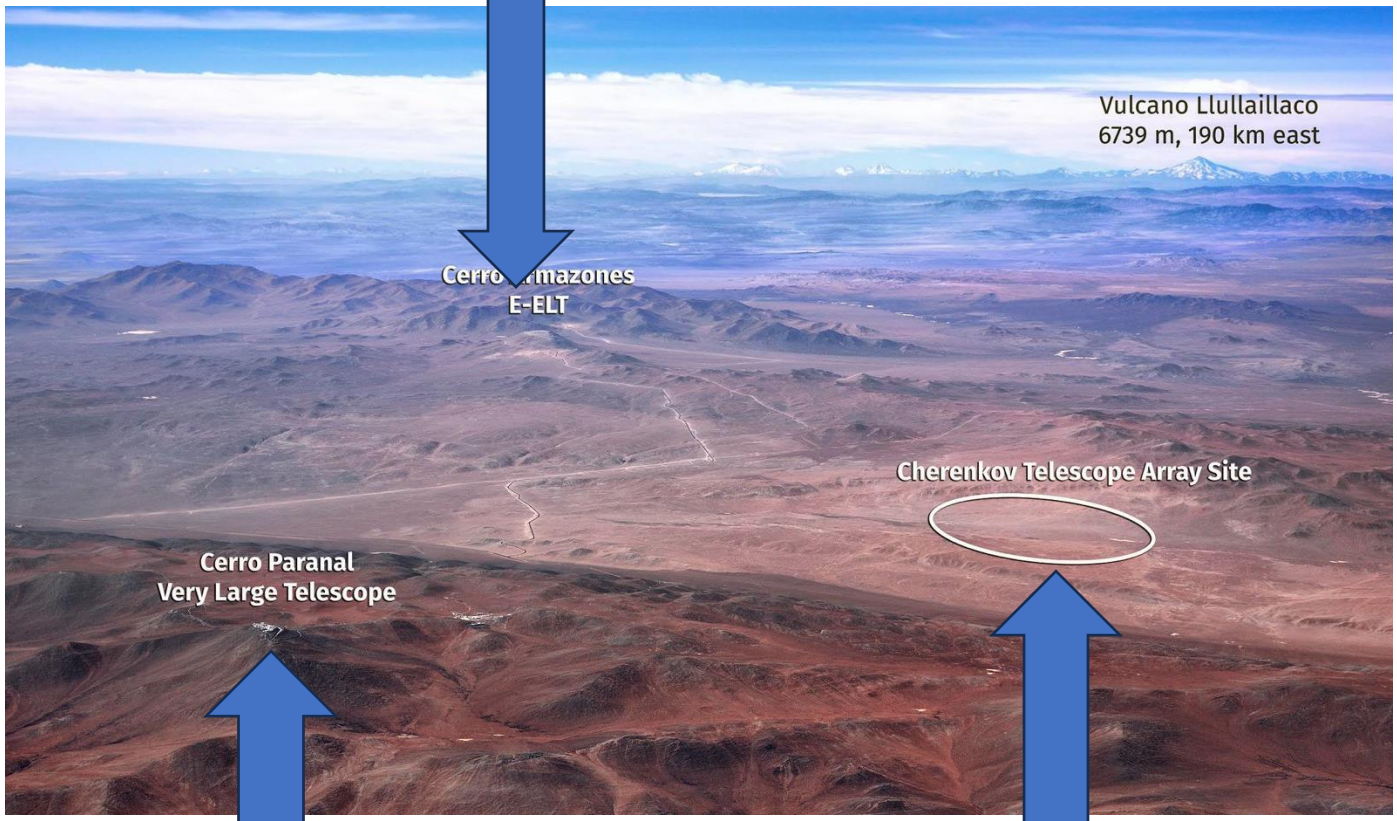
First LST1 at CTA North on Oct.2018

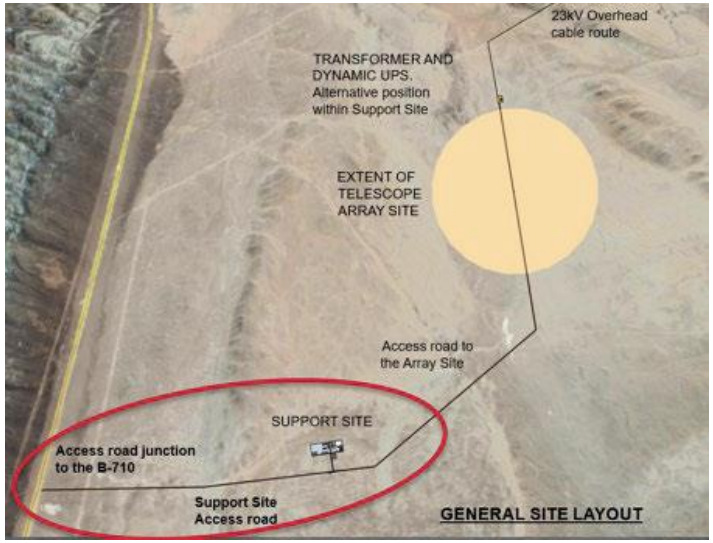




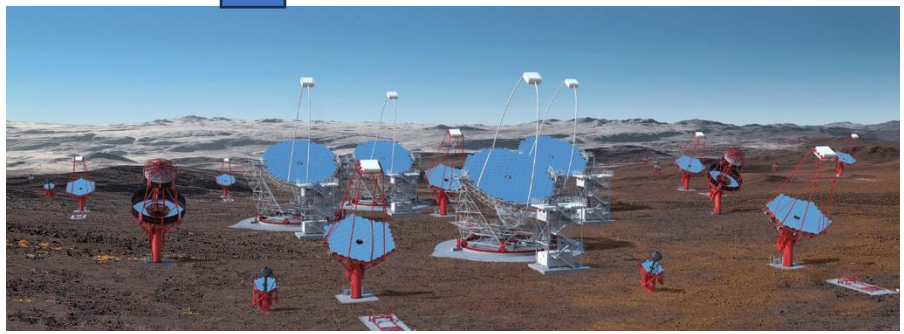
CTAO South in Paranal Chile







Access Road will be completed this year. Powerline and concrete foundations will be installed in 2026



5 SSTs and 2 MSTs will be shipped and installed in 2026/2027

CTAO | LST COLLABORATION

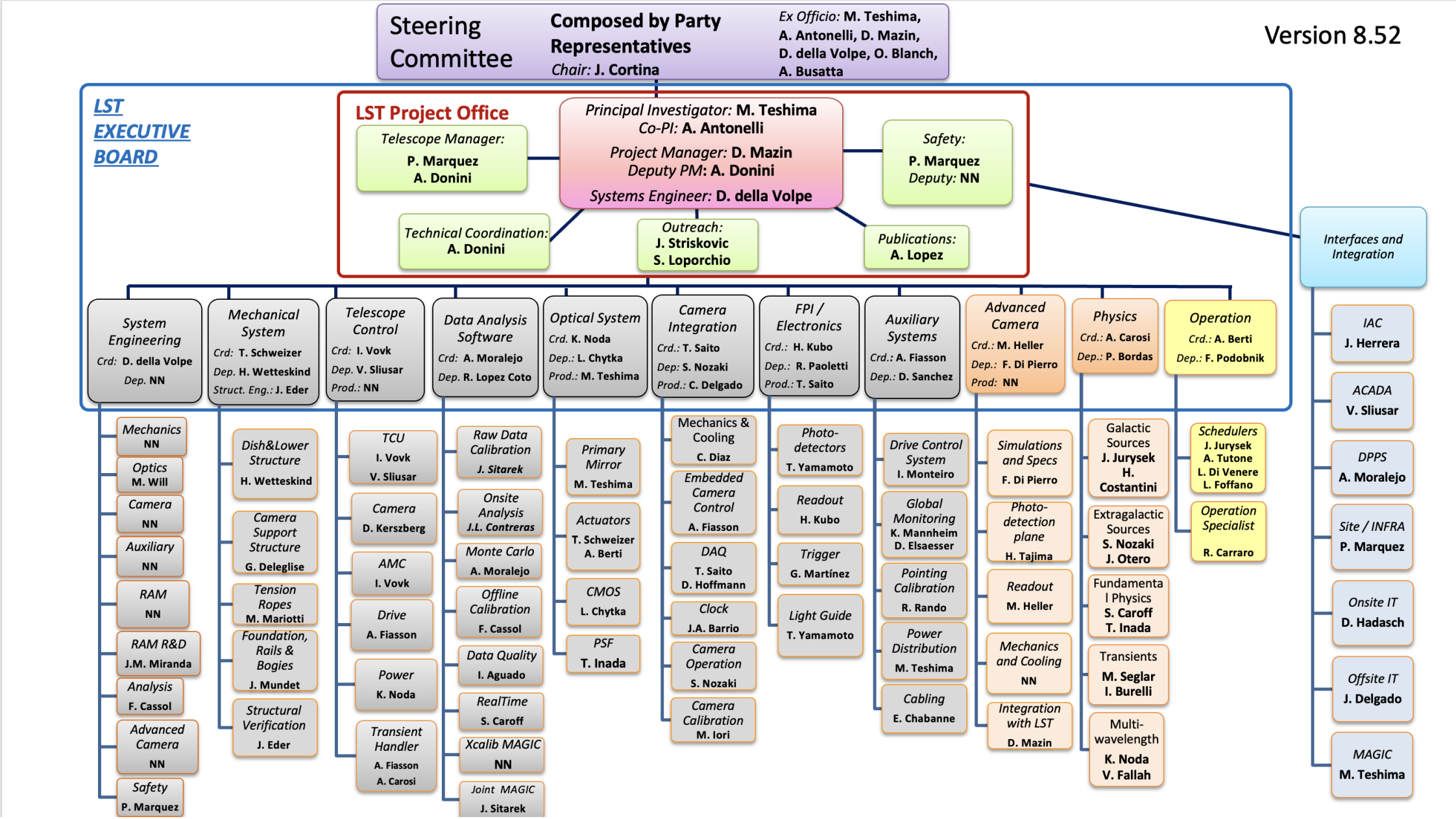
LST Collaboration

LST statistics			
	Members	Scientists + Students	Authors
Bulgaria	2	2	2
Brazil	3	2	2
Spain	92	61	56
France	42	21	21
Croatia	9	9	9
Czechia	19	19	12
Germany	49	42	39
Switzerland	22	19	16
Italy	129	103	78
Japan	87	82	65
Poland	5	5	5
Total	459	365	305

We have a good number of people

CTAO | LST COLLABORATION

LST Collaboration



Large-Sized Telescope

Mirrors: JP
Interface plates: JP, DE, BR
Actuators: JP, CH, DE
CMOS CAM: JP

Tension cables: IT

Camera Support Structure: FR

calibration: IT, HR, IN, DE

Camera electronics: JP, IT, ES, CH
Camera mechanics: ES
Camera safety: FR

Telescope structure: DE, ES

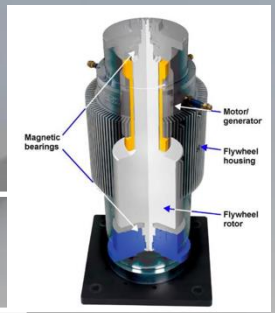
Rail: DE, ES

Camera Access Tower: DE,ES

Bogies: ES, DE

Foundation: ES

FlyWheels (2x300kW) energy storage and UPS: JP



May 2024

LST4
March 2025

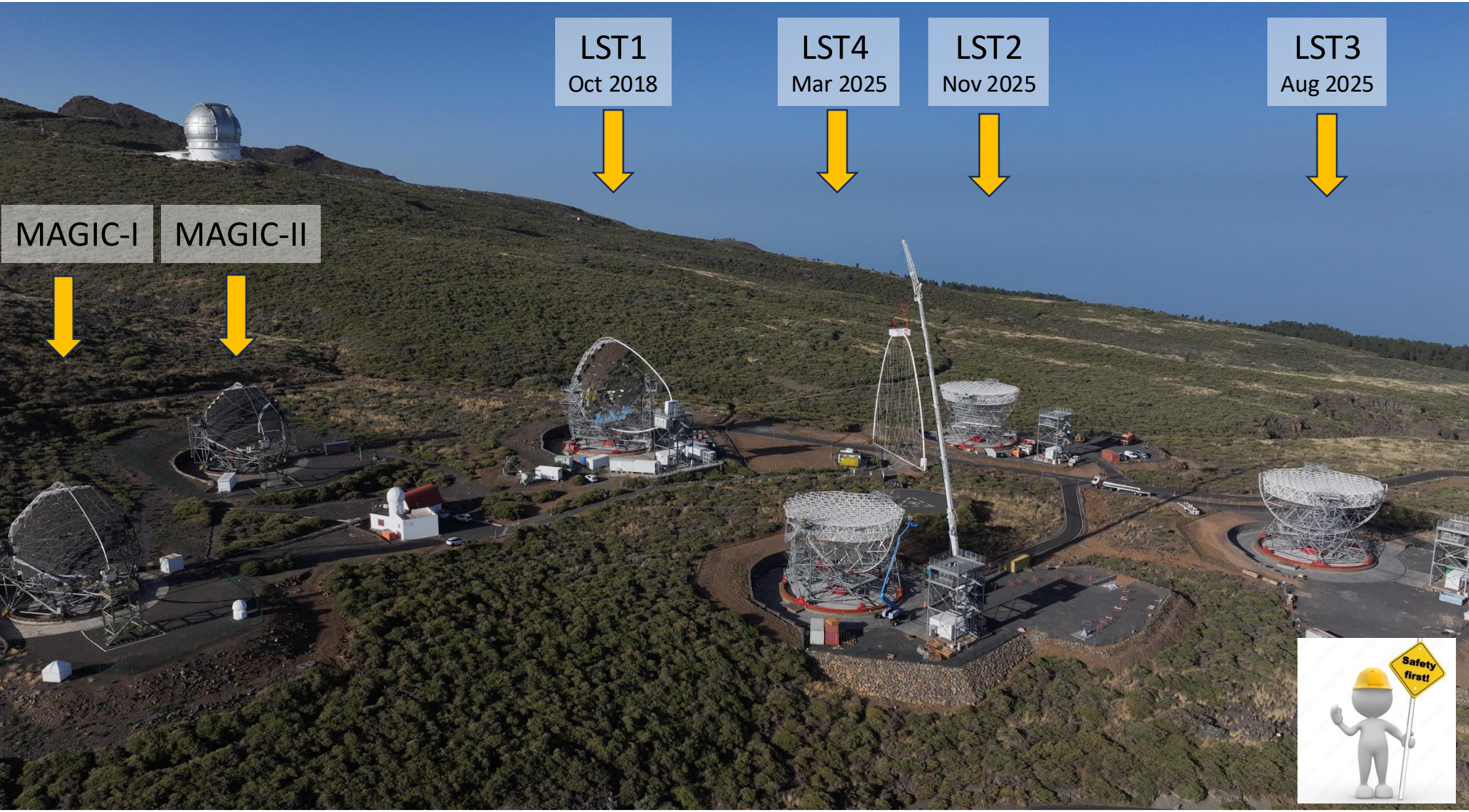
LST1
October 2018

LST2
November 2025

LST3
August 2025

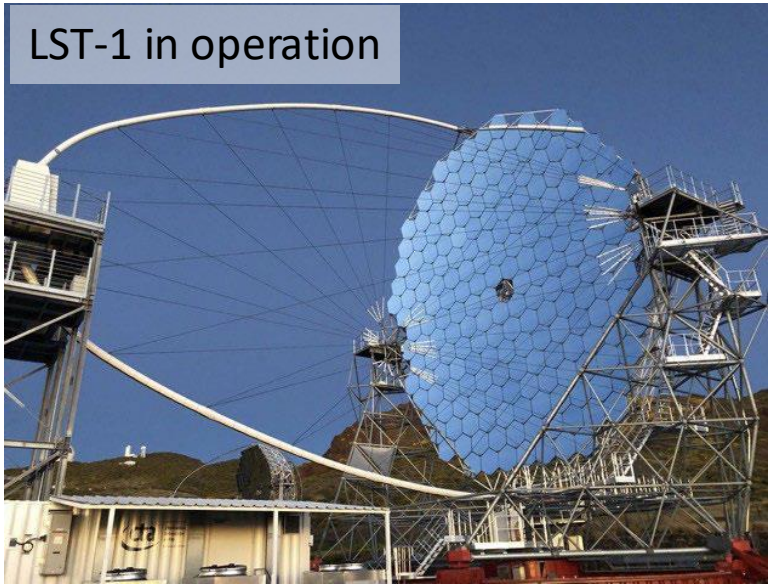
LST4 ARCH-CSS installation

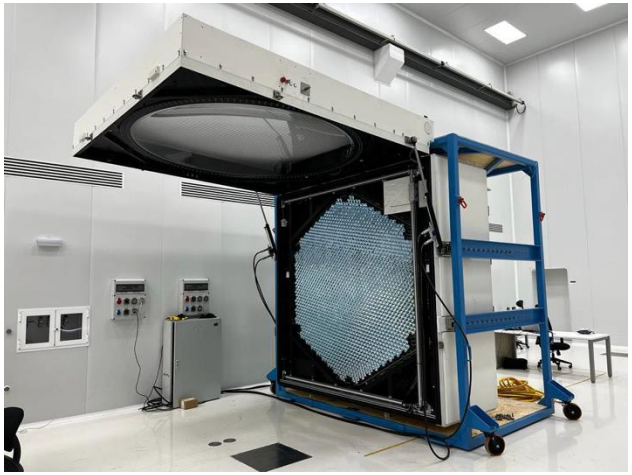
on 22.Aug.2024



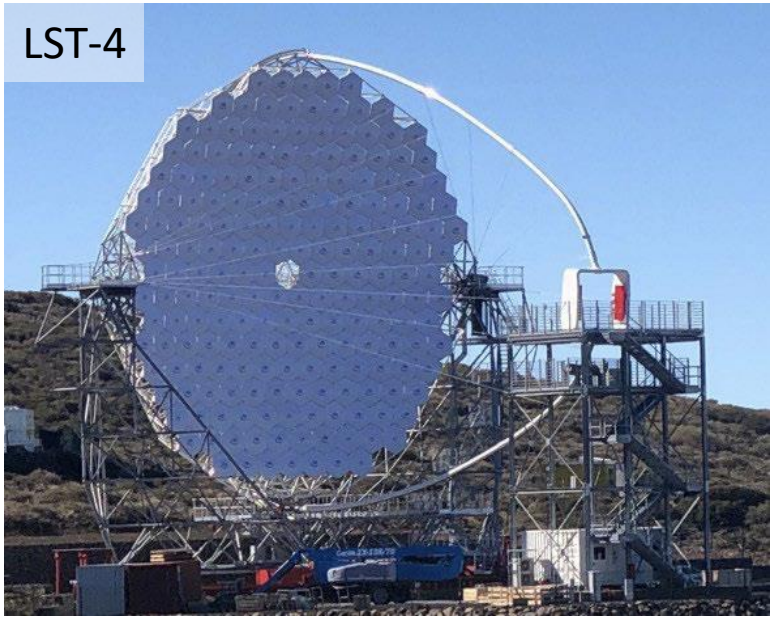
December 2024

Constructions of LST2-4 are on-going



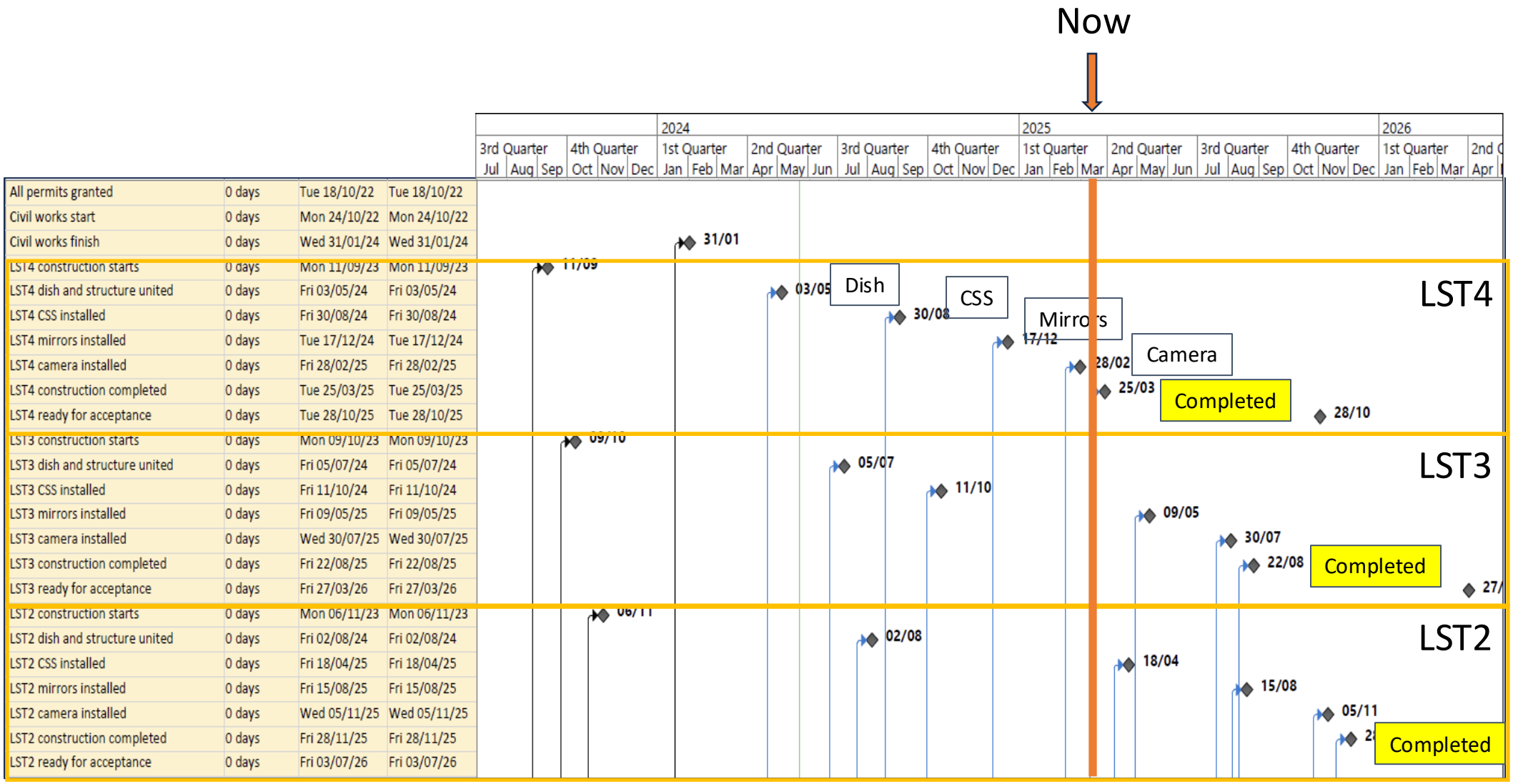


QC and Calibration of 3 Cameras were done at IACTEC Tenerife



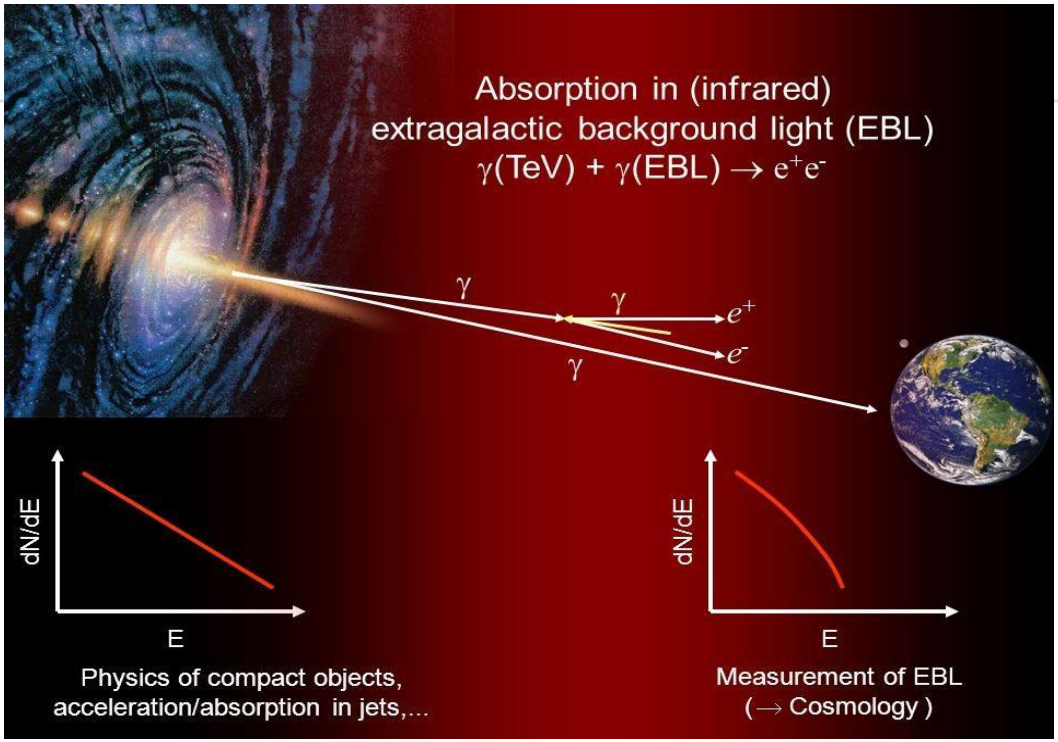
CTAO | LST COLLABORATION

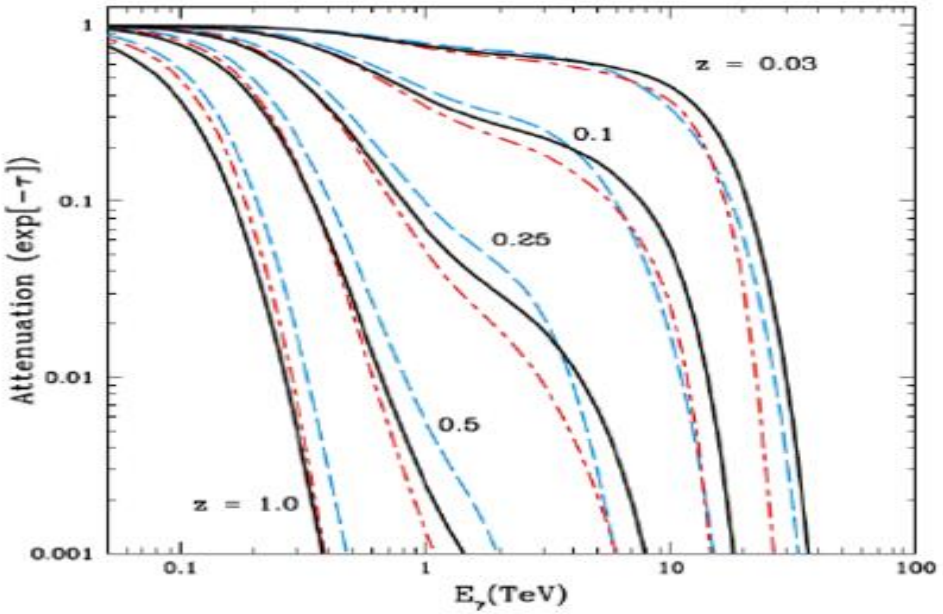
Schedule for the LST2-4 construction

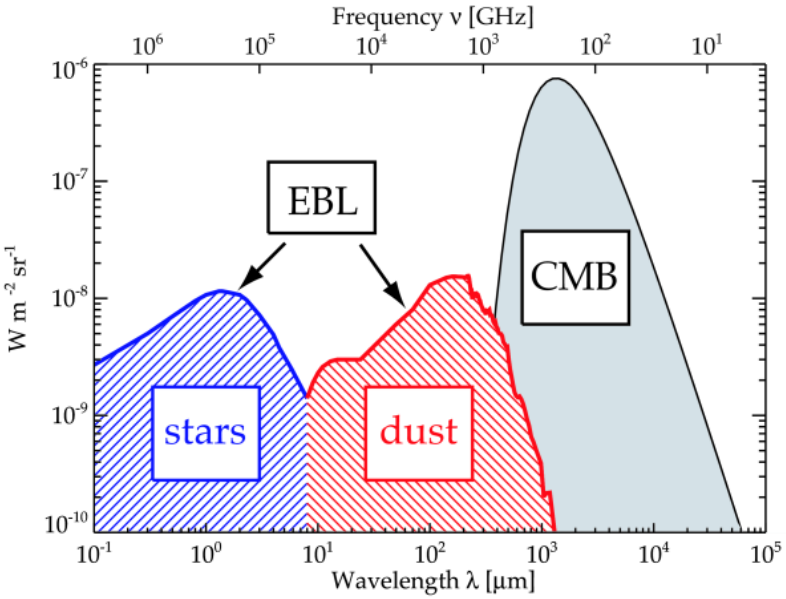


All permits granted	0 days	Tue 18/10/22	Tue 18/10/22
Civil works start	0 days	Mon 24/10/22	Mon 24/10/22
Civil works finish	0 days	Wed 31/01/24	Wed 31/01/24
LST4 construction starts	0 days	Mon 11/09/23	Mon 11/09/23
LST4 dish and structure united	0 days	Fri 03/05/24	Fri 03/05/24
LST4 CSS installed	0 days	Fri 30/08/24	Fri 30/08/24
LST4 mirrors installed	0 days	Tue 17/12/24	Tue 17/12/24
LST4 camera installed	0 days	Fri 28/02/25	Fri 28/02/25
LST4 construction completed	0 days	Tue 25/03/25	Tue 25/03/25
LST4 ready for acceptance	0 days	Tue 28/10/25	Tue 28/10/25
LST3 construction starts	0 days	Mon 09/10/23	Mon 09/10/23
LST3 dish and structure united	0 days	Fri 05/07/24	Fri 05/07/24
LST3 CSS installed	0 days	Fri 11/10/24	Fri 11/10/24
LST3 mirrors installed	0 days	Fri 09/05/25	Fri 09/05/25
LST3 camera installed	0 days	Wed 30/07/25	Wed 30/07/25
LST3 construction completed	0 days	Fri 22/08/25	Fri 22/08/25
LST3 ready for acceptance	0 days	Fri 27/03/26	Fri 27/03/26
LST2 construction starts	0 days	Mon 06/11/23	Mon 06/11/23
LST2 dish and structure united	0 days	Fri 02/08/24	Fri 02/08/24
LST2 CSS installed	0 days	Fri 18/04/25	Fri 18/04/25
LST2 mirrors installed	0 days	Fri 15/08/25	Fri 15/08/25
LST2 camera installed	0 days	Wed 05/11/25	Wed 05/11/25
LST2 construction completed	0 days	Fri 28/11/25	Fri 28/11/25
LST2 ready for acceptance	0 days	Fri 03/07/26	Fri 03/07/26

Gamma Ray Horizon
Access the deep Universe with LSTs



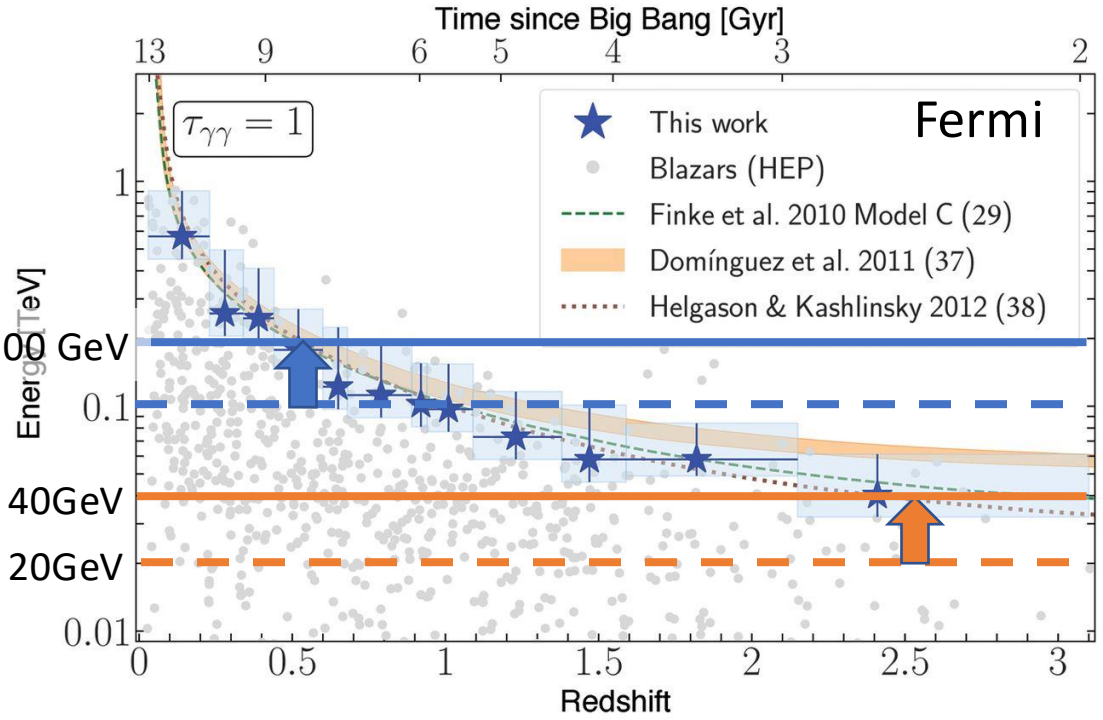




MST@45° Eth 200 GeV

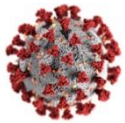
LST@45° Eth 40GeV

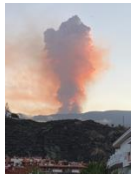
LST@25° Eth 20GeV

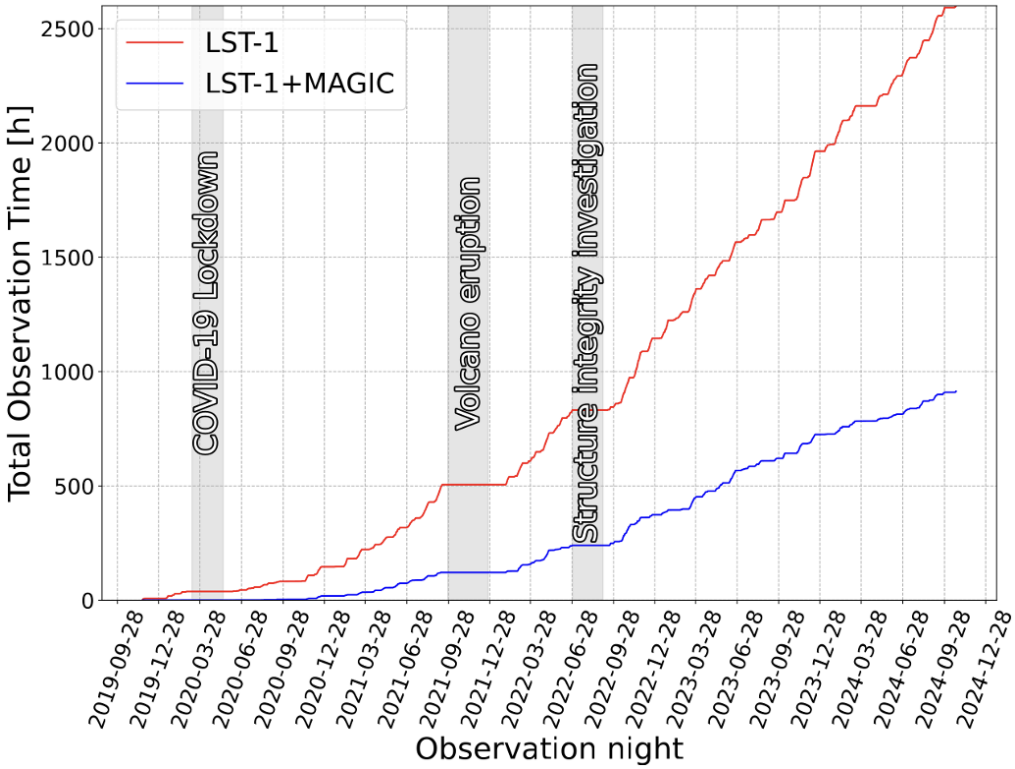


LST1 has been collecting data for more than 2500hrs

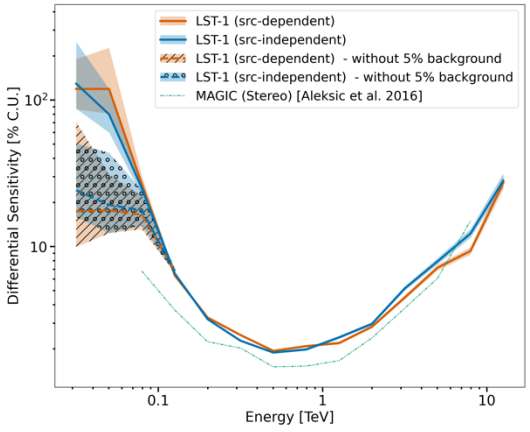
Oct 2018: LST1 Inaugurated
Jan 2020: Scientific operation started

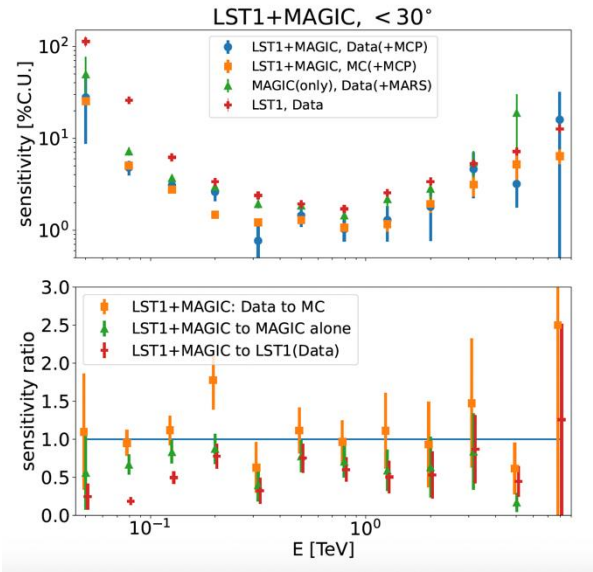






LST-1 mono and LST-1 + MAGIC Sensitivities with Crab observation

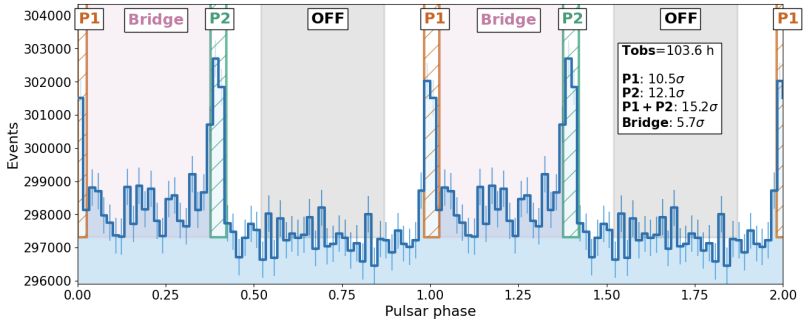




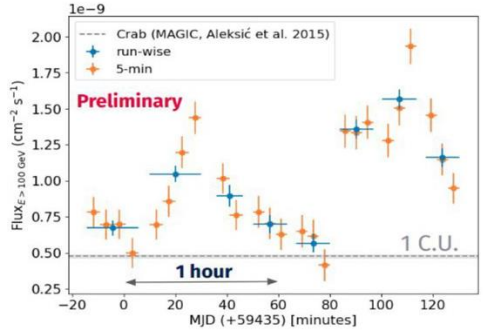
CTAO | LST COLLABORATION

Many scientific results are already delivered

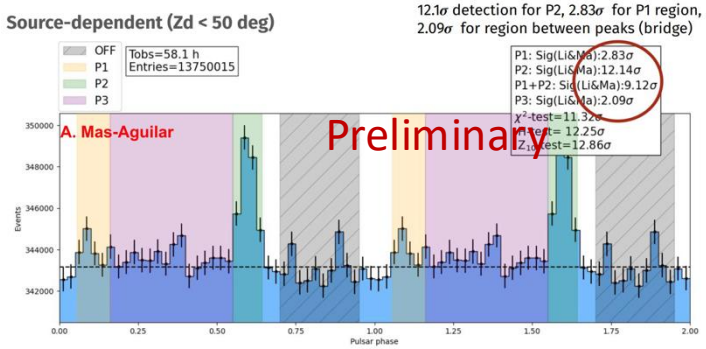
Crab pulsar above 20GeV



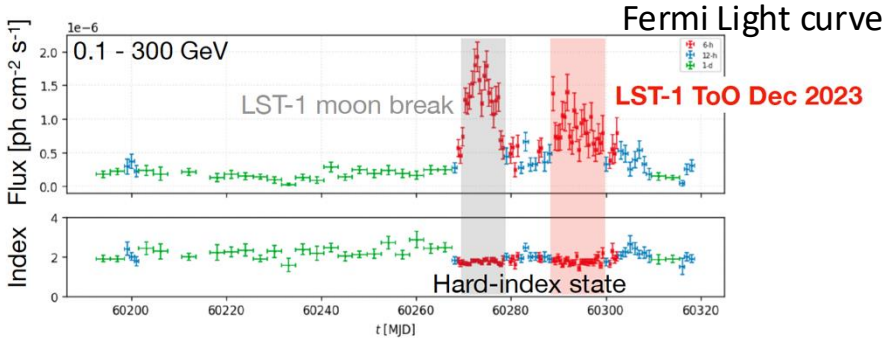
BL Lac intranight fast variability



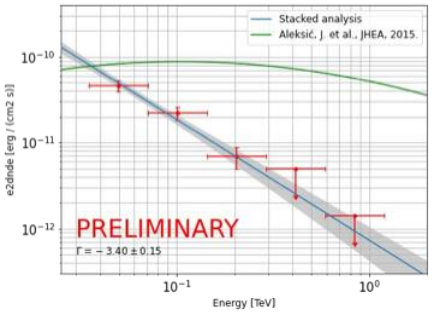
Geminga pulsar above 15GeV



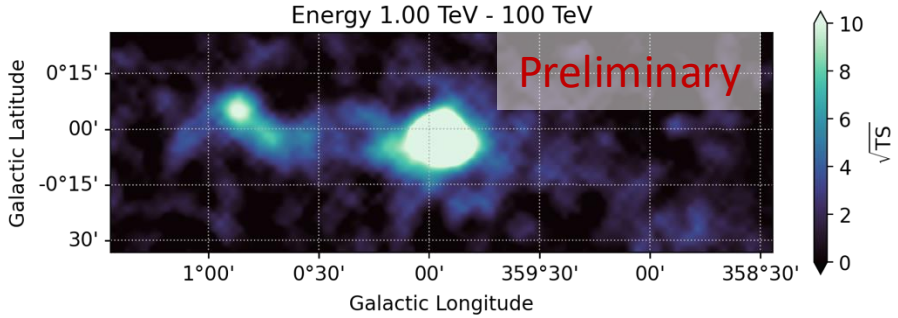
OP313: discovery of the most distant VHE AGN

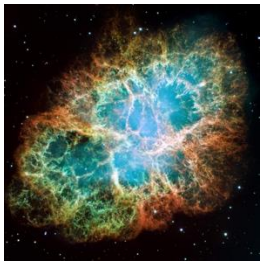


Symbiotic Nova RS Ophiuchi

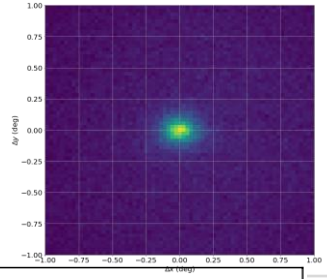


Galactic Center 39hrs (Sgr A*, diffuse)



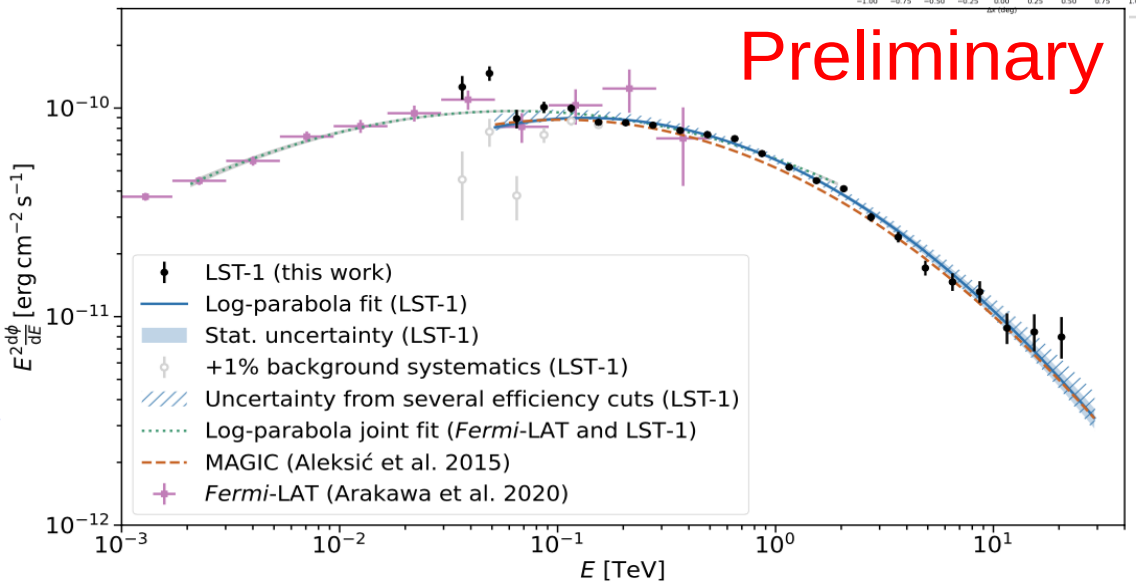


Crab Nebula and Pulsar



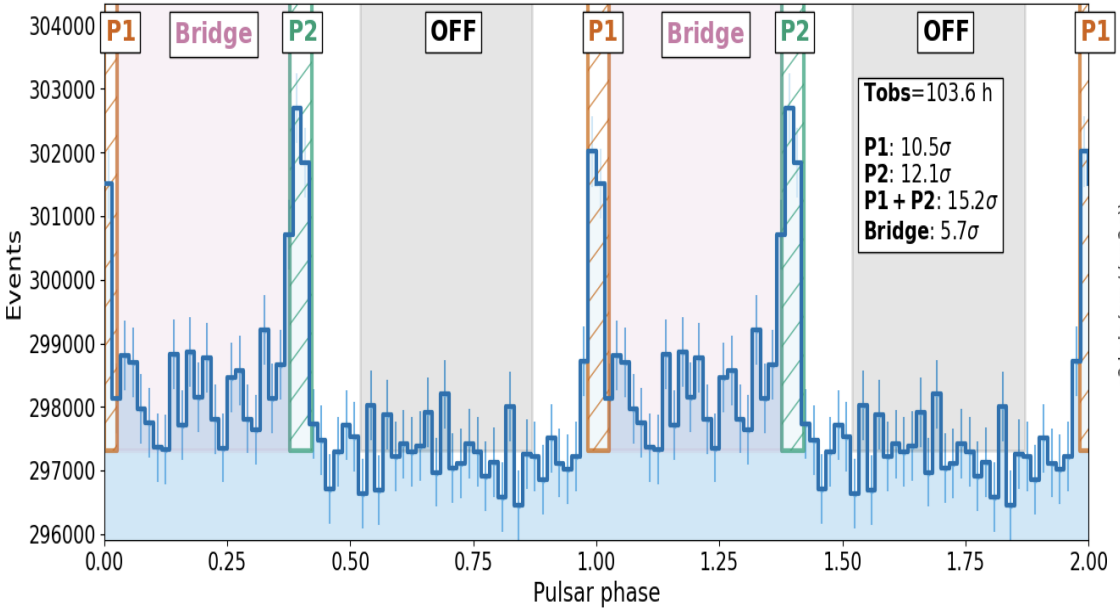
Crab Nebula spectrum

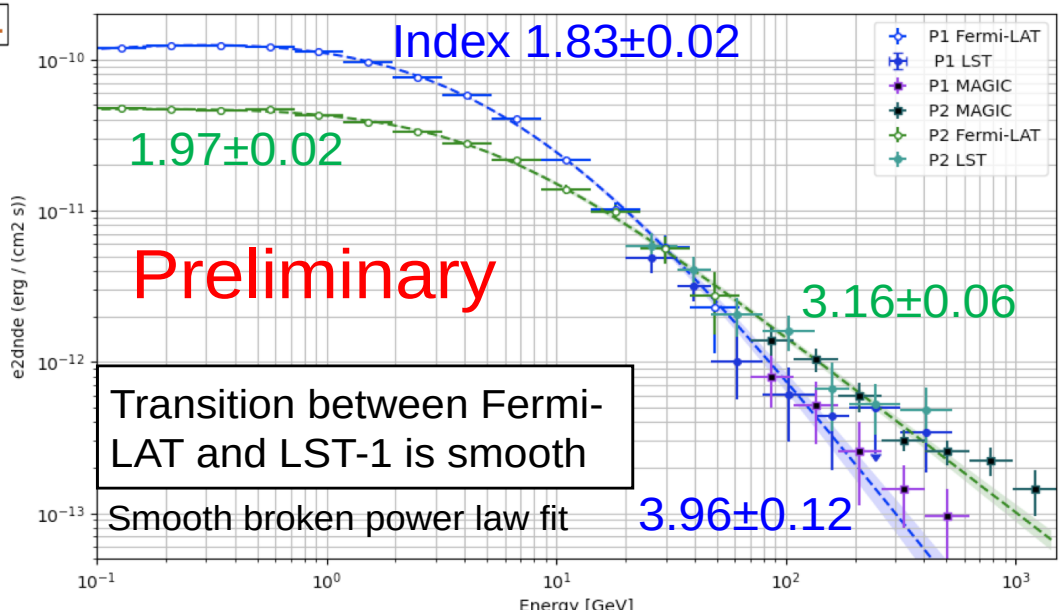
- 34.2 hours of data
- Systematic errors: gray points correspond to the effect of +1% background
- Consistent with MAGIC and Fermi-LAT



Crab pulsar

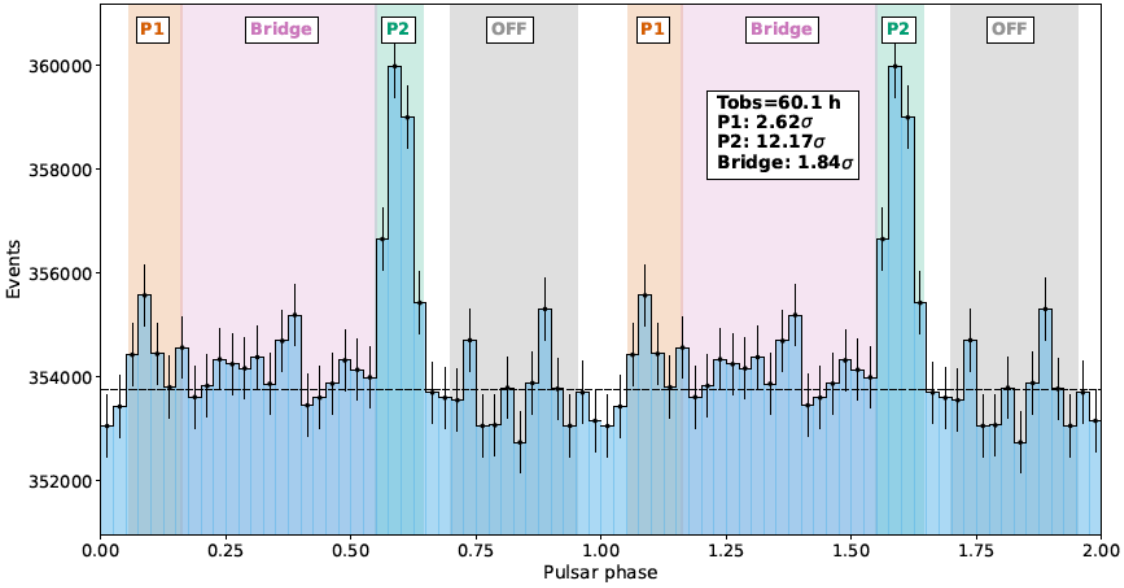
- Significant detection down to few tens of GeV



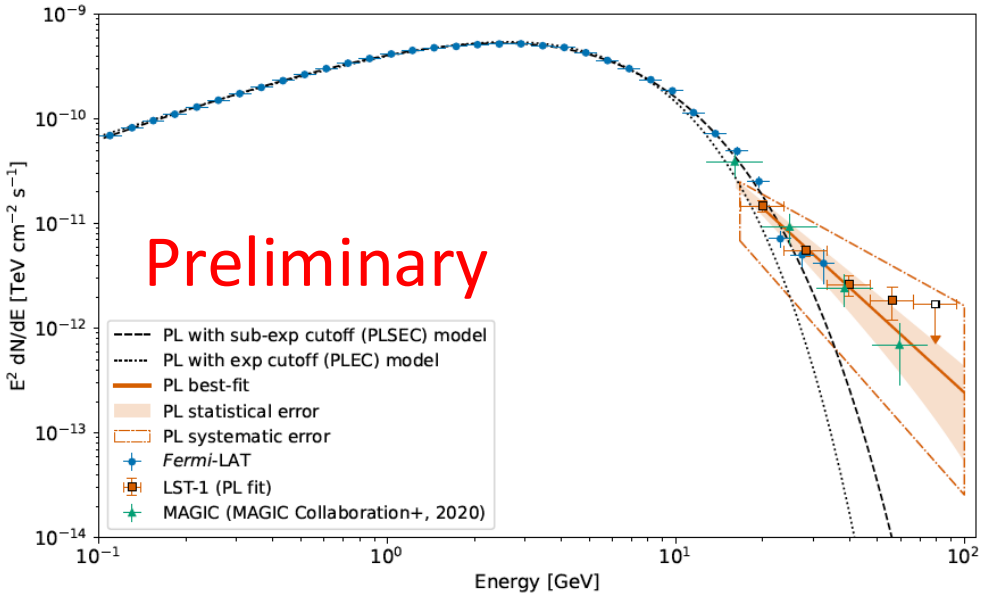


Geminga Pulsar observation with LST-1 (soon published)

- 60hrs observation
- Zenith angle <50
- P1: 2.6 σ
- P2: 12.2 σ



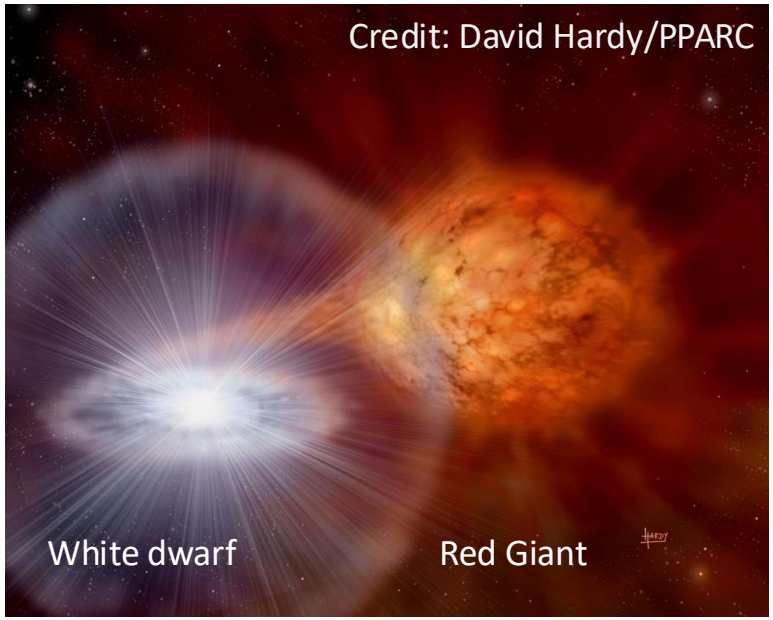
- The energy threshold is estimated to be 20GeV.
- Spectral Index Γ = 4.5 ± 0.4

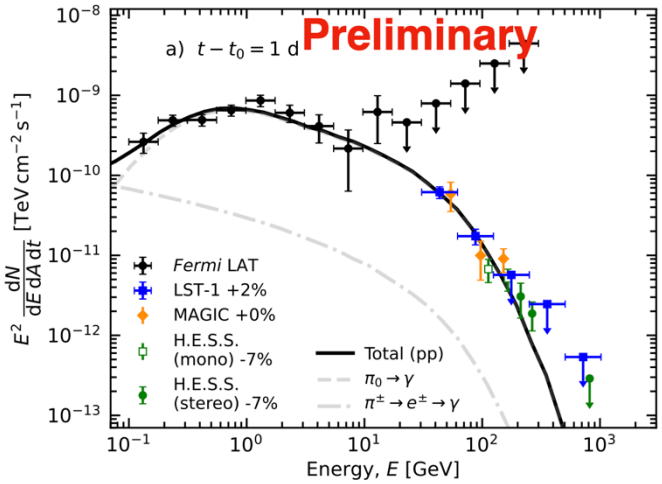


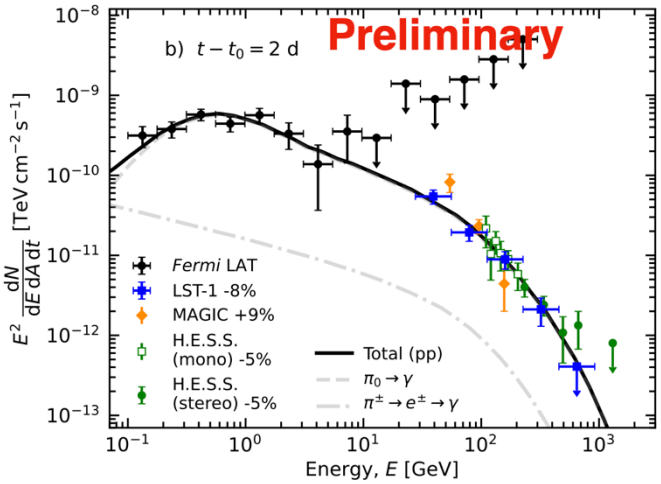
RS Ophiuchi Outburst in August 2021: Evolution of the Energy Spectrum

- RS Ophiuchi is a recurrent Nova.
  - Explosions, 1898, 1933, 1958, 1985, 2006, 2021
  - Mag 12.5 (low state) ➔ Mag 4.7 (~1000 times)
  - Binary System with a White Dwarf and a Red Giant
  - Accumulation of material on the WD and then thermonuclear reaction make recurrent explosions

- The Hadronic model is preferred.
- Cutoff energy increased with time.

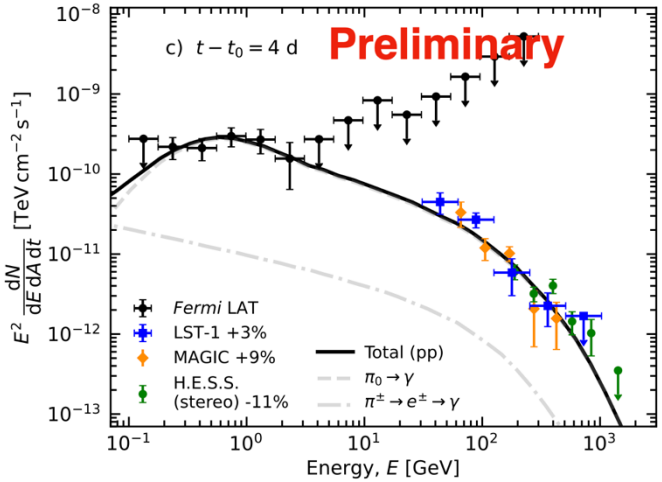






Preliminary

Parameter	Best-fit value on observation day		
	Day 1	Day 2	Day 4
Hadronic ECPL model with systematics			
Slope, Γ_p	$-2.16^{+0.19}_{-0.18}$	$-2.49^{+0.05}_{-0.04}$	$-2.42^{+0.16}_{-0.16}$
$E_{c,p}$ [TeV]	$0.21^{+0.12}_{-0.11}$	$0.9^{+0.2}_{-0.2}$	$1.1^{+0.7}_{-0.7}$
LST-1 syst. [%]	2^{+5}_{-5}	-8^{+8}_{-7}	3^{+6}_{-5}
MAGIC syst. [%]	0^{+7}_{-6}	9^{+6}_{-7}	9^{+6}_{-6}
H.E.S.S. syst. [%]	-7^{+9}_{-7}	-5^{+6}_{-5}	-11^{+4}_{-4}
$\chi^2/N_{d.o.f}$	17.8/12	20.0/19	20.0/13
χ^2_{red}	1.48	1.05	1.54
AIC	29.8	32.0	32.0

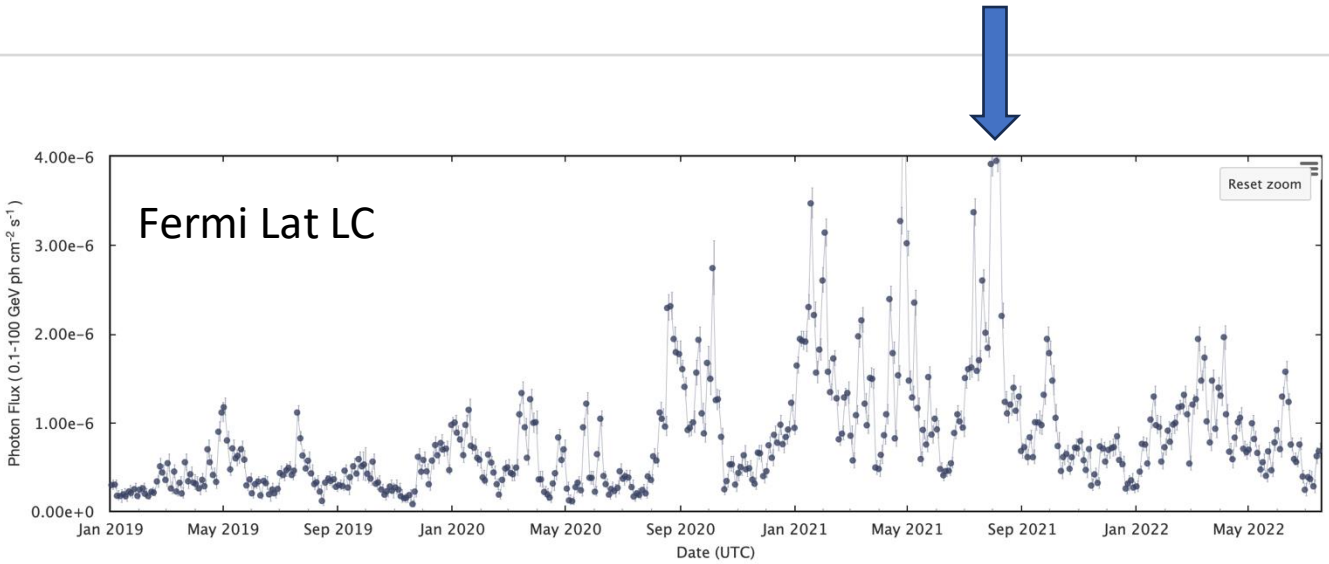


CTAO | LST COLLABORATION

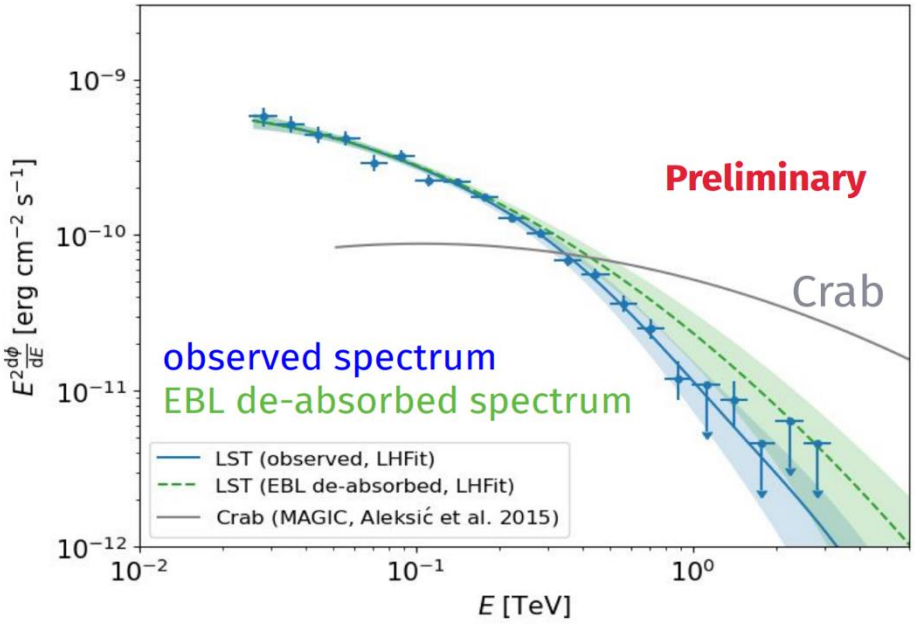
BL Lac Flare 2021

- BL Lac Flare 2021
- BL Lac: IBL, z= 0.069

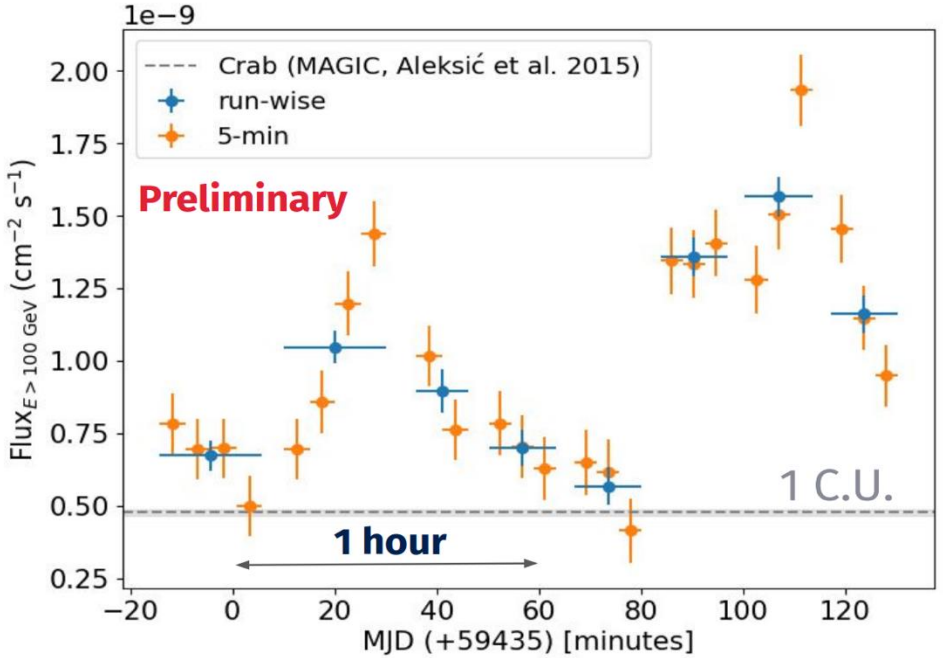
- Spectrum observed > 25GeV
- August 9, about 3-5 Crab Unit at 30-100 GeV
- Very fast variability (<5min)



Aug 9, 2021



Intranight LC on 9 August, 5 min fast variability



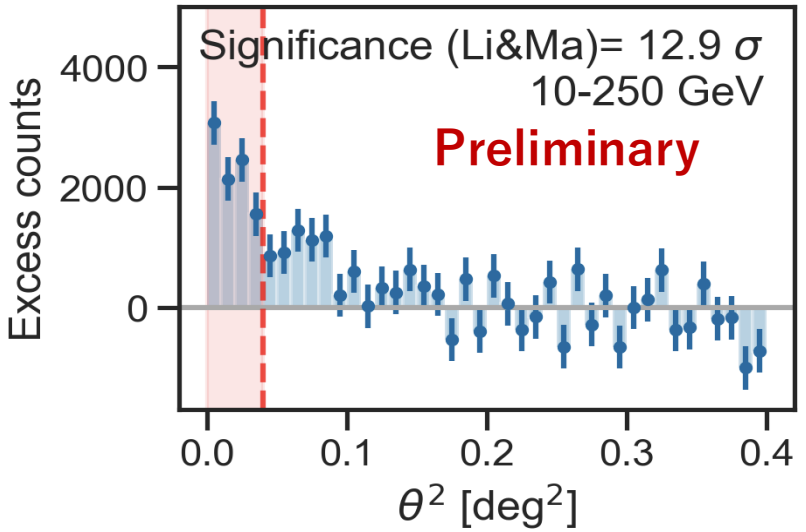
Discovery of OP313 (z = 0.997) with LST-1

First detection of VHE gamma-ray emission from FSRQ OP 313 with LST-1

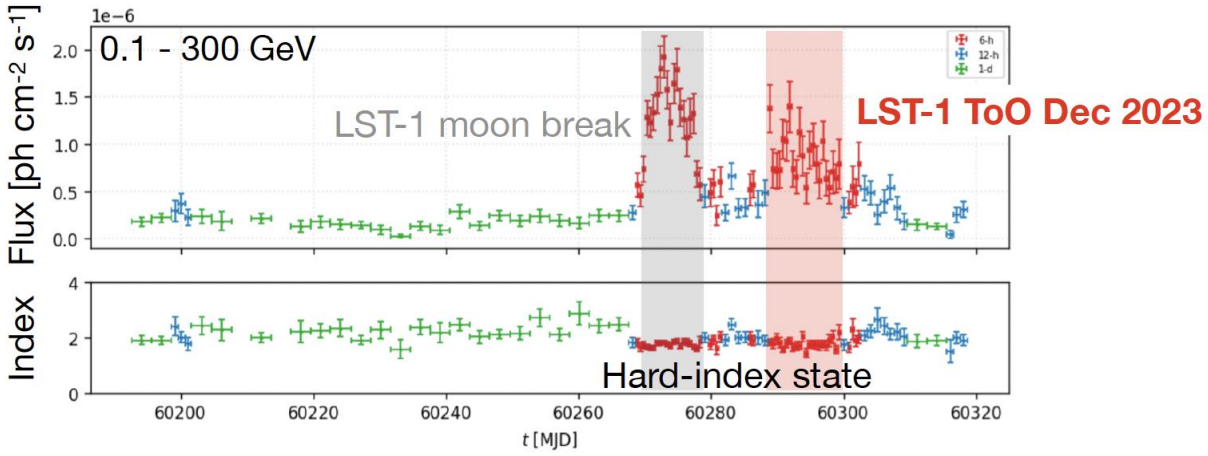
ATel #16381; *Juan Cortina (CIEMAT) for the CTAO LST collaboration*
*on **15 Dec 2023; 14:31 UT***
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

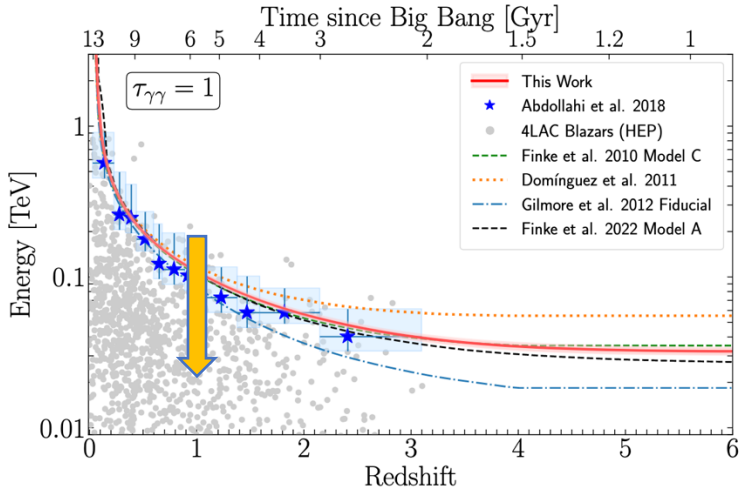
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, AGN, Blazar, Quasar

Stacking all December data 2023 data (14.6hrs)
13 sigma excess below 250GeV, No detection above 250GeV
Publication with detailed analysis is expected soon.

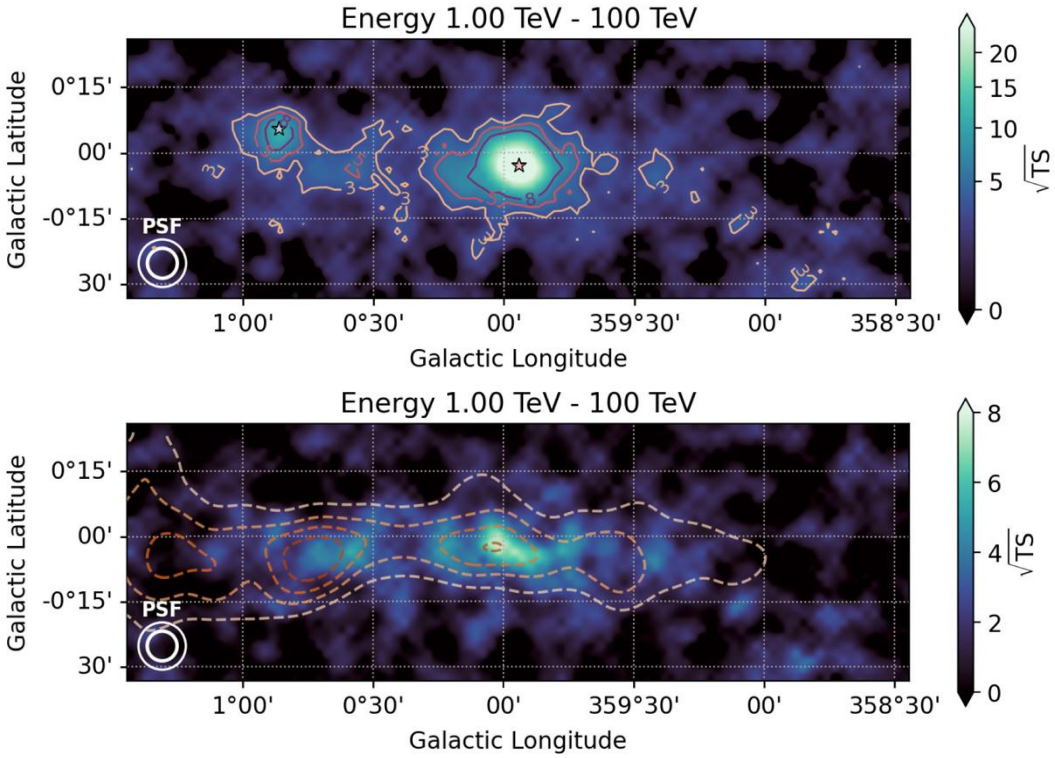


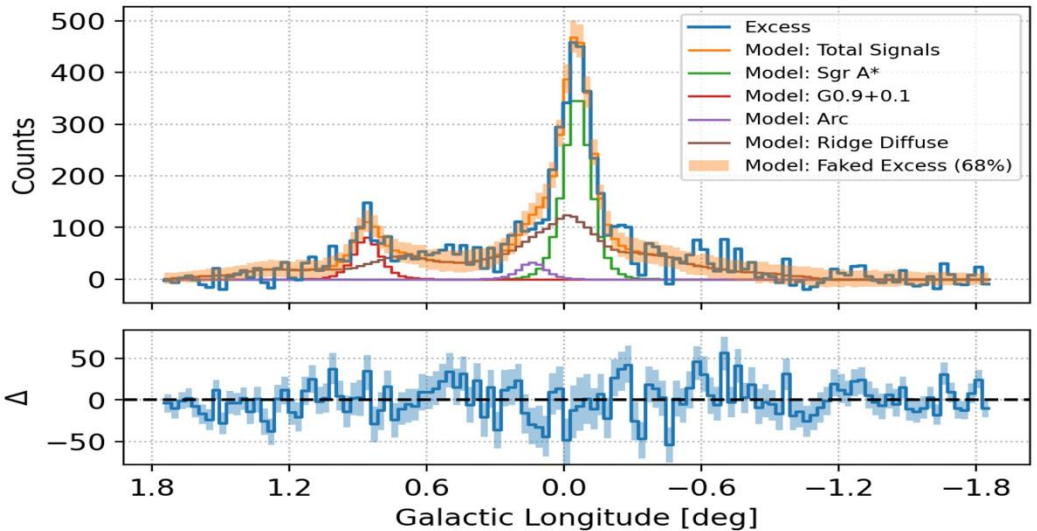
Fermi Light Curve of OP313





Galactic Center region

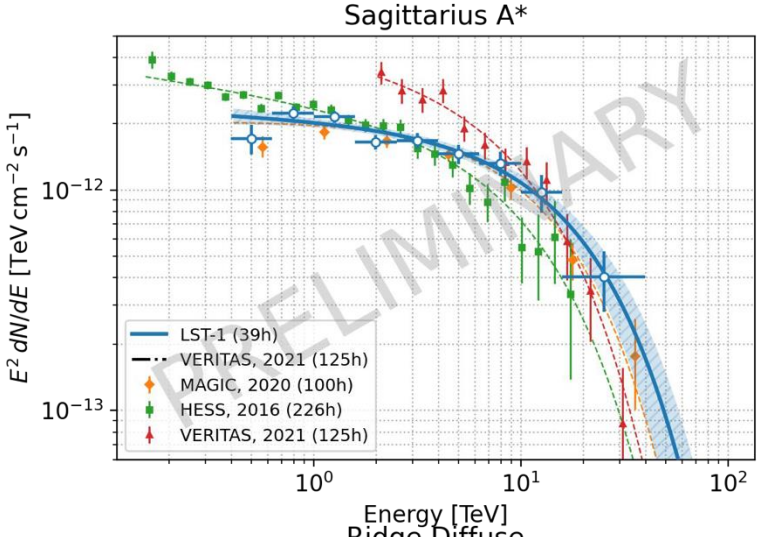


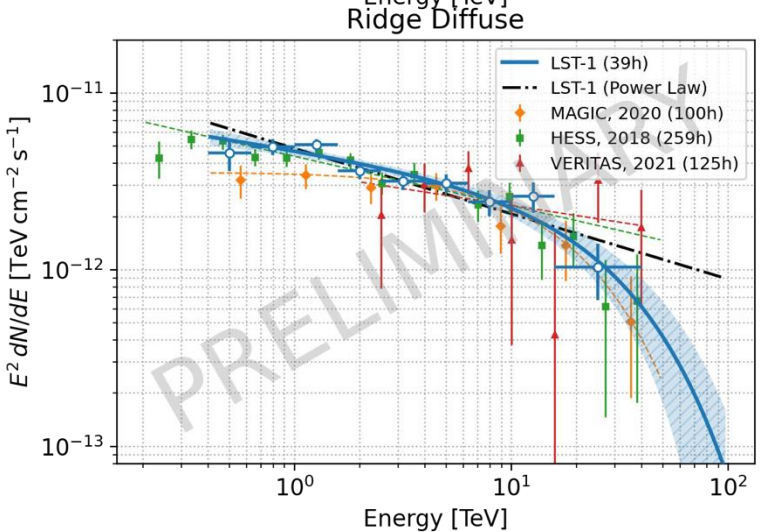


The galactic center is observed for 39hrs with the Large Zenith Angle Technique (ZD 58-68 deg).

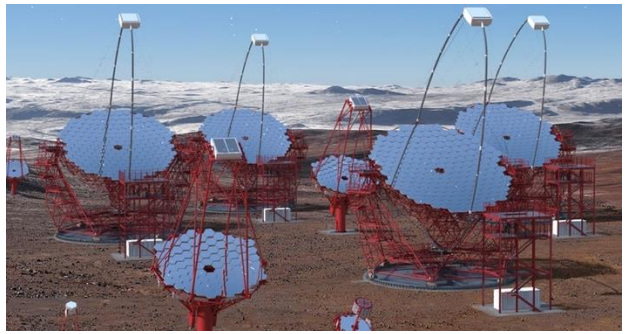
Pros: Getting several times larger collection area

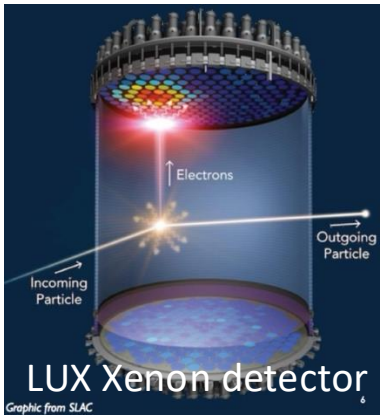
Cons: Higher Threshold Energy (> 300GeV)

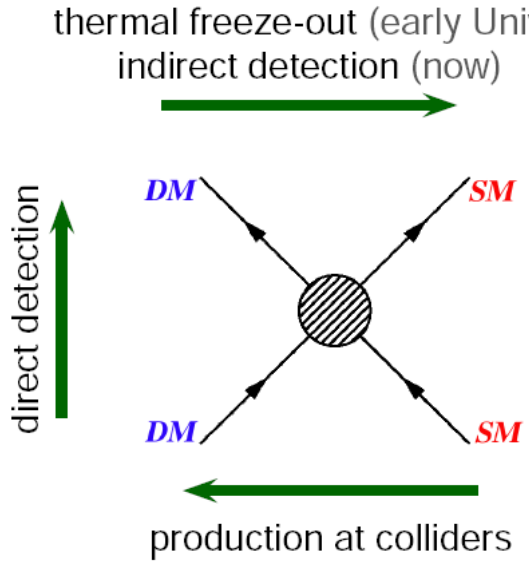


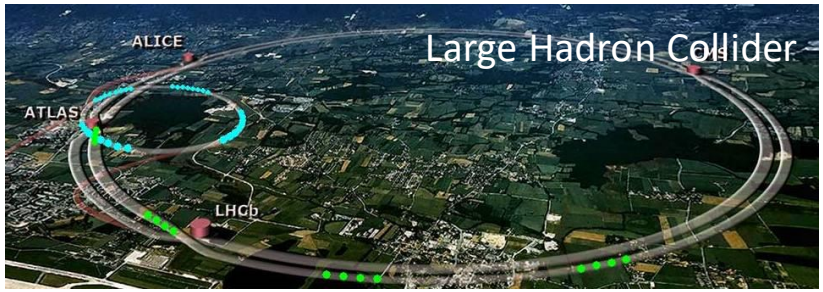


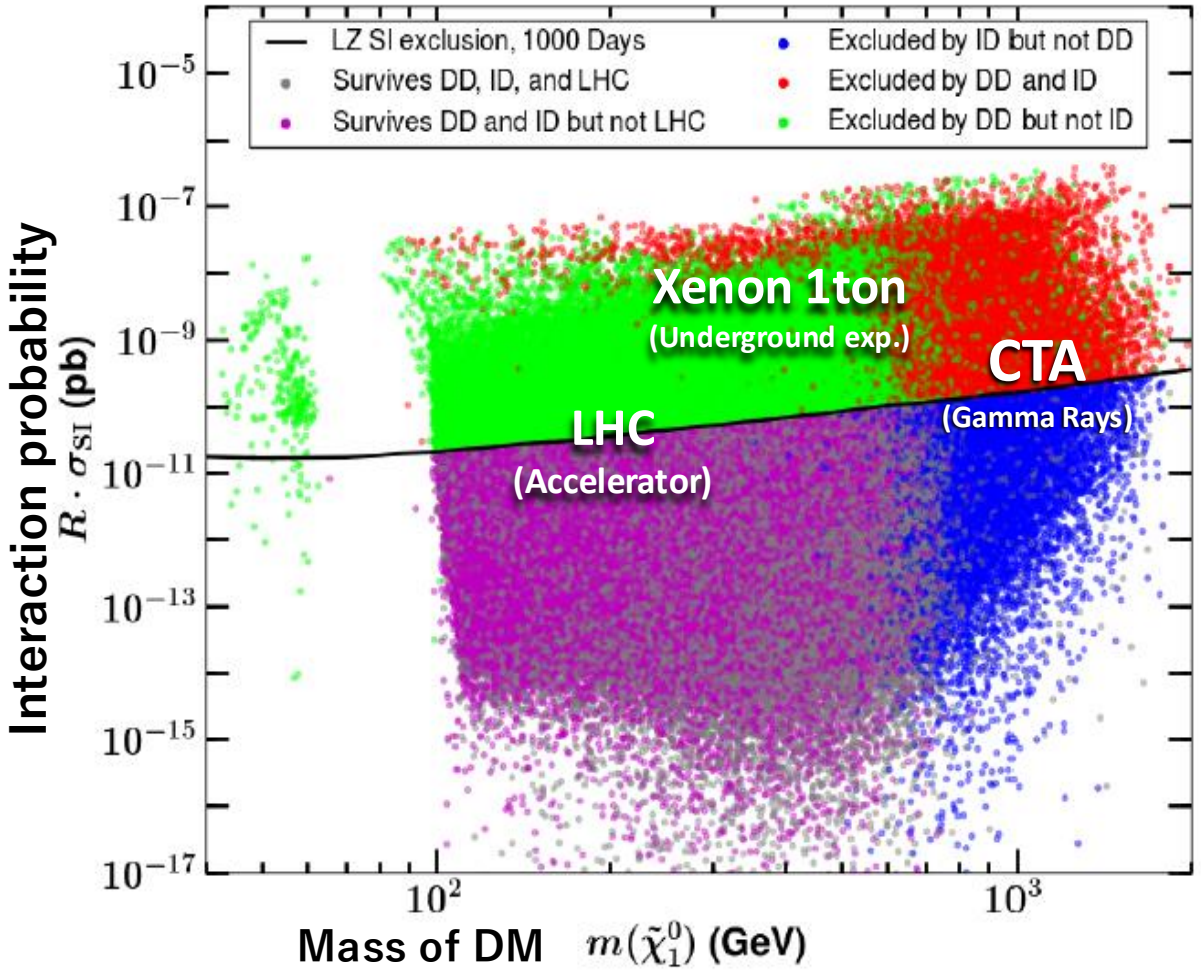
Complementarity of different approaches
Direct, Indirect, and Collider Experiment











- Explore Dark Matter in the Galactic Center and Dwarf Sph. Galaxies
- CTA has the best sensitivity above 700GeV
- LST North has a good sensitivity with LZA technique

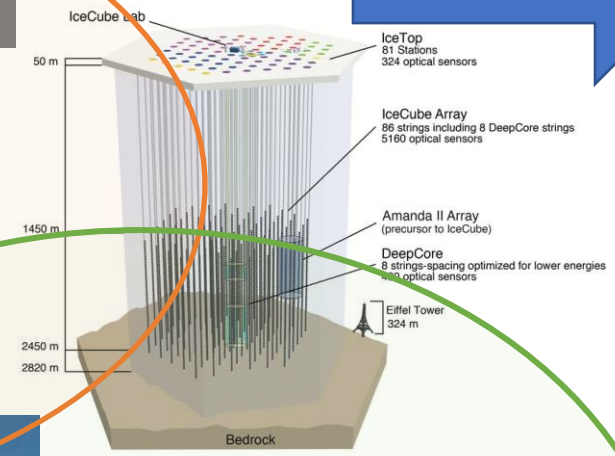
CTAO | LST COLLABORATION

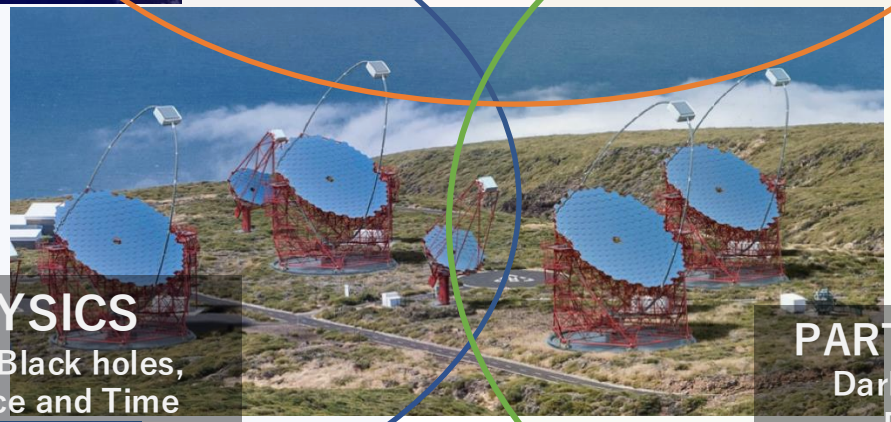
Multi-messenger and Multi-wavelength Astrophysics

Wave AstroPhysics

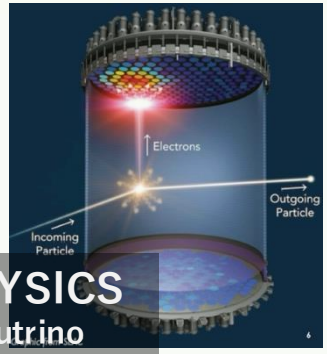
Particle Physics

ASTRO-PARTICLE PHYSICS
Cosmic Ray Physics
High Energy Astrophysics





ASTRO-PHYSICS
Gamma Ray Bursts, Black holes,
Neutron Stars, Space and Time



PARTICLE PHYSICS
Dark Matter, Neutrino
Energy Frontier

Summary

- We confirmed that the first Large-Sized Telescope, LST1, fulfilled the requirements and the design performance, including a 20-second fast follow-up capability.
- LST2, LST3, and LST4 will be completed by the summer of 2026, and then commissioning with four LSTs will start in 2026.
- The LST Array and CTA Observatory will achieve x10 higher sensitivity than currently running telescopes in 20 - 300 GeV.

- The CTAO ERIC started on January 07, 2025.
  - The construction of CTA South will be boosted.
  - 2025-2026 Infra Construction in CTA South
  - 2026- Telescope Construction (2MSTs, 5SSTs in 2026/2027)
  - 14 MSTs and 35 SSTs in the South will be completed in five years
- The LST Array and CTA Observatory will contribute significantly to multi-messenger and time-domain astronomy.