Status of CTA and LST

Takayuki Saito (ICRR)
On behalf of CTA-Japan Consortium

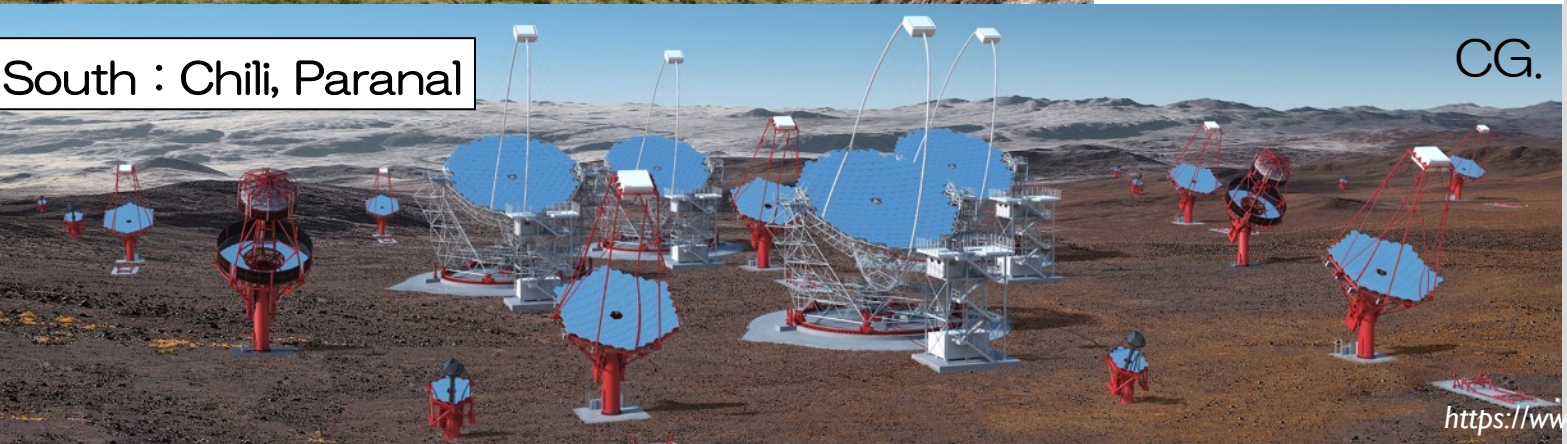
Extreme Universe 2023, Feb 6th -7th, @ Kashiwa Campus, Univ. of Tokyo

Cherenkov Telescope Array

- Next generation VHE gamma-ray observatory (20 GeV – 300 TeV)
- Array of tens of IACTs over a ~km^2 area
- 3 different sizes of telescopes, (LST, MST and SST)
- One array in each hemisphere.
- 25 different countries are participating
- More than 1500 Scientists are involved.

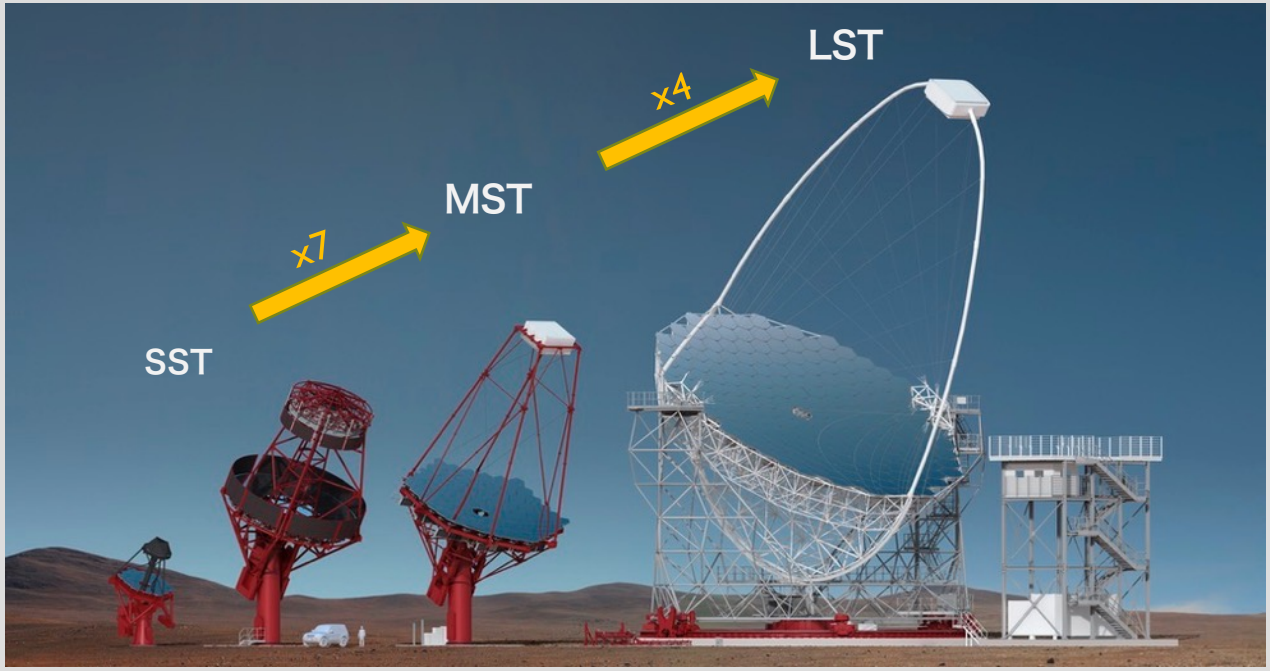
North : Spain, LaPalma island

South : Chili, Paranal



https://www.cta-observatory.org/

TELESCOPE DESIGN

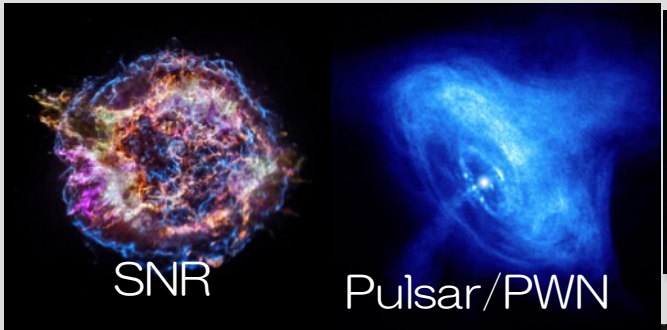


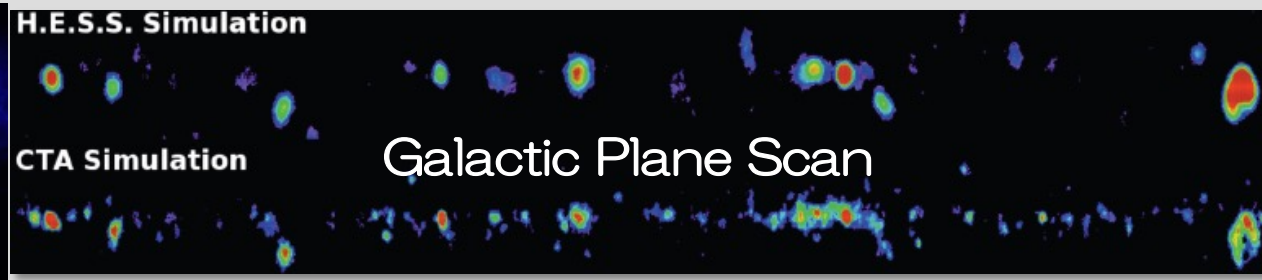
Telescope Types	SST	MST		LST
Optics	Schwarzschild-Couder	SC	DC	Parabolic (Isochronous)
FoV and Camera	10.5 deg SiPM	~10 deg SiPM	7.5 deg PMT	4.3 deg PMT
Mirror Diameter	4.3m	9.7 m	11.5m	23m
Energy Range	3 TeV - 300 TeV	100GeV - 10TeV		20GeV – 2000GeV
Science Targets	Galactic Sources PeVatron (UHE CR)	Galactic Sources Nearby AGNs (z<0.5) Dark Matter		Transient Sources AGNs(z<2), GRBs(z <4) Dark Matter

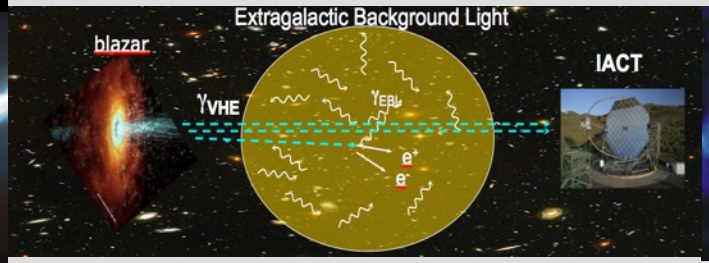
Science with CTA

Three major themes

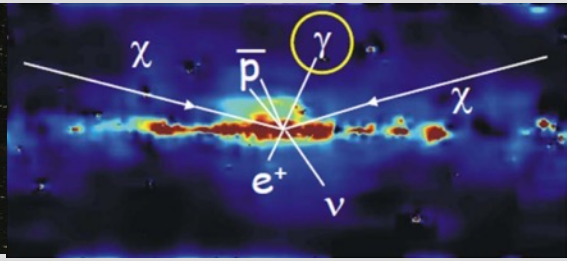
1. **Understanding the Origin and Role of Relativistic Cosmic Particles**
   - Acceleration site and mechanism
   - Feedback to star formation and galaxy evolution
2. **Probing Extreme Environments**
   - Physical process at work close to neutron stars and black holes.
   - characteristics of relativistic jets, winds and explosions
3. **Exploring Frontiers in Physics**
   - Dark matter, Quantum Gravity, axion-like particles







EBL Study

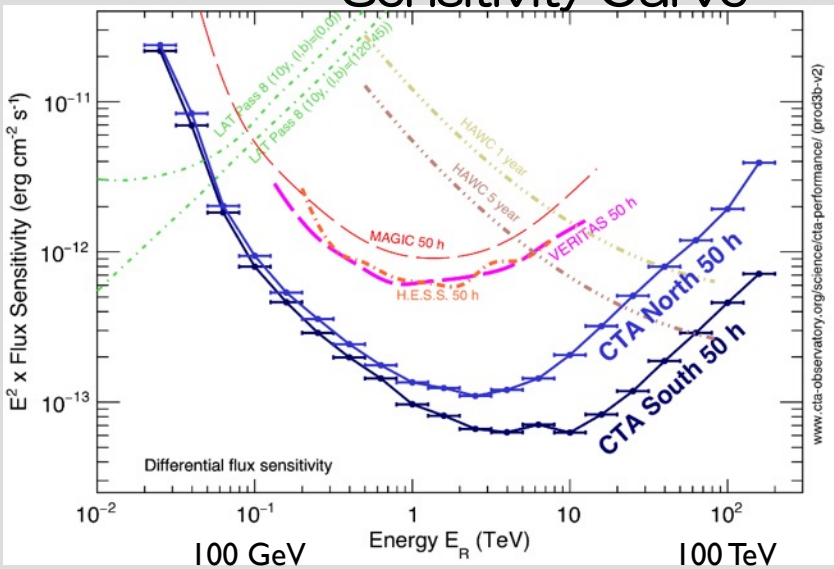


DM annihilation/decay Search

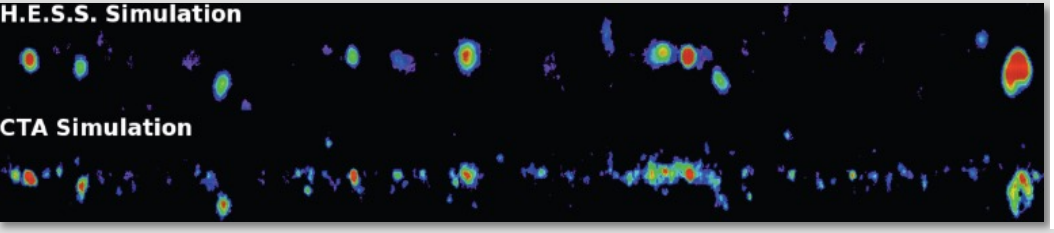
Capability of CTA

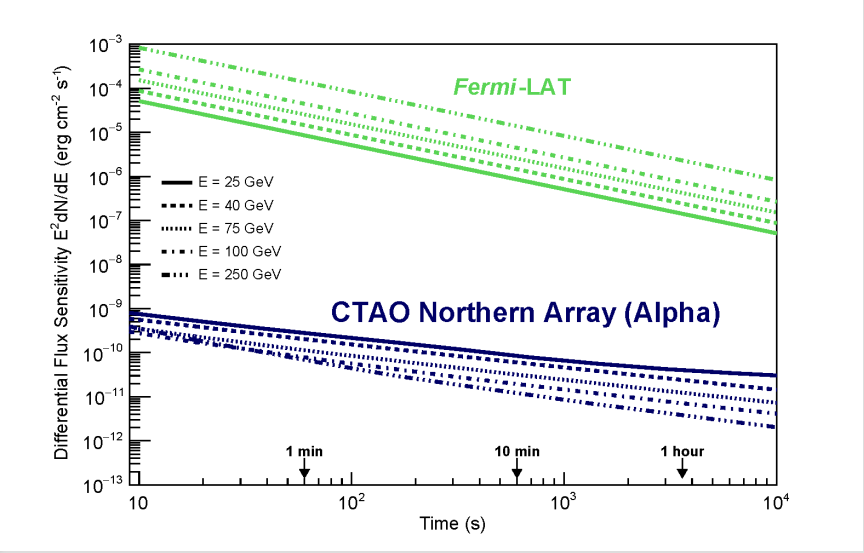
- 10 times more sensitive than existing instruments
- An energy resolution of 10 percent
- Rapid slewing in as low as 20 seconds
- Energies as low as 20 GeV
- Energies up to 300 TeV
- A field of view of 4.3 – 10.5 degrees
- An angular resolution approaching one arcminute

Sensitivity Curve



4 -5 orders
better than Fermi-LAT

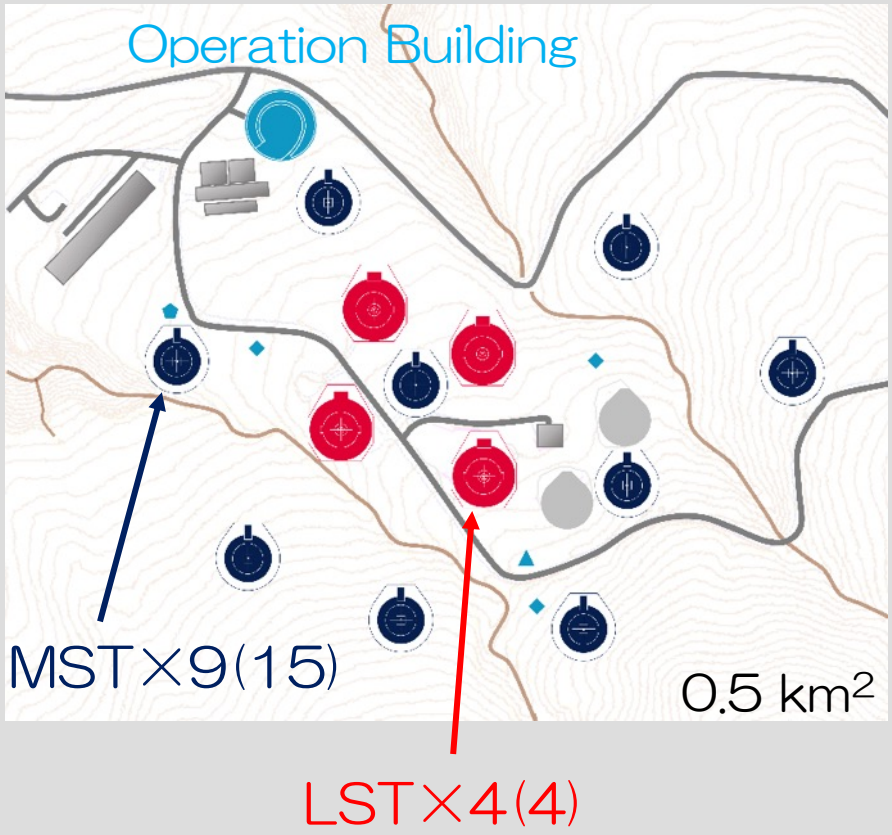




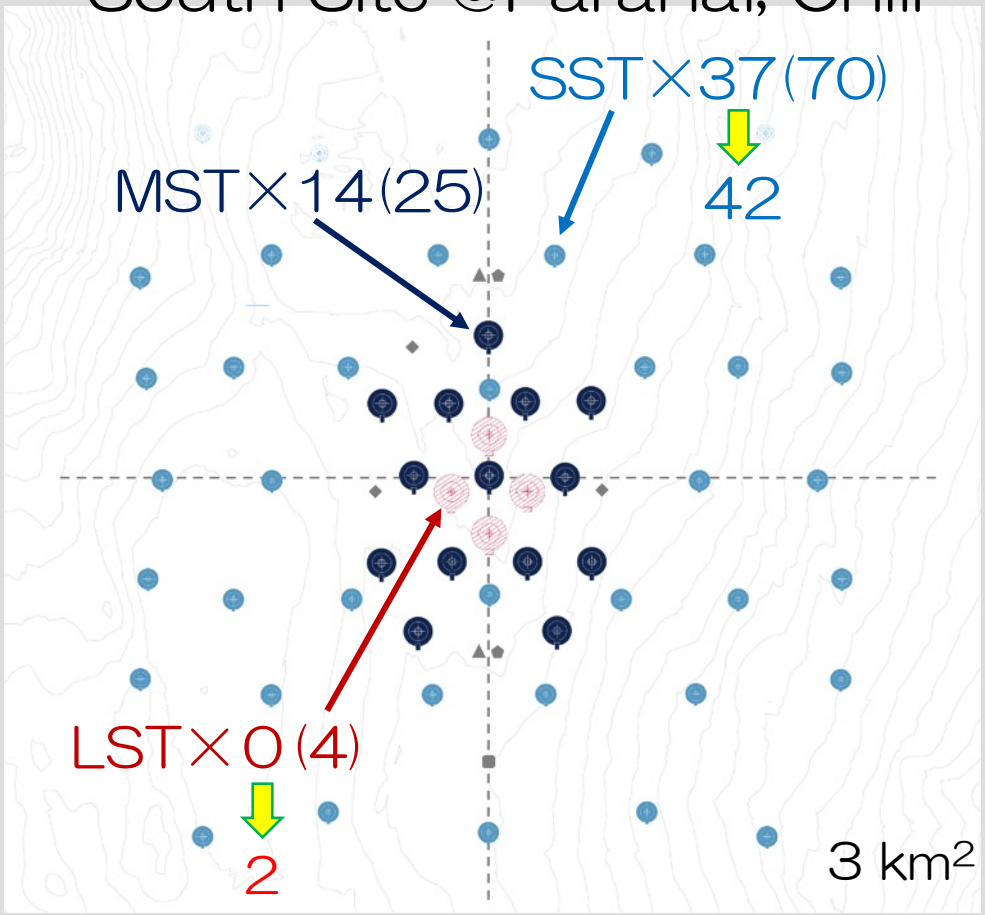
Array configuration(first phase)

Number in ( ) is the goal

North Site@LaPalma, Spain



South Site @Paranal, Chili



Recently INFN Italy won the budget as "post-covid recovery funds".
LST×2 + SST×5 will be built in CTA-South. (see later slide)

CTA AND LST TIMELINE

Organization

- 2023 CTAO ERIC will be founded

North

- 2023-2025 LST2-4 construction.
- 2023-2028 9 MST construction.

South

- 2024-2028 14MST + 37 SST
- 2023-2025 LST5-8 construction?

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Organization	CTAO gGmbH (Heidelberg)										
				CTAO ERIC (European Research Infrastructure Consortium)							
Alpha Config	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LST North	Comissioning and Operation of LST1					Operation as 4 LST Array				Observatory Operation	
	CDR		Deployment of LST2-4								
MST North	Design and Finance		INFRA	Construction of 9MSTs							
CTA South	Array config, Finance and CDR		INFRA		Construction and Deplyment of 14 MSTs						
					Construction and Deployment of 37 SSTs						
Extension	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LST South		Finance / CDR		Construction of 4 LSTs ???			Operation ???				

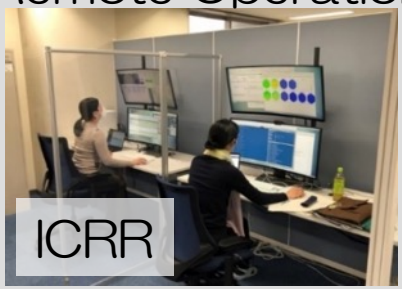
Operation Modes at CTA north
-- step by step upgrade --

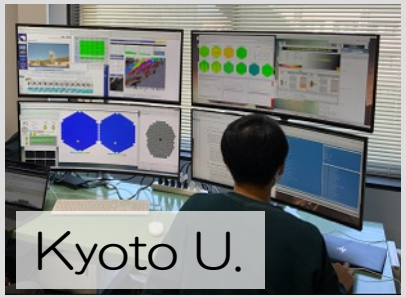
- 2019 ~ : **Monoscopic** Operation with **LST1**
  - See the results in later slides.
- 2021 ~ : **Joint Observation** with **LST1** and **MAGIC** (Offline Stereo Analysys)
- 2023 ~ : **Stereo Observation** with **LST1** and **MAGIC** (Coincidence Trigger)
- 2025 ~ : Observation with 4 LSTs.

- 2029 ~ : CTA-north array observations (4 LSTs + 9 MSTs).

LST1 Operation @LaPalma, Spain

Remote Operation



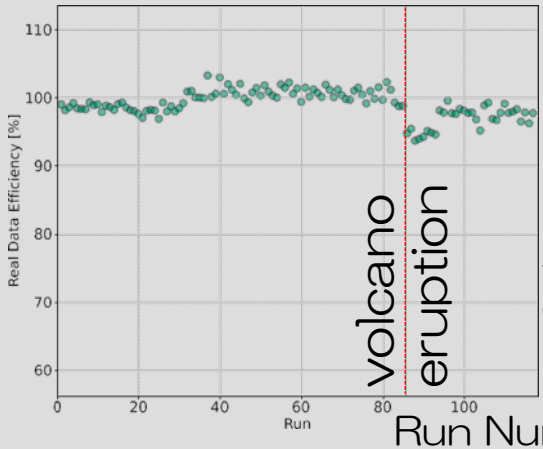


+France, Italy,
Croatia, Bulgaria

Sci. Operation Since Jan. 2020, > 800 hours

- Suspension of operation
  - Mar. – Jun. 2020 (COVID-19)
  - Sep. 2021– Jan. 2022 (Volcano)
  - Jul – Aug. 2022, (Storage Problem)

Photo-collection Efficiency

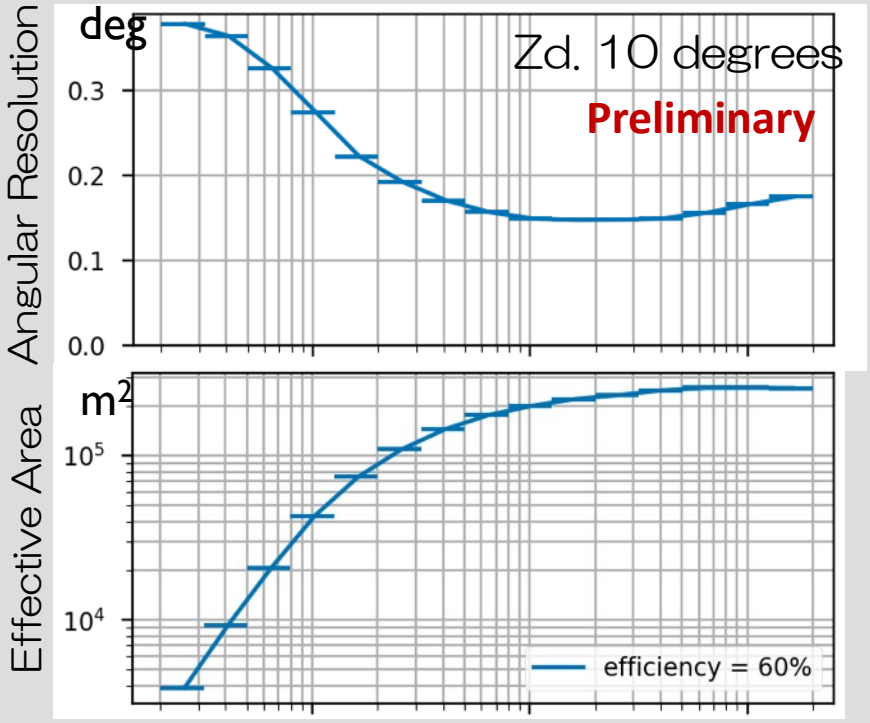


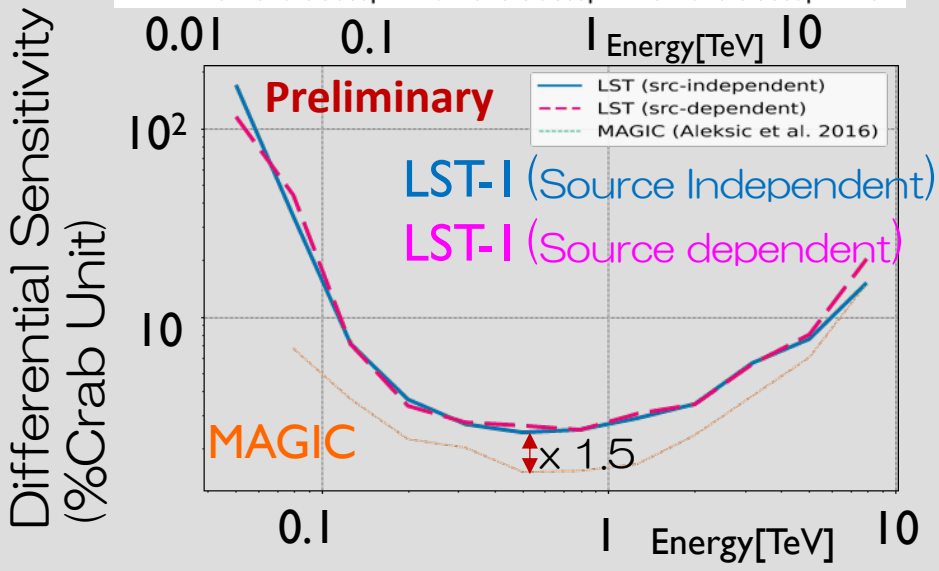
Nov. 2020 - Mar. 2022

Stable

(apart from volcano ash effect)

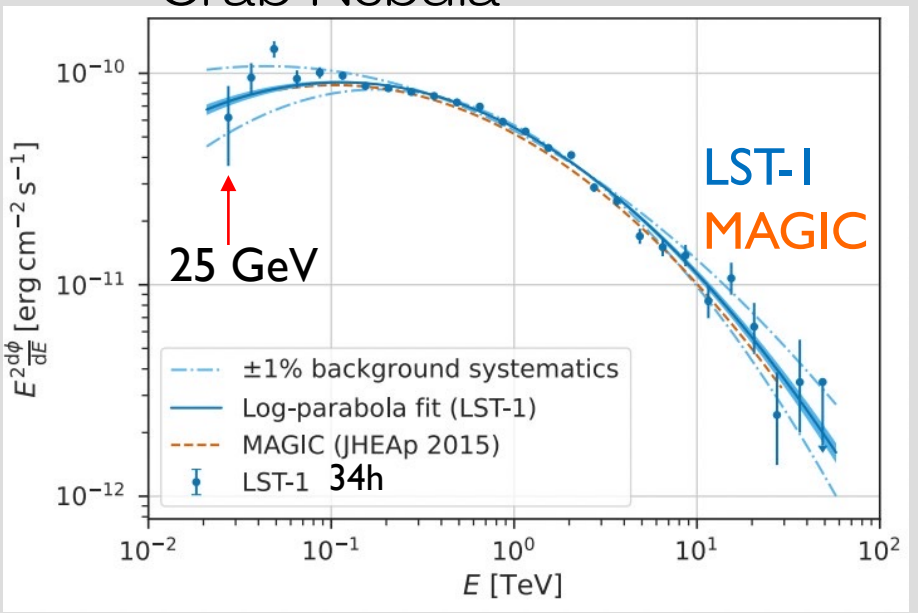
LST-1 Performance and +Crab Obs.



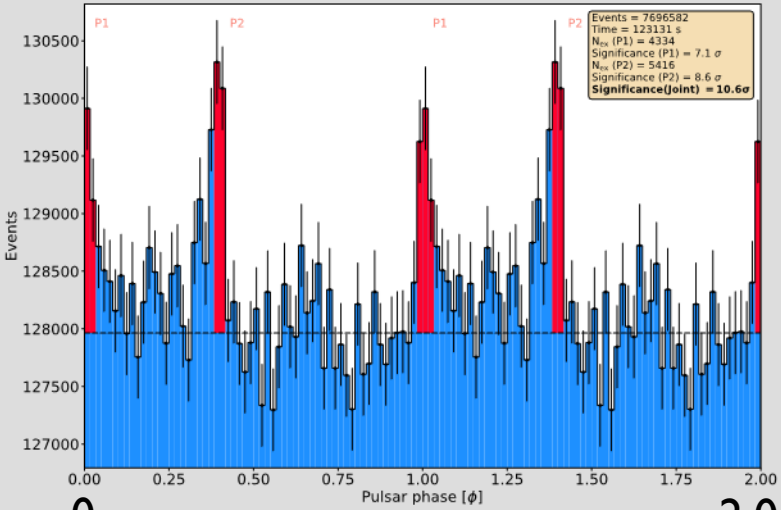


【Publication in prep】

Crab Nebula



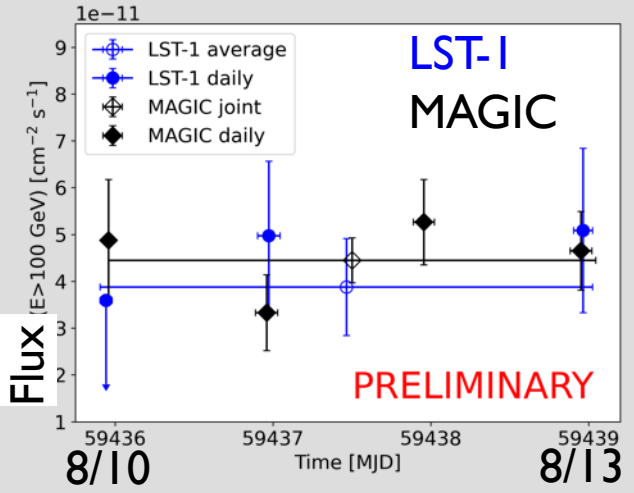
Crab Pulsar 34h



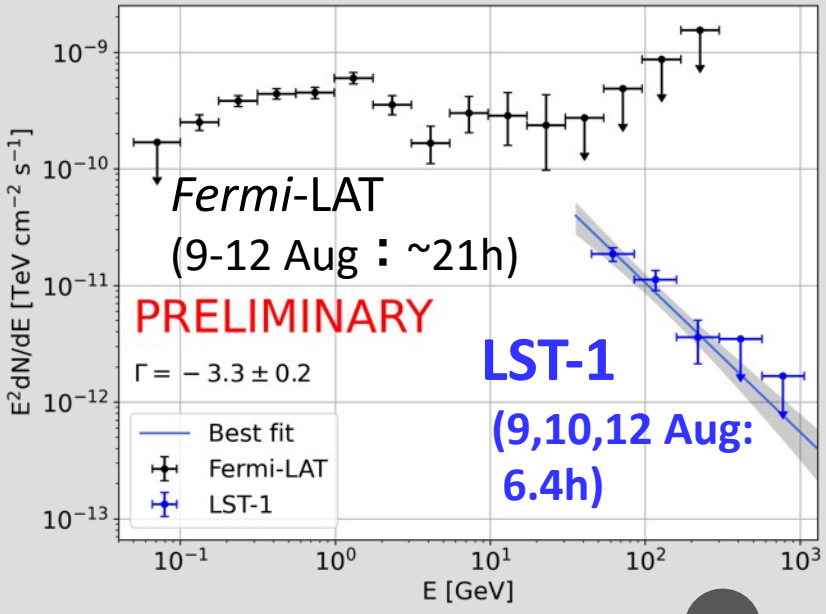
LST-1 Observation : Recurrent Nova

RS Ophiuchi

- Recurrence Period : ~15 years
- Detected by Fermi on Aug 8th, 2021
- Since Aug. 9th Obsevation by IACTs
  Detected by HESS, MAGIC and LST1
  (First Nova detection at VHE)



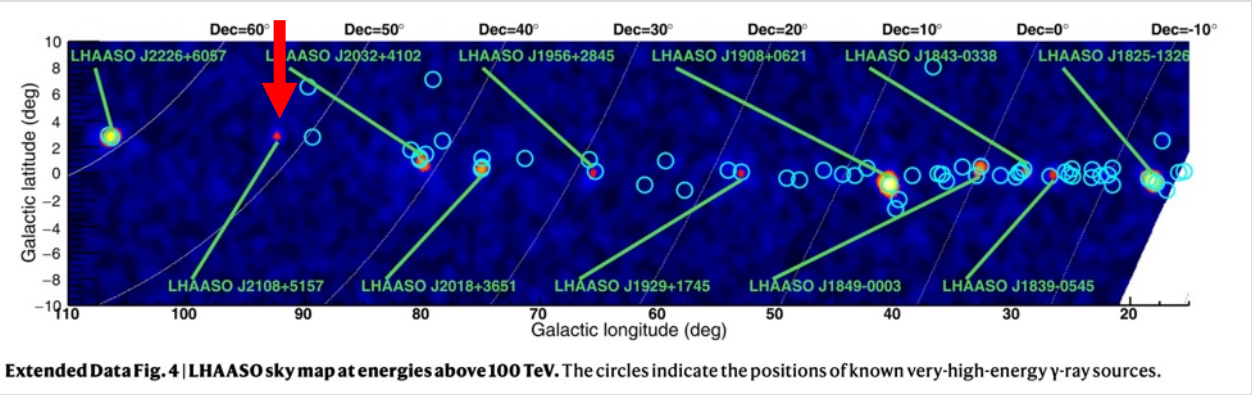
H.E.S.S. Collaboration 2022; MAGIC Collaboration 2022; Fermi Archival data



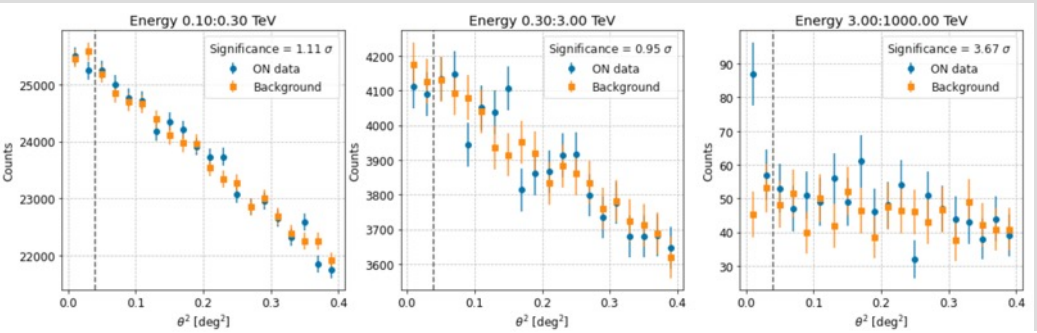
【Publication in preparation】

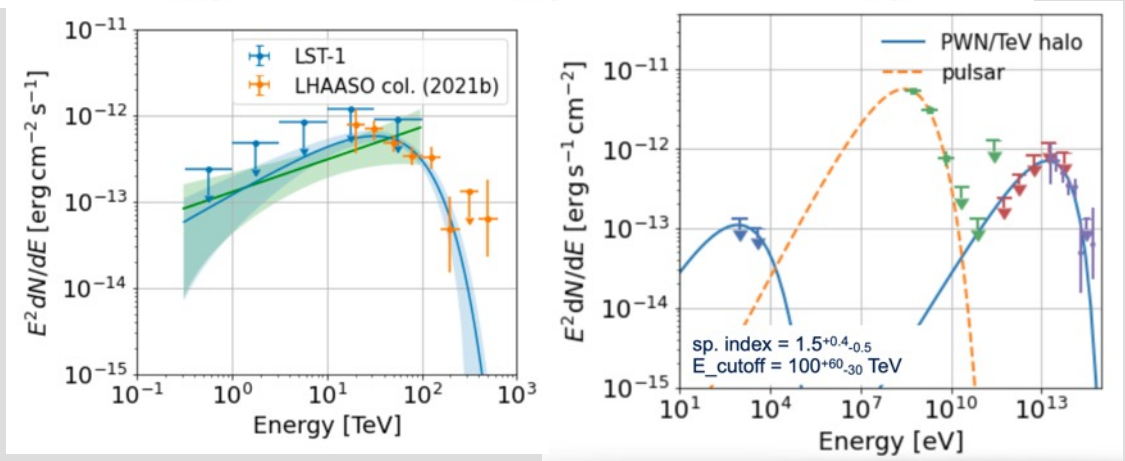
Y. Kobayashi (ICRR)

LST-1 Observation : LHAASO J2108+5157



Extended Data Fig. 4 | LHAASO sky map at energies above 100 TeV. The circles indicate the positions of known very-high-energy γ-ray sources.





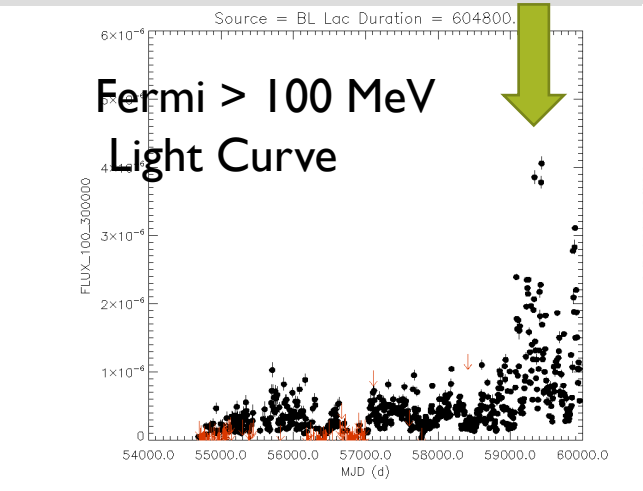
- One of the 12 >100 TeV sources from LHAASO (Nature volume 594, 2021)
- UL on extension: 0.26 deg
- No X-ray counter part
- Possible counter part in GeV, **4FGL J2108.0+5155** , likely to be a pulsar

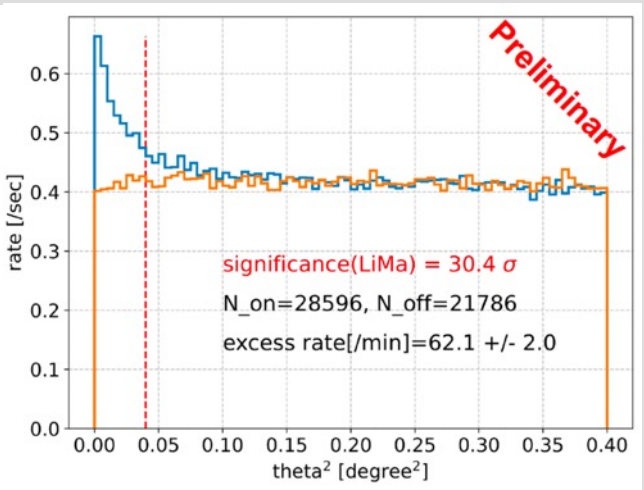
- LST1 Observed it in June - Sep 2021 for 49.3 hours after cuts.
- Only 3.6 sigma > 3 TeV

- Upper Limits constrain the emission model well. PWN TeV halo scenario can explain the emission very well.

LST collaboration, A&A (submitted)
https://arxiv.org/pdf/2210.00775.pdf

LST-1 Observation : BL Lacertae Flare





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

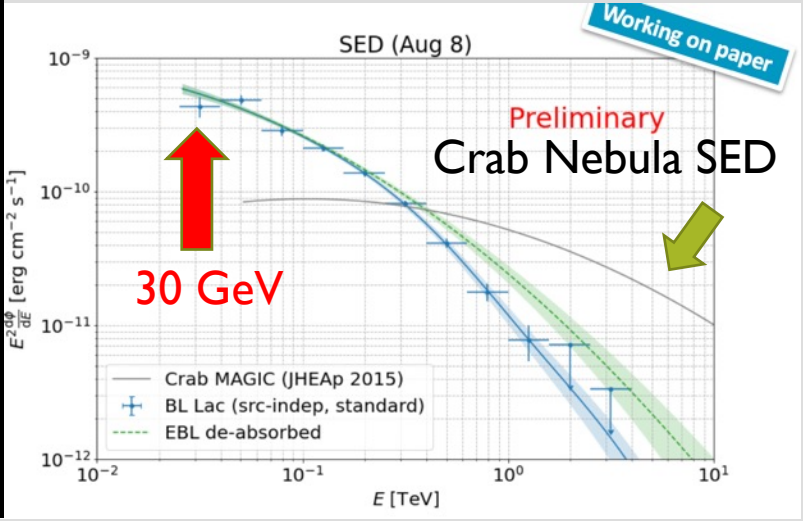
ATel #14783; *Juan Cortina for the CTA LST collaboration*
on 13 Jul 2021; 21:03 UT
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

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).



- Historical Flare in optical and gamma-ray reported in Summer 2021
- LST1 Observed it in August 2021.
- Huge signal detected and Atel was sent.
- Brighter than Crab below 300 GeV
- Spectrum measured from <u>30 GeV</u>
- Intra-night variability is also being studied.

S. Nozaki, (Kyoto, MPI)

【Dedicated Publication in prep】

LST-1 Observation : NGC 1275

[Previous | Next | ADS]

Detection of enhanced very-high-energy gamma-ray emission from the radio-galaxy NGC1275 with the LST-1

ATel #15819; *Juan Cortina (CIEMAT) for the CTA LST collaboration*
on 21 Dec 2022; 22:29 UT
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

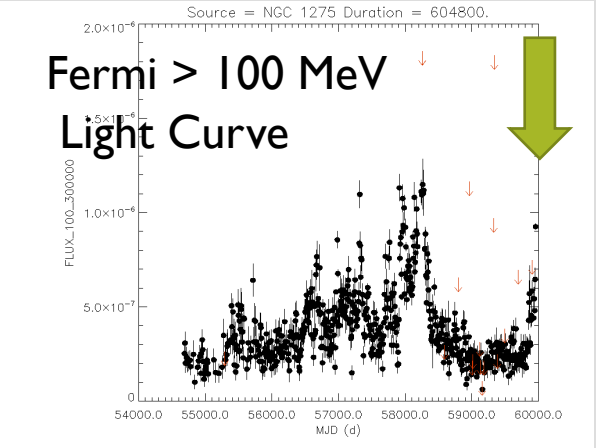
Subjects: Gamma Ray, TeV, VHE, AGN, Transient

Referred to by ATel #: 15820, 15823, 15852, 15856

Tweet

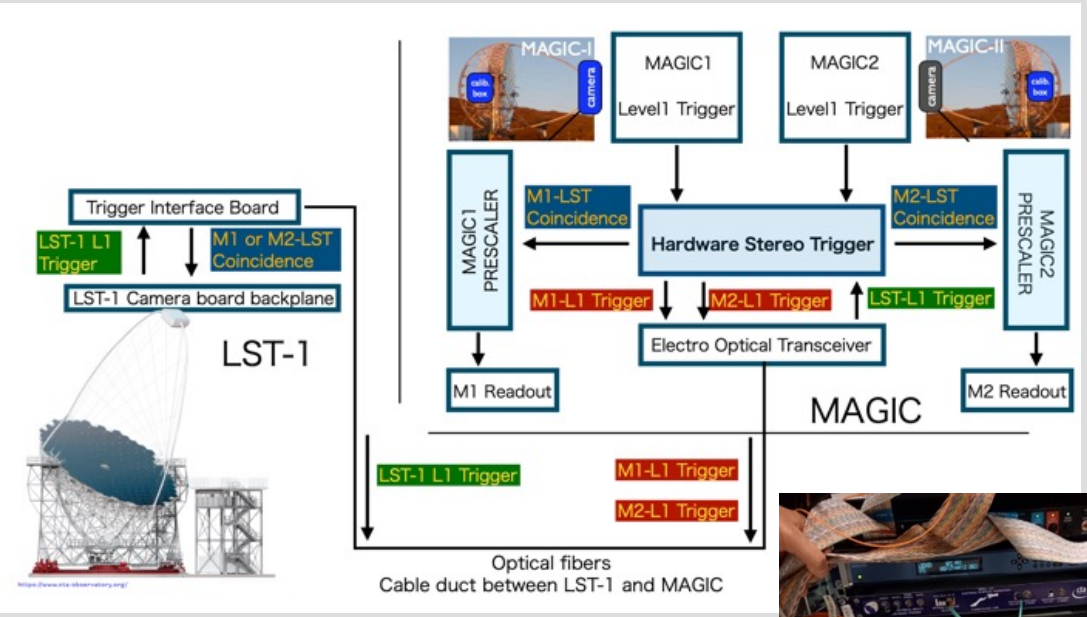
The LST-1 telescope has observed an increase in the very-high-energy (VHE; >100 GeV) gamma-ray flux from the radio-galaxy NGC1275 (RA=03:19:48.1, DEC=+41:30:42, J2000.0). The LST-1 observed NGC1275 on the night of December 20 to December 21, 2022 (MJD 59934), triggered by an increase in gamma-ray flux detected by MAGIC and Fermi-LAT. In the preliminary offline analysis of the LST-1 data, NGC1275 has been detected with a significance of more than 10 sigma with an average flux of approximately 3.0 x 10^-10 cm^-2 s^-1 above 100 GeV, i.e. 70% that of the Crab Nebula, varying from 140% to below 30% at the beginning and at the end of the observation, respectively. Note though that this is the result of a quick-look analysis. 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 NGC1275 will continue during the next few nights, multi-wavelength observations are encouraged. The preliminary offline analysis has been performed by Chaitanya Priyadarshi (cpriyadarshi@ifae.es) and Seiya Nozaki (nozaki@mpp.mpg.de). The LST-1 contact persons for these observations are Juan Cortina (juan.cortina@ciemat.es), Masahiro Teshima (mteshima@mppmu.mpg.de) and Mireia Nievas (mnievas@iac.es).

Fermi > 100 MeV Light Curve



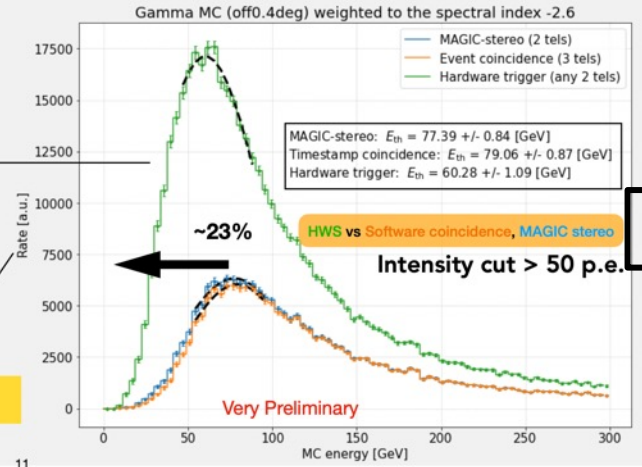
- A radio galaxy in Perseus Cluster.
- High activity reported in December 2022 (after ~5 years of quiescence state).
- LST1 Observed it and detected a signal with more than <u>10 sigma</u>
- Atel was sent.
- Analysis is on-going

LST-MAGIC Hardware Coincidence Trigger



- Trigger Signal can be exchanged between MAGIC and LST1 through optical fiber between them.
- Compared with Off-line coincidence analysis, big advantage especially for low energy events.
- Good exercise for 4 LST stereo observation.

MAGIC stereo: (M1, M2)
Timestamp coincidence: (M1,M2,LST1)
HWS: (M1, M2) or (M1, LST1) or (M2, LST1) or (M1, M2, LST1)

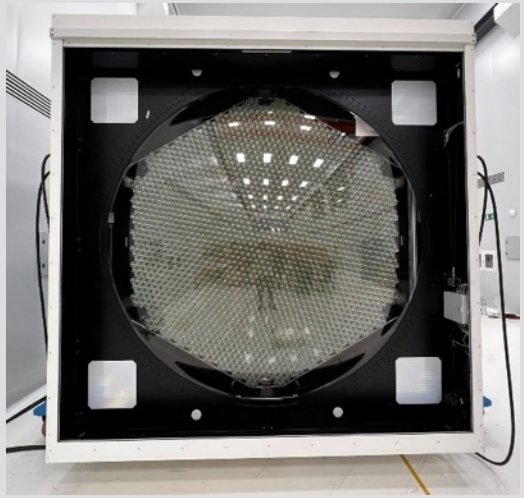


Event rate of HWS is higher because you have any 2 combination
In this figure, the rates from different combination are simply added

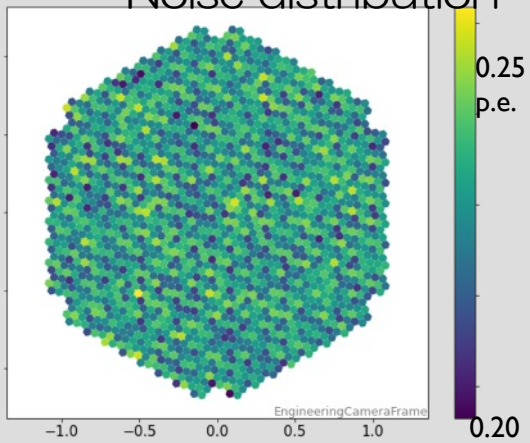
J. Baxter, D. Mazin (ICRR)

LST 2-4 Preparation Status : Camera and Optics

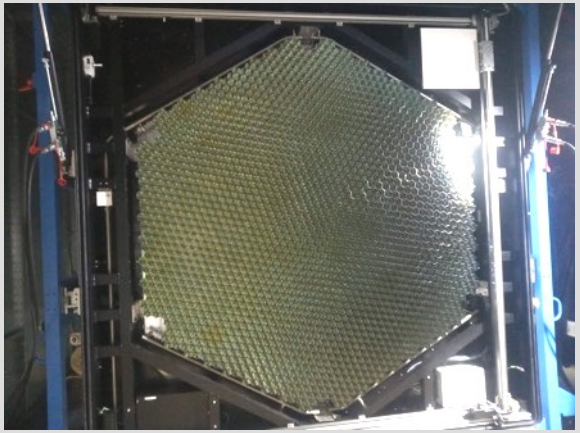
LST-2@Tenerife Integration Test



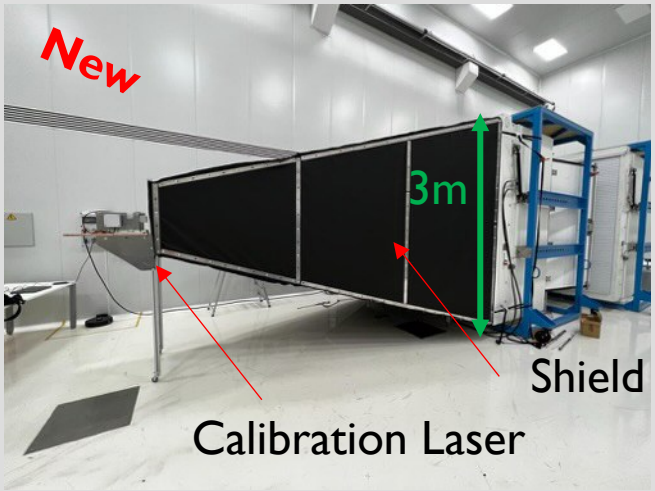
Noise distribution



LST-3@Barcelona Building up



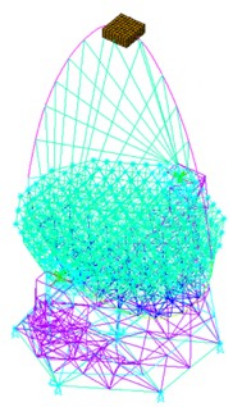
LST-4@Tenerife Integration Test

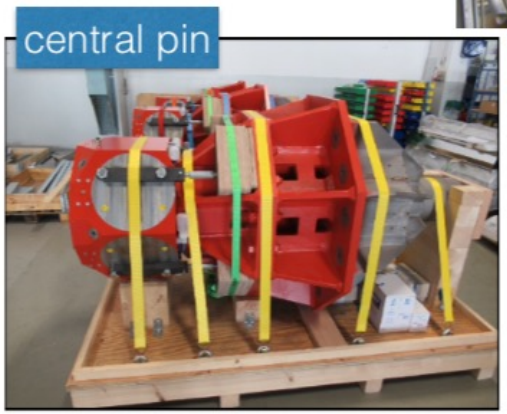


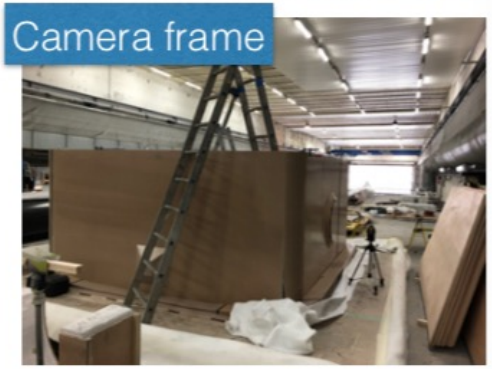
Mirror Facet

630 for LST2-4
(Stored@LaPalma)

LST 2-4 Preparation Status

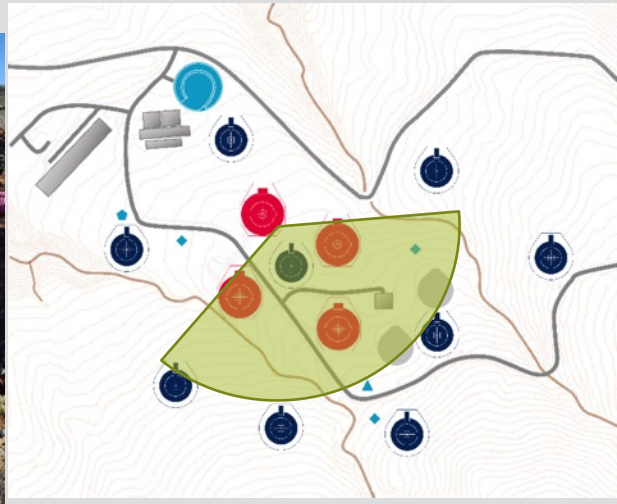


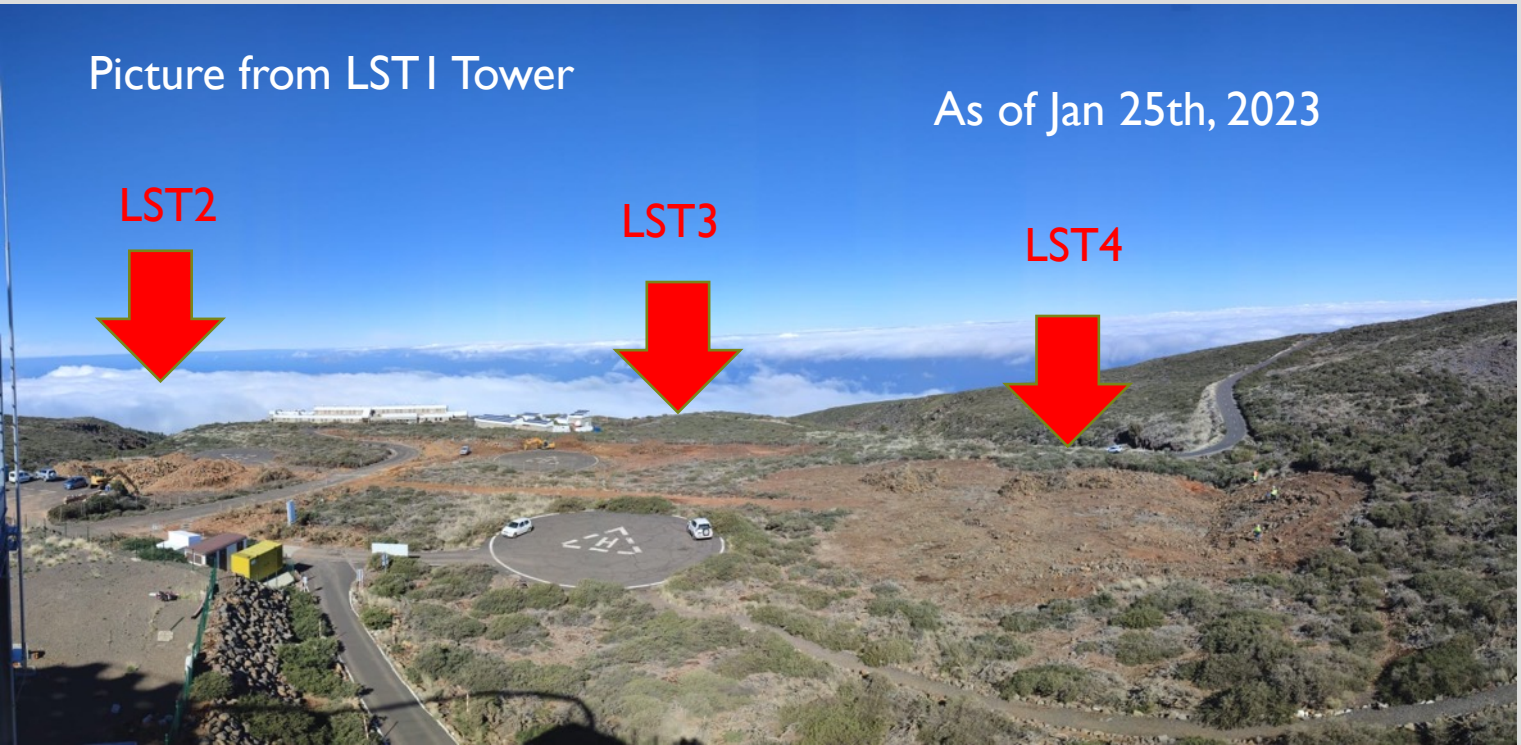




Construction permission has been issued by local government.
Construction Started ⇒ LST2-4 to be completed by Early 2025.

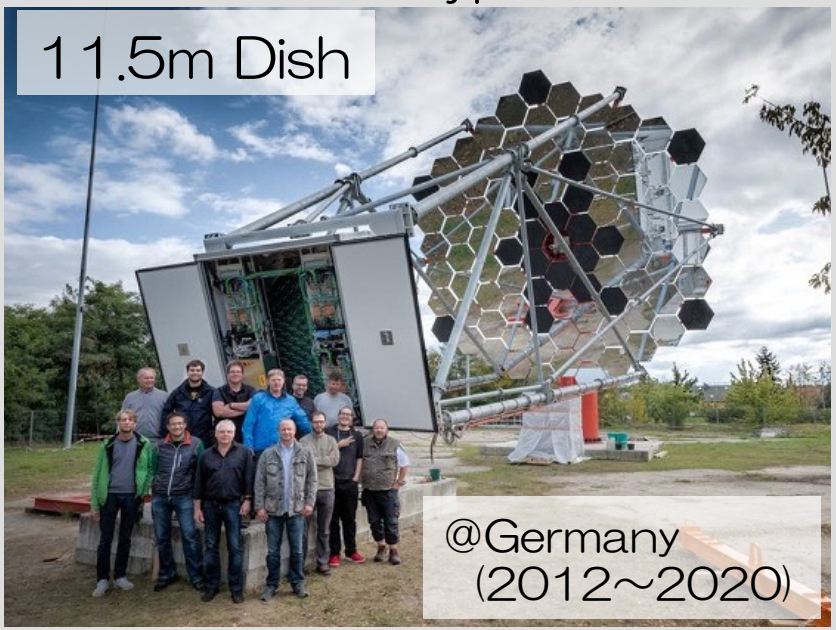
LST 2-4 Construction Status





Middle Sized Telescope (MST) Prototype

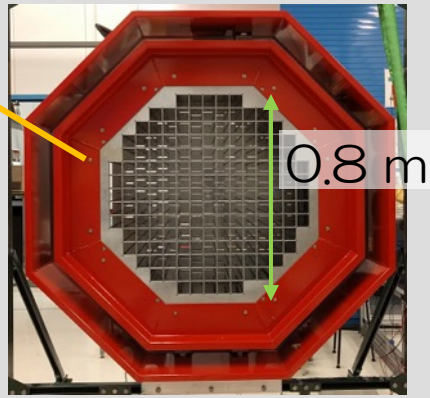
- Davies-Cotton type MST



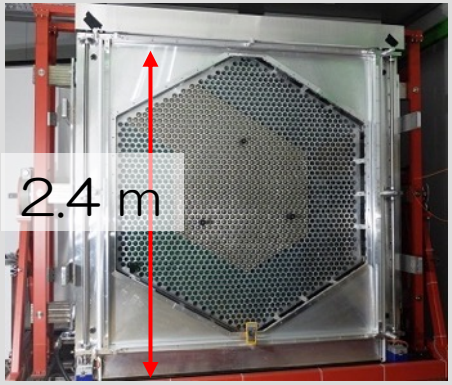
- Schwarzschild-Couder type SCT

Pri, 9.7m+ Sec. 5.4m

- Camera
  11k SiPM

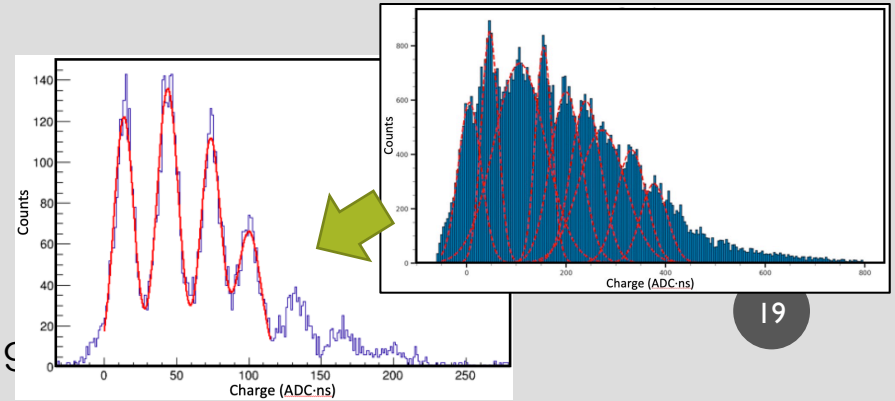


Camera ~1800 PMT



- 1 Camera to LaPalma (2023Q4)
  ⇒MST1 will be built
- Pathfinder to be built in Paranal (2024)

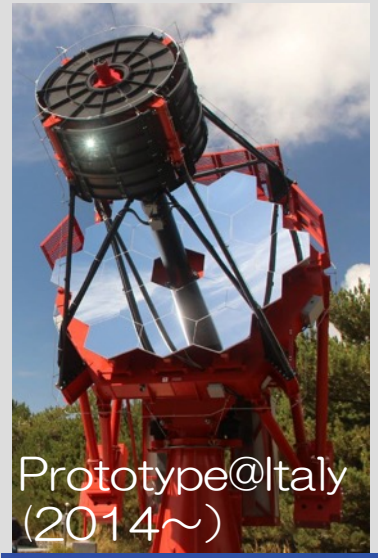
- Crab Nebula detected in 2020
- Camera Upgrade (SiPM & readout)



- Two types of readout (digital/analog)
  (digital one was mounted on HESS-II for test 201

Small Sized Telescope (SST) Prototype

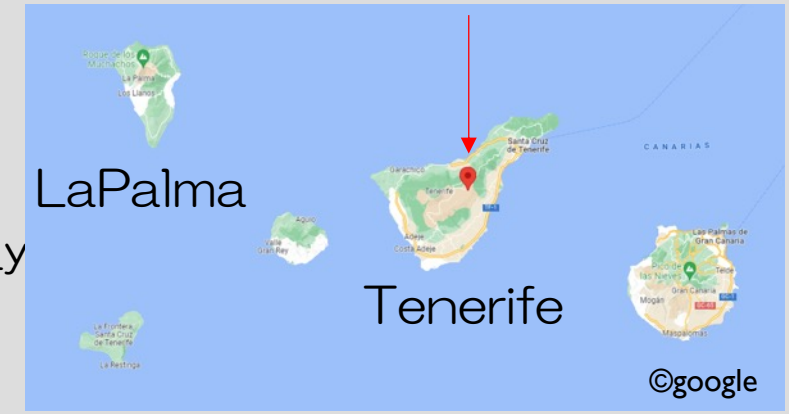
ASTRI Pri.4.3 m +Sec1.8 m
FoV 9.6 deg
SiPM(2368 ch)



Crabu Nebula
Detected in 2019

As infra of South site is not ready, a prototype array will be built in Tenerife.

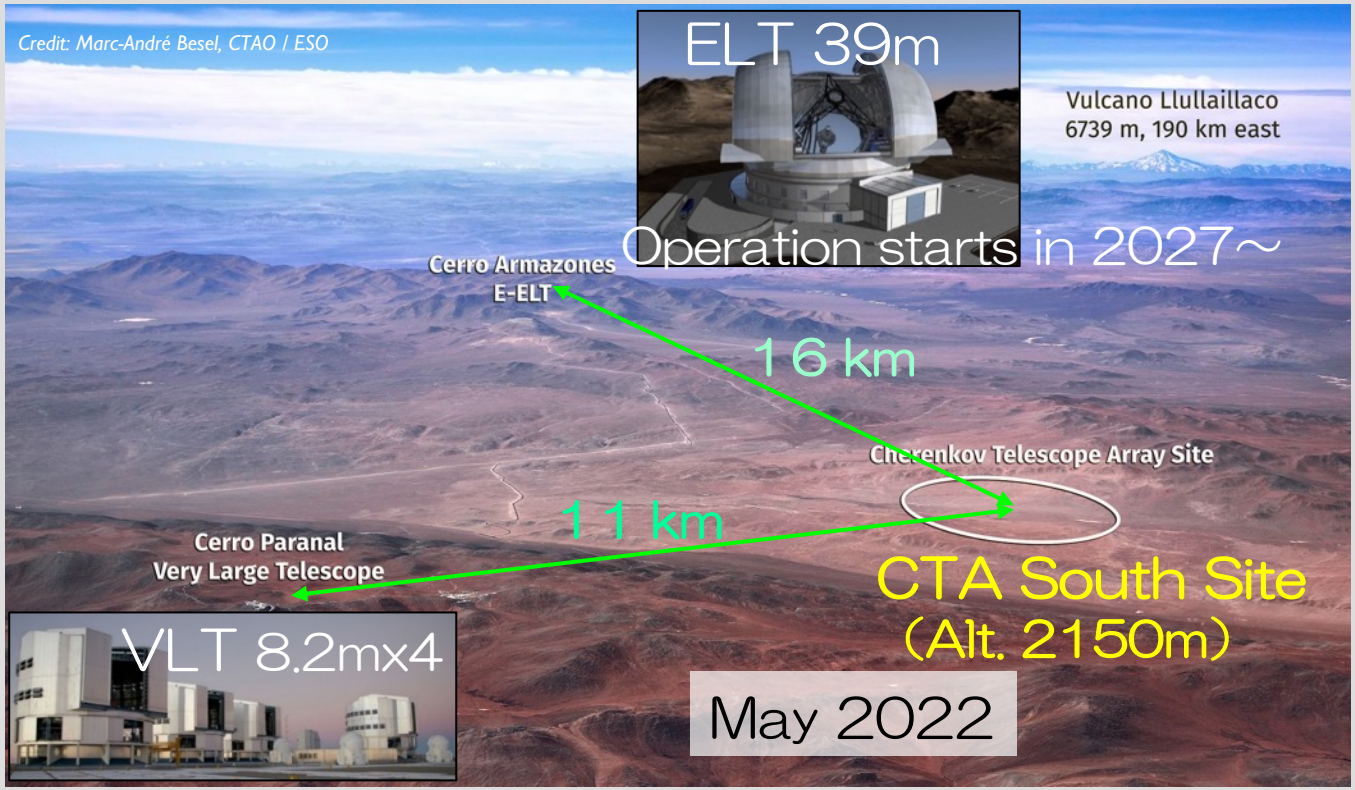
Plan to build 9 telescope array

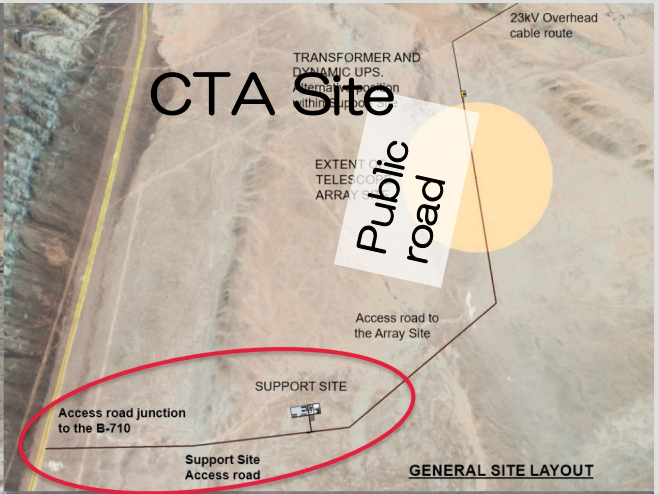


Foundation for 9 telescopes has completed.
⇒ 3 + 6 Telescopes is being built

Completion rendering

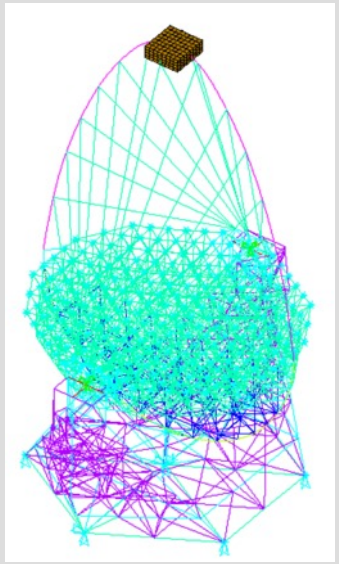
CTA South Site@Paranal, Chili

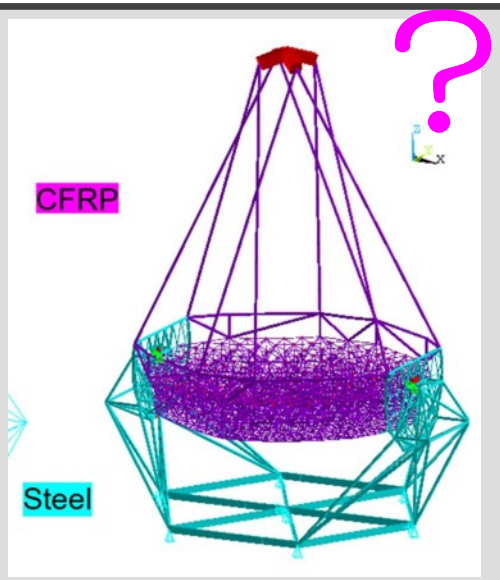


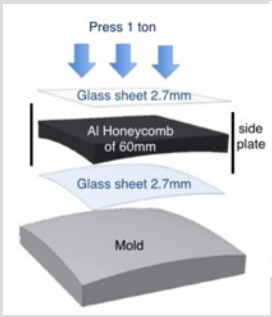


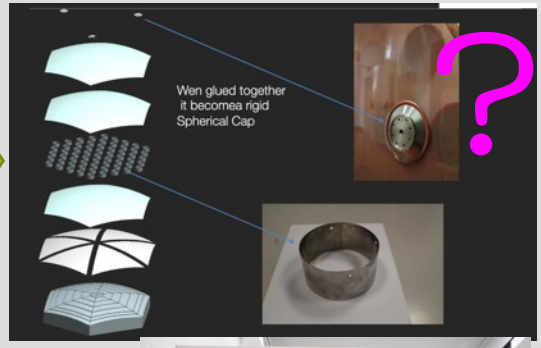
Road Construction from Public road to CTA site

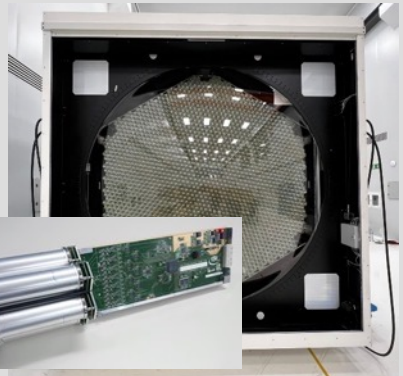
LST5-6 (LST South)

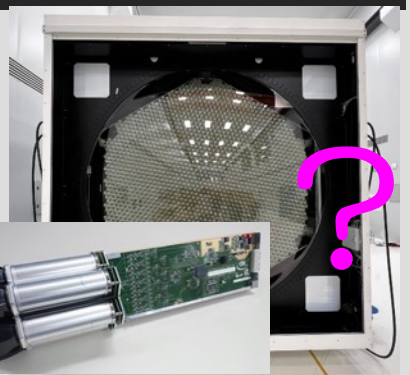






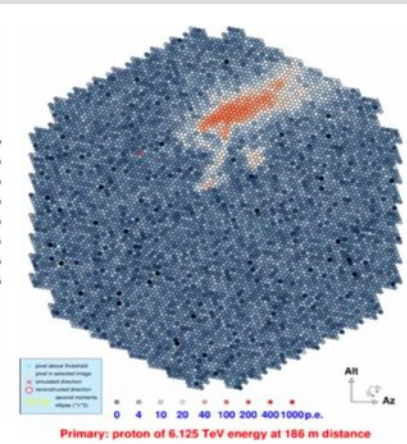


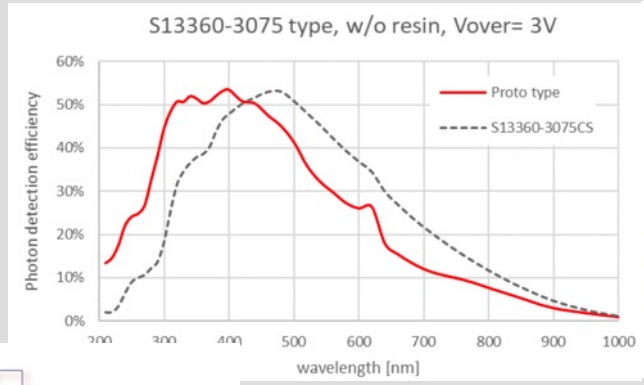


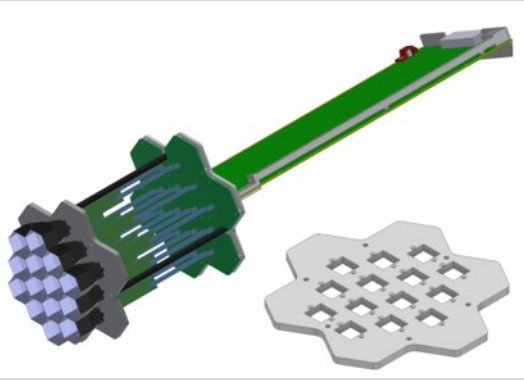


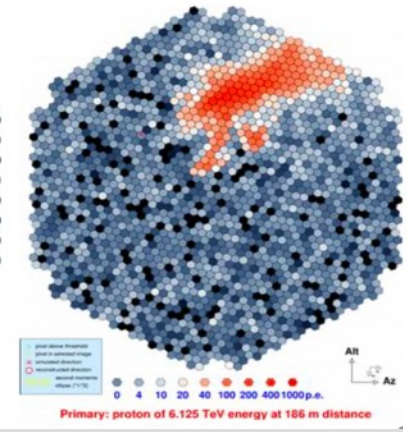
- “Post-covid recovery funds” in Italy INFN
- All elements must be delivered by the end of 2025.
- Environmental conditions are different.
  - Earthquake
  - Dust
  - dryness
- Camera -> Bascially a copy of North’s. ?
- Mirror -> to be studied ?
- Structure -> To be modified ? Design study is on going.
- Internal design review is schedued in this month in Rome.

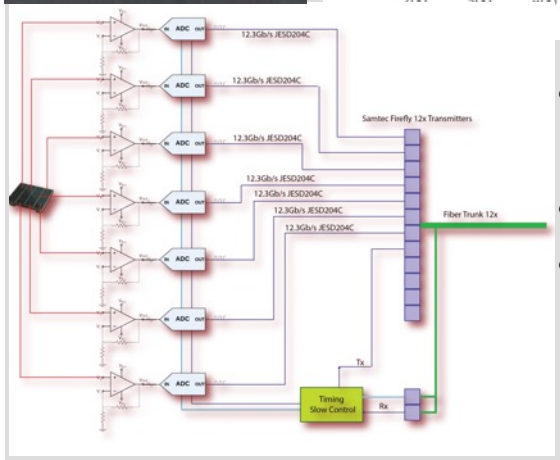
Advanced Camera Development

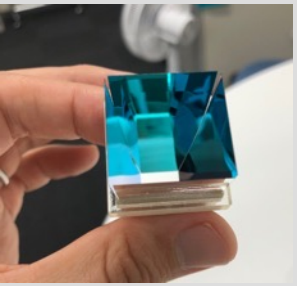


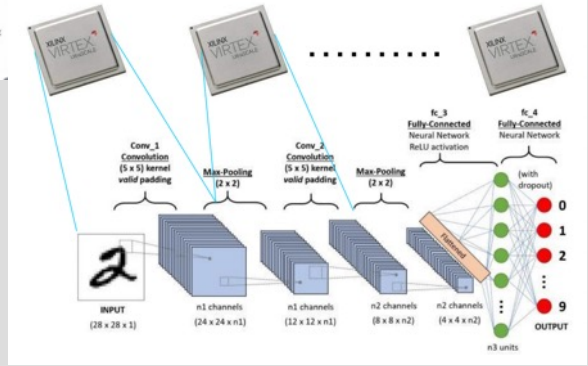












- Current Camera was designed 10 years ago. Room to be improved.
- New design has finer pixels.
- PMT -> SiPM
  - Higher QE.
  - Higher Night Sky BG
- Digitize output signal before trigger
- Digital Trigger using DeepLearning technique at FPGA

Summary

- Step by Step development of CTA north :
  - LST1 Mono observation ⇒ Several publications up-coming
    - Performance and Crab Observation
    - Known Blazars
    - BL Lac
    - Recurrent Nova
    - LHAASO J2108
    - Others including technical papers.
    - 2 Atels (BL Lac and NGC1275)
  - LST-1 - MAGIC joint observation.
    - Regularly performed. Calibration is on-going
    - Hardware Trigger Exchange is being implemented.
  - LST-2,3,4
    - All elements ready.
    - Construction permission has been recently given and construction has started.
    - To be completed by 2025
  - MST1-9 joins in 2029
- CTA South
  - Infrastructure is being constructed.
  - Budget for 2 LSTs has been secured. (Italy)
  - Design study is on-going.
- Camera Upgrade – R&D for SiPM advanced camera is on-going