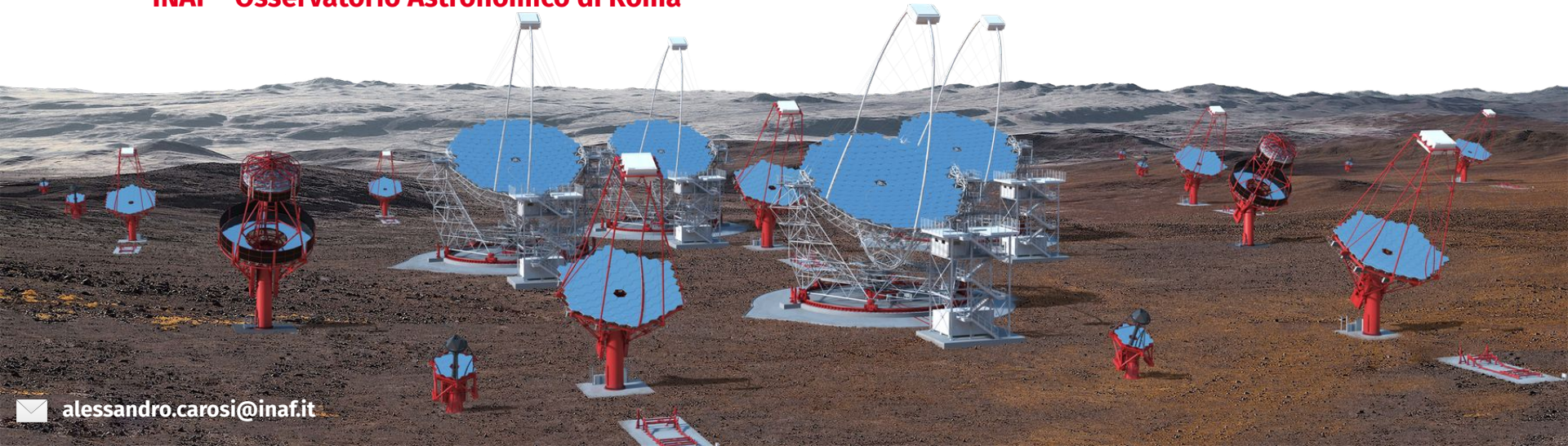
First Views of the VHE sky from the LST-1 prototype

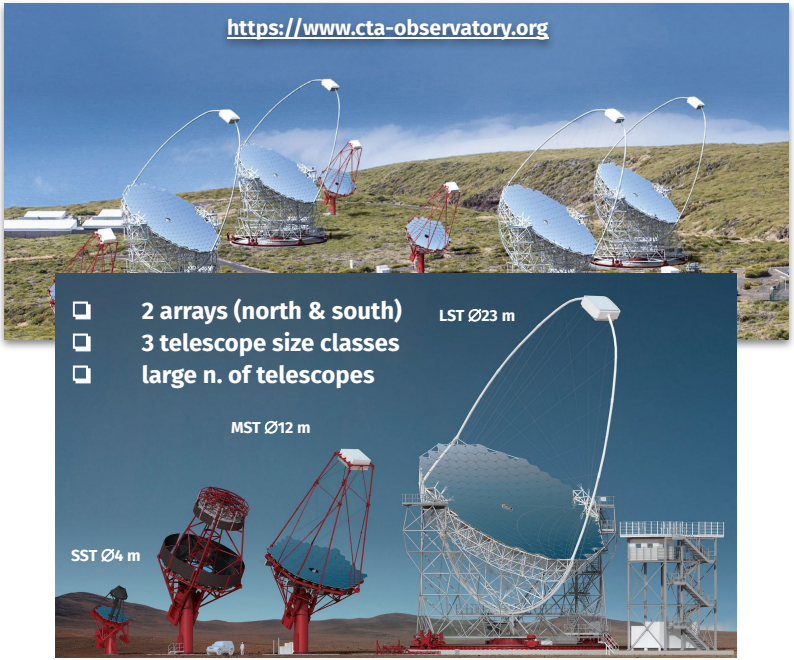
Alessandro Carosi [*] **for the CTA-LST Project**
[(*)] **INAF - Osservatorio Astronomico di Roma**

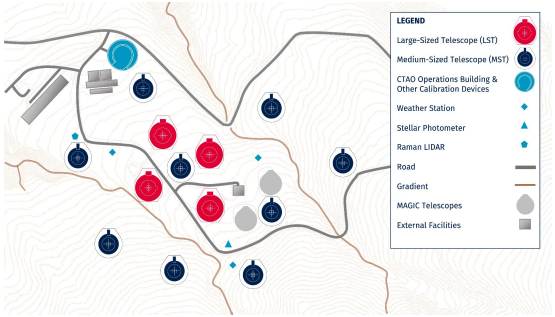


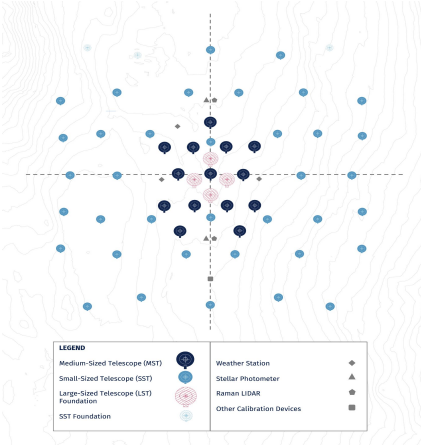
alessandro.carosi@inaf.it

The Cherenkov Telescope Array

Large-sized Telescope (LST) is a part of the Cherenkov Telescope Array Observatory (CTAO): the facility for Very High Energy gamma-ray astrophysics in the next decades







alpha configuration (first phase):

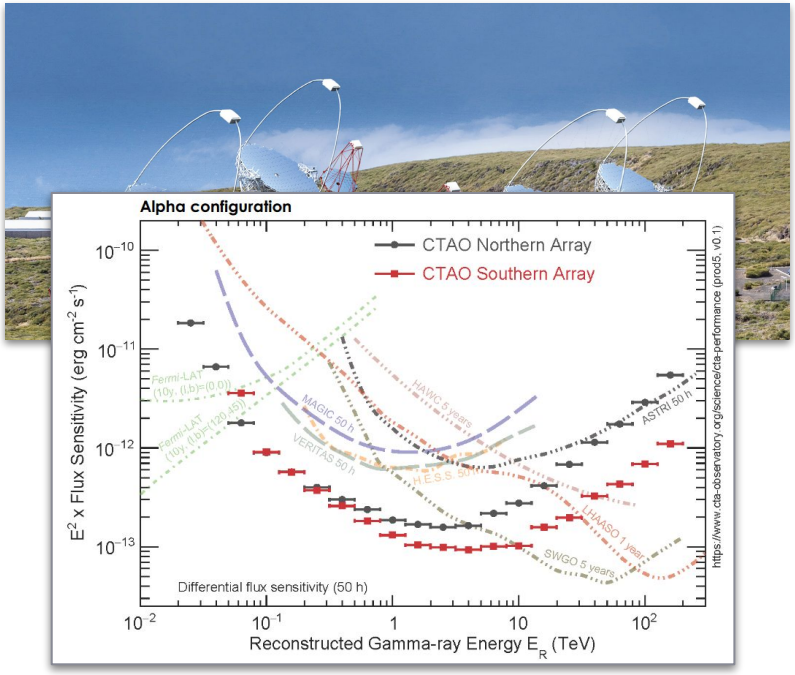
North: 4 LST + 9 MST
South: 14 MST + 37 SST

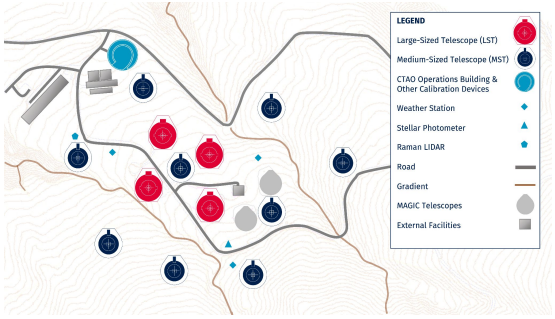
omega configuration (ultimate goal):

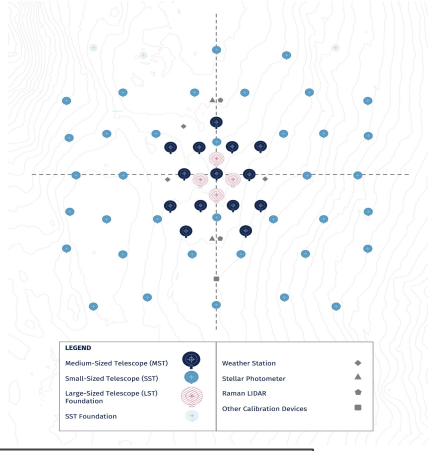
North: 4 LST + 15 MST
South: 4 LST + 25 MST + 70 SST

The Cherenkov Telescope Array

Large-sized Telescope (LST) is a part of the Cherenkov Telescope Array Observatory (CTAO): the facility for Very High Energy gamma-ray astrophysics in the next decades







- near full sky coverage
- wider energy range (~20 GeV - 300 TeV)
- higher sensitivity: ~5-10x current IACT
- better angular resolution: ~5x current IACT
- larger FoV: 2.5x current IACT

The LST-1 Prototype

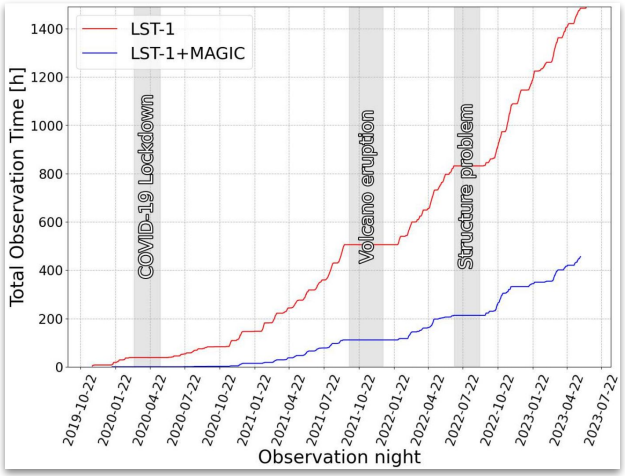
LST statistics

	Members	Scientists + Students	Authors
Bulgaria	2	2	2
Brazil	3	2	2
Spain	90	56	56
France	42	21	25
Croatia	10	10	9
Czechia	16	16	10
Germany	47	40	38
Switzerland	15	12	11
Italy	109	92	68
Japan	82	78	63
Poland	3	3	4
Total	419	332	288

The LST-1 prototype, the first 23-m class telescope for the CTA, is performing regular observations on a wide range of astrophysical sources

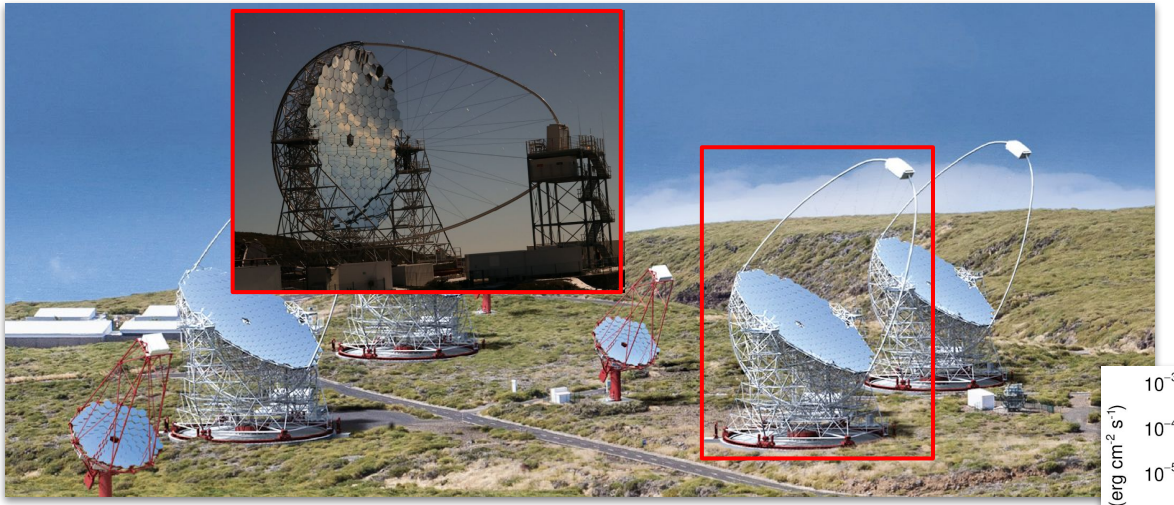
The LST-1 Prototype

The LST-1 prototype at the CTA North site



Telescope was inaugurated in October 2018. >1400 h of observation taken (Jan. 2020 - June 2023).

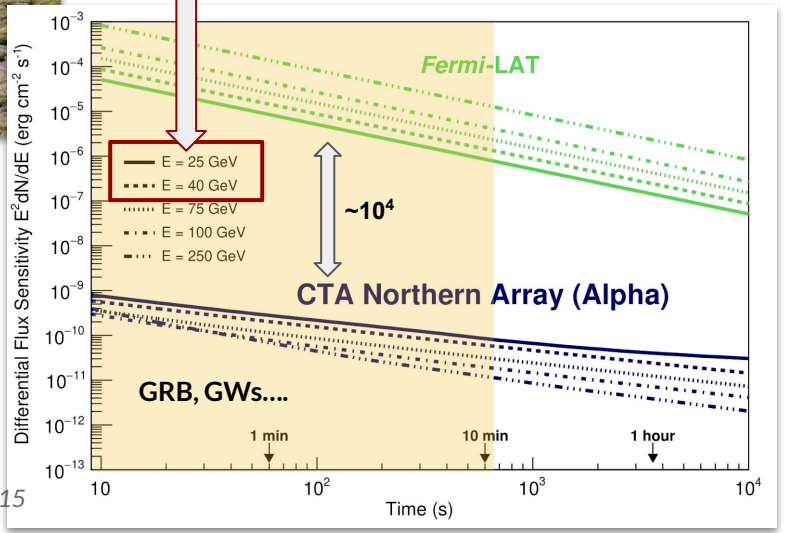
The LST-1 Prototype



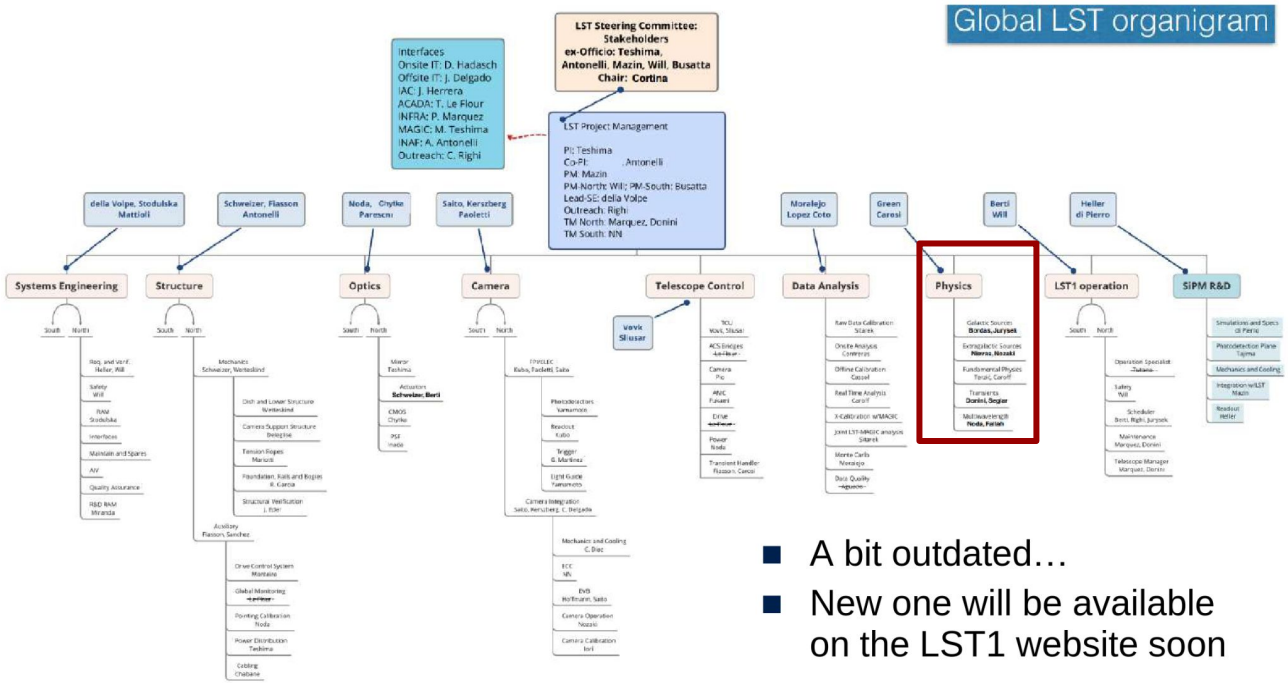
- Camera: 1855 PMTs, FoV ~ 4.3°
- Parabolic mirror: 23 m, ~400 m²
- Focal length: 28 m
- Moving weight: ~100 tons

- Low energy threshold (down to ~20 GeV)
- Large effective area at multi-GeV range
  (~ 10^4 x Fermi-LAT @ ~ some mins. timescale)
- Fast slewing capabilities (~20 s/180^0 in azimuth)

LST "sweet range"
(CTA sensitivity dominated by LSTs)



The LST-1 Prototype: science organization



- A bit outdated…
- New one will be available on the LST1 website soon

From M. Will ppt

PHYS BOARD

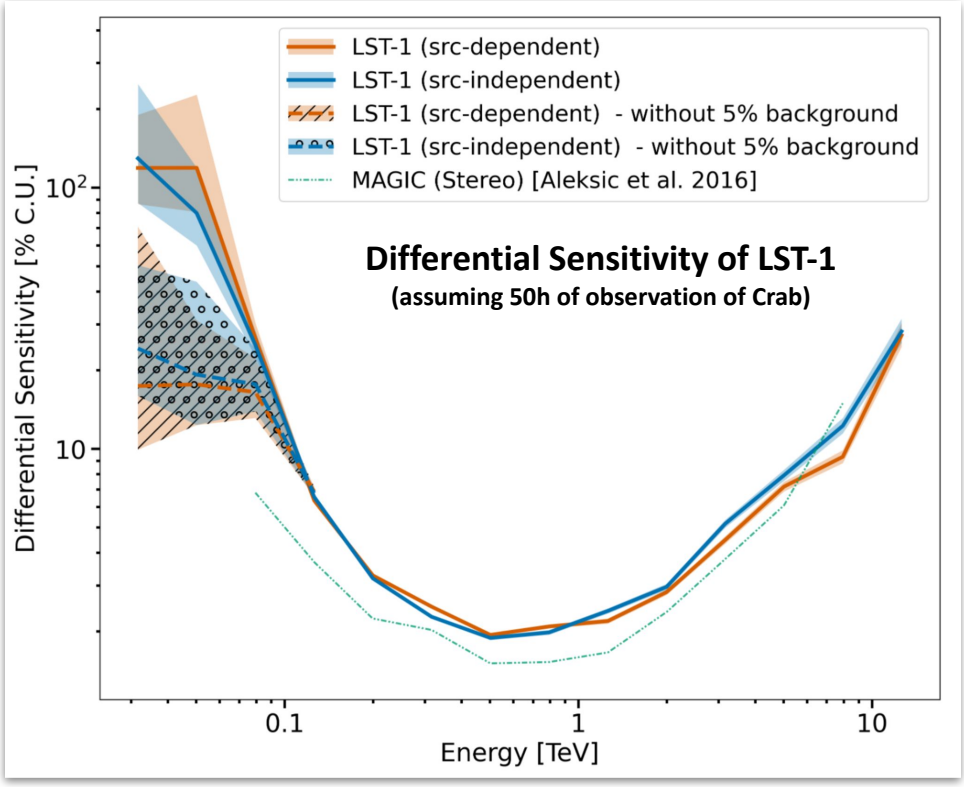
+

GAL (lst-galactic)
EGAL (lst-extragalactic)
TRAN (lst-transients)
FUND (lst-fundamental)
MWL (lst-mwl)

@cta-observatory.org

See talks by experts on each PWG

The LST-1 Prototype: performance

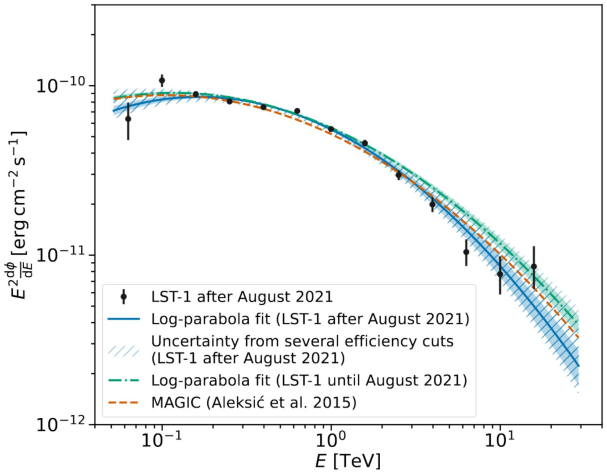


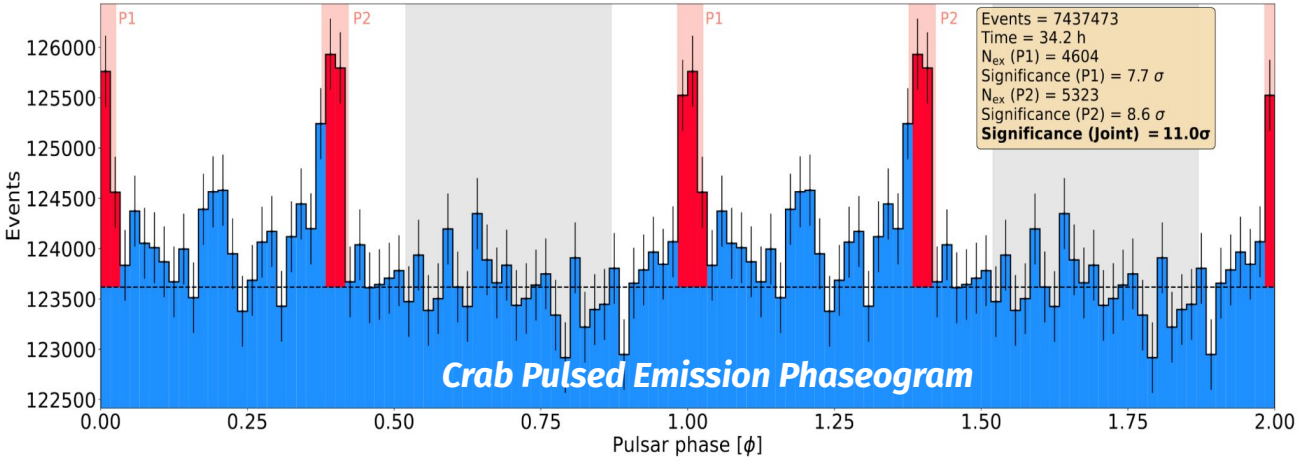
Sensitivity evaluated with real Crab data:

- energy range widened to lower energy compared to MAGIC
- MAGIC (stereo system) ~1.5 x better sensitivity then LST-1 (mono) - As expected by the difference between mono and stereo systems

ApJ, 956, 80 (2023)

Performance & early science





Crab Nebula traditionally used as standard candle for VHE observations:

- ❏ Source physics + telescope performances (threshold, cross-calibration, energy resolution…)
- ❏ Clear detection of P1 and P2 → **E_{thr} down to ~25 GeV**

ApJ, 956, 80 (2023)

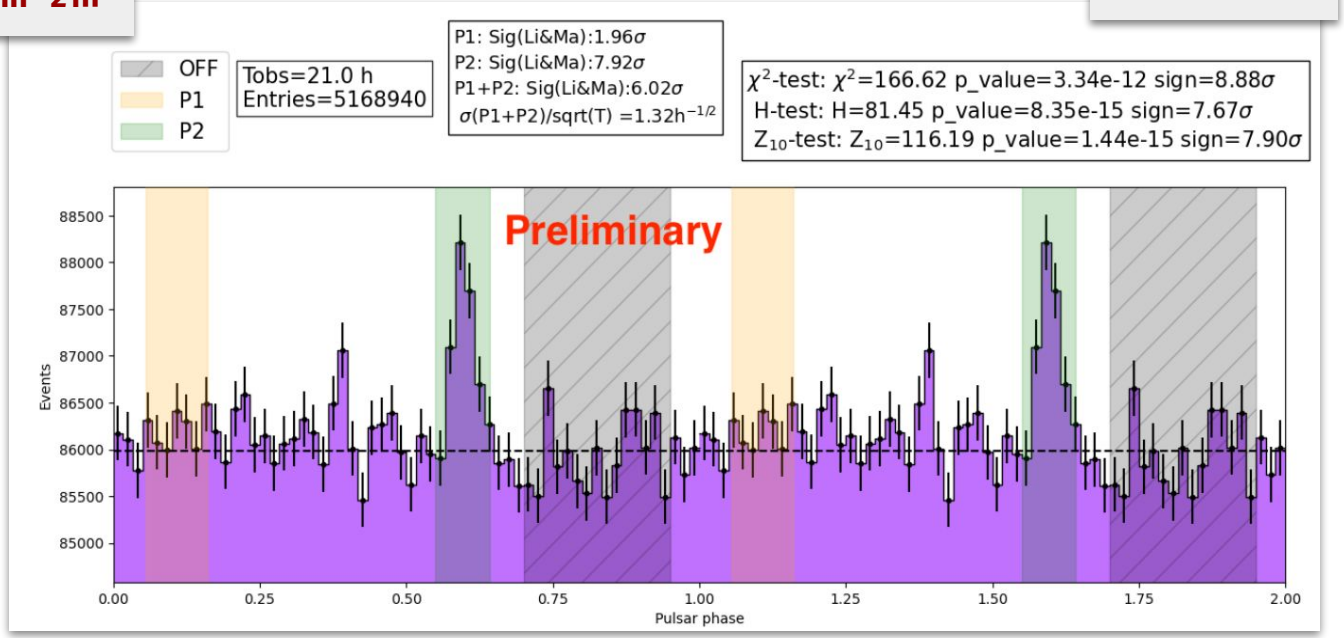
Pulsar: Geminga (PSR J0633+1746)

- **Performance at lower energies confirmed by the detection of Geminga (PSR J0633+1746)**

Detected at ~8σ in ~21h

PoS ICRC2023 (2023) 569

- Being a soft spectrum source, the detection of Geminga confirms the good performance in the 15-30 GeV band, one of the main scientific drivers of LST
- MAGIC: 6.3σ after 80 hours for P2
  (MAGIC coll., A&A 643 (2020) L14)



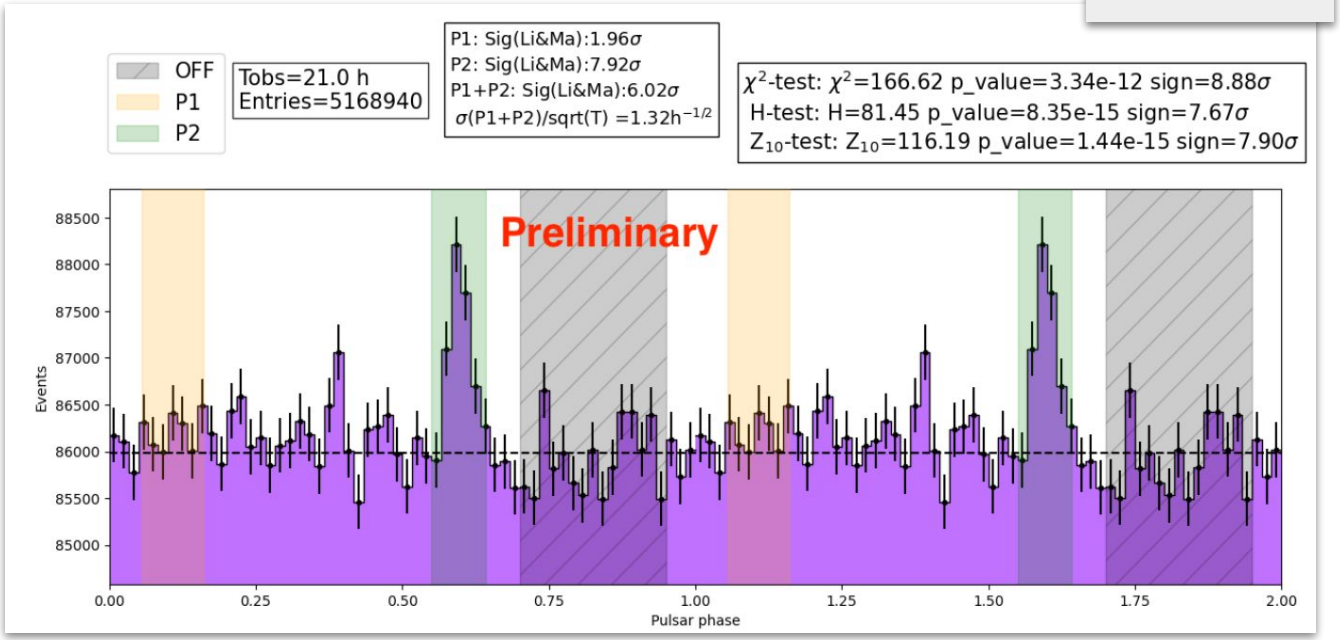
Pulsar: Geminga (PSR J0633+1746)

- **Performance at lower energies confirmed by the detection of Geminga (PSR J0633+1746)**

- Pulsars are obviously a primary target for LST-1

See talks by Pol, Franca...

PoS ICRC2023 (2023) 569



Early Science: Transients

Short time-scale transients represent a still marginally explored science case although they are key science targets for both current IACT collaborations and for LST-1. Short time-scale follow-ups often differ from normal observations:

- interruption of nominal operations, fast repointing, special setup, custom data analysis
- They cover all areas of the experiment: instrument, analysis & physics

Source	Duration	Energy Release	Energy Source
		[erg]	
Fast Radio Burst (FRB)	<~msec	~10^{50}	B field (?)
Gamma-ray Burst (GRB)	msec - min	~ 10^{49} - 10^{53}	Gravity
Tidal Disruption Event (TDE)	min - months	~10^{52}	Gravity
Supernovae (SNe)	min - years	~10^{44}	Gravity
Active Galactic Nuclei (AGN)	min -days	~10^{43} erg/s	Gravity

+ GW, Nu....

Hot topics at the frontiers of VHE and multi-messenger astrophysics

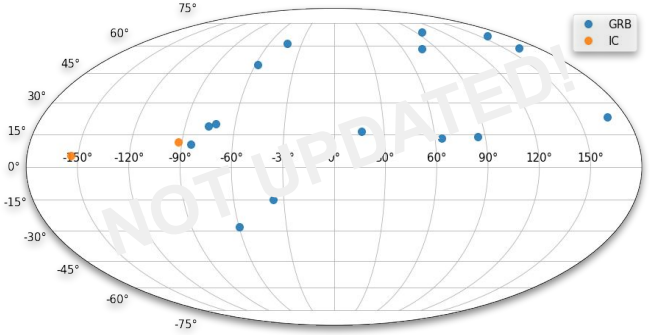
Requirements:

- low energy threshold
- fast repointing
- synergies with other facilities

Early Science: Transients observation

- **Low energy threshold is of primary importance also for transient observations (EBL absorption). First regular follow-up started at the end 2020/beginning of 2021 :**

  - Several events observed so far (GRB, Nu, SN and GW during O4)
  - Gal. Transients (Magnetar (SGR 1935…), Novae…)
  - dedicated automatic procedure has been implemented and is being optimized
  - Initial science already possible (hopefully not for long, with ULs…)



The quest for GRB detection is (finally) over, now it's physics/population study time:

- Do all GRB have a VHE component? Which is the emission mechanism?
- VHE comes from prompt and/or afterglow?
- Which are the parameter space for the GRB VHE emitters?
- The detections we got so far are puzzling!

Early Science: Transients observation

- **Low energy threshold is of primary importance also for transient observations (EBL absorption). First regular follow-up started at the end 2020/beginning of 2021 :**

  - Several events observed so far (GRB, Nu and GW during O4)
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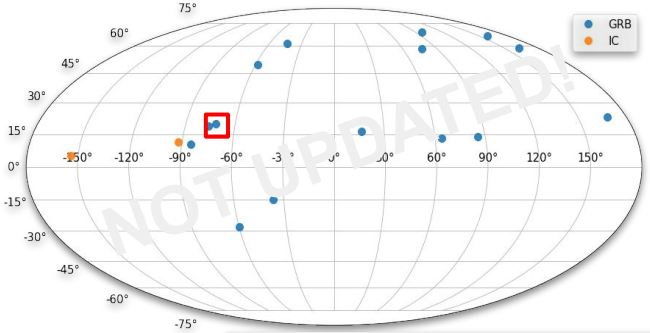
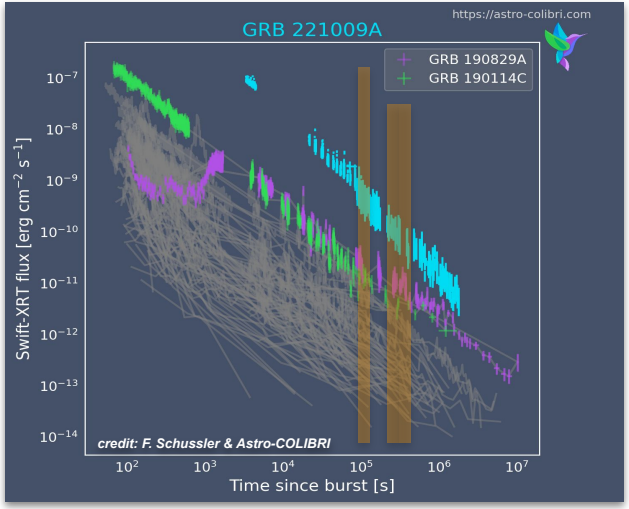




Super-powerful GRB
E_{iso} ~ 2x10^{54} erg
z = 0.151
detected at ~100 GeV but not with IACT

See A. Berti, A. Simongini talks tomorrow

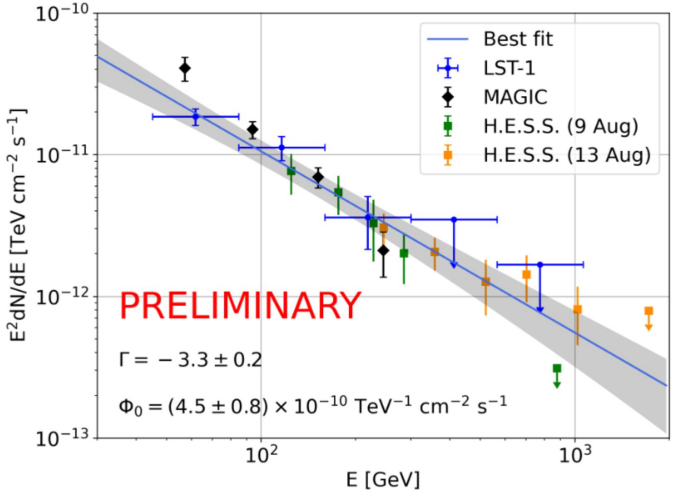
LST (first) observation (telescope operated from remote!):

2022/10/10 ~21:34 UTC T_0 + 1.1 x 10^5 sec (~31 h, reduced HV)

Optimization of analysis ongoing

Early Science: RS Ophiuchi Nova

Novae are thermonuclear explosions caused by accumulation of material from donor star on a surface of a white dwarf (WD)



- System **is not** disrupted after the nova event -> cycle restarts
  - Most novae detected only once:
  - Outburst once every (hundreds of) thousand years

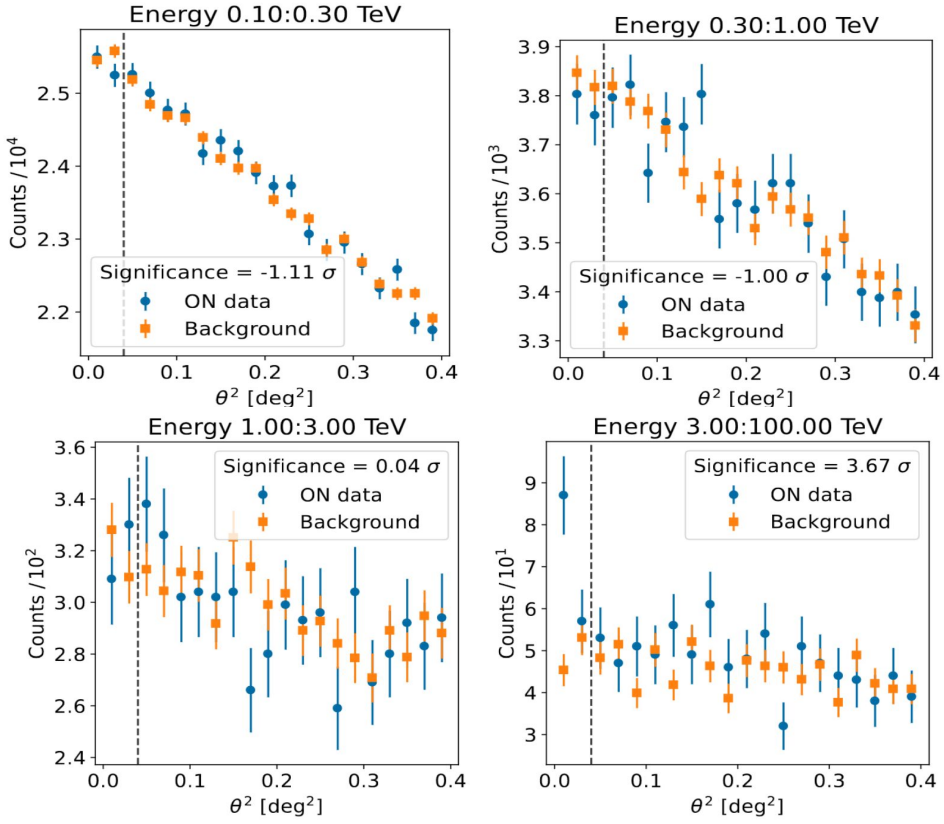
- Some novae show repeated outbursts within few years/human lifetime: recurrent novae (RN)
  - 10 known RN in the Galaxy with repetition rate <100 y
  - For a symbiotic nova to be RN, the WD must be massive (≥1.1 M ⊙) (if M > 1.44 M ⊙ → Sn Ia)

RS Oph is a recurrent symbiotic nova which displays major outbursts every 14.7 years

Observed and detected on August 2021

⇨ **Novae established as a new type of VHE emitters**

Early Science: candidate Pevatron Observation

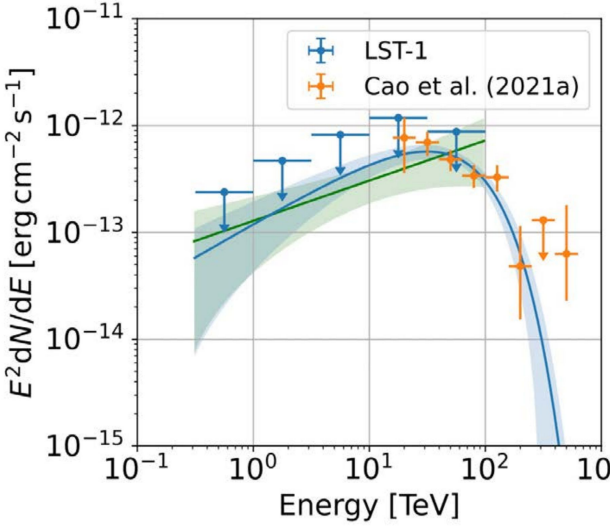


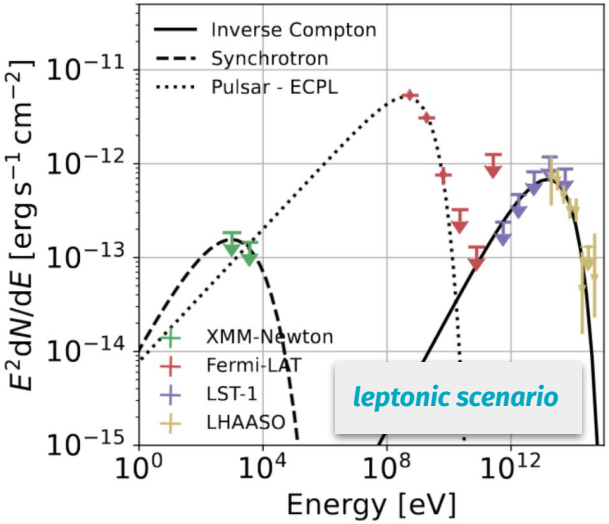
LHAASO J2108+5157 is the first gamma-ray source directly discovered in the UHE band (~100 TeV)

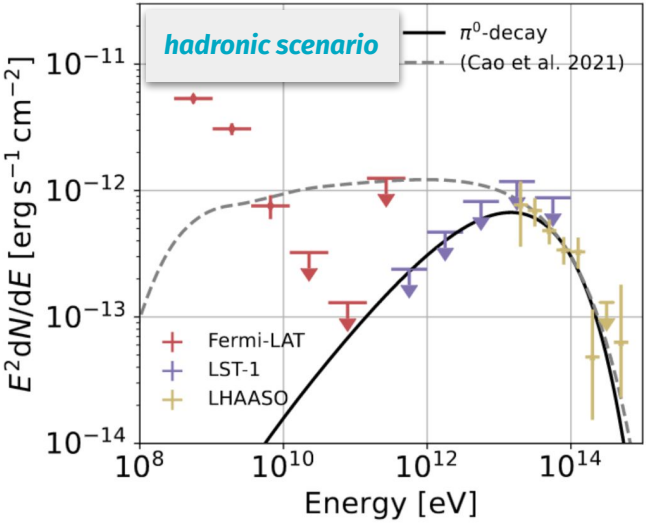
- ~ 91 hour observation
- No X-ray or VHE counterpart (3.7σ in the few TeV band) → **constraining upper limits achieved**
- First Science publication by LST-1

A&A, 673, A75 (2023)

Early Science: Candidate Pevatron Observation





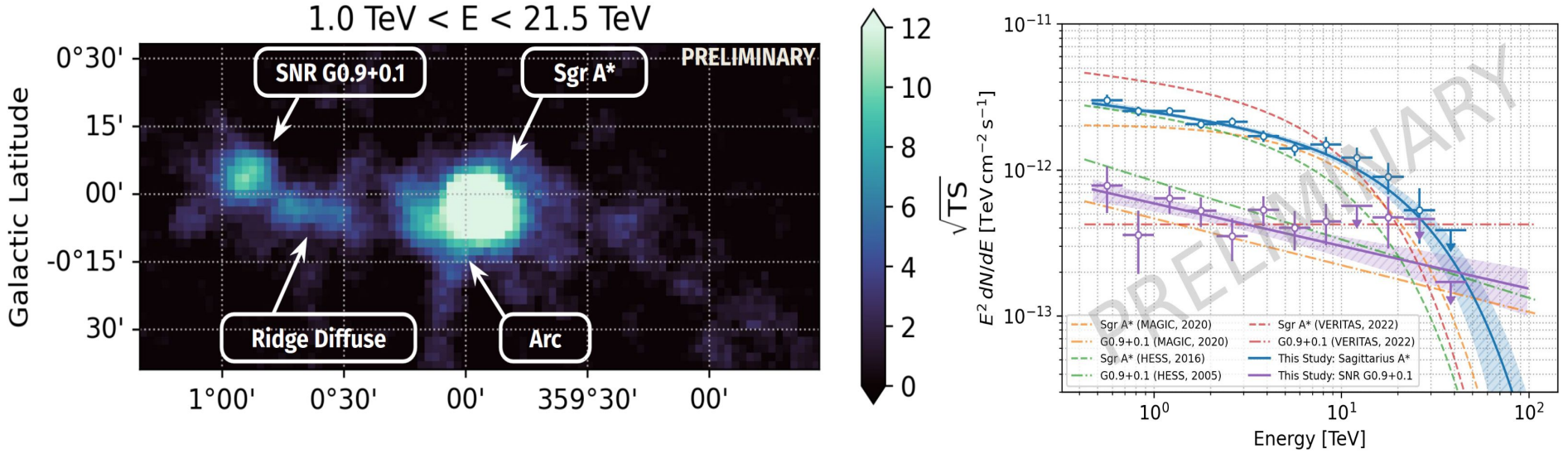


Two possible scenarios:

A&A, 673, A75 (2023)

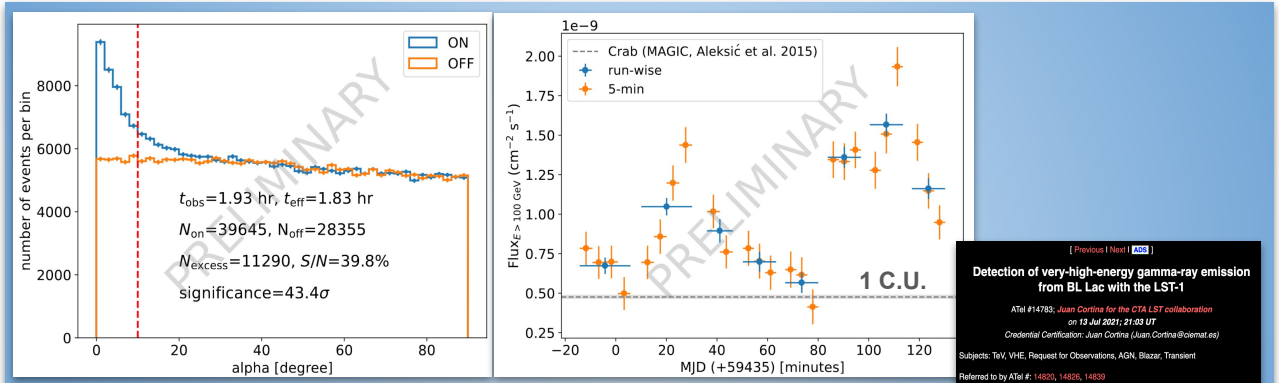
- PWN/TeV halo
- VHE/UHE gamma rays are produced interactions of relativistic CR with thermal protons followed by π0 decay (molecular clouds presents around source position)

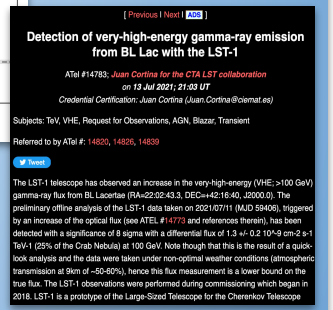
Early Science: Galactic Center



- Detection of prominent signals, and verification of extended-source observations
- SED results in line with the ones from the current-generation telescopes

Early Science: Monitoring Old Friends




[Previous | Next | 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)

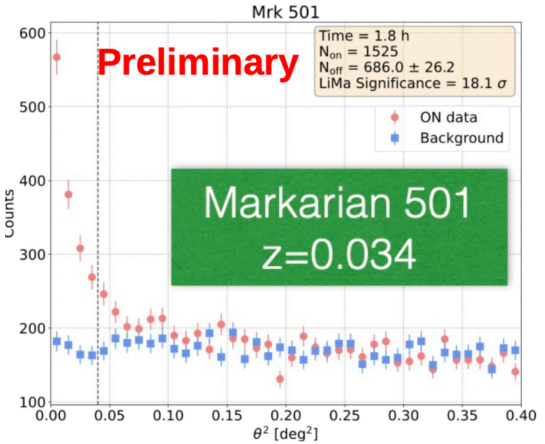
Subjects: TeV, VHE, Request for Observations, AGN, Blazar, Transient

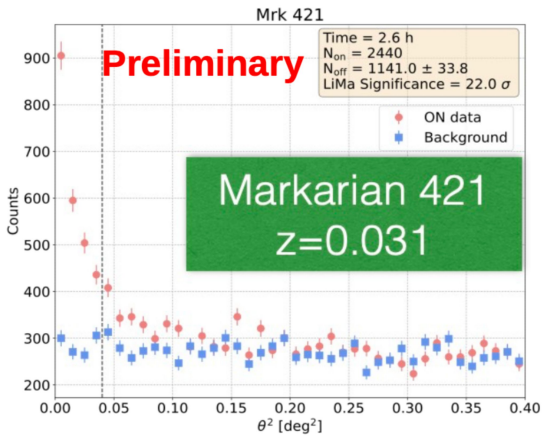
Referred to by ATel #: 14820, 14826, 14839

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 ~50-80%), 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

- First **LST-1 ATel**: BL Lac flare on July 11th 2021, **ATel #14783**
  - Source monitored also in August 2021
  - detected sub-hour-scale intra-night variability 3–4 times higher than the flux of the Crab Nebula above 100 GeV





- Detection and monitoring of several known AGNs up to z~0.5 *(Mrk 421, Mrk 501, 1ES 1959+650, 1ES 0647+250, PG 1553+113…)*

	Mrk421	Mrk 501	1ES1959+650	1ES0647+250	PG 1553+113
AGN type	HBL	EHBL	HBL	HBL	HBL
Redshift	0.031	0.034	0.048	0.45±0.05	0.433
Obs. date	2020/12/12 -2022/05/23	2020/07/10 -2022/06/29	2020/07/11 -2022/05/05	2020/12/16 -2020/12/21	2021/04/08 -2022/05/23
Obs. time BF/AF cut (h)	68.5/31.9	67.2/39.7	21.3/11.8	8.8/8.2	12.2/9.9
Significance	31 σ	21 σ	12 σ	7 σ	16 σ
Condition	Dark (No Moon) + Clear Sky				

See dedicated talks during egal session (M.Nievas, E. Prandini….)

Toward the LSTs Array

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14 Jan 2024; 21:57 UT

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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)

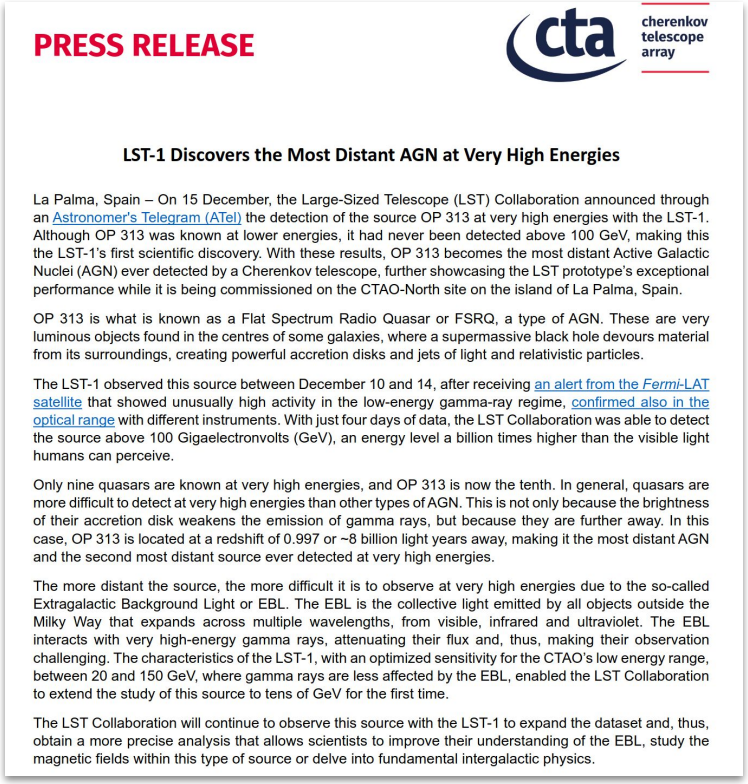
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, AGN, Blazar, Quasar

Post

The Large-Sized Telescope (LST-1) on La Palma has been monitoring the very distant Flat Spectrum Radio Quasar (FSRQ) OP 313 (z=0.997, Schneider et al. 2010, AJ, 139, 2360) since November 2023. Following the announcement of enhanced gamma-ray emission by Fermi-LAT (ATel #16356) and several optical facilities (ATel #16360) in early December, the Fermi-LAT emission of OP 313 has been closely monitored using the FlaapLUC pipeline (Astronomy and Computing, Volume 22, p. 9-15, 2018). This monitoring revealed the detection of renewed activity in the high-energy (HE, E>100 MeV) band and so, Target of Opportunity observations with LST-1 were triggered on December 10th 2023. OP 313 was detected by LST-1 with a preliminary offline analysis using data from 2023/12/11 to 2023/12/14. It was detected with a significance greater than 5 sigma and an integrated flux, above 100 GeV, at 15% flux of the Crab Nebula. LST-1 observations on OP 313 will continue during the next few nights and therefore multi-wavelength observations are highly encouraged. LST-1 is a prototype of the Large-Sized Telescope for the Cherenkov Telescope Array Observatory, and is located on the Canary island of La Palma, Spain. The telescope design is optimized for observation of gamma rays in the range from 20 GeV to 3 TeV. The preliminary offline analysis has been performed by Daniel Morcuende (dmorcuende@iaa.es), Jorge Otero-Santos (joteros@iaa.es) and Seiya Nozaki (nozaki@mpp.mpg.de). The LST-1 contact persons for these observations are Masahiro Teshima (mteshima@mpp.mpg.de) and Juan Cortina (juan.cortina@ciemat.es).

Related

- 16381 First detection of VHE gamma-ray emission from FSRQ OP 313 with LST-1
- 16360 Optical follow-up of the gamma-ray flare of the blazar OP 313 reveals a bright state with high polarization degree
- 16356 Fermi-LAT detection of renewed gamma-ray activity from the FSRQ OP 313, and enhanced gamma-ray activity from the FSRQ ON 393
- 15931 Polarimetric results of B2 1308+326
- 15930 POLARIMETRIC RESULTS OF B2 1308+326
- 15870 The Blazar TON 0599 is now in a particularly bright state in the optical as well
- 15515 The FSRQ B2 1308+326: an unusual gently sloping dimming after absolute maximum at R~12.6
- 15496 B2 1308+326 is dimming after the highest optical state
- 15492 FSRQ B2 1349+308 : Upper limits from a neutrino search with IceCube
- 15485 NIR Flare of the Blazar HB89 1308+326
- 15483 Fermi-LAT detection of enhanced gamma-ray activity from the FSRQ OP 313 (B2 1308+32)
- 15480 ATLAS photometry of 1308+326 shows continued brightening
- 15476 The FSRQ B2 1308+326: new absolute maximum at R~12.8 without dimming signs
- 15474 Unprecedented Optical Flare Continues in Blazar 1308+326, Reaching Historic Maximum Brightness
- 15459 The FSRQ B2 1308+326: reaching the new absolute maximum and still brightening
- 15447 An update on B2 1308+326
- 15441 Bright Optical Flares in Blazars 1156+295 and 1308+326
- 15428 A recent NIR flare of the



PRESS RELEASE

cherenkov telescope array

LST-1 Discovers the Most Distant AGN at Very High Energies

La Palma, Spain – On 15 December, the Large-Sized Telescope (LST) Collaboration announced through an Astronomer's Telegram (ATel) the detection of the source OP 313 at very high energies with the LST-1. Although OP 313 was known at lower energies, it had never been detected above 100 GeV, making this the LST-1's first scientific discovery. With these results, OP 313 becomes the most distant Active Galactic Nuclei (AGN) ever detected by a Cherenkov telescope, further showcasing the LST prototype's exceptional performance while it is being commissioned on the CTAO-North site on the island of La Palma, Spain.

OP 313 is what is known as a Flat Spectrum Radio Quasar or FSRQ, a type of AGN. These are very luminous objects found in the centres of some galaxies, where a supermassive black hole devours material from its surroundings, creating powerful accretion disks and jets of light and relativistic particles.

The LST-1 observed this source between December 10 and 14, after receiving an alert from the *Fermi*-LAT satellite that showed unusually high activity in the low-energy gamma-ray regime, confirmed also in the optical range with different instruments. With just four days of data, the LST Collaboration was able to detect the source above 100 Gigaelectronvolts (GeV), an energy level a billion times higher than the visible light humans can perceive.

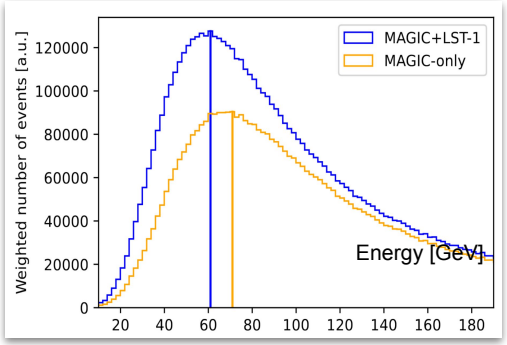
Only nine quasars are known at very high energies, and OP 313 is now the tenth. In general, quasars are more difficult to detect at very high energies than other types of AGN. This is not only because the brightness of their accretion disk weakens the emission of gamma rays, but because they are further away. In this case, OP 313 is located at a redshift of 0.997 or ~8 billion light years away, making it the most distant AGN and the second most distant source ever detected at very high energies.

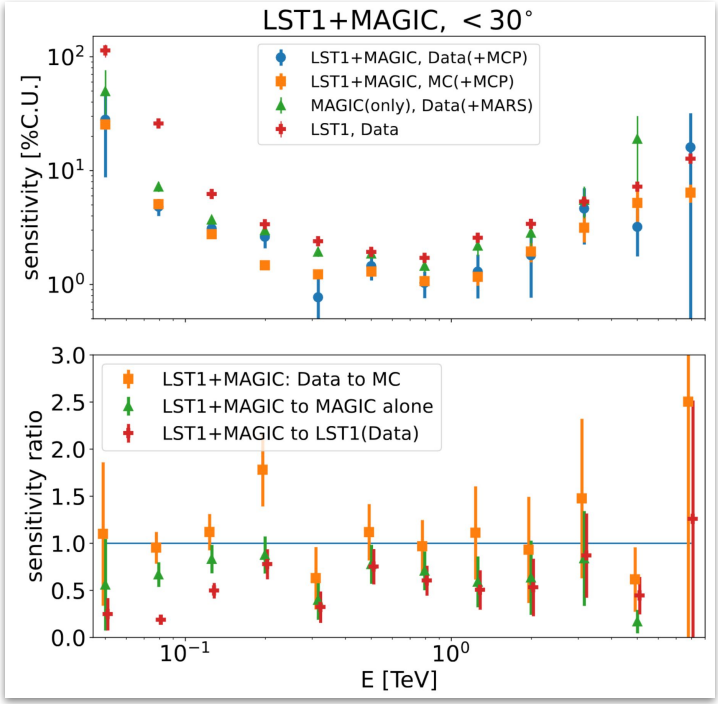
The more distant the source, the more difficult it is to observe at very high energies due to the so-called Extragalactic Background Light or EBL. The EBL is the collective light emitted by all objects outside the Milky Way that expands across multiple wavelengths, from visible, infrared and ultraviolet. The EBL interacts with very high-energy gamma rays, attenuating their flux and, thus, making their observation challenging. The characteristics of the LST-1, with an optimized sensitivity for the CTAO's low energy range, between 20 and 150 GeV, where gamma rays are less affected by the EBL, enabled the LST Collaboration to extend the study of this source to tens of GeV for the first time.

The LST Collaboration will continue to observe this source with the LST-1 to expand the dataset and, thus, obtain a more precise analysis that allows scientists to improve their understanding of the EBL, study the magnetic fields within this type of source or delve into fundamental intergalactic physics.

Expanding the gamma-ray horizon!

LST-1 + MAGIC observations





- **Separation between MAGICs and LST-1 is ~100m. A dedicated pipeline is in place to analyze stereo MAGIC & LST data**

- joint observations allow detection of 30% (40%) lower fluxes than MAGIC alone (LST-1 alone) (better background suppression)

- "Performance paper": **A&A, 680, A66 (2023)**

LST-1 Proposals

Call for LST Cycle II Mono Proposals is open:

- ❏ Internal **only** to LST (the PI needs to be an LST member)
  - 500 hours (dark time) dedicated to LST Mono observations
  - commissioning activities during this period still have priority over scientific data taking
  - Observations must be achievable with LST-1 alone
- ❏ External scientists are allowed to be included on LST proposals. Their participation should be justified in the proposal. They are allowed to analyze LST data beyond (and including) DL3. They will also be required to sign an NDA to ensure no results spread outside of LST and to satisfy the MAGIC+LST MOU which requires "that such information will be treated confidentially".
- ❏ Cycle II begins on March 23rd, 2023
- ❏ Deadline for Proposals: February 2nd, 2024

Toward the LSTs Array

- Civil works ended for LST-2, -3 & -4
- End of Installation foreseen by 2025

Conclusions

- The prototype telescope LST-1 was inaugurated at CTA Northern Array in La Palma in 2018. Telescope is now ending the commissioning phase.
- LST-1 Science program has been established, first round of preparation of (mono) observational proposals has been concluded this year.
- Despite the sensitivity of a stand-alone telescope, observations and results are coming covering a wide range of scientific targets (Galactic sources, transients, TeV Blazars...).
- The possibility to perform combined observation together with MAGIC will provide a significant improvement in the sensitivity, anticipating the scientific potential of the full-configured CTAO.

Conclusions

- 2023 was the year of first publications….many more soon to come!