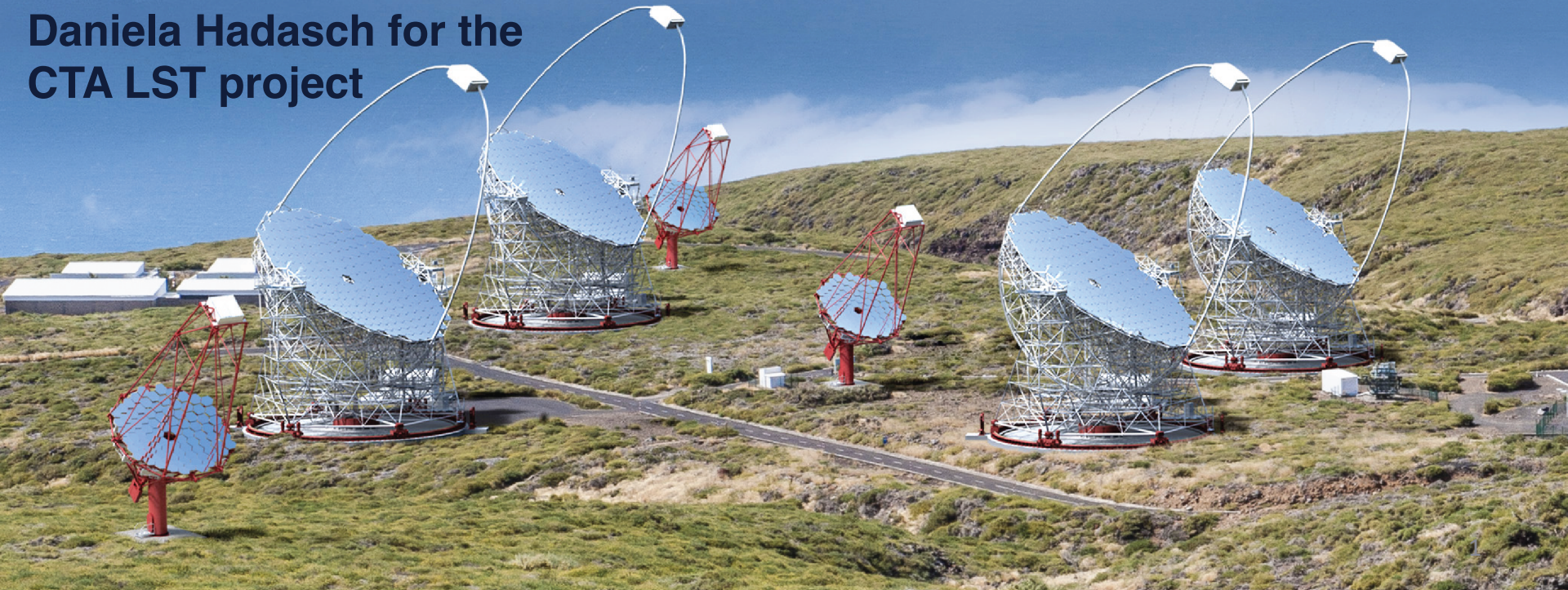
cherenkov telescope array

ICRR Institute for Cosmic Ray Research University of Tokyo

東京大学 THE UNIVERSITY OF TOKYO

Status of the CTA Large-Sized Telescopes

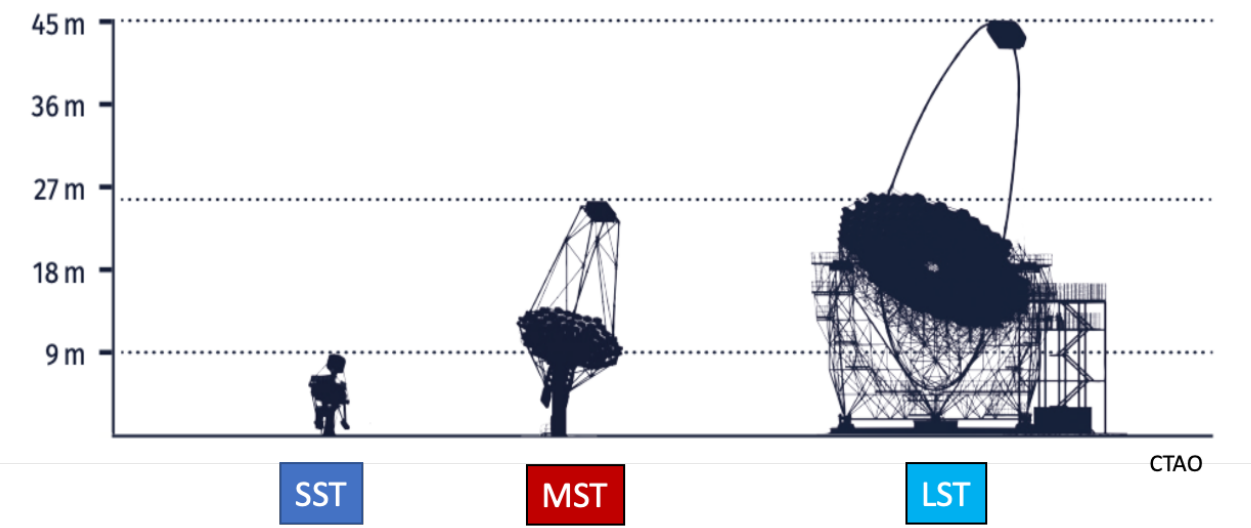
Daniela Hadasch for the
CTA LST project



Overview

- Past
  - Idea of the Cherenkov Telescope Array
- Present
  - Current telescopes & sensitivity
  - Reached physics results
- Future
  - Future telescopes
  - Expected sensitivities

The Cherenkov Telescope Array - three types of telescopes



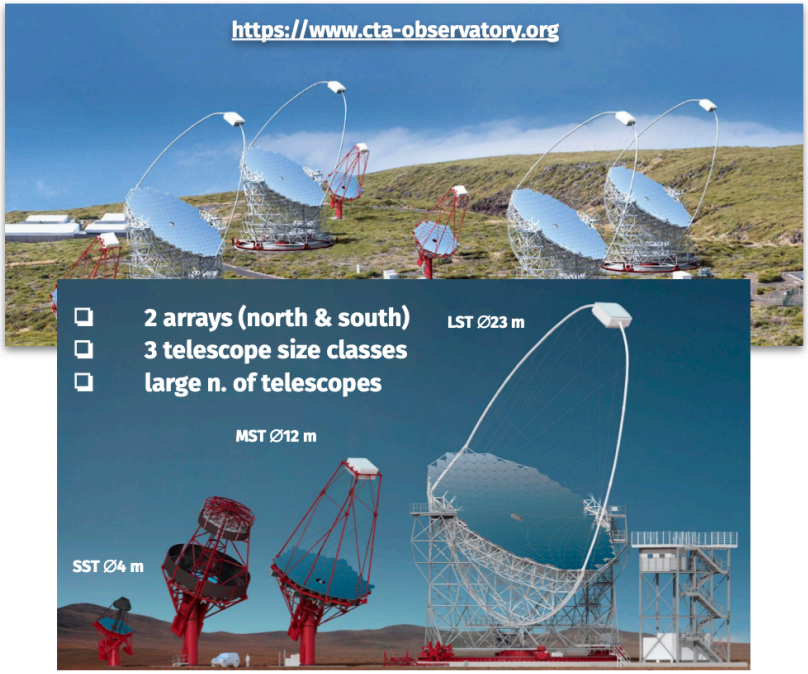
Small-Sized Telescope (SST)
Precision measurements in a still little explored energy range
100TeV range largely unexplored

Medium-Sized Telescope (MST)
Deepest sensitivity ever
Arcmin angular resolution
Large FoV
Surveys & precision studies

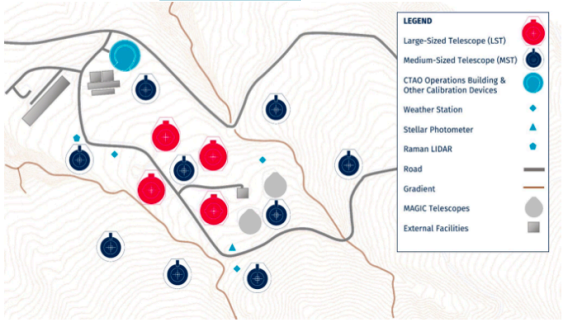
Large-Sized Telescope (LST)
Lowest energies (tens of GeV)
Cosmological sources
Deepest sensitivity for short timescales
Time domain largely unexplored

The Cherenkov Telescope Array

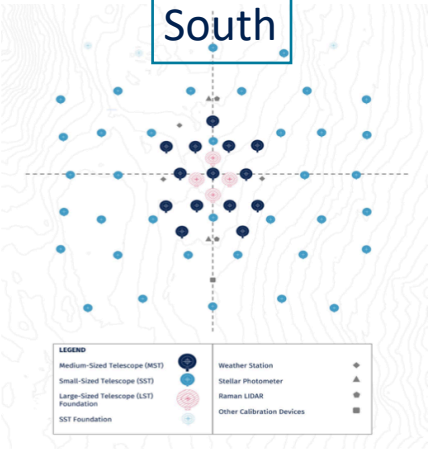
The facility for Very High Energy gamma-ray astrophysics in the next decades



North



South



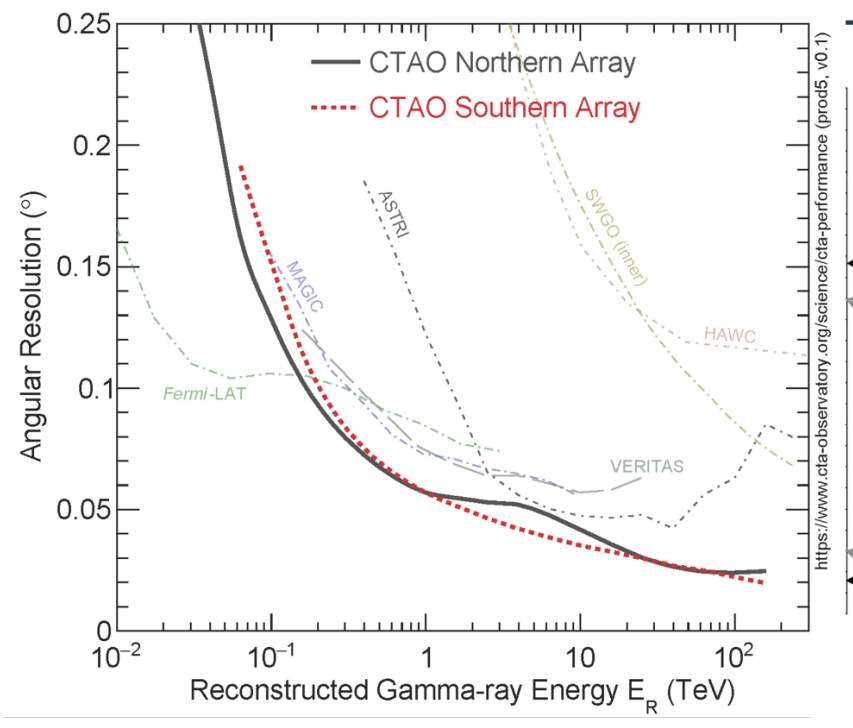
alpha configuration (first phase):

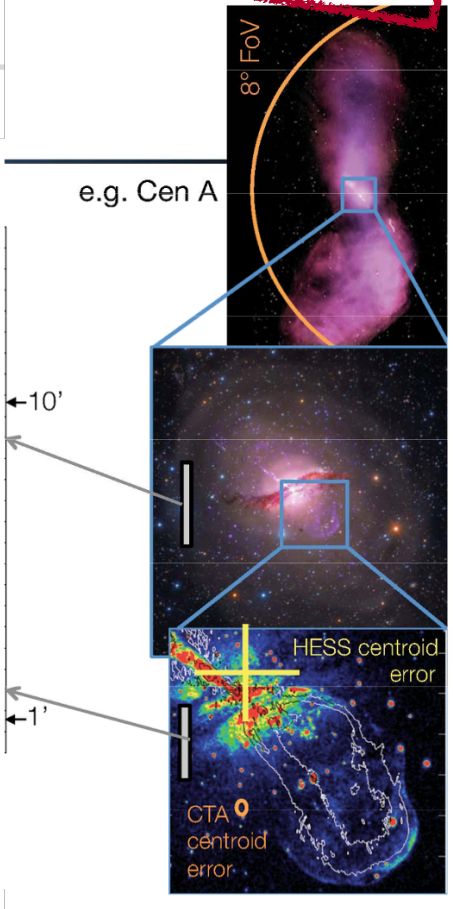
North: 4 LST + 9 MST
South: 14 MST + 37 SST

omega configuration (ultimate goal):

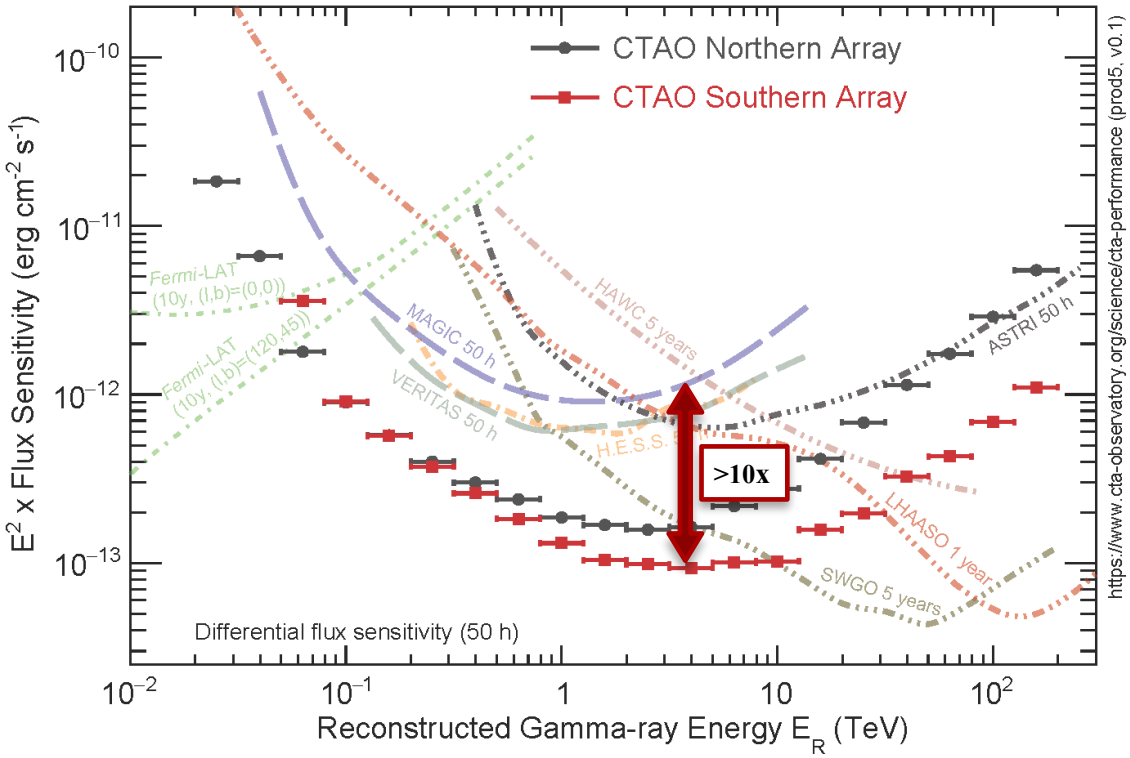
North: 4 LST + 15 MST
South: 4 LST + 25 MST + 70 SST

Angular resolution





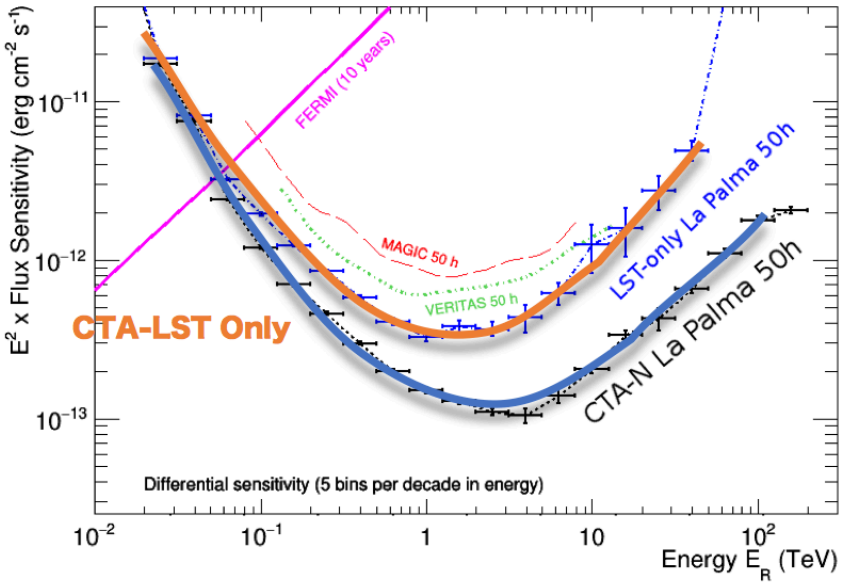
Sensitivity

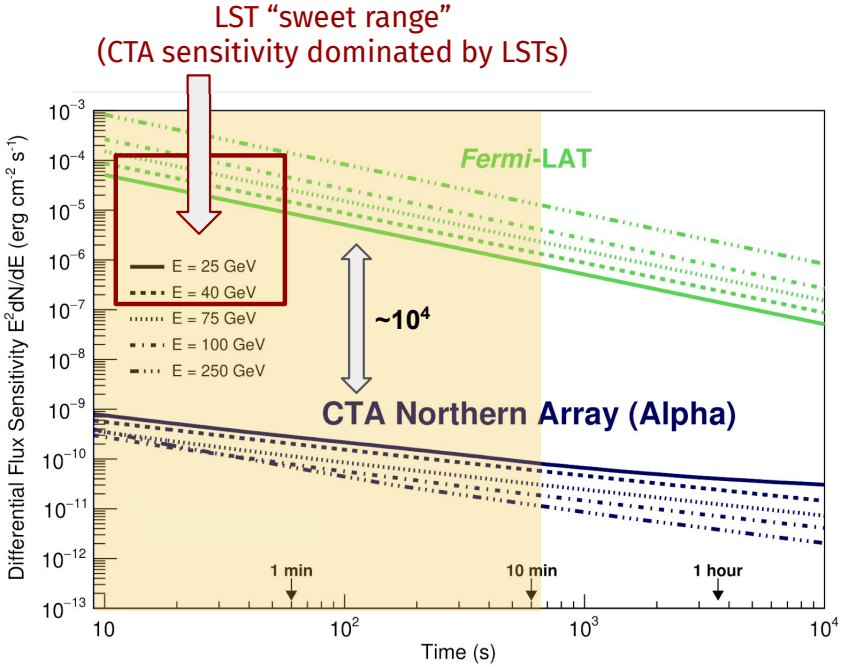


- Near full sky coverage
- Wider energy range (~20 GeV - 300 TeV)
- Higher sensitivity: 5-10x current IACTs

CTA-LSTs only

- Array of 4 LSTs already a significant improvement in sensitivity.
- Very well suited for transient studies and spectrally soft sources from the beginning on.

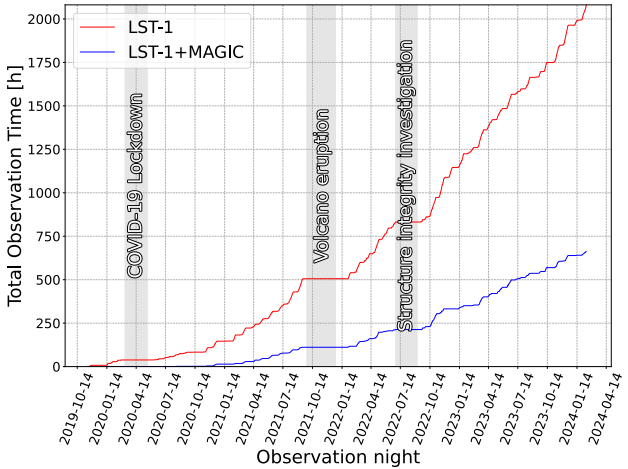


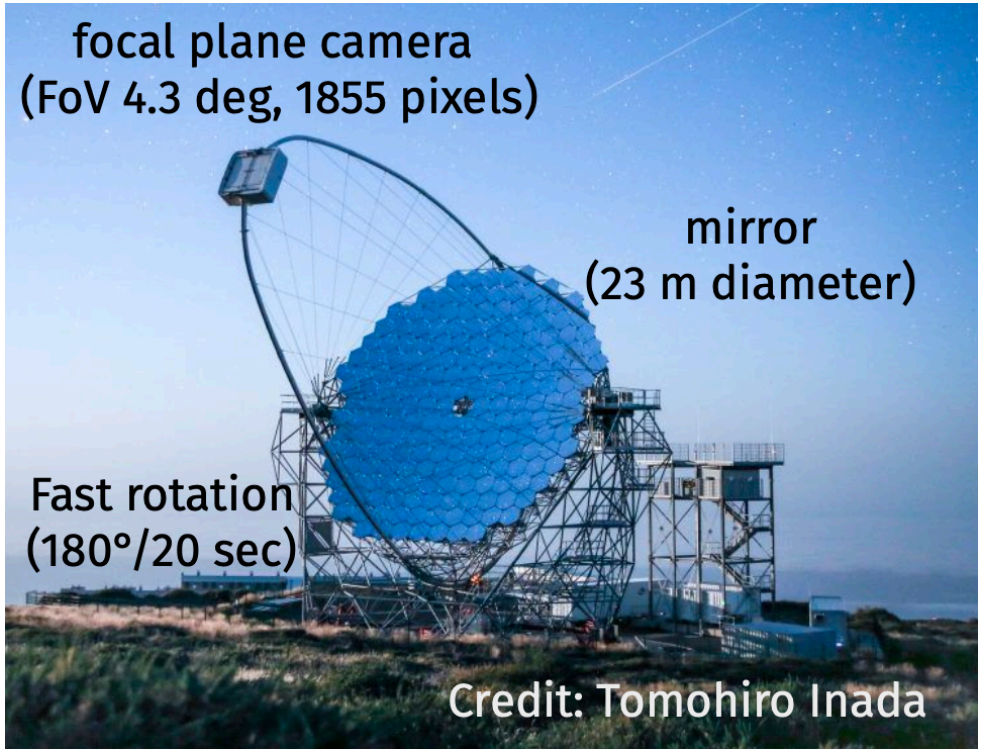


The first Large-Sized Telescope (LST-1)

Present

- LST-1 inaugurated in 2018.
- >2000 h taken from Jan. 2020 - Jan 2024.
- Low energy threshold (~20GeV)

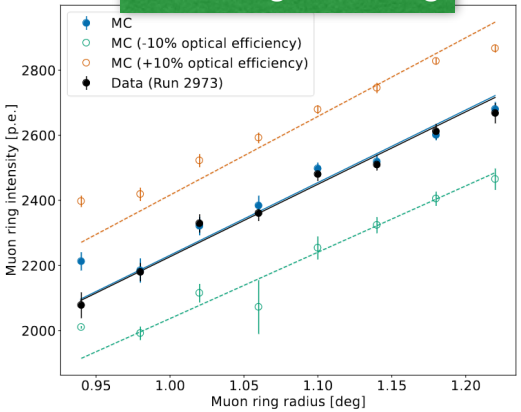




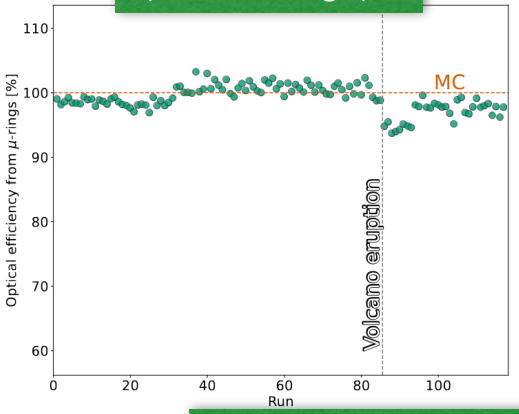
Telescope performance: Crab

Present

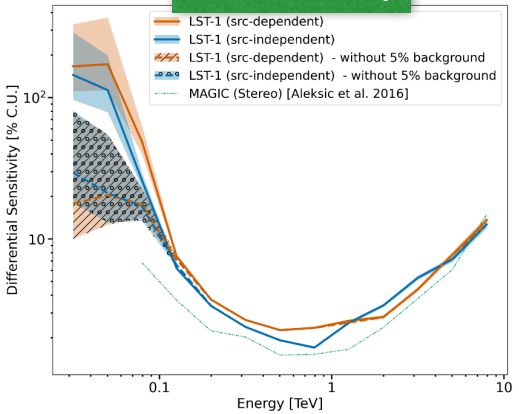
muon ring matching



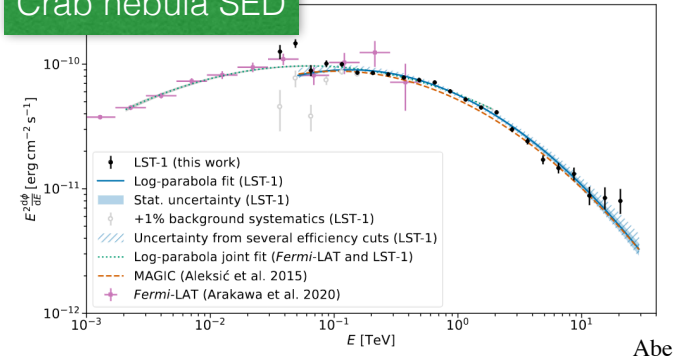
optical throughput



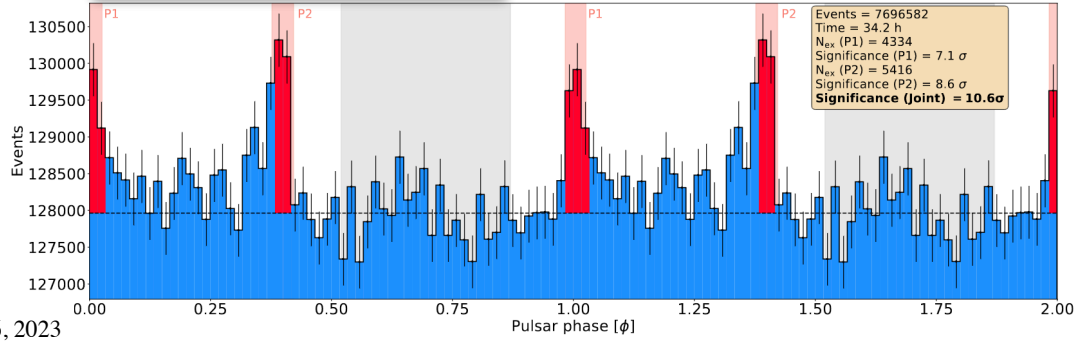
flux sensitivity



Crab nebula SED



Crab pulsar phaseogram



Abe et al., ApJ, 956, 2023

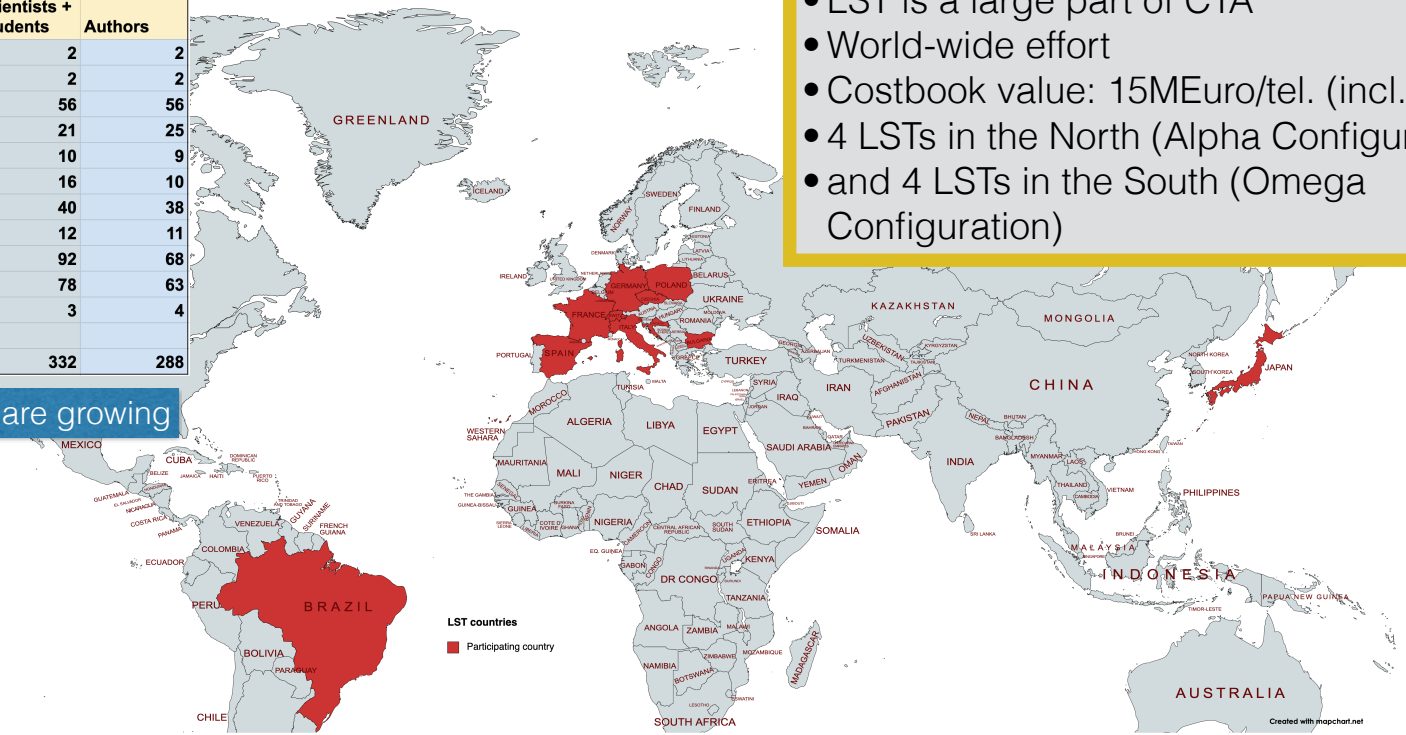
The LST collaboration

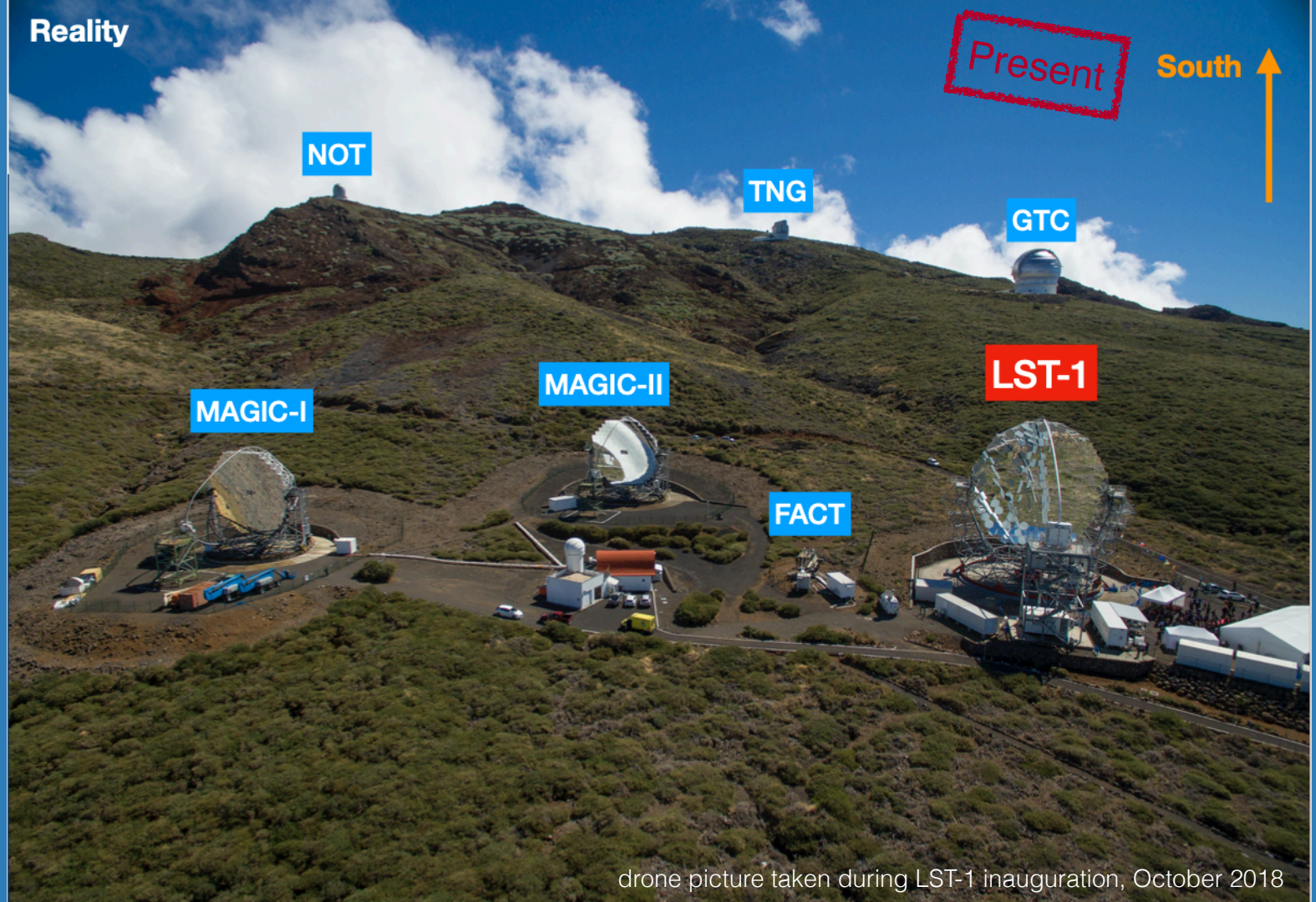
Present

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

numbers are growing

- LST is a large part of CTA
- World-wide effort
- Costbook value: 15MEuro/tel. (incl. FTE)
- 4 LSTs in the North (Alpha Configuration)
- and 4 LSTs in the South (Omega Configuration)

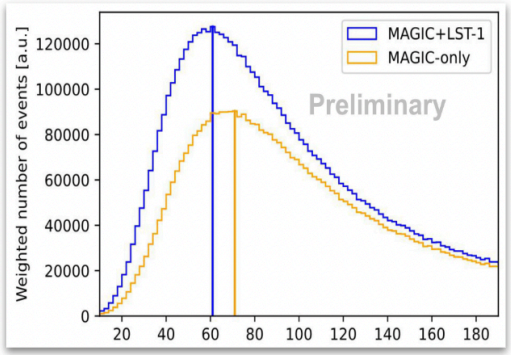


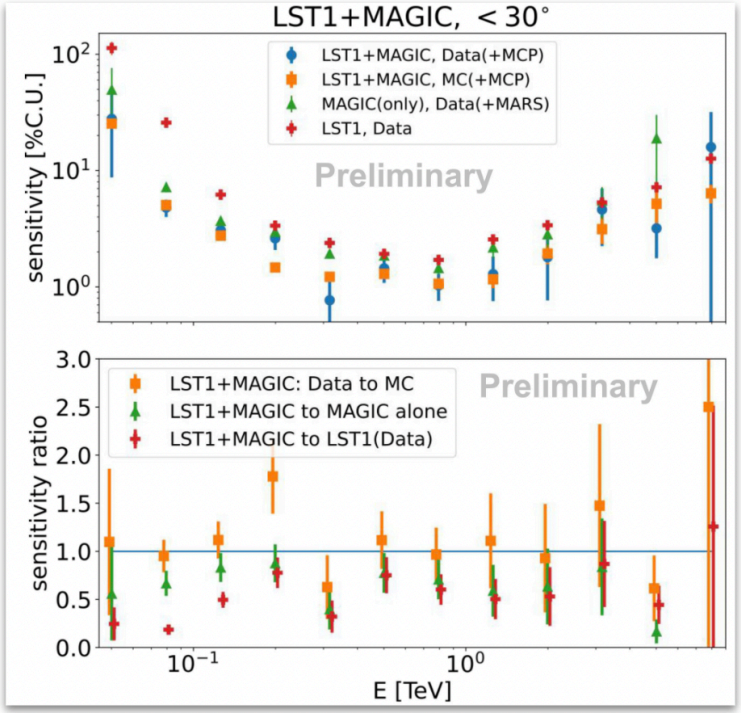


drone picture taken during LST-1 inauguration, October 2018

LST-1 + MAGIC performance

Present

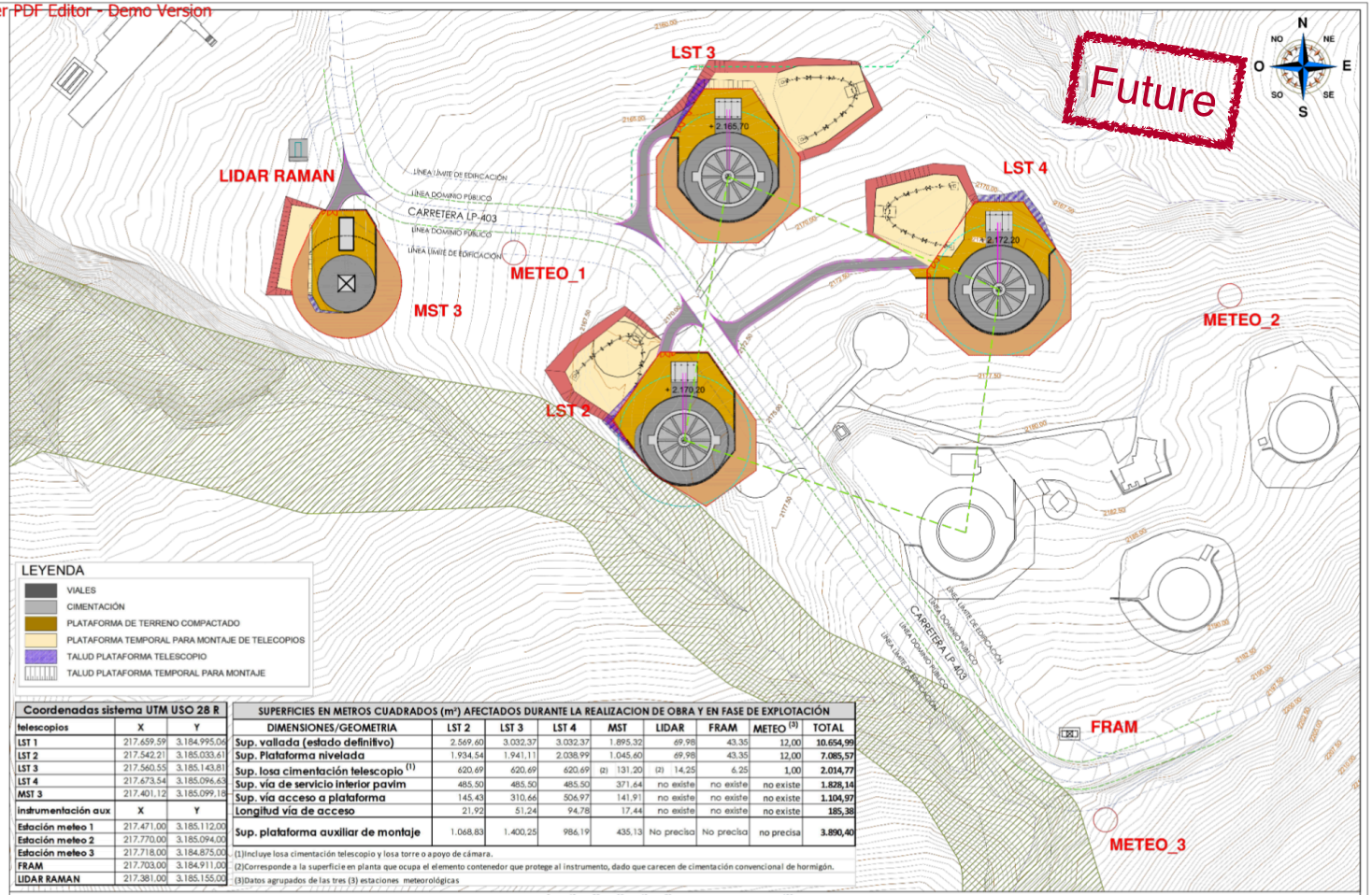




- **Separation between MAGICs and LST-1 is ~100m. A dedicated pipeline is in place to analyze stereo MAGIC & LST data**

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

A&A 680, A66 (2023)



Coordenadas sistema UTM USO 28 R

telescopios	X	Y
LST 1	217.659,59	3.184.995,06
LST 2	217.542,21	3.185.033,61
LST 3	217.560,55	3.185.143,81
LST 4	217.673,54	3.185.096,63
MST 3	217.401,12	3.185.099,18
instrumentación aux	X	Y
Estación meteo 1	217.471,00	3.185.112,00
Estación meteo 2	217.770,00	3.185.094,00
Estación meteo 3	217.718,00	3.184.875,00
FRAM	217.703,00	3.184.911,00
LIDAR RAMAN	217.381,00	3.185.155,00

SUPERFICIES EN METROS CUADRADOS (m²) AFECTADOS DURANTE LA REALIZACION DE OBRA Y EN FASE DE EXPLOTACIÓN

DIMENSIONES/GEOMETRIA	LST 2	LST 3	LST 4	MST	LIDAR	FRAM	METEO (3)	TOTAL
Sup. vallada (estado definitivo)	2.569,60	3.032,37	3.032,37	1.895,32	69,98	43,35	12,00	10.654,99
Sup. Plataforma nivelada	1.934,54	1.941,11	2.038,99	1.045,60	69,98	43,35	12,00	7.085,57
Sup. losa cimentación telescopio (1)	620,69	620,69	620,69	(2) 131,20	(2) 14,25	6,25	1,00	2.014,77
Sup. vía de servicio interior pavim	485,50	485,50	485,50	371,64	no existe	no existe	no existe	1.828,14
Sup. vía acceso a plataforma	145,43	310,66	506,97	141,91	no existe	no existe	no existe	1.104,97
Longitud vía de acceso	21,92	51,24	94,78	17,44	no existe	no existe	no existe	185,38
Sup. plataforma auxiliar de montaje	1.068,83	1.400,25	986,19	435,13	No precisa	No precisa	no precisa	3.890,40

(1)Incluye losa cimentación telescopio y losa torre o apoyo de cámara.
(2)Corresponde a la superficie en planta que ocupa el elemento contenedor que protege al instrumento, dado que carecen de cimentación convencional de hormigón.
(3)Datos agrupados de las tres (3) estaciones meteorológicas

PLANTA EMPLAZAMIENTO DE TELESCOPIOS E INSTALACIONES AUXILIARES SOBRE CARTOGRAFÍA ESCALA 1:1000

0 10 20 30 40 50 100 m

PROYECTO:
PROYECTO EJECUCIÓN
PROYECTOS DE LOS TELESCOPIOS LST-2, LST-3, LST-4 Y MST-03 E INSTRUMENTACIÓN AUXILIAR DEL CHERENKOV TELESCOPE ARRAY

Unión Europea
Fondo Europeo de desarrollo Regional
"Una manera de hacer Europa"
El presente contrato está financiado con cargo al proyecto de "Los cuatro Large Size Telescopes (LST) del CTA-Norte en el ORM" de referencia ESFRI-2017-IAC-12 del Ministerio de Ciencia, Innovación y Universidades, co-financiado en un 85% con fondos Europeos de Desarrollo Regional (FEDER) del Programa Operativo de Crecimiento Inteligente 2014-2020. El mencionado proyecto está co-financiado por el Gobierno de Canarias, a través de la Consejería de Economía, Industria, Comercio y Conocimiento.
Gobierno de Canarias
Consejería de Economía, Industria, Comercio y Conocimiento

AUTOR DEL PROYECTO: **UTE-LST**

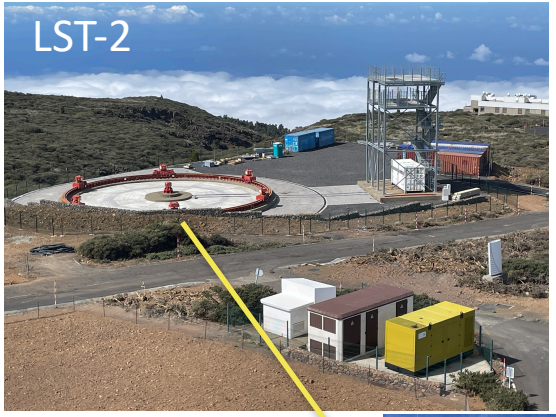
PLANO: **PLANTA EMPLAZAMIENTO DE TELESCOPIOS E INSTALACIONES AUXILIARES SOBRE CARTOGRAFÍA**

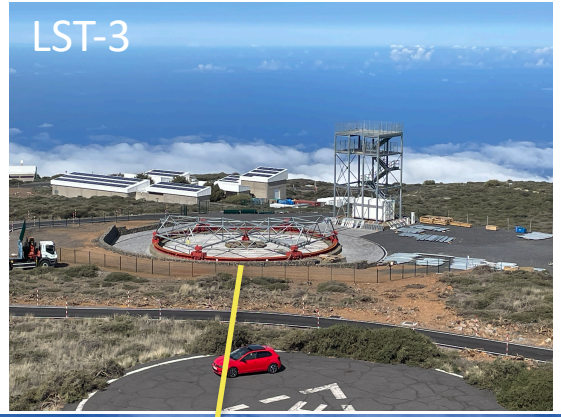
FASE	VERSIÓN	ESCALA:	FECHA:
P	1	1/1000	ABRIL 2021
R			
A			PLANO Nº:
B		CODIGO:	5
C			

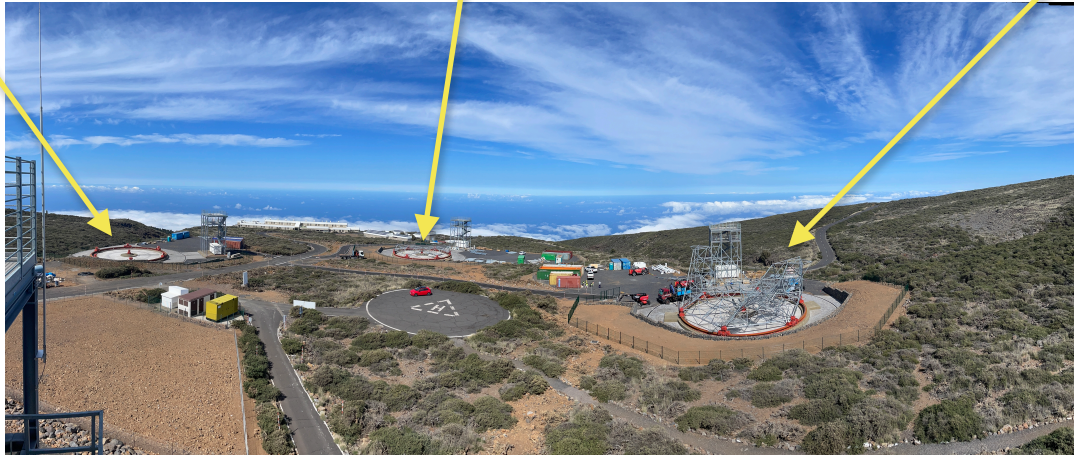
LST2-4

good progress, no significant delays

Present







Construction order:
LST-4, LST-3, LST-2

End of construction:

LST4 June 2025

LST3 August 2025

LST2 October 2025

LST-1 Science results

Present

JPL-Caltech/NASA

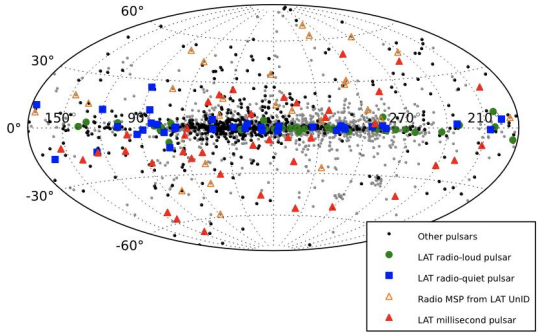
Galactic Science

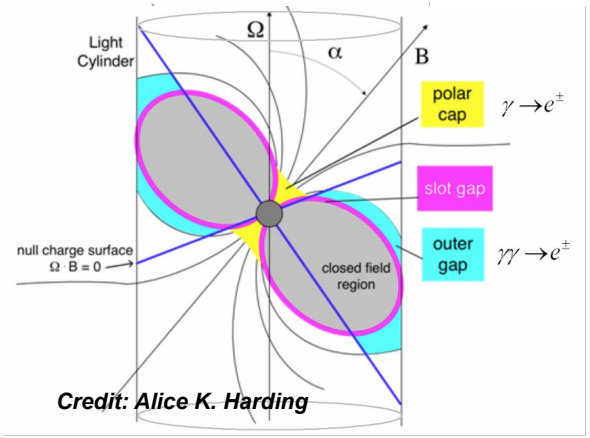
Fast slewing and low threshold makes LST-1 an ideal instrument for fast transients and spectrally soft sources.

Pulsars with the LST-1

- About 300 pulsars detected with *Fermi*-LAT, spectra displaying a characteristic PL + Exp. cutoff at a few GeV
- A few of them deviate from this Exp. cutoff and show a spectral tail extending up to 100 x GeV's and even to the TeV regime
- Three pulsars detected so far with IACTs: The Crab, Vela, Geminga.
- The origin the gamma-ray emission at VHEs in pulsars is still not clear (e.g "polar cap", "slot gap"or "outer gap" models)
- Are these systems "unique", or there is a whole TeV pulsar population to be detected?

Second Fermi Large Area Telescope catalog of gamma-ray pulsars

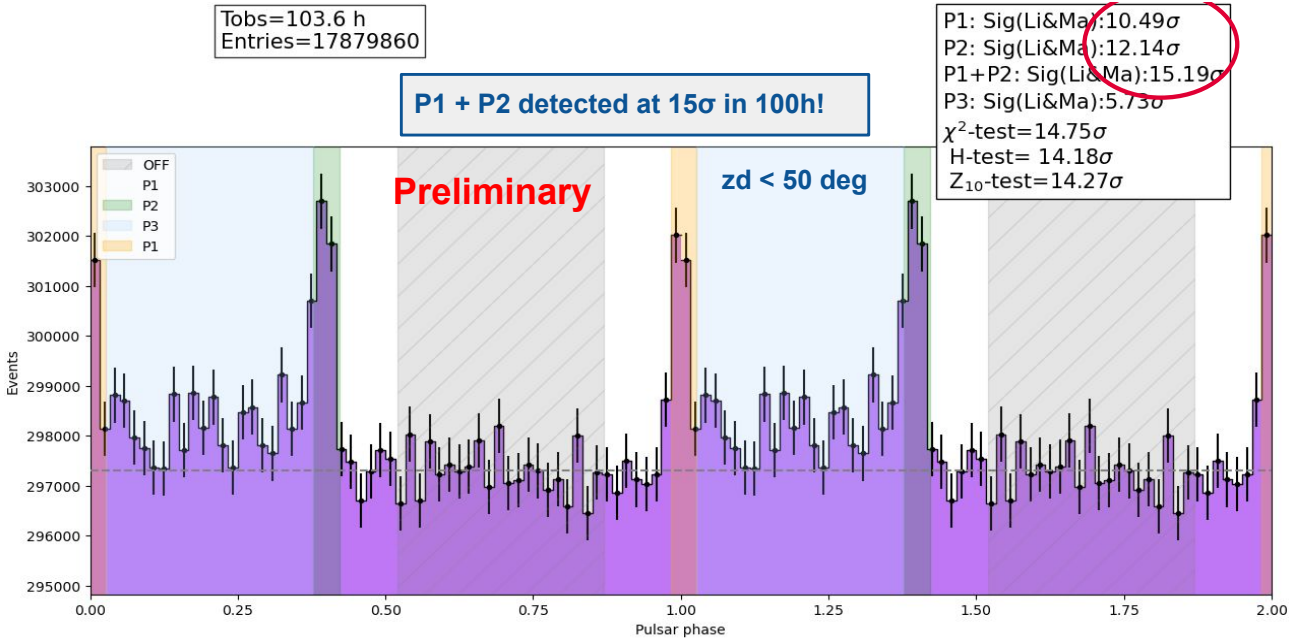




Credit: Alice K. Harding

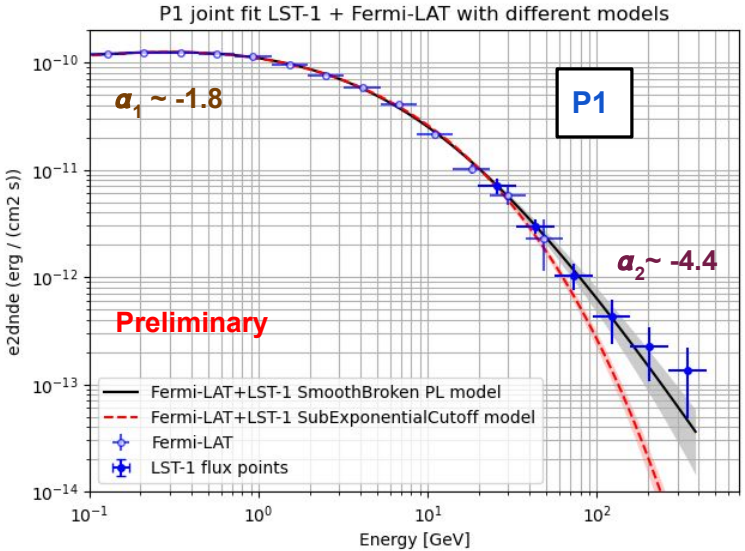
Crab pulsar phaseogram

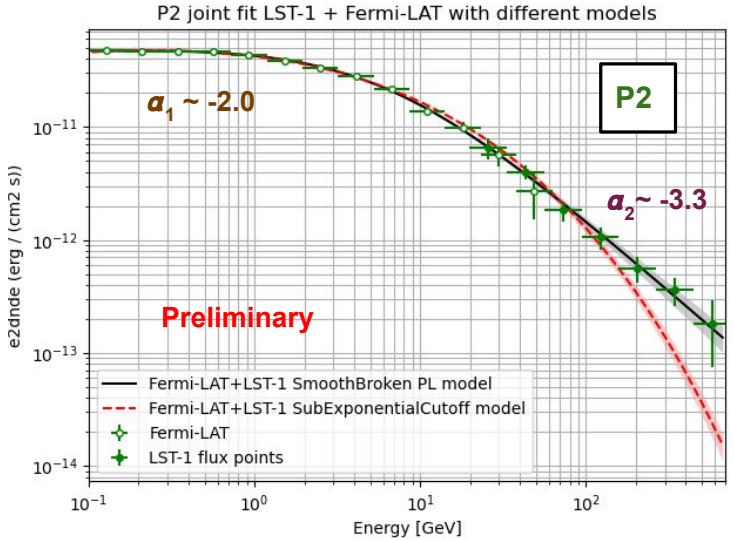
- Observed during LST-1 commissioning (Sep. 2020 - Jan. 2023)
- Time after quality cuts: ~103h for Zd < 50deg



Crab pulsar spectra

- SED shows PL up to 450 GeV for P1 & 700 GeV for P2 (Confirms MAGIC results > 500 GeV)
- Syst. uncertainties in spectral indices: ~10% and ~5% for P1 and P2.
- Dedicated LAT analysis (13 yrs) ⇒ smooth transition with LST-1
- Joint fit: preference for a smooth Broken PowerLaw model ⇒ PowerLaw extension at VHEs





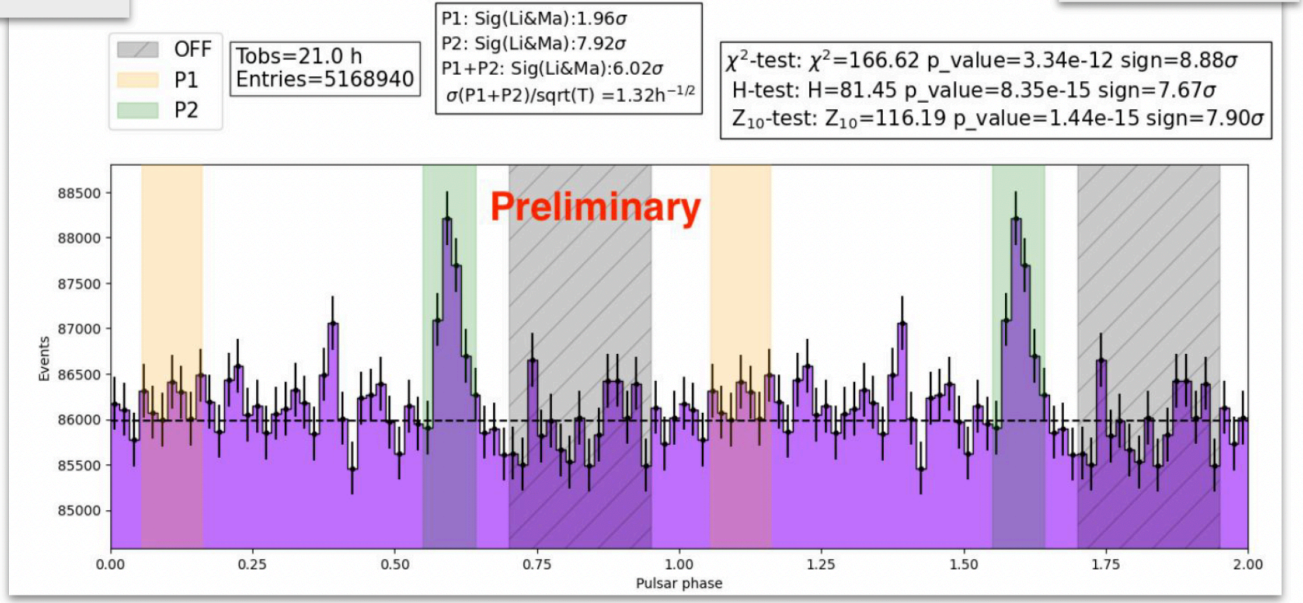
Pulsar: Geminga (PSR J0633+1746)

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

Detected at ~8σ in ~21h

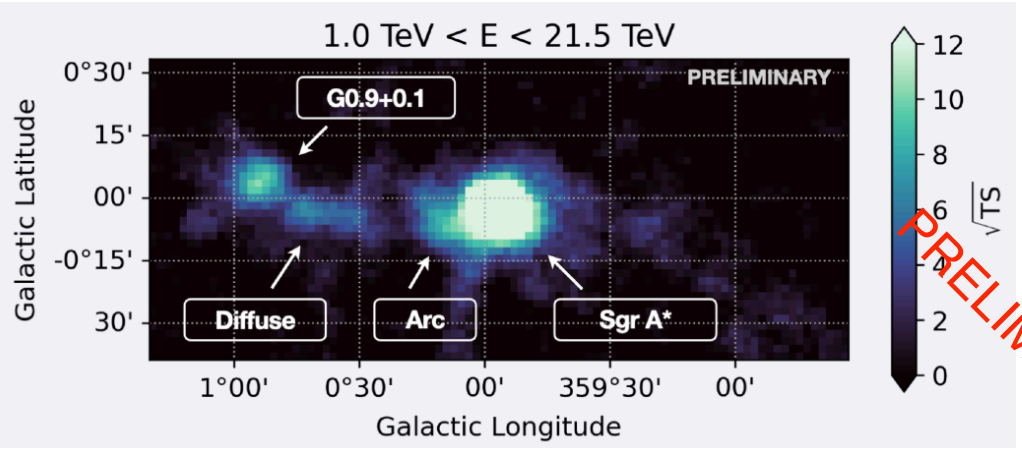
- Being a soft spectrum source, the detection of Geminga confirms the good performance in the 15-30 GeV band, one of the main scientific drivers of LST
- MAGIC: 6.3σ after 80 hours for P2
  (MAGIC coll., A&A 643 (2020) L14)

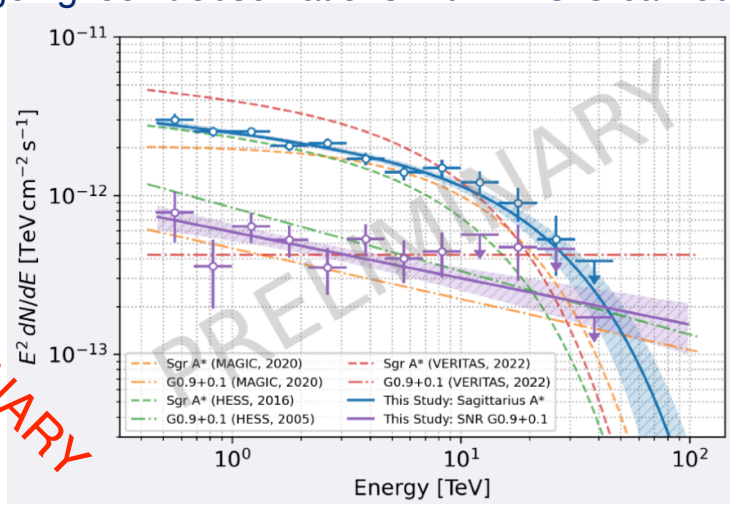
PoS ICRC2023 (2023) 569



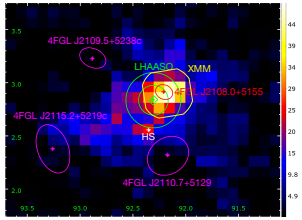
PeVatron candidate: Galactic center

- LST-1 has observed the Galactic Center, the first proposed Galactic PeVatron (H.E.S.S. Collaboration 2016)
- LST-1 observations at Large Zenith Angles (LZA) in 2021 - 2023, for a total of about 40h.
- Standard analysis software lstchain + dedicated (in development) background modelling
- Sgr A* & SNR G0.9+0.1: SEDs in line with current-generation telescopes —> LZA & 3D analysis feasible.
- More advanced analysis, including the diffuse emission, is ongoing. Joint observations with MAGIC carried out.

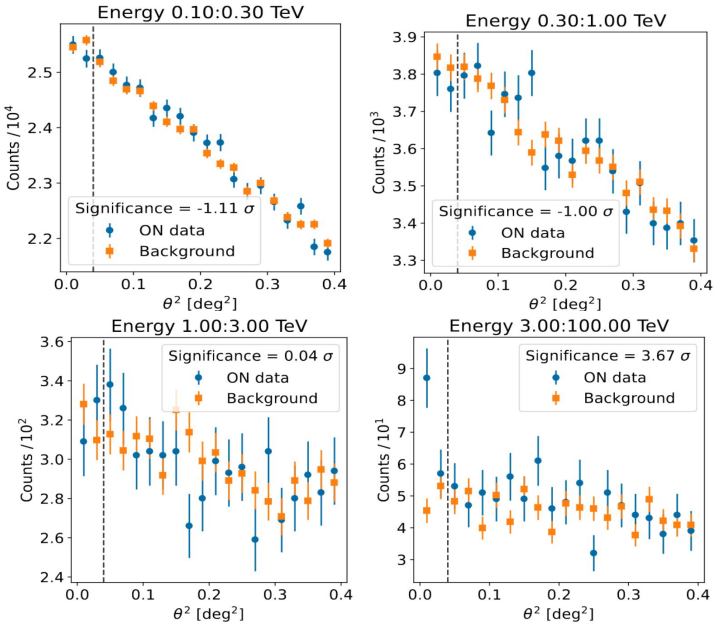




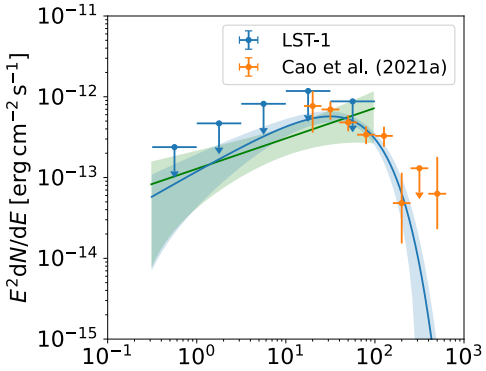
PeVatron LHAASO J2108+5157



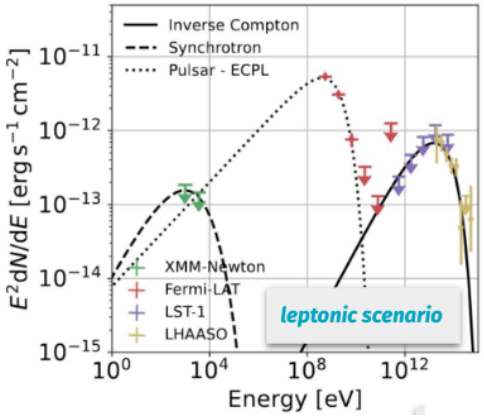
- LHAASO J2108 is one of the first 12 UHE (E > 100 TeV) sources detected by LHAASO, and the only one without any associated counterpart at TeVs.
- LST-1 data set: 91h taken from June to Sept. 2022 => 50h after quality cuts selection
- Dedicated *Fermi*-LAT and XMM-*Newton* analysis
- LST-1 analysis yields a hint for an excess (3.7σ) at E > 3 TeV.
- First scientific publication by the LST-1 Collaboration (Abe et al. 2023)

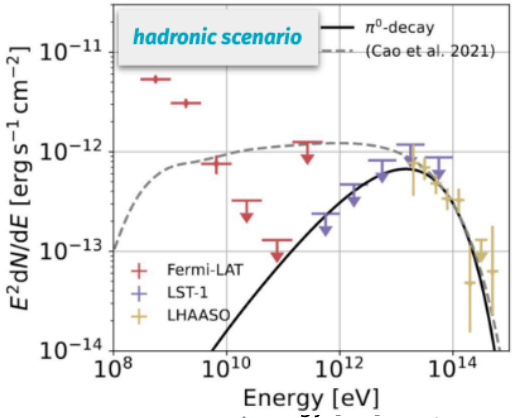


PeVatron LHAASO J2108+5157



- Both leptonic (IC) and hadronic (pp interactions in nearby Molecular Clouds) considered
- The LST-1 and LHAASO observations can be explained as IC emission by relativistic electrons with a cutoff energy of 100^{+70} TeV.
- The low magnetic field in the source imposed by the X-ray upper limits on synchrotron emission is compatible with PWN / TeV halo, but no pulsar detected.



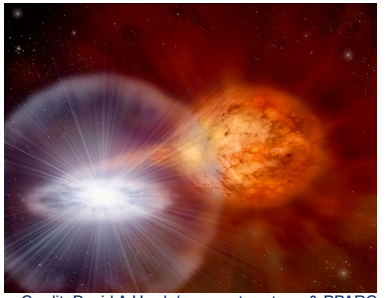


- UHE emission and LST hint of hard spectrum could work in a hadronic scenario (protons from middle-aged SNR + MC interaction), but then the HE counterpart may not be related?

Abe et al. (CTA-LST collaboration) 2023

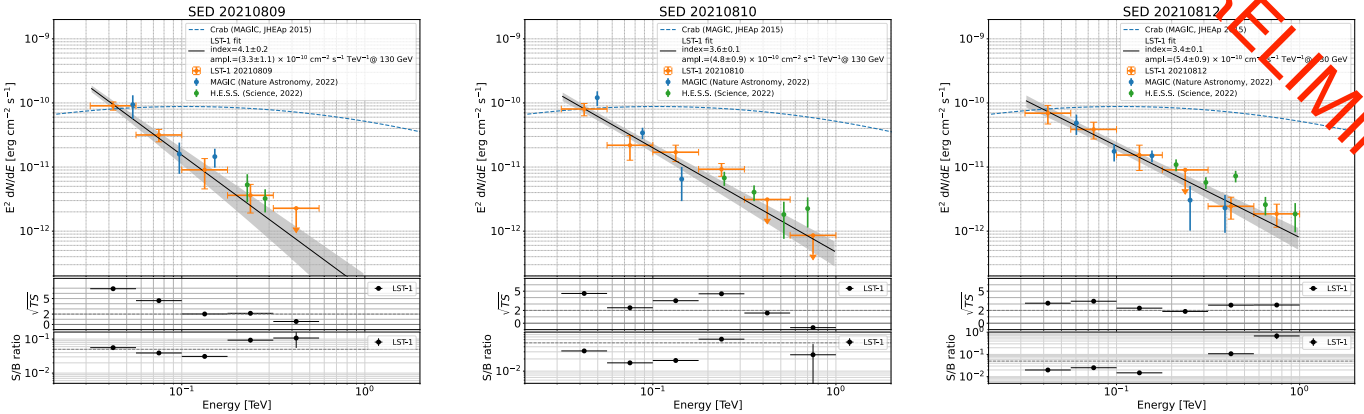
Nova: RS Ophiuchi

- RS Oph: symbiotic binary of white dwarf + red giant star. d~2.45 kpc
- Recurrent nova outbursts every ~15 yrs
- August 2021: first nova ever detected at VHE gamma-rays (MAGIC, H.E.S.S.)
- LST-1 also observed and detected RS Ophiuchi
- t_obs = 6.5h accumulated in the first 3 nights of the outburst
- 12 σ detection for the 3 nights combined, 6 - 8 σ each night



Credit: David A.Hardy/ www.astroart.org & PPARC.

SEDs consistent with MAGIC and H.E.S.S

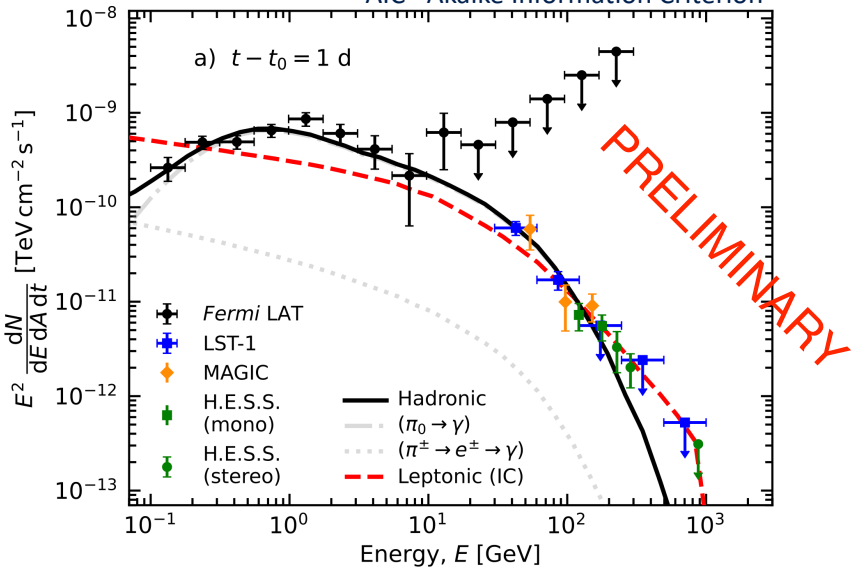


PRELIMINARY

Nova: RS Ophiuchi

- Gamma-ray emission modelled in an hadronic and a leptonic scenario
- retrieve spectra of injected particles (using LST-1, MAGIC, H.E.S.S. and LAT)
- hadronic model preferred ($AIC_{had} = 95.6$, $AIC\_{lep} = 128.8$)

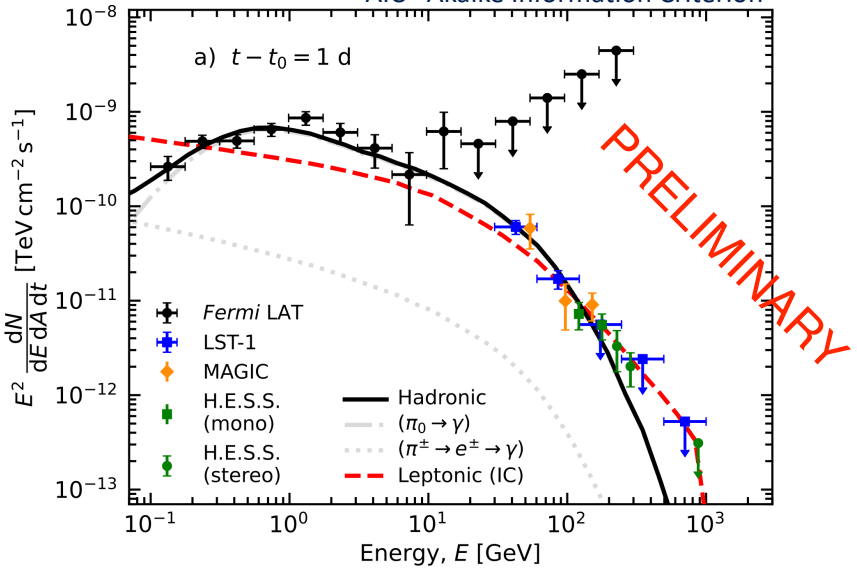
AIC =Akaike Information Criterion



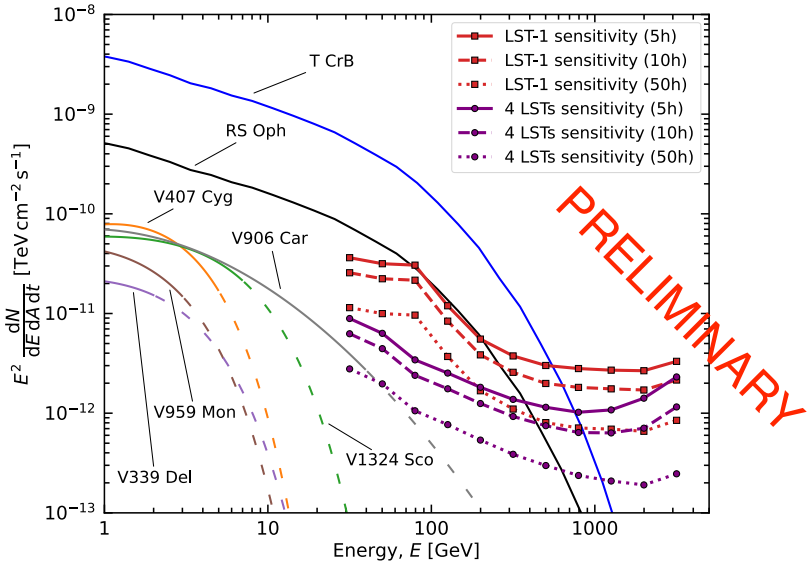
Nova: RS Ophiuchi and follow-ups

- Gamma-ray emission modelled in an hadronic and a leptonic scenario
- retrieve spectra of injected particles (using LST-1, MAGIC, H.E.S.S. and LAT)
- hadronic model preferred ($AIC_{had} = 95.6$, $AIC\_{lep} = 128.8$)

AIC =Akaike Information Criterion

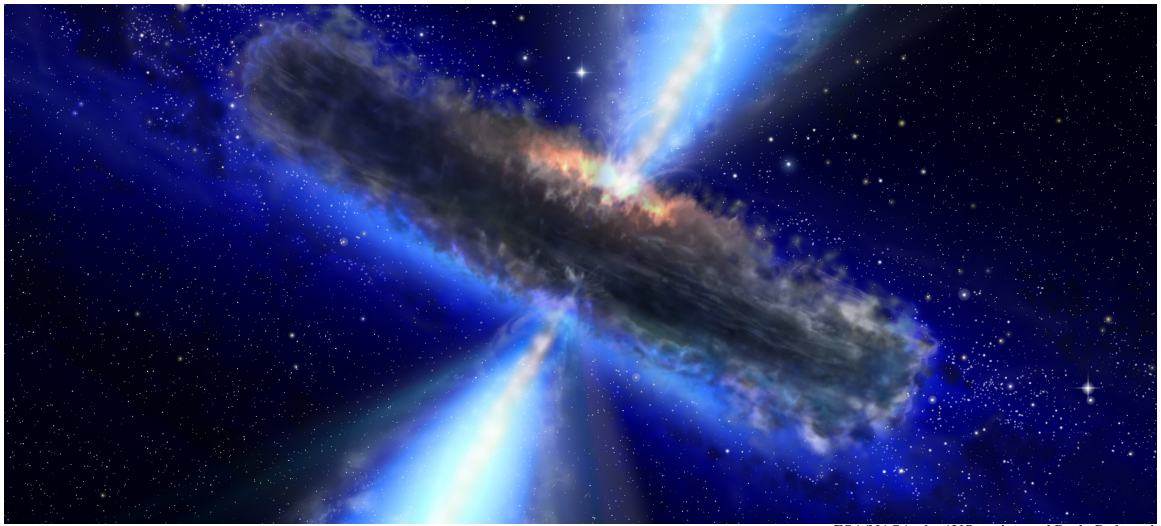


- Can LST-1 (or the full LST array) detect more novae (T CrB, classical novae)?
- very different γ-ray emission among different systems
- LST sensitivities computed using either classical (LAT) or RS Oph spectra



LST-1 Science results

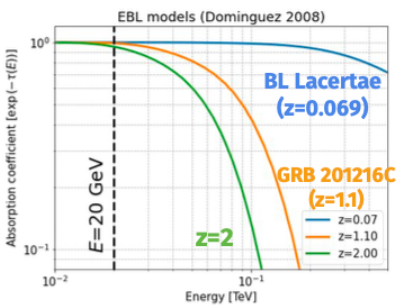
Present



ESA/NASA, the AVO project and Paolo Padovani

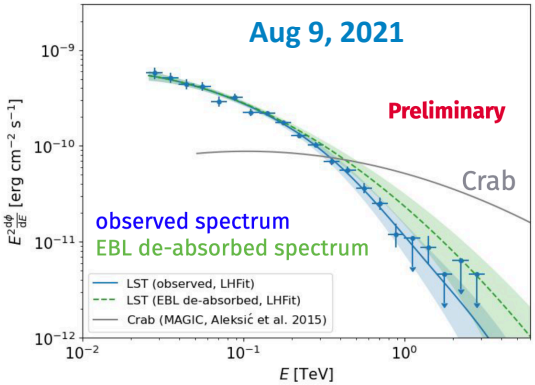
Extra-Galactic Science

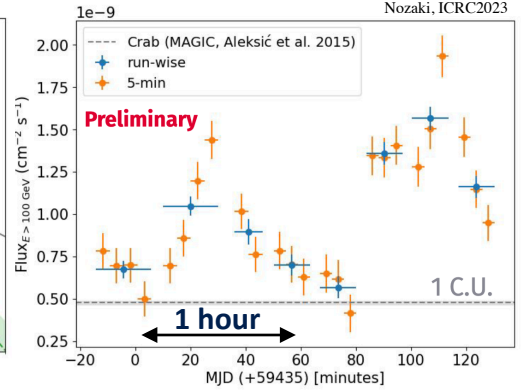
Low energy threshold (~20GeV) suited for extragalactic observations because gamma rays are less absorbed by extragalactic background light (EBL).

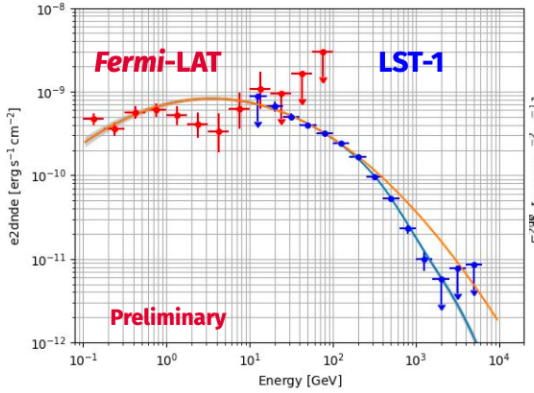


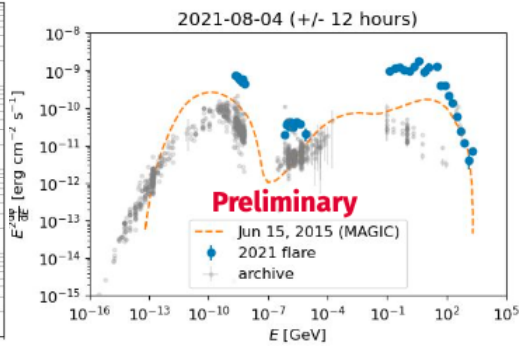
BL Lac flare

- Intermediate-synchrotorn-peak BL Lac type object
- Redshift z = 0.069
- VHE gamma-ray emission only during high states
- Multiple gamma-ray flare periods since 2020
- LST observed flare of BL Lac: 17.6h in July-Aug 2021
- Significant intra-night flux variability (>100 GeV) on Aug 9
  - 3-4 Crab Unit (C.U.) at the peak
- Fast variability time scale indicates a small size of emission region
  - $R < ct_{var}\ \delta \sim 10^{15}$cm
- Joint binned likelihood analysis using *Fermi*-LAT and LST-1 data
  - Smooth connection between Fermi-LAT and LST-1 spectrum
- Modeling & interpretation using multi-wavelength data is ongoing





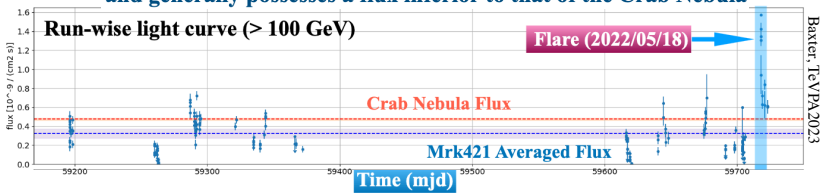




AGN Zoo: Monitoring Active Galactic Nuclei

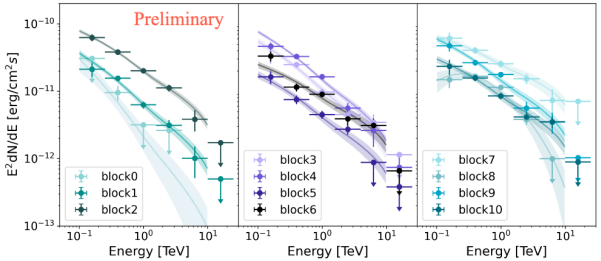
Mrk421, Mrk501, 1ES 1959+650, 1ES 0647+250, PG 1553+113, BL Lac

Mrk421: exhibits low flux variability and generally possesses a flux inferior to that of the Crab Nebula

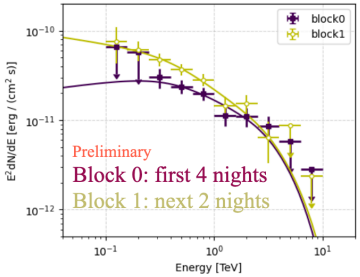


Source	Observation date	Redshift	Observation time before/after cut (h)	Detection significance (σ)
Mrk 421	2020 Dec. 12 - 2022 May 23	0.031	68.5 / 31.9	31
Mrk 501	2020 July 10 - 2022 June 29	0.034	67.2 / 39.7	21
1ES 1959+650	2020 July 11 - 2022 May 5	0.048	21.3 / 11.8	12
1ES 0647+250	2020 Dec. 16 - 2020 Dec. 21	0.45±0.05	8,8 / 8.2	7
PG 1553+113	2021 Apr. 8 - 2022 May 23	0.433	12.2 / 9.9	16

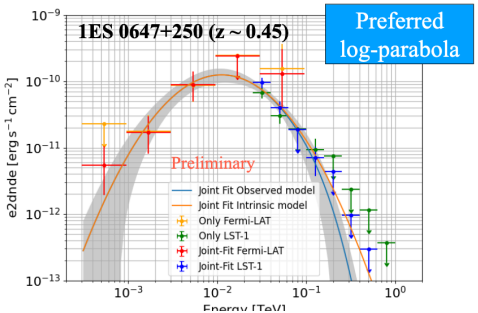
Mrk501: Tracked temporal evolution of a spectrum consisting of 11 blocks via the Bayesian block algorithm

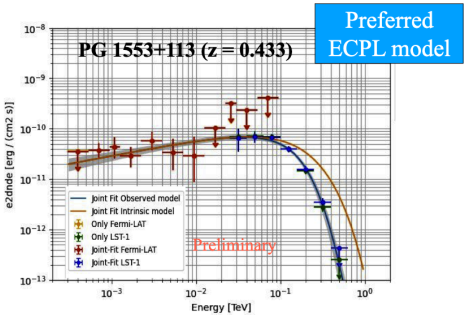


1ES1959: 4 blocks, fitted by ECPL + EBL absorption



Distant VHE sources ES 0647+250 and PG 1553+113: Effectively reconstructed a spectrum that seamlessly connects with the Fermi-LAT observational data from the corresponding time period





- **Exceptional flares with intra-night variability**
- **Spectral variation over time**
- **Spectra reconstructed down to a few tens of GeV**

Flat spectrum radio quasar: OP313

- Flat spectrum radio quasars (FSRQs): most powerful sources.
  - Strong flux variability, but the flare mechanism is still unresolved.
  - Only nine detected so far at very-high energies, likely due to internal absorption of VHE gamma-ray photons within the source.
- OP313: high redshift z=0.997 (furthest blazar ever)—> gamma-ray absorption by EBL —> challenging for the sensitivity of current-generation Cherenkov telescopes
  - **First detection at VHE with the LST-1 in December 2023 (ATel #16381).**
- This detection confirms outstanding sensitivity of LST-1 and capability to perform exciting physics results!

LST-1 Science results

Present

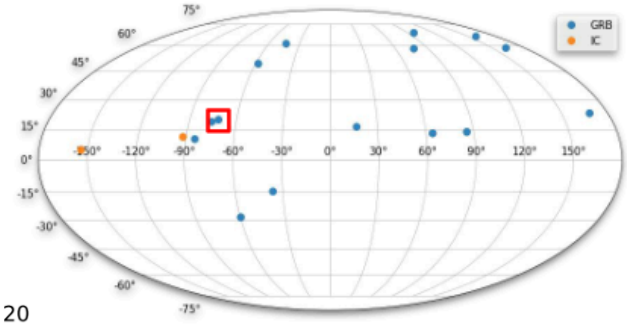
NASA/ESA

Transients

Fast slewing and low threshold of LST-1 suitable for observations of transient sources from the beginning on.

GRB 221009A

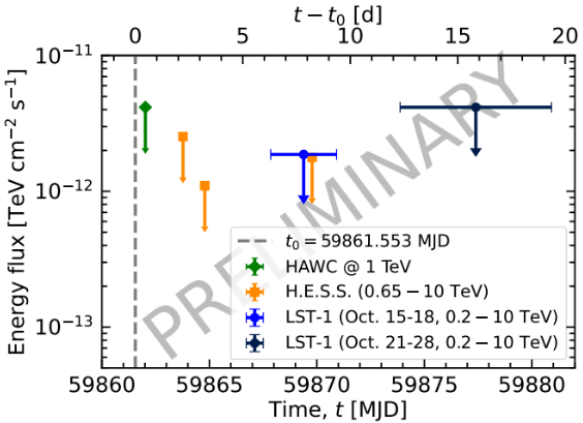
- **Low energy threshold is of primary importance also for transient observations (EBL absorption). First regular follow-up started at the end 2020/beginning of 2021 :**
  - Several events observed so far (GRB, Nu and GW during O4)
  - dedicated automatic procedure has been implemented and is being optimized
  - Initial science already possible (hopefully not for long, with ULs…)
  - **Super-powerful GRB: E_{iso} ~ 2x10^{54} erg** @ z = 0.151
  - Detected at ~100 GeV but not with IACT

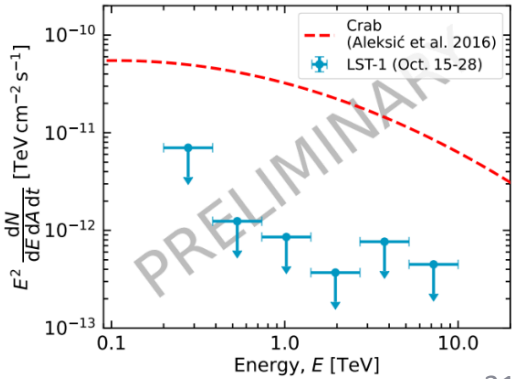


LST (first) observation (telescope operated from remote!):

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

Optimization of analysis ongoing





Summary: LST-1 & Early science

- Present: LST-1 shows high science performance.
  - We are doing high quality Galactic and Extra-galactic science with one telescope!
- Near Future: LST2-4 will provide even better sensitivity —> new exciting scientific results to be expected in 2025!
- Future: Full Cherenkov Telescope Array will be the most sensitive observatory ever at VHEs!

Summary: LST-1 & Early science

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- Future: Full Cherenkov Telescope Array will be the most sensitive observatory ever at VHEs!

The future is bright,
but the present is already shiny!

Thank you!


The
LST collaboration
LST General Meeting, Munich
5 min
2 min