

First Science Results from the LST prototype for CTA

CTA LST Collaboration

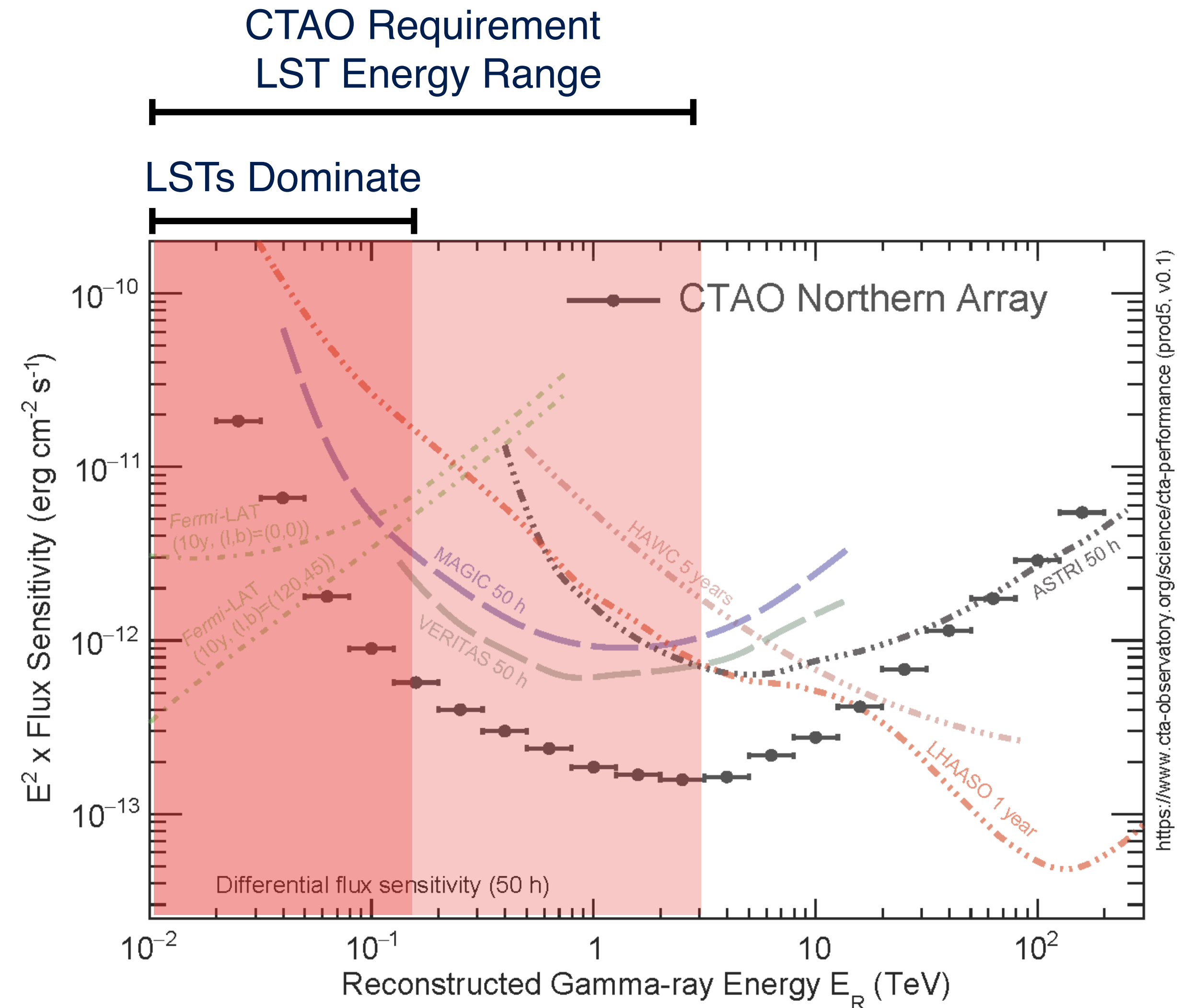
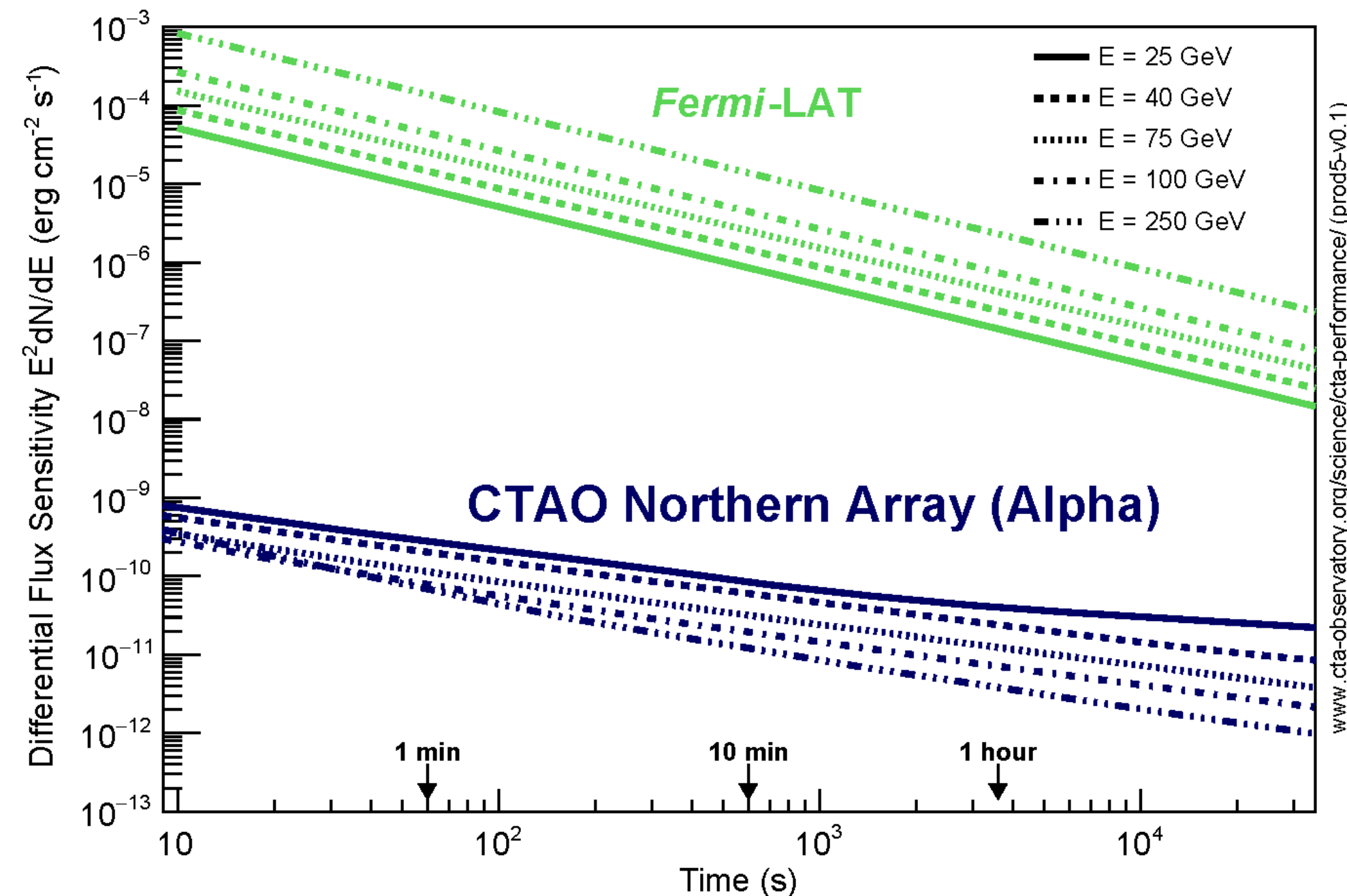


- The CTA LST Collaboration consists of 250+ scientists from 12 countries
- Learn more at : <https://www.cta-observatory.org/project/technology/lst/>
- Learn more at : <https://www.lst1.iac.es/collaboration.html>



Performance of the CTAO Northern Array

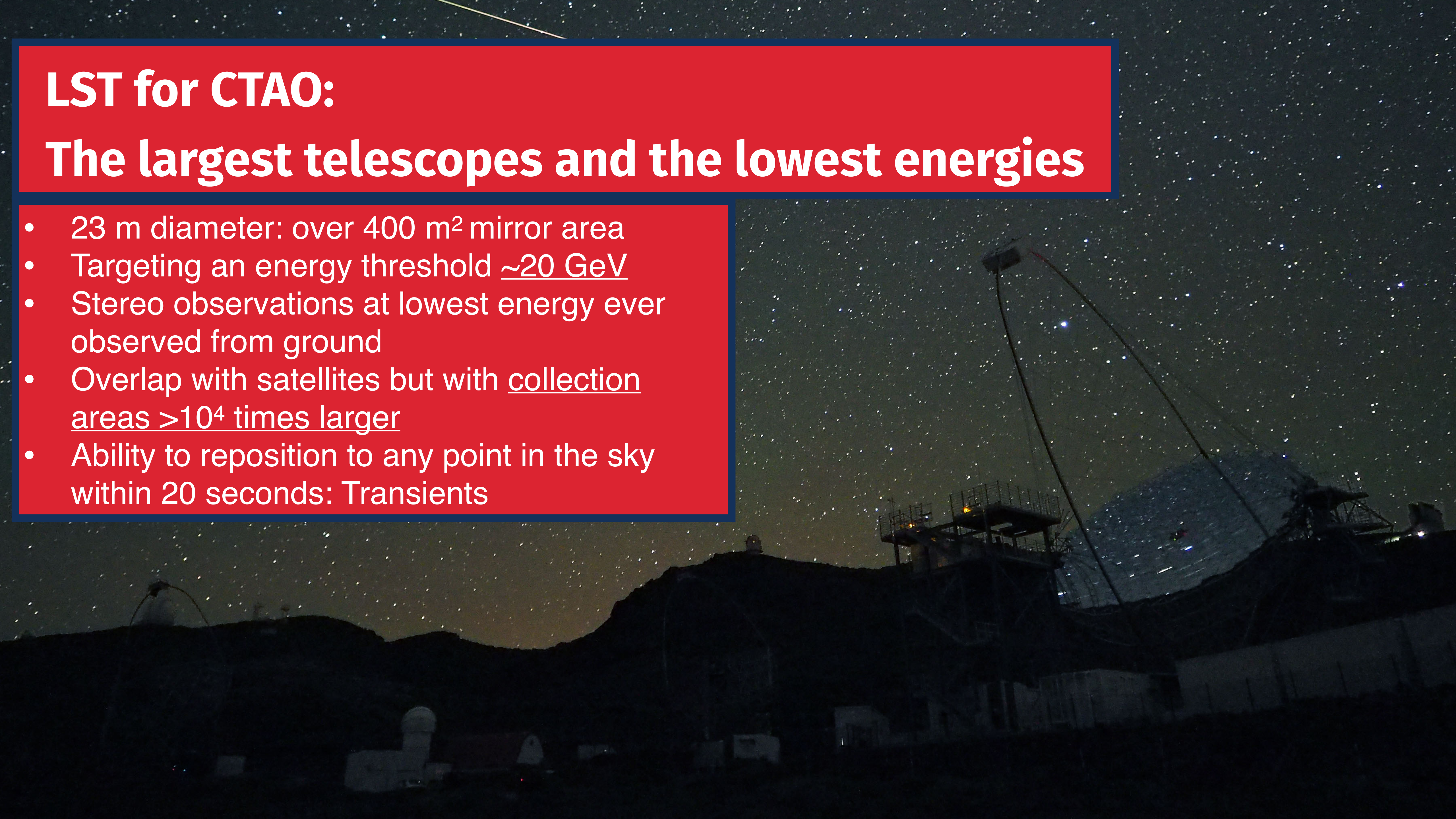
- LSTs dominate CTAO sensitivity below 150 GeV
- Ideal for fast transients and soft sources



LST for CTAO:

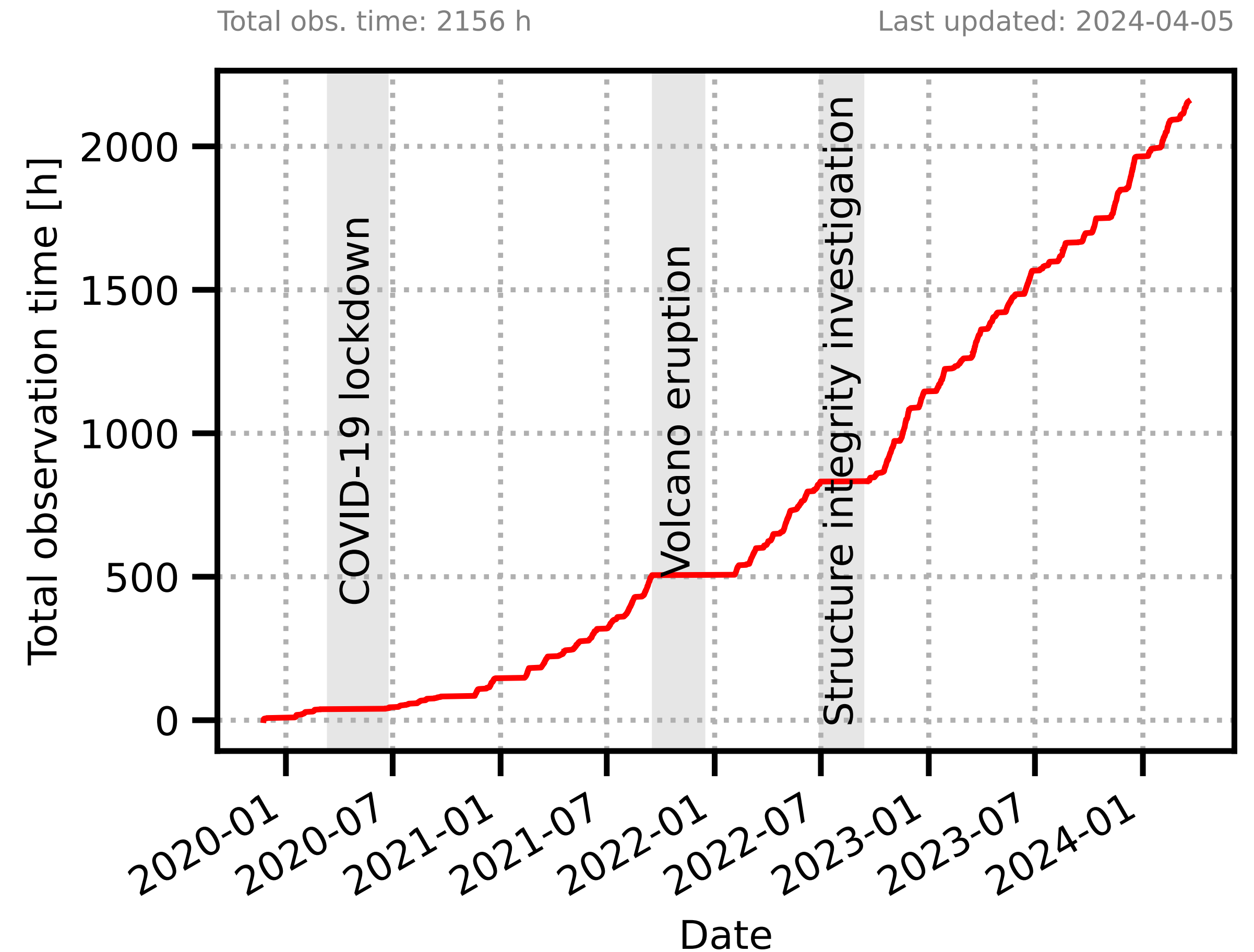
The largest telescopes and the lowest energies

- 23 m diameter: over 400 m² mirror area
- Targeting an energy threshold ~20 GeV
- Stereo observations at lowest energy ever observed from ground
- Overlap with satellites but with collection areas >10⁴ times larger
- Ability to reposition to any point in the sky within 20 seconds: Transients



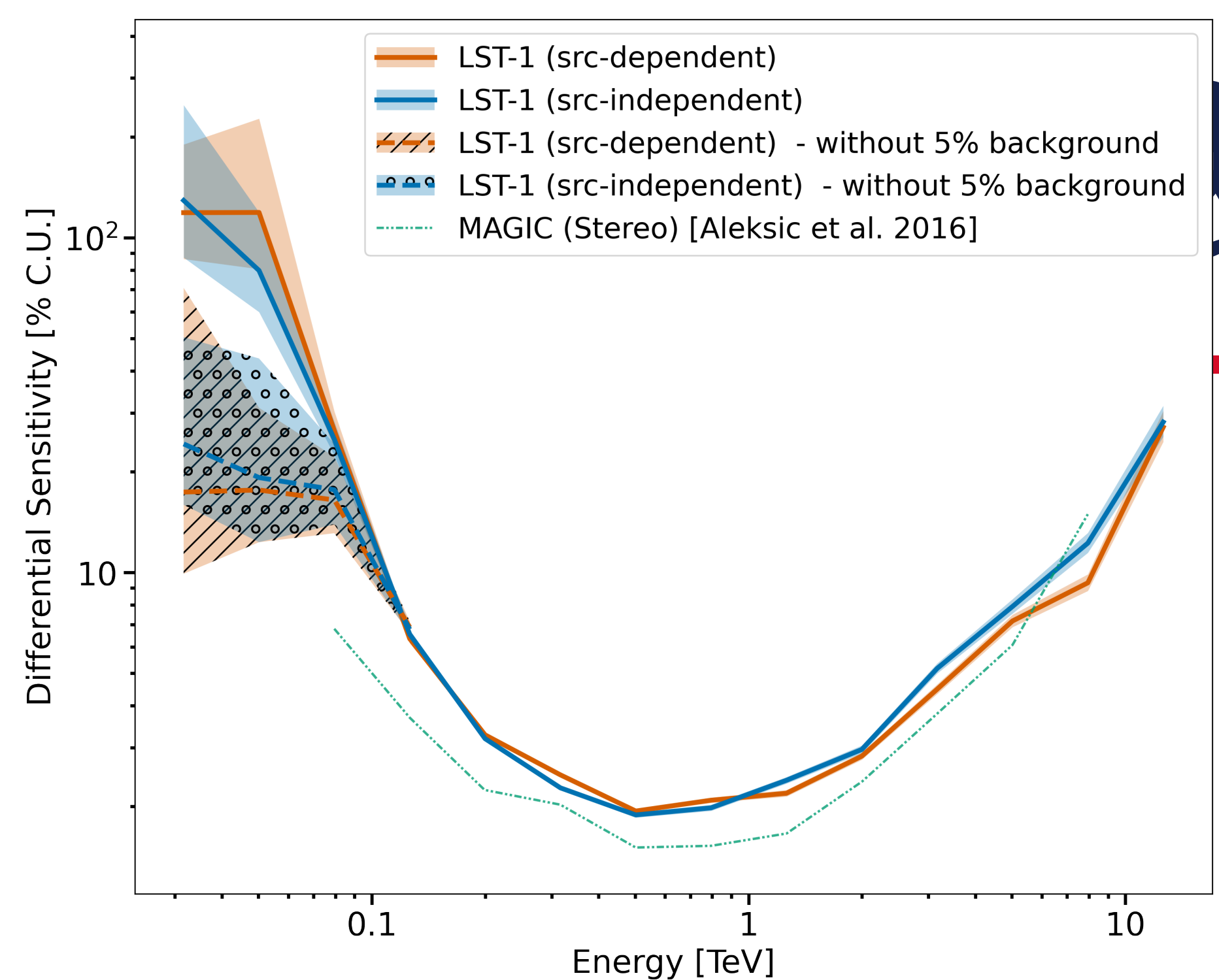
Status of the Project

- LST-1 first telescope at CTAO site:
 - Telescope inaugurated in 2018
 - Under commissioning: Covid-19, supply-chain crisis, volcano, inflation...
 - 2000+ hours of data taken by April 2024
 - Current data-taking efficiency > 90% in dark time, almost at 95% requirement
- LST-2, LST-3, and LST-4: under construction
- LST-South: Funded through PNRR

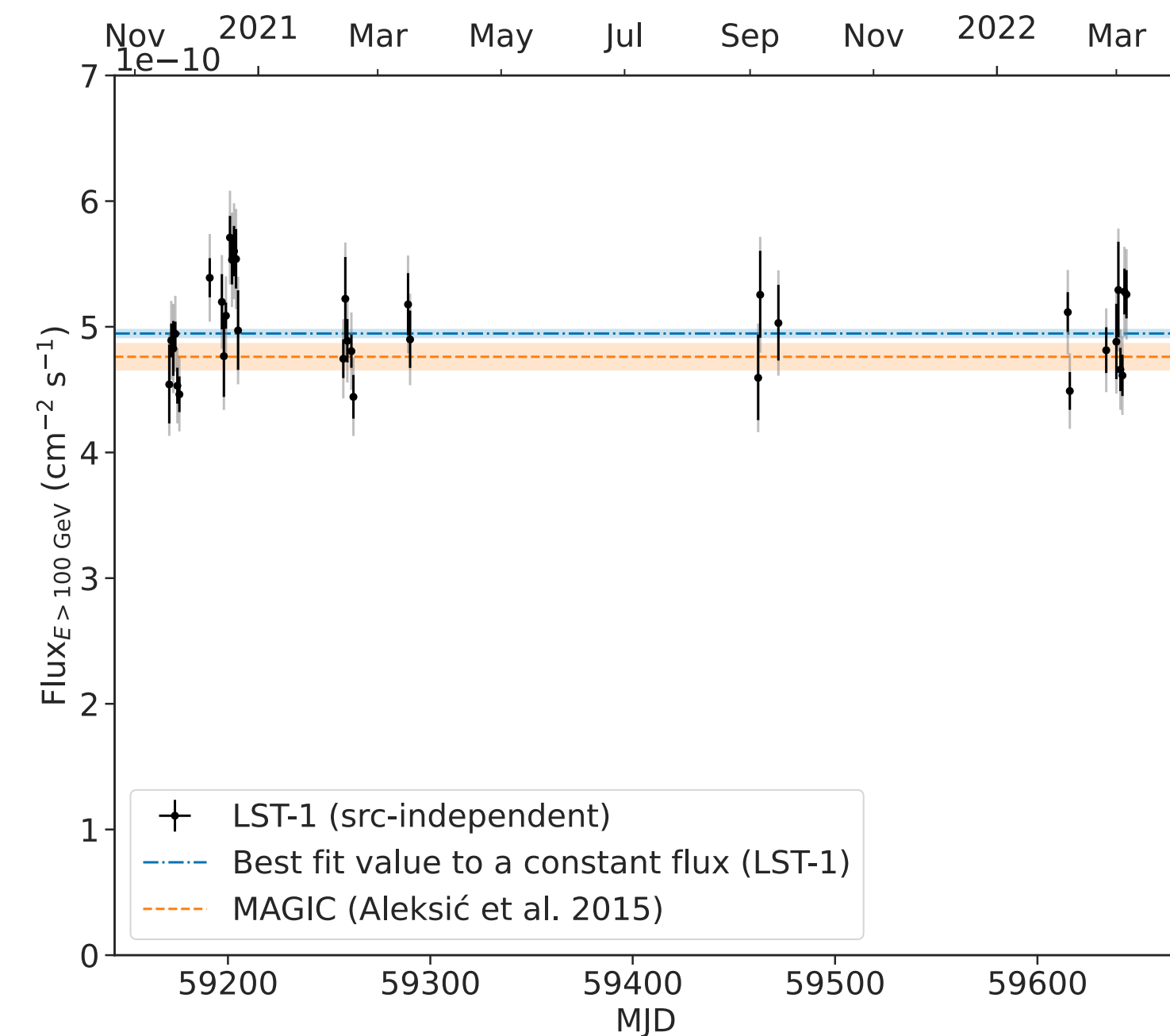
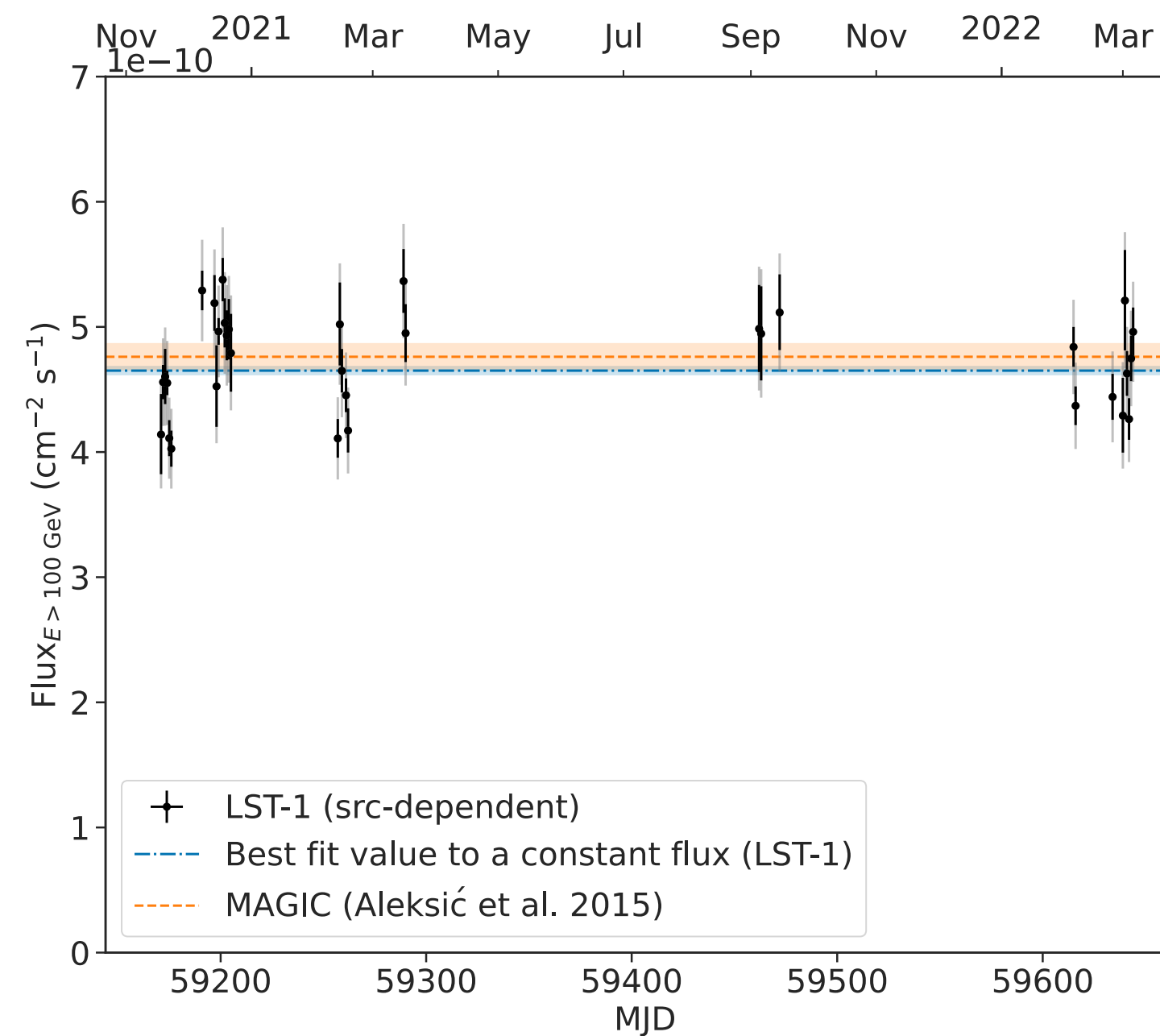


Performance: Sensitivity

- Able to measure Crab Nebula down to 30 GeV
- Roughly 1.5x less sensitive than MAGIC Stereoscopic Telescopes
 - Consistent with single telescope performance vs Stereoscopic system
- Systematics from background begin to dominate below 50 GeV
 - Expected for single telescope
 - Will be reduced with stereo trigger
- Published in [Abe, H., et al.: ApJ, 956:80 \(2023\)](#)

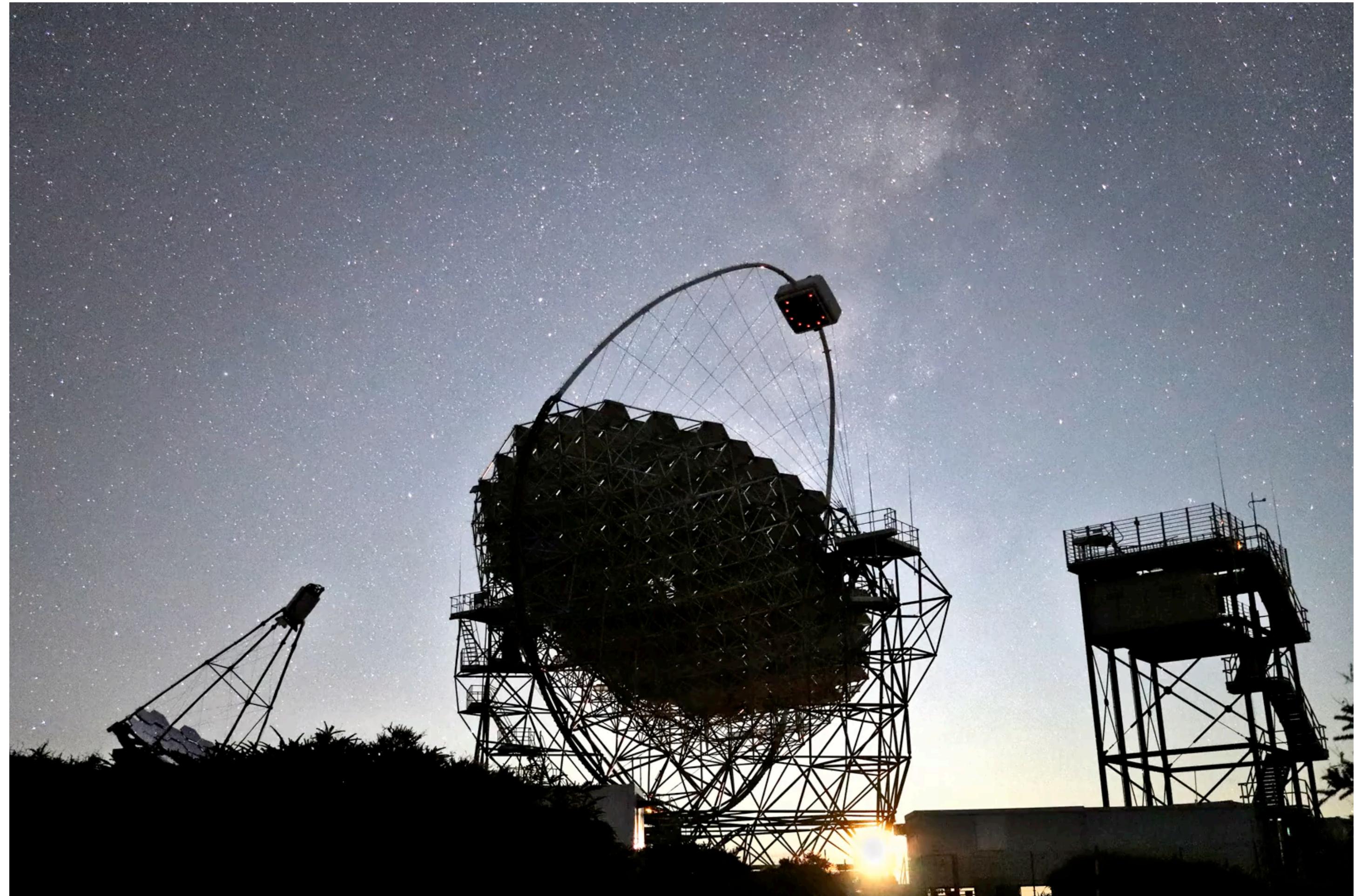


Cherenkov telescope array



LST-1 is Ready for Science

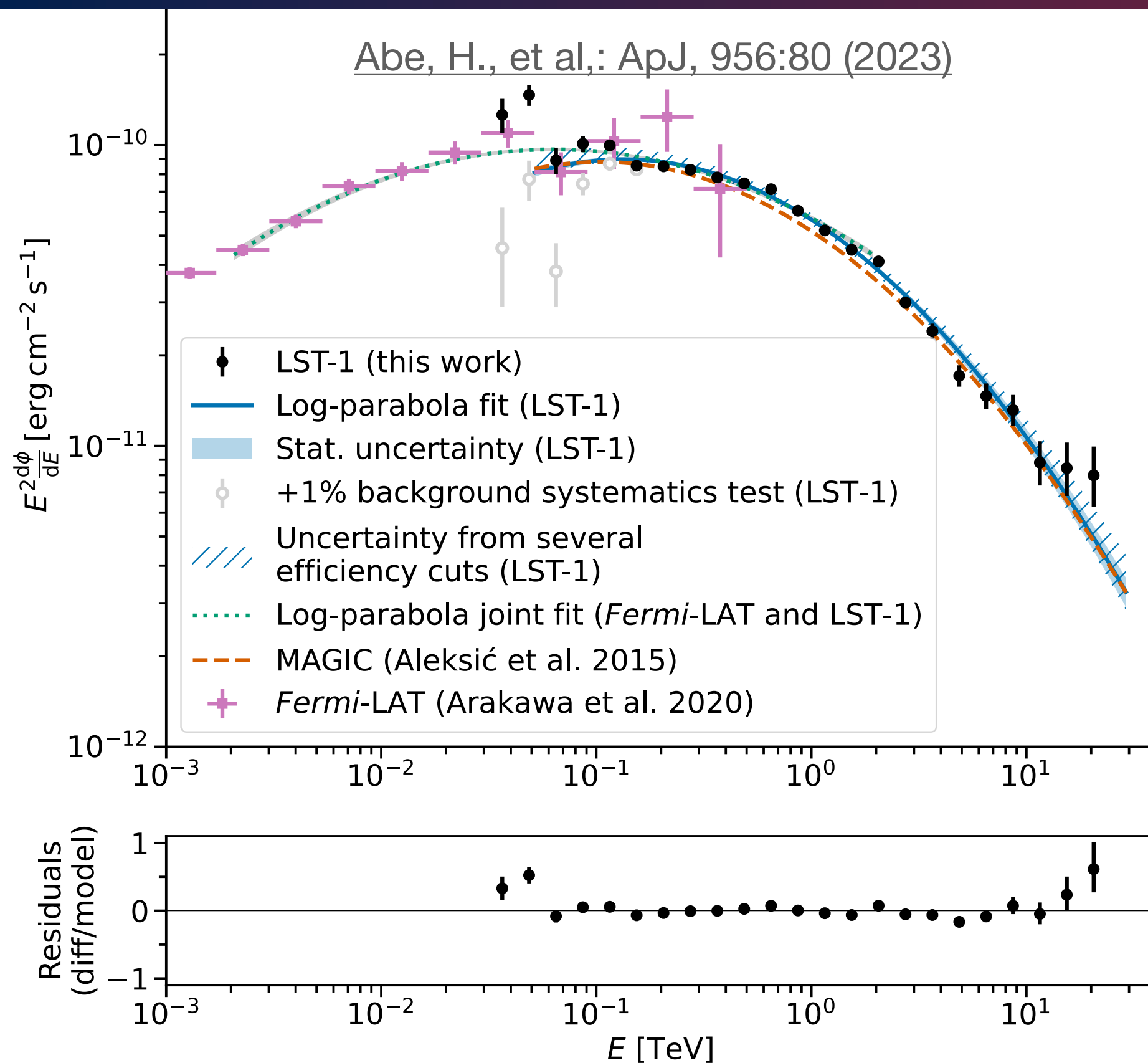
- The LST Performance Paper is published
- We are confident in the understanding of our telescope
- Already number of publications and more submitted



Galactic Science

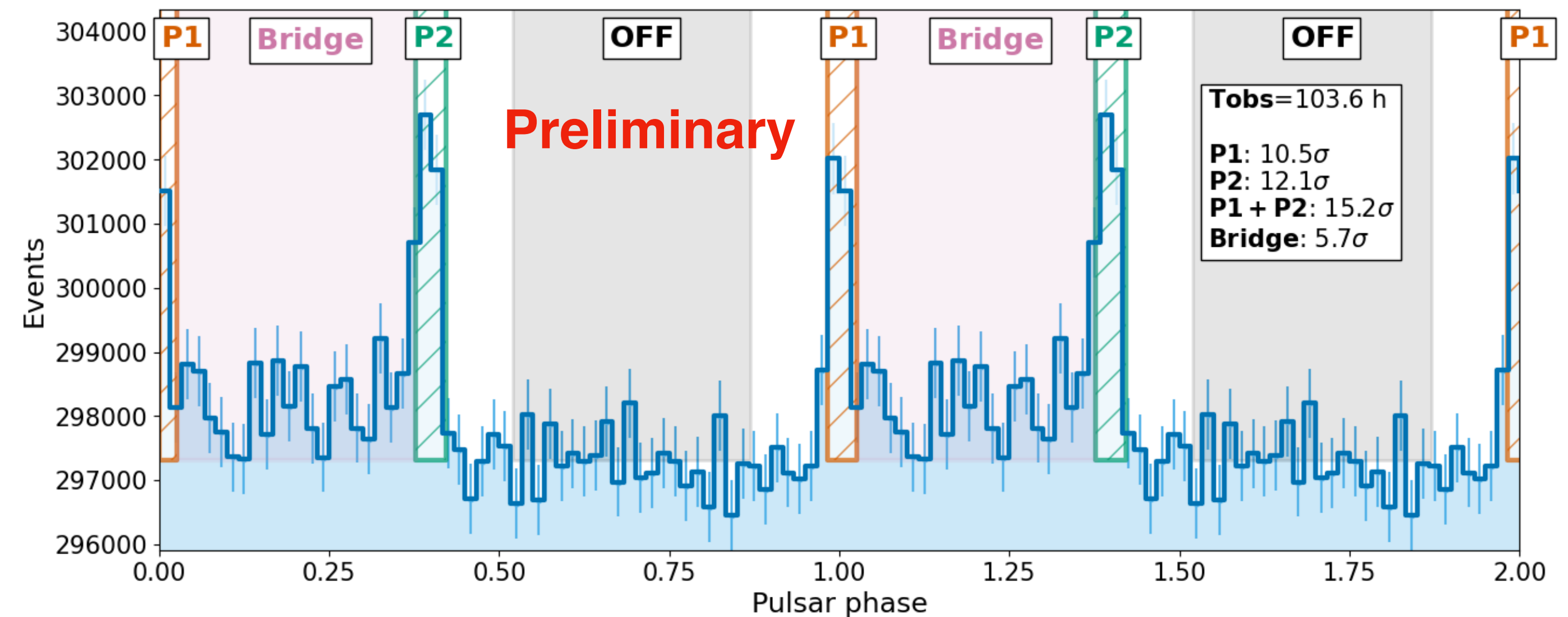


Crab Nebula and Pulsar



Crab Pulsed Emission Phaseogram

See Giulia's poster for more info!

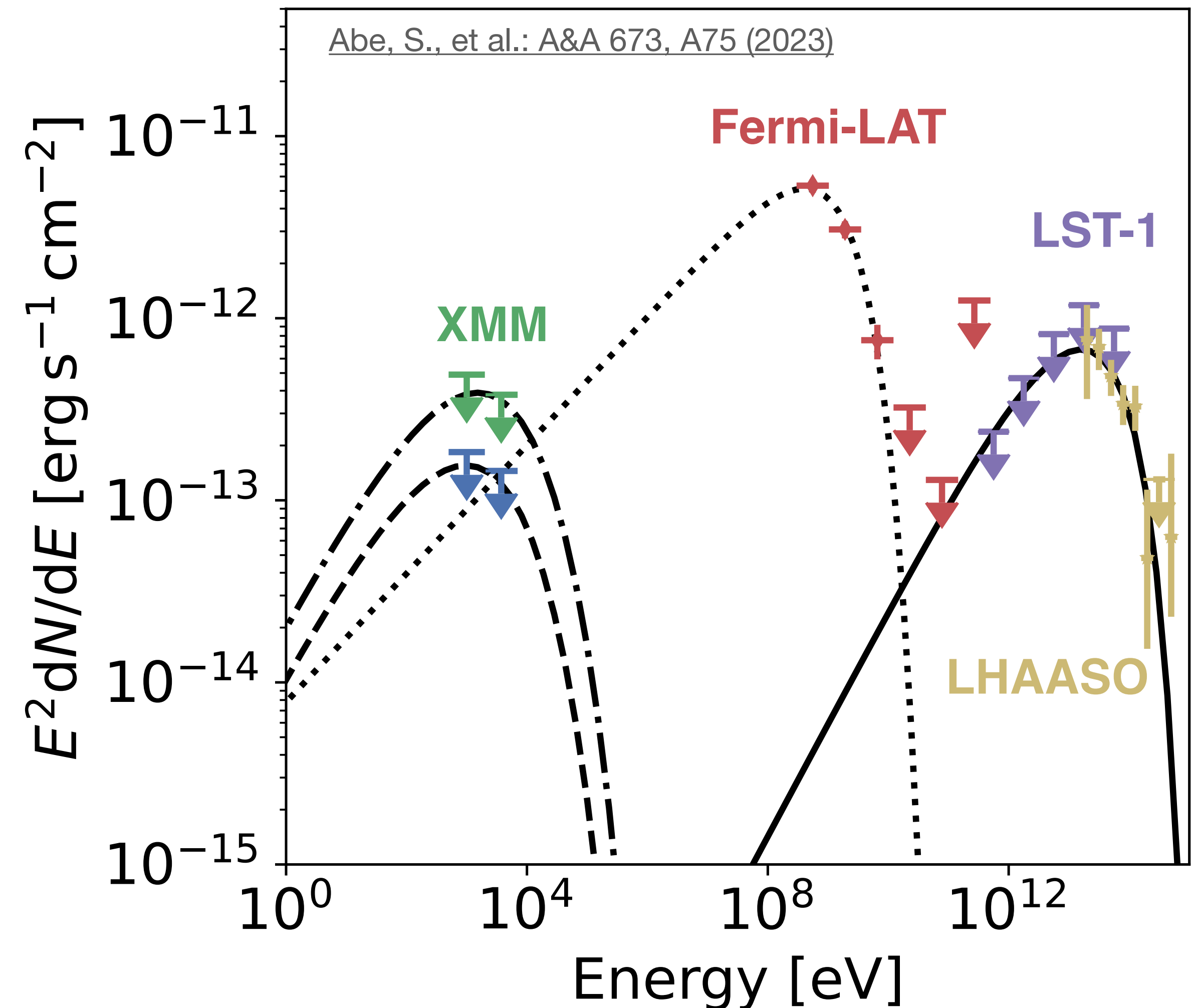


- Yes, we looked at the Crab Nebula and Pulsar
- 34 hours of effective time
- Able to measure Crab Nebula down to 30 GeV

- Pulsed emission detected down to 20 GeV
- LST-1 Crab Pulsar paper submitted to A&A

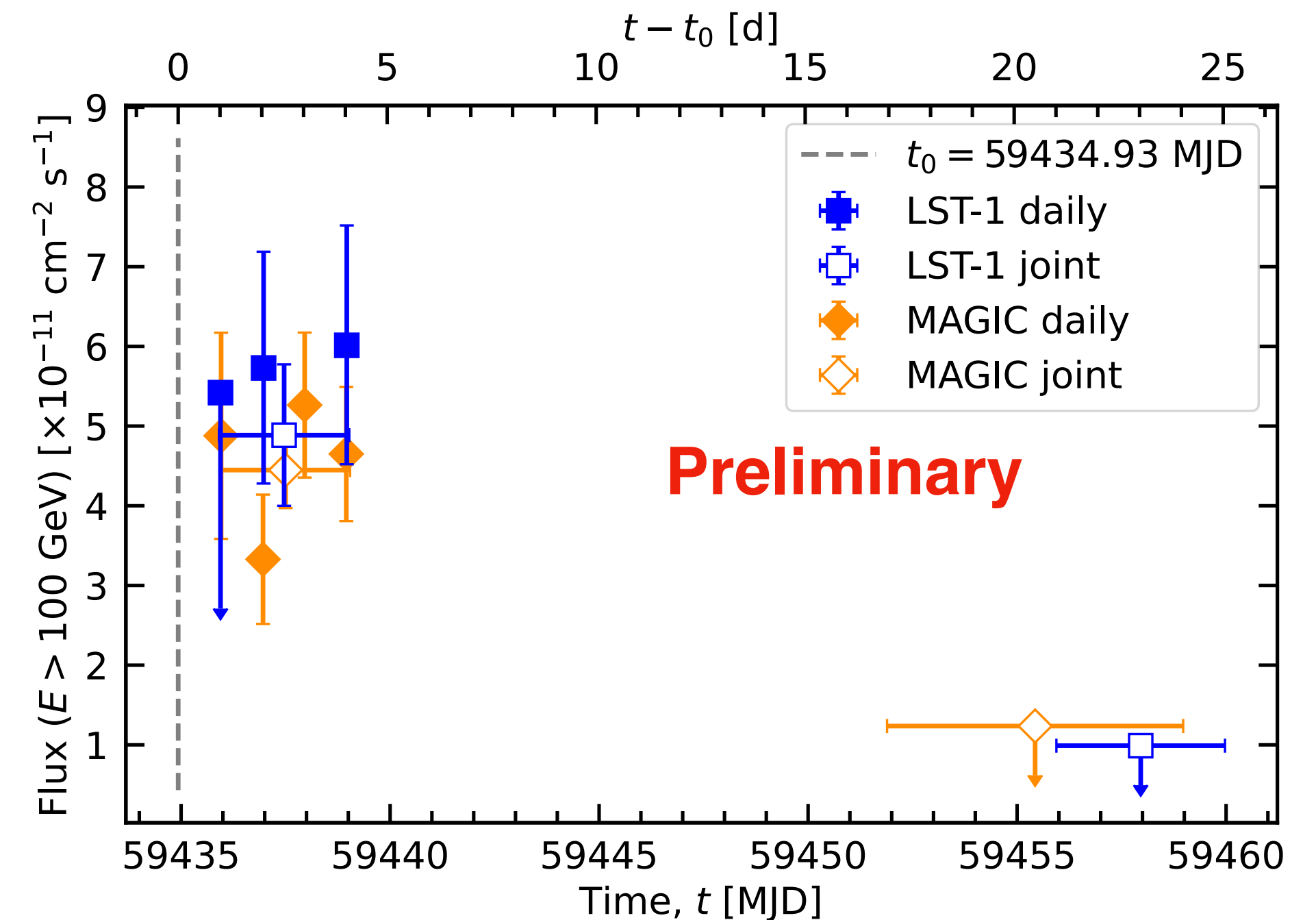
LHAASO J2108+5157

- [Cao et al. 2021](#): PeVatron, reported to be point-like (<0.26 deg). No X-ray or VHE counterpart, possible LAT counterpart, but soft spectrum (pulsar?)
- 91 hour observation, no detection but relevant upper limits.
- Able to confidently exclude simple hadronic emission scenario
- [Abe, S., et al. A&A, 673, A75 \(2023\)](#) proposed possible TeV halo associated with soft Fermi-LAT source
- Other interpretations such as illuminated MC from SNR
 - [de la Fuente, E., et al.: A&A 675, L5 \(2023\)](#) and [Mitchell A. M. W., 2023, arXiv, arXiv:2310.18007](#)



First VHE-detect Nova: RS Ophiuchi

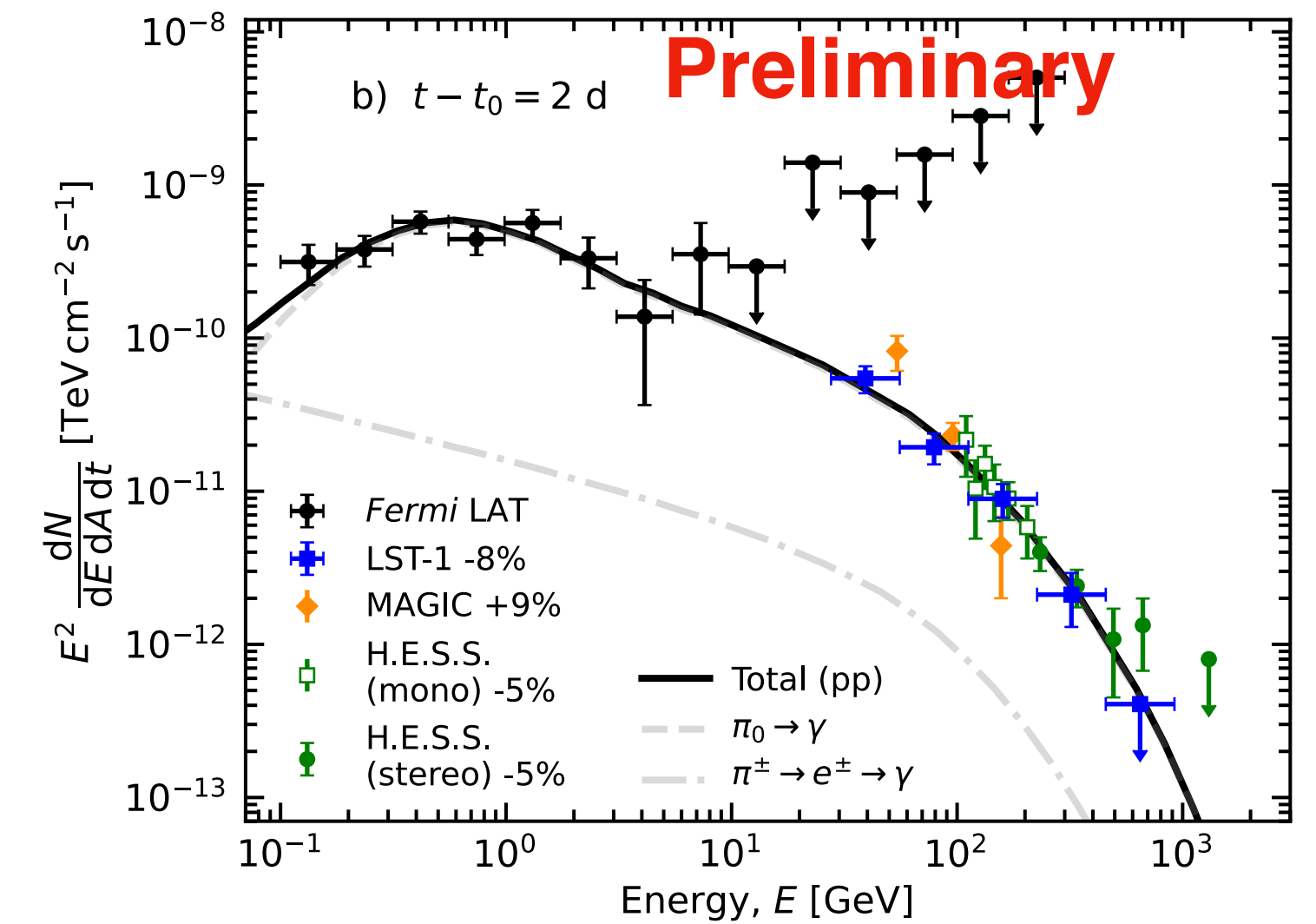
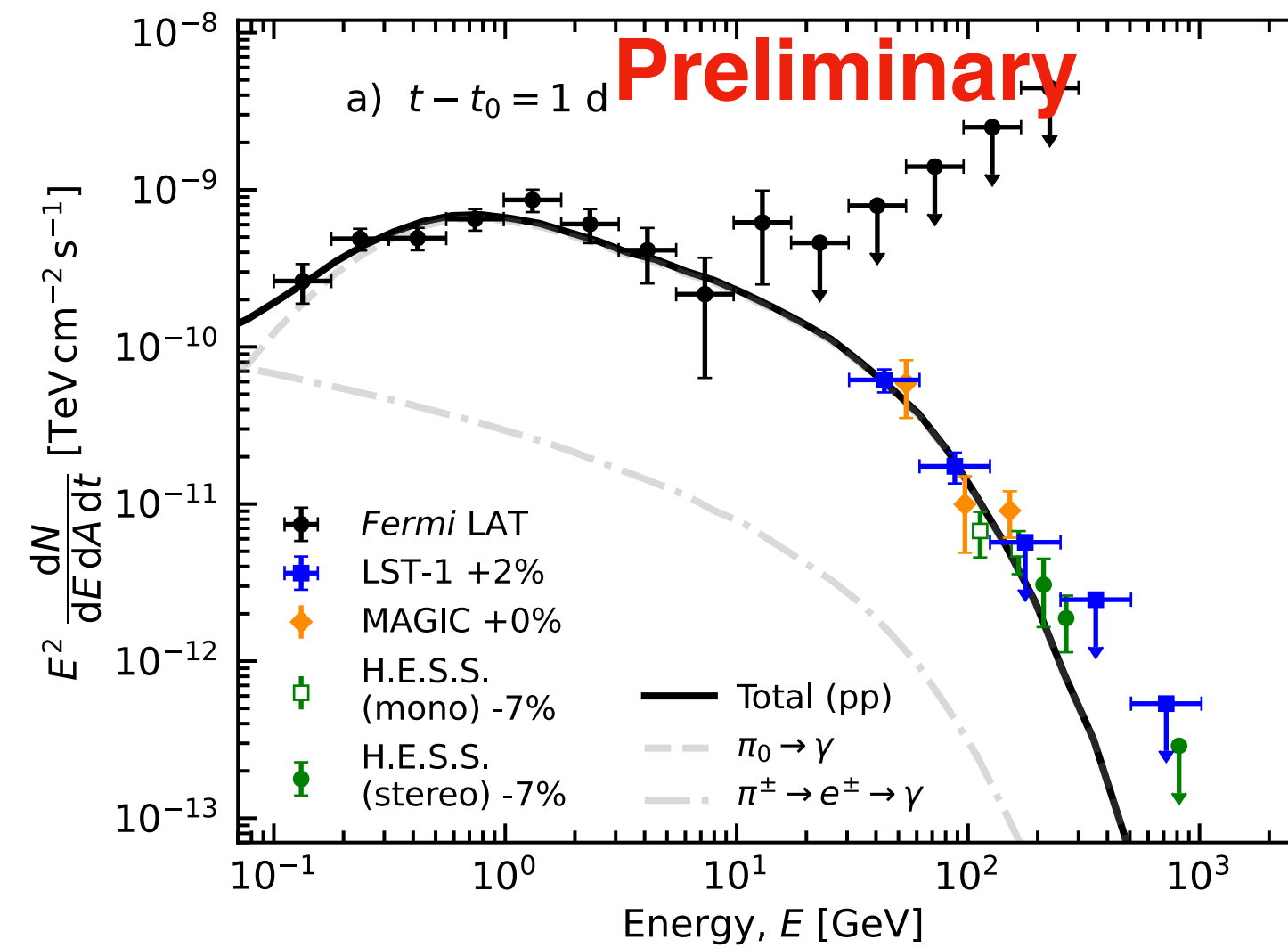
- In 2021, the recurrent symbiotic nova RS Oph went into outburst
- In addition to MAGIC ([Acciari 2022](#)) and H.E.S.S. ([H.E.S.S. Collab 2022](#)), LST-1 detected VHE emission from RS Oph
- Detected with 6.6σ for three of the four following days
- Evidence for a spectral hardening as novae evolves and increase in cutoff energy



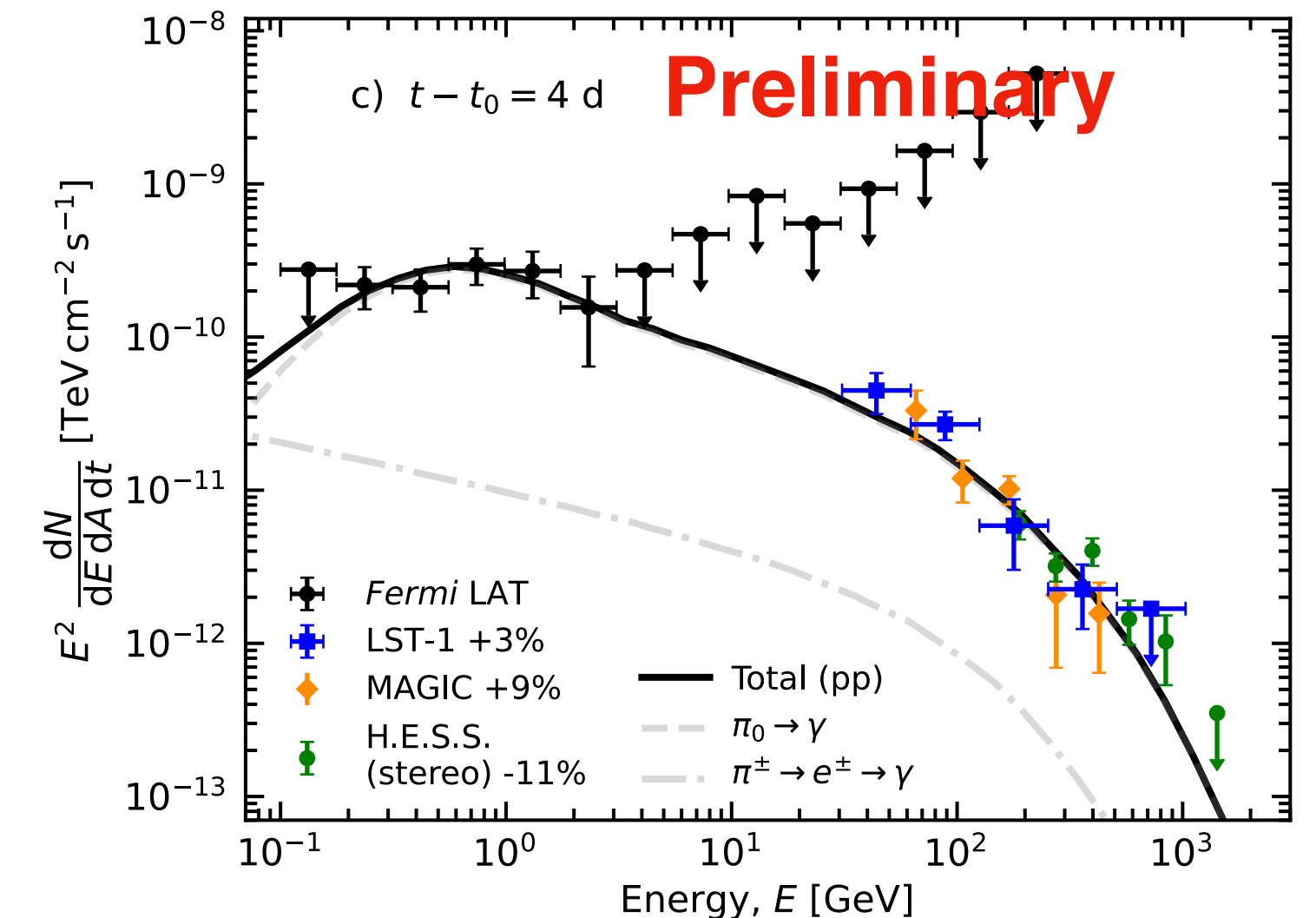
Observation day	Γ	ϕ_0 [$10^{-10} \text{ TeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$]
Preliminary		
Day 1	-4.2 ± 0.3	3.3 ± 1.3
Day 2	-3.65 ± 0.13	5.9 ± 1.0
Day 4	-3.50 ± 0.15	5.9 ± 1.1
Day 1, 2 and 4	-3.73 ± 0.10	5.2 ± 0.7

First VHE-detect Nova: RS Ophiuchi

- Hadronic model preferred
- Model includes systematic uncertainty associated with different IACTs
- Clearly, the cutoff energy increases with time
- Including estimates for T CrB with LST-1
- Paper currently within internal review



Parameter	Best-fit value on observation day		
	Day 1	Day 2	Day 4
Preliminary			
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



Extra-Galactic Science



BL Lac Flare 2021: CTAO's First ATel

[[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

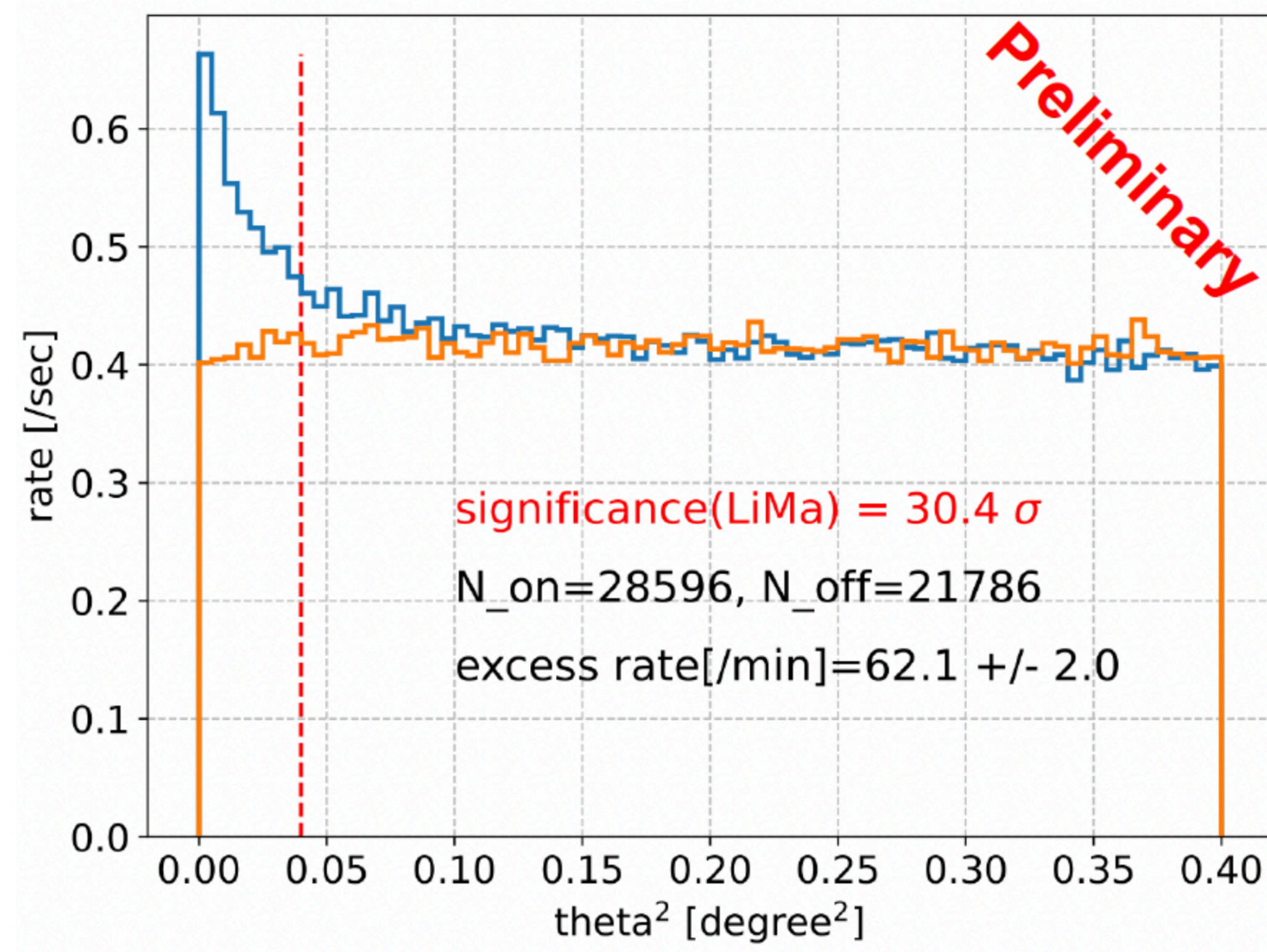
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

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

Referred to by ATel #: [14820](#), [14826](#), [14839](#)



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 $1.3 \pm 0.2 \cdot 10^{-9} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$ (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

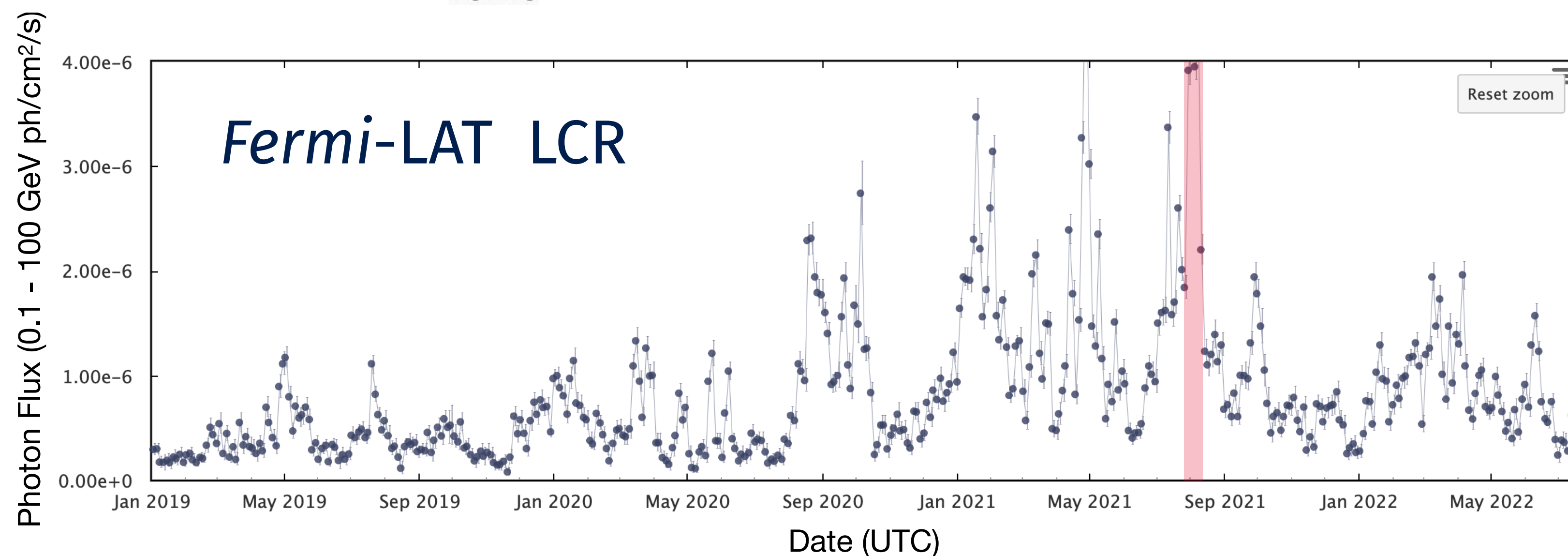
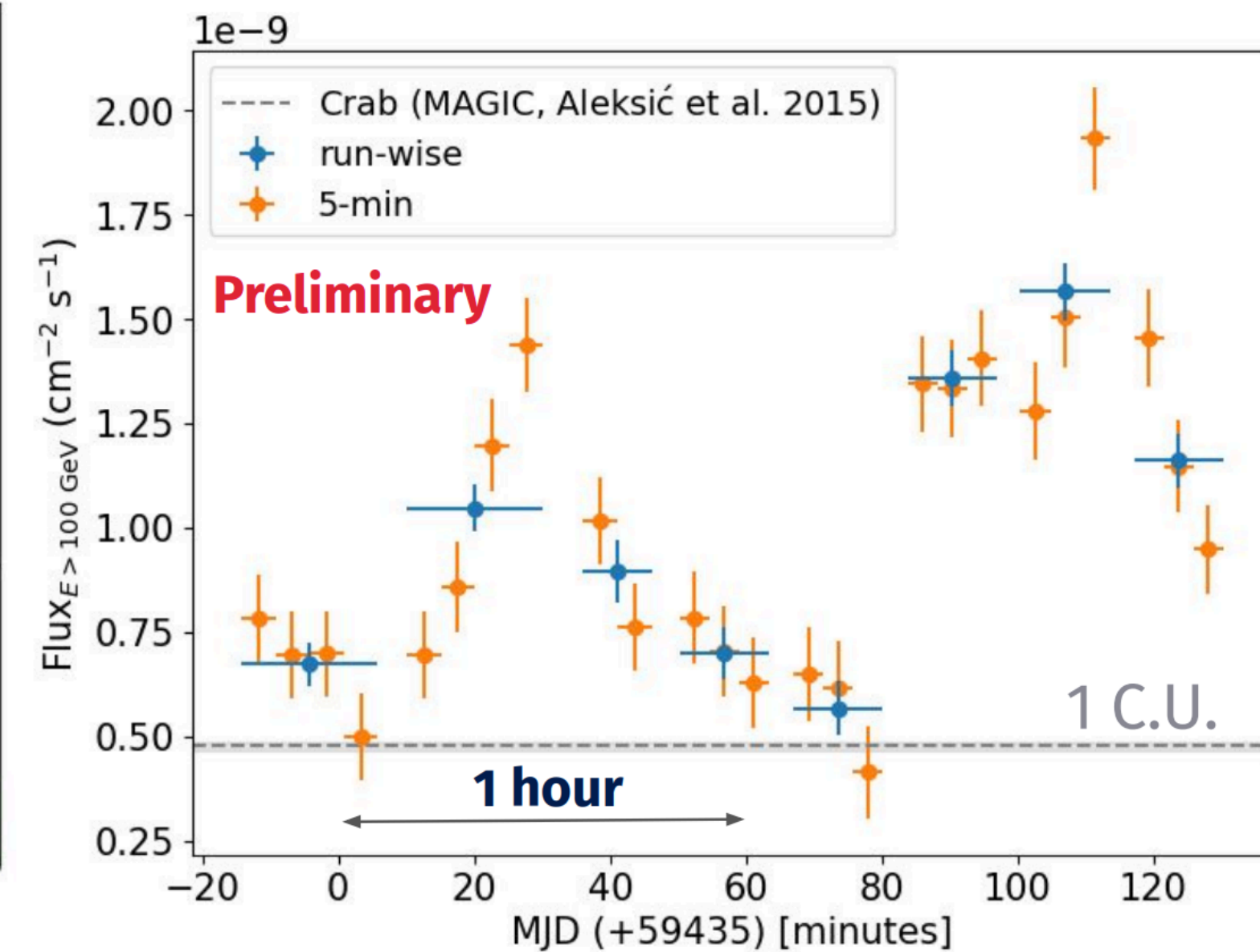
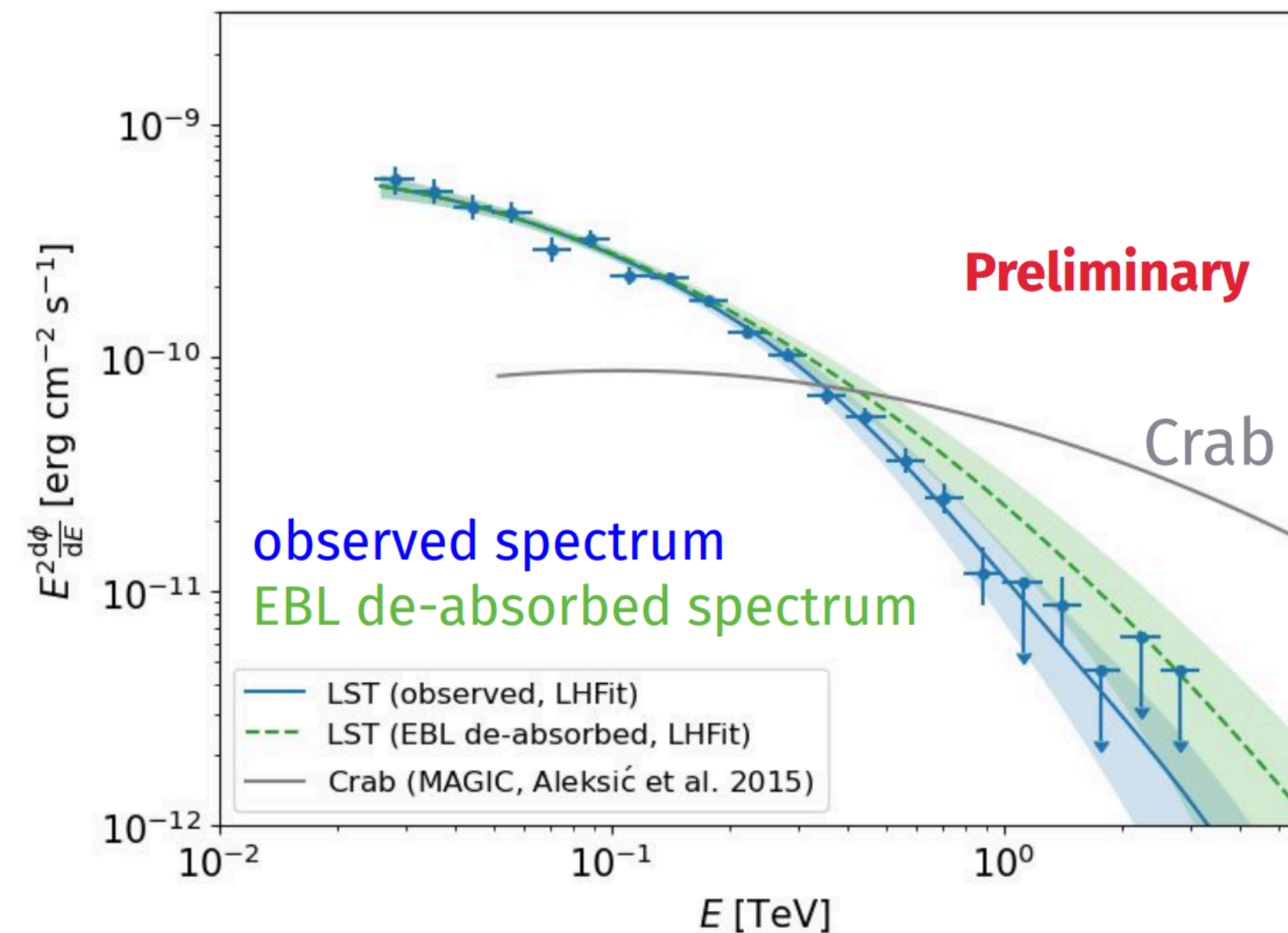


- Fast response by LST and CTAC
- ATel was Published under 48 hours of observation with confirmation and cross-check

BL Lac Flare 2021

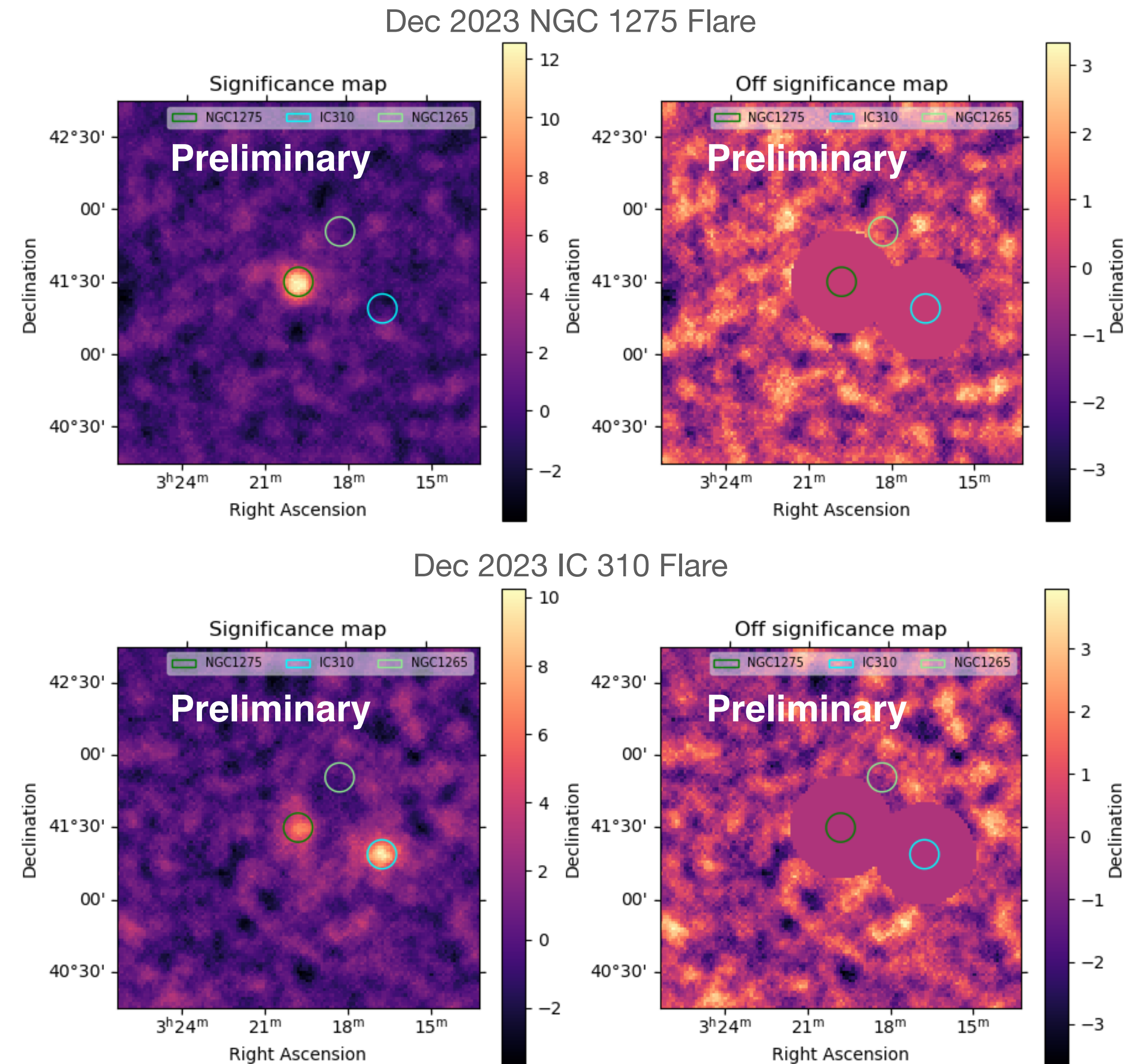
- IBL at $z=0.069$
- August 8th 2021: High state > 1 crab for $E < 300$ GeV
- Soft spectrum allows to extract spectral point at **30 GeV in < 2 hour** observation
- Intra-run variability being examined
- Paper being written
- Explore LST capability for short-time scale variability and Lorentz invariance studies
- **Poster contribution from Cyann Plard on BL Lac LIV studies**

Aug 9, 2021

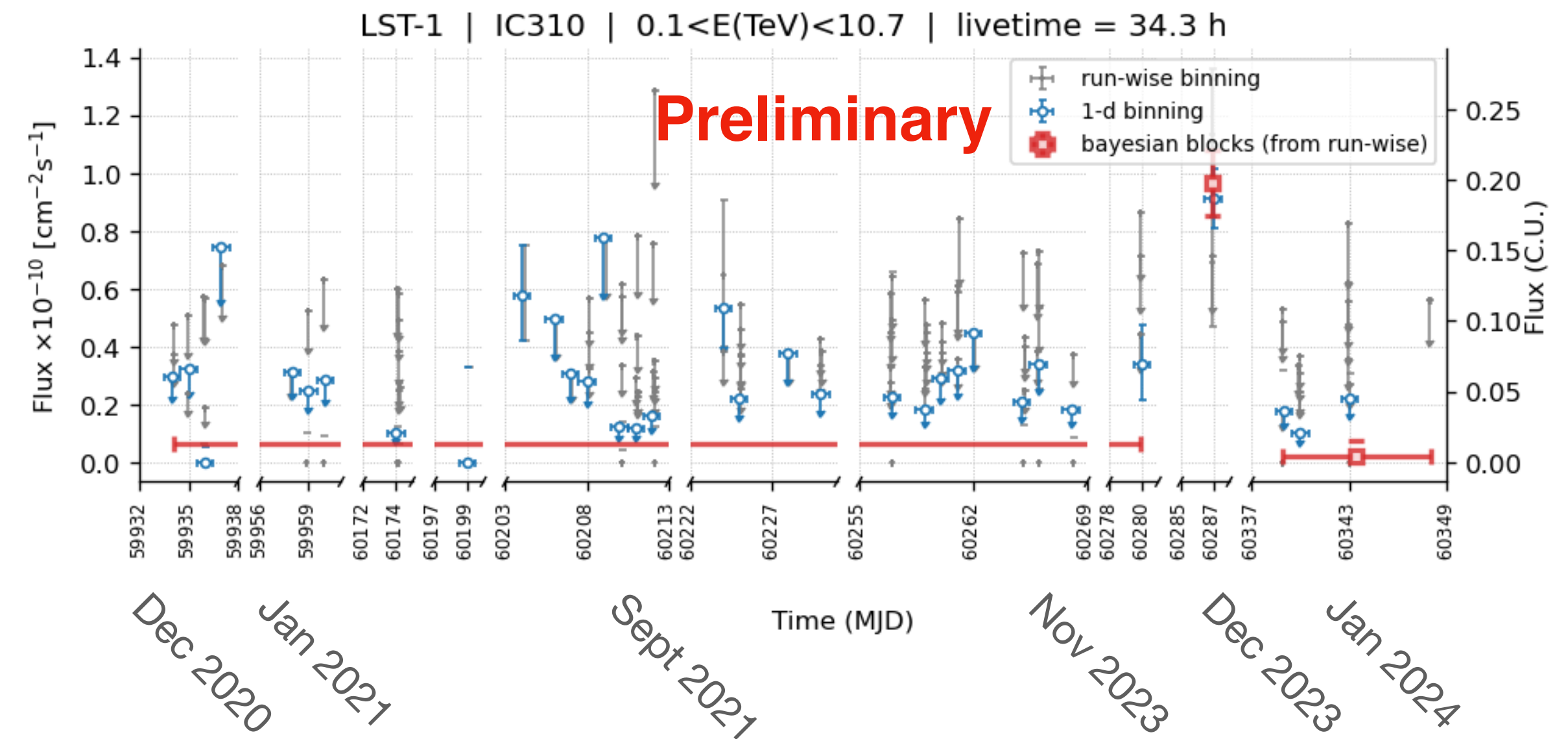
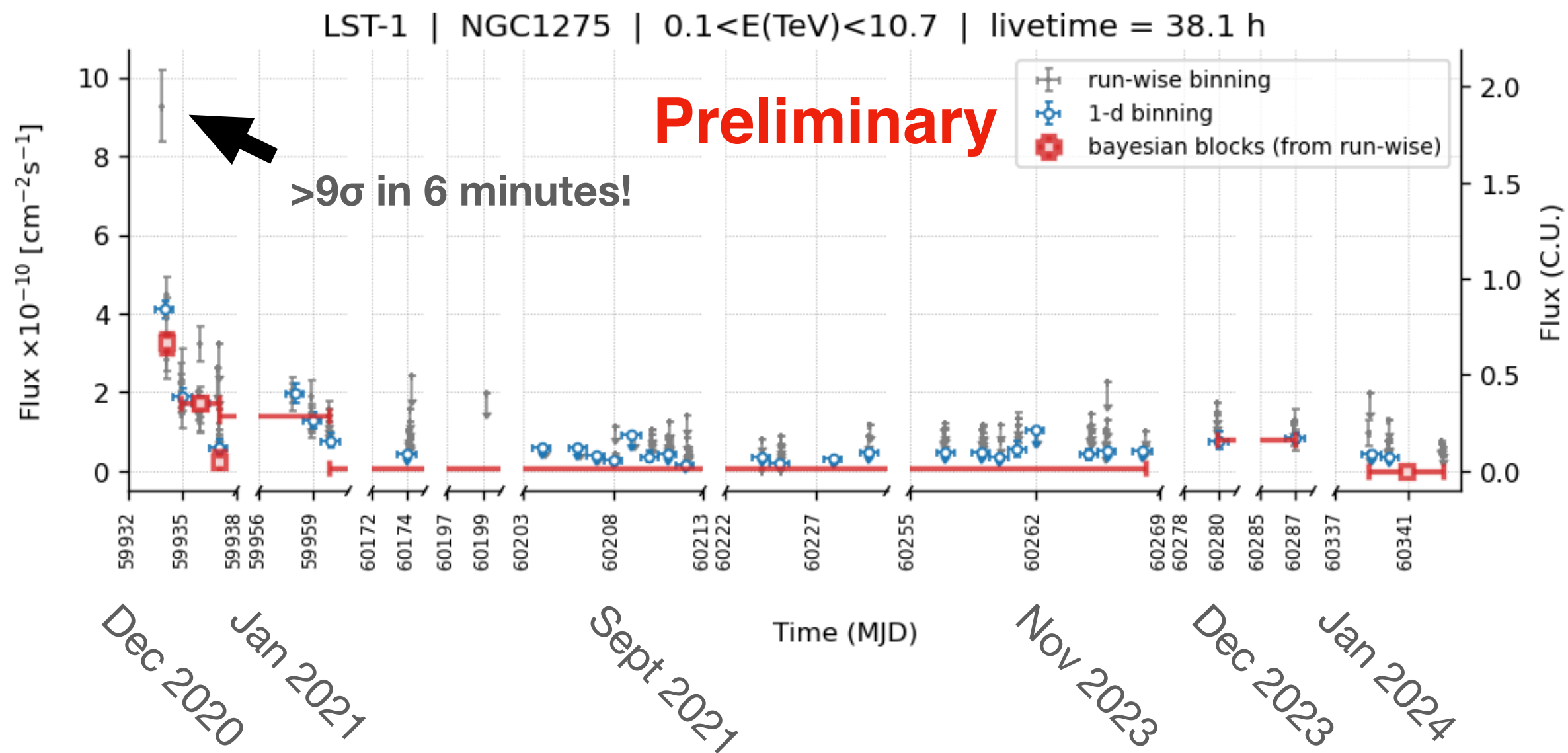


Radio Galaxies : Perseus Cluster

- Cluster of radio galaxies in Perseus; ideal targets for LST: NGC 1275 and IC 310
- Timeline of Observations
 - NGC 1275 detected in Dec 2020, and then quiet afterwards
 - NGC 1275 began flaring again in December 2022 - January 2023
 - Again in December 2023, NGC 1275 and IC 310 began flaring together
 - While observing cluster, detected a single night flare of IC 310



Radio Galaxies : Perseus Cluster



- Data for starts ~ 50 GeV and extends to several TeV
- Stresses the importance for CTAO to have sensitivity and wide energy coverage from LSTs, MSTs, and SSTs
- **NGC 1275:**
 - Interacting elliptical+spiral system
 - Used for dark matter, CR and magnetic field studies
- **IC 310:**
 - Lenticular host galaxy, strongly bent jet
 - Using short time variability able to study region close to SMBH ([Science, 346, 6213 \(2014\)](#))

OP 313

- Most distant AGN detected by an IACT, $z = 0.997$
- Only ten FSRQ ever detected in VHE
- First VHE source discovered by LST-1
- Daniel will discuss more details in the next talk

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

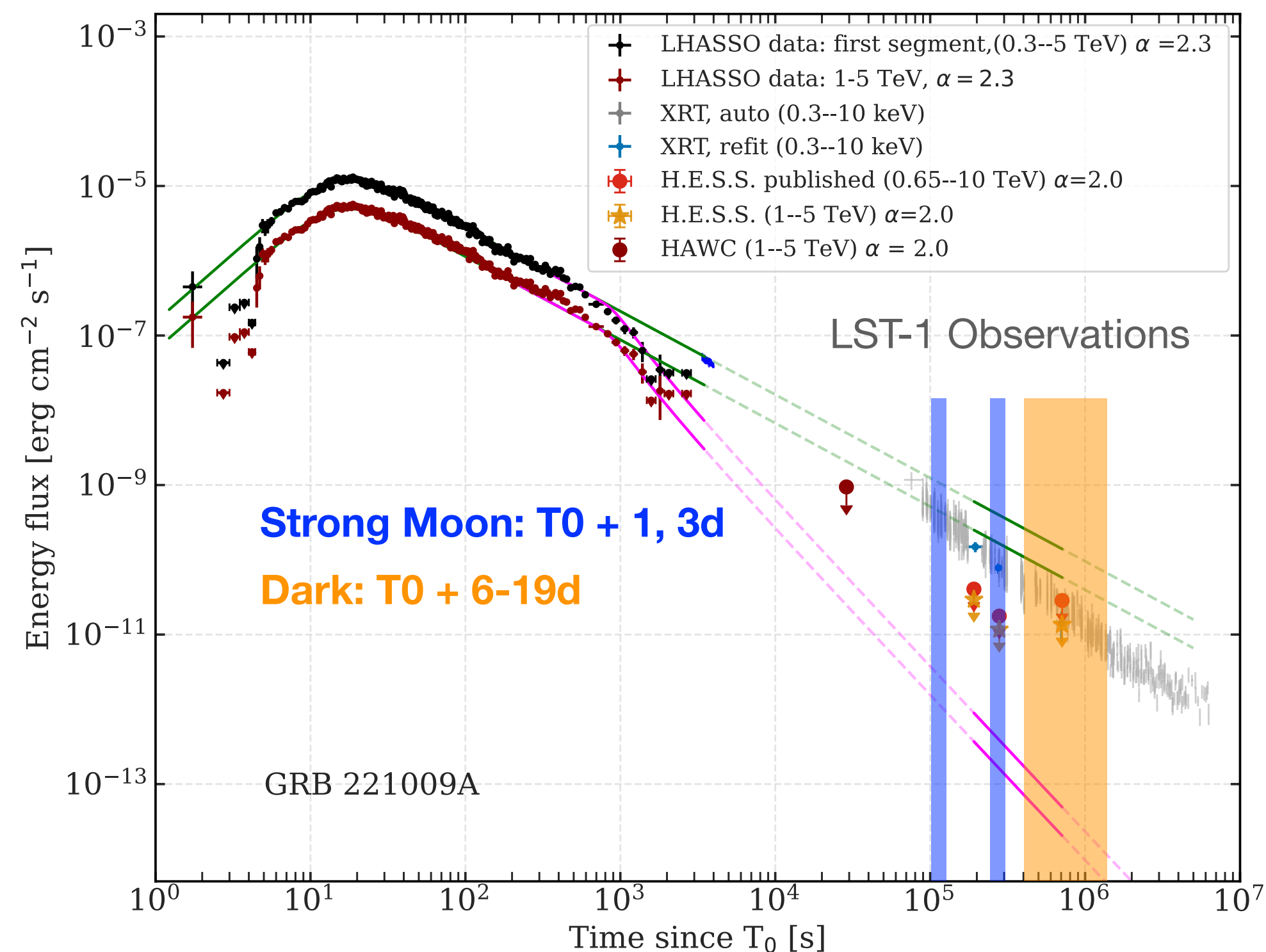
Announcement

2023-December-26

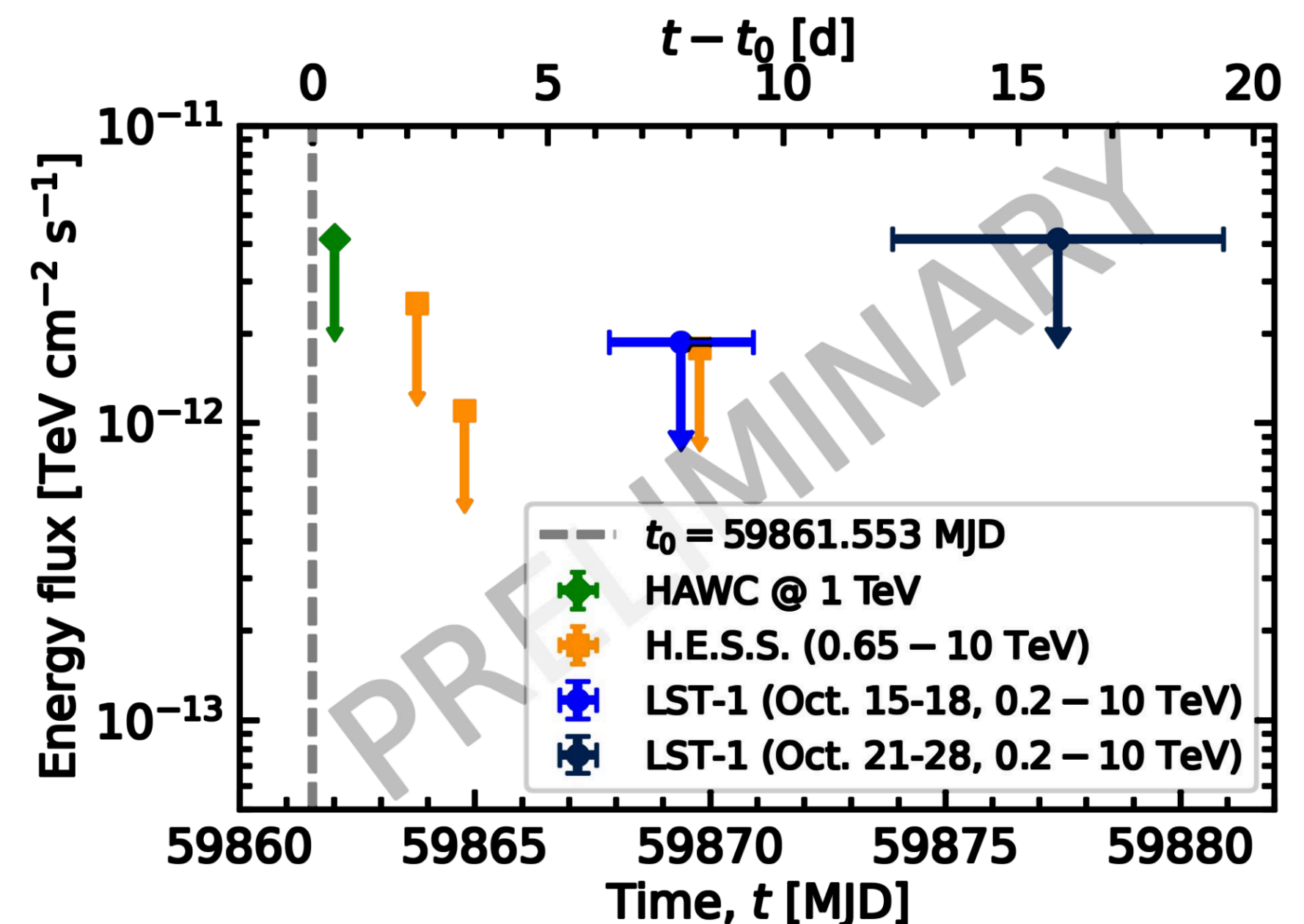
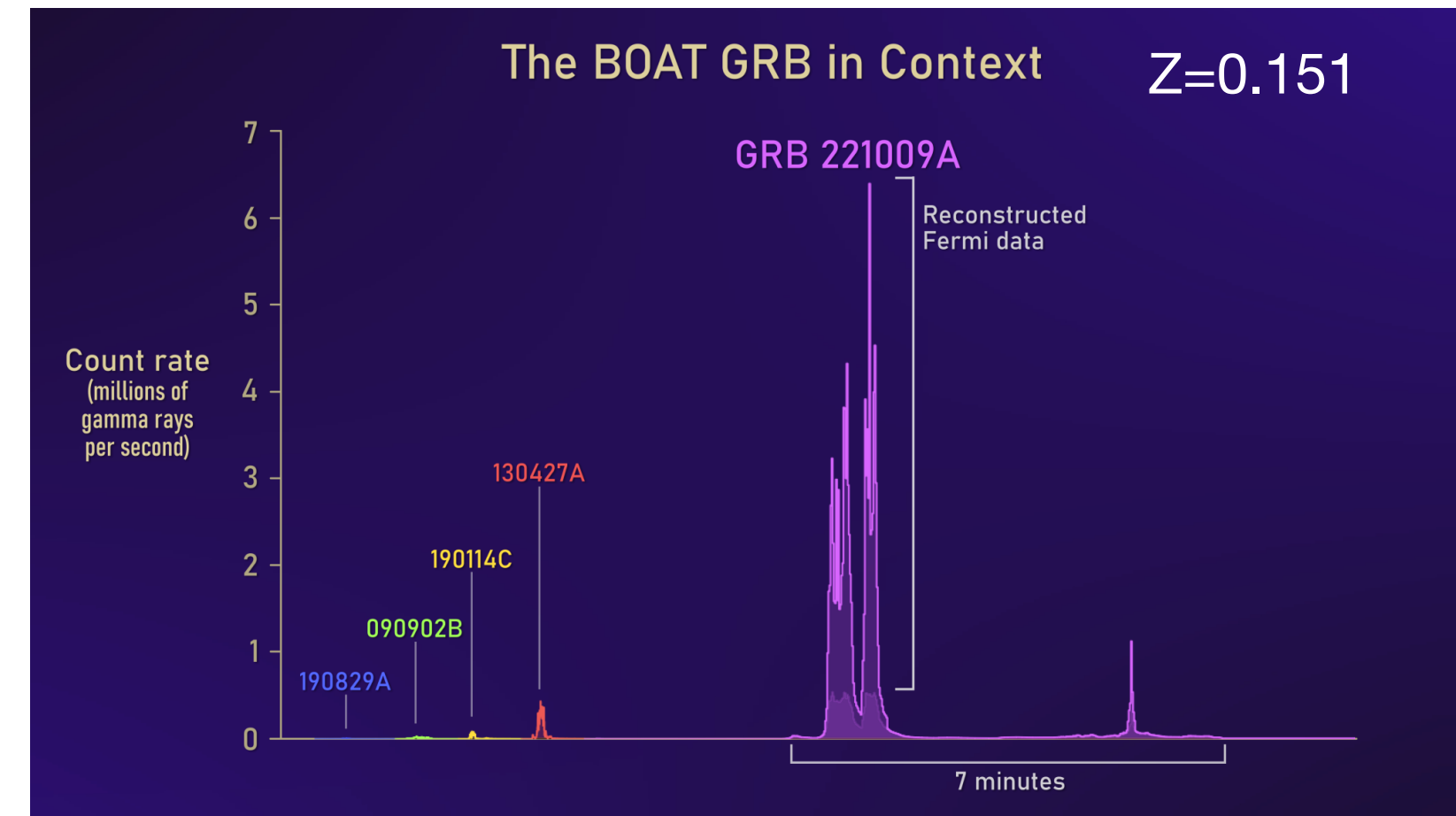
LST-1 Discovers the Most Distant AGN at Very High Energies

GRB 220109a (aka The B.O.A.T.)

- Observations with LST1 started 31h after the burst
 - First two observing nights under strong moonlight
 - Several days under dark/low moonlight afterwards
- Upper limit derived (>6 days after the burst)
- Moonlight data under verification (detailed MC and calibration needed)

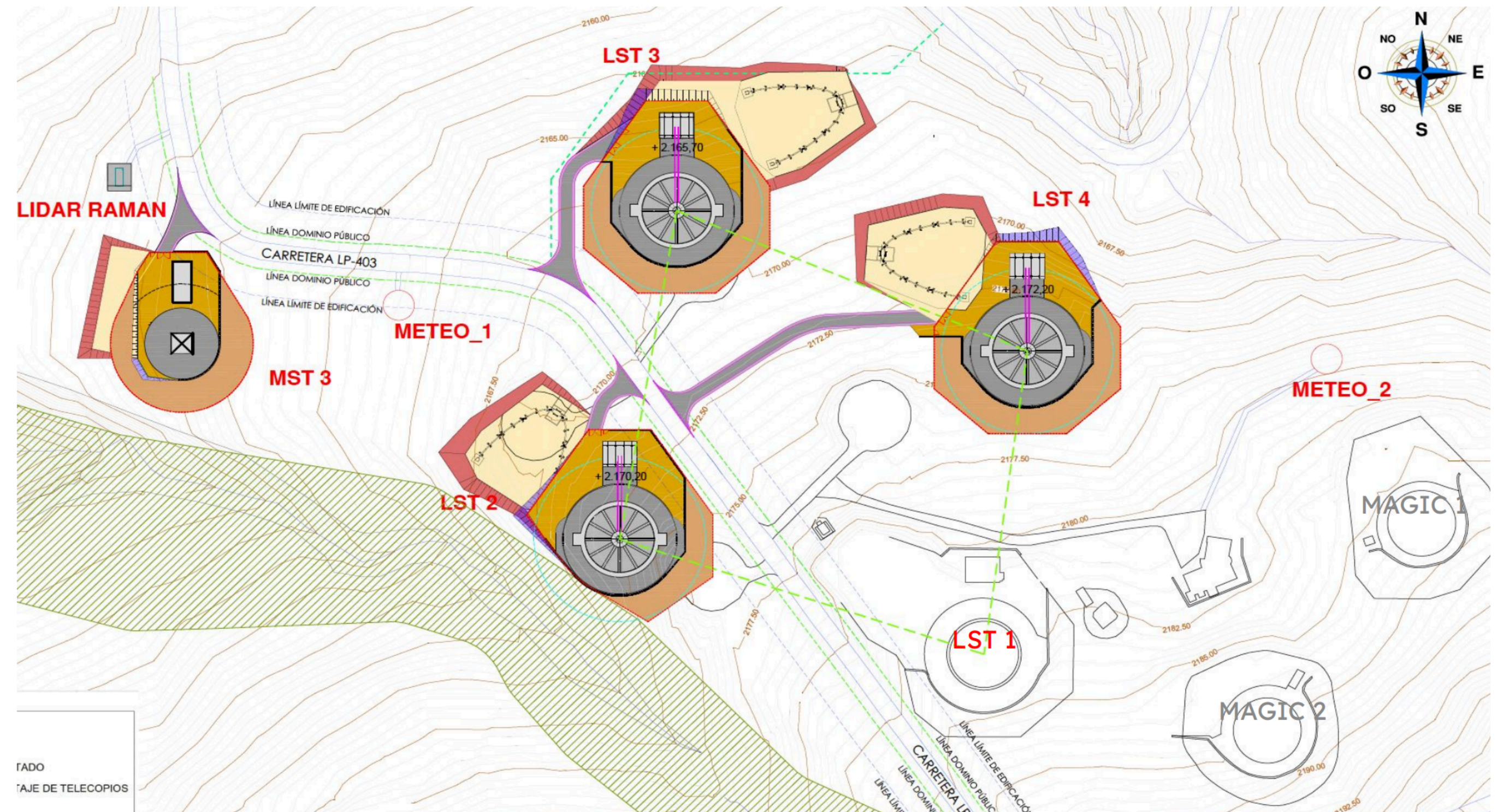


Jean Damascene Mbarubucyeye et al., ICRC 2023



The Future

- Three more LSTs are currently under construction
- INAF has funding for 2+ LSTs for the CTAO Southern Site through PNRR
- LST-1 has also started intensity interferometry observations with MAGIC
- Second cycle of internal LST proposals just began



Credit: Jelena Strišković

LST-2



LST-3



LST-1



LST-4



From: 31-03-2024

I cannot talk about everything!

- We have several presentations and posters I didn't have time to cover
- **Posters/Flash Talks**
 - Very High Energy gamma-ray pulsars with the LST-1 - **Giulia Brunelli**
 - Muon Image Analysis for the Large-Sized Telescope of the Cherenkov Telescope Array - **Vadym Voitsekhovskiy**
 - Lorentz invariance violation search with the Cherenkov Telescope Array Observatory Large-Sized Telescope - **Cyann Plard**
- **Talks:**
 - Large zenith angle observation of the PeVatron candidate SNR G106.3+2.7 with LST-1 and MAGIC - **Marie-Sophie Carrasco**
 - First observations of CTA-LST1 and MAGIC as an optical interferometer - **Juan Cortina**

Conclusions

- The prototype telescope LST-1 was inaugurated at CTAO Northern Array in La Palma in 2018.
 - So far as tested: performance of the telescope expected follows CTAO requirements.
- Performance and data analysis well understood
 - Promising observations and results ranging from Galactic: Crab(s), RS Oph, LHAASO J2108, to Extragalactic: BL Lac, OP 313, and beyond: GRB221009a
- Over 2000 hours taken: first papers already out with even more to come soon!

LST Publications

- Observations of the Crab Nebula and Pulsar with the Large-sized Telescope Prototype of the Cherenkov Telescope Array: [Abe, H., et al.: ApJ, 956:80 \(2023\)](#)
- Performance of the joint LST-1 and MAGIC observations evaluated with Crab Nebula data: [Abe, H., et al.: A&A, 680, A66 \(2023\)](#)
- Multiwavelength study of the galactic PeVatron candidate LHAASO J2108+5157: [Abe, S., et al. A&A, 673, A75 \(2023\)](#)
- Star tracking for pointing determination of Imaging Atmospheric Cherenkov Telescopes. Application to the Large-Sized Telescope of the Cherenkov Telescope Array: [Abe, K., et al.: A&A, 679, A90 \(2023\)](#)
- A novel image-correction method for cloud-affected observations with Imaging Atmospheric Cherenkov Telescopes: Accepted to A&A
- Estimation of the atmospheric absorption profile with isotropic background events observed by Imaging Atmospheric Cherenkov Telescopes: Accepted to JHEAP