



LST
COLLABORATION



The most ancient VHE blazar yet: detection of FSRQ OP 313 at $z=0.997$ with LST-1

The furthest VHE gamma-ray blazar

11th International Fermi Symposium | 9 to 13 September 2024 | College Park, Maryland

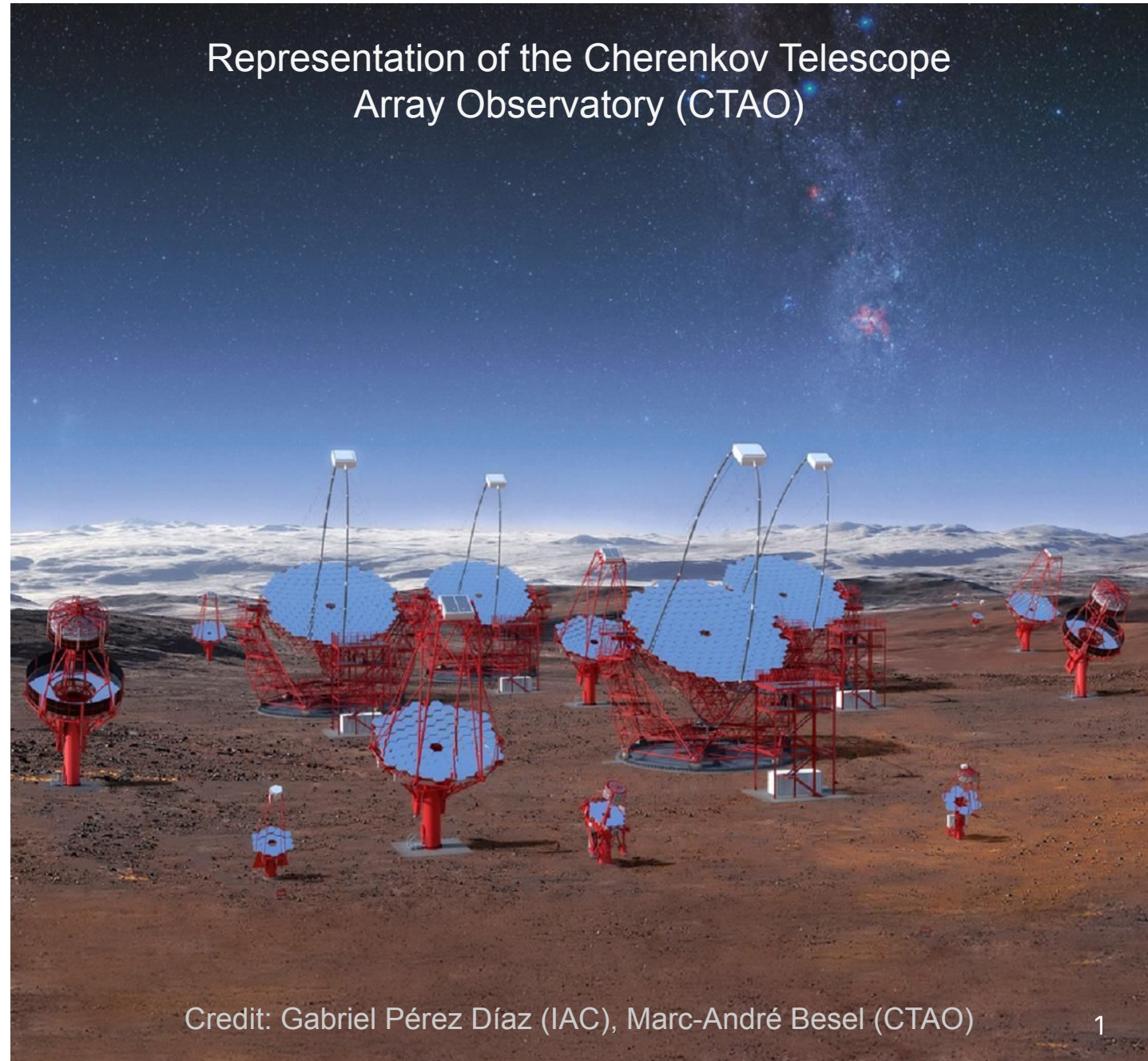
Jorge Otero-Santos (Instituto de Astrofísica de Andalucía - CSIC)

D. Morcuende, M. Nievas Rosillo, D. Sanchez, A. Arbet-Engels, J. Baxter, S. Nozaki, L. Heckmann, E. Visentin,
R. De Menezes, F. Di Pierro for the CTA-LST Project

CTAO

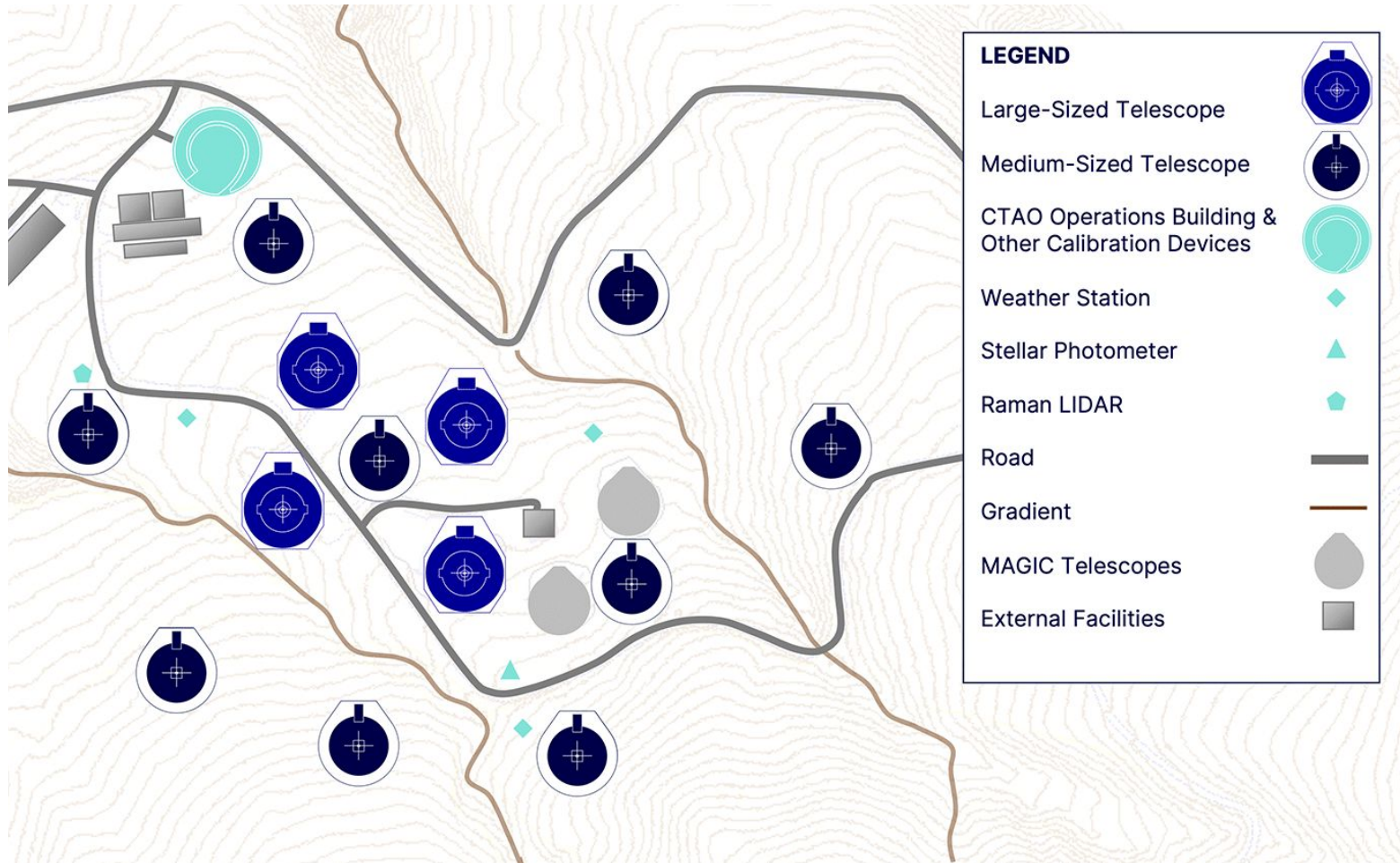
- Cherenkov Telescope Array Observatory
- Two sites:
 - CTAO-North: Roque de los Muchachos Observatory (La Palma, Spain)
 - CTAO-South: Paranal Observatory (Atacama Desert, Chile)
- Three telescope types:
 - Large-Sized Telescopes (LSTs)
 - Medium-Sized Telescopes (MSTs)
 - Small-Sized Telescopes (SSTs)

Representation of the Cherenkov Telescope Array Observatory (CTAO)

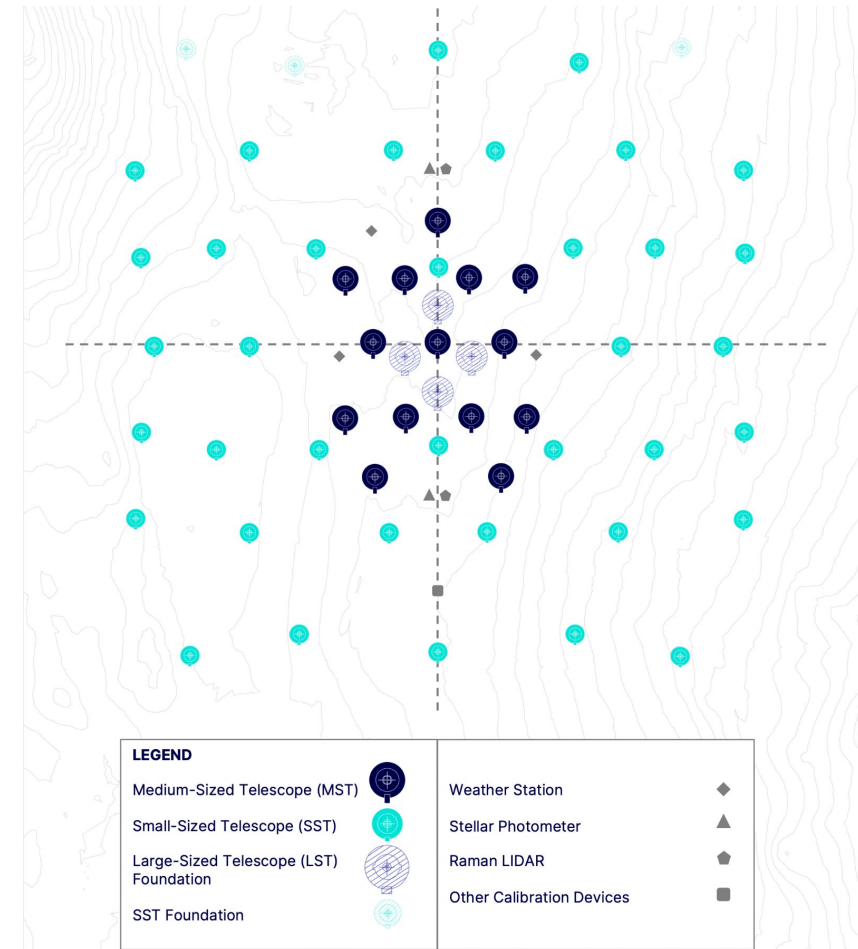


CTAO

CTAO-North

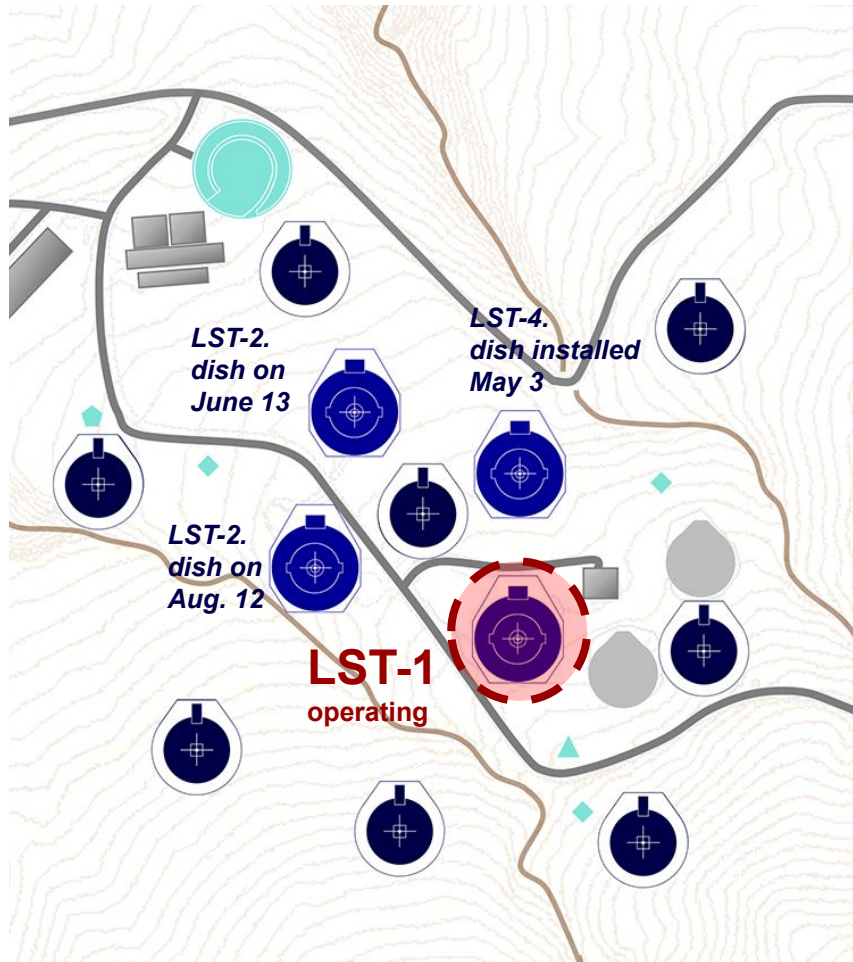


CTAO-South



CTAO

CTAO-North



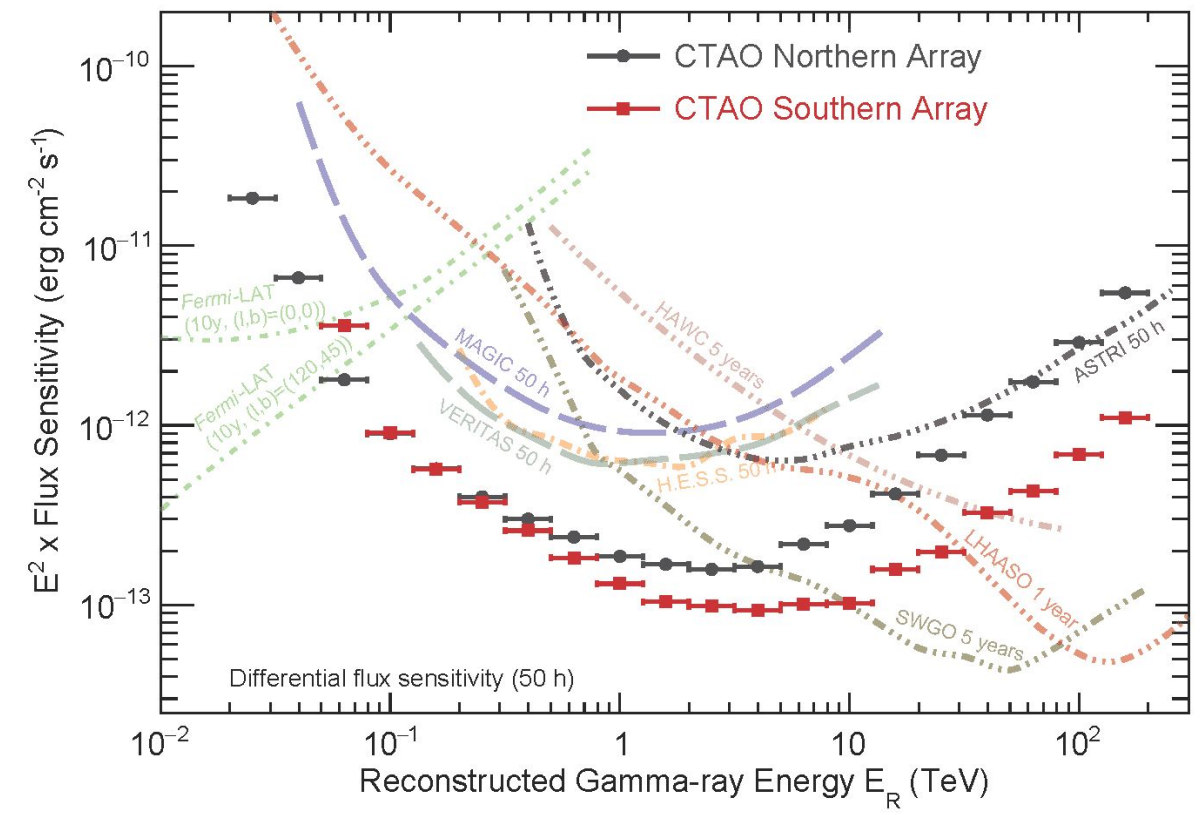
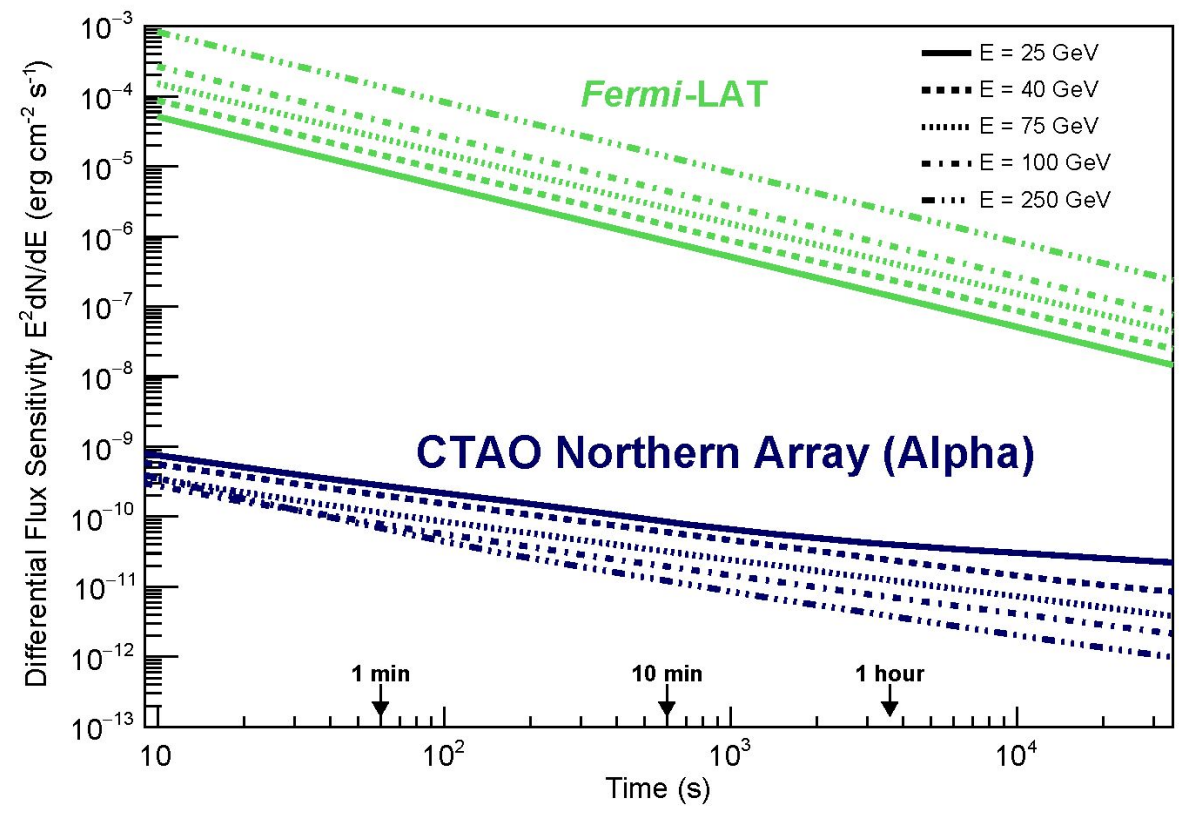
CTAO-North already under construction



Credit: Alicia López Oramas (IAC)

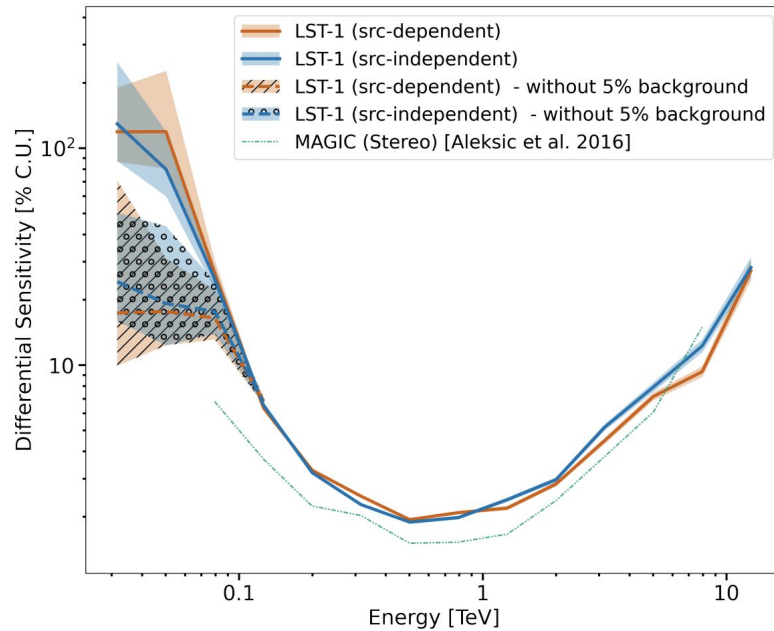
CTAO

- Improved sensitivity by a factor 10 with respect to the current generation of Cherenkov telescopes



LST-1

- First telescope of the northern array
- Operating since 2020
- **Lowest energy threshold** among current Cherenkov telescopes: ~ 30 GeV



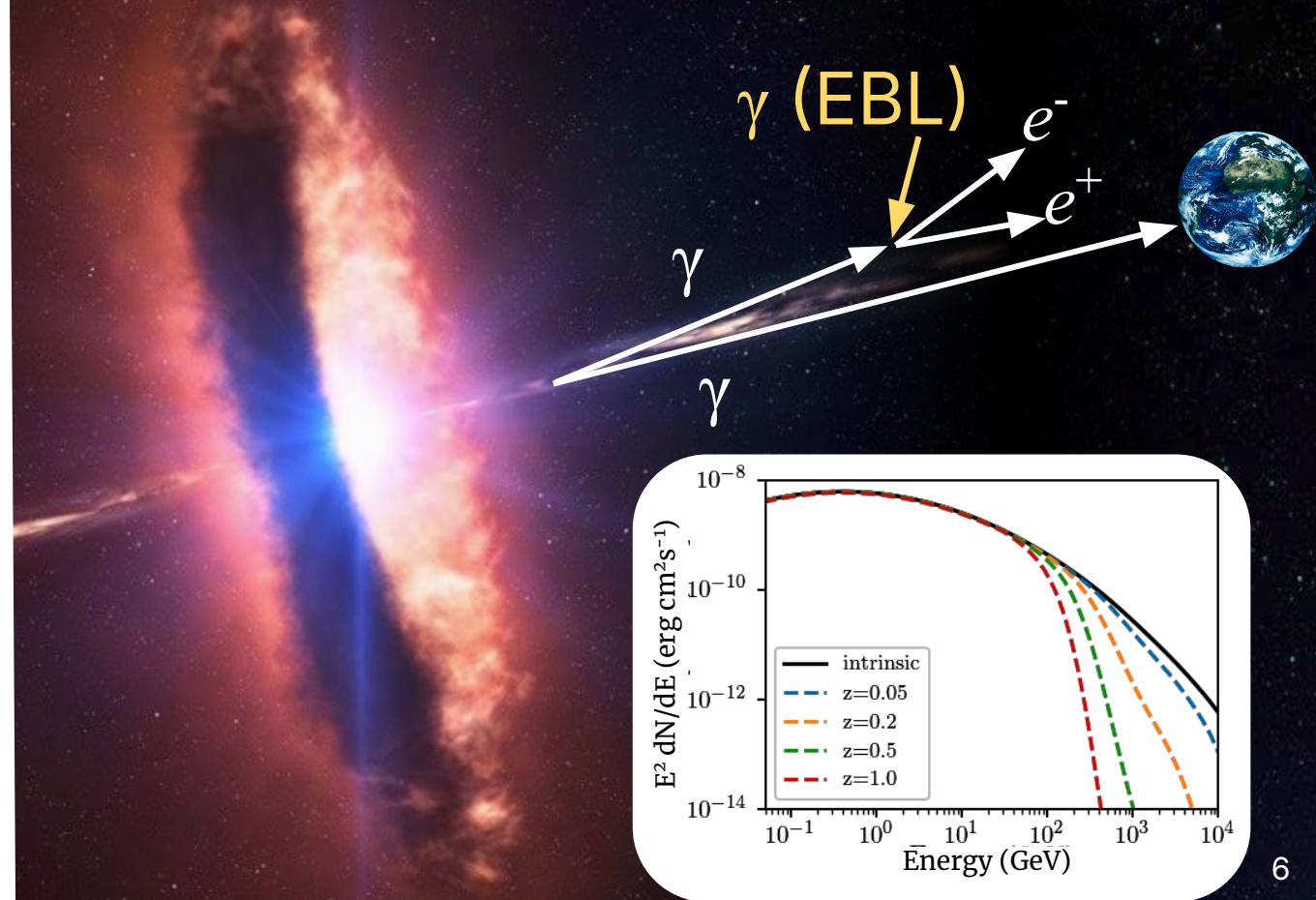
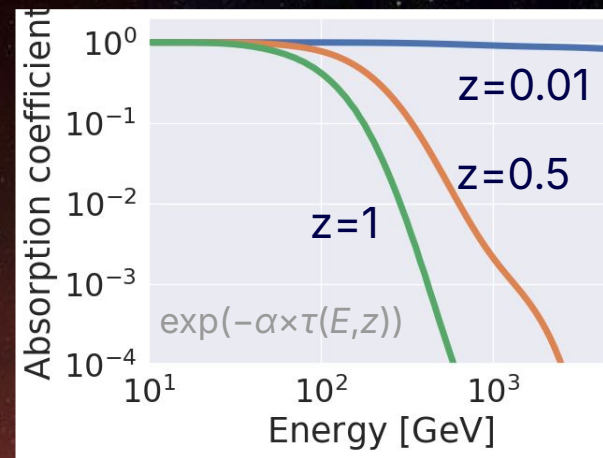
Large-Sized Telescope prototype for the future CTAO

23 m

Fast rotation 180° / 20 s

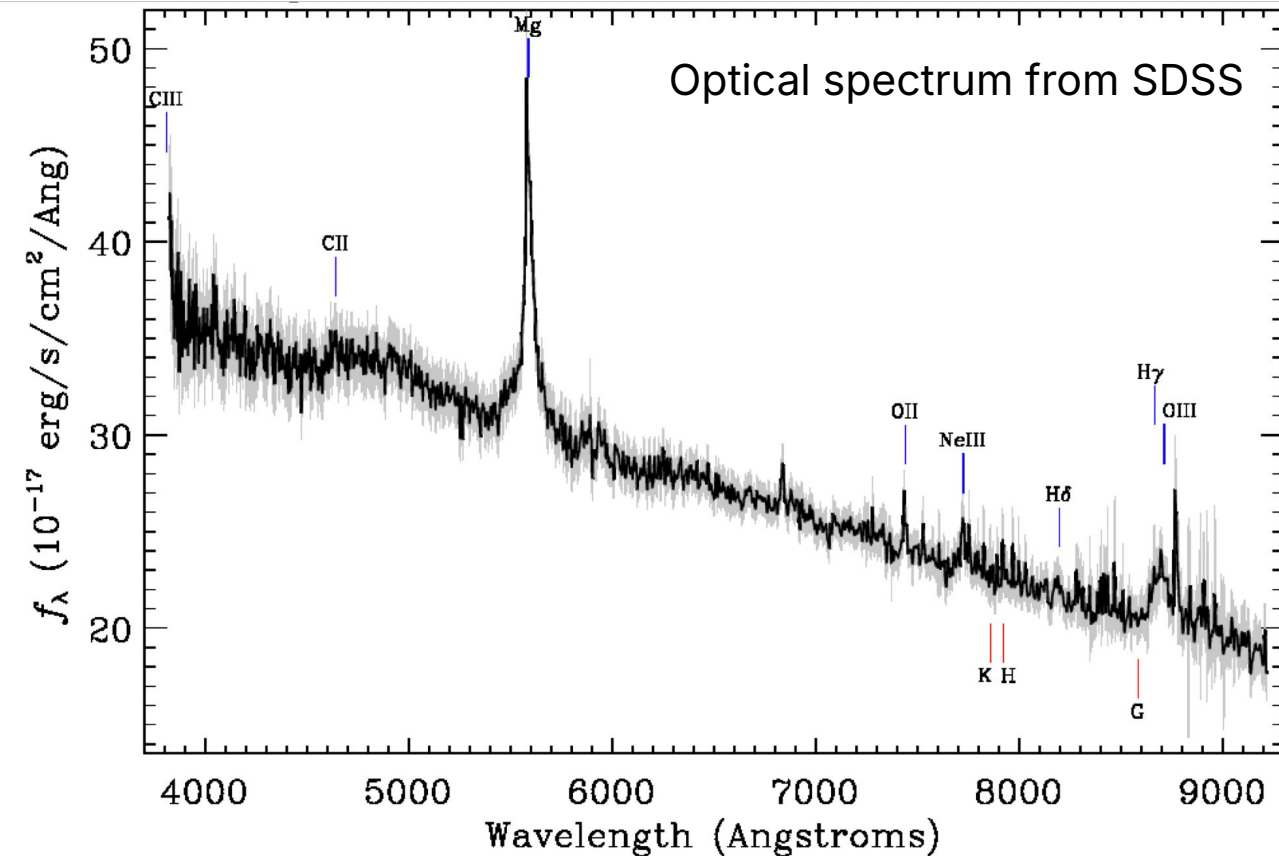
LST-1

- First telescope of the northern array
- Operating since 2020
- **Lowest energy threshold** among current Cherenkov telescopes: ~30 GeV
- **Key for distant extragalactic sources:** VHE (>100 GeV) gamma rays strongly attenuated due to extragalactic background light (EBL)
- Pushes the boundary of visible VHE gamma-ray universe $z \gtrsim 1$ from ground-based telescopes



Quasar OP 313

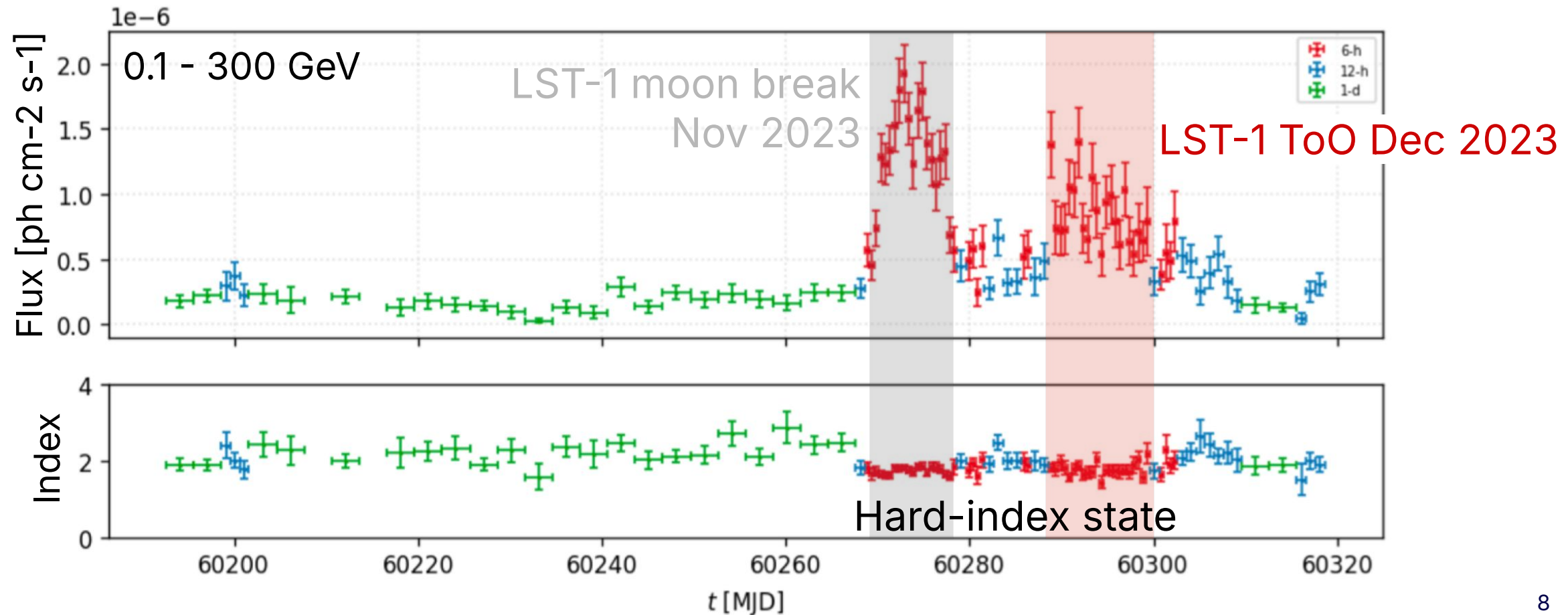
- Distant ($z = 0.9973$) flat-spectrum radio quasar (FSRQ)
 - Only 9 known at VHE before
- Not detected at VHE before
 - Several attempts by MAGIC (2014 & 2019)
 - Also observed by LST-1 in 2022 (no detection)
- Strong attenuation at VHE due to EBL
- Possible internal absorption of its gamma-ray emission



Fermi-LAT monitoring

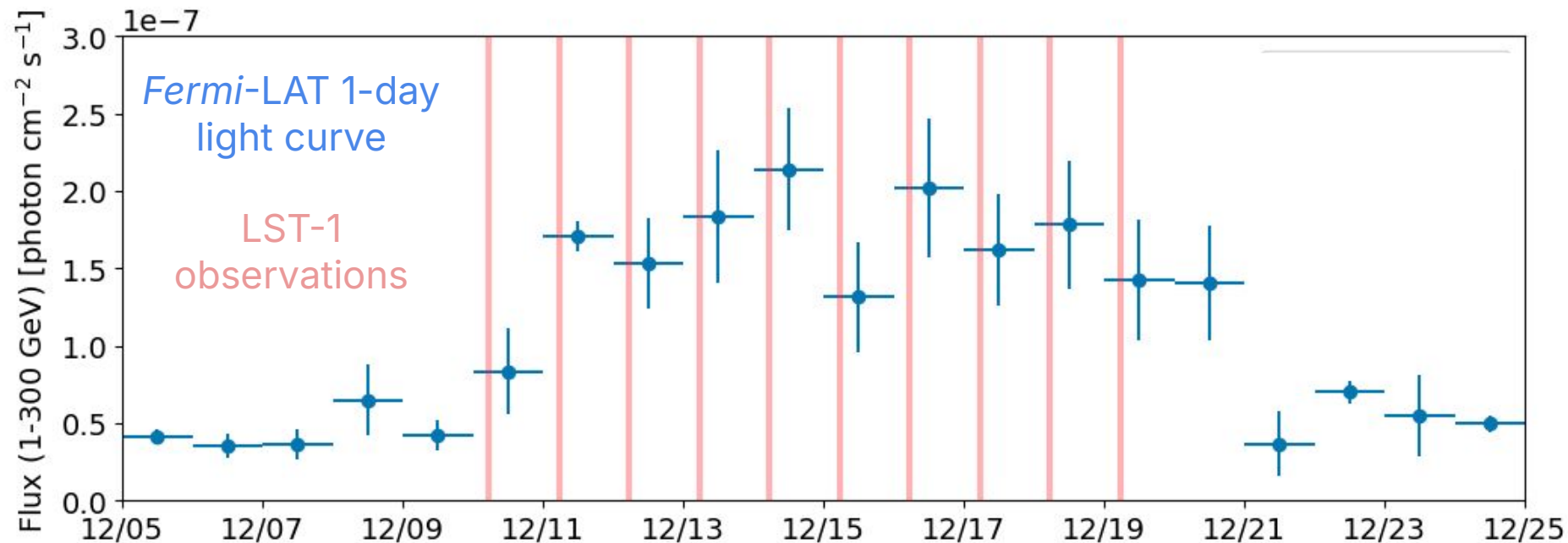
Flaring episodes since November 2023 (LST-1 moon break)

LST-1 ToO observations started on December 9th, 2023



LST-1 observation campaign

- LST-1 daily observations from Dec 9 to 18, 2023 (15 h) + few days in Jan 2024 (5 h)
 - Good coverage of flare observed by *Fermi*-LAT
- Telescope pointing zenith angle > 30 deg (energy threshold ≈ 40 GeV)



First VHE detection of OP 313

- Detected with $>5\sigma$ (Li&Ma) with data up to Dec 14th, 2023 (~6 h)
- ATel issued by LST-1 (#16381):
10th FSRQ detected in VHE gamma rays



The Astronomer's Telegram

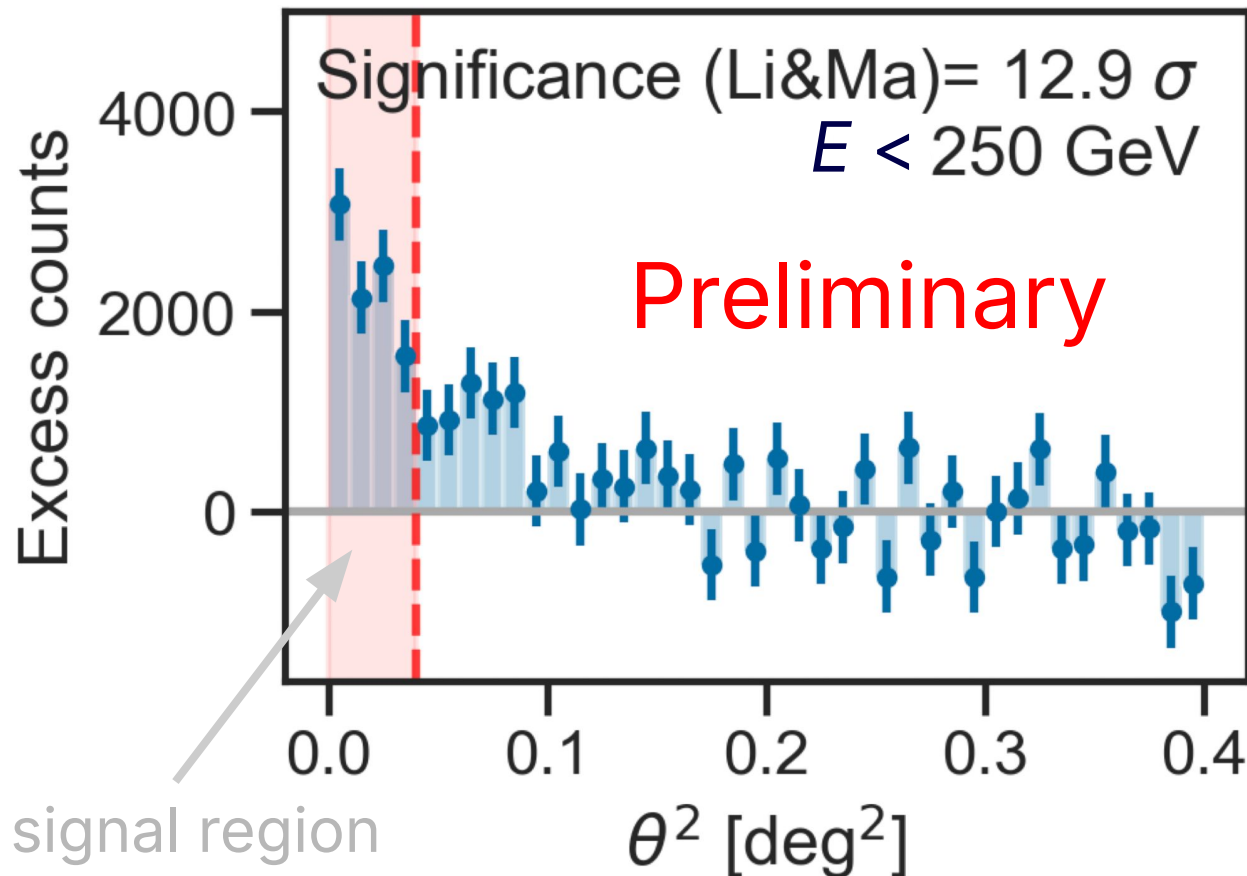
First detection of VHE gamma-ray emission from FSRQ OP 313 with LST-1

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

First VHE detection of OP 313

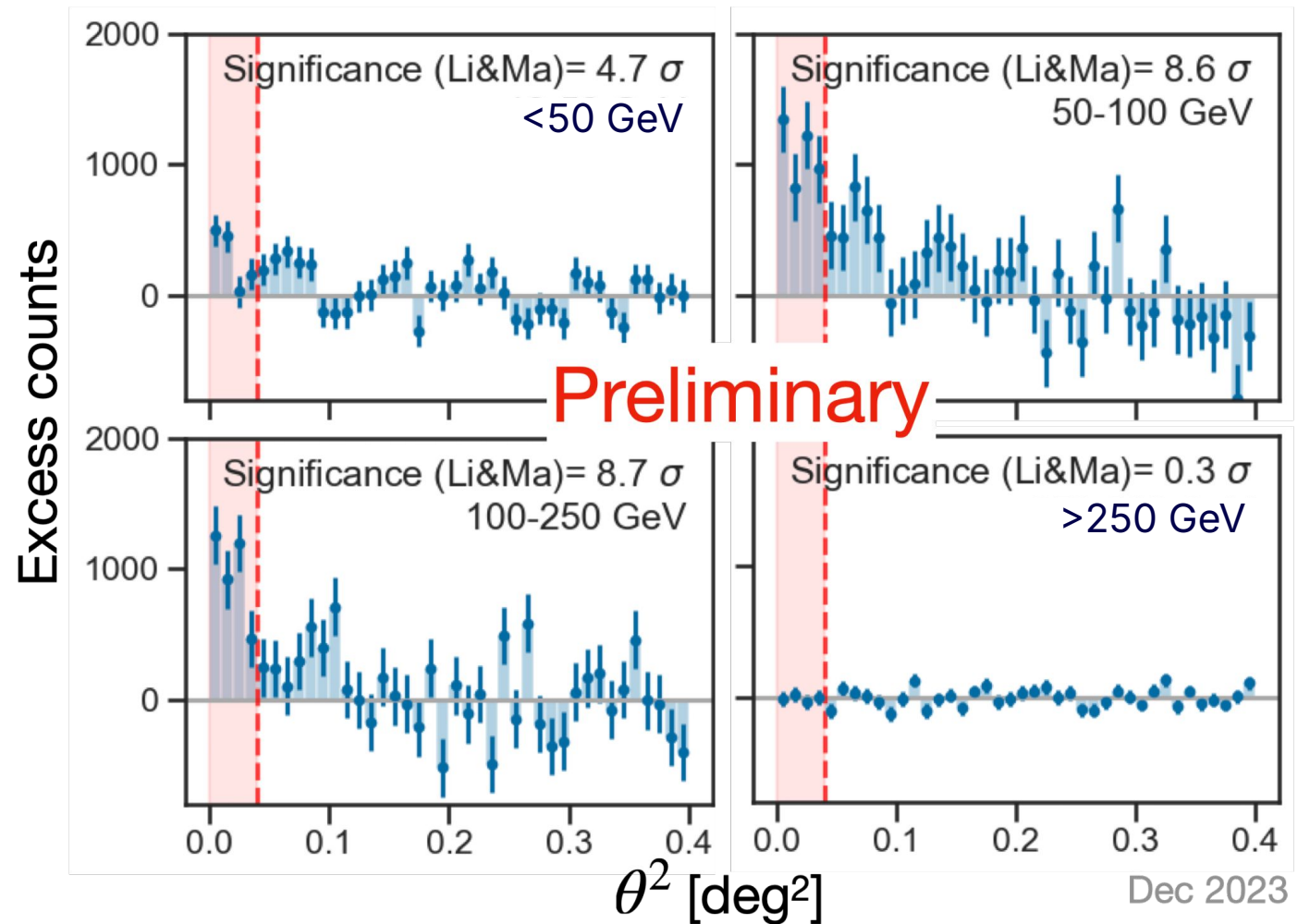


- All December 2023 data (15 h):
Significance (Li&Ma) $\approx 13\sigma$
- No detection at higher energies
- No detection from Jan 2024 observations (5 h)

$\theta^2 \sim$ angular distance between reconstructed positions of the γ -ray excess events and the source location

Energy range of the observed VHE emission

- Strong attenuation at VHE: gamma-ray excess detected <250 GeV
- Average VHE flux (>100 GeV): 28% Crab flux in December 2023



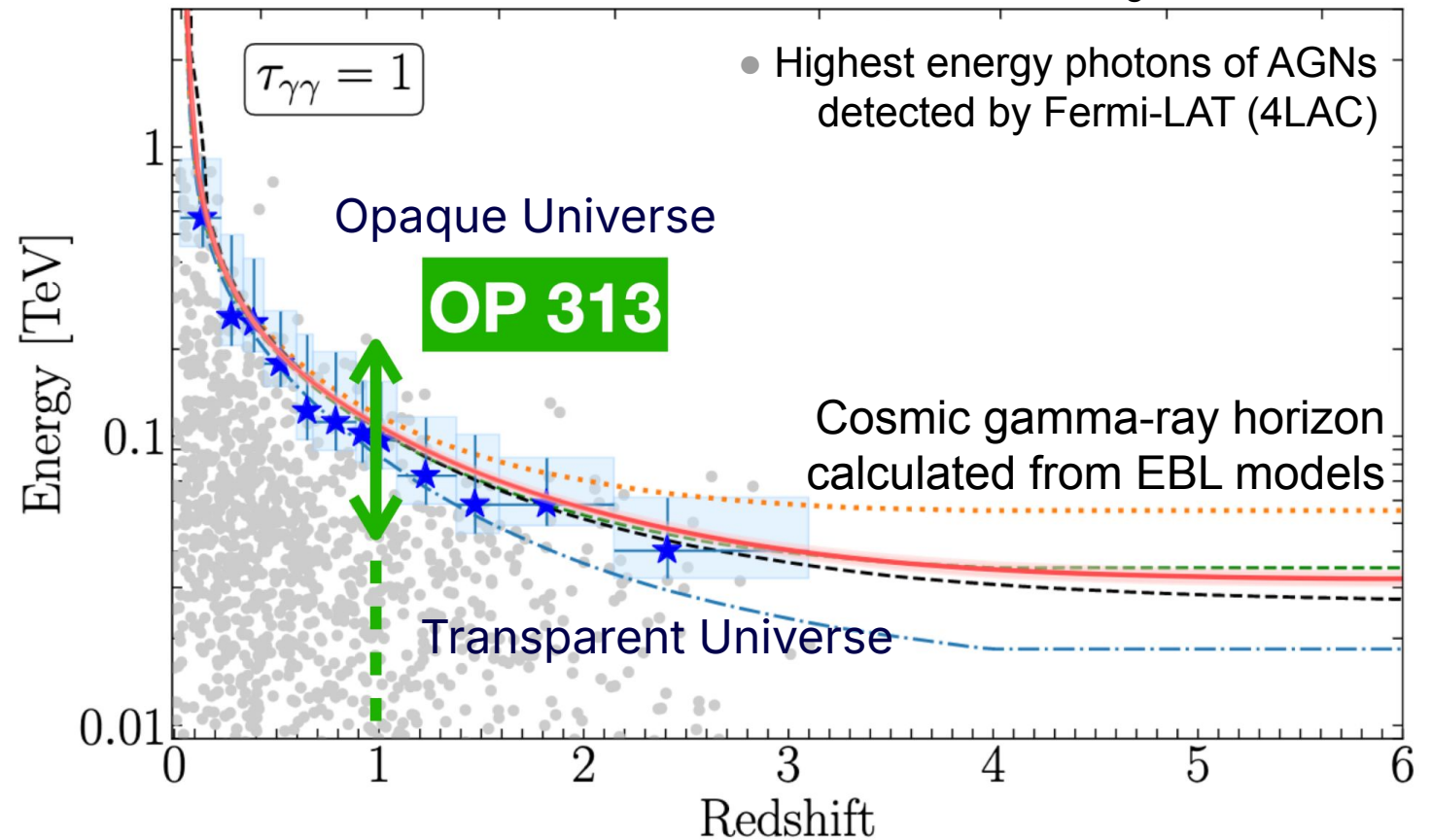
Most distant VHE blazar

Excellent source to test EBL models at $z \sim 1$

Dominguez et al., 2024

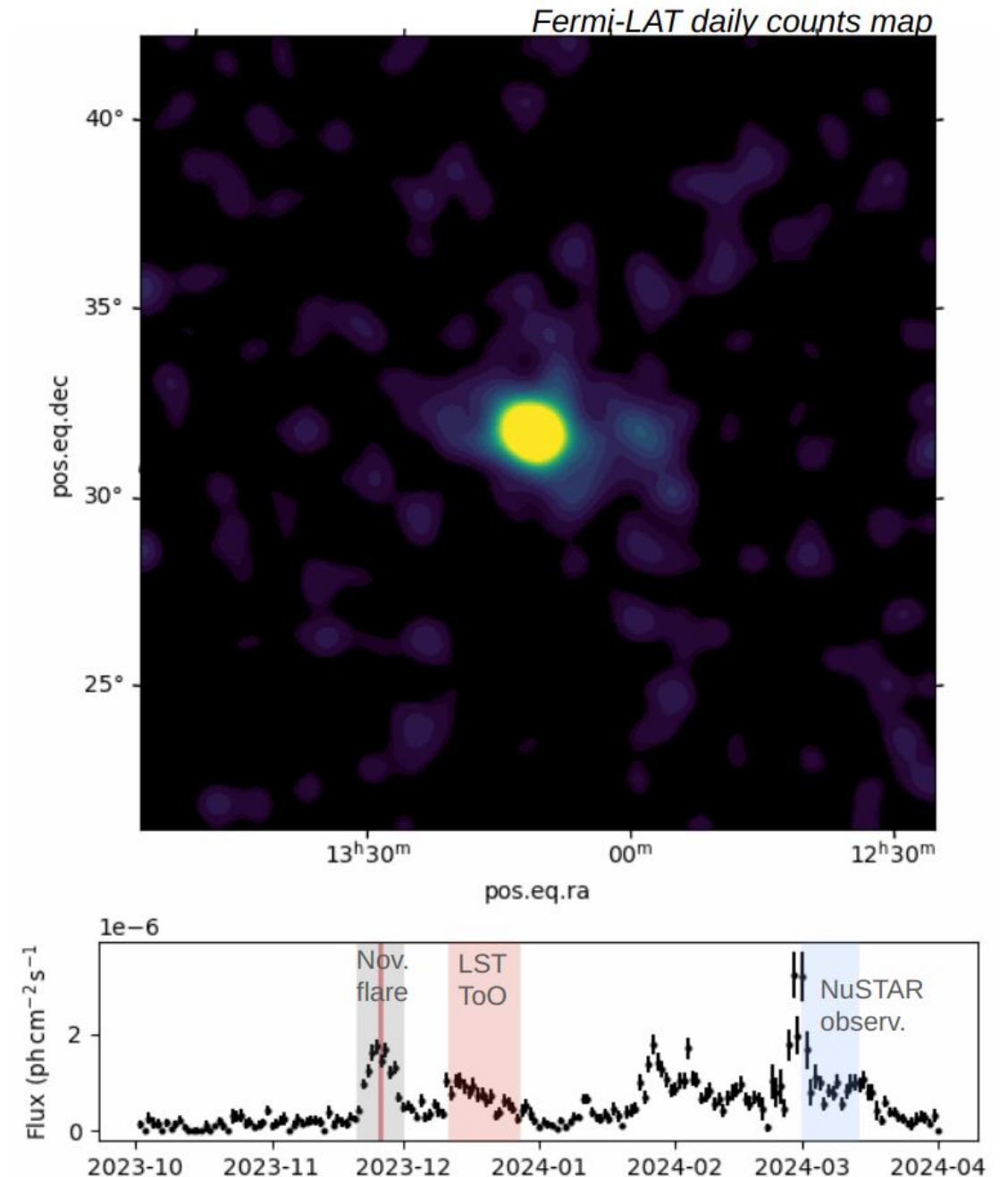
Source	Redshift	Type
GRB 201216C	1.1	GRB
OP 313	0.9973	FSRQ
PKS 0346-27	0.991	FSRQ
S3 0218+35	0.954	FSRQ
PKS 1441+25	0.939	FSRQ
Ton 599	0.7247	FSRQ
PKS 0903-57	0.695	IBL
B2 1420+32	0.682	FSRQ

Most distant VHE sources (TeVCat)



Ongoing work

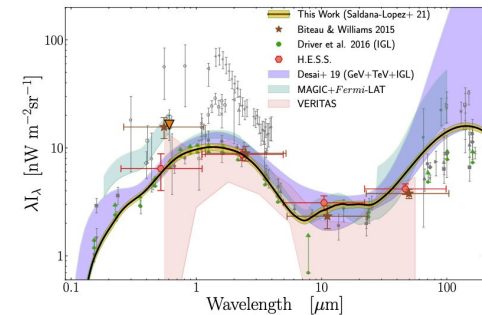
- **LST-1 monitoring** of OP 313 based on the flux state in the *Fermi*-LAT band
- Extensive **multiwavelength follow-up** campaign
- Very active in *Fermi*-LAT since November 2023
- Among the **top most luminous AGN** ever observed by the LAT



Ongoing work

- Gamma-ray spectral energy distribution (SED) of simultaneous LST-1 and Fermi-LAT data
 - Constrain EBL models at redshift $z \sim 1$ (scanning EBL normalization, α)

$$\left(\frac{dF}{dE}\right)_{\text{obs}} = \left(\frac{dF}{dE}\right)_{\text{int}} \times e^{-\alpha \times \tau(E,z)}$$

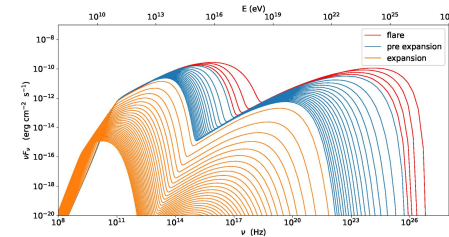
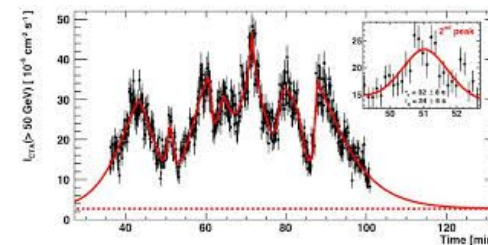
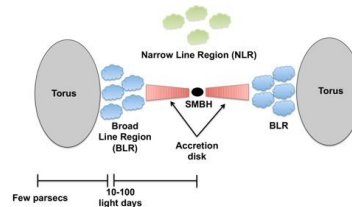


- Intrinsic cut-off in the spectrum at VHE?

- Broadband SED modeling using multiwavelength observations

- Variability studies (long- and short-term)

- Broad line region studies



Bonus:

Taking advantage of the extensive multiwavelength coverage:

A new multi-wavelength analysis and data management workflow based on ...

 A **Python** package for **gamma-ray** astronomy

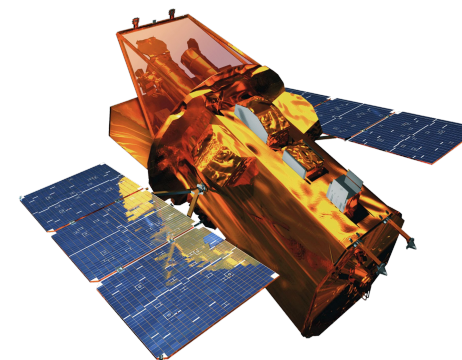
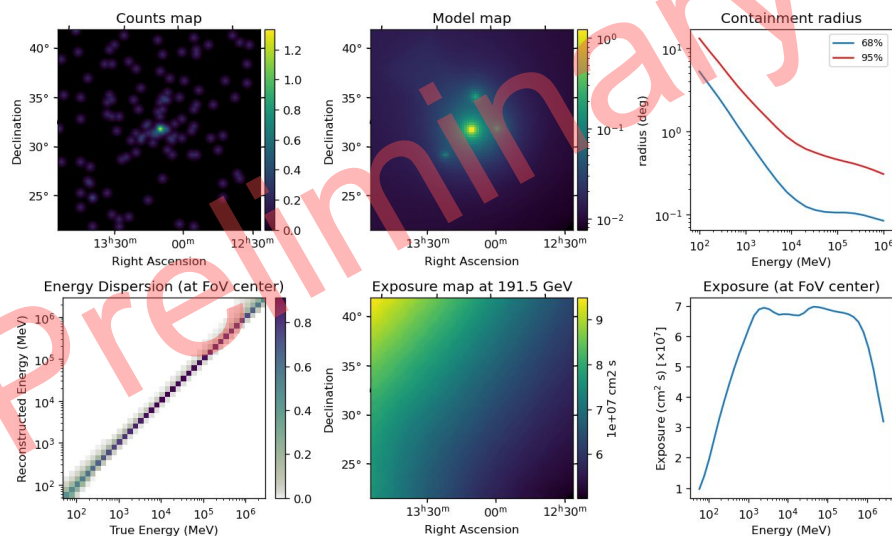
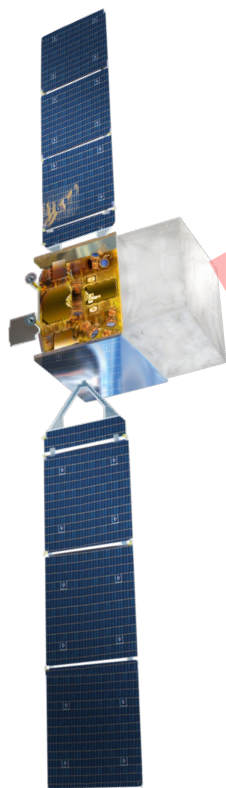
1st Goal: publish *binned event data* from optical to gamma-rays (>11 orders of magnitude)

2nd Goal: full forward folding (events, IRFs) analysis: no more flux points !

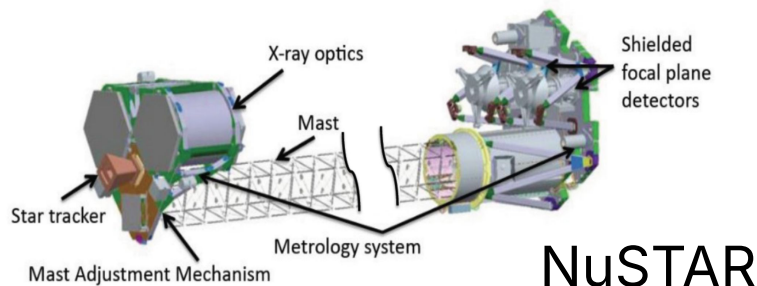
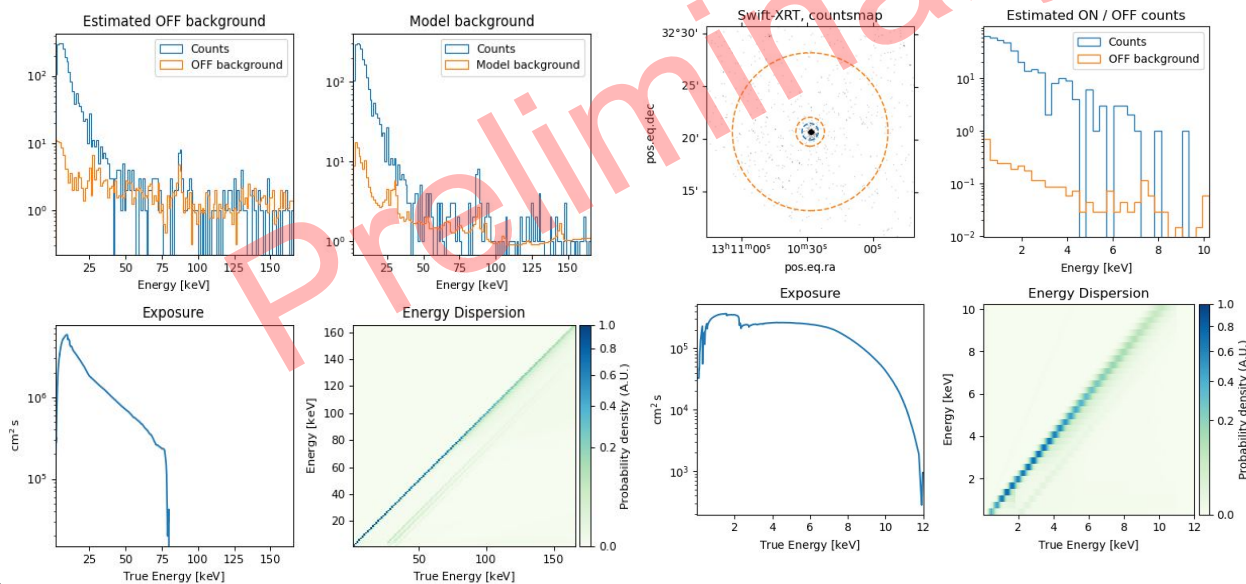
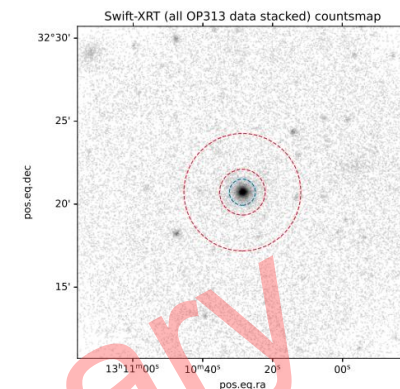
MWL gammamapy workflow

Multi-instrument data management

Fermi-LAT

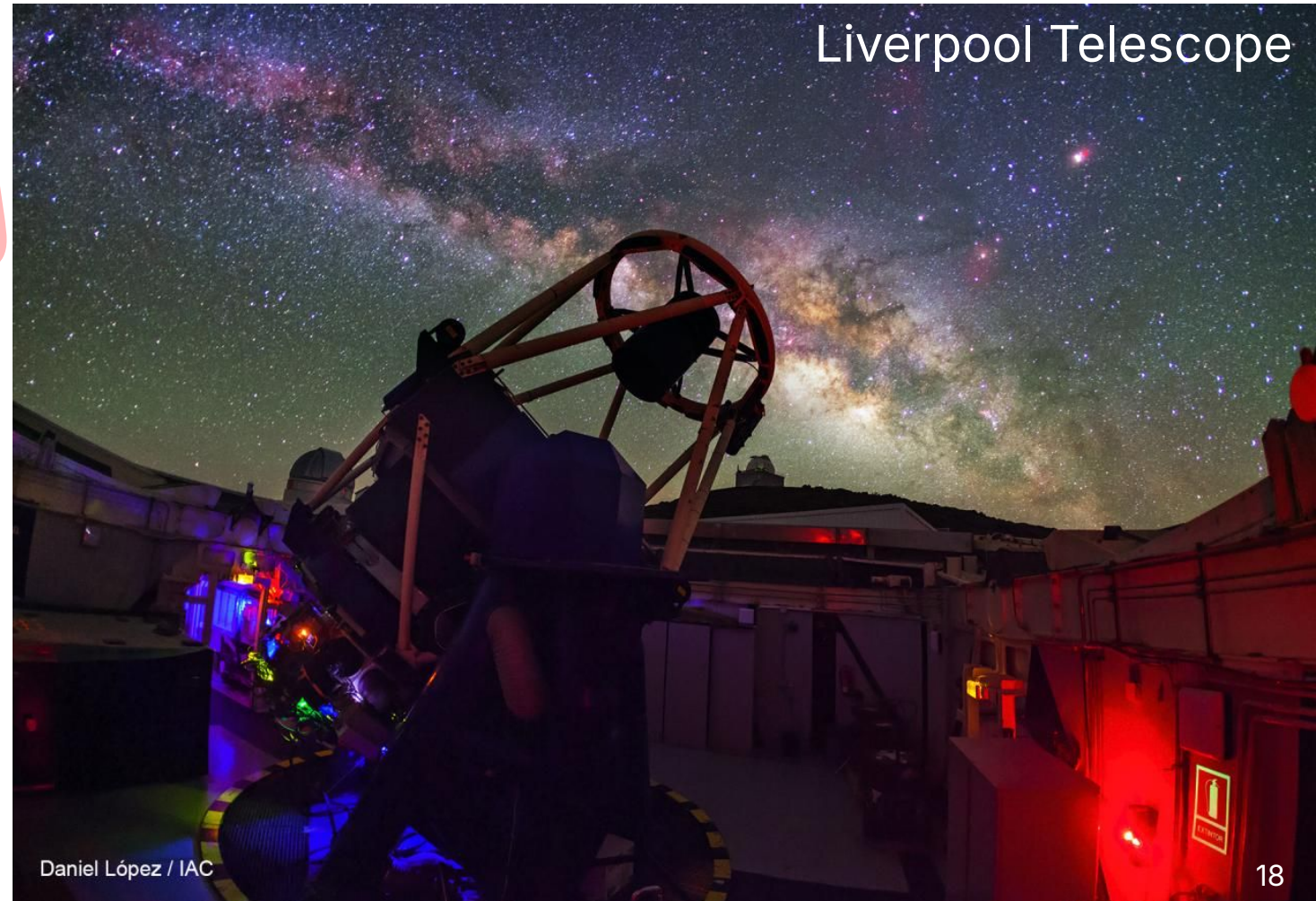
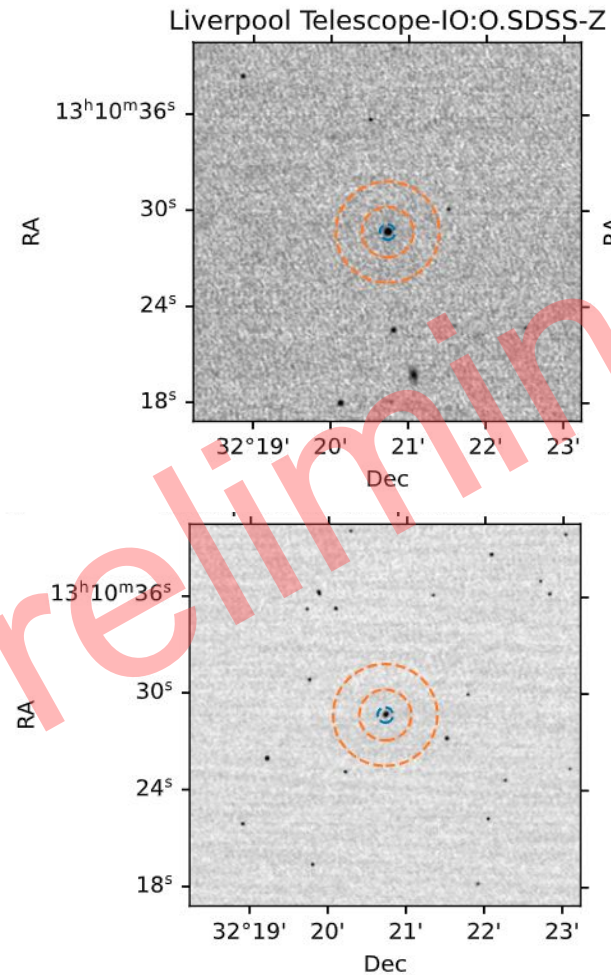


Swift-UVOT/XRT



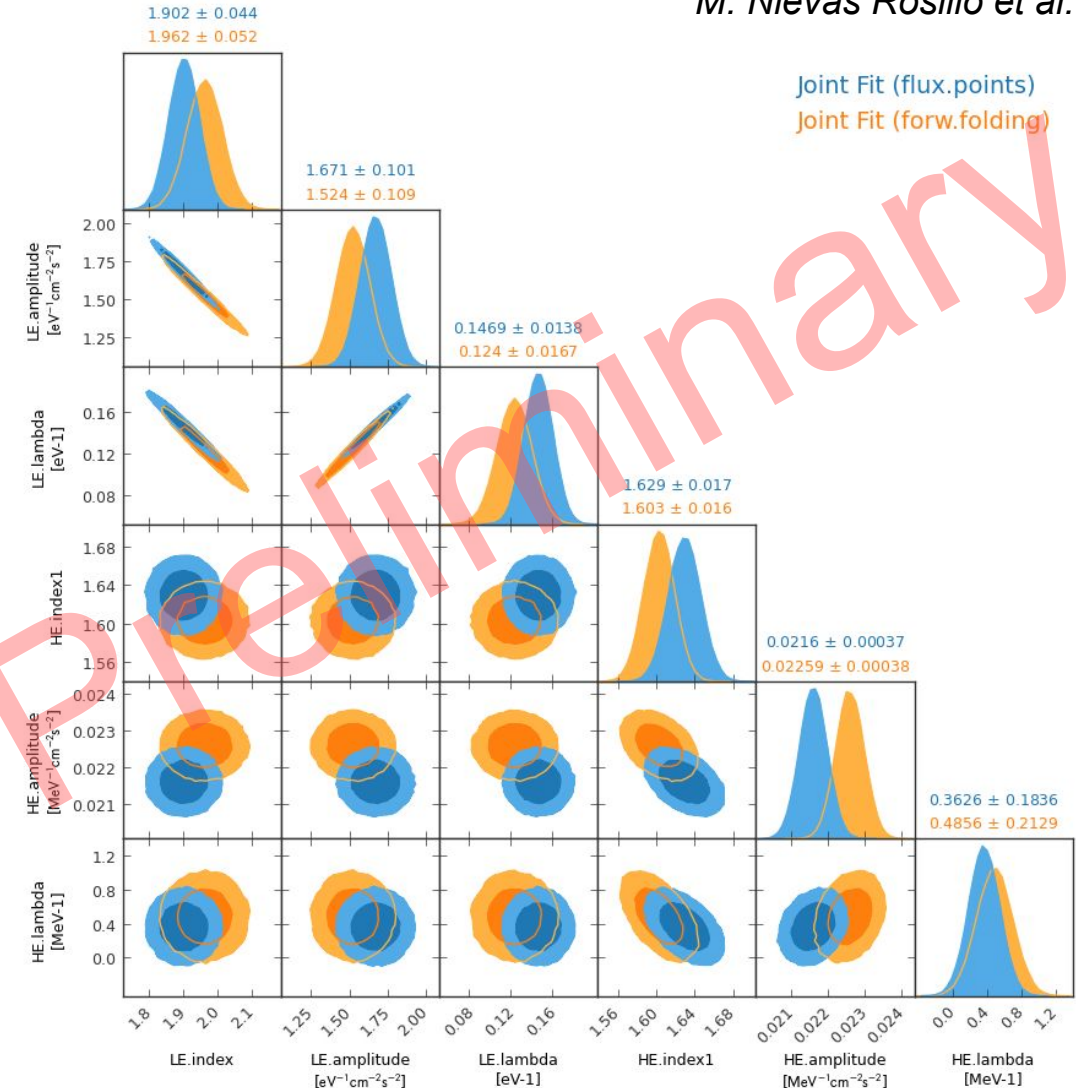
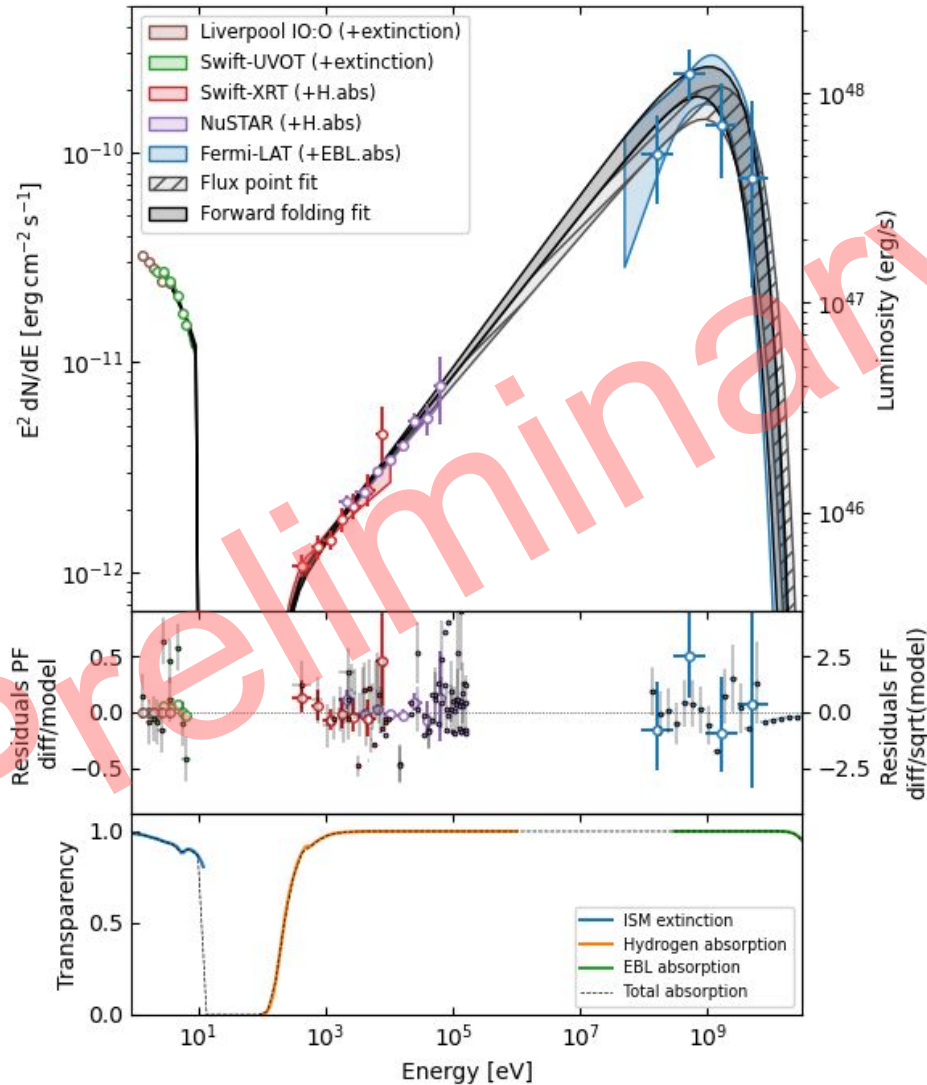
MWL gammapy workflow

Multi-instrument data management



MWL gammapy workflow

M. Nievas Rosillo et al. (in prep)



Summary

- LST-1 ToO triggered due to a **high-flux state** in the *Fermi-LAT* band
- **First detection** of **VHE** gamma-ray emission from quasar **OP 313**
 - **Prompt reaction** of LST Collaboration (observations and analysis)
 - **First VHE source discovered by LST-1**
 - **Furthest VHE blazar ever detected** ($z = 0.997$)
 - Important **milestone for LST-1** (low energy threshold \rightarrow distant sources)
 - Ongoing: broadband emission modeling and EBL models tests
- **Publication coming soon**. Stay tuned!
- Ongoing publication on a complete **analysis workflow from optical to VHE gamma rays with gammapy** (draft written, currently under review)

Keep tuned for more results!

Thank you

This work was conducted in the context of the CTA-LST Project. We gratefully acknowledge financial support from the agencies and organizations listed here: <https://www.ctao.org/for-scientists/library/acknowledgments/>



LST
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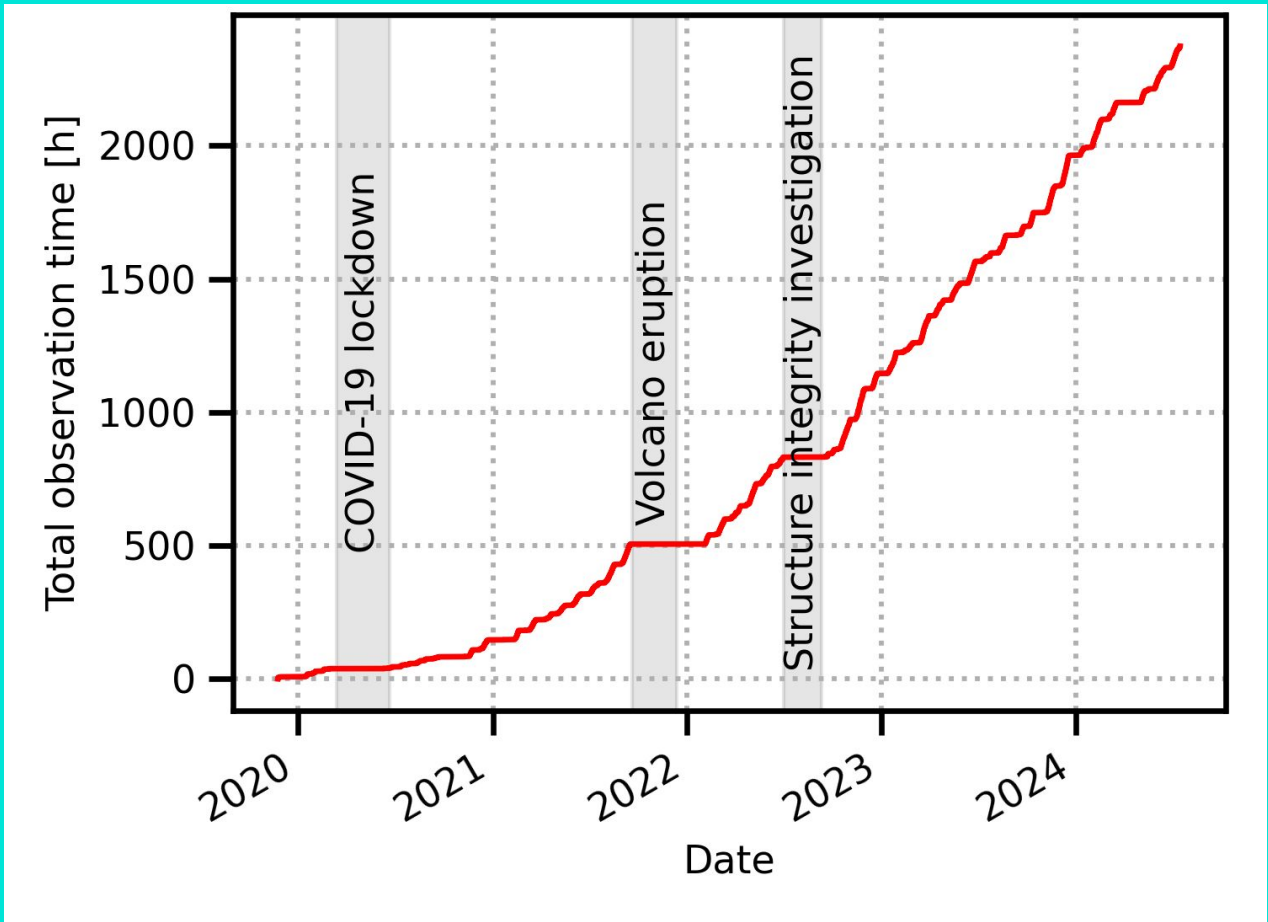


www.ctao.org

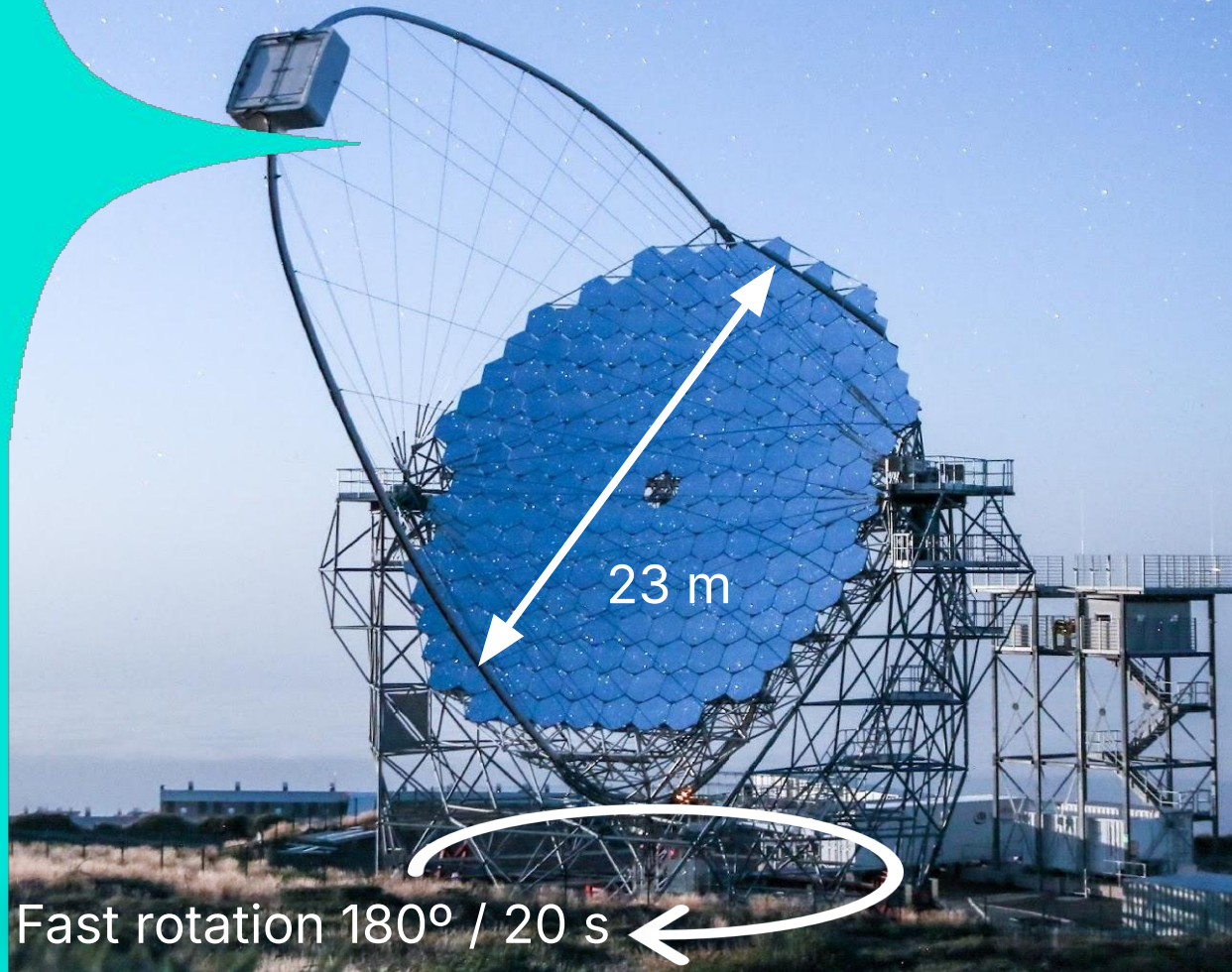
Backup

LST-1

- ~2500 hours of data collected so far

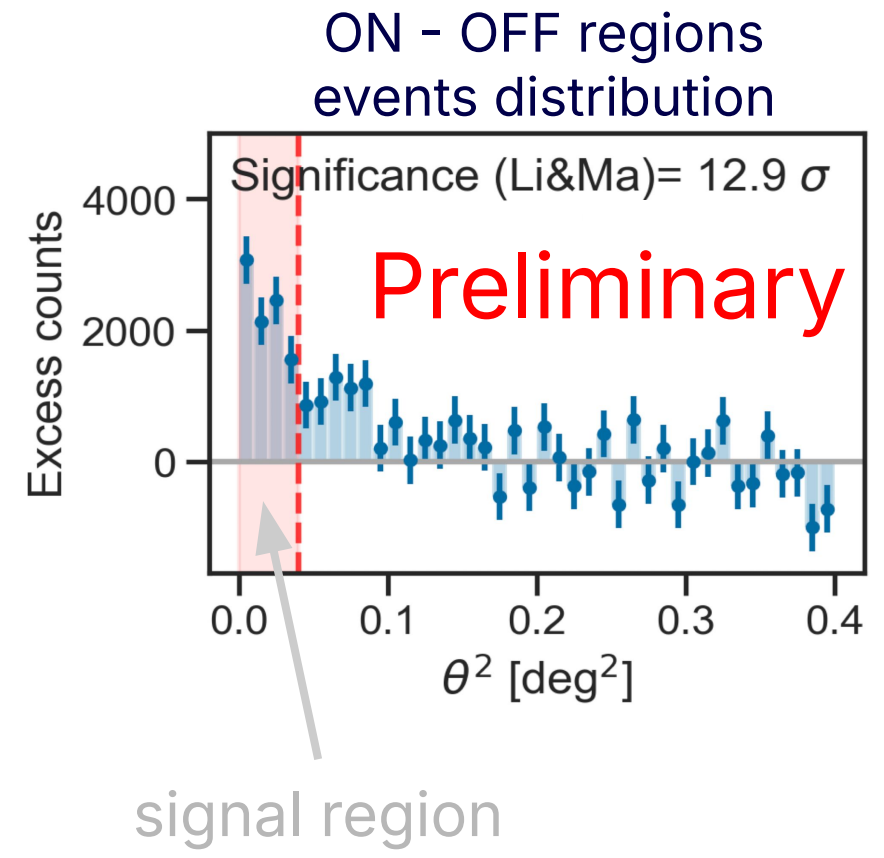
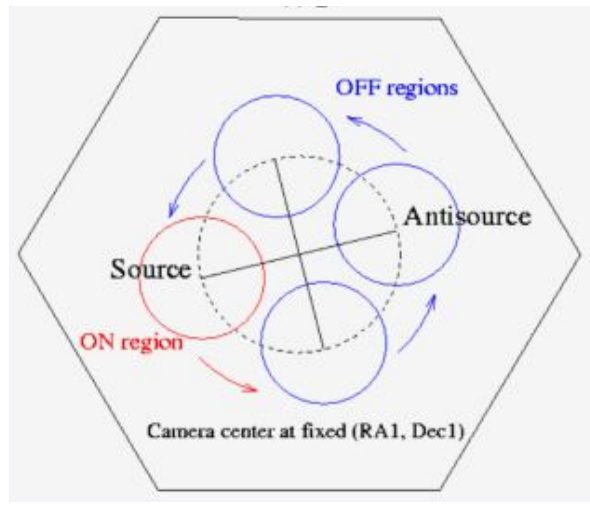
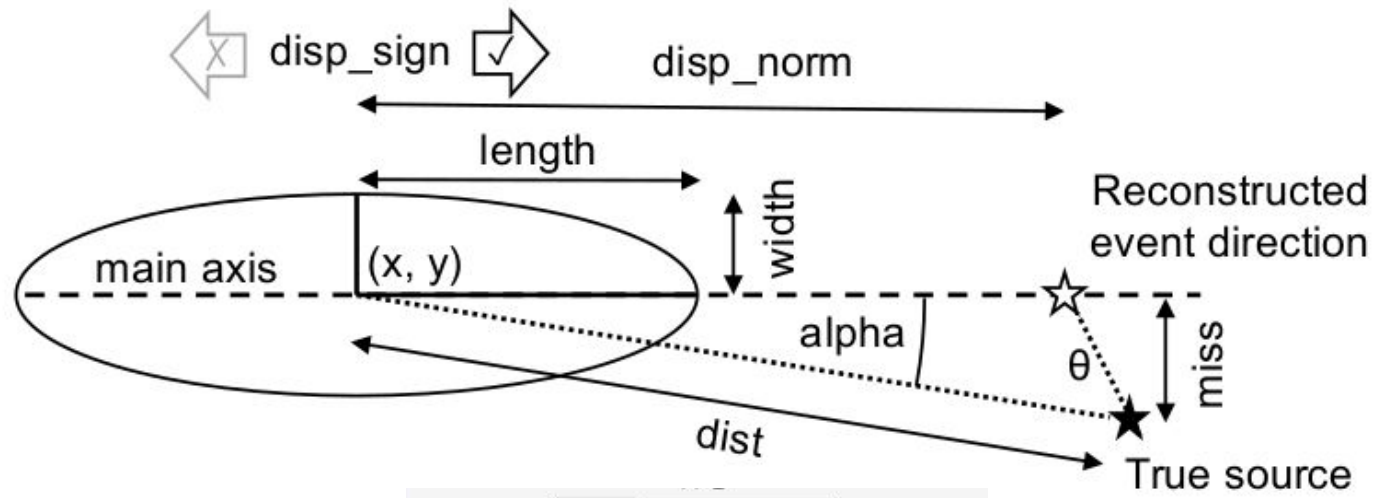


Large-Sized Telescope prototype for the future CTAO



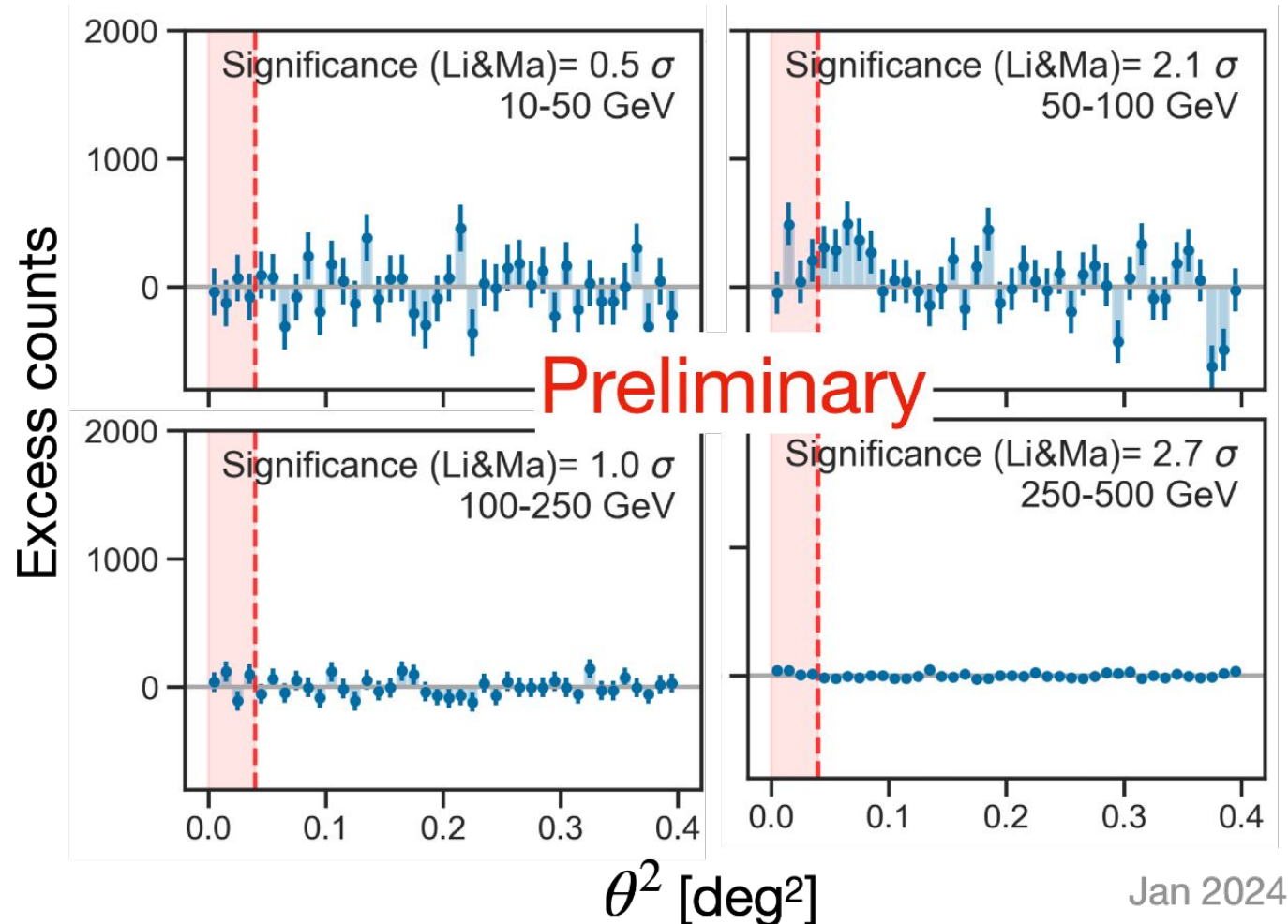
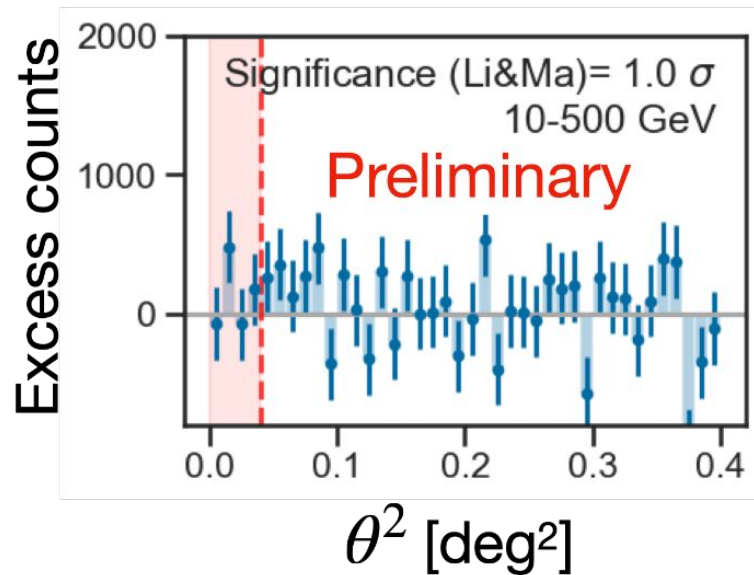
Credit: Tomohiro Inada

Significance of detection



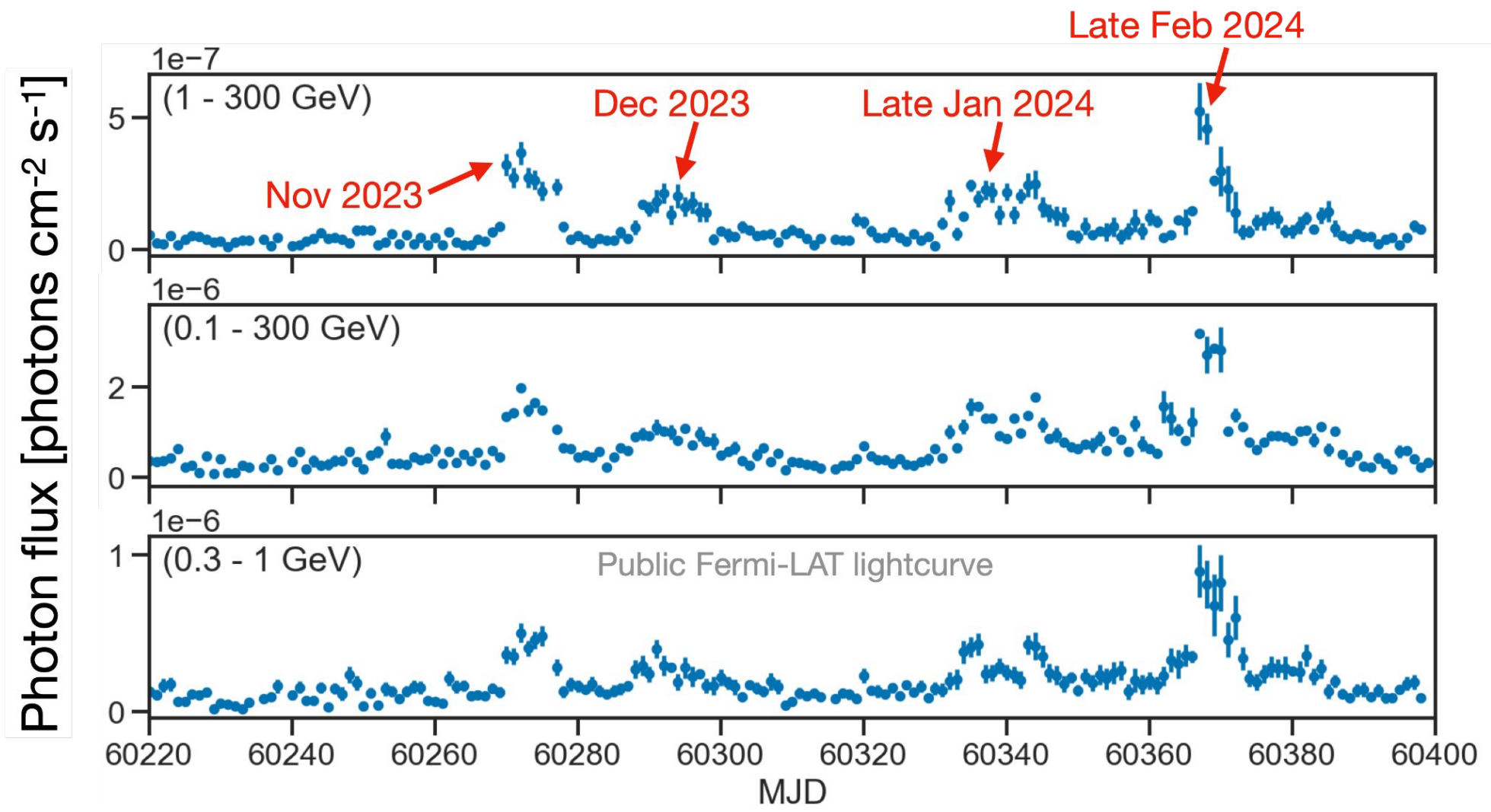
No VHE detection in Jan 2024

- Observations continued during January (low state)
- No detection



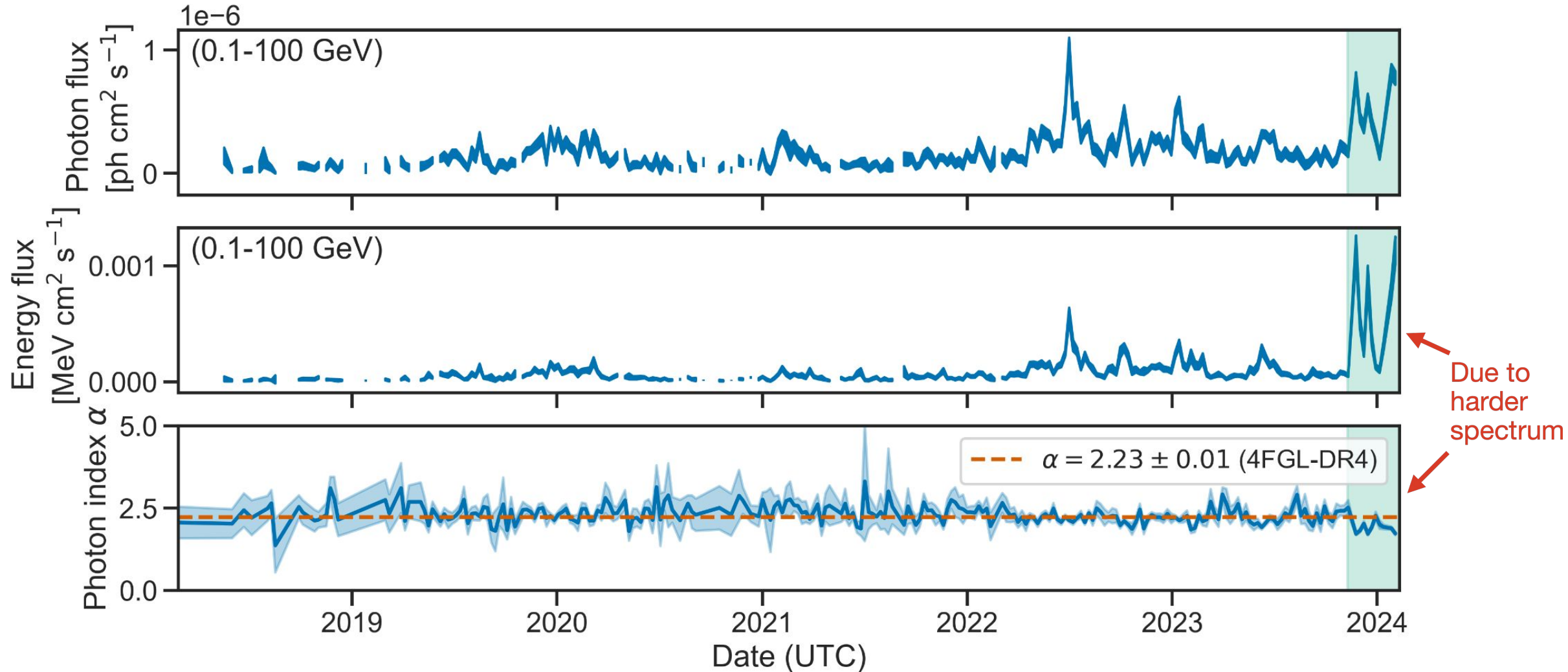
Jan 2024

Fermi-LAT monitoring



Fermi-LAT monitoring

Most energetic flare to date



EBL SED

(Dominguez+ 2023) [arXiv:2306.09878](https://arxiv.org/abs/2306.09878)

