

The roadmap to CTAO AGN Science: Early results on AGNs of LST-1

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Daniel Morcuende (Instituto de Astrofísica de Andalucía - CSIC)
for the extragalactic science working group of the CTAO-LST Project



CTAO

- CTAO-North and CTAO-South sites
- Three telescope sizes: LST, MST, SST
- Better (x10) sensitivity, angular and energy resolution
- Wider energy range (20 GeV - 300 TeV)
- Aiming to detect $O(1000)$ VHE (>100 GeV) gamma-ray sources

(See presentations by M. Teshima and A. López Oramas)



Artistic rendering of CTAO-North. Credit: CTAO



Situation in Aug 2024. Credit: Alicia López Oramas (IAC)

LST-1

- Operating since 2020 @ Roque de los Muchachos Observatory (La Palma)
- **Low energy threshold** (~ 20 GeV)
- Fast rotation ($180^\circ / 20$ s)
- **Soft / transients / distant sources**

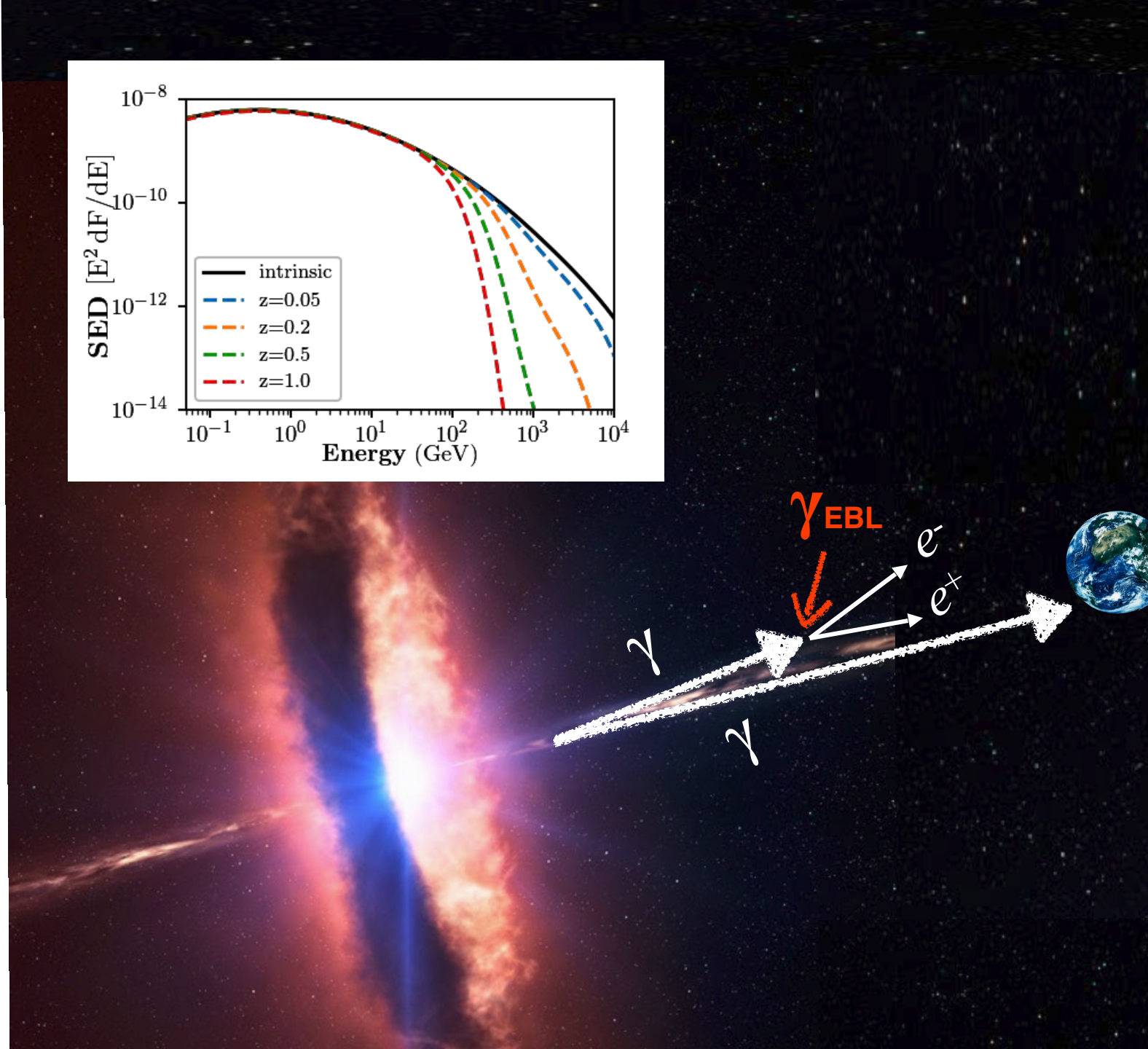
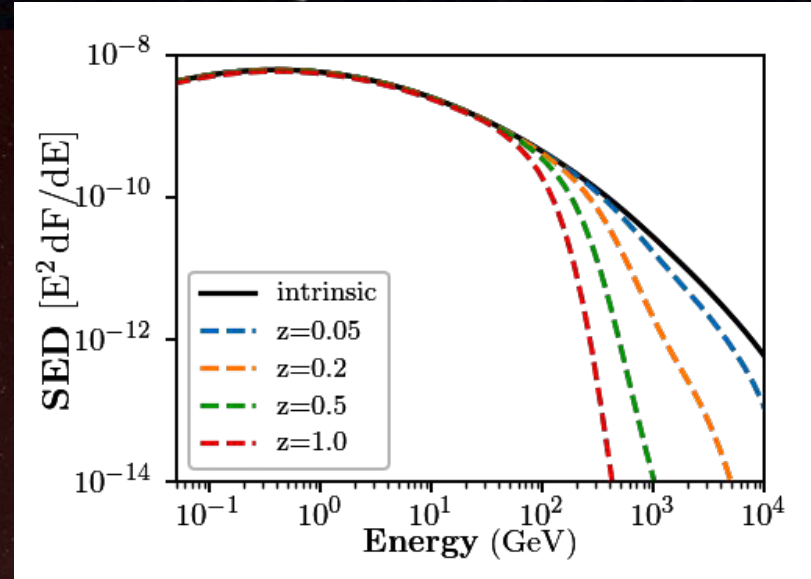
Large-Sized Telescope prototype for the future CTAO



Credit: Tomohiro Inada

LST-1

- **Key for distant extragalactic sources:** attenuation due to extragalactic background light (EBL)
- **Pushes the boundary of visible VHE gamma-ray universe $z \gtrsim 1$** from ground-based telescopes



AGN Science Projects with LST-1

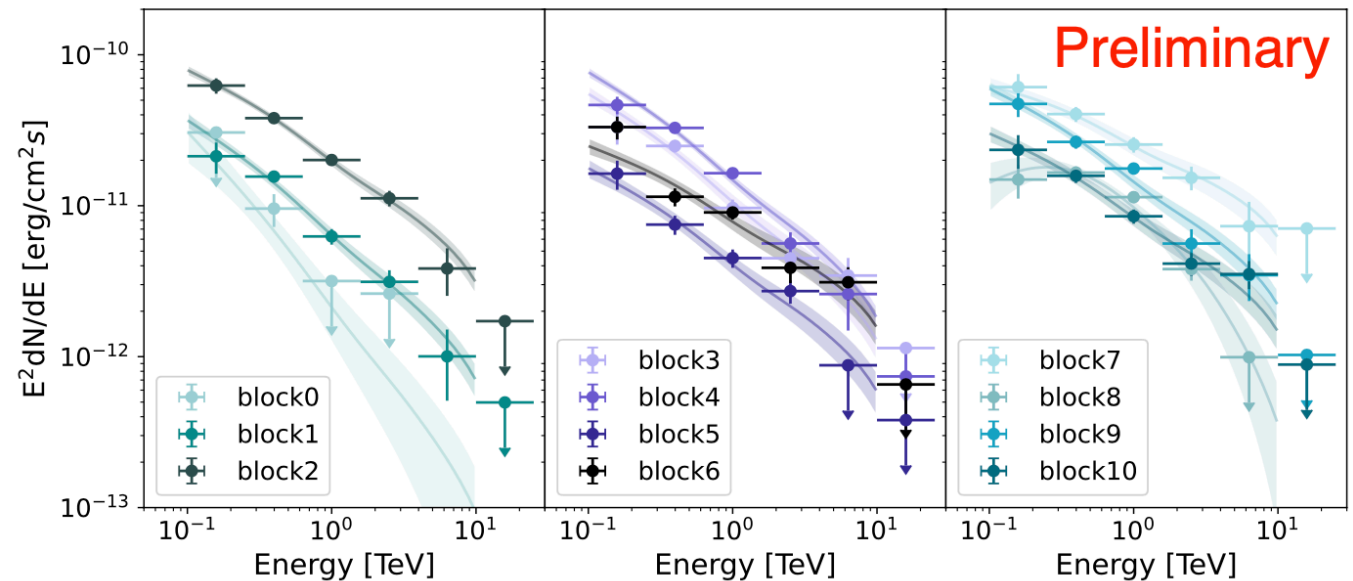
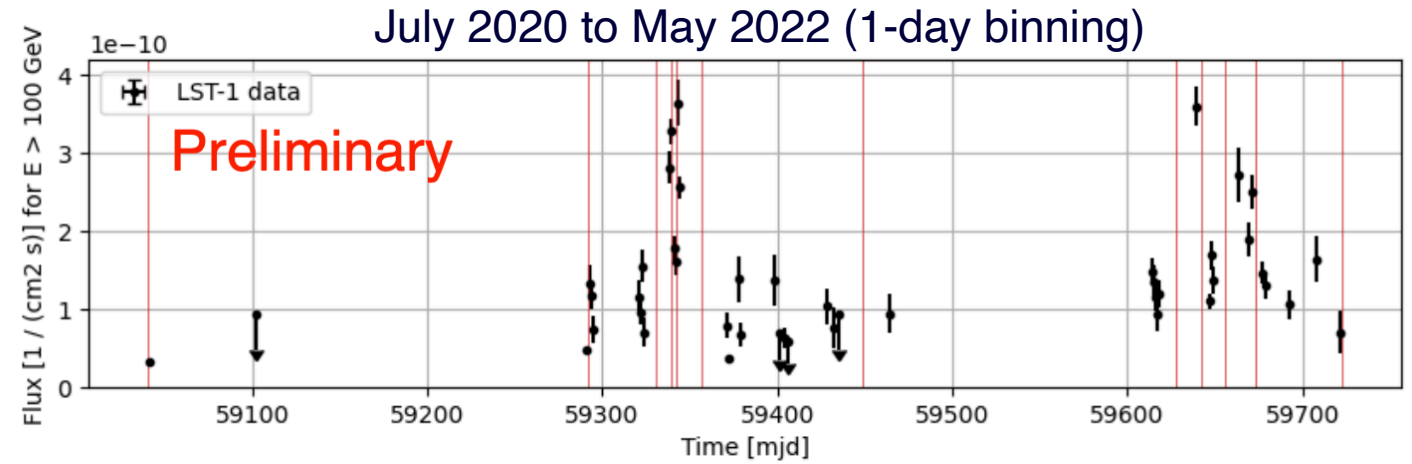
- **1000 h of AGN observations**
- **Monitoring campaigns** of several AGNs
 - Well-known near blazars (Mrk 421, Mrk 501, 1ES 1959+650, BL Lacertae)
 - More distant ones (PG 1553+113, 1ES 0647+250)
 - Radio galaxies (e.g. Perseus cluster: NGC 1275, IC 310)
- **Time of opportunity (ToO) observations** based on alerts from different instruments (Fermi-LAT, optical band, neutrino telescopes)
 - Flares
 - **Detection of new sources at VHE**

Monitoring of known blazars

Mrk 501

Bayesian blocks
to identify different flux states

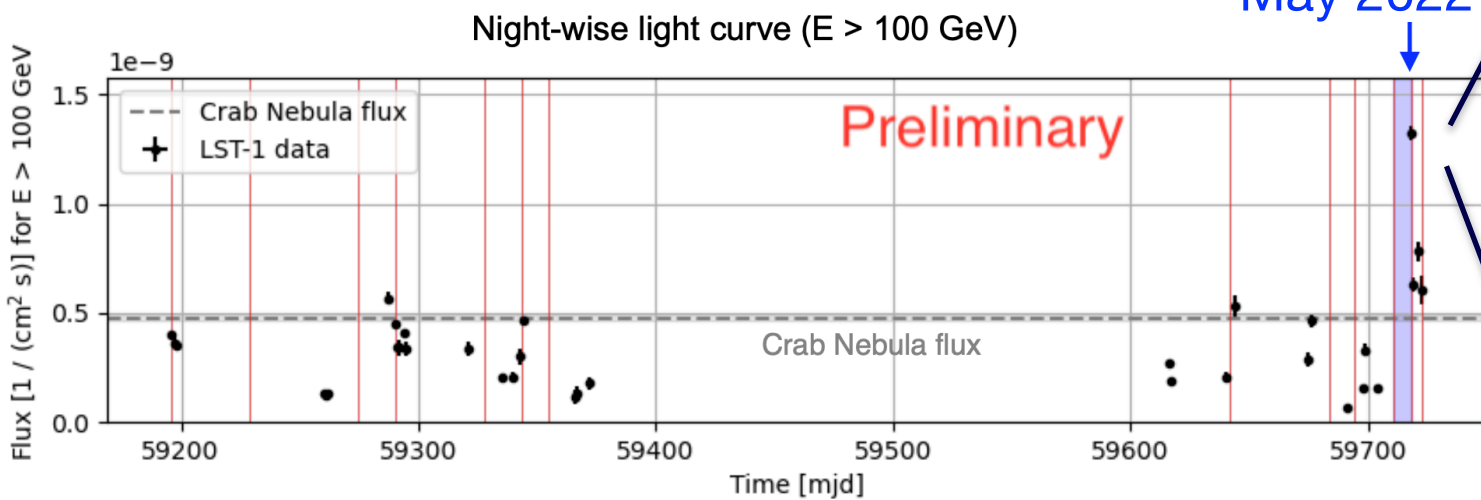
SED for each block
reveals **spectral variability**



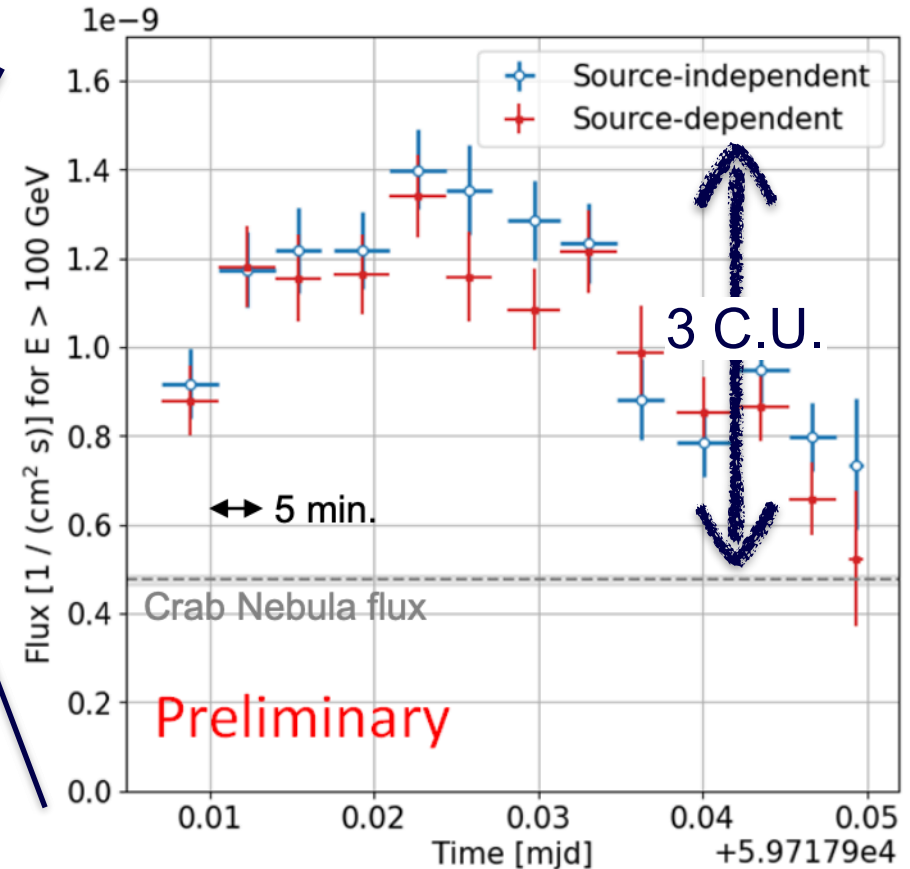
Monitoring of known blazars

Mrk 421

Short-timescale variability



Between 2020 and 2022 (~ 30 h)



BL Lacertae flares

- Brightest flares observed by LST-1 in 2021 and 2022
- Short timescale (sub-hour) variability detected

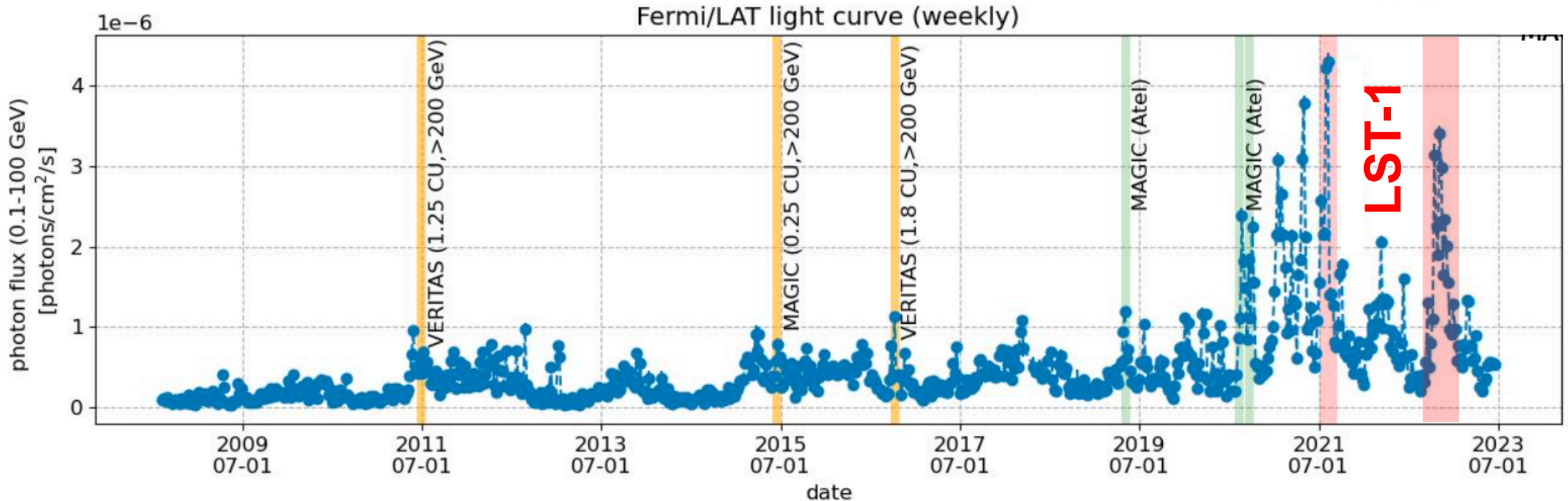
The
Astronomer's Telegram

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

ATel #14783; *Juan Cortina for the CTA LST collaboration*

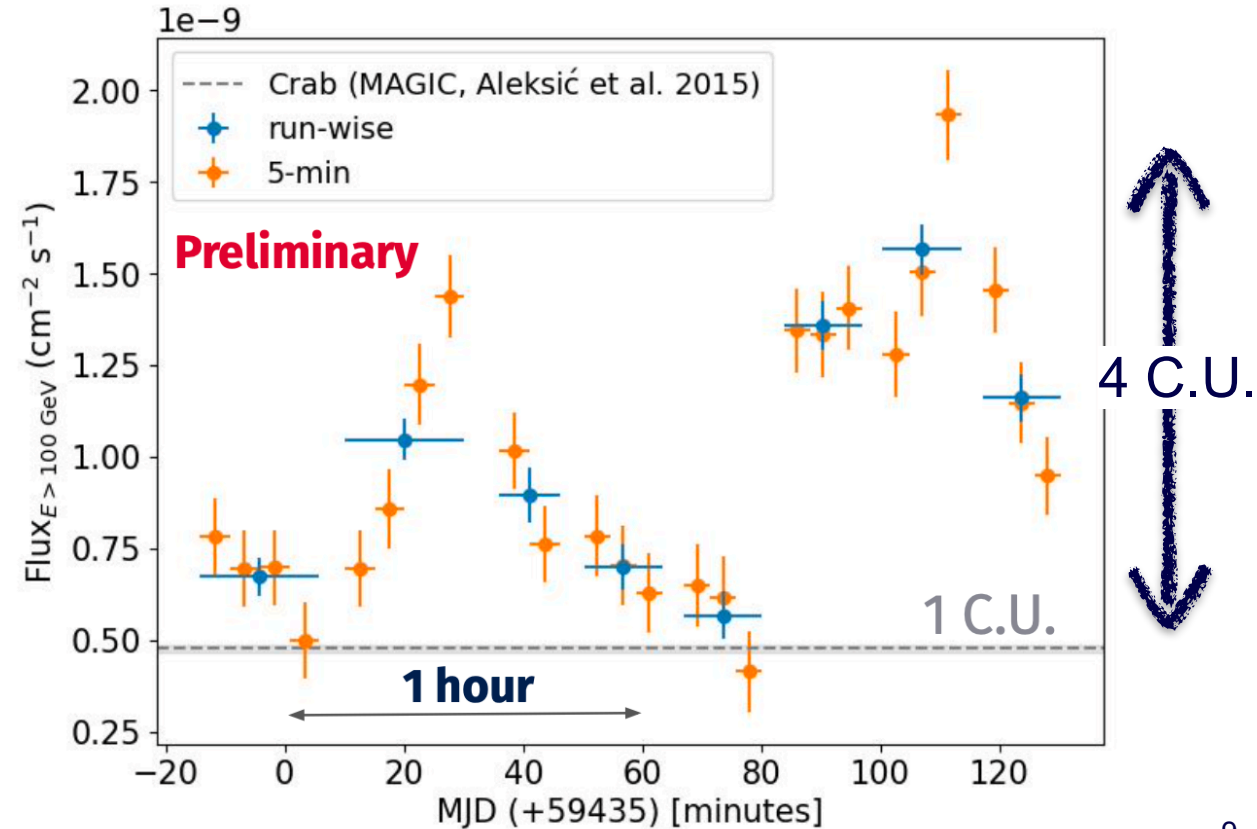
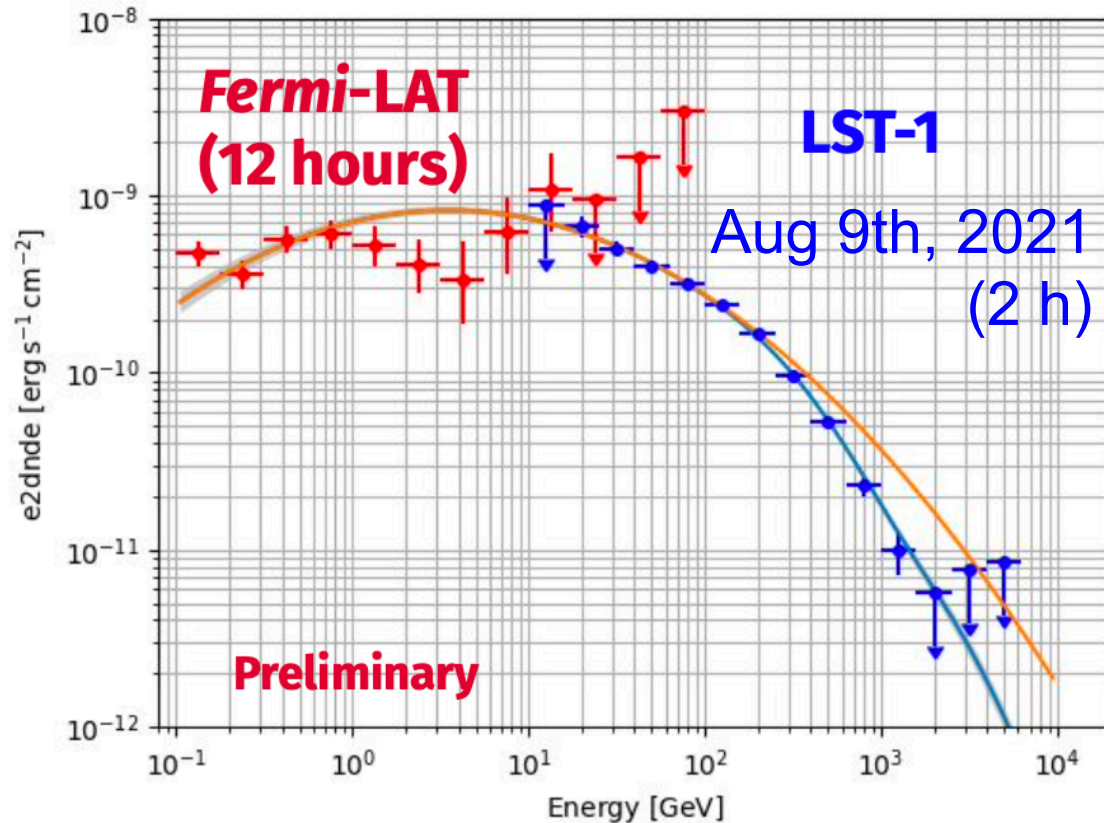
on 13 Jul 2021; 21:03 UT

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



BL Lacertae flares

- Brightest flares observed by LST-1 in 2021 and 2022
- Short timescale (sub-hour) variability detected



Radio galaxies: Perseus Cluster

- **NGC 1275** and **IC 310** detected by LST-1
- NGC 1275: Clear **spectral variability** over the whole period
- IC 310: Mostly ULs, but detected on Dec 2023 (0.2 C.U.)

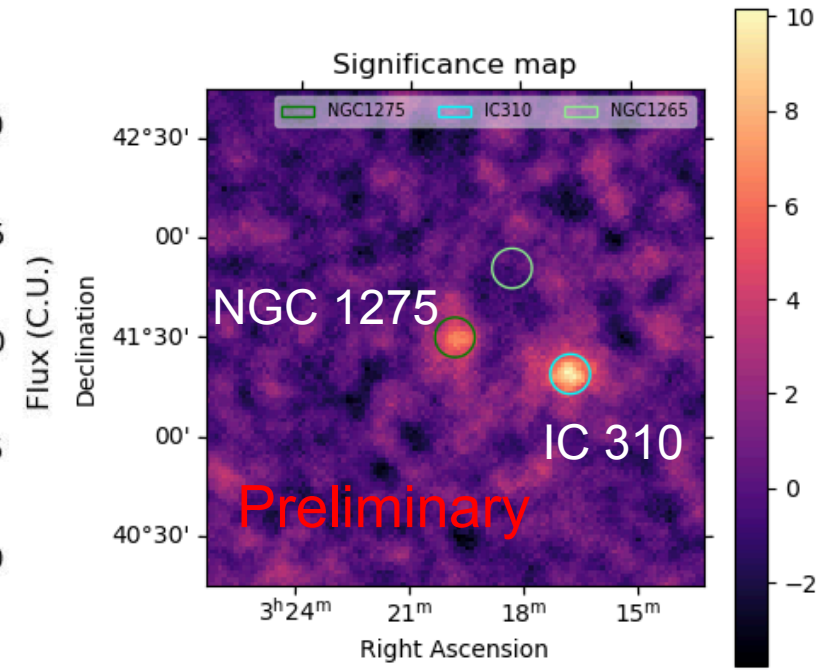
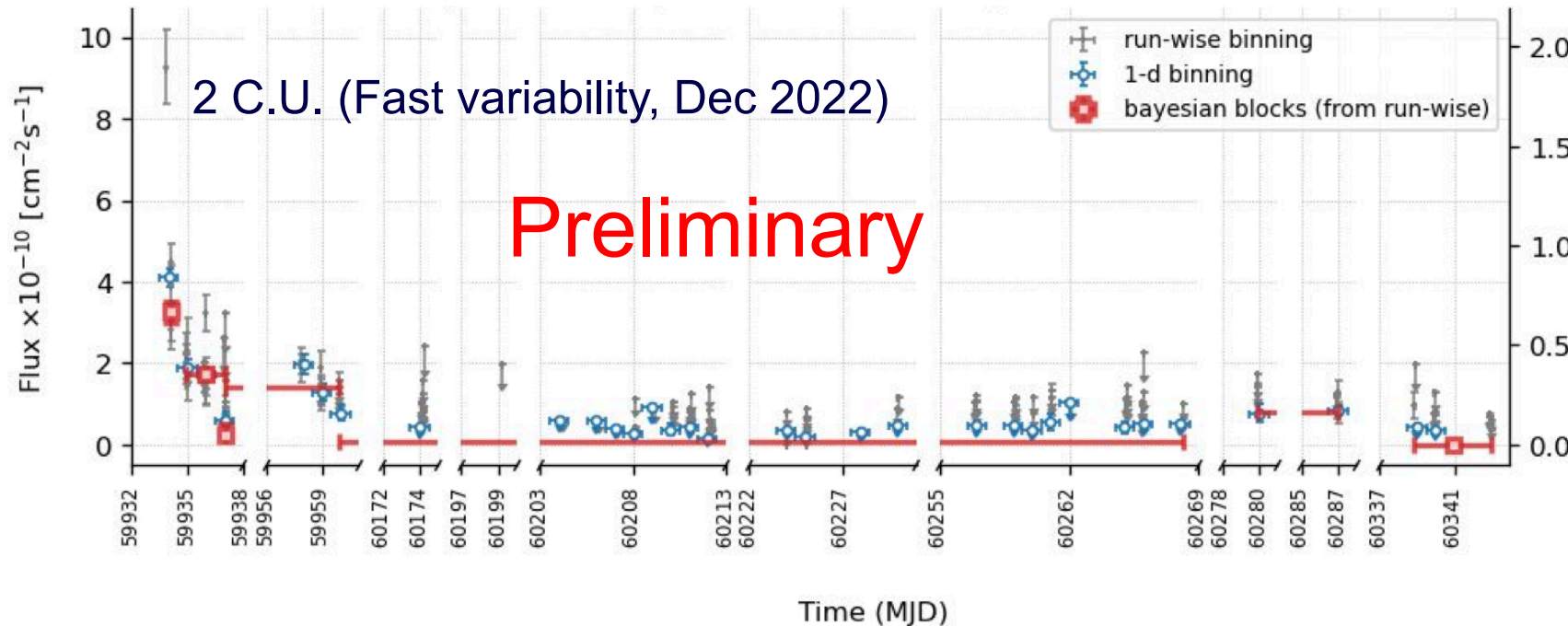
The Astronomer's Telegram

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

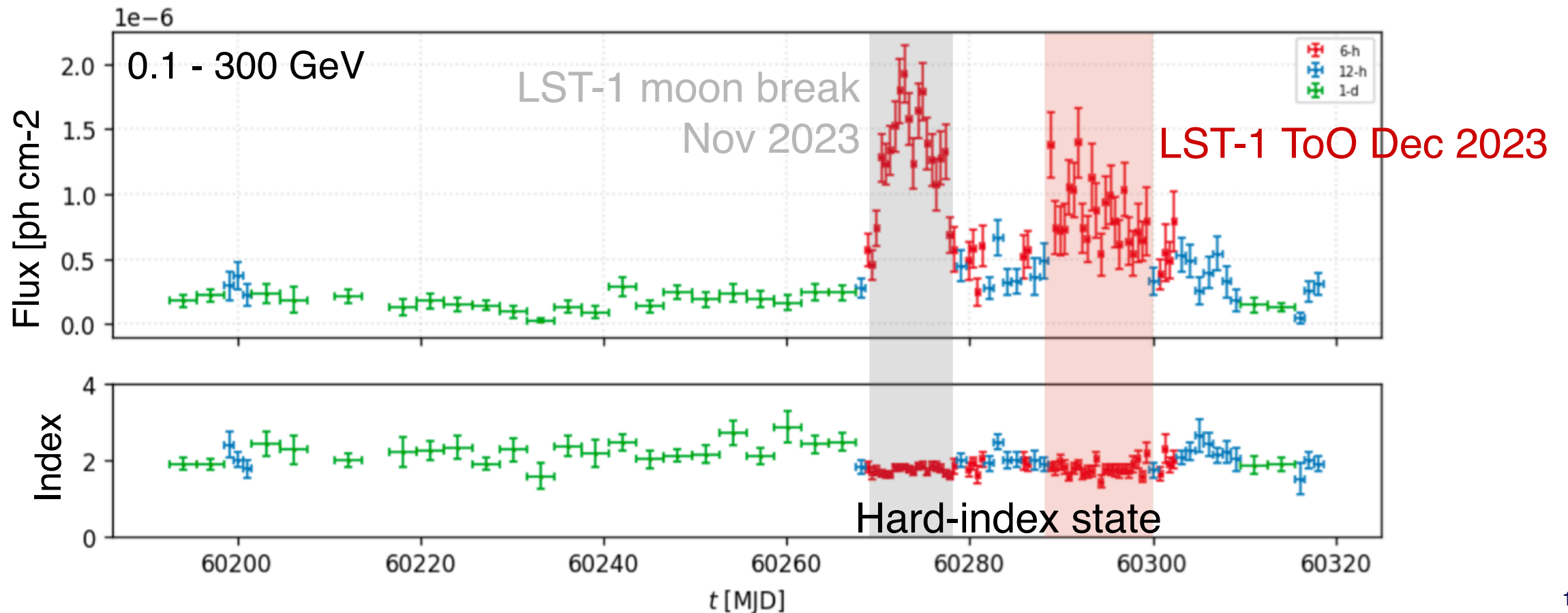
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

LST-1, E>100 GeV (Dec 2022 - early 2024)

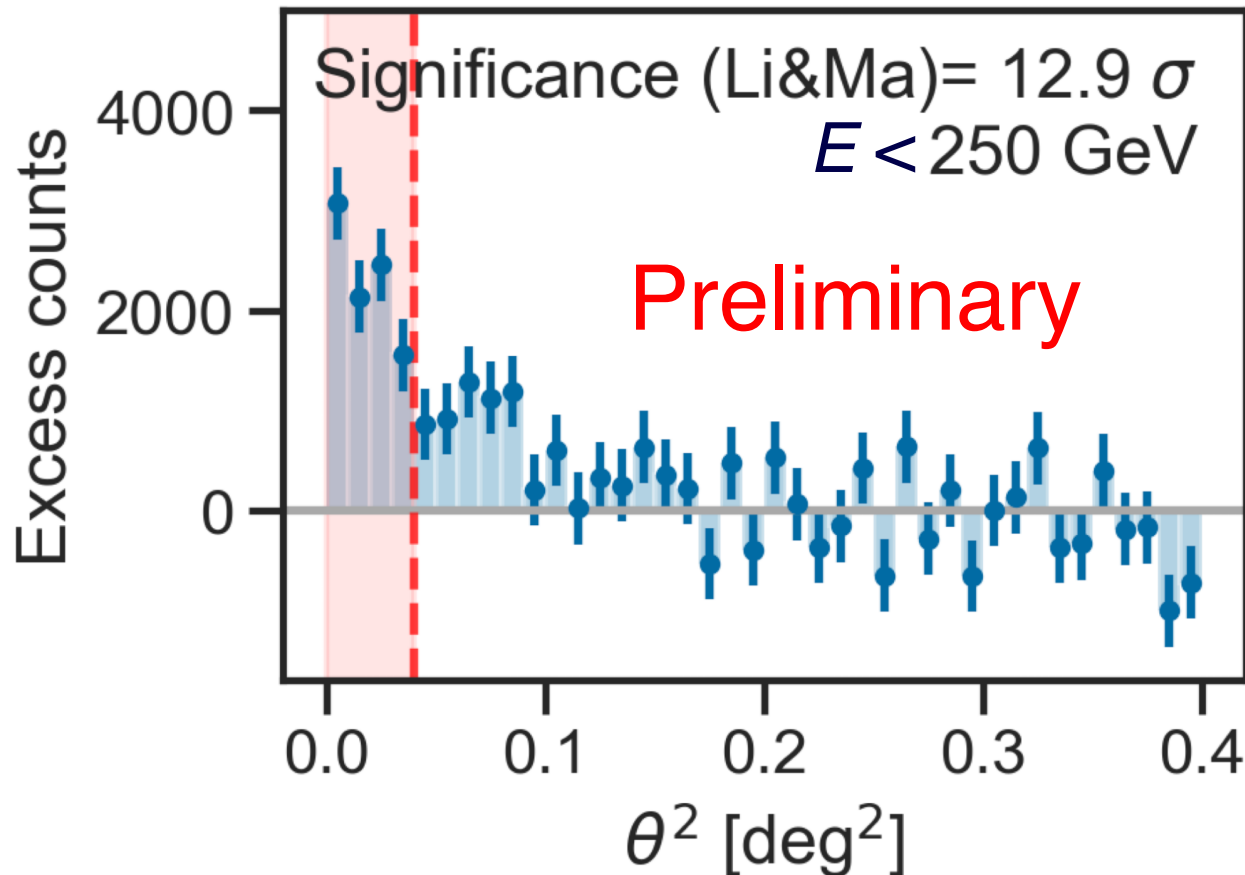


First VHE detection of OP 313 ($z = 0.997$)

- Very active in Fermi-LAT since November 2023 (one of the most luminous AGN ever observed by LAT)
- LST-1 observations since December 2023 (good coverage of flare observed by Fermi-LAT)



First VHE detection of OP 313 ($z = 0.997$)



- December 2023 data (15 h)
- Average VHE flux ($>100 \text{ GeV}$) 0.28 C.U.
- Detection confirmed by MAGIC
- 10th FSRQ at VHE

The
Astronomer's Telegram

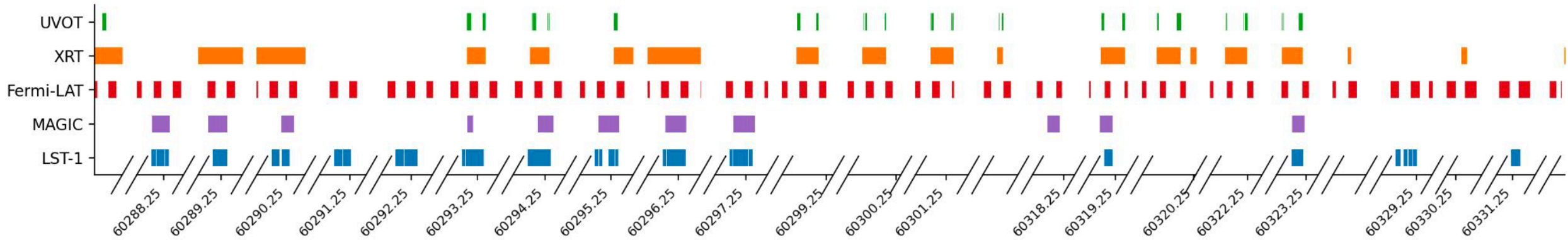
First detection of VHE gamma-ray emission from FSRQ
OP 313 with LST-1

ATel #16381; *Juan Cortina (CIEMAT) for the CTAO LST collaboration*

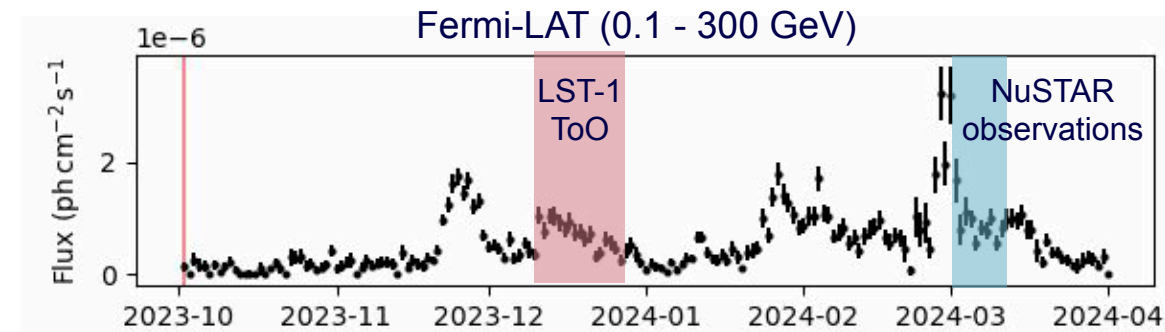
on 15 Dec 2023; 14:31 UT

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

OP 313: ongoing work and prospects

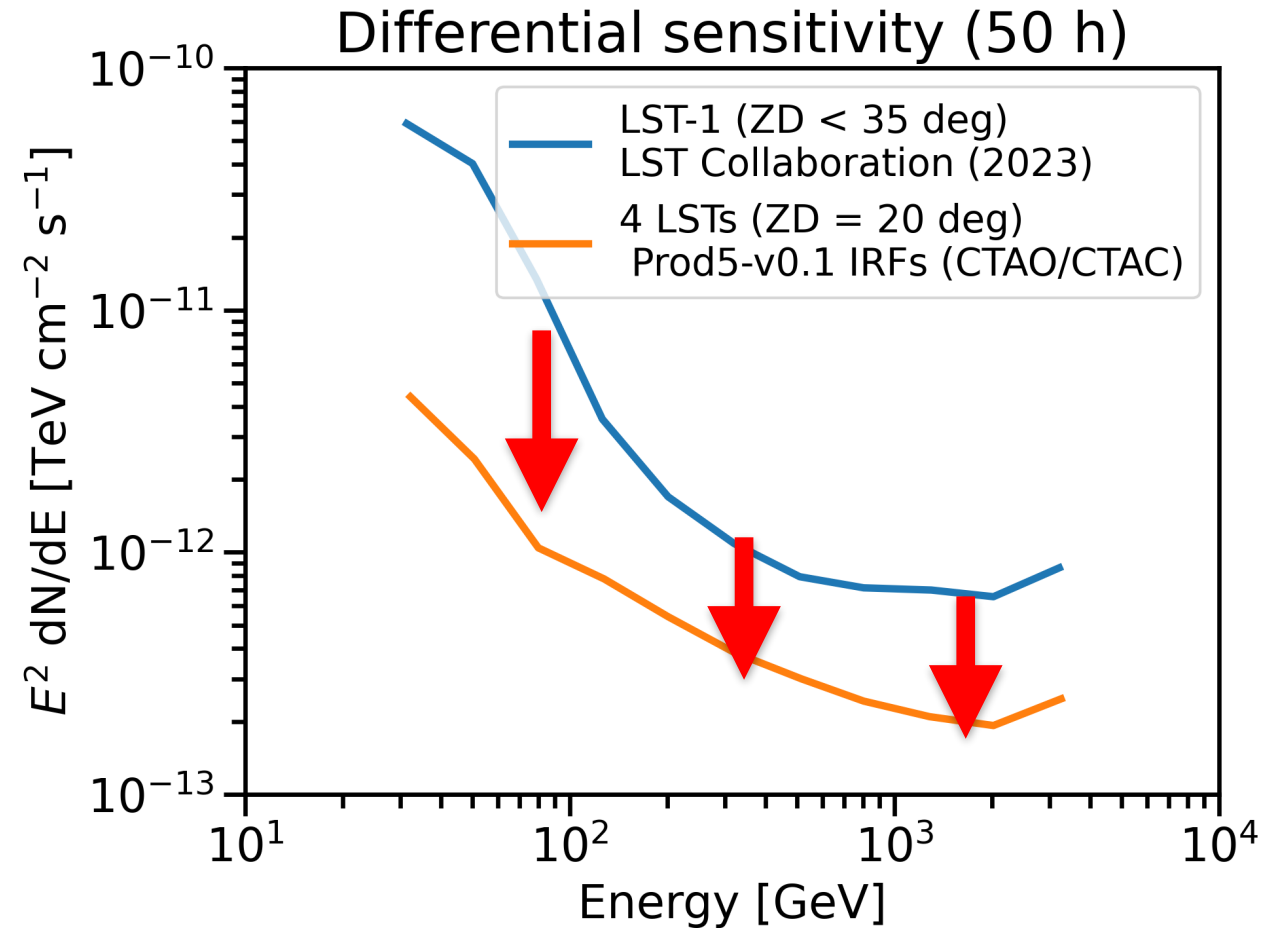


- Gamma-ray spectrum and EBL constraints
- Extensive multiwavelength follow-up campaign
- Broadband SED modeling
- Variability studies (long-term and short-term)
- Broad line region studies
- Deep exposure nights: optical, X-rays & gamma-rays



Outlook: more LSTs

- Rest of LSTs expected for 2026
- Boost of performance (about x10 better sensitivity)
- Better background rejection will lower systematics (important at low energies)



Summary

- LST-1 has proven great potential for AGN science
 - Several known VHE AGNs monitored
 - ToO campaigns: prompt reaction to flaring episodes (alerts, observations and results)
 - Important milestone: 1st detection of OP313 at VHE, the most distant VHE AGN
 - Low energy threshold → distant sources
- Several publications on AGNs coming soon
- Better detection capabilities with more LSTs soon



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
COLLABORATION

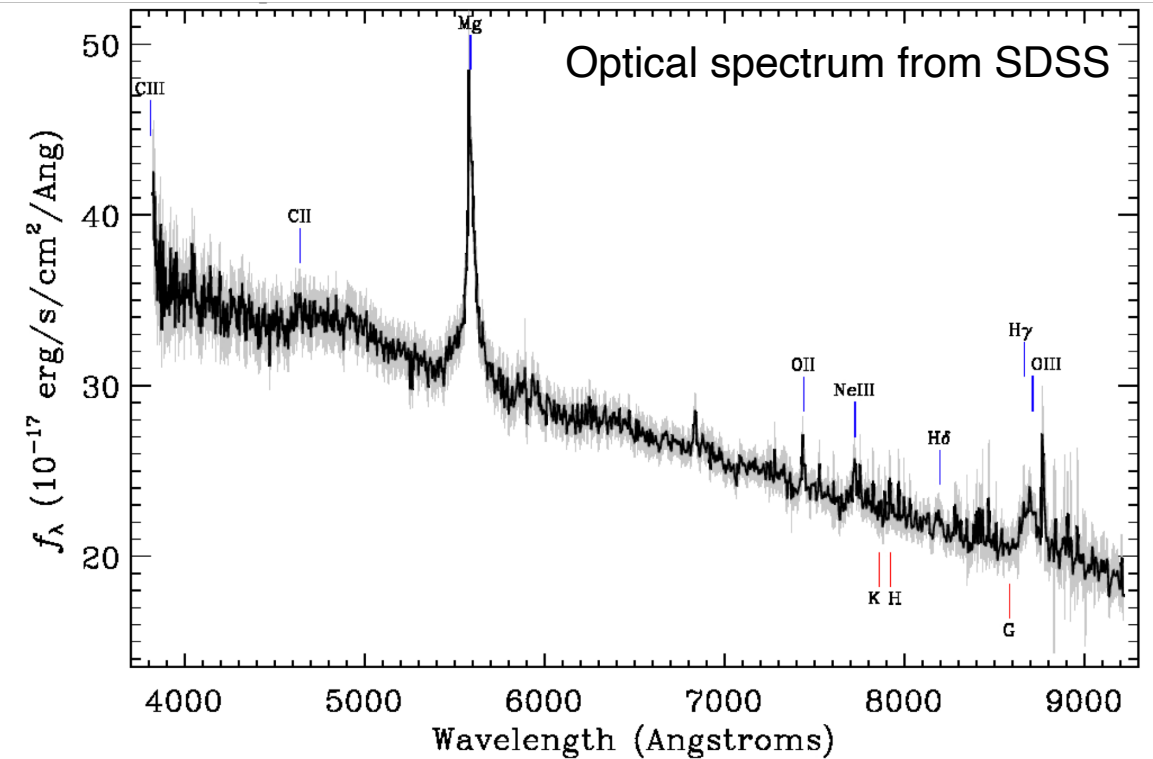


www.ctao.org

Backup

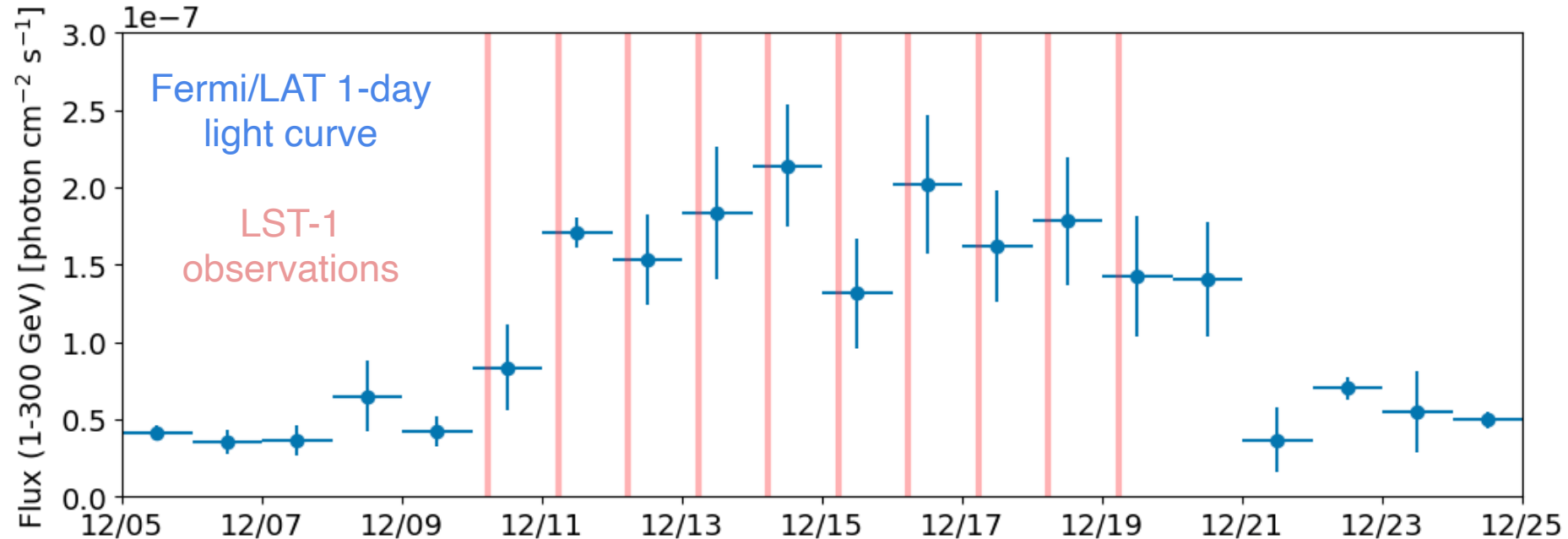
Quasar OP 313

- 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)
- Strong attenuation at VHE due to EBL
- Possible internal absorption of its gamma-ray emission



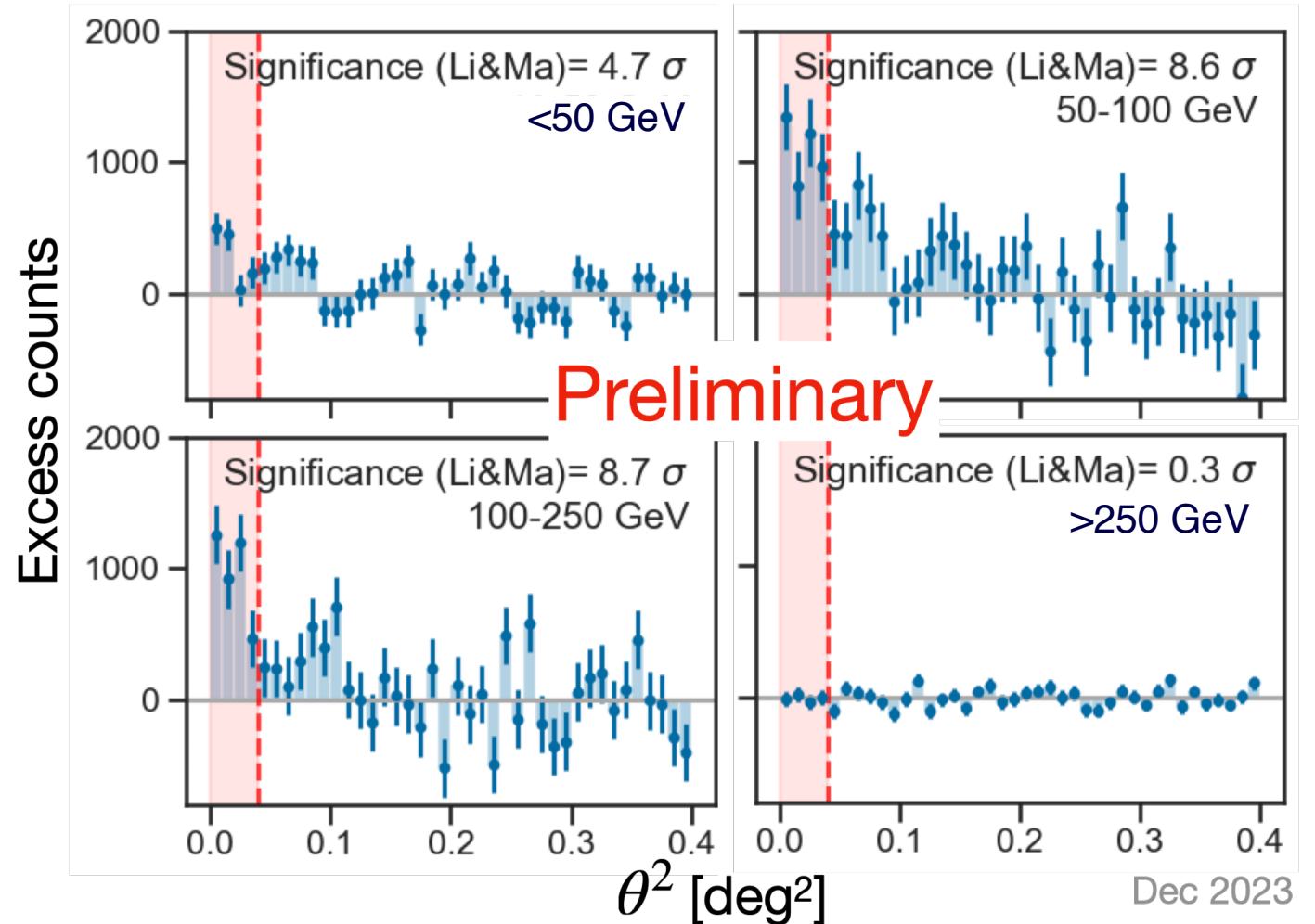
LST-1 observation campaign

- 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)



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



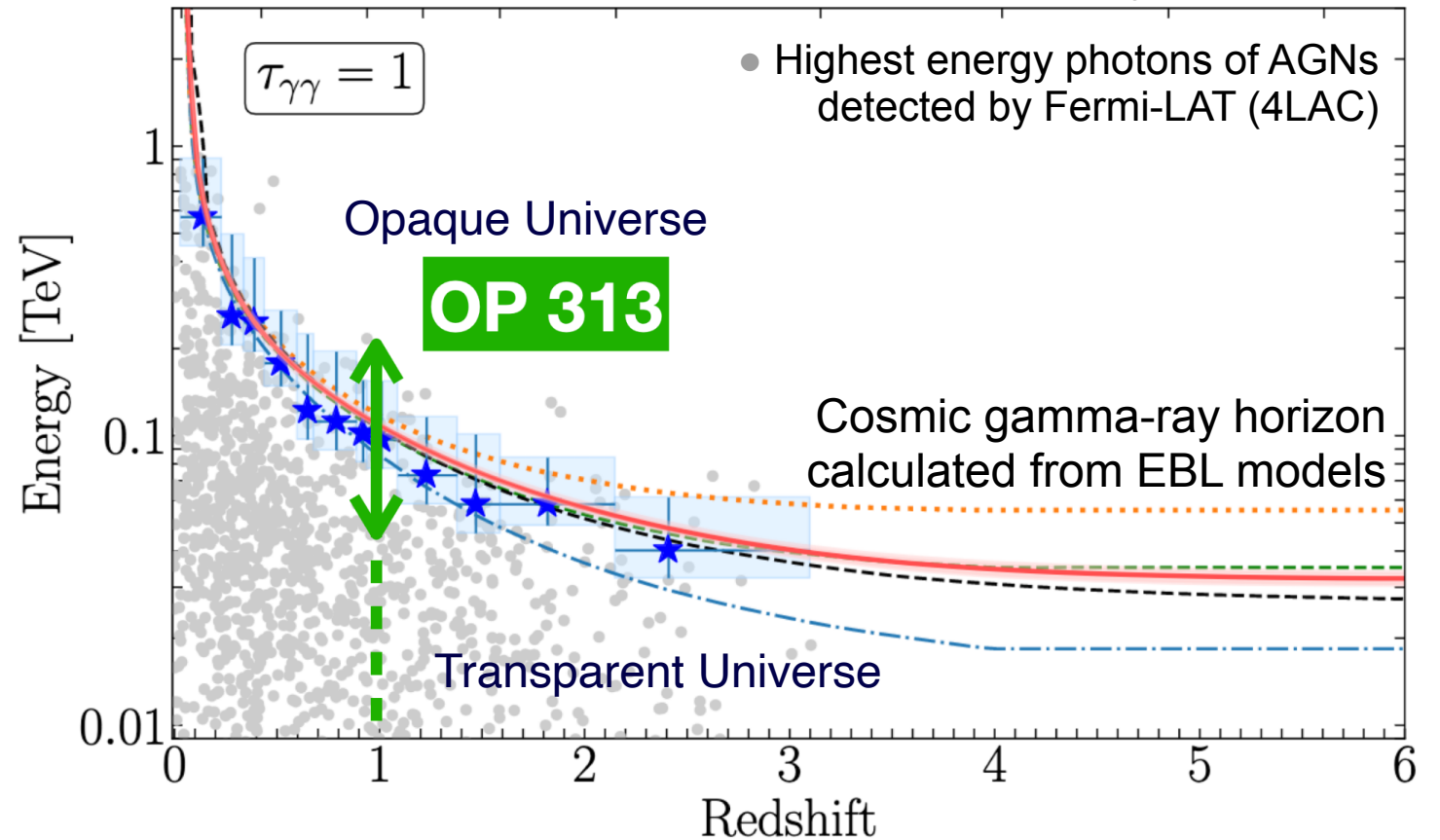
Most distant VHE blazar

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

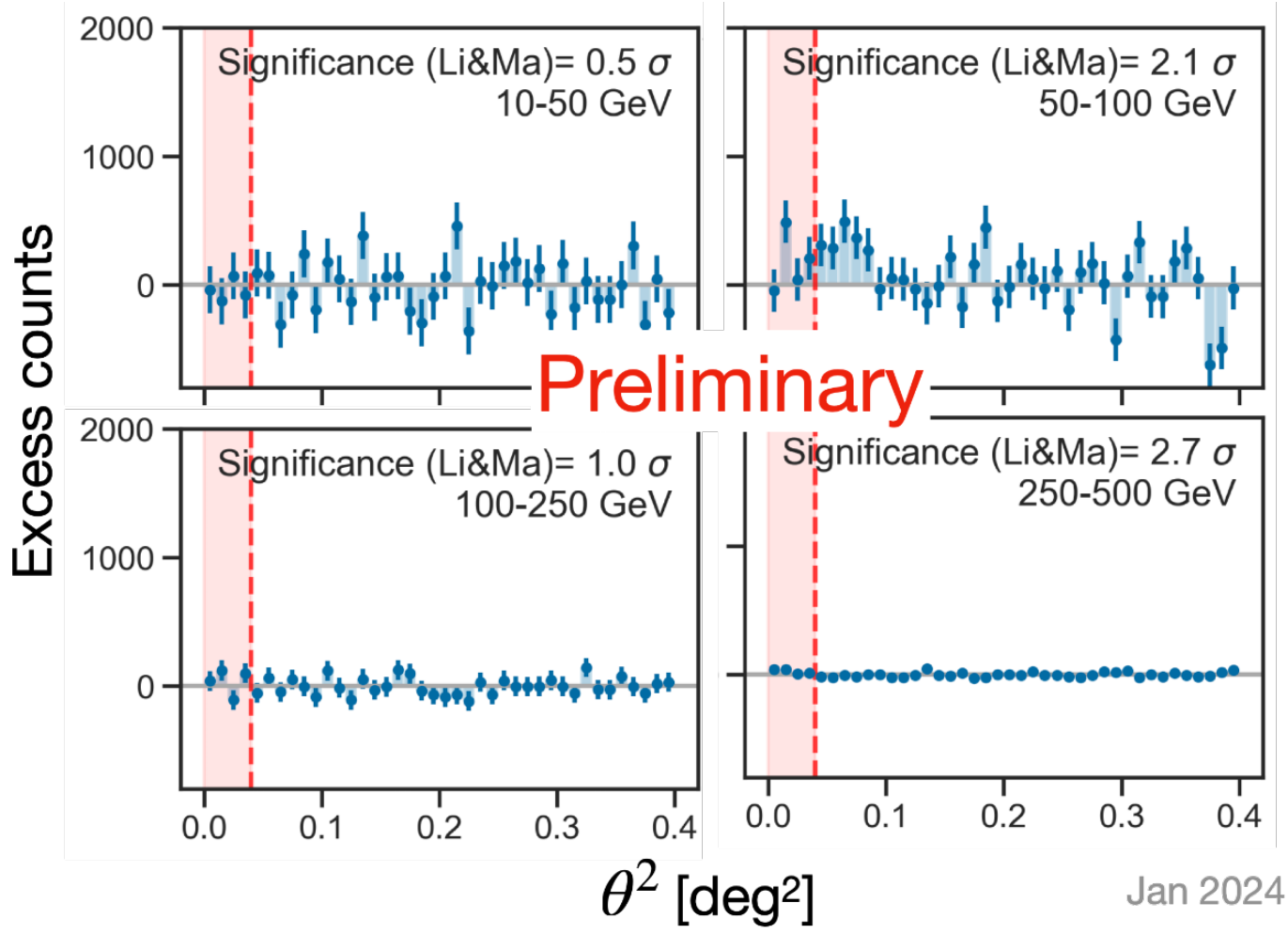
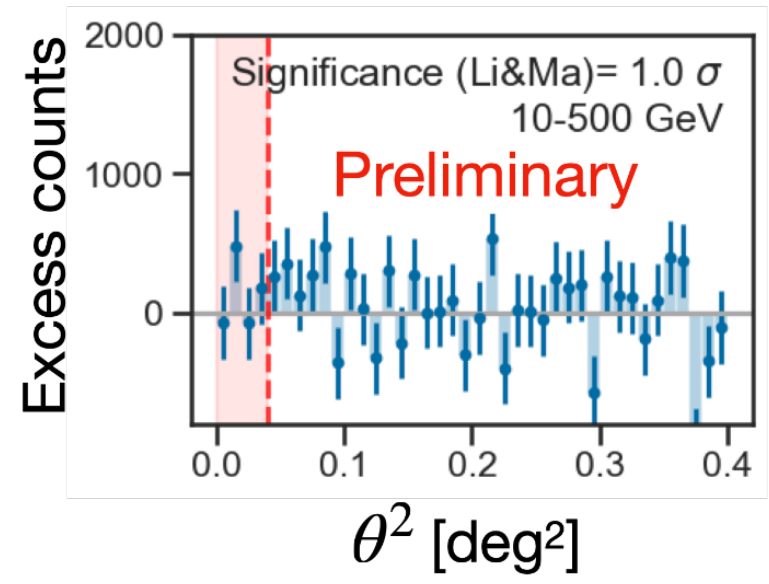
Dominguez et al., 2024

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)

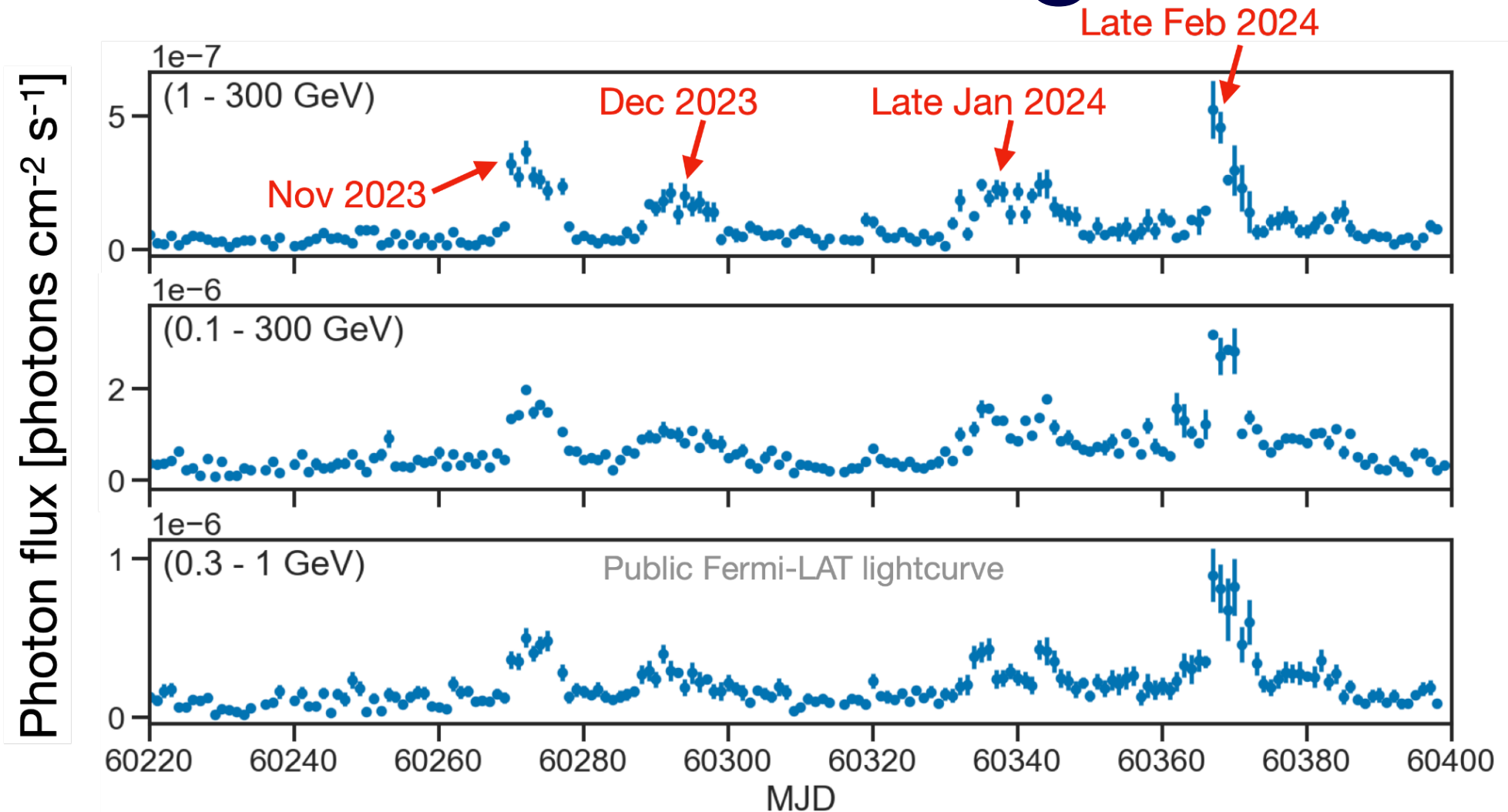


No VHE detection in Jan 2024



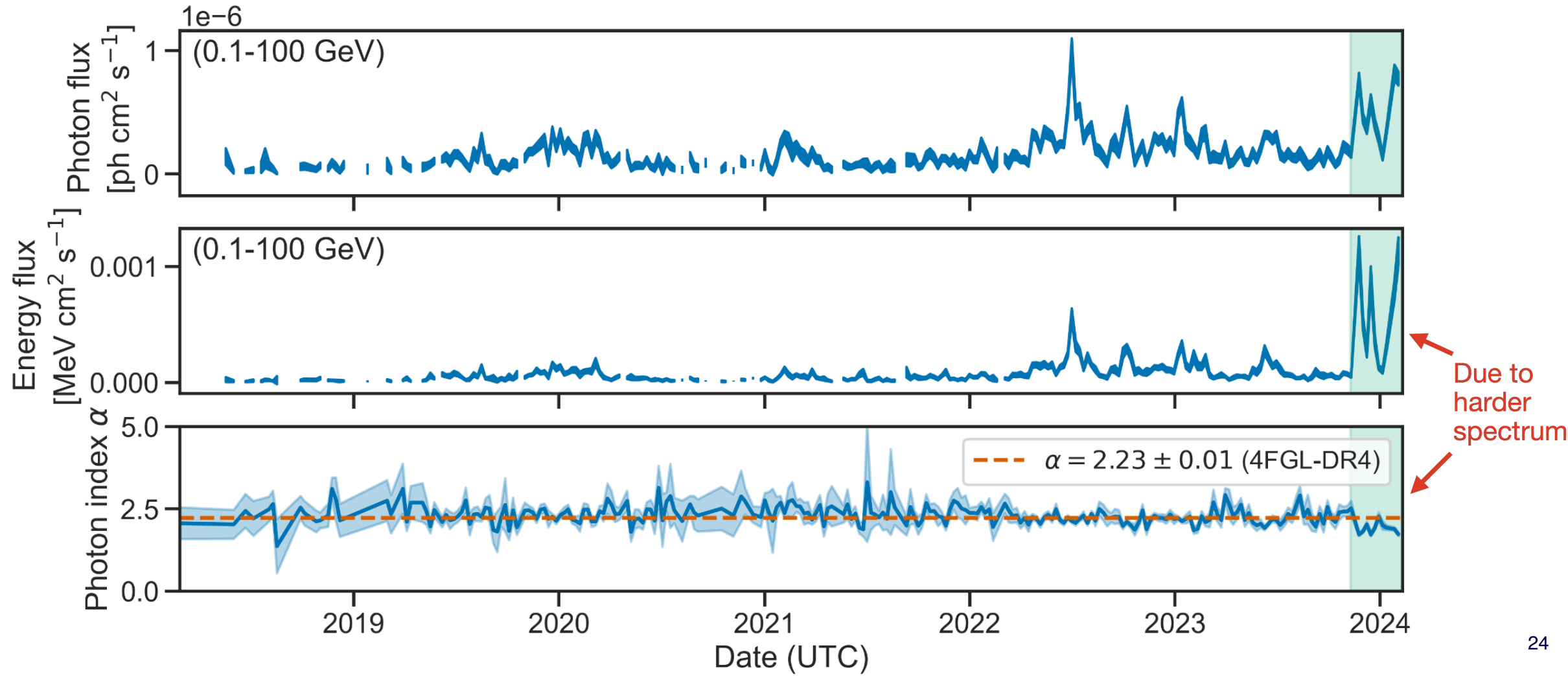
Jan 2024

Fermi-LAT monitoring



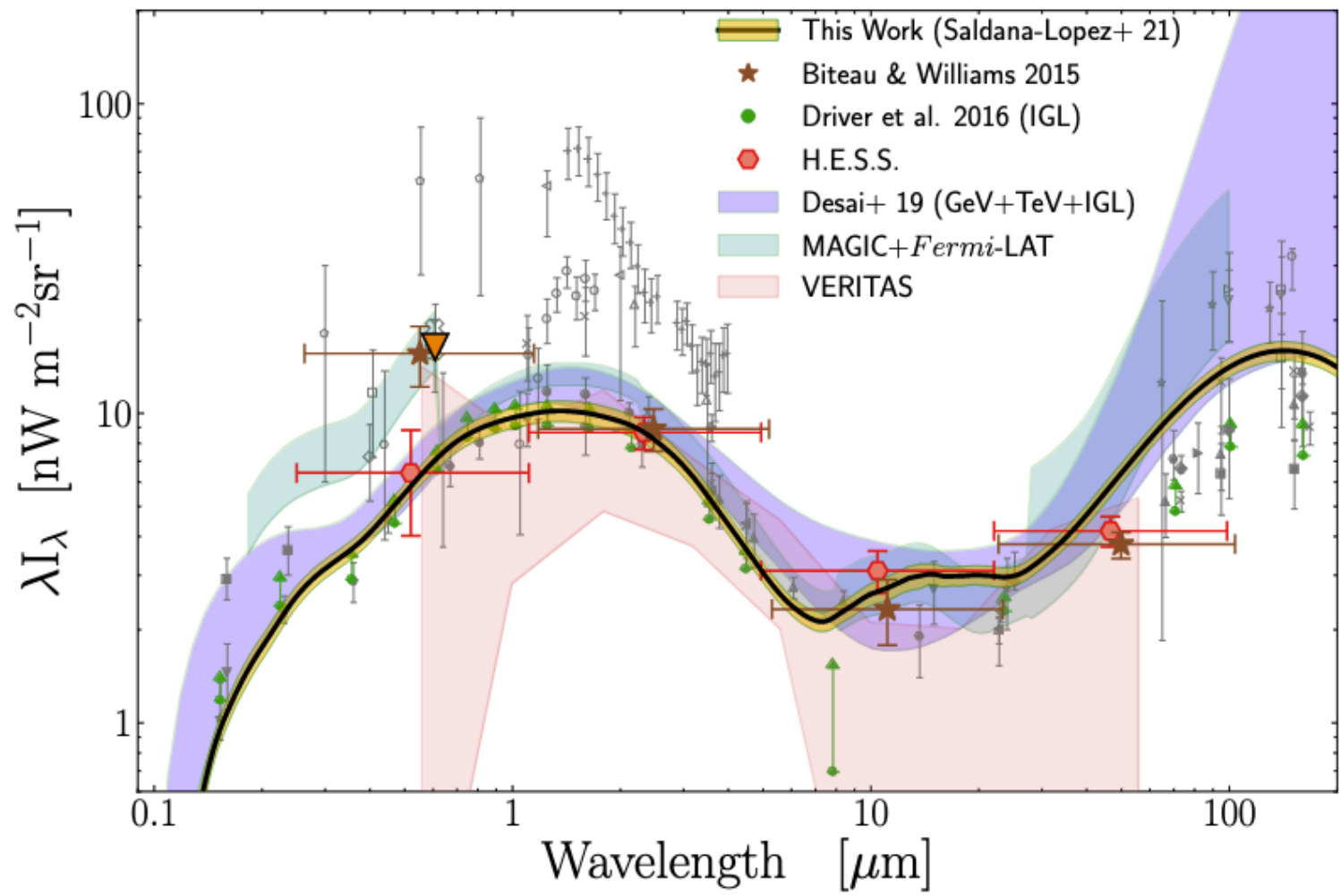
Fermi-LAT monitoring

Most energetic flare to date



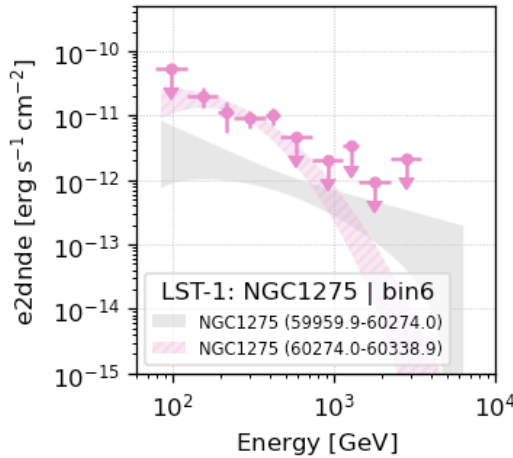
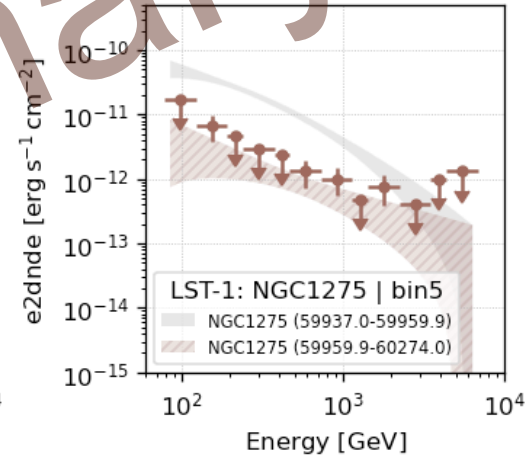
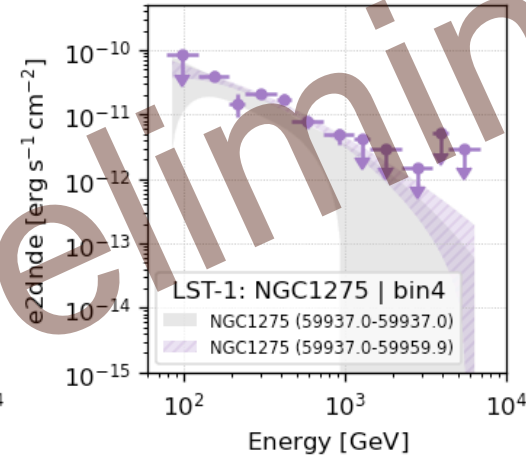
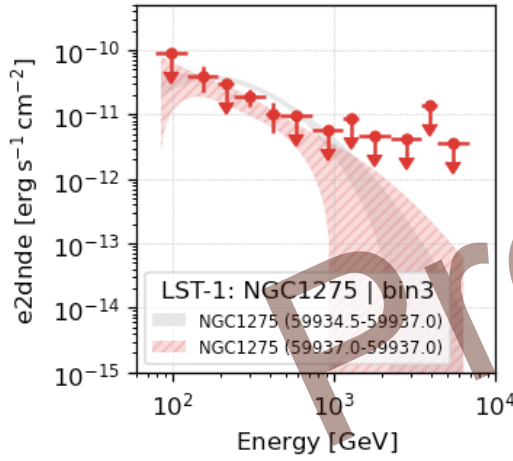
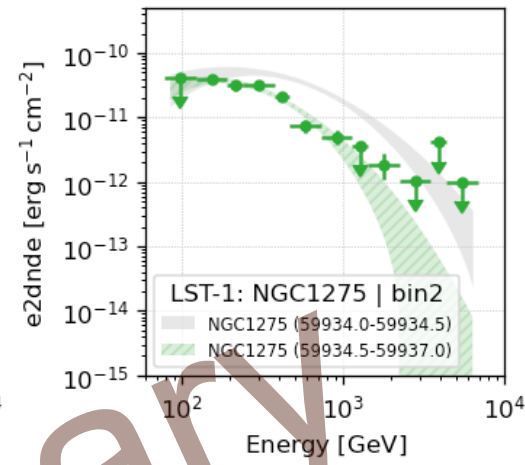
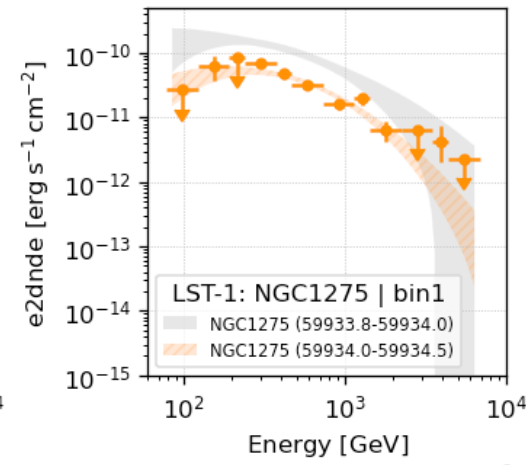
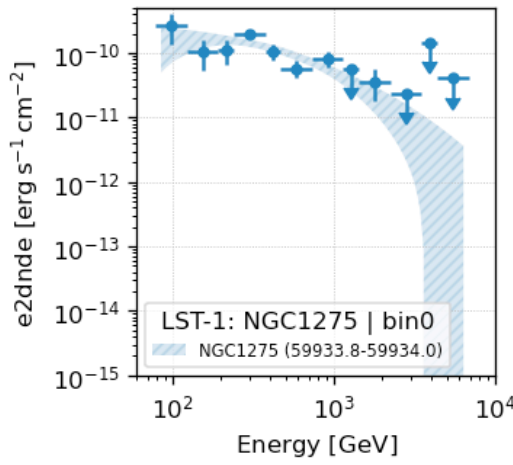
EBL SED

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

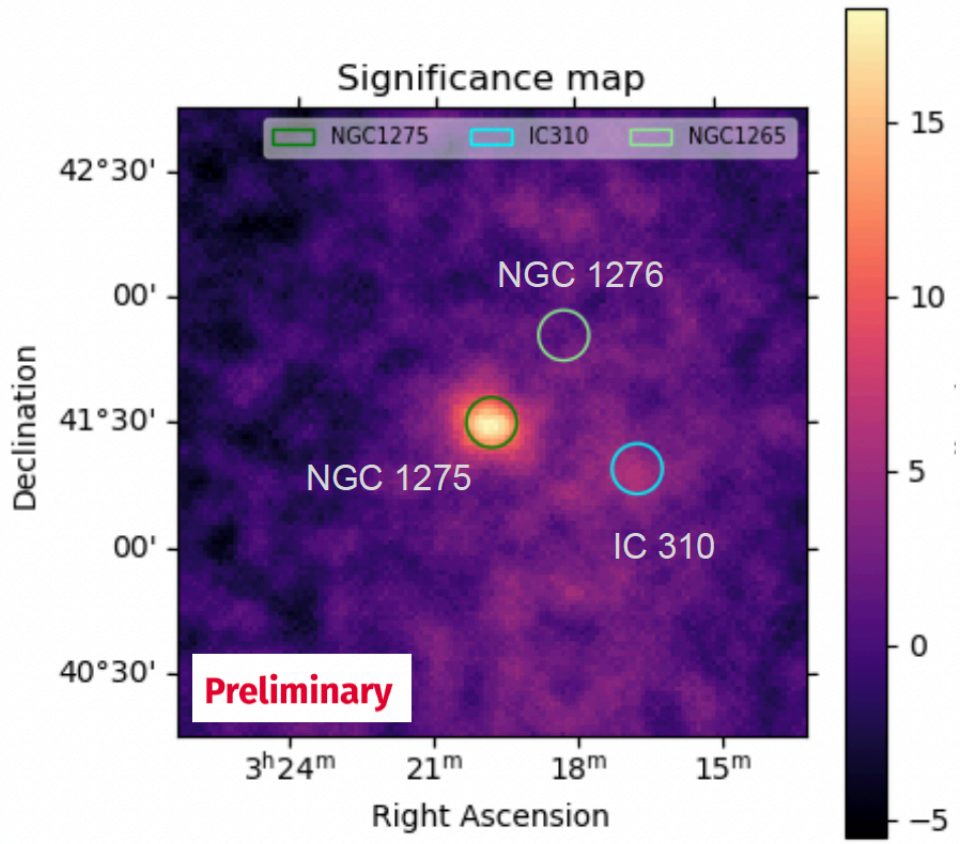


NGC 1275 BB SEDs

SEDs for the different Bayesian Blocks, each grey spectrum corresponds to the one from the previous block



NGC 1275 and IC 310



2023-12-08

