

Recent Extragalactic Observations at Very High Energies by LST-1

Abhradeep Roy

On behalf of: CTAO-LST Collaboration



CTAO

LST
COLLABORATION

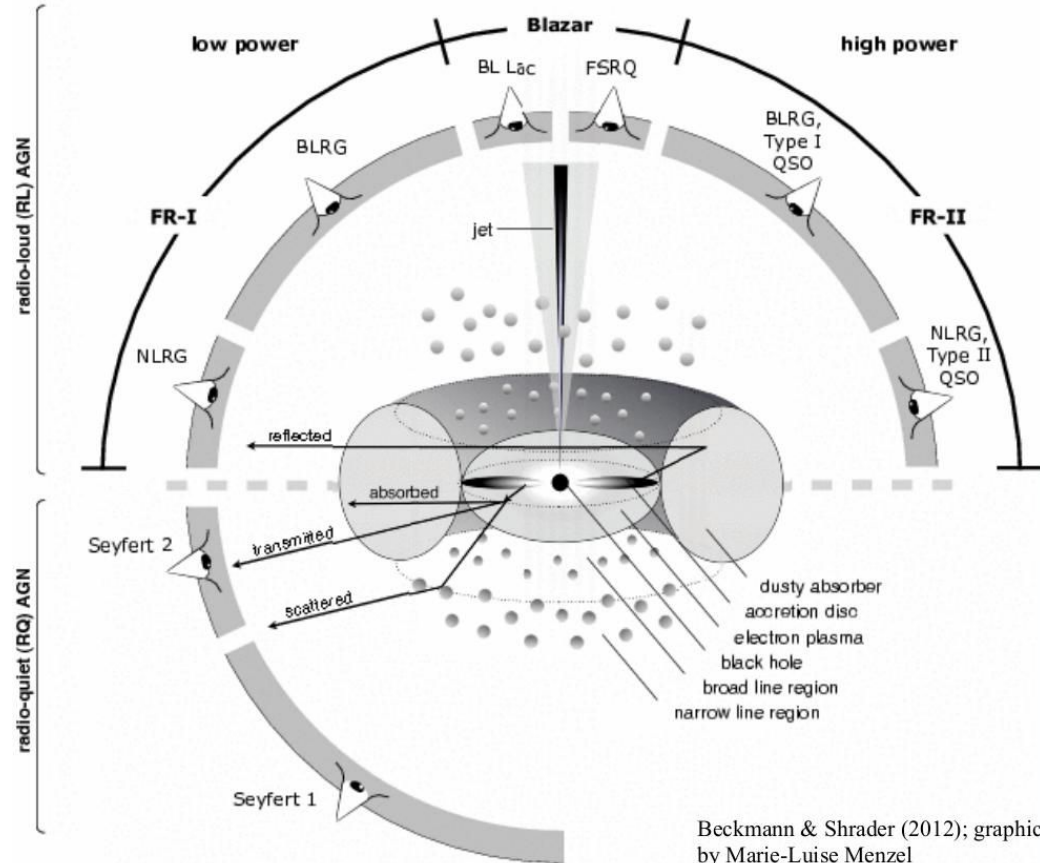
Outline

1. The Large Sized Telescope-1

2. Observed blazars

- a. Mrk 421
 - b. Mrk 501
 - c. 1ES 1959+650
 - d. 1ES 0647+250
 - e. PG 1553+113
 - f. OP 313
 - g. 1ES 1218+304
- } Nearby sources ($z < 0.03$)
- } Distant sources ($z > 0.4$)

3. Summary

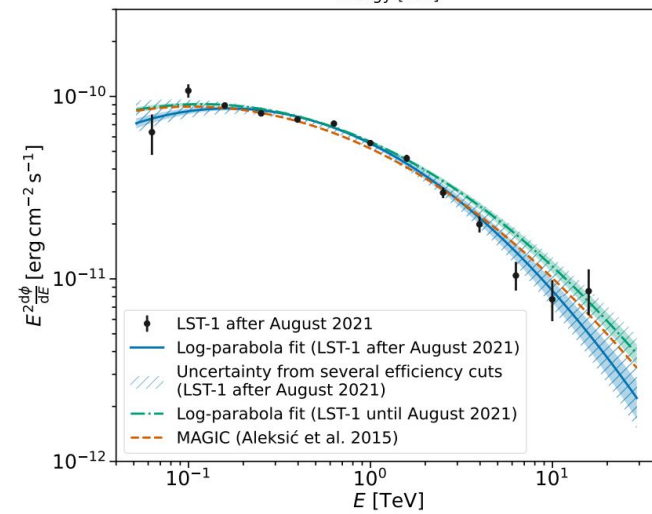
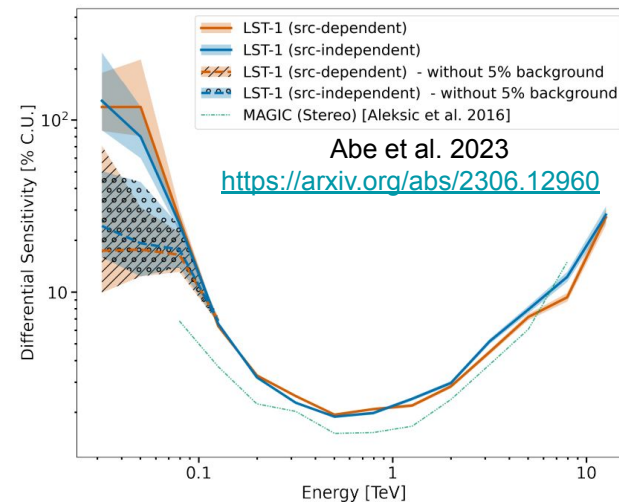


Beckmann & Shrader (2012); graphic by Marie-Luise Menzel

The Large Sized Telescope-1

Credit: Tomohiro Inada

Diameter 23 m
Pixels 1855 PMT
FOV 4.5°
 E_{\min} ~20 GeV

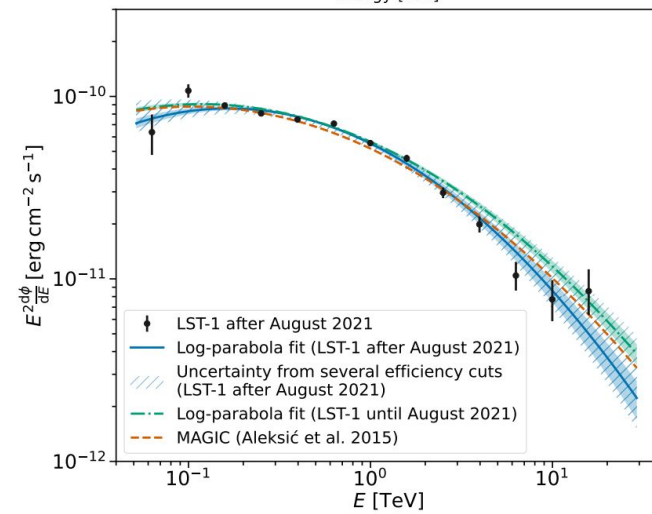
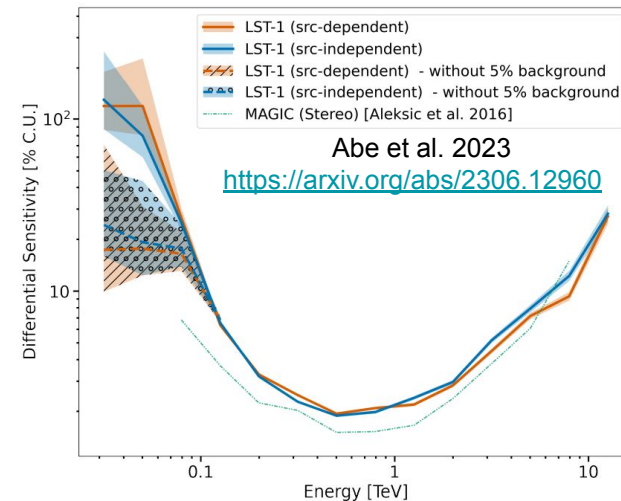


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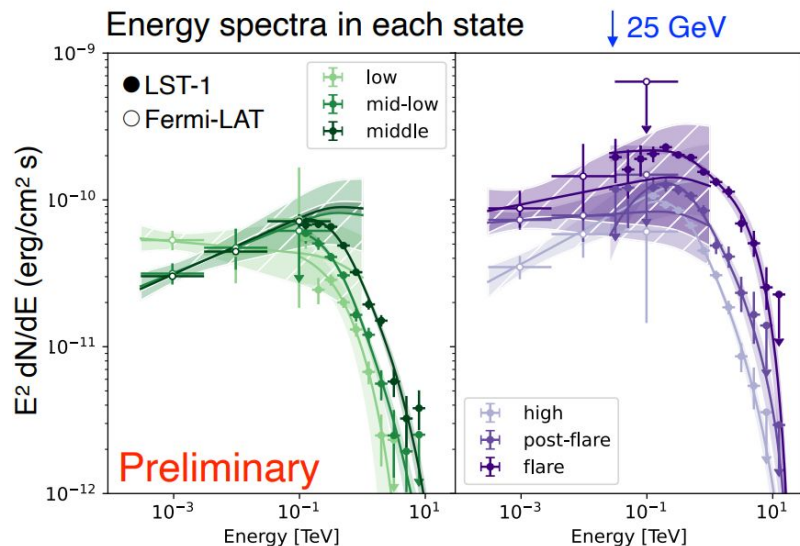
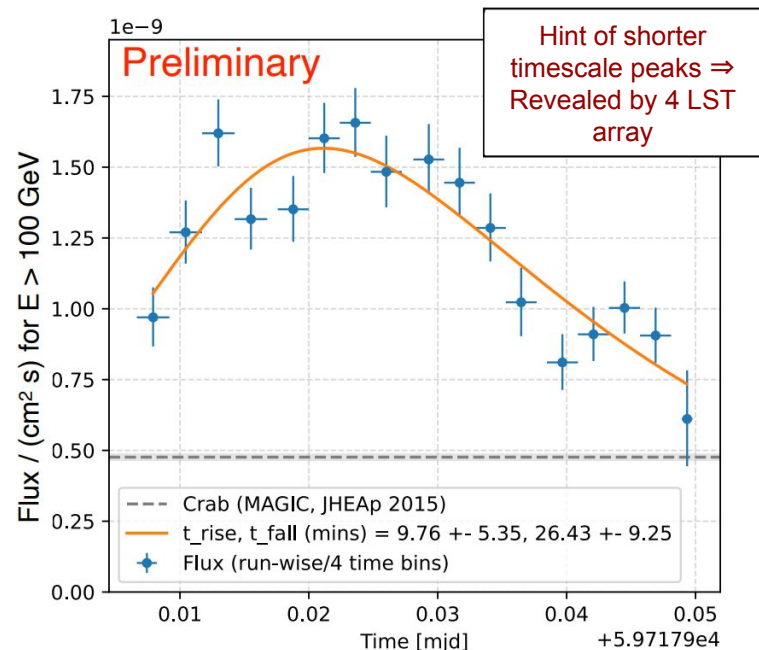
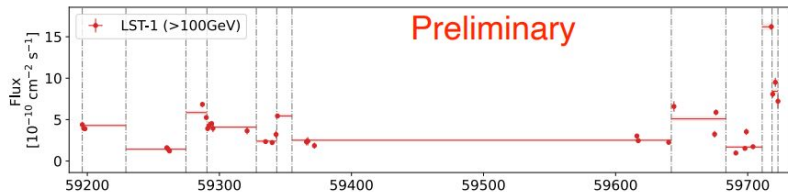


Observed Blazars

Mrk 421 ($z = 0.031$)

- Observation time: 31.9 hrs (2020 to 2022)
- Detection significance: 53σ
- Flare on 2022-05-18 (~ 3 crabs at >100 GeV)

- Bayesian blocks to identify states of activity
- Fast variability observed during flare.
- Rise time: ~ 10 min, Fall time: ~ 26 min
- Compact emission region: $0.2 - 3 \times 10^{15}$ cm

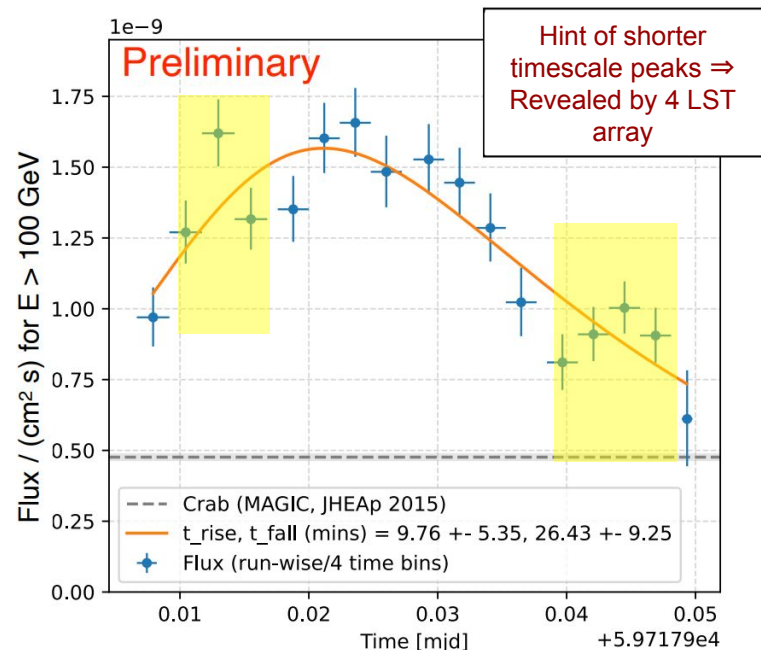
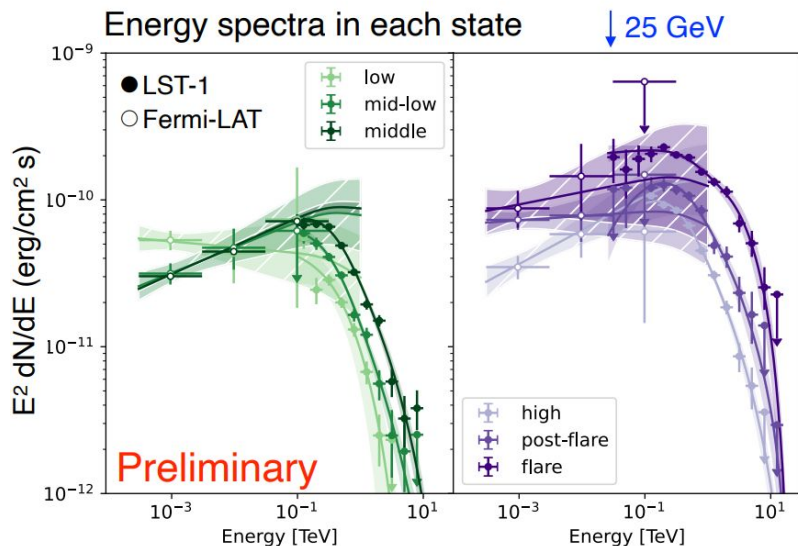
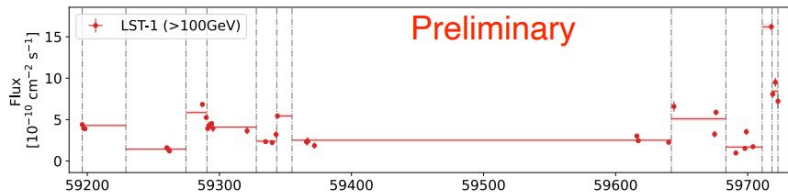


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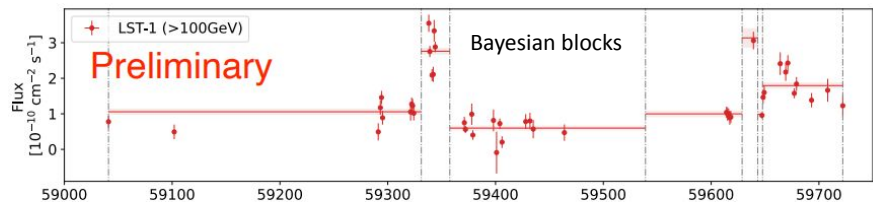
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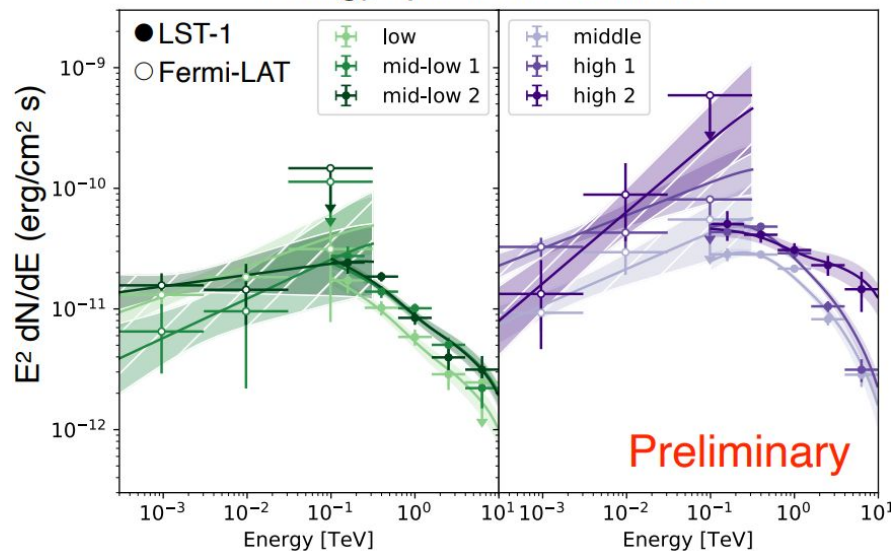
Observed Blazars

Mrk 501 ($z = 0.034$)

- Observation time: 39.7 hrs (2020 to 2022)
- Detection significance: 21σ



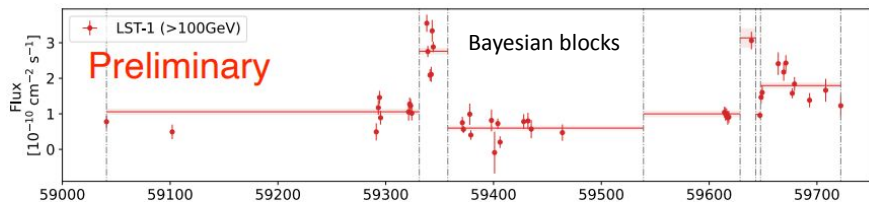
Energy spectra in each state



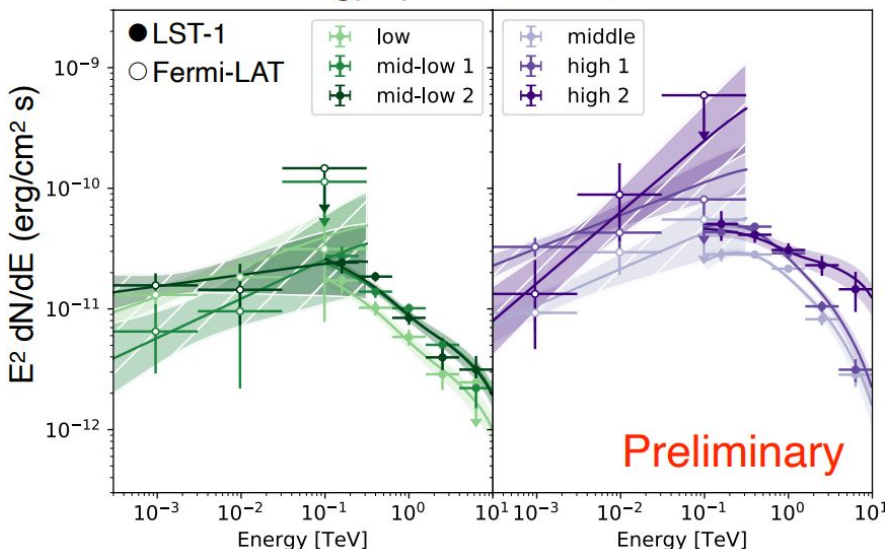
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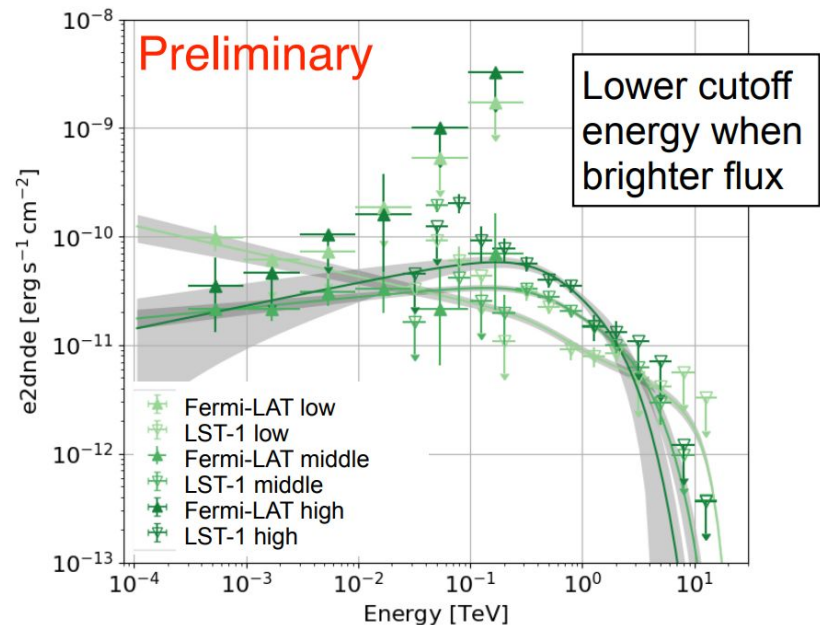
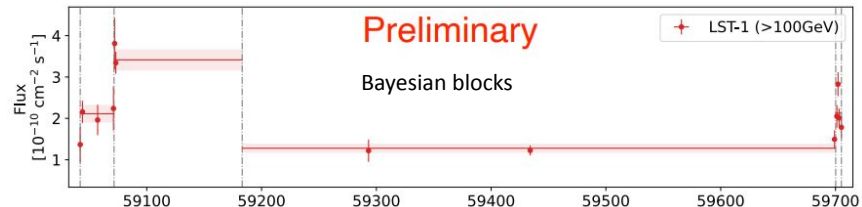


Energy spectra in each state



1ES 1959+650 ($z = 0.048$)

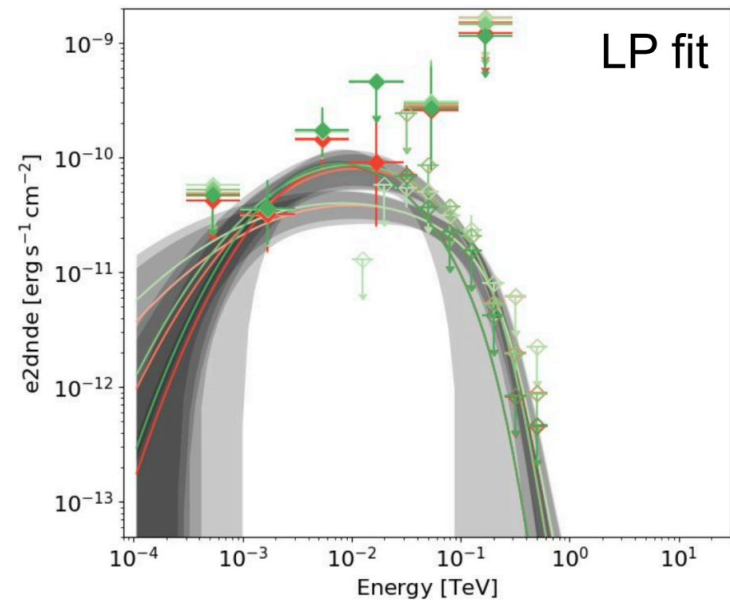
- Observation time: 11.8 hrs (2020 to 2022)
- Detection significance: 13 σ



Observed Blazars

1ES 0647+250 ($z = 0.45$)

- Observation time: 8.2 hrs (2020 to 2022)
- Detection significance: 7σ
- Joint Fermi-LAT + LST1 fit performed

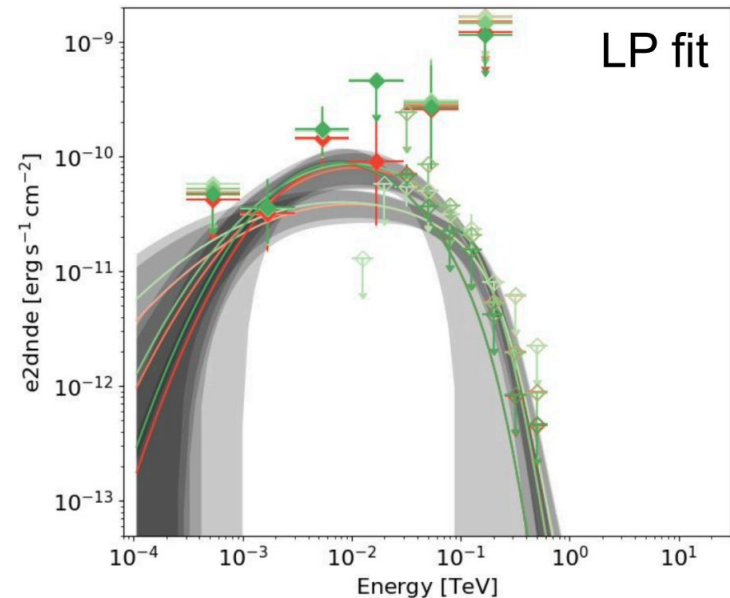


- Obs model: LAT M, LST C
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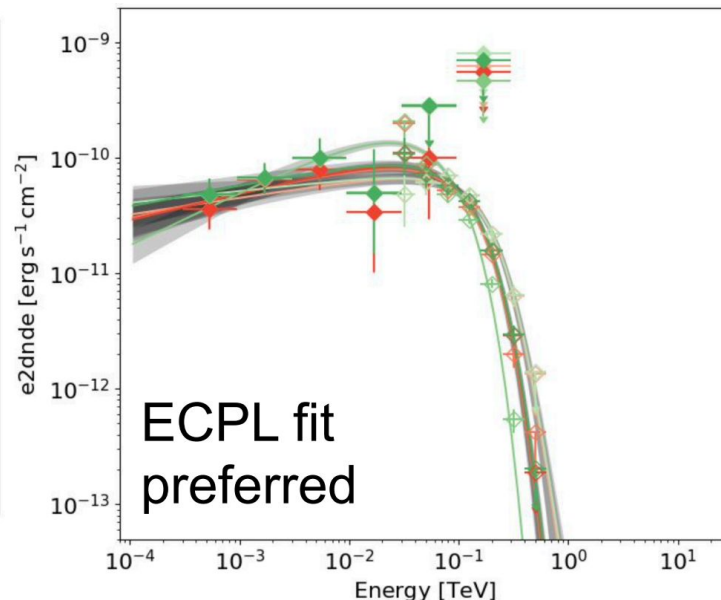
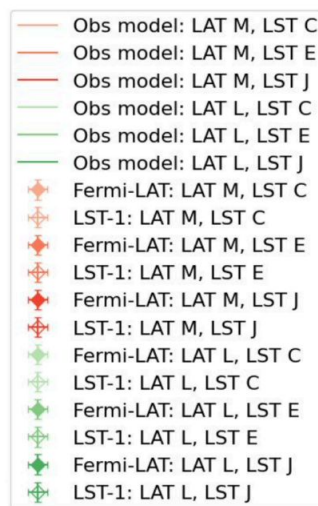
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PG 1553+113 ($z = 0.433$)

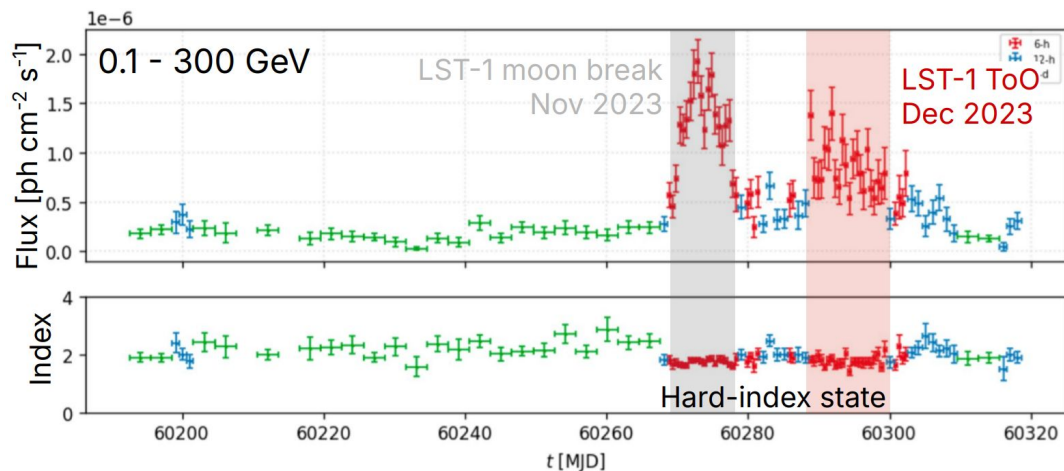
- Observation time: 9.9 hrs (2020 to 2022)
- Detection significance: 16σ
- Joint Fermi-LAT + LST1 fit performed



Observed Blazars

OP 313 ($z = 0.997$)

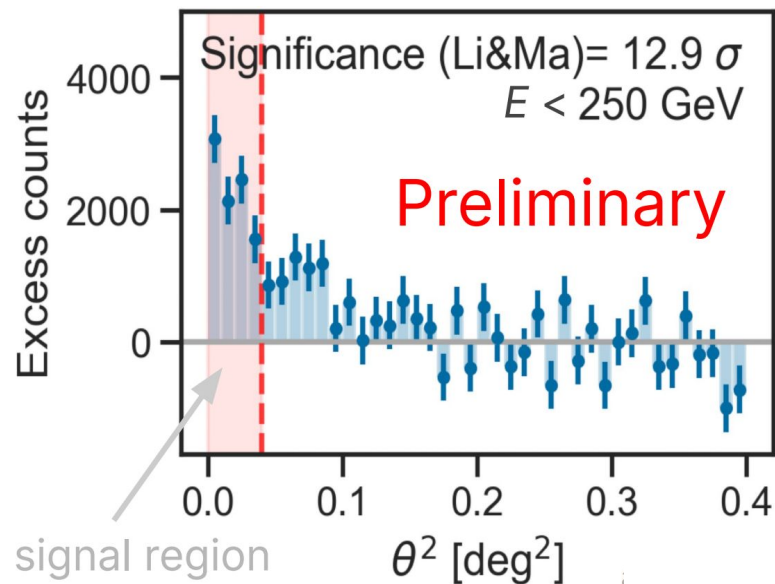
- The most distant quasar detected in VHE by LST1 ([ATel #16381](#)).
- Only 10th FSRQ in VHE.
- Observation time: 15 hrs (During flare in December 2023)
- Detection significance: 13σ
- Flux = 0.28 Crabs (>100 GeV)
- Multiple ongoing projects: variability, EBL, MWL etc.



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



Observed Blazars

1ES 1218+304 ($z = 0.182$)

- High-energy peaked BL Lac – TeV discovery by MAGIC on 2006-05 ([Albert et al. 2006](#))
- VHE variability observed by VERITAS ([Acciari et al. 2010](#))
- Observed spectral index ~ 3.0 (MAGIC and VERITAS)

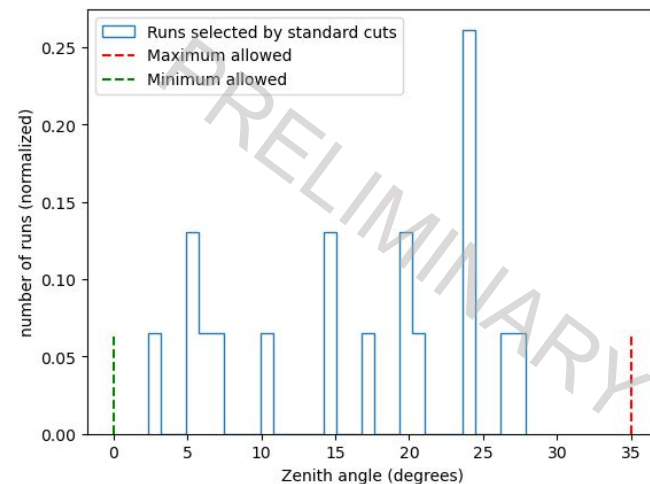
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LST-1 Observation

- **Period:** 2023-02-28 to 2023-04-12
- **Duration:** 18 hours – 40% in moonlight (Rejected by standard cuts!)
- **Tools:** lstchain-v0.10.11 (DL1 to DL3) → gammapy-1.1 (post DL3)



Observed Blazars

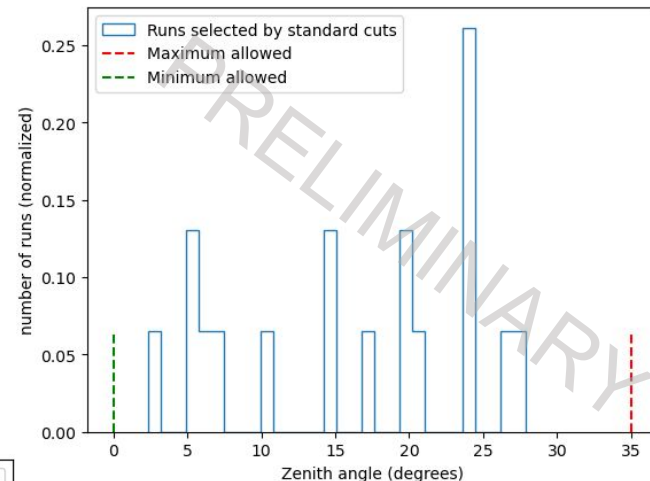
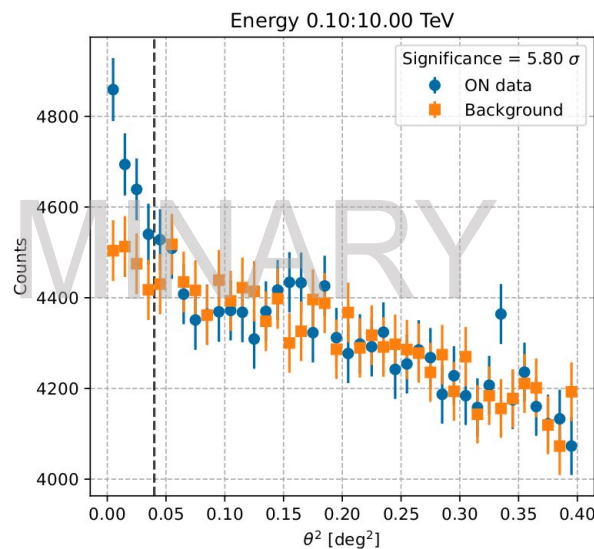
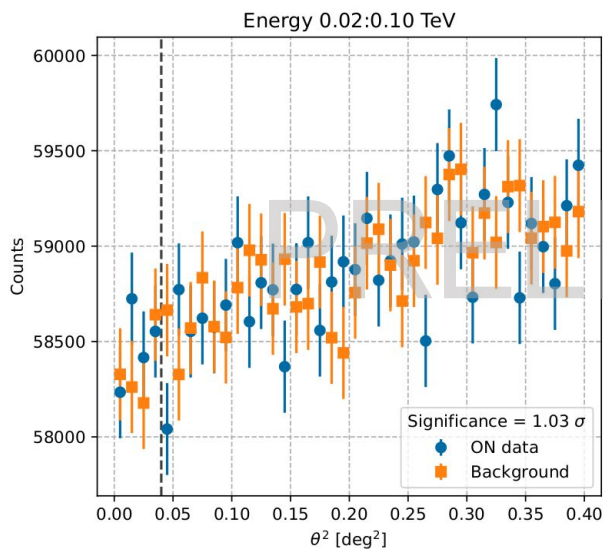
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Theta² distribution of Runs 12108:12382 with 3 wobbles and cut at 0.04, for total time 4.39 hr



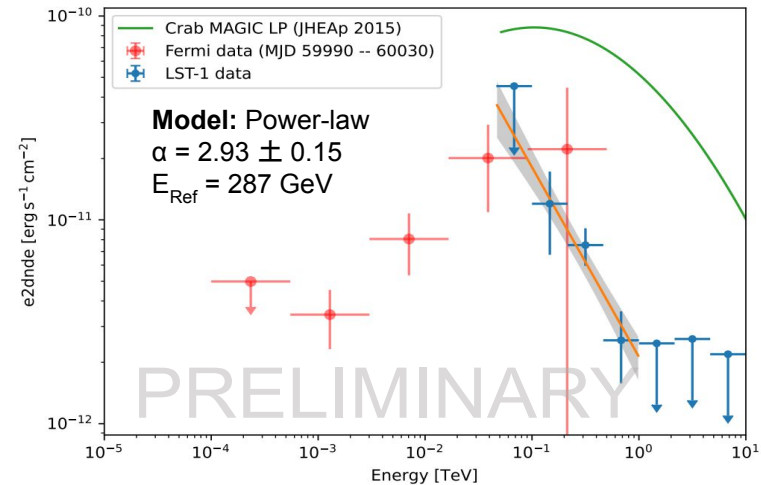
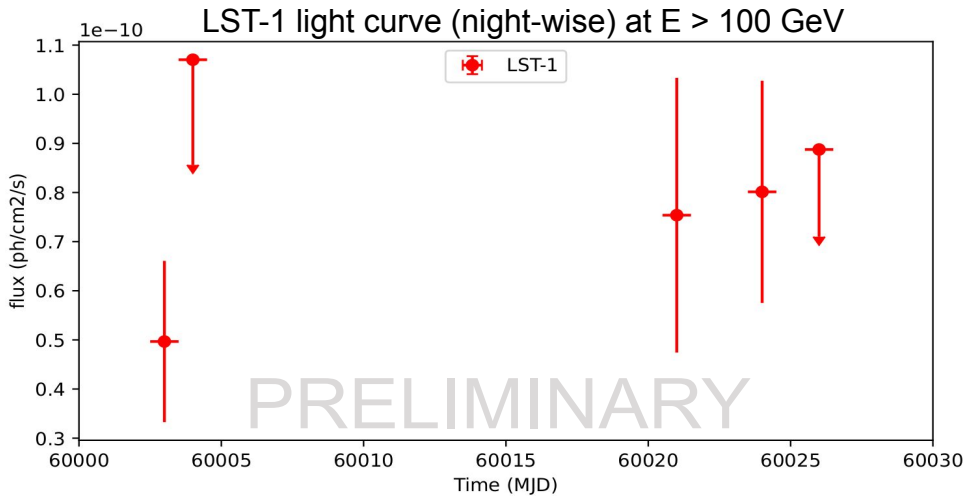
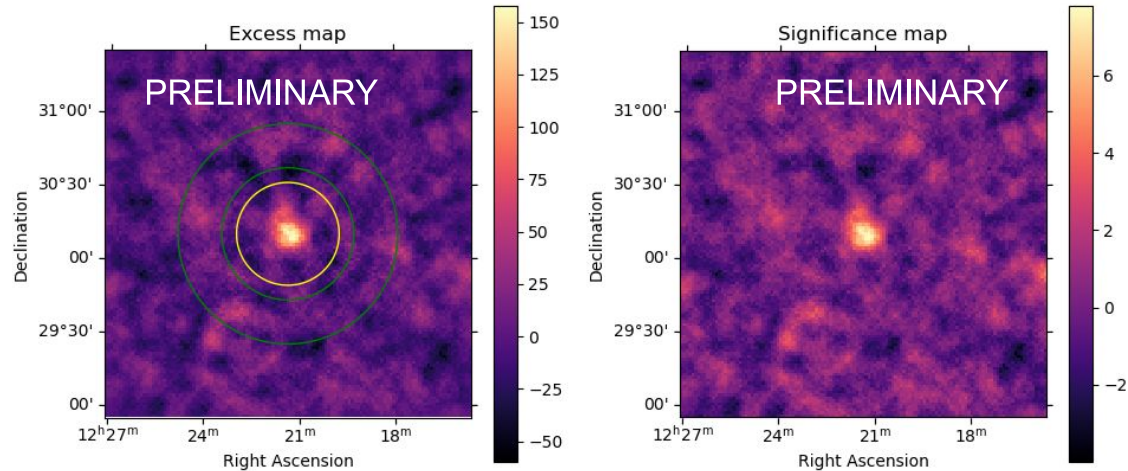
Source Detection:

- Selected duration by quality cuts: 4.4h
- Energy-dependent dynamic gammaress cut with 70% efficiency.
- Detection with 5.8 σ significance.

Observed Blazars

1ES 1218+304 ($z = 0.182$)

- Flux (> 100 GeV) $\approx 12\%$ Crab
- VHE spectral slope is comparable to literature.
- Flux variability study is not possible.



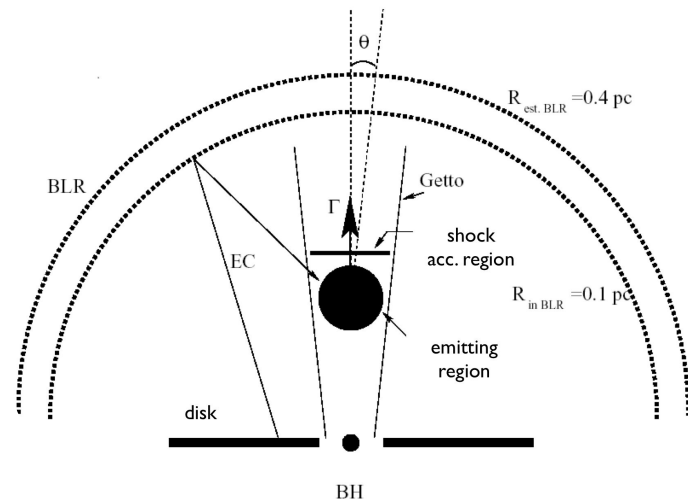
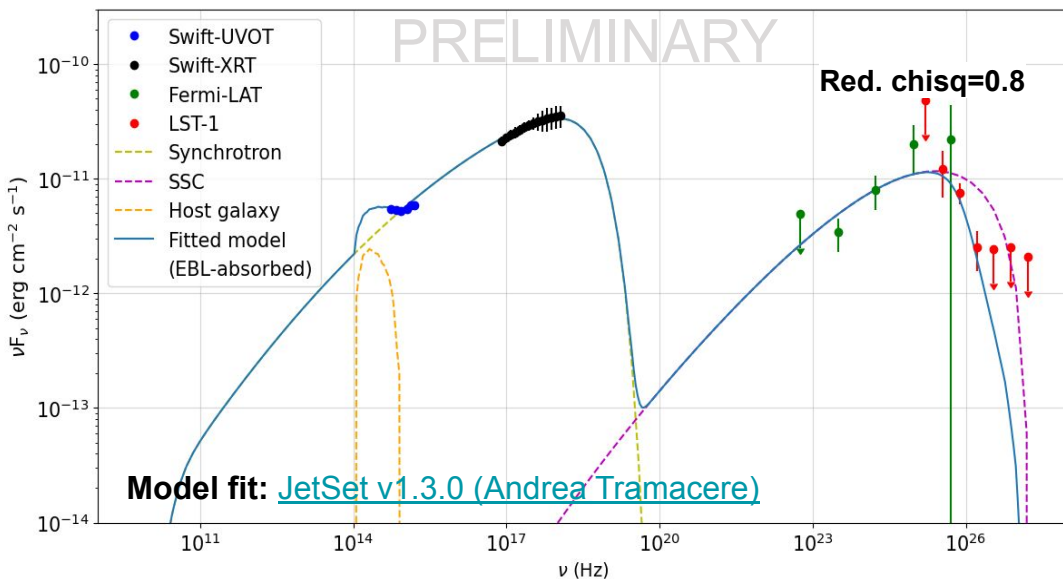
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- Quasi-simultaneous Swift-UVOT, Swift-XRT and Fermi-LAT data.
- Leptonic Synchrotron Self-Compton model with a spherical emission zone.
- $t_{\text{var}} \lesssim 1$ day [Sato et al. 2008, Acciari et al. 2010].
- Log-parabolic particle energy distribution:

$$f(\gamma) = (\gamma/\gamma_0)^{-(s+r \log(\gamma/\gamma_0))}$$

- **Fixed parameters:** $R = 2.5 \times 10^{16}$ cm; $\delta = 20$
- EBL absorption: Franceschini et al. 2008



SED model parameters:

Particle density, N	$= 12.7 \pm 1.9 \text{ cm}^{-3}$
Magnetic field, B	$= 0.09 \pm 0.01 \text{ G}$
Index, s	$= 2.17 \pm 0.04$
Curvature parameter, r	$= 0.13 \pm 0.02$
Minimum Lorentz factor, γ_{min}	$= 44 \pm 7$
Maximum Lorentz factor, γ_{max}	$= (9 \pm 1) \times 10^5$
Reference Lorentz factor, γ_0	$= (1.0 \pm 0.1) \times 10^4$

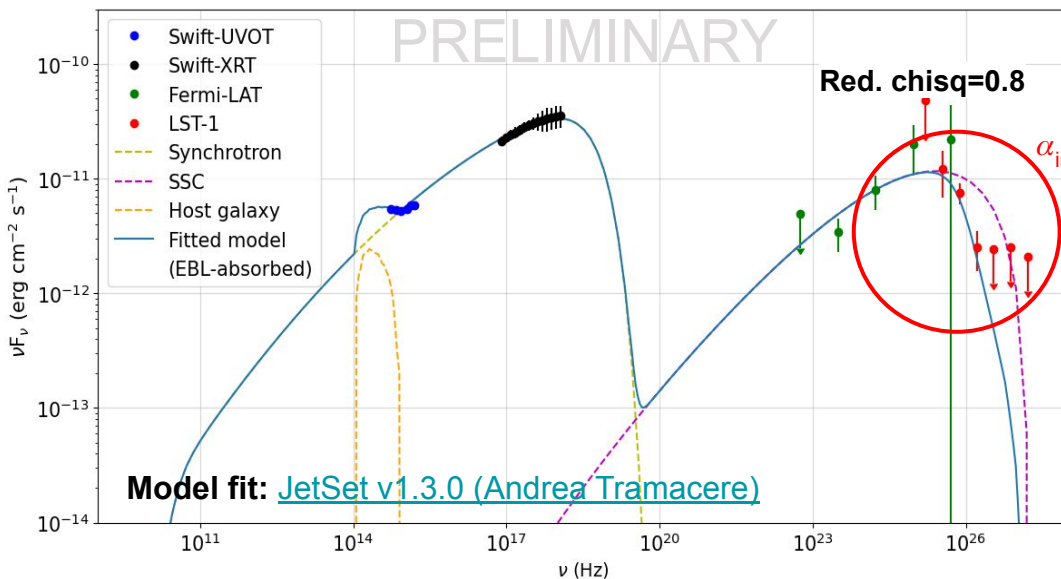
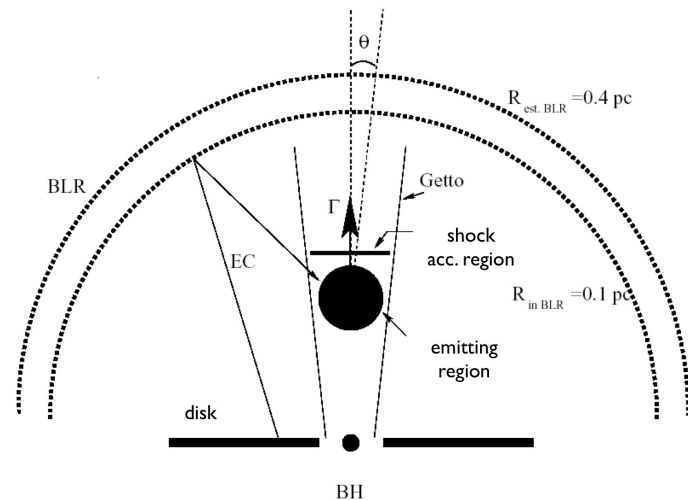
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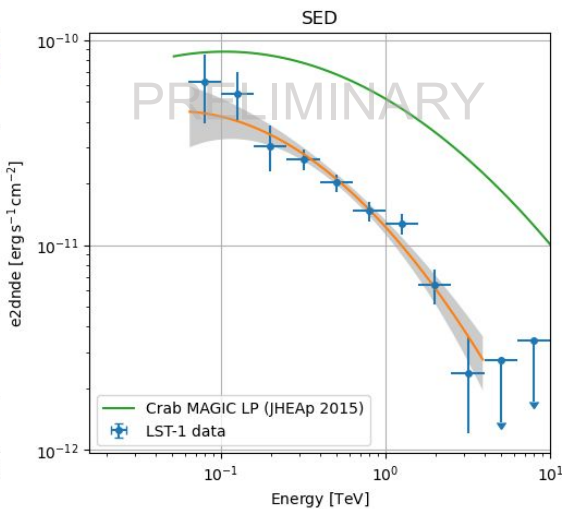
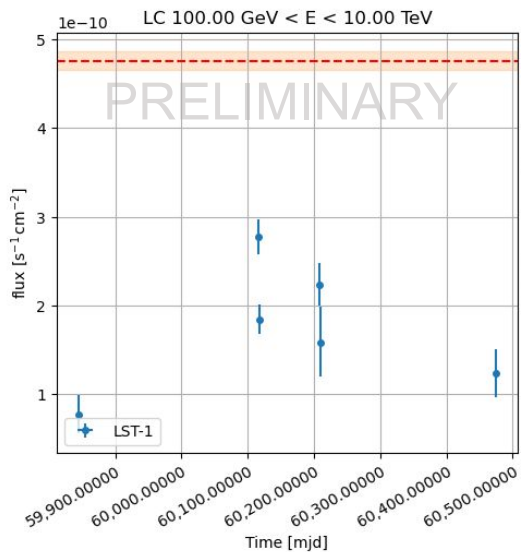
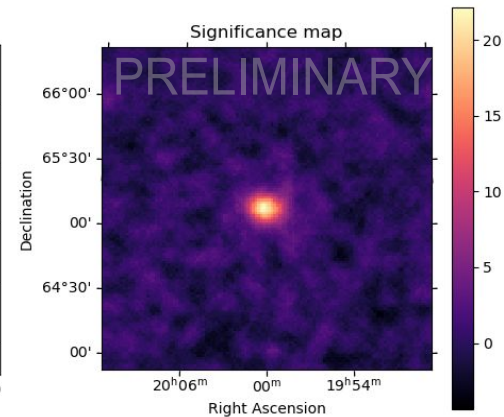
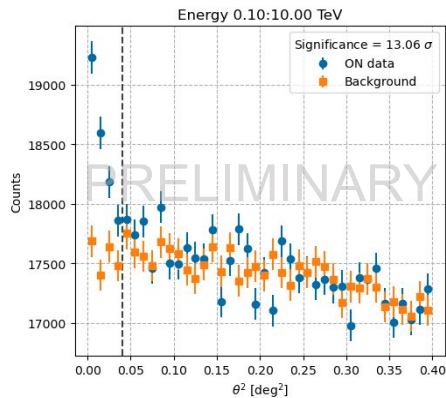
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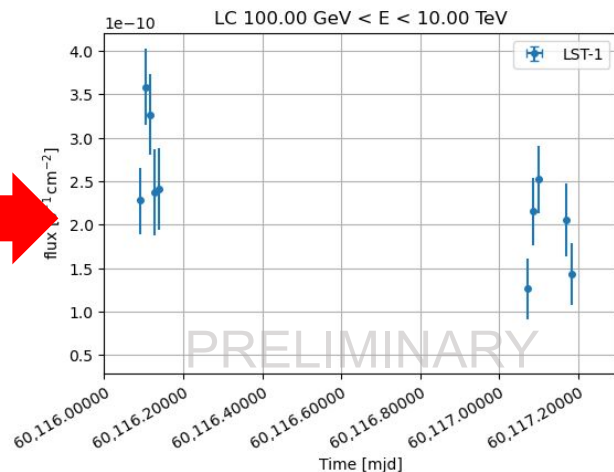
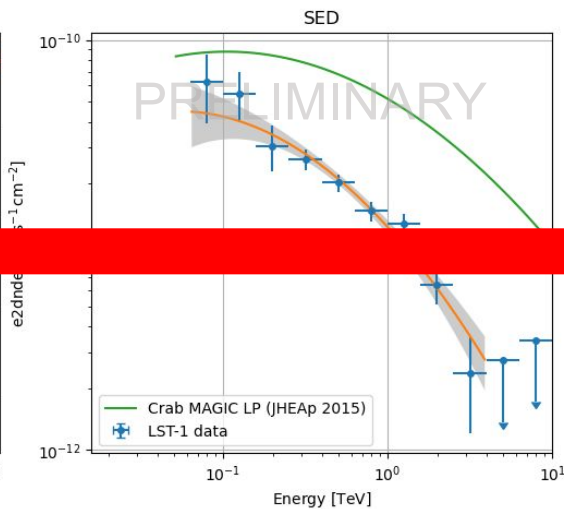
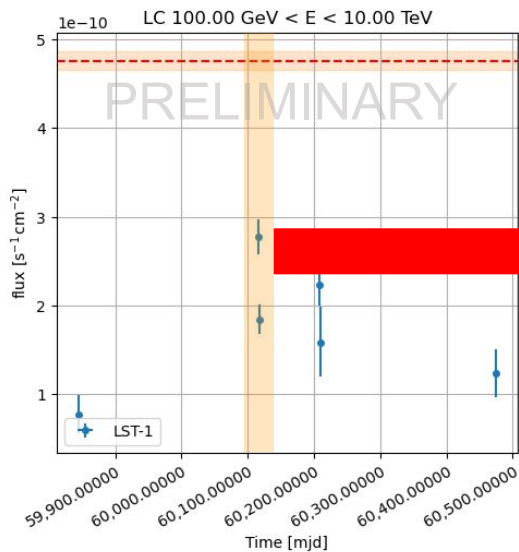
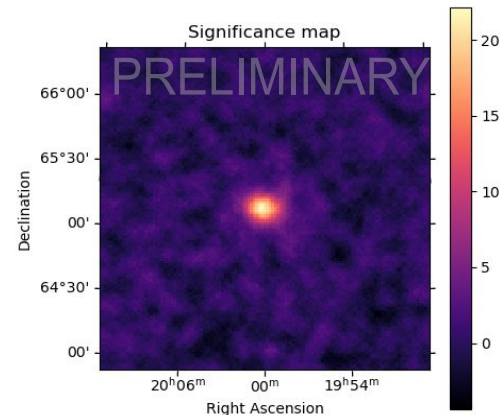
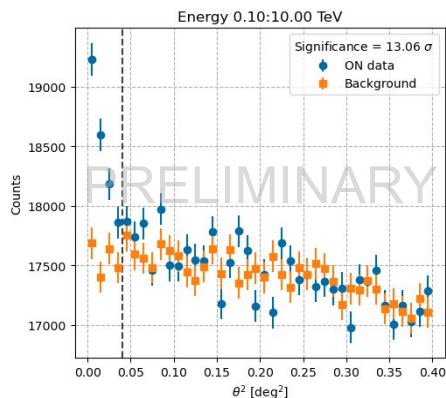
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- Standard data quality cut: 5.63 hrs.
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- Standard data quality cut: 5.63 hrs.
- Detection significance 13σ .
- Similar flux level as 2020 – 2022 period ($\sim 40\%$ Crab).
- Hint of intraday variability.
- Shortest flux doubling timescale, $t_{\text{var}} = 26$ min
- Assuming $\delta = 10 - 50$, emission region size, $R \lesssim (0.4 - 2) \times 10^{15}$ cm.
- Time-resolved broadband SED might be interesting.



Summary

- Spectral variability study of well-known AGN with LST1 data in 2020 – 2022.
- Good agreement between simultaneous Fermi-LAT and LST-1 spectrum.
- Sensitive to variable gamma-ray sources above 25 GeV for low zenith observations.

- Detection of OP 313, the highest redshift ($z = 0.997$) FSRQ till date.
 - ◆ Several projects on OP 313 are ongoing.

- Detection of 1ES 1218+304 with 4.4 hours of LST1 observation
 - ◆ Comparable VHE spectral index
 - ◆ Multiwavelength SED modelling
 - ◆ Diffusive shock acceleration is viable

- Ongoing projects:
 - ◆ BL Lac: LST-1 observation of flares in 2020, 2021 and 2022.
 - ◆ OP 313: VHE flux variability, MWL SED, BLR study, EBL constraints

- My involvements:
 - ◆ MAGIC + LST1 joint observations of 1ES 1218+304
 - ◆ Multiwavelength study of 1ES 1959+650
 - ◆ LST-1 flare advocate in 2024 October-November season.

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