TeVPA 2023

cta cherenkov telescope array

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Observation of Active Galactic Nuclei Through the Eyes of CTA LST-1

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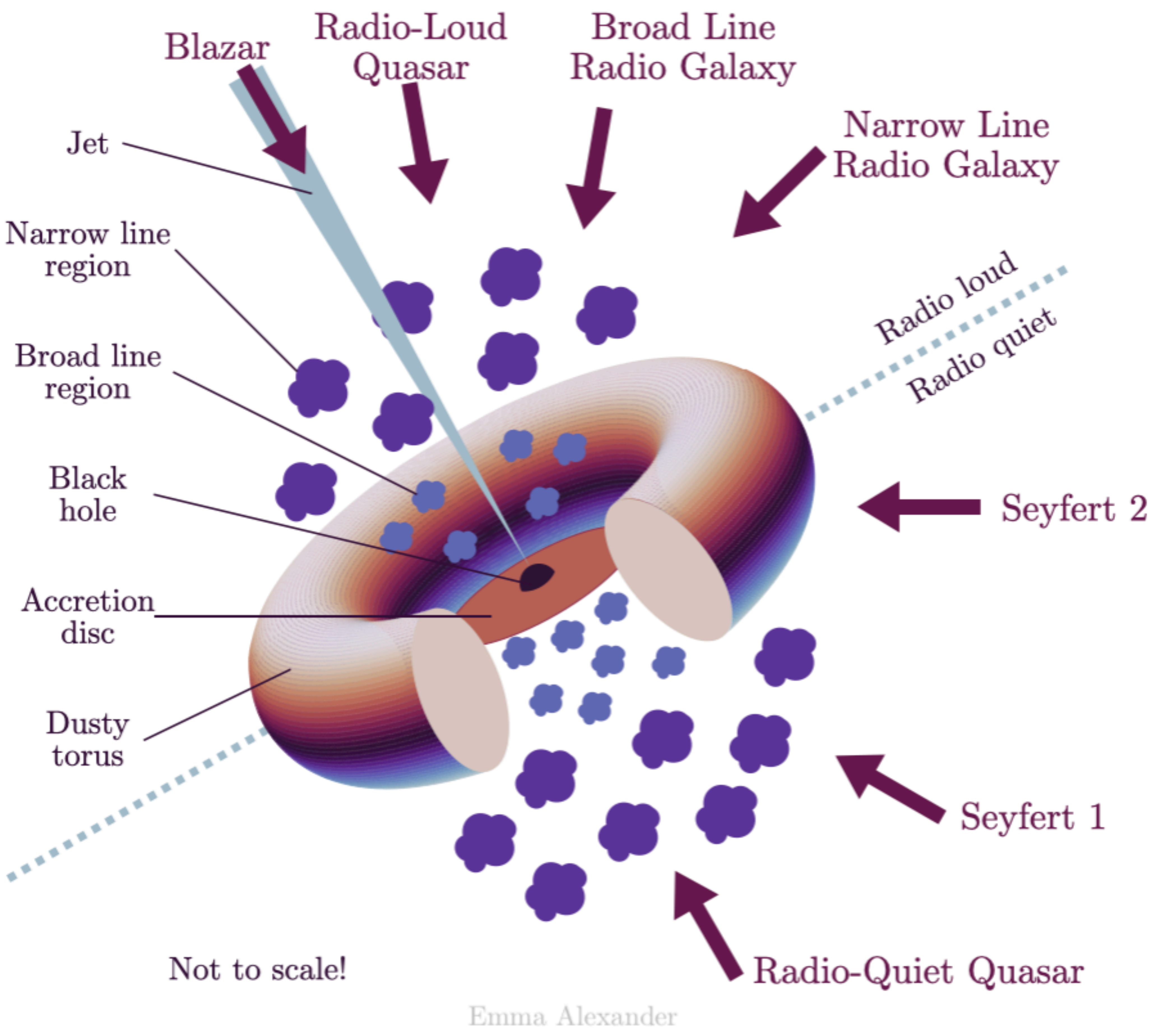
Active Galactic Nuclei (AGN)



- **Blazars**, whose jet is pointing towards us, dominate the high-energy extragalactic sky
  - **BL Lac**: weak or absent broad emission lines in UV/opt spectra
  - **FSRQ**: broad emission lines in opt spectra

- While its emission across the EM spectrum, **the two fundamental questions concerning gamma-ray blazar observations** are:
  - **What** types of particles are responsible for the radiation?
  - **Where** is the jet's emission zone?

Active Galactic Nuclei (AGN)

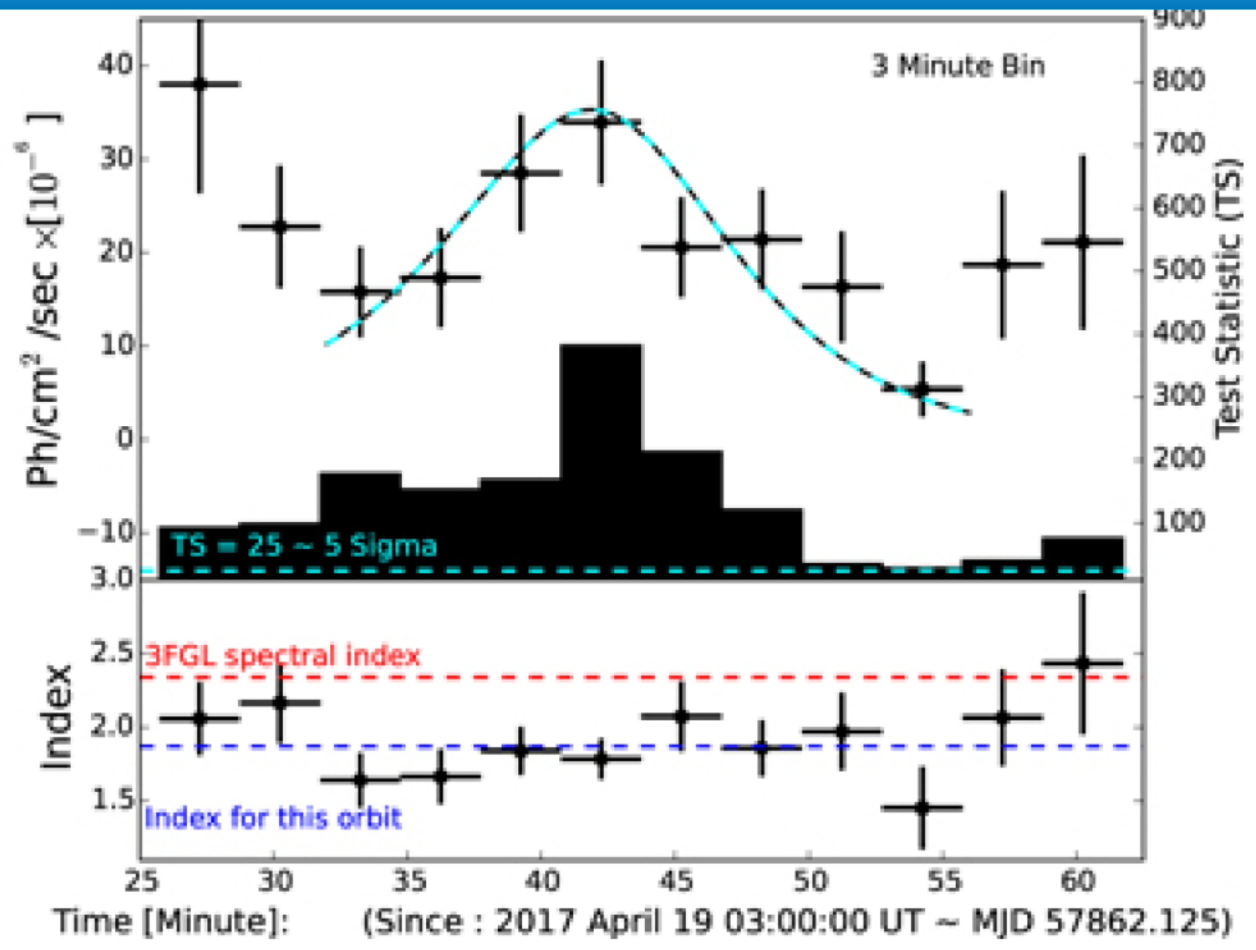
✓ Observing **short-time variability**

- helps to **identify the location of the emission** from the causality, further **challenging the blazar models**

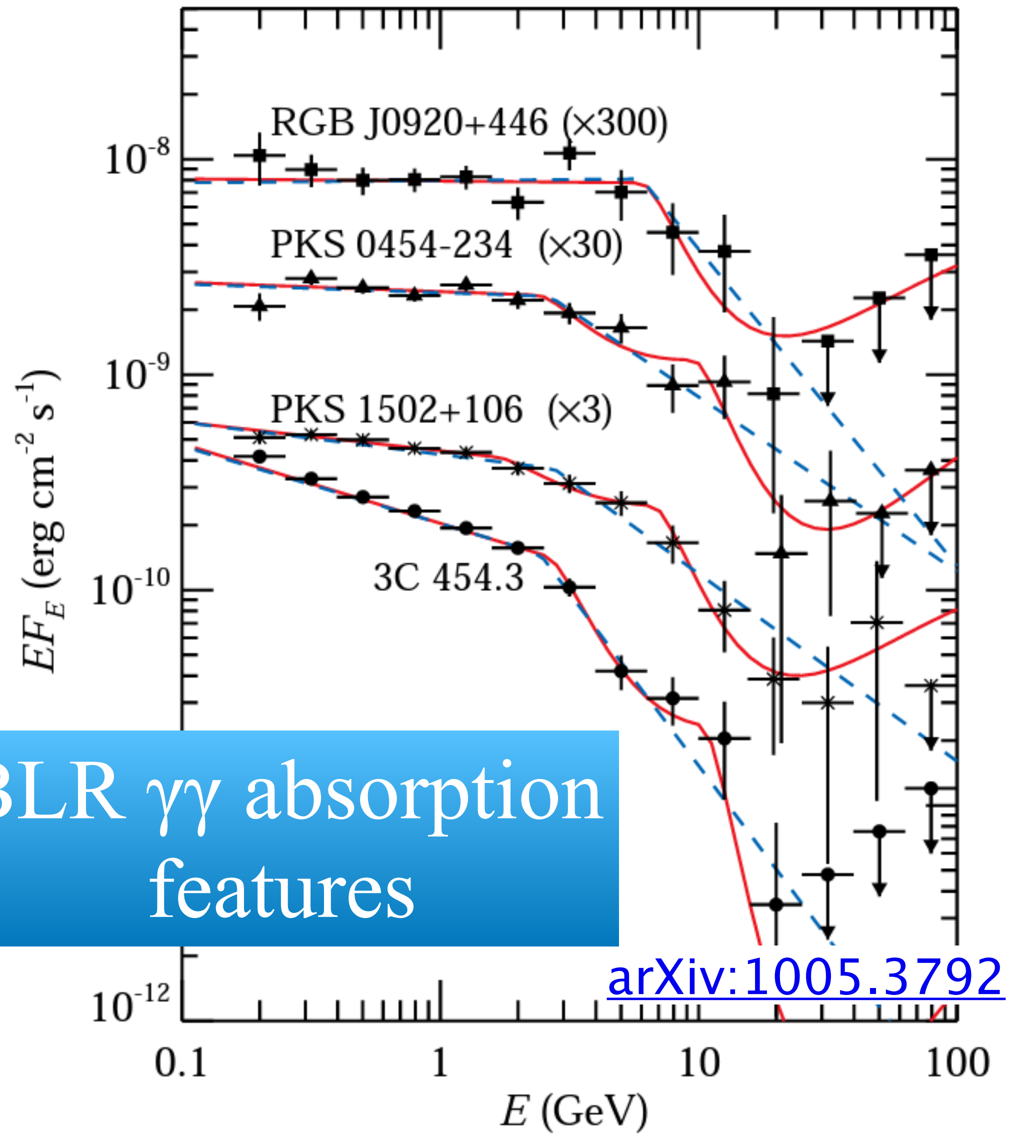
✓ Observing **detailed (good quality) gamma-ray spectra**

- helps to confirm **BLR γγ absorption features**, providing a diagnostic for the **location of the emission**
- might provide **a smoking-gun signatures of hadronic process** in the multi-TeV spectra

Short-timescale γ-Ray Variability in CTA 102



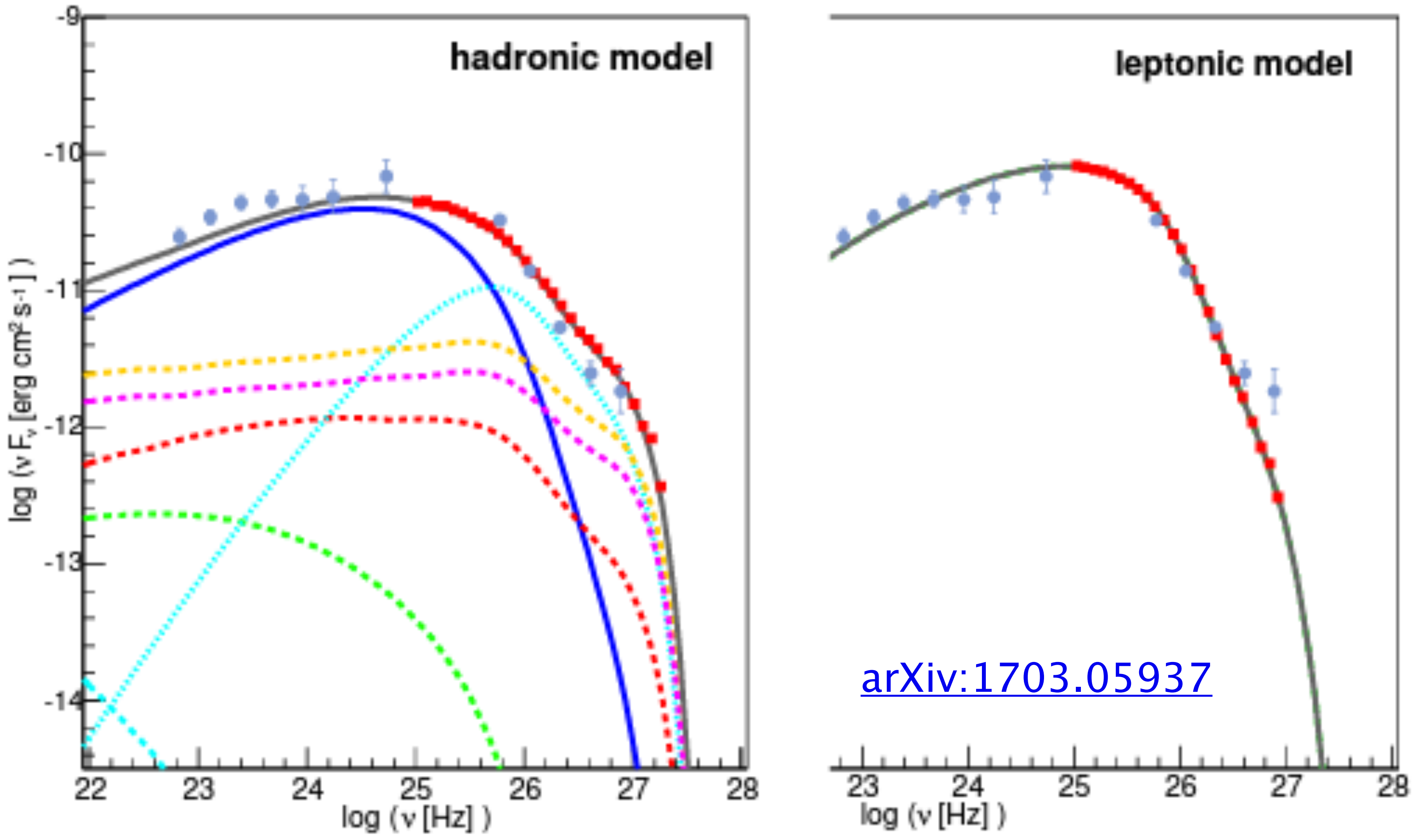
https://ui.adsabs.harvard.edu/abs/2018ApJ...854L..26S/abstract



BLR γγ absorption features

arXiv:1005.3792

Expected signatures from hadronic emission processes



arXiv:1703.05937

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A gamma ray telescope with
high sensitivity over GeV-TeV energy band

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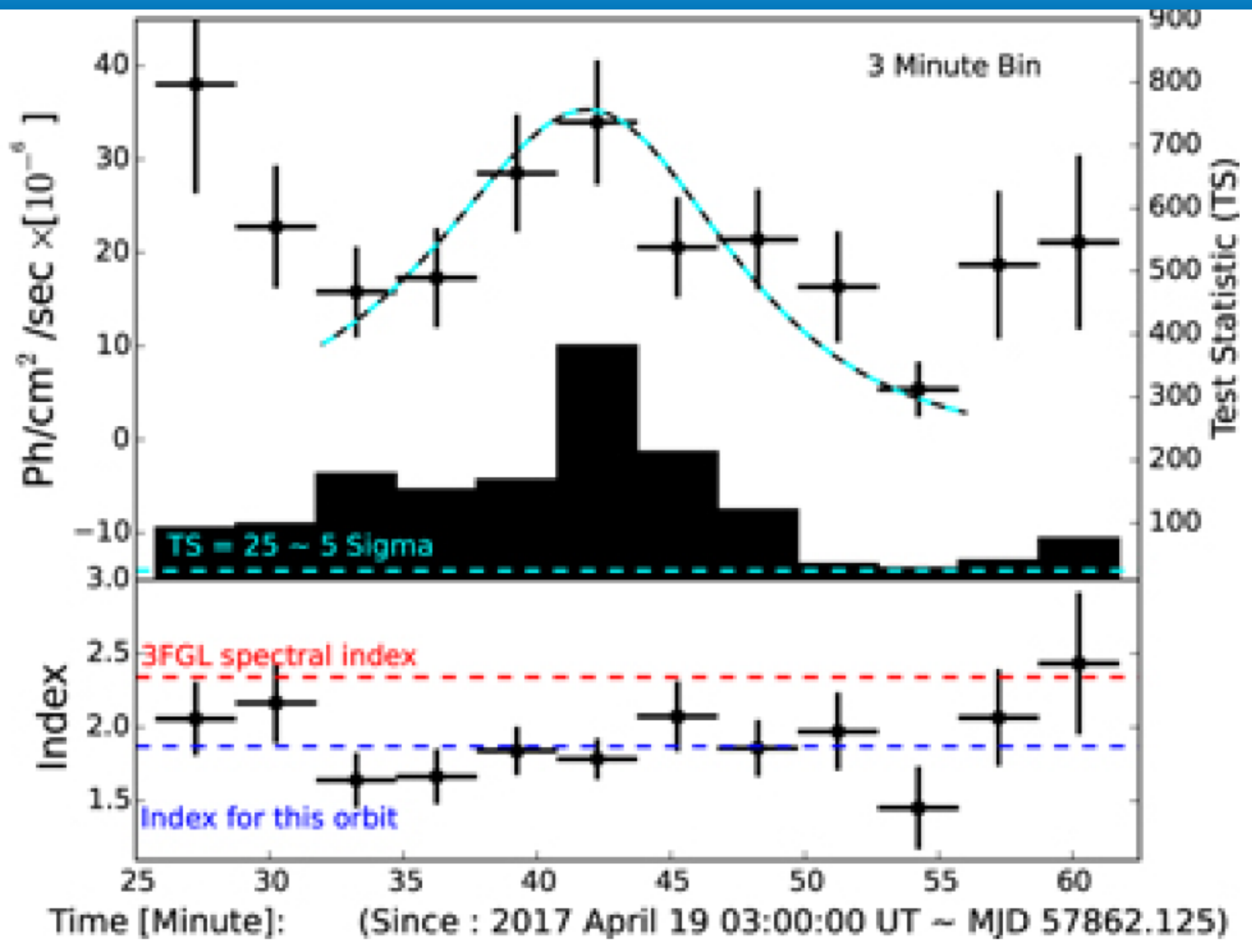

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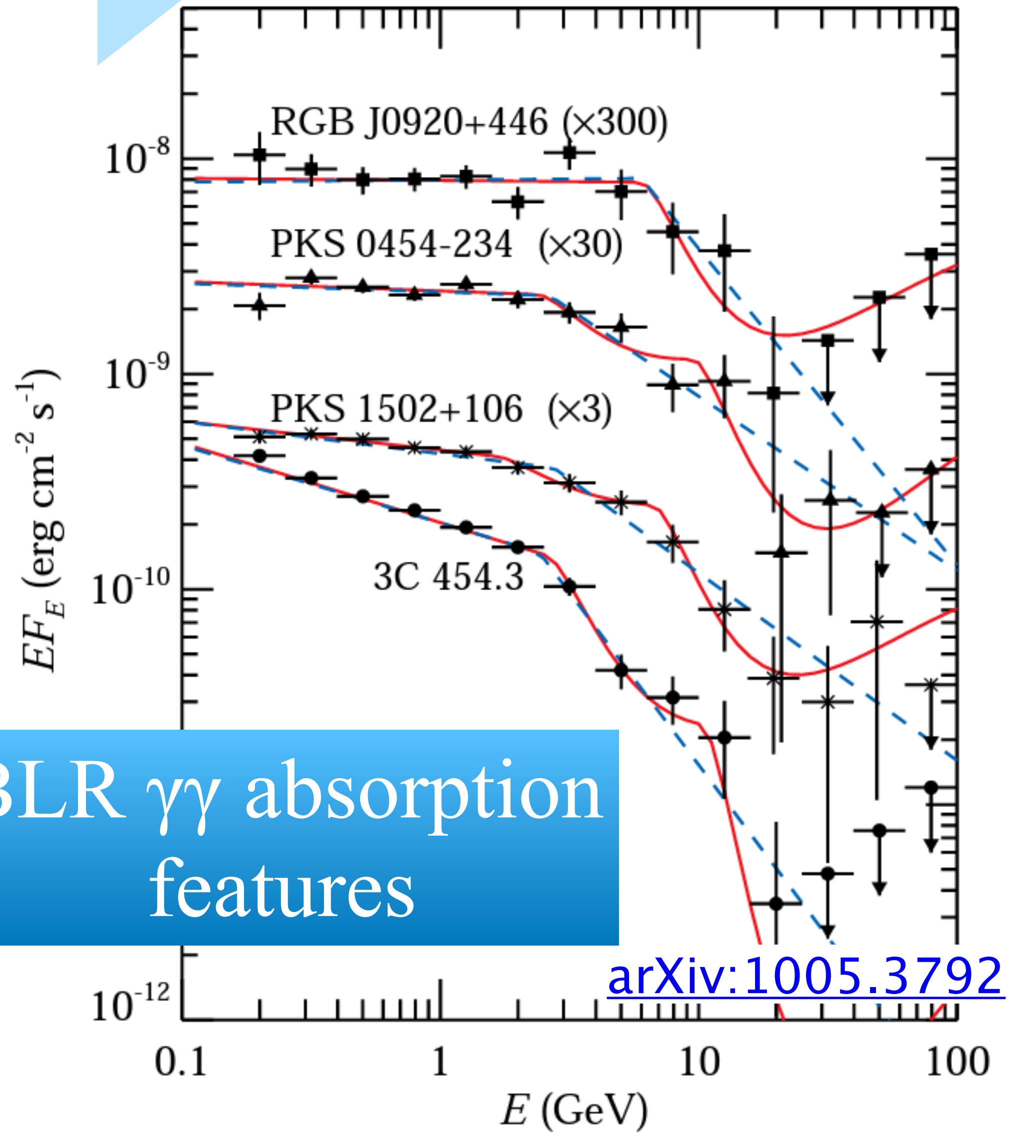

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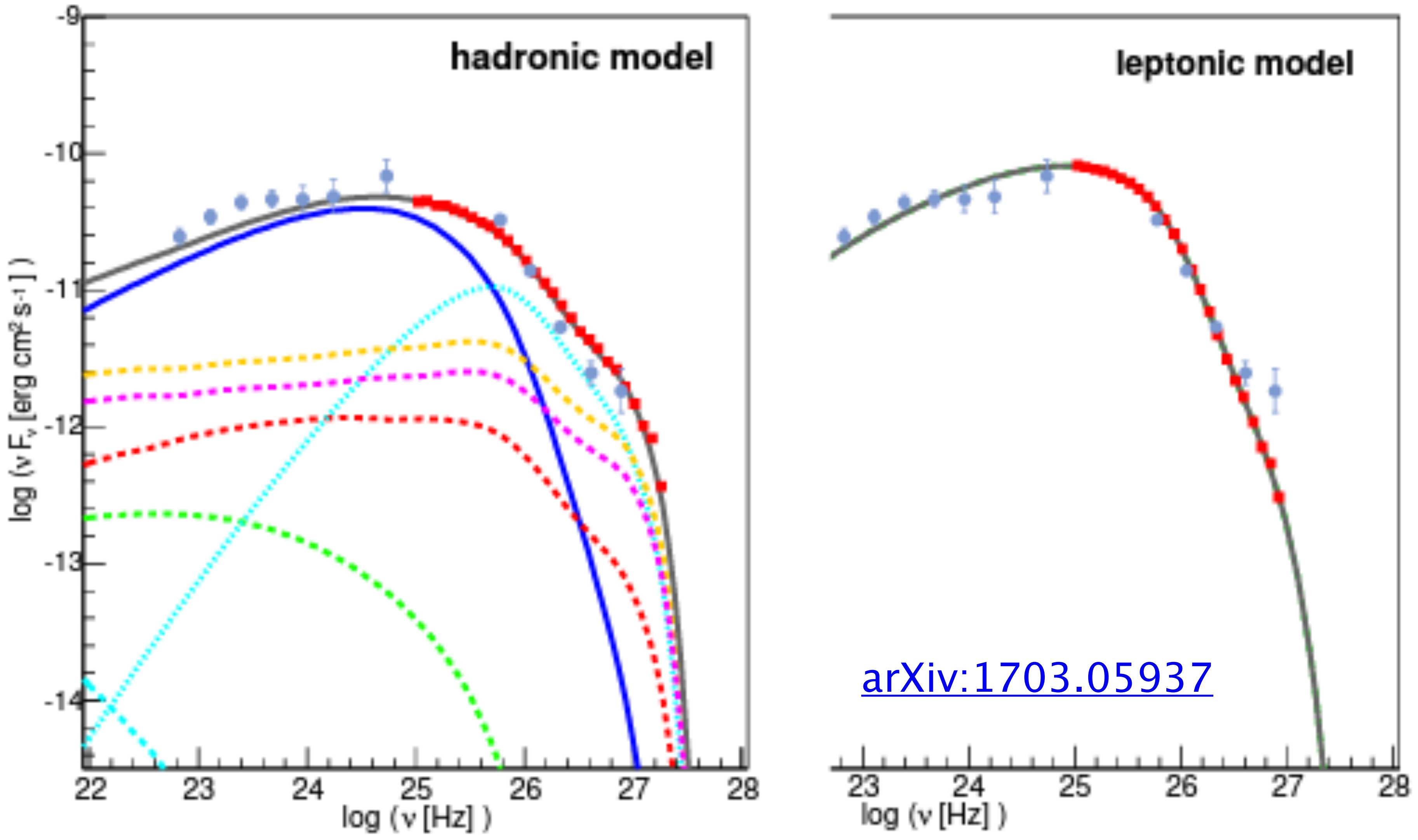

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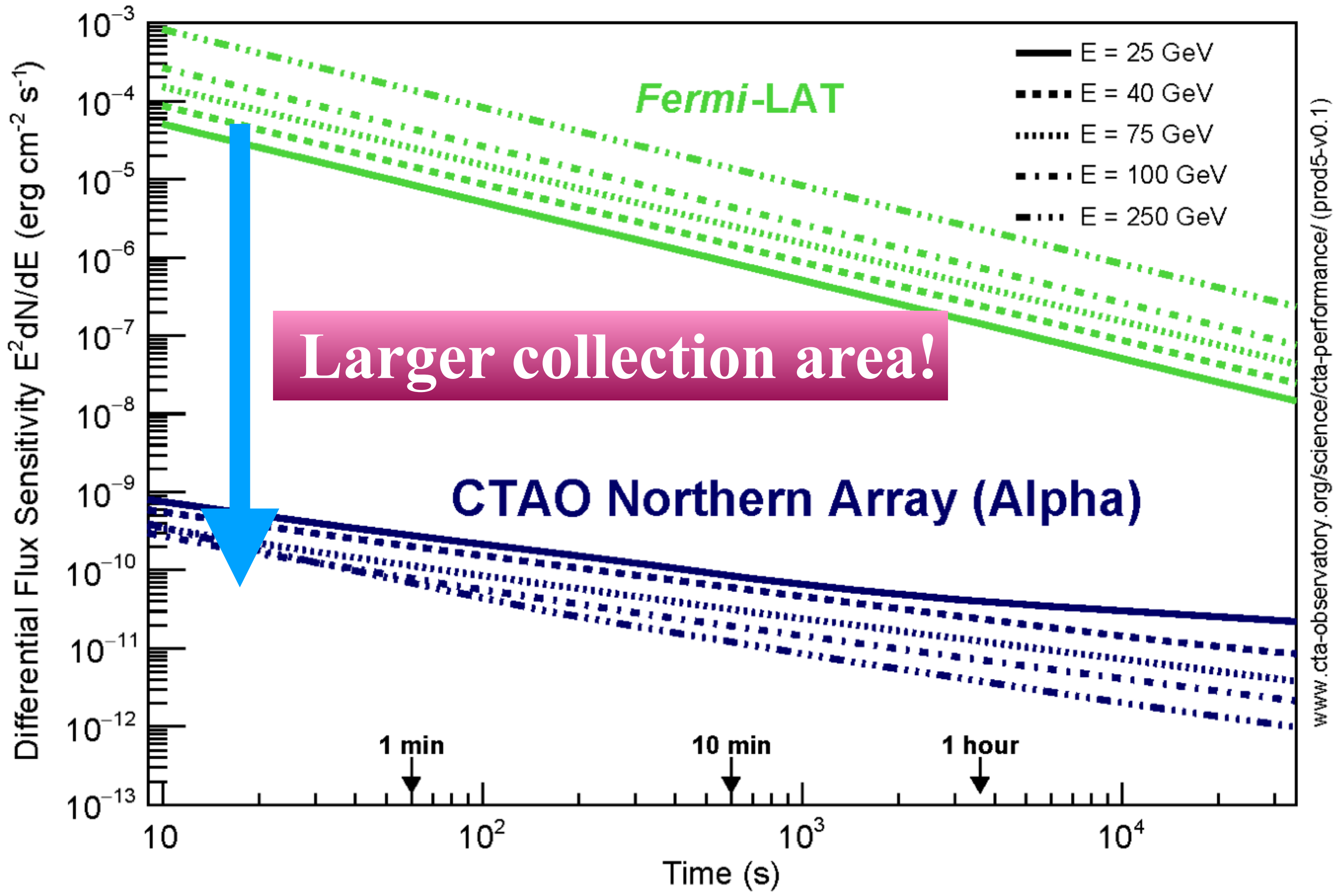
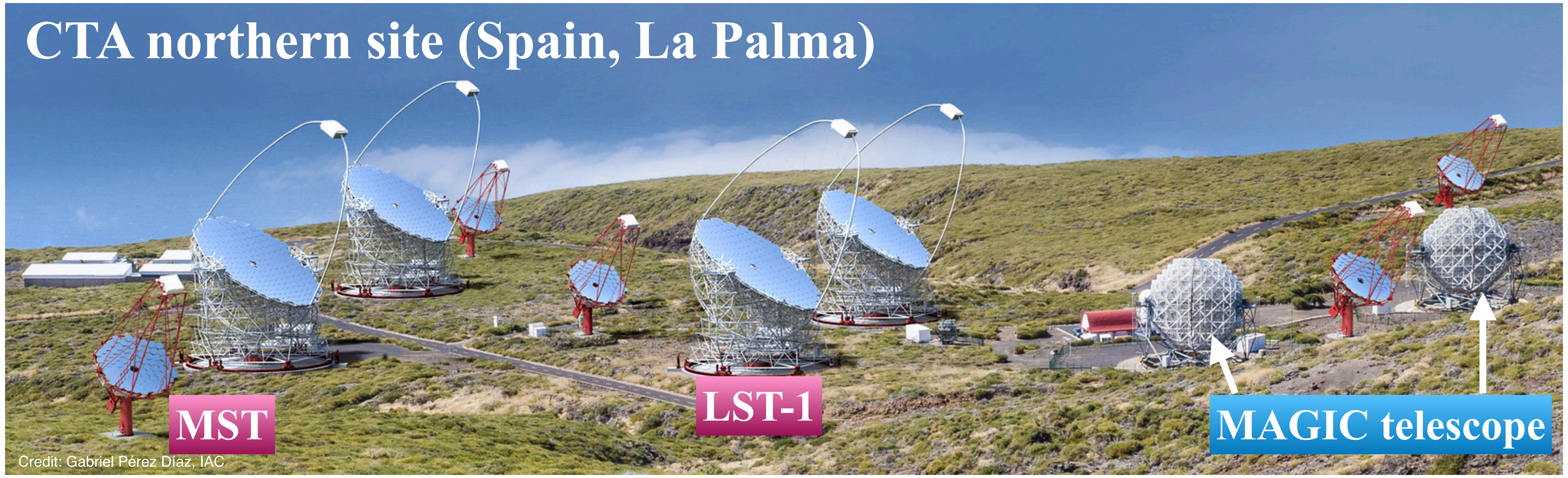
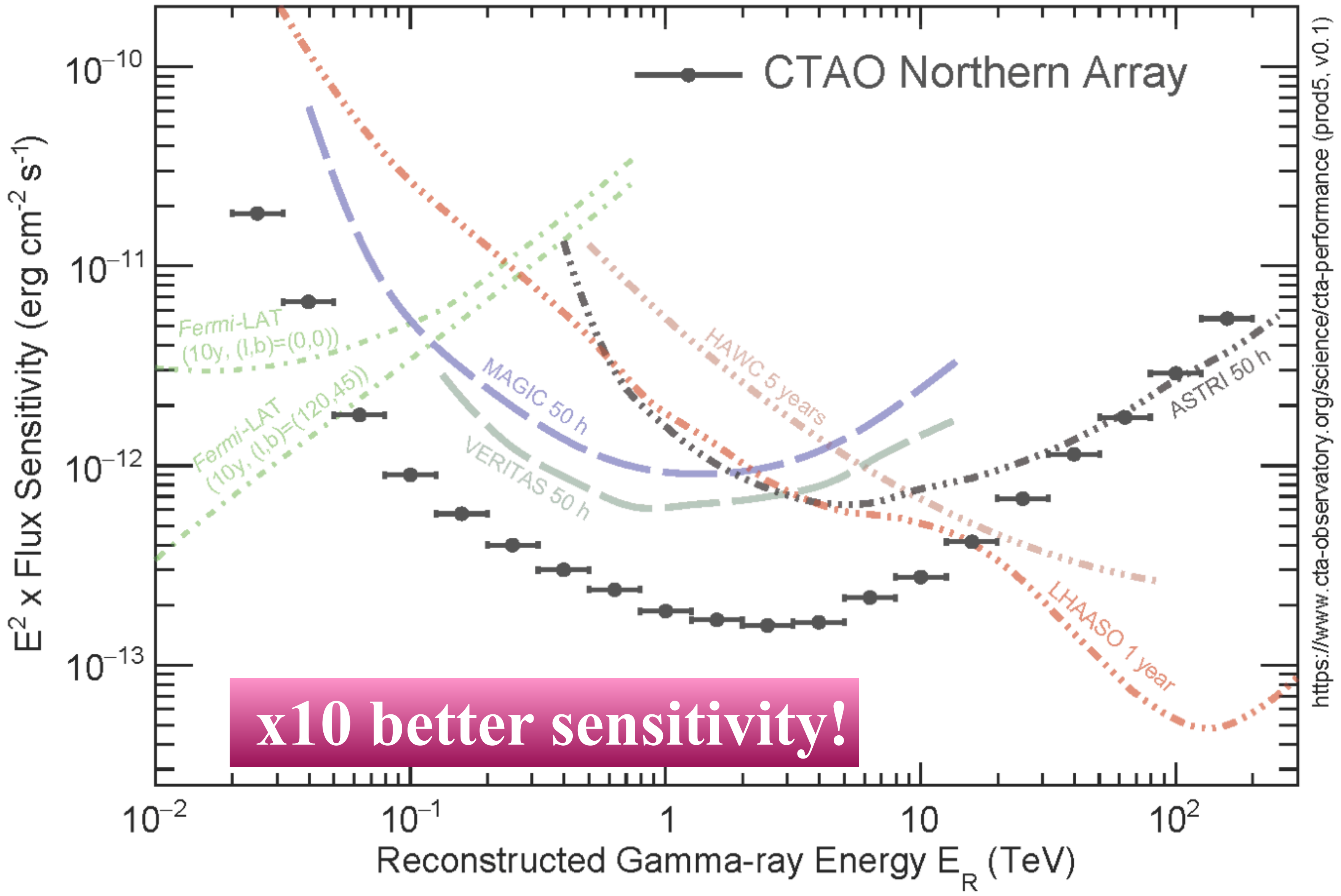
Cherenkov Telescope Array (CTA)

Next generation ground-based instrument for gamma-ray astronomy at very-high energies

- Located in the northern and southern hemispheres with 64 telescopes
- Northern CTA: 4 Large-Sized Telescopes + 9 Medium-Sized Telescopes, located in La Palma, Spain
- **x10 better sensitivity + wide energy coverage of 20 GeV-300 TeV**
- LST-1 started observation since 2018





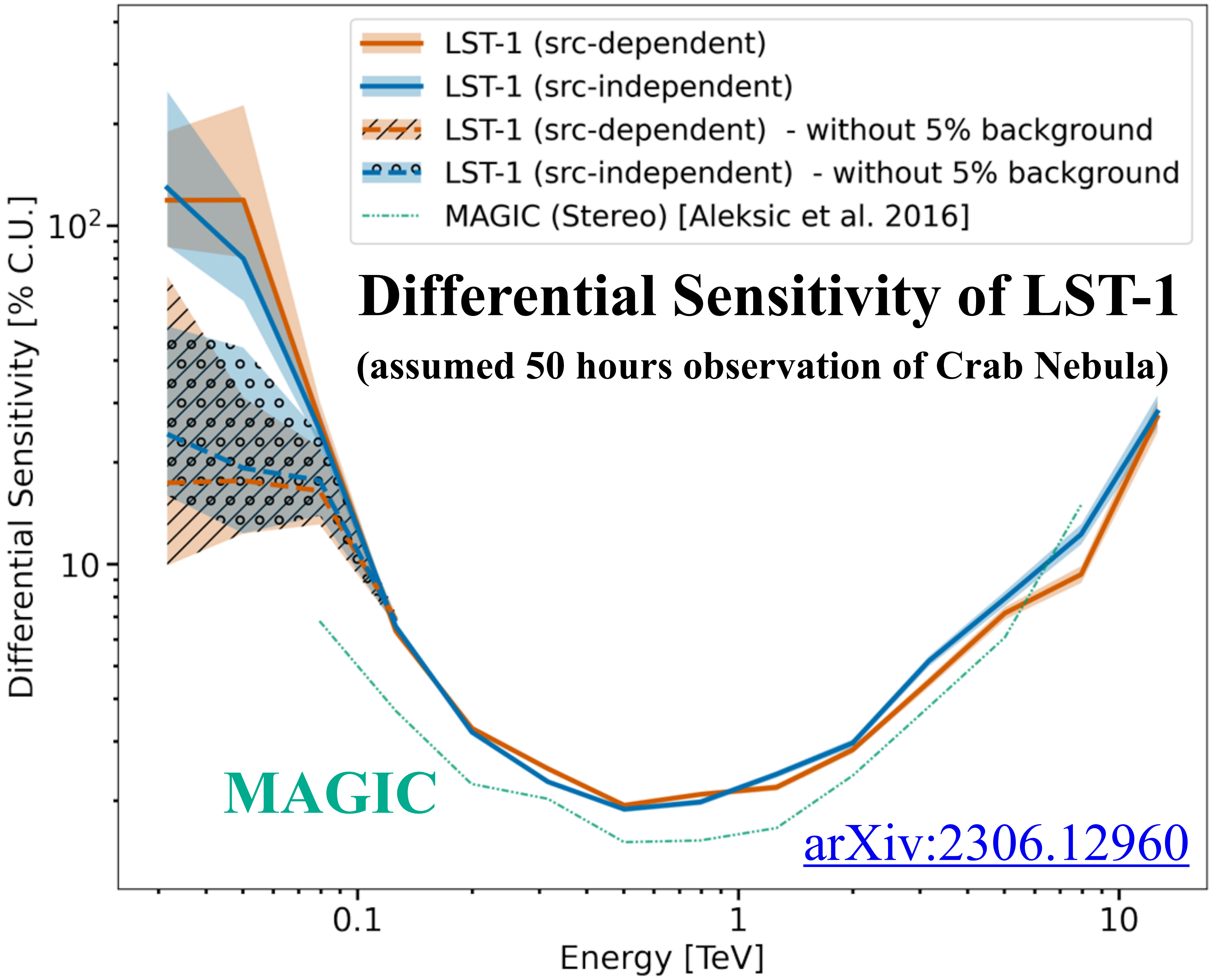


Large-Sized Telescope (LST)

LSTs are designed to give optimal performance in the lowest region of the energy range covered by CTA, down to ≃ 20 GeV

- Reposition to any point in the sky **within 20 seconds**
- In July 2023, a performance paper on LST-1 was published based on the observational data of the Crab Nebula
  - The energy threshold at trigger level was estimated to be **20 GeV**, increasing to ≃ **30 GeV after data analysis**
- Suitable for **transient/soft/distant** sources

Crédito: Iván Jiménez (IAC)



Active Galactic Nuclei Observation with LST-1

LST-1 detected (> 5 σ) 6 known TeV blazars:
Mrk421, Mrk501, 1ES 1959+650, 1ES 0647+250, PG 1553+113, BL Lac

- A paper is slated for publication, along with contemporaneous data acquired by the Fermi-LAT
- LST-1 detected a flare from BL Lac in 2021 [icrc2023_pos]. This is a separate project and will not be covered in this talk
- In this talk, we present analyses of energy spectra and the light curves reconstructed, down to energies of a few tens of GeV, close to the energy threshold of the LST design

	Mrk421	Mrk 501	1ES1959+650	1ES0647+250	PG 1553+113
AGN type	HBL	HBL	HBL	HBL	HBL
Redshift	0.031	0.034	0.048	0.45±0.05	0.433
Obs. date	2020/12/12 -2022/05/23	2020/07/10 -2022/06/29	2020/07/11 -2022/05/05	2020/12/16 -2020/12/21	2021/04/08 -2022/05/23
Obs. time BF/AF cut (h)	68.5/32.4	67.2/39.7	21.3/11.8	8.8/8.2	12.2/9.9
Significance	34 σ	21 σ	12 σ	7 σ	16 σ
Condition	Dark (No Moon) + Clear Sky				

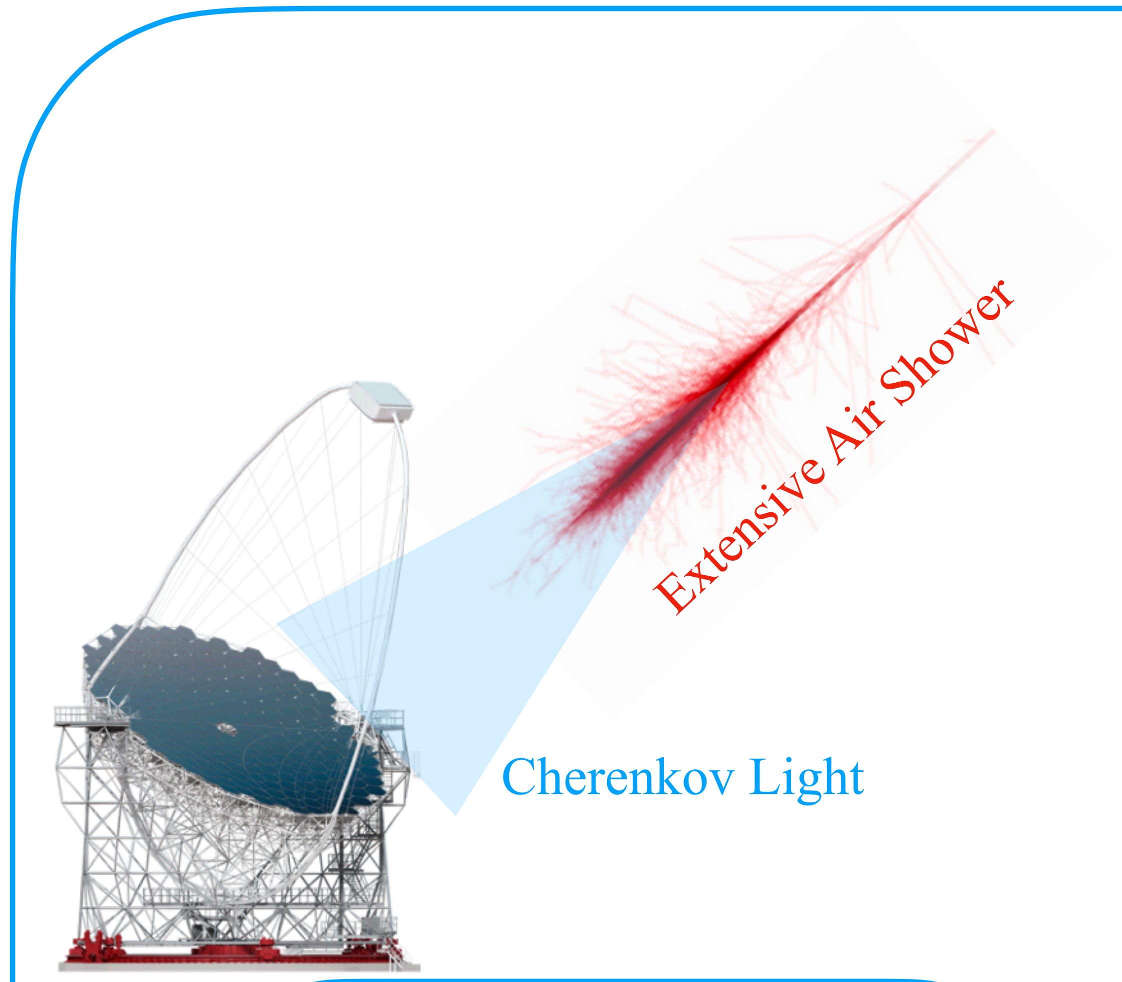
LST-1 Data Analysis Method

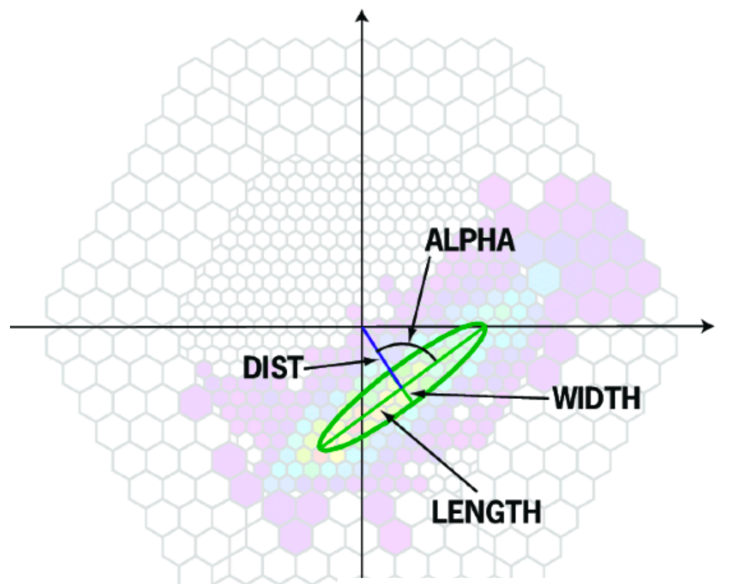
We used cta-lstchain for creating IRFs and event list, and Gammapy for subsequent processes

- Python-based pipeline **cta-lstchain v0.9.12/0.9.13** (dedicated analysis tool for LST data)
- For the generation of high-level visualizations, including SED and Light Curves, we employed **Gammapy v1.0.1**
  - **Gammapy**: open-source Python package for gamma-ray astronomy built on Numpy, Scipy and Astropy

cta-lstchain

https://github.com/cta-observatory/cta-lstchain



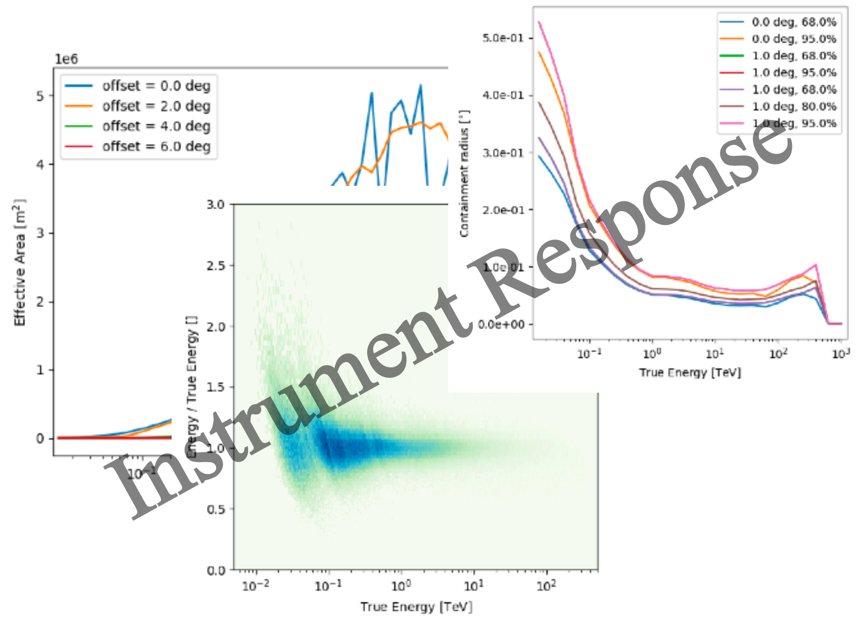


K Satalecka at el (2010)

Direction

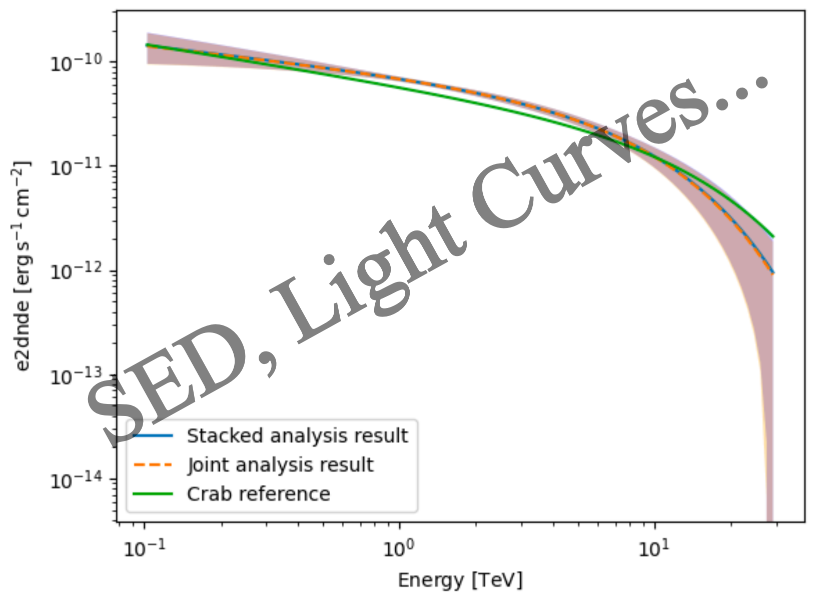
Gammaness

Energy



Gammapy

https://github.com/gammapy/gammapy

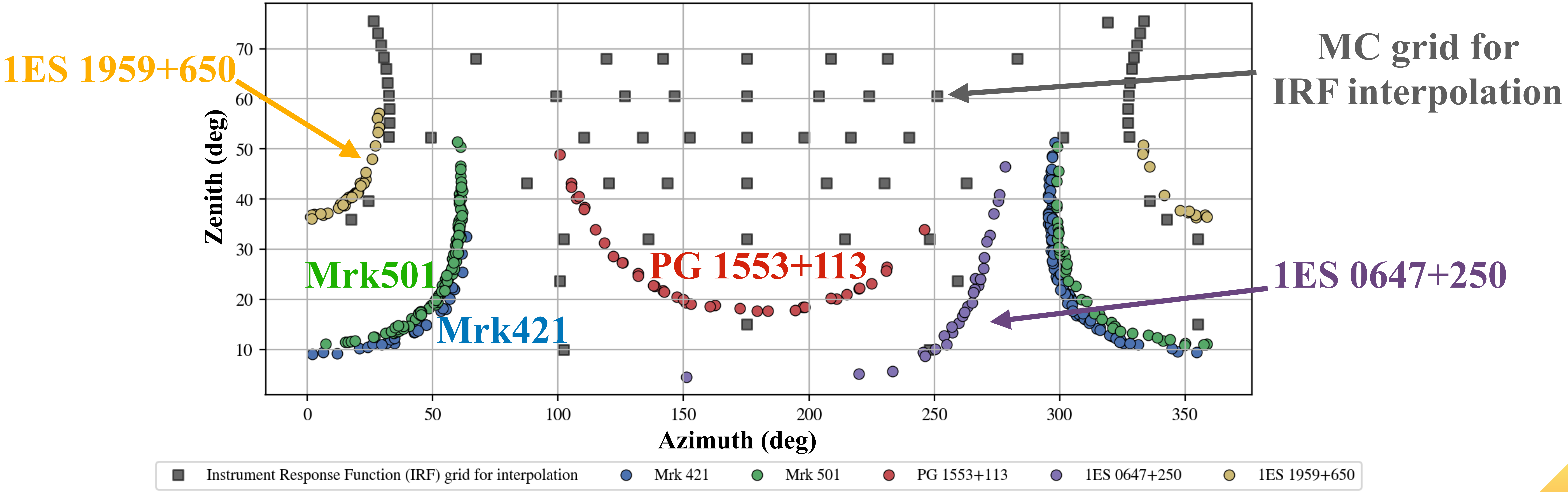


DL0 Raw DAQ output → **DL1** Image Parameters → **DL2** Shower Parameters → **DL3** IRF + event list → **DL4** Scientific Quantities

LST-1 Data Analysis Method

Perform IRF interpolation to minimize the discrepancy between Simulation and Data

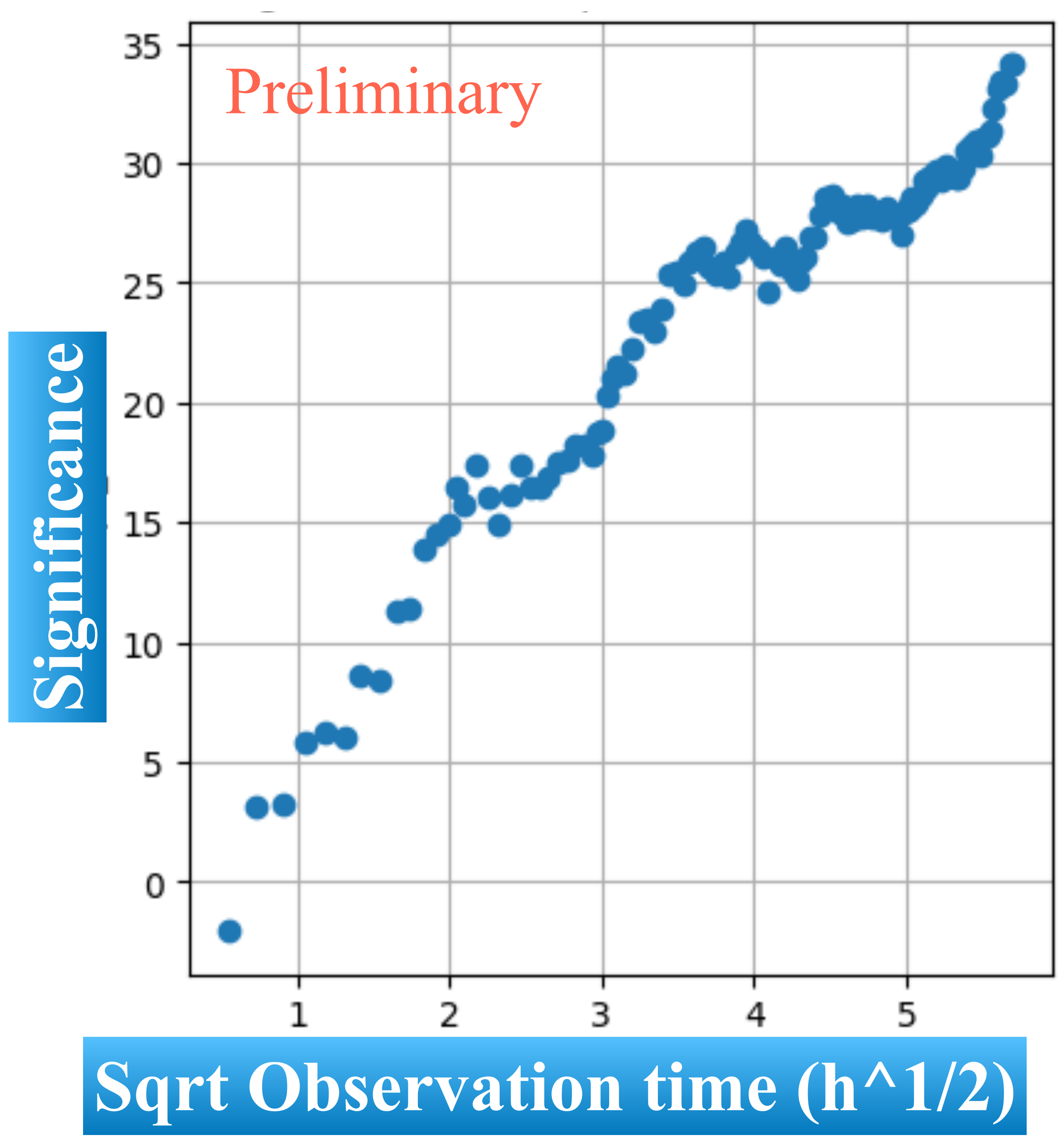
- Reconstruction of primary particle information using Random Forest trained with MC simulation of gamma-ray and cosmic-ray showers as input
- The Estimation of the IRFs at given telescope pointing direction was performed through the interpolation of Monte Carlo (MC) simulations, generated on a grid in the (zenith, azimuth) plane

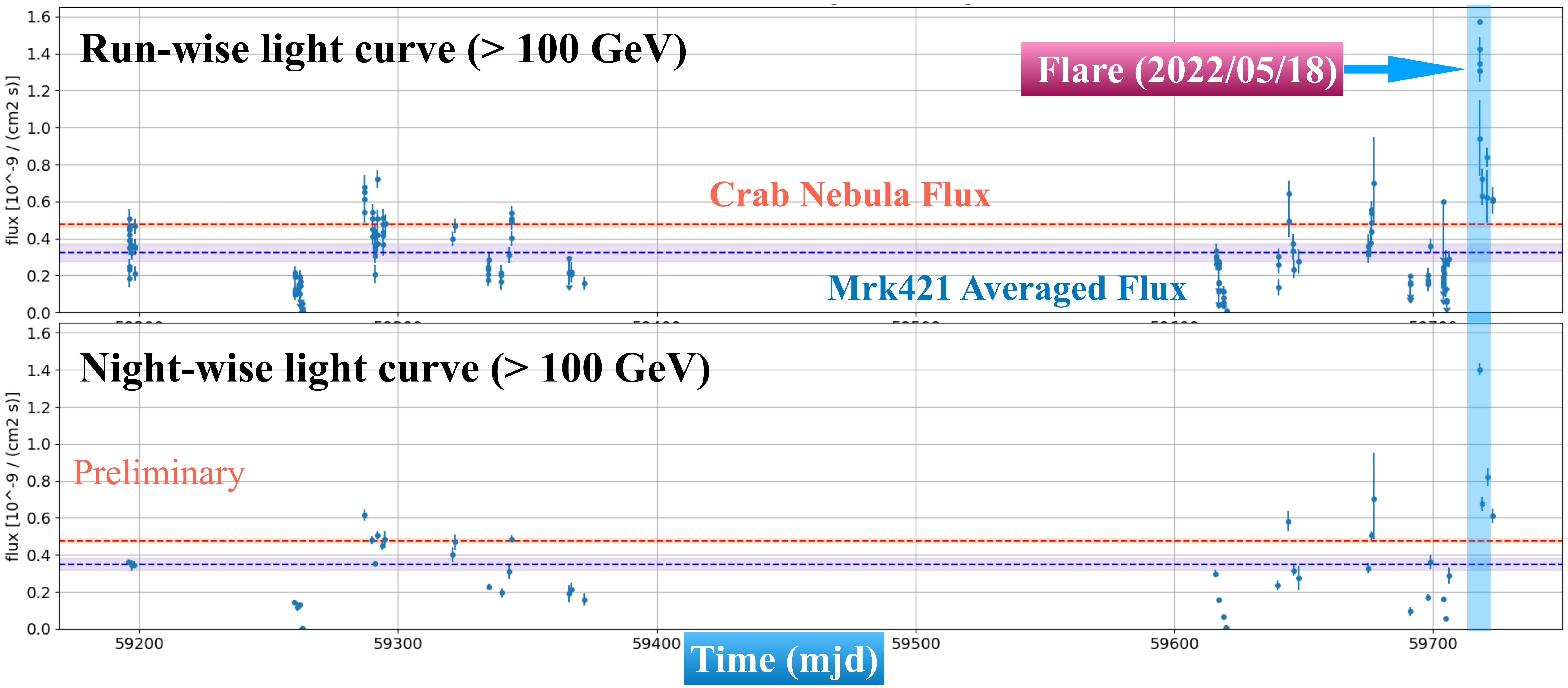


Light Curves of Mrk421

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

- Data period: 2020/12/12 - 2022/05/23 (118 runs, 32.4 h)
- Zenith angle: 9 - 52.5 deg
- A Flare was observed in May 2022

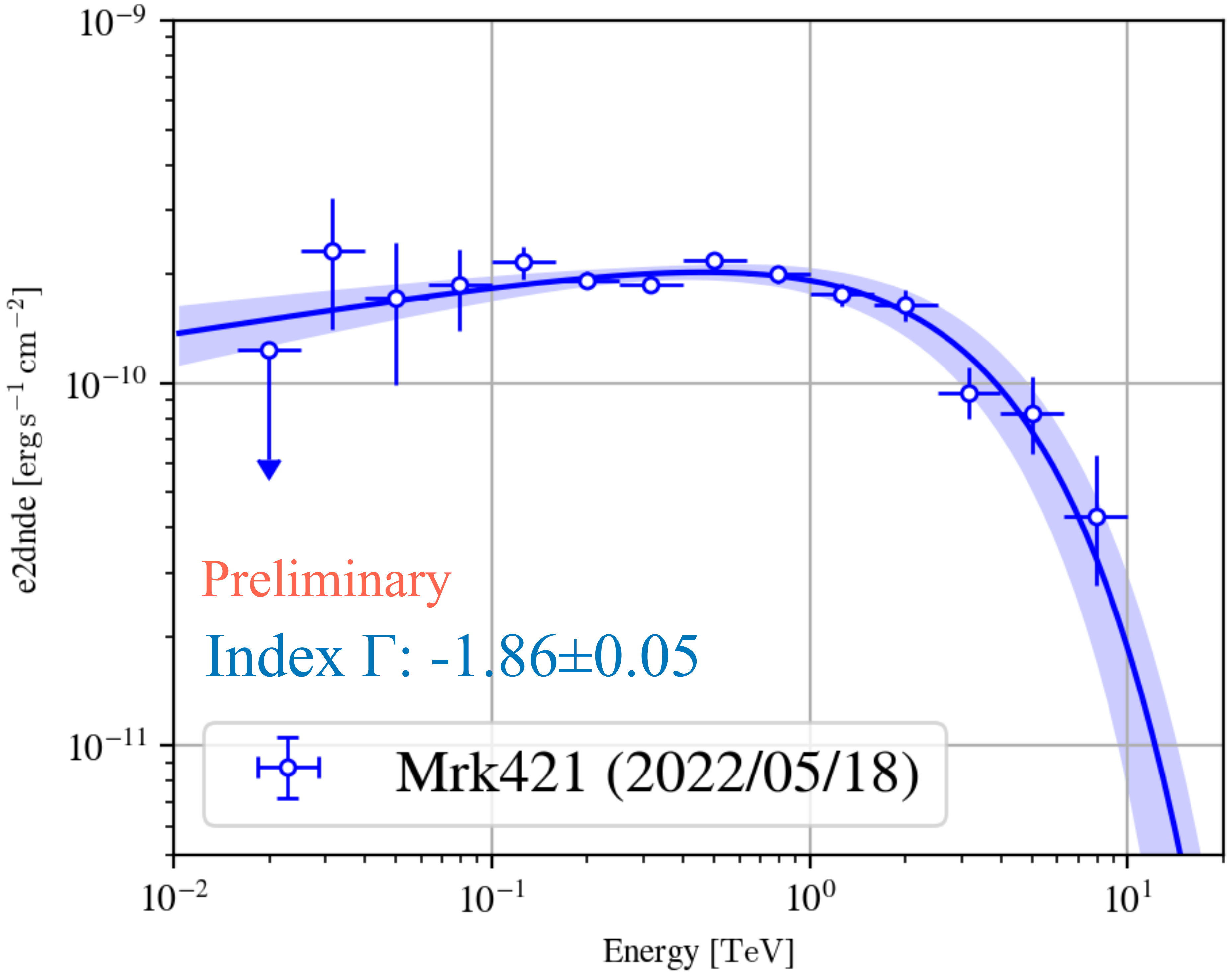


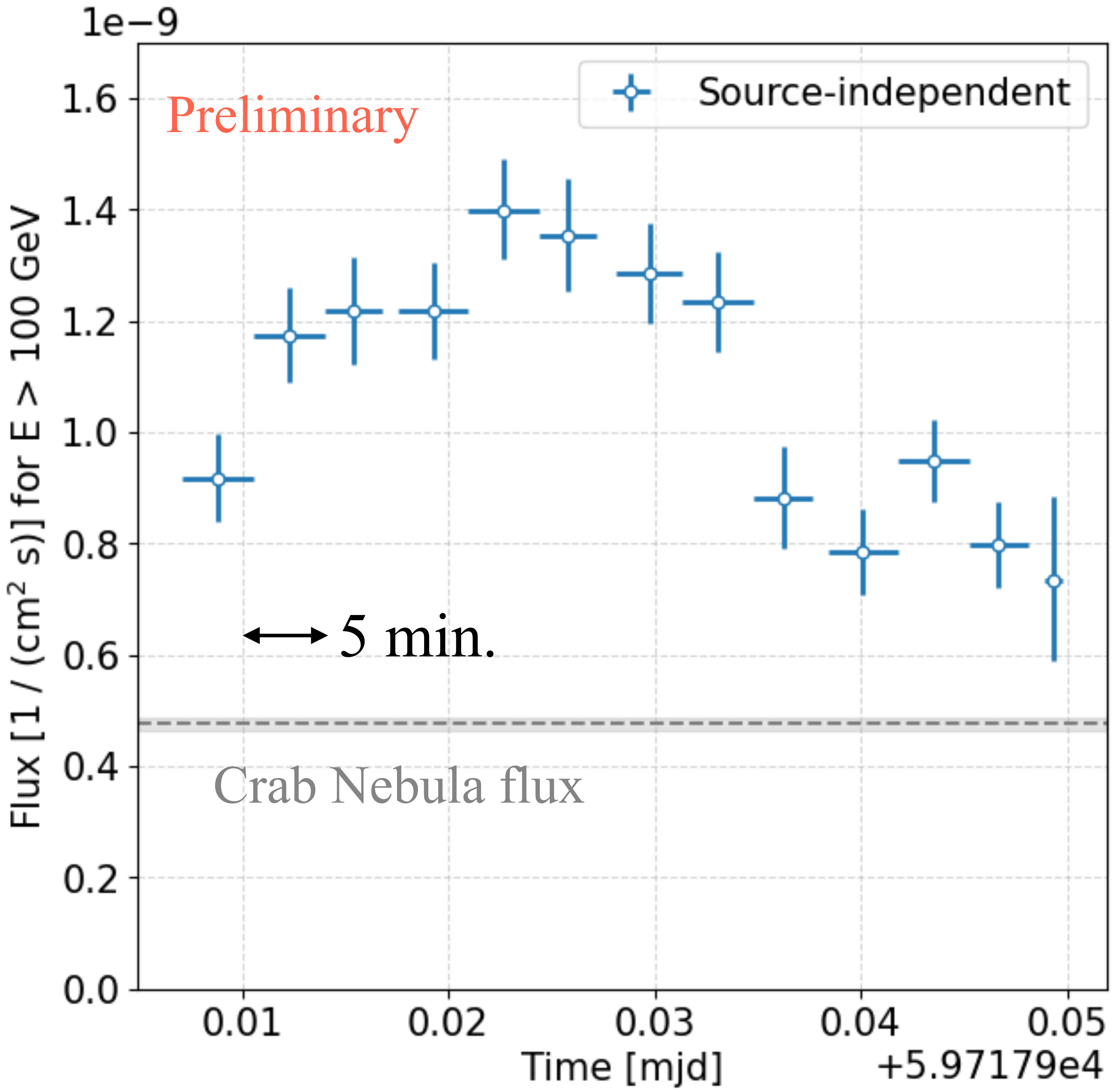


Mrk421 Flare in 2022-05-18

Mrk421 flare was detected in 2022/05/18
~3 times brighter than Crab Nebula's flux at > 100 GeV

- Spectra are measured down to ~25 GeV, and well fitted by the exponential cutoff power law (ECPL) function
- Concurrently, intra-night light curve and flux variability time scale are under examination

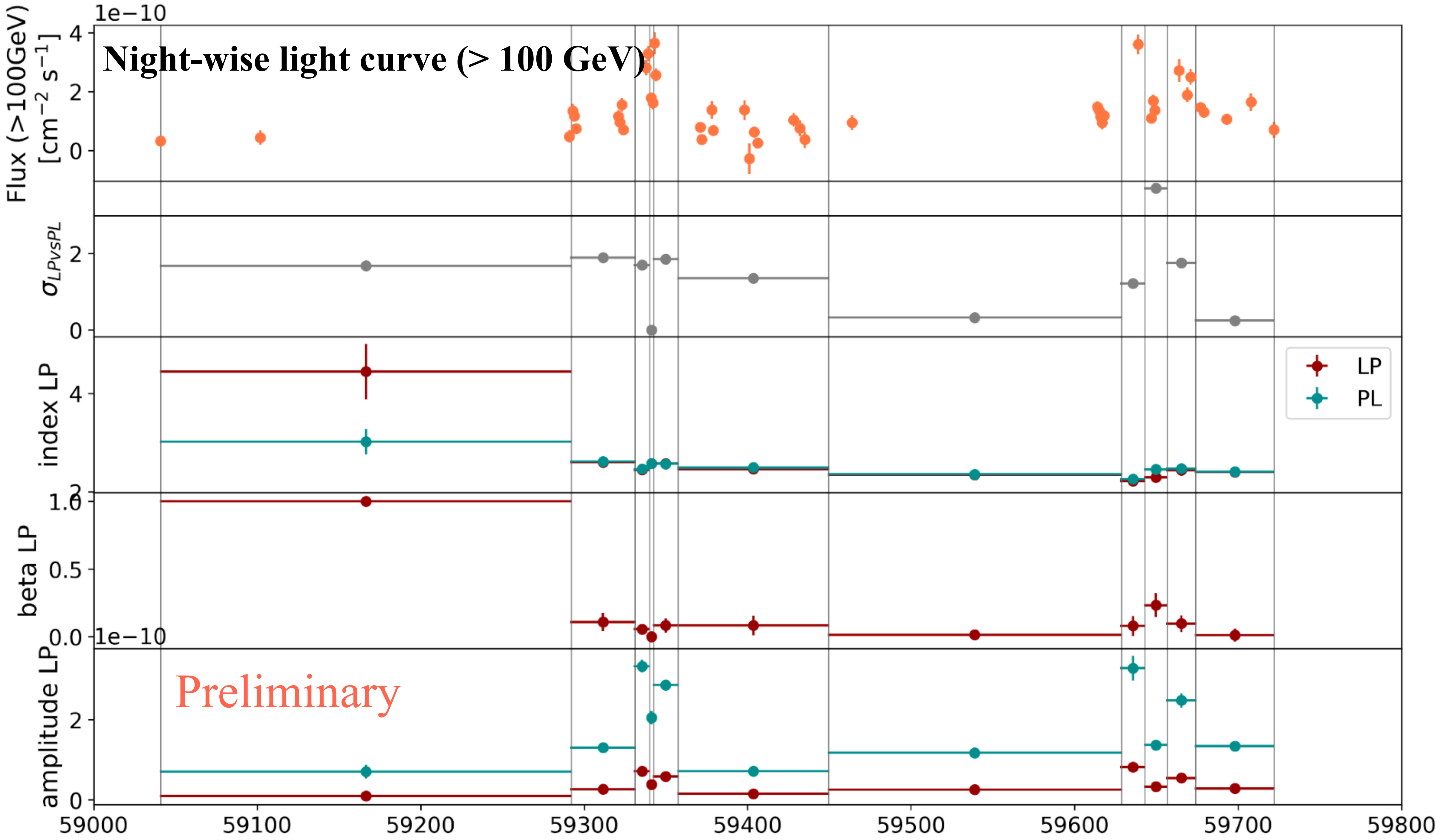




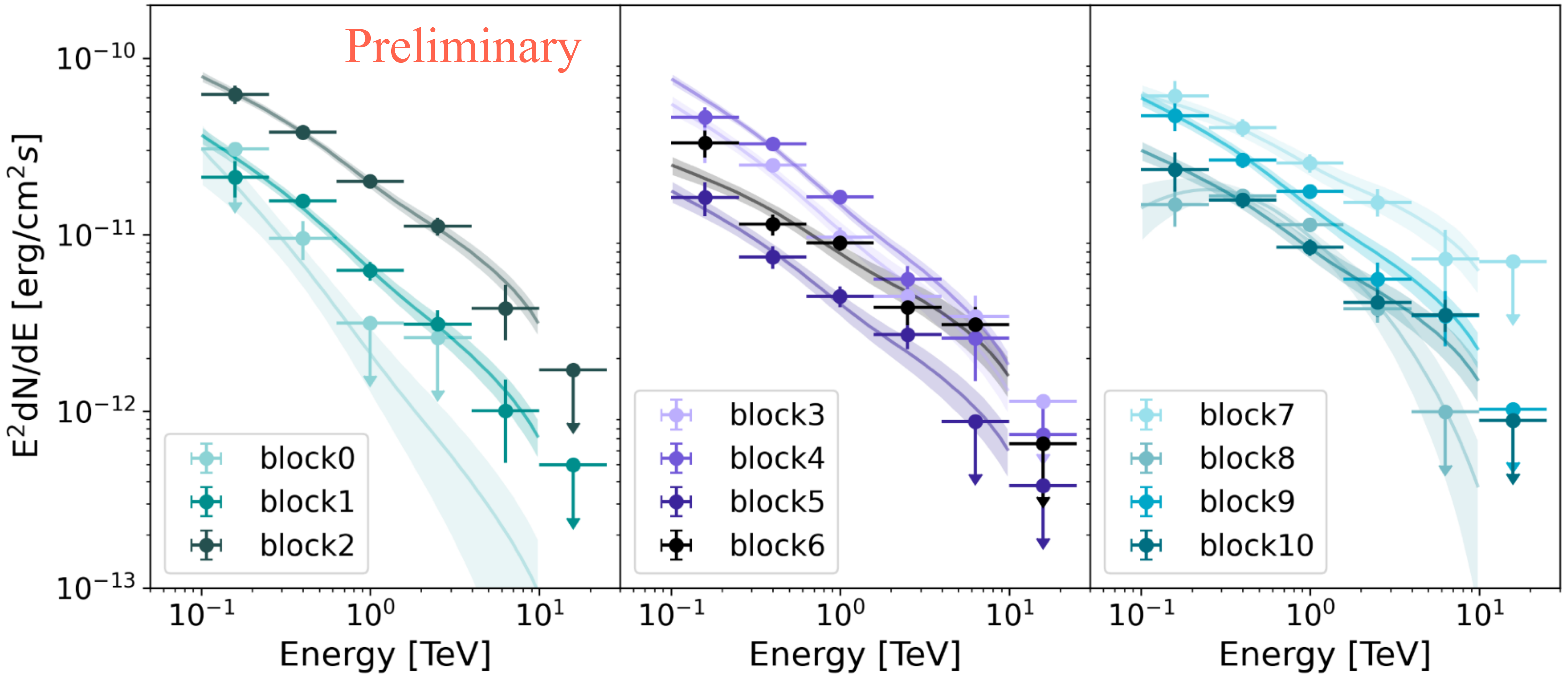
Mrk501 Light Curves and SEDs

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

- Data period: 2020/07/10 - 2022/05/22 (153 runs, 39.7 h)
- The spectrum variation, already verified in VHE gamma, was also properly confirmed in our data set



Preferred model
Block 8: log-parabola + EBL Others: power-law + EBL

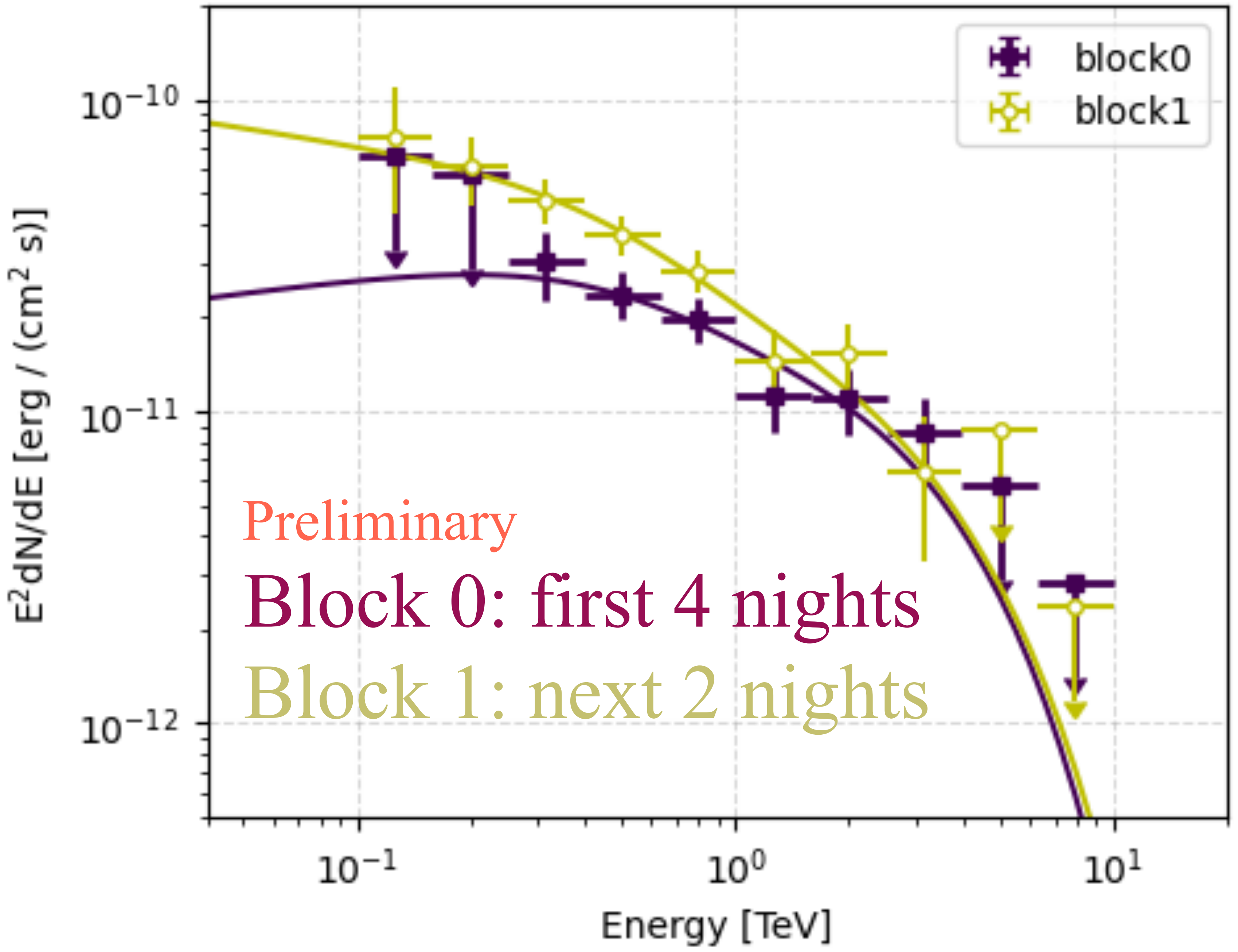


1ES 1959+650 Light Curves and SEDs

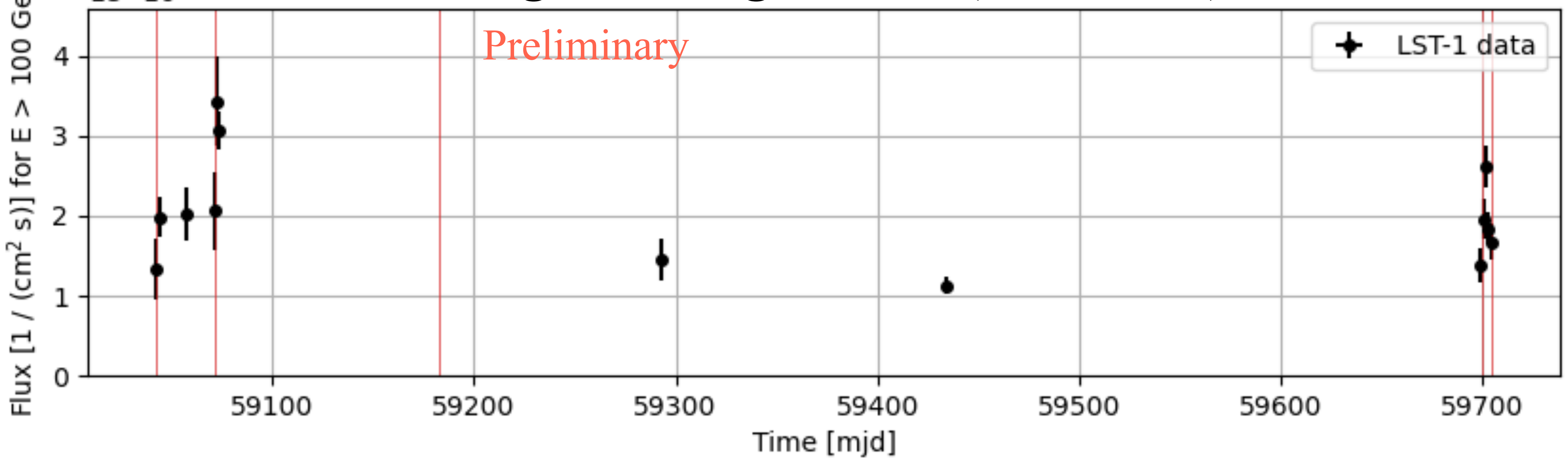
After conducting Bayesian block analysis on the light curve, 4 separate blocks were identified

- Data period: 2020/07/11 - 2022/05/05 (11.8 h)
- Well fitted by ECPL function + EBL absorption

Typical SED



Night-wise light curve (> 100 GeV)



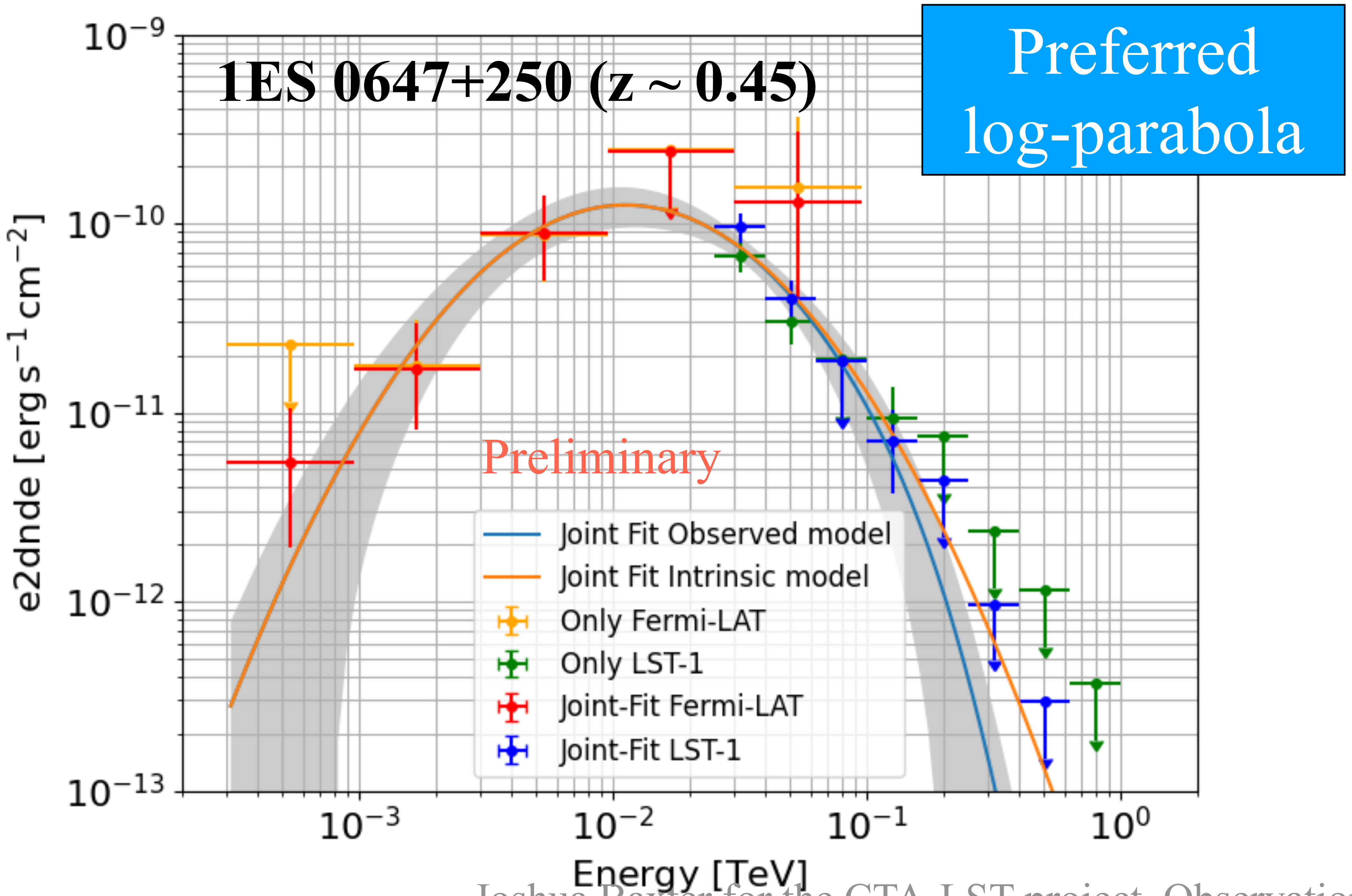
Distant VHE sources: 1ES 0647+250 and PG 1553+113

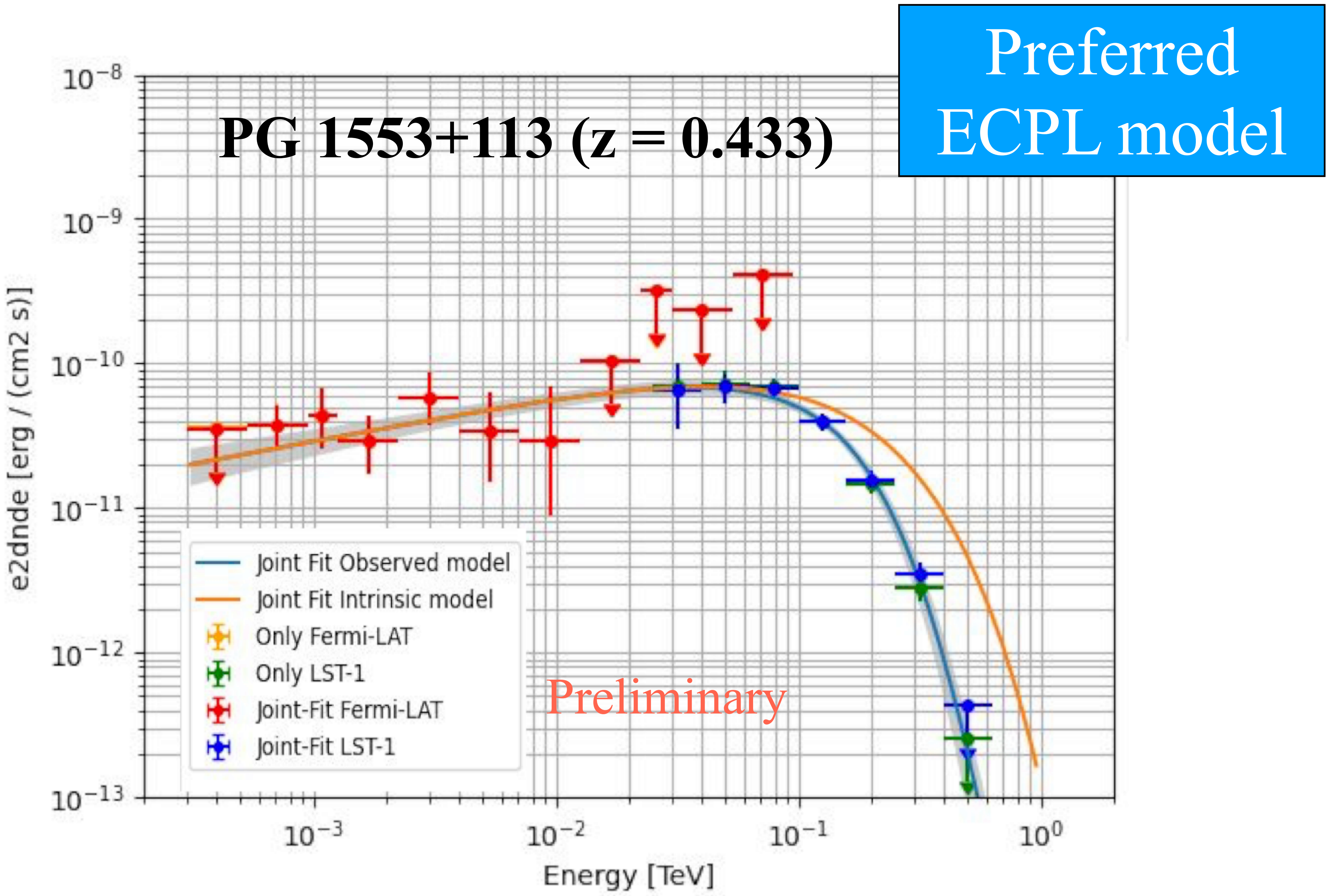
Effectively reconstructed a spectrum that seamlessly connects with the Fermi-LAT observational data from the corresponding time period

- Joint-fit with Fermi-LAT data using dedicated Gammapy-based pipeline ***Asgardpy*** https://asgardpy.readthedocs.io/en/latest/

based on Gammapy

- Variability of these two sources is currently not confirmed by LST-1
  - The variation in PG 1553+113 has already been ascertained in Fermi-LAT observations, making it scientifically imperative to maintain ongoing surveillance through LST-1





Summary

Completed in 2018, LST-1 initiated scientific observations since 2020 and has already detected several known AGNs

- Our analysis encompassed data from five blazars:
  Mrk 421, Mrk 501, 1ES 1959+650, 1ES 0647+250, and PG 1553+113
- Spectra were reconstructed down to a few tens of GeV, closely approaching the LST-1 threshold
- Variability in the spectra of the three AGNs in the vicinity was duly observed
- A flare from Mrk 421 on May 18, 2022 was detected, with a flux approximately three times brighter than that of the Crab Nebula at energies above 100 GeV; intra-night variability was also assessed
- We have established a joint-fit analytical tool *Asgardpy* for correlating LST-1 and Fermi-LAT data, thereby elucidating the assumed intrinsic spectral model

- We gratefully acknowledge financial support from the agencies and organizations listed at
  www.cta-observatory.org/consortium_acknowledgments/