AGN observations with the CTAO LST-1

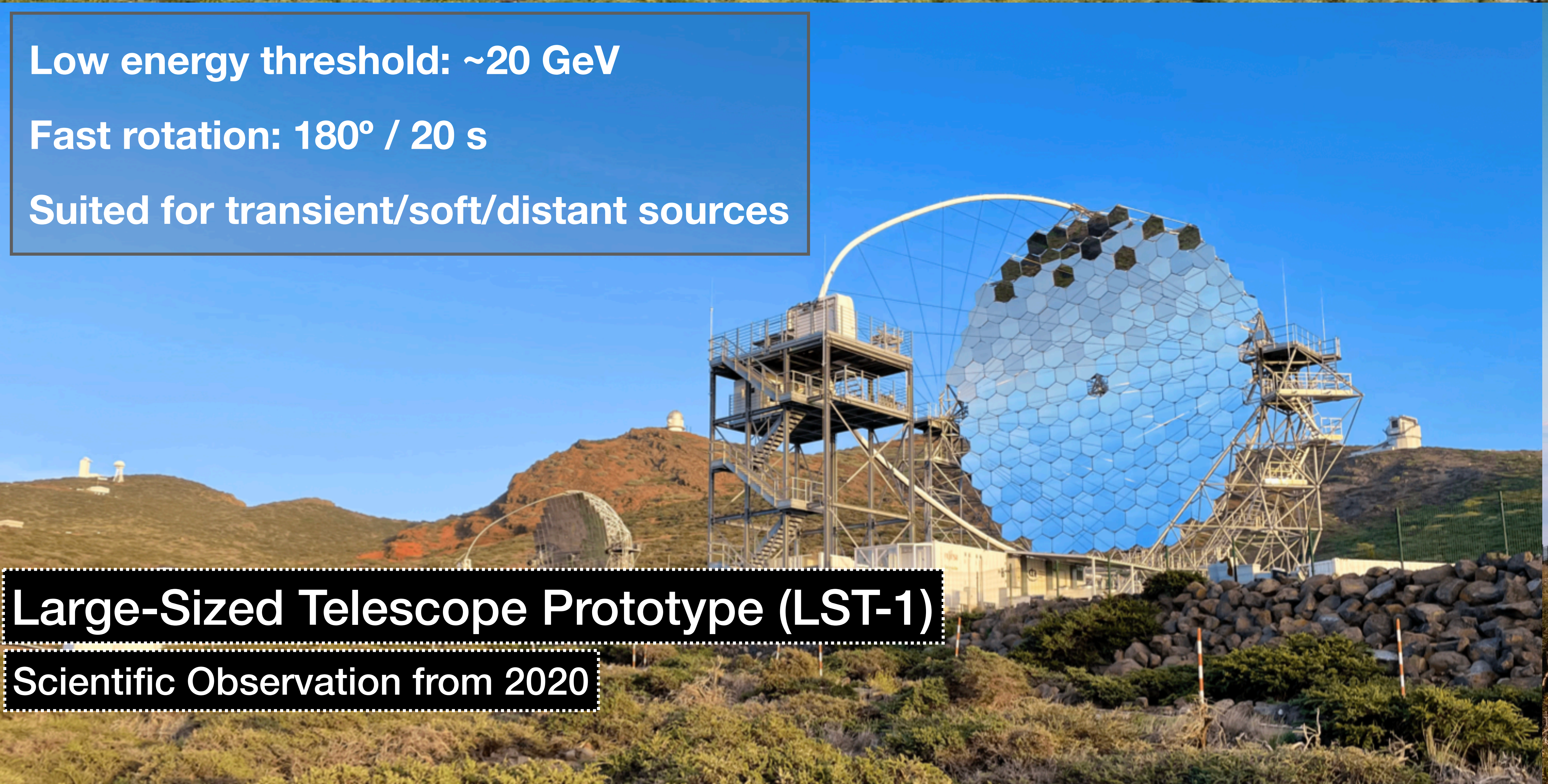
2025 第3回領域研究会

Joshua Baxter (バクスタージョシュア稜)

Institute for Cosmic Ray Research, University of Tokyo

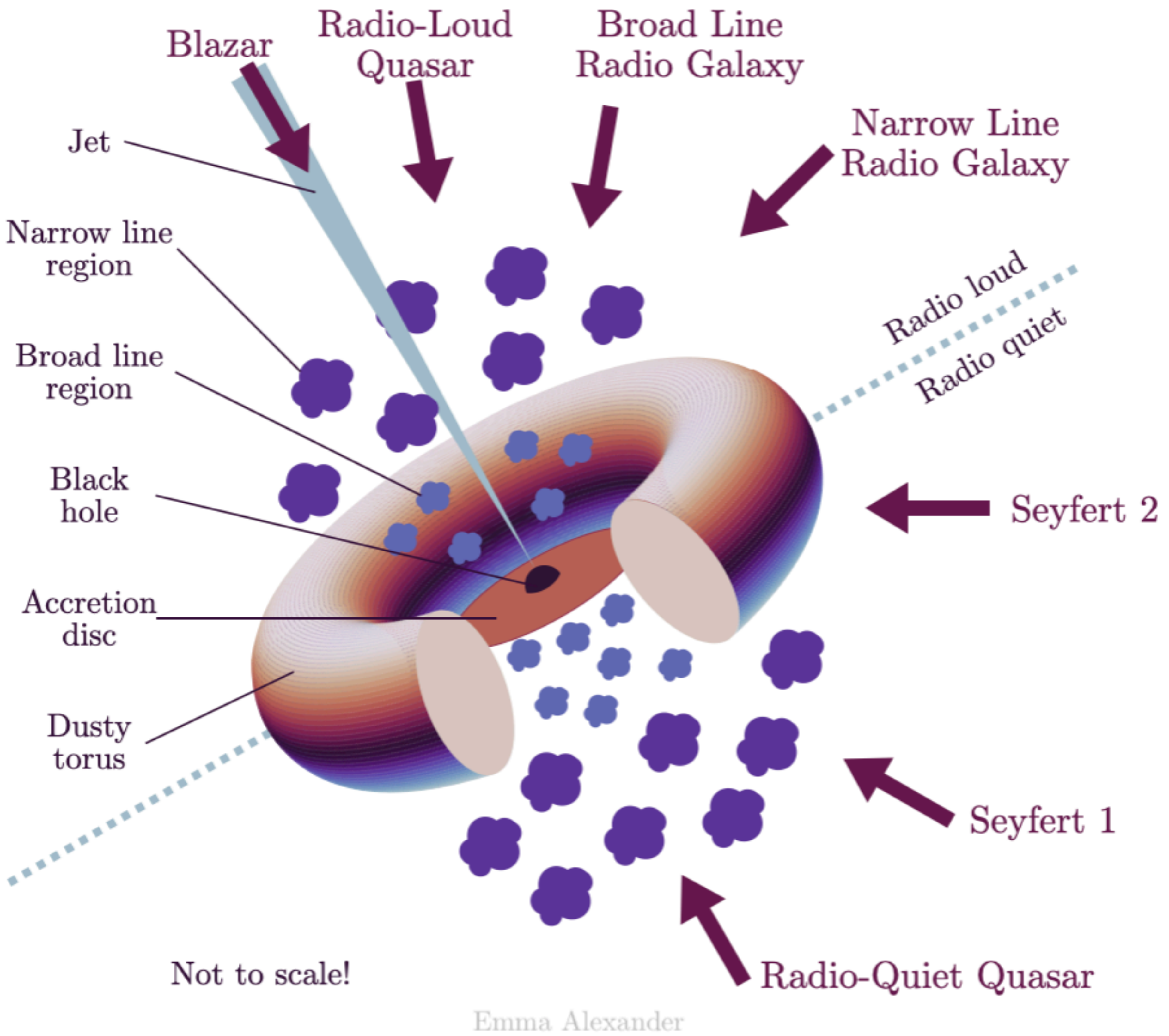
On behalf of LST collaboration

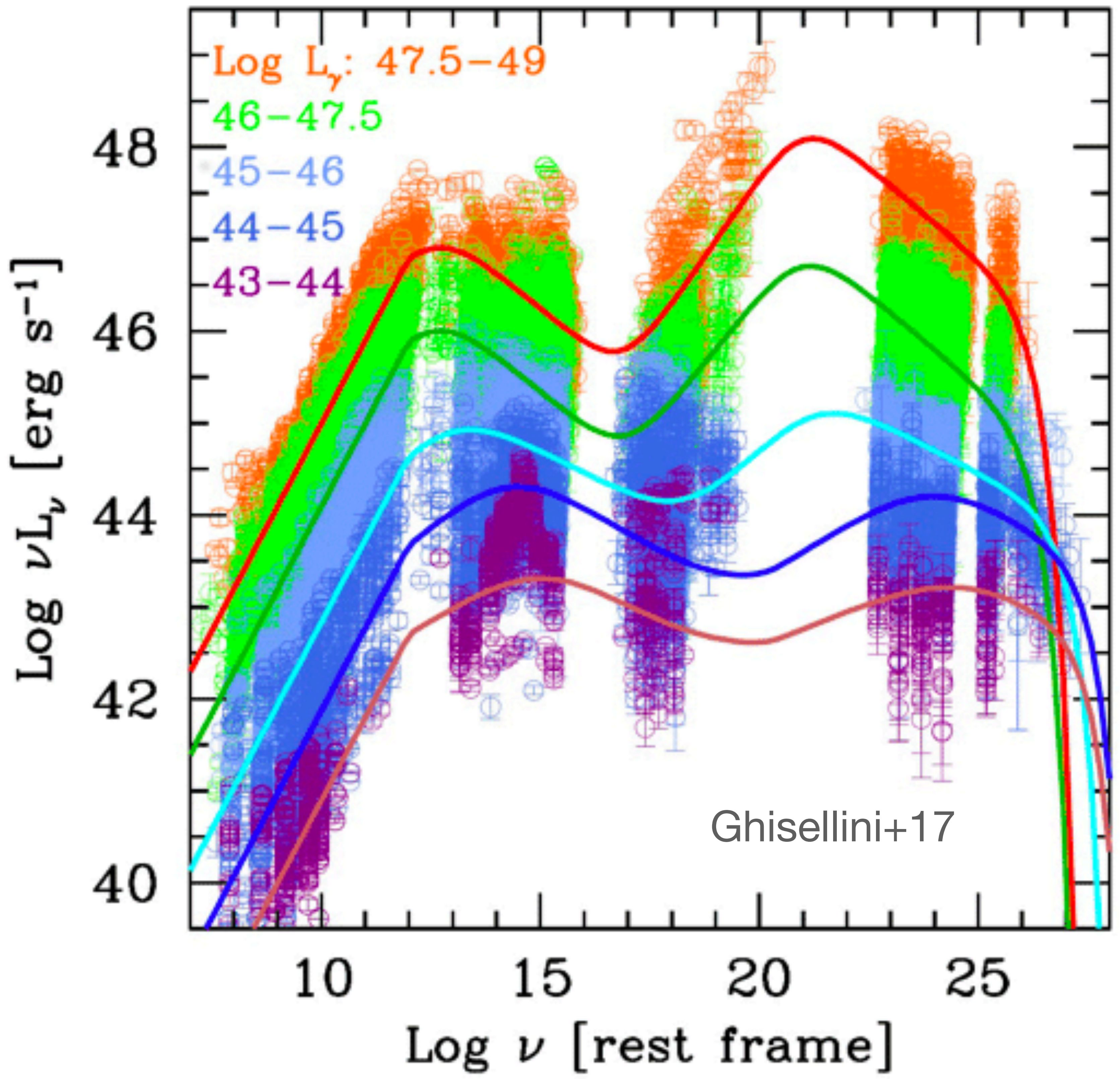
The Next-Generation Cherenkov Telescope Observatory (CTAO) @ La Palma, Spain



Active Galactic Nuclei (AGN)

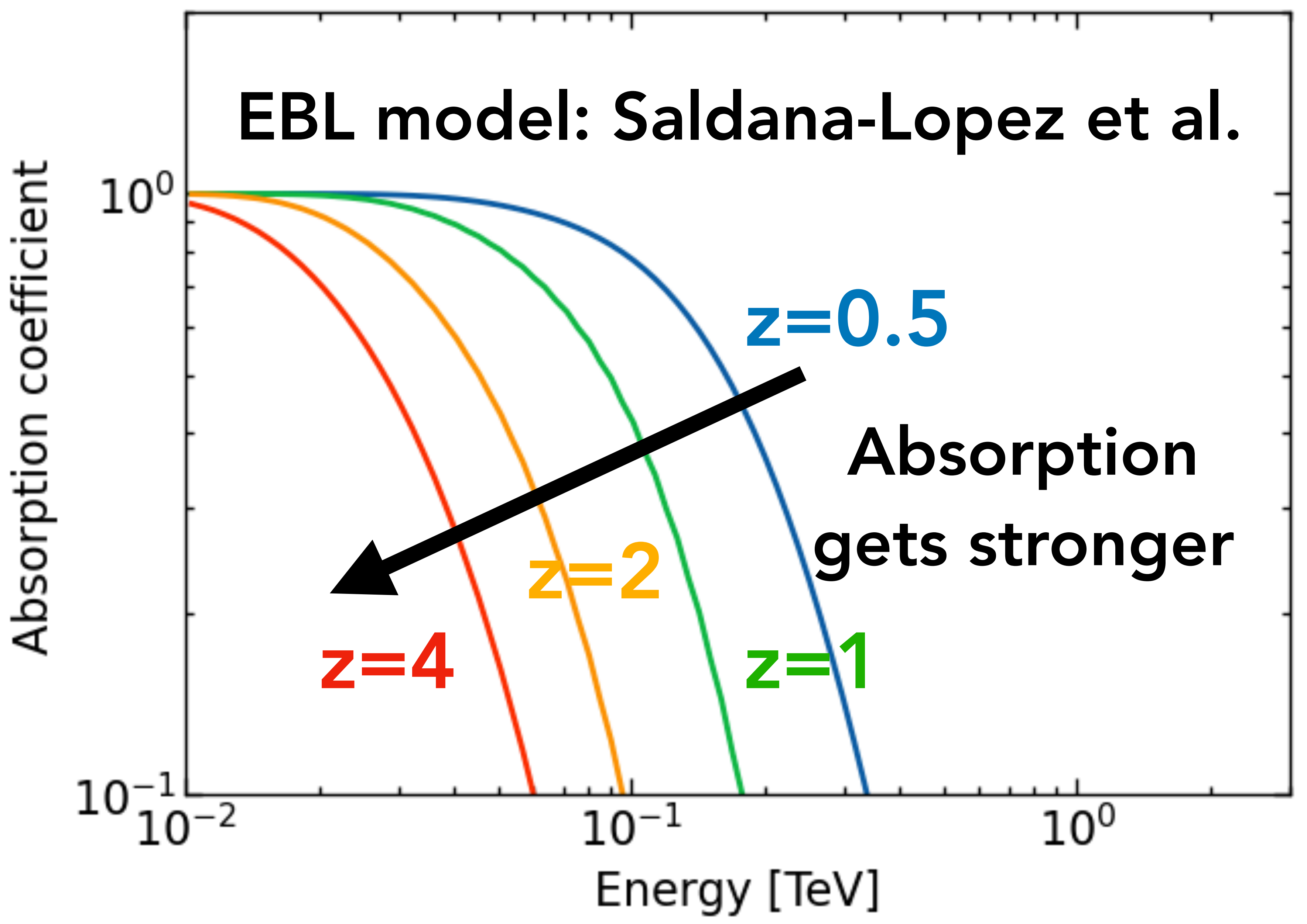
- This talk focuses in blazars: active galactic nuclei (AGN) with relativistic jets pointing towards the Earth
- Emission extending from **radio** to **gamma rays**
  - **Low energies**: synchrotron emission, relativistic electrons moving under the influence of the jet's magnetic field
  - **High energies**: still under debate: IC scattering (leptonic), proton synchrotron (hadronic), Pion Production (hadronic), etc...

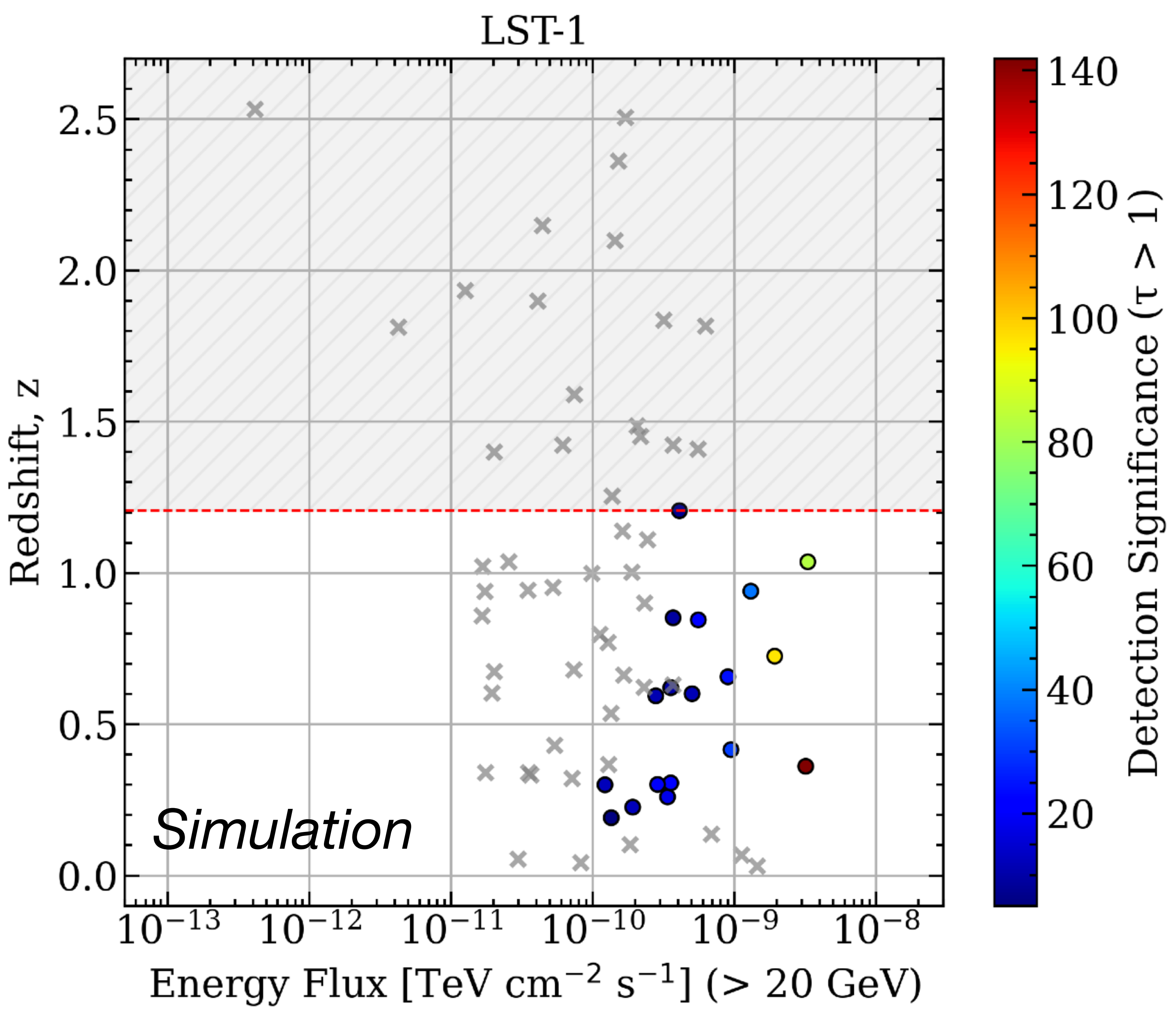


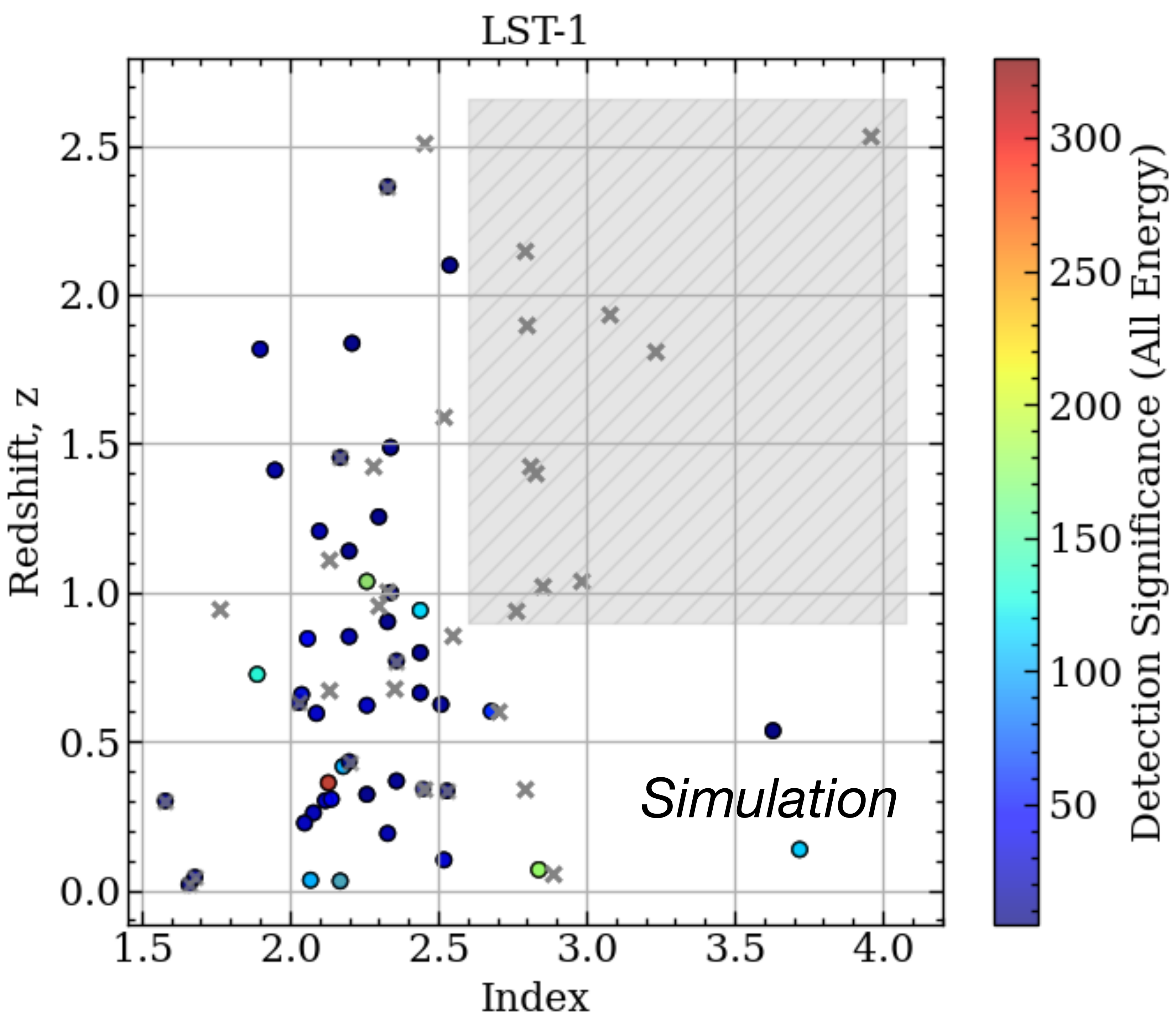


LST-1 for distant blazars (z~1)

- The low energy threshold of LST-1 has enabled detections of distant blazars, including **OP 313 (z = 0.997)** and **PKS 1725+123 (z = 0.58)**
  - Simulations indicate that LST-1 could already detect sources out to roughly **z ≈ 1.2**
- The mono configuration provides lower sensitivity compared to MAGIC, although this can be compensated through coordinated joint observations with MAGIC telescopes



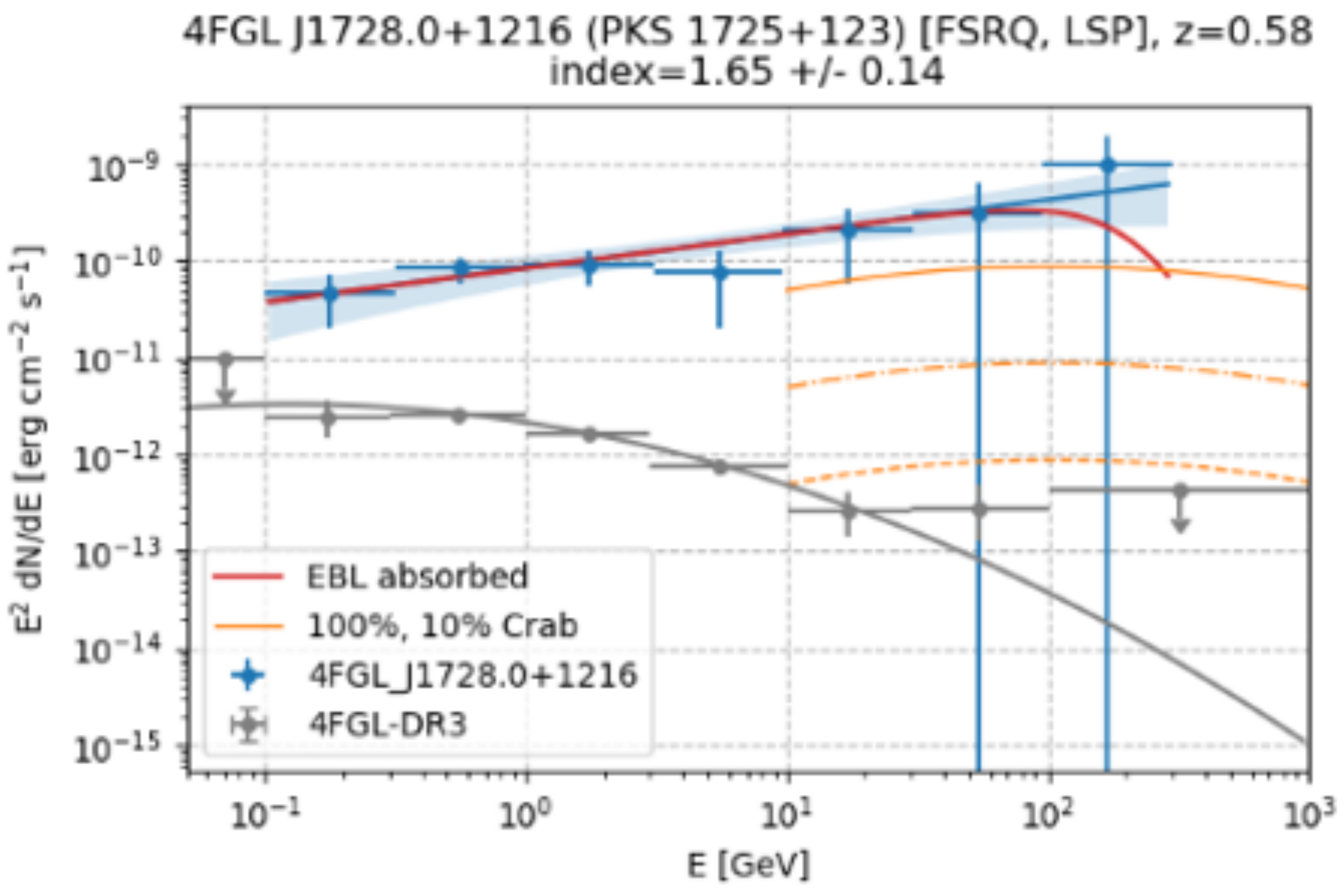


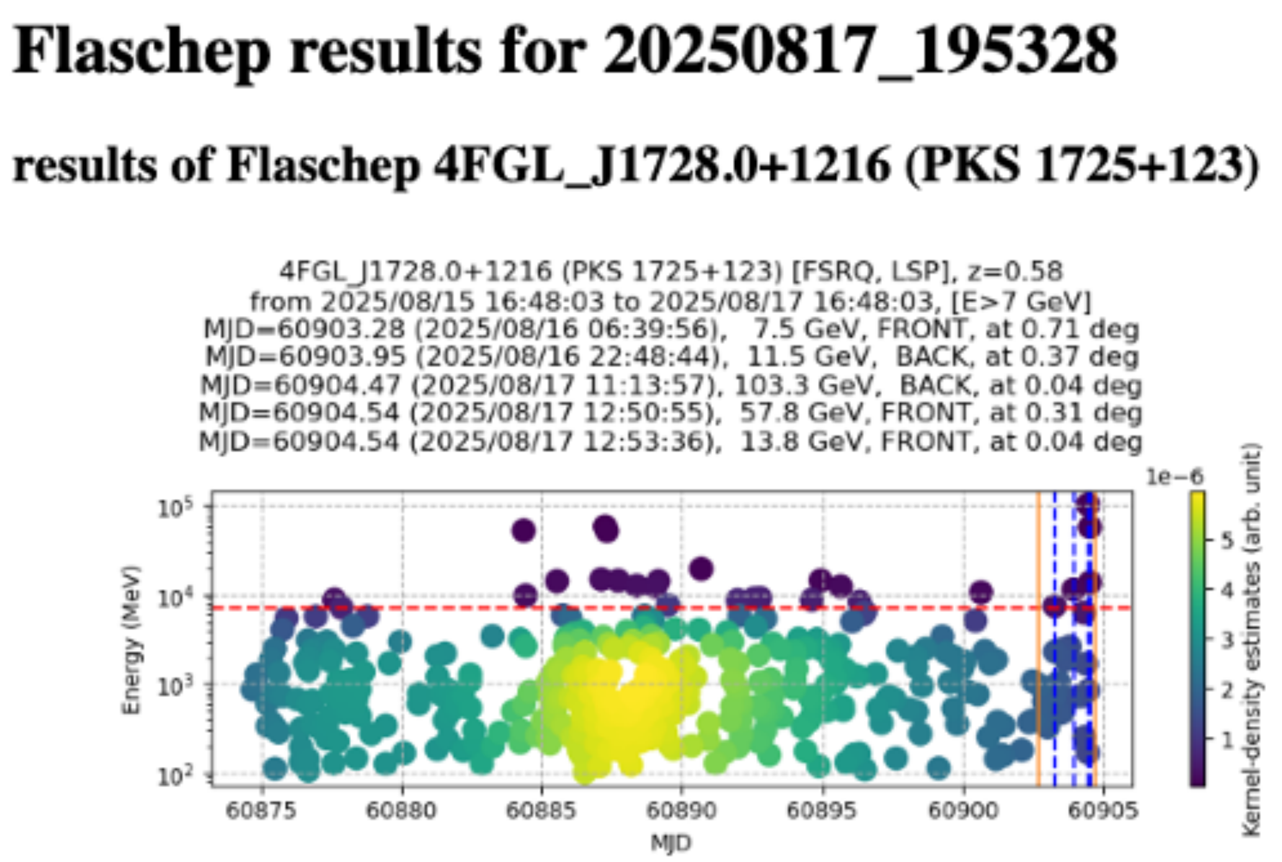


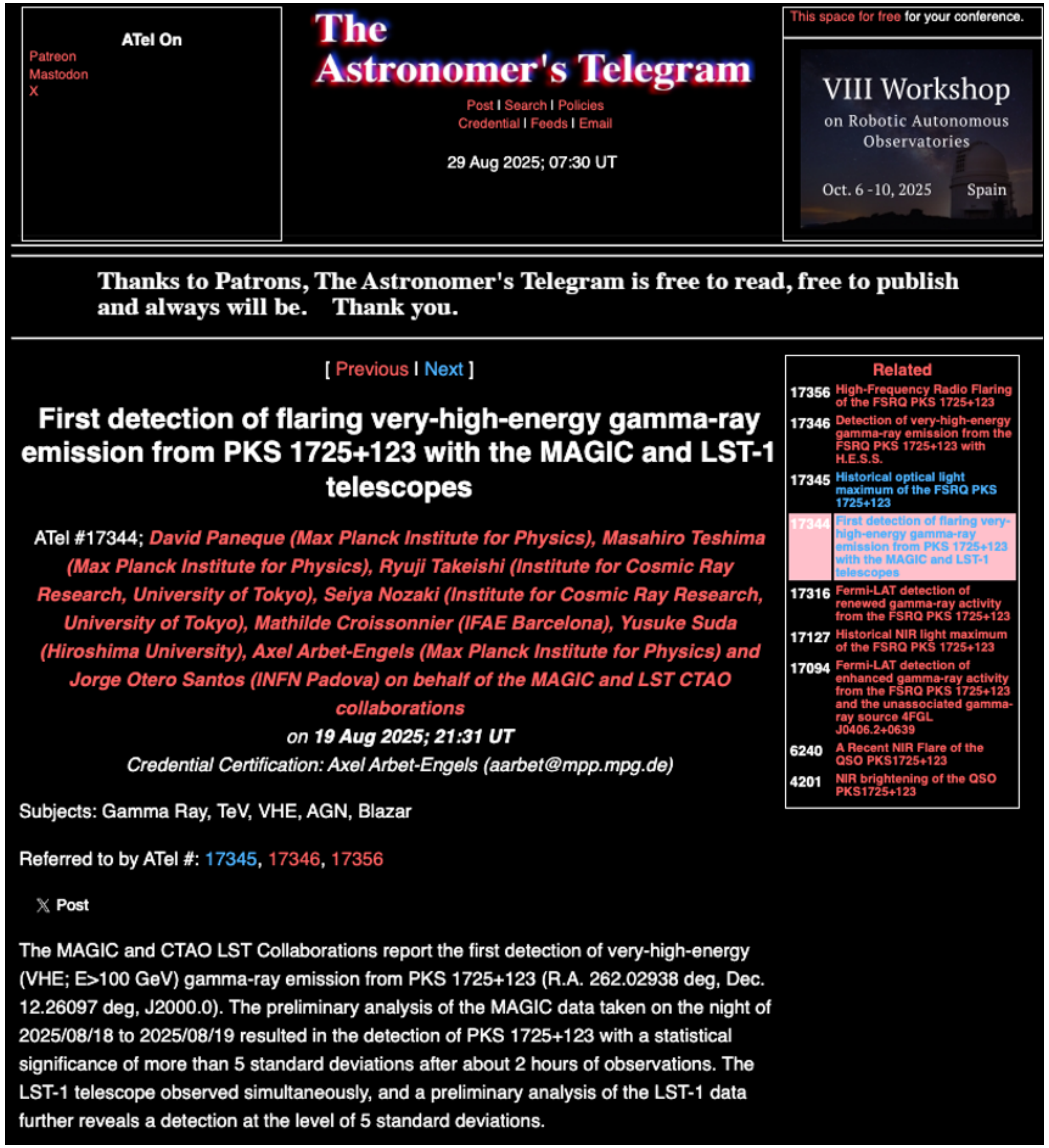
"VHE γ-ray observations of bright BL Lacs with the Large-Sized Telescope prototype (LST-1) of the CTAO" https://doi.org/10.1093/mnras/staf1728

First detection of VHE γ-ray emission from PKS 1725+123 (August 19th, 2025)

- ToO observations using daily Fermi-LAT monitoring (developed by S. Nozaki et al.)
  - Public Fermi-LAT data are automatically analyzed each day
  - The pipeline searches for flaring AGN in real time
  - If the extrapolated VHE flux is favorable and the observing conditions (zenith angle, Moon) are acceptable, a ToO observation is triggered
- First VHE γ-ray detection from PKS 1725+123
  - LSP Quasar, z ~0.586 (Shaw et al., 2013)
  - MWL observation/Modeling ongoing







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First detection of flaring very-high-energy gamma-ray emission from PKS 1725+123 with the MAGIC and LST-1 telescopes

ATel #17344; *David Paneque (Max Planck Institute for Physics), Masahiro Teshima (Max Planck Institute for Physics), Ryuji Takeishi (Institute for Cosmic Ray Research, University of Tokyo), Seiya Nozaki (Institute for Cosmic Ray Research, University of Tokyo), Mathilde Croissonnier (IFAE Barcelona), Yusuke Suda (Hiroshima University), Axel Arbet-Engels (Max Planck Institute for Physics) and Jorge Otero Santos (INFN Padova) on behalf of the MAGIC and LST CTAO collaborations*
on 19 Aug 2025; 21:31 UT
Credential Certification: Axel Arbet-Engels (aarbet@mpp.mpg.de)

Subjects: Gamma Ray, TeV, VHE, AGN, Blazar

Referred to by ATel #: 17345, 17346, 17356

Post

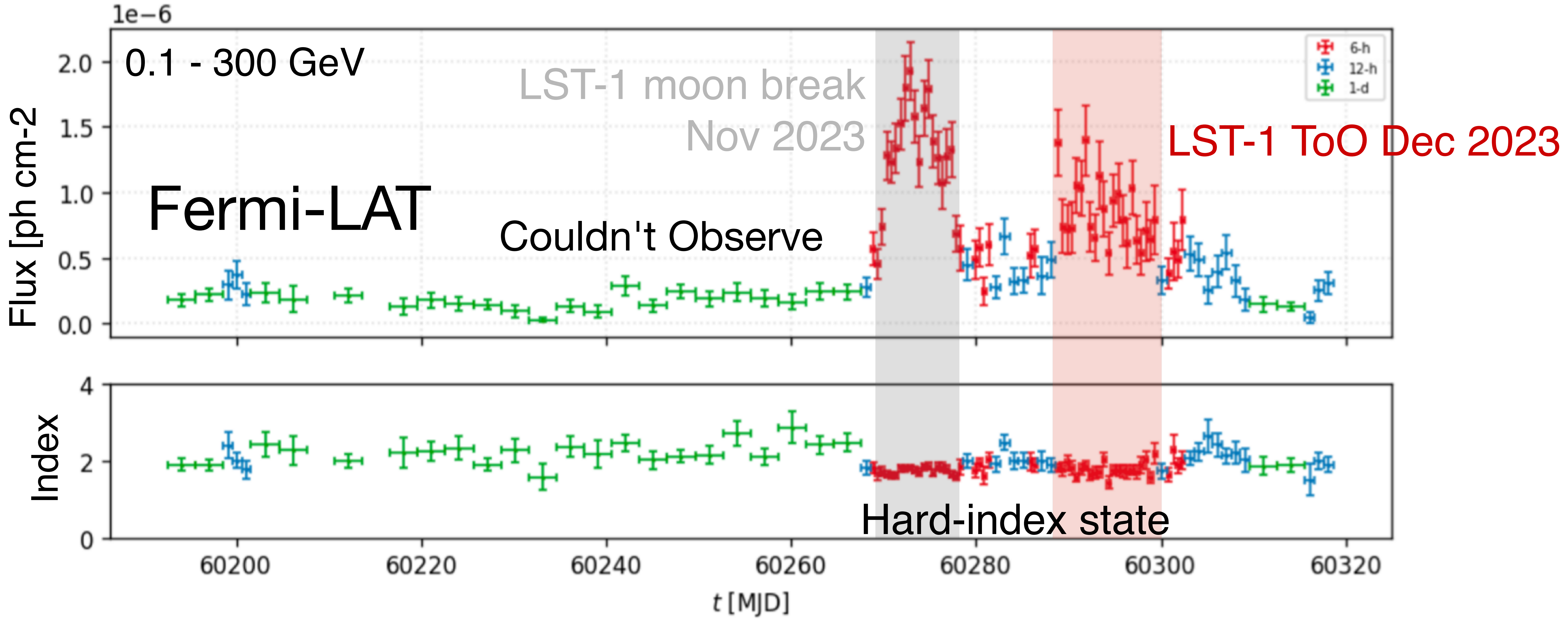
The MAGIC and CTAO LST Collaborations report the first detection of very-high-energy (VHE; E>100 GeV) gamma-ray emission from PKS 1725+123 (R.A. 262.02938 deg, Dec. 12.26097 deg, J2000.0). The preliminary analysis of the MAGIC data taken on the night of 2025/08/18 to 2025/08/19 resulted in the detection of PKS 1725+123 with a statistical significance of more than 5 standard deviations after about 2 hours of observations. The LST-1 telescope observed simultaneously, and a preliminary analysis of the LST-1 data further reveals a detection at the level of 5 standard deviations.

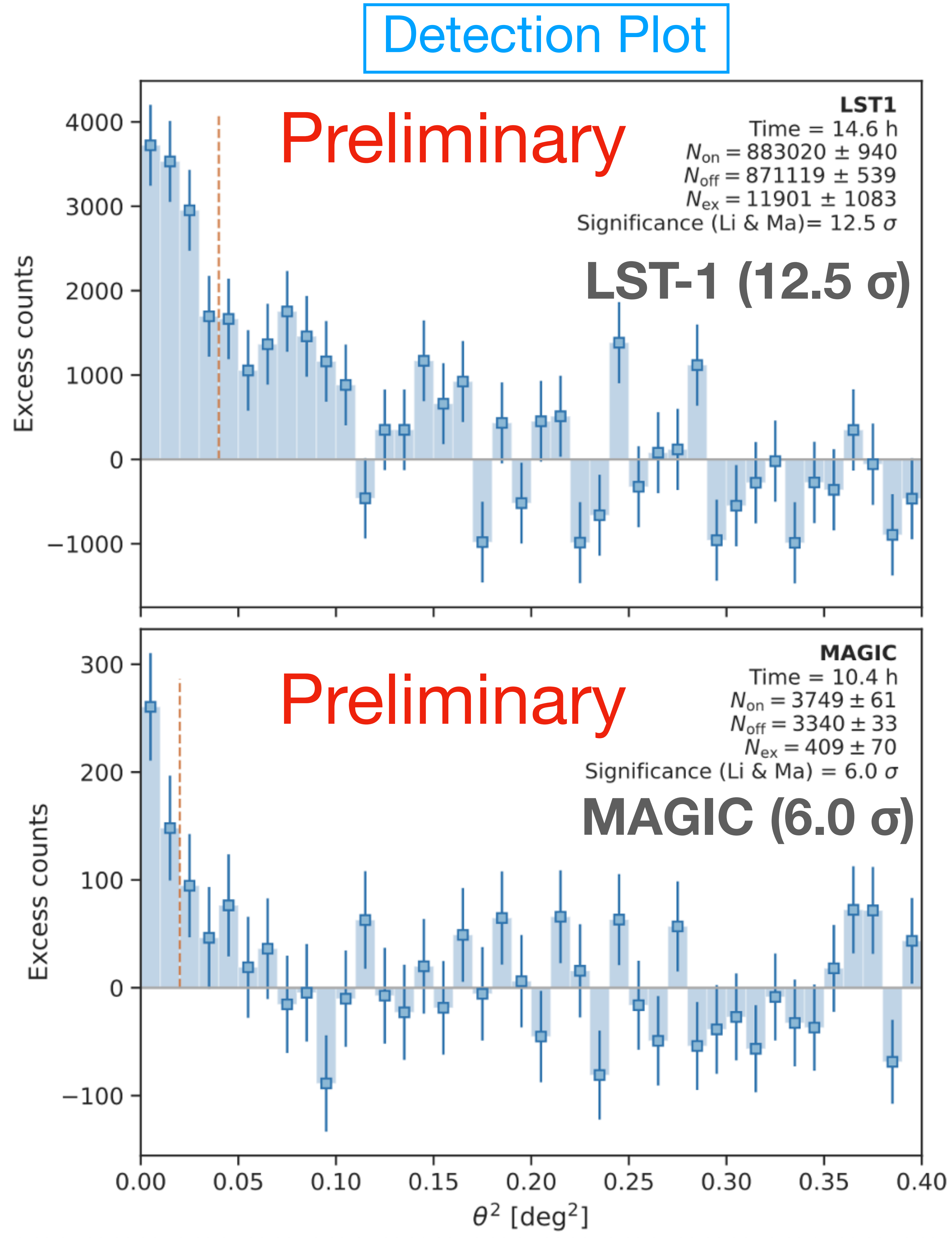
Related

17356	High-Frequency Radio Flaring of the FSRQ PKS 1725+123
17346	Detection of very-high-energy gamma-ray emission from the FSRQ PKS 1725+123 with H.E.S.S.
17345	Historical optical light maximum of the FSRQ PKS 1725+123
17344	First detection of flaring very-high-energy gamma-ray emission from PKS 1725+123 with the MAGIC and LST-1 telescopes
17316	Fermi-LAT detection of renewed gamma-ray activity from the FSRQ PKS 1725+123
17127	Historical NIR light maximum of the FSRQ PKS 1725+123
17094	Fermi-LAT detection of enhanced gamma-ray activity from the FSRQ PKS 1725+123 and the unassociated gamma-ray source 4FGL J0406.2+0639
6240	A Recent NIR Flare of the QSO PKS1725+123
4201	NIR brightening of the QSO PKS1725+123

Discovery of VHE γ-ray emission from OP 313

- Flux enhancement observed with Fermi-LAT (GeV) since Nov 2023
- LST-1 and MAGIC joined in from December, with excellent overlap during the flare
- A total of ~15 hours of observations (>60 GeV) by LST-1 were dedicated in December 2023.



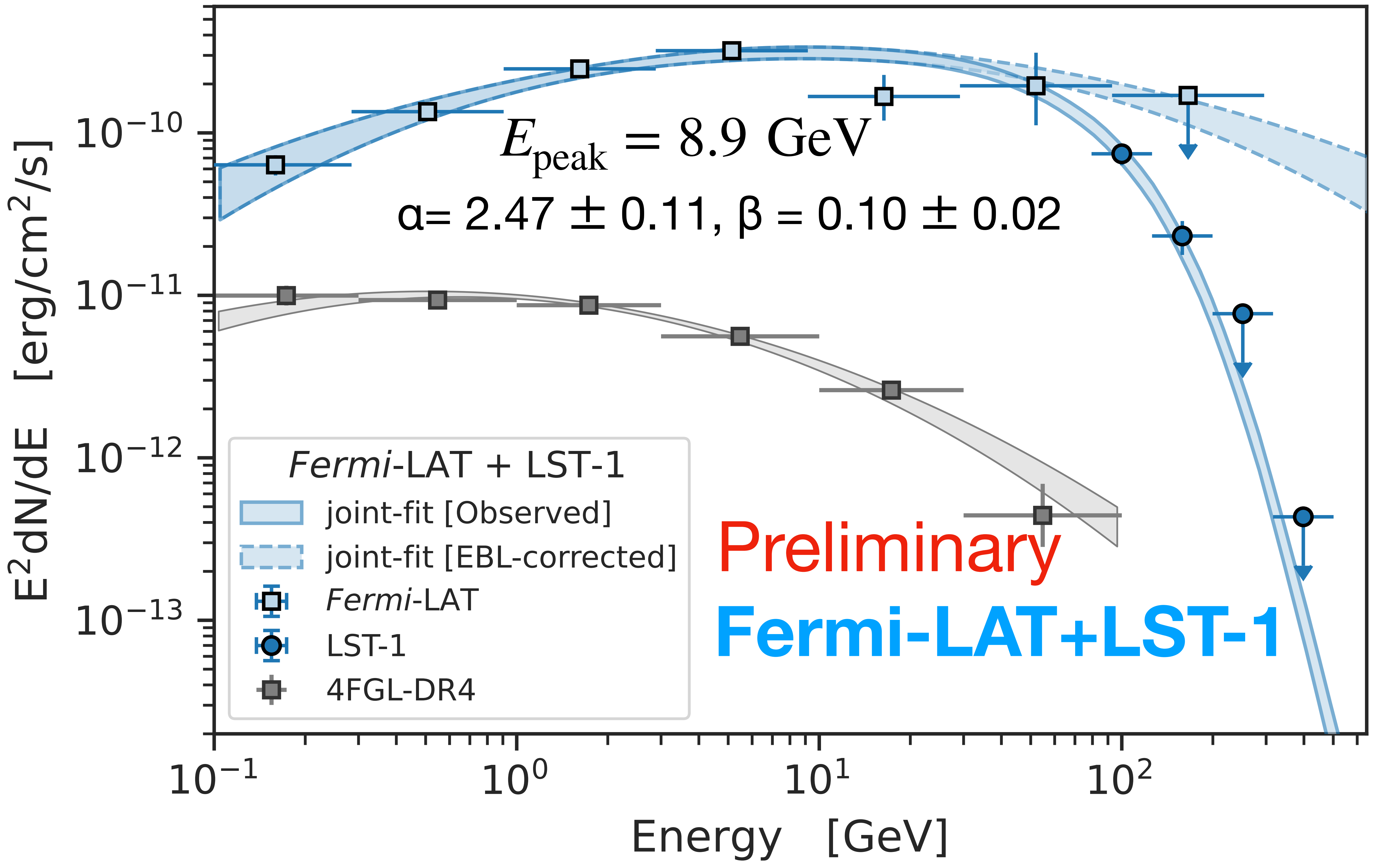


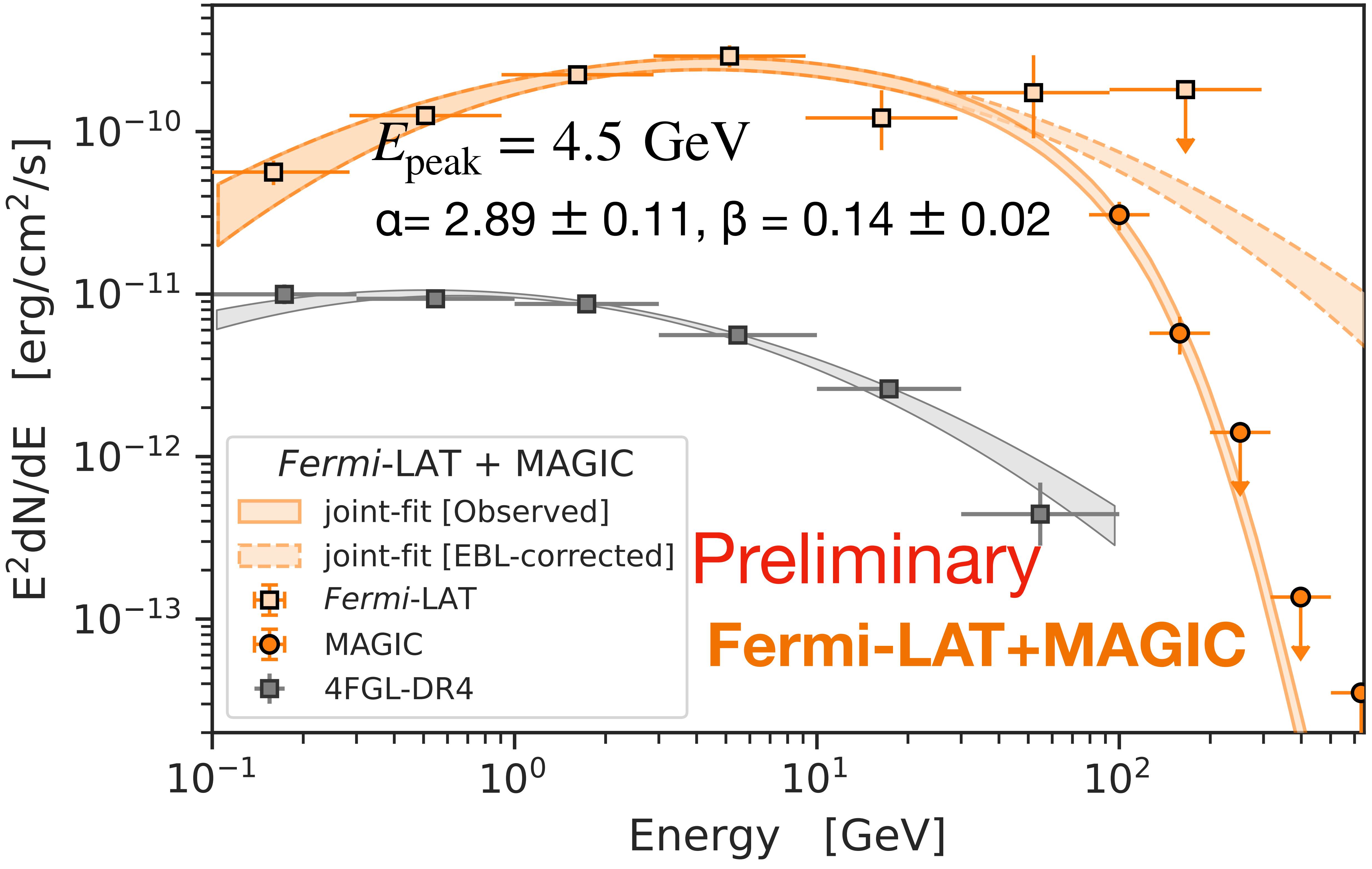
HE/VHE Spectral Energy Distribution of OP 313

- Well described by LogParabola with exponential cutoff (LPEC)

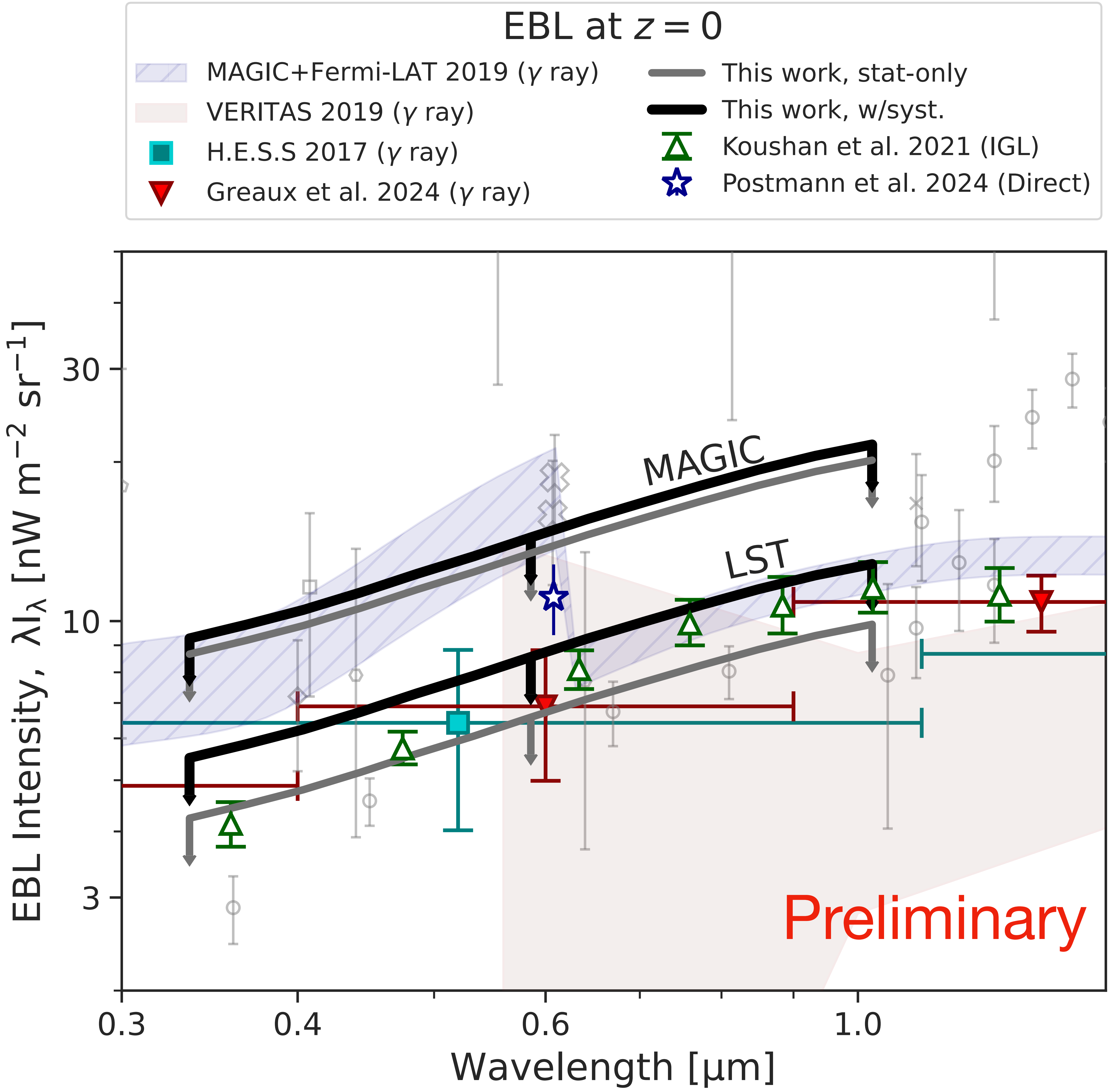
$$\phi(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha-\beta \log\left(\frac{E}{E_0}\right)}$$

- VHE flux reached **0.3 Crab Units** during the flare
  - No VHE detection in January
- Peak energy shifted by nearly an order of magnitude higher during the flare





Constraints to the Intensity of Extragalactic Background Light



The HE and VHE observations allow us to set constrains to the EBL density, resulting in a upper limit at 0.6 μm of $\lambda I_\lambda < 6.72\ \mathrm{nWm^2sr^{-1}}$ with LST-1 data

- $F_{\mathrm{obs}} = \exp(-\alpha\, \tau(z, E_\gamma)) \times F_{\mathrm{int}}$
  - $\tau(z, E_\gamma)$: optical depth for gamma-ray propagation
  - α : scaling factor
- Baseline EBL model: Saldana-Lopez et al. (2021)
- Spectral fits performed with α fixed between 0 and 3, assuming intrinsic models: LP, LPEC, PLEC
- Upper limit on scaling factor: $\alpha_{\mathrm{stat,95\%}} < 1.14$
  - Corresponding upper limit on EBL density: $\lambda I_\lambda < 6.72$ nW m^{-2} sr^{-1} $(\lambda = 0.6\,\mu\mathrm{m})$
- Result is in **good agreement with integrated galaxy light (IGL)** estimates

Multi-wavelength Observation on OP 313

LST-1 (23 m IACT, La Palma)

- First CTA-LST prototype; sensitivity down to ~20 GeV
- Dec 10–19: ~15 h (flare state) → VHE detection
- Jan 2024: ~5 h (low state) → no detection

MAGIC (2 × 17 m IACTs, La Palma)

- Dec 10–19: ~10 h (flare)
- Jan 9–20: ~4 h (low state)

Fermi-LAT

- HE γ rays, 50 MeV–1 TeV
  Continuous coverage (Dec–Jan)

Swift (XRT + UVOT)

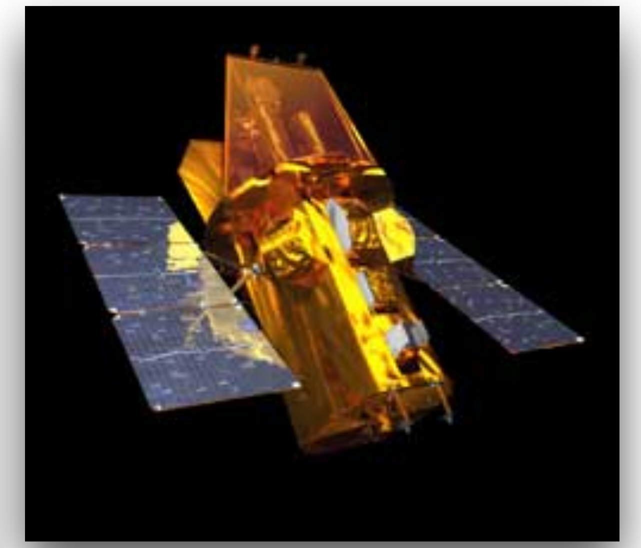
- X-rays (0.3–10 keV), optical/UV (6 filters)

Optical telescopes

- Sierra Nevada, IAC80, Kanata, Tuorla, Las Cumbres, Siena/Seveso/Montarrenti, surveys (ASAS-SN, ZTF, ATLAS)
- Photometry + polarimetry in BVRI, Sloan g,r,i

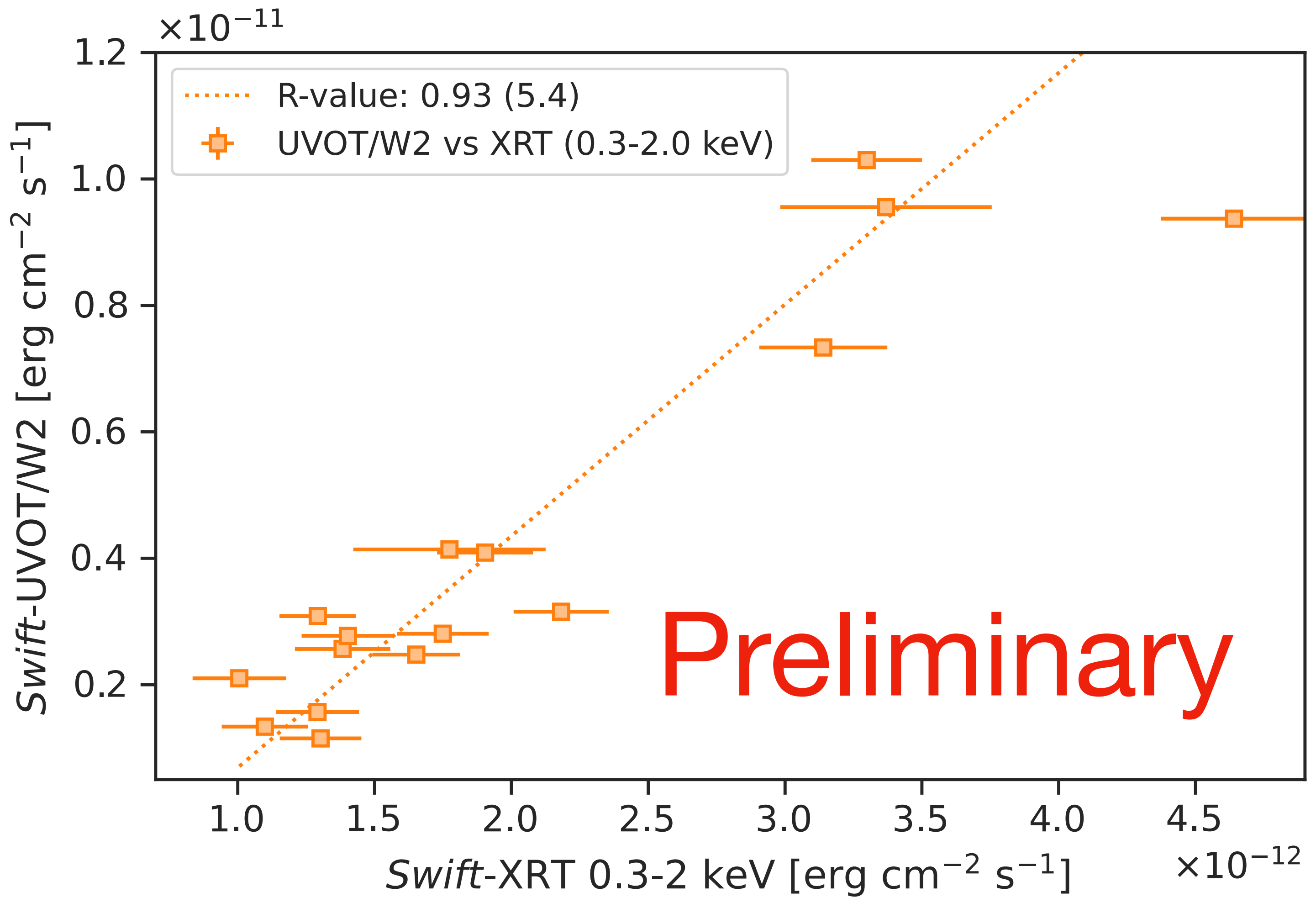
Radio/mm

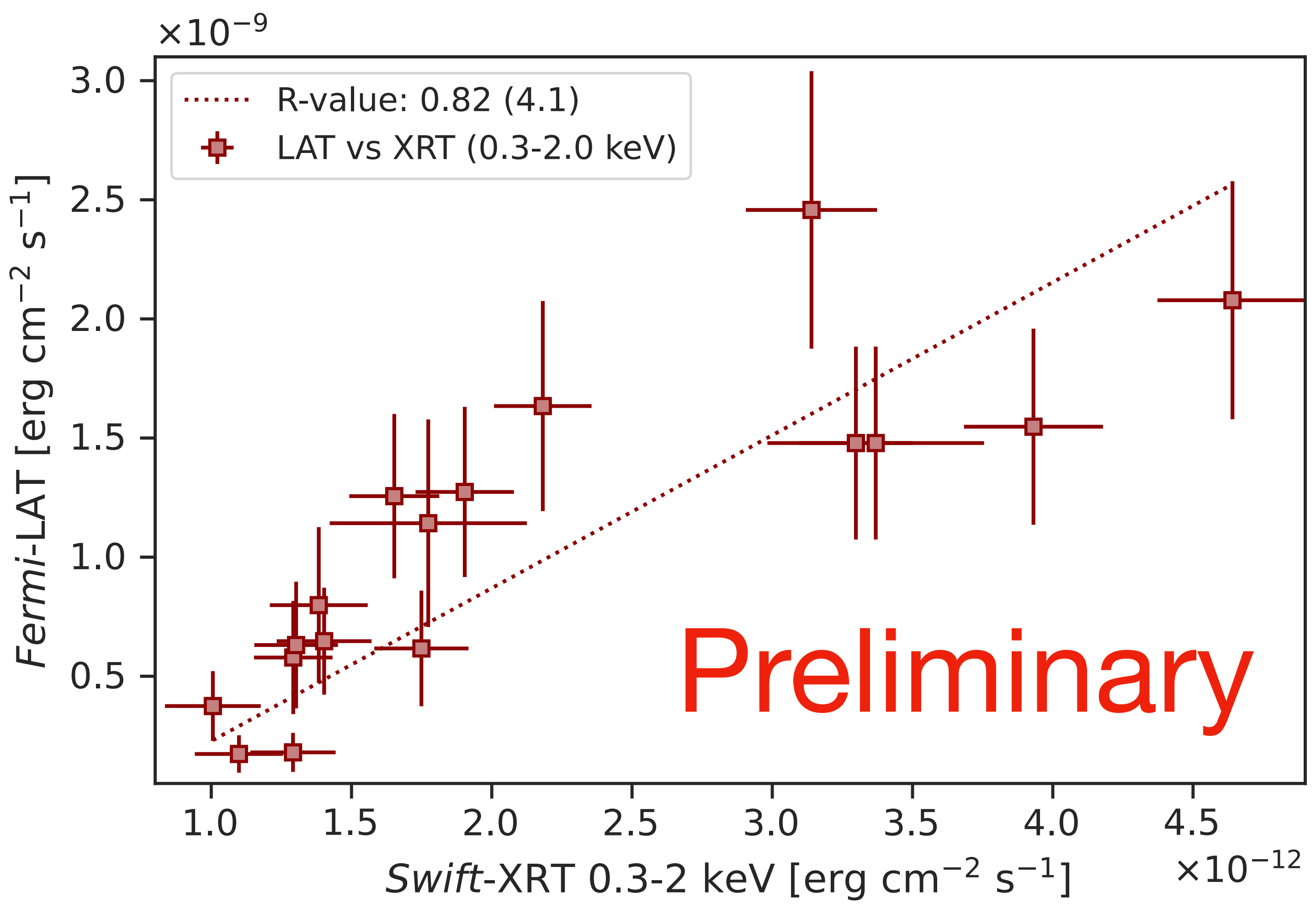
- SMA (Hawaii): 8 epochs, incl. flare & low state
- Effelsberg (Germany): 4 epochs (multi-band, polarimetry)

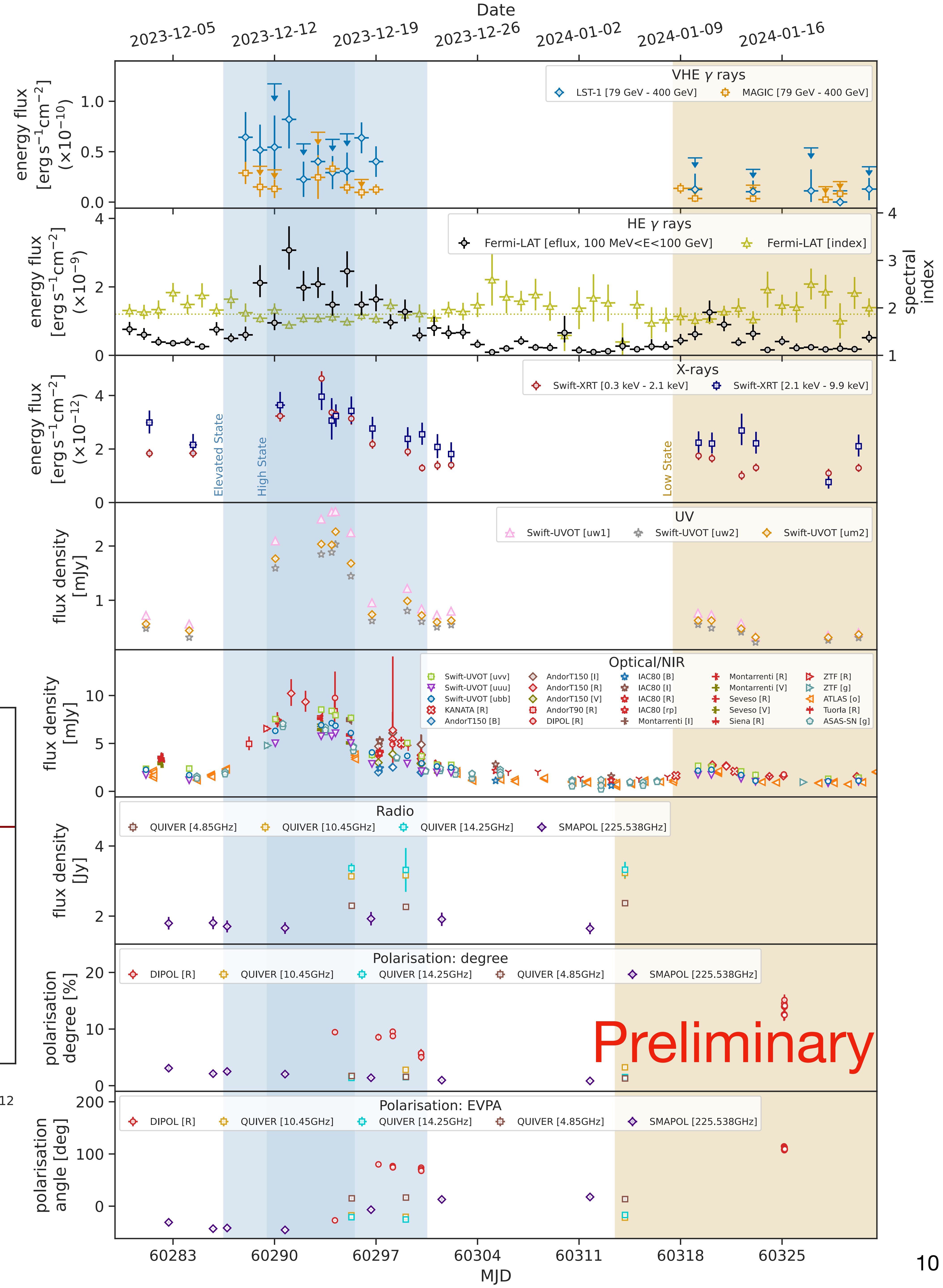


Multi-wavelength Observation on OP 313

- Clear VHE detection in December 2023
- Only upper limits obtained in January 2024
- Excellent multi-wavelength coverage, spanning from radio to VHE γ-rays
- The analysis is currently under collaboration review (essentially complete, now in the final stages of internal adjustments)

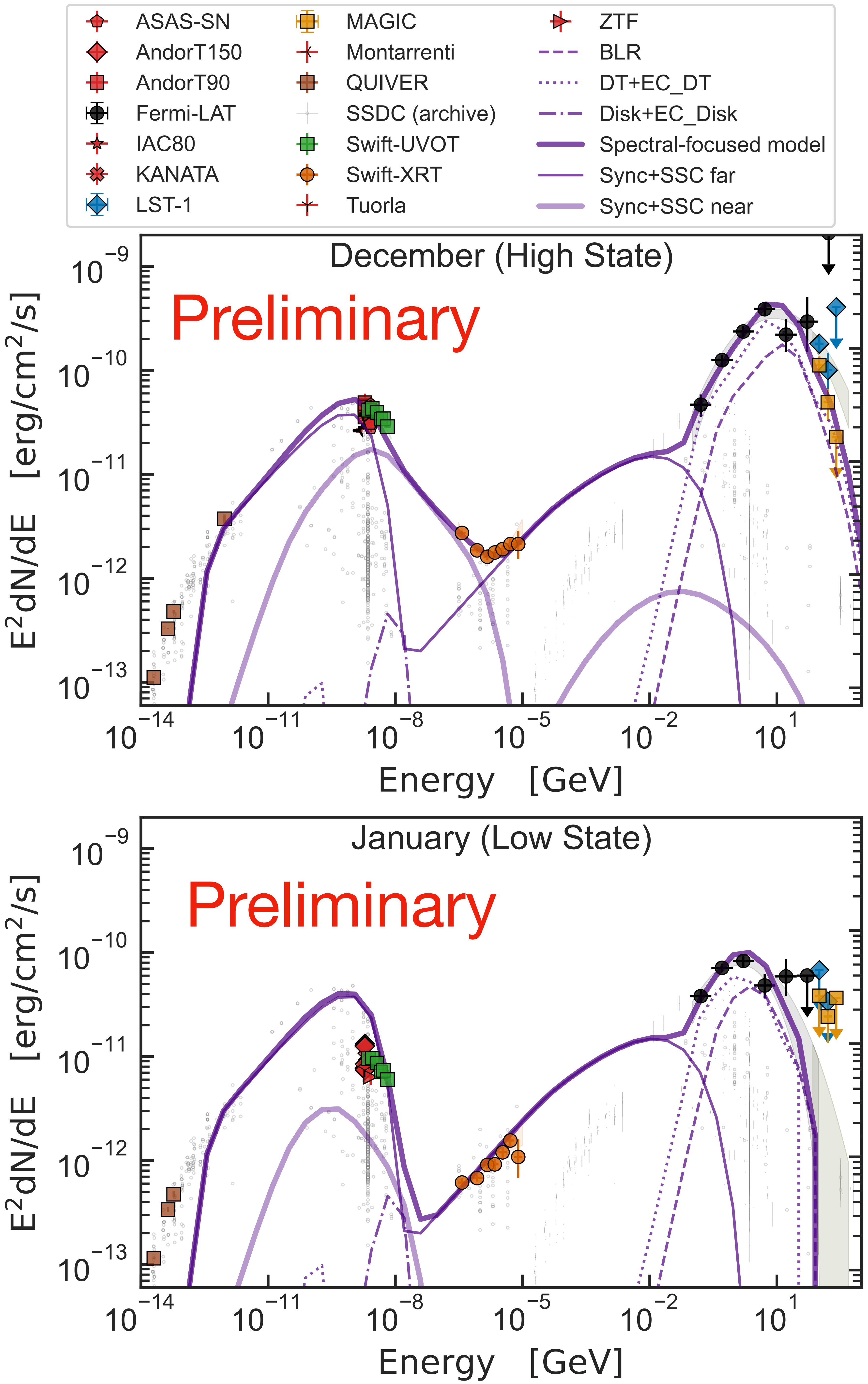






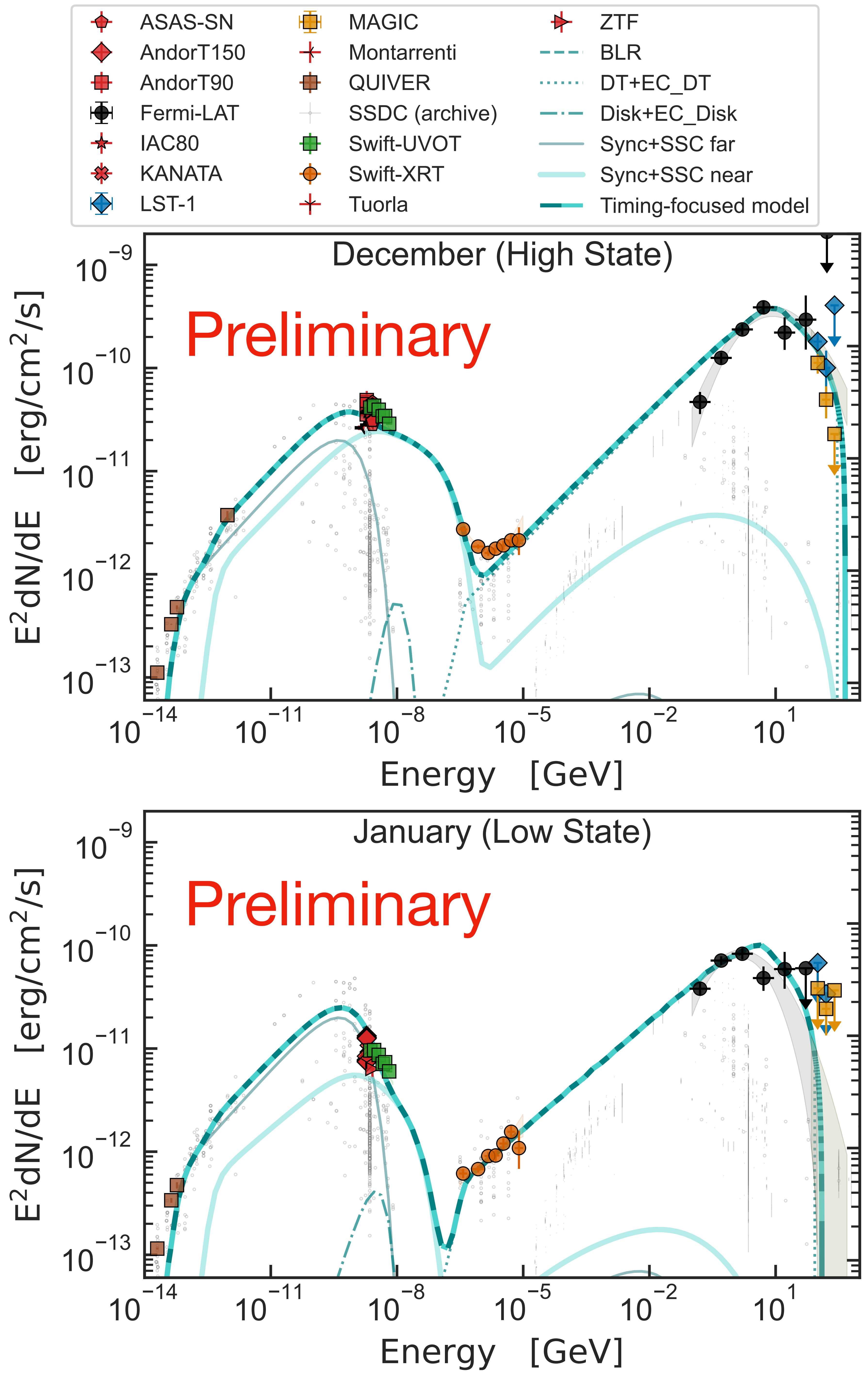
OP 313 broadband modeling

- Leptonic model with two independent zones required
- **Spectral-focused model**: Tuned to reproduce the SEDs
  - Stable “far” zone (radio, optical, and part of the X-ray emission)
  - Variable “near” zone (low-energy X-rays and gamma rays)
    - Located close to the BLR
      → EC emission from both the BLR and dusty torus (DT)
    - Doppler factor ≈ 100 required
    - Electron index: 1.8 (pre-break) / 4.0 (post-break), in both states
    - State changes explained by
      → decreased break and maximum electron energies
      → cooling and injection variations



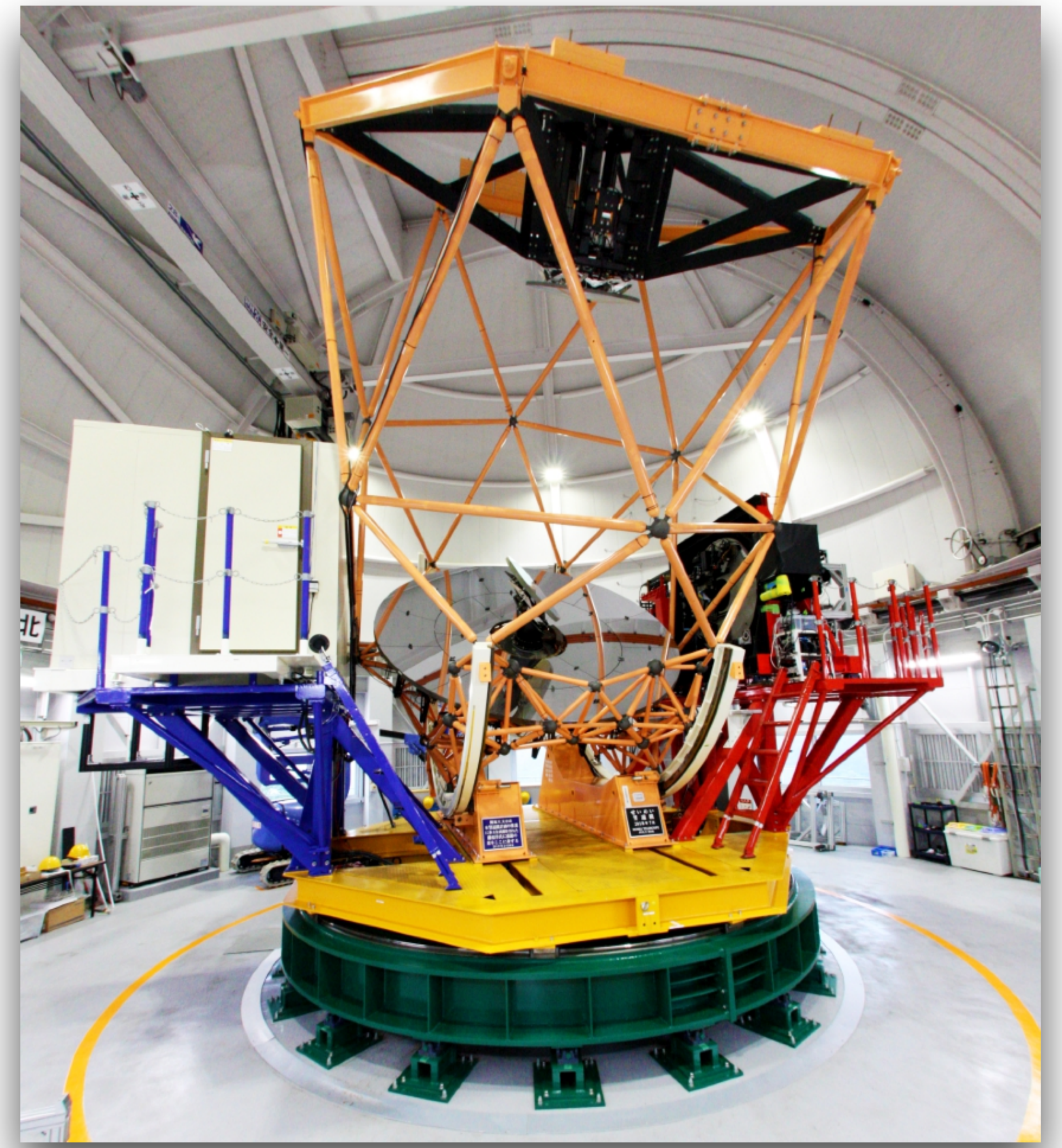
OP 313 broadband modeling

- Leptonic model with two independent zones required
- **Timing-focused model:** Based on the observed MWL correlations
  - Stable "far" zone (radio)
  - Variable "near" zone (optical/UV to γ-rays)
    - Located well beyond the BLR
      → Dusty torus (DT) becomes the dominant EC photon field
    - Doppler factor ≈ 50
    - Electron index: 2.2 before / 3.3 after the break (flare)
    - State changes explained by
      → softening of the indices (2.3 / 3.6)
      → decrease in break and maximum electron energies
      → cooling and injection variations



Future Outlook for LST: Strengthening Optical ToO Follow-ups

- With the detection of OP 313 and subsequent events, LST-1’s low energy threshold has made VHE observations of FSRQs a realistic and recurring possibility.
  → The upcoming 4-LST era is expected to increase such detections even further.
- During flares, the thermal components in the optical–UV band are essential, since they directly constrain
  → the seed-photon fields for EC models, and
  → the physical state of the BLR at the time of the γ-ray emission.
- At present, optical follow-up of blazar flares relies heavily on European facilities (TNG / NOT / LT).
  → However, FSRQ flares evolve on tens-of-minutes timescales, and the longitudinal separation often prevents strictly simultaneous observations with LST-1.
- As a first step, I submit ToO proposal for the 2026A semester using the Seimei Telescope:
  → KOOLS-IFU for broad-band spectroscopy (Mg II, Hβ, Hα, etc.),
  → TriCCS for simultaneous g/r/i imaging.
- In the longer term, establishing a coordinated framework with OISTER is nice!

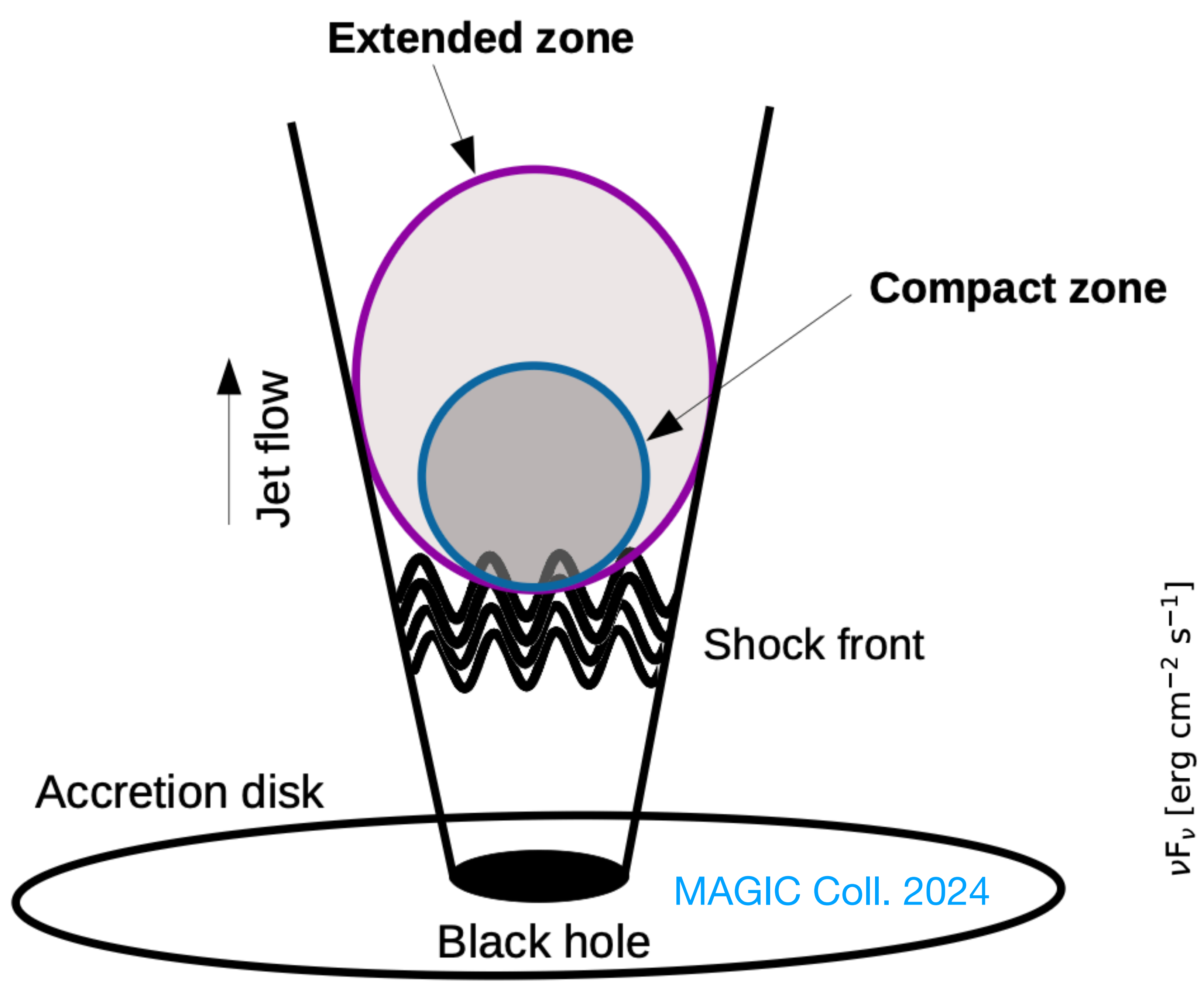


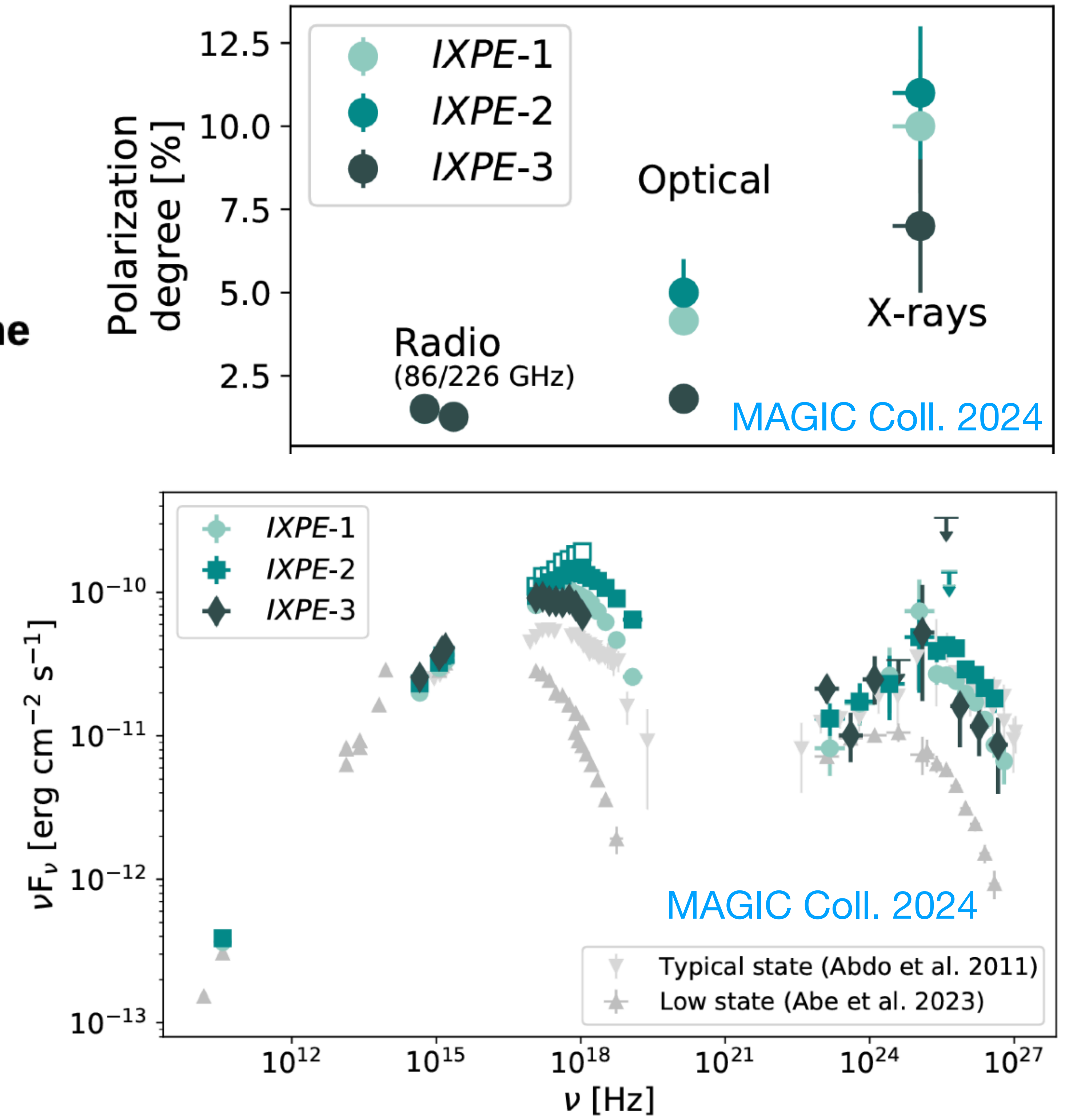
Future Outlook for LST: Simultaneous observation with X-rays

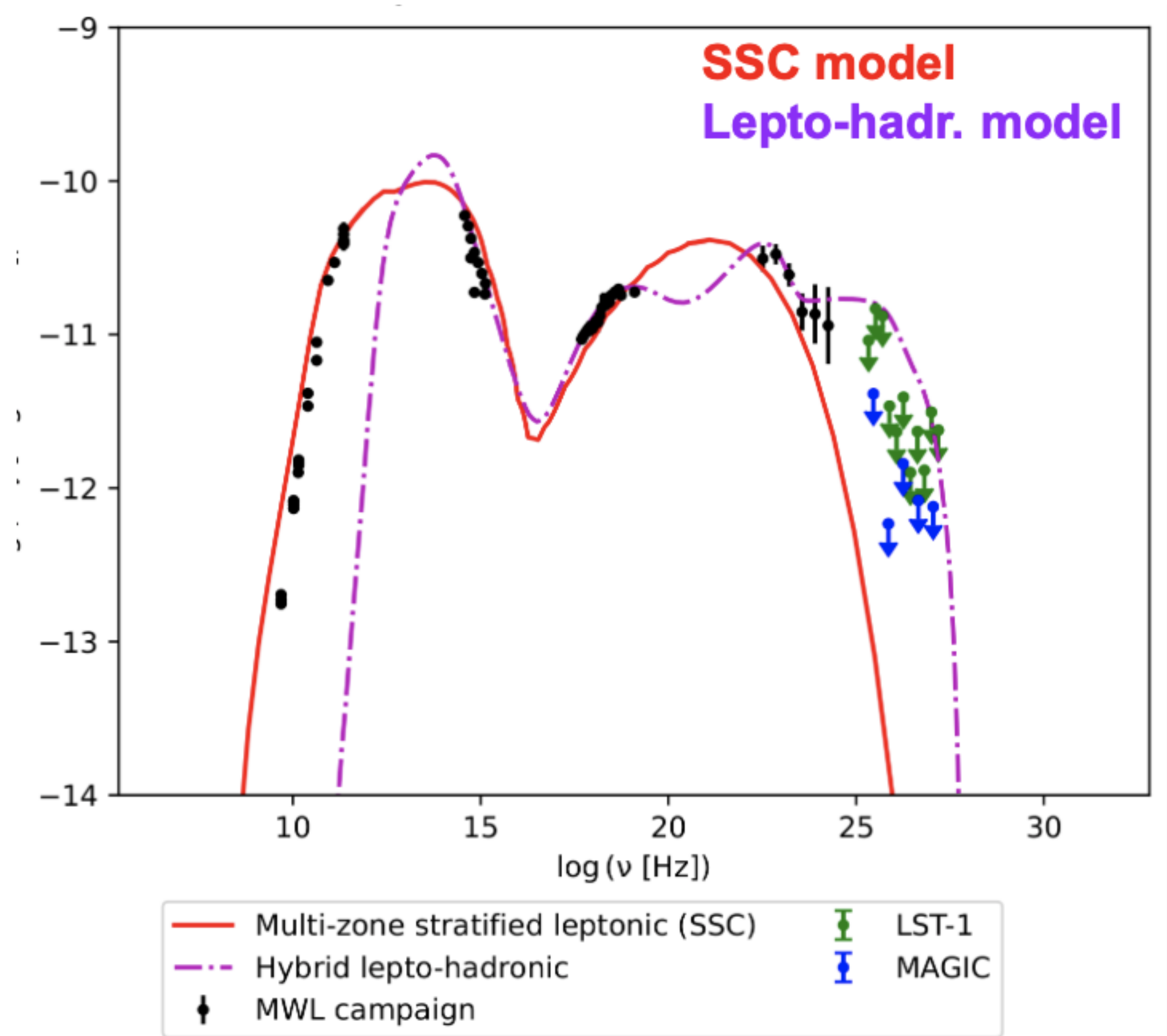
- The MAGIC telescopes, already have a well-developed framework for simultaneous observations with IXPE
- As a good example, see the MAGIC + IXPE simultaneous observations in 2022 (MAGIC+ 2024):
  - Polarization degree:
    - X-ray polarization is about a factor of two higher than in the optical
    - Clear drop in polarization during IXPE-3
  - X-ray polarization angle: Consistent with the optical, aligned with the radio jet orientation

  → LST should also aim to contribute to this kind of work in the future (blazar selection and coordinated X-ray simultaneous observations)

- LST-1 and MAGIC followed the BL Lac IXPE campaign in November 2023
  - BL Lac observed by IXPE between November 7 and 17, 2023
  - Using the simultaneous LST-1/MAGIC data to constrain or exclude the possibility of hybrid emission, and to confirm pure leptonic SSC emission
  - Modeling is currently ongoing







Summary

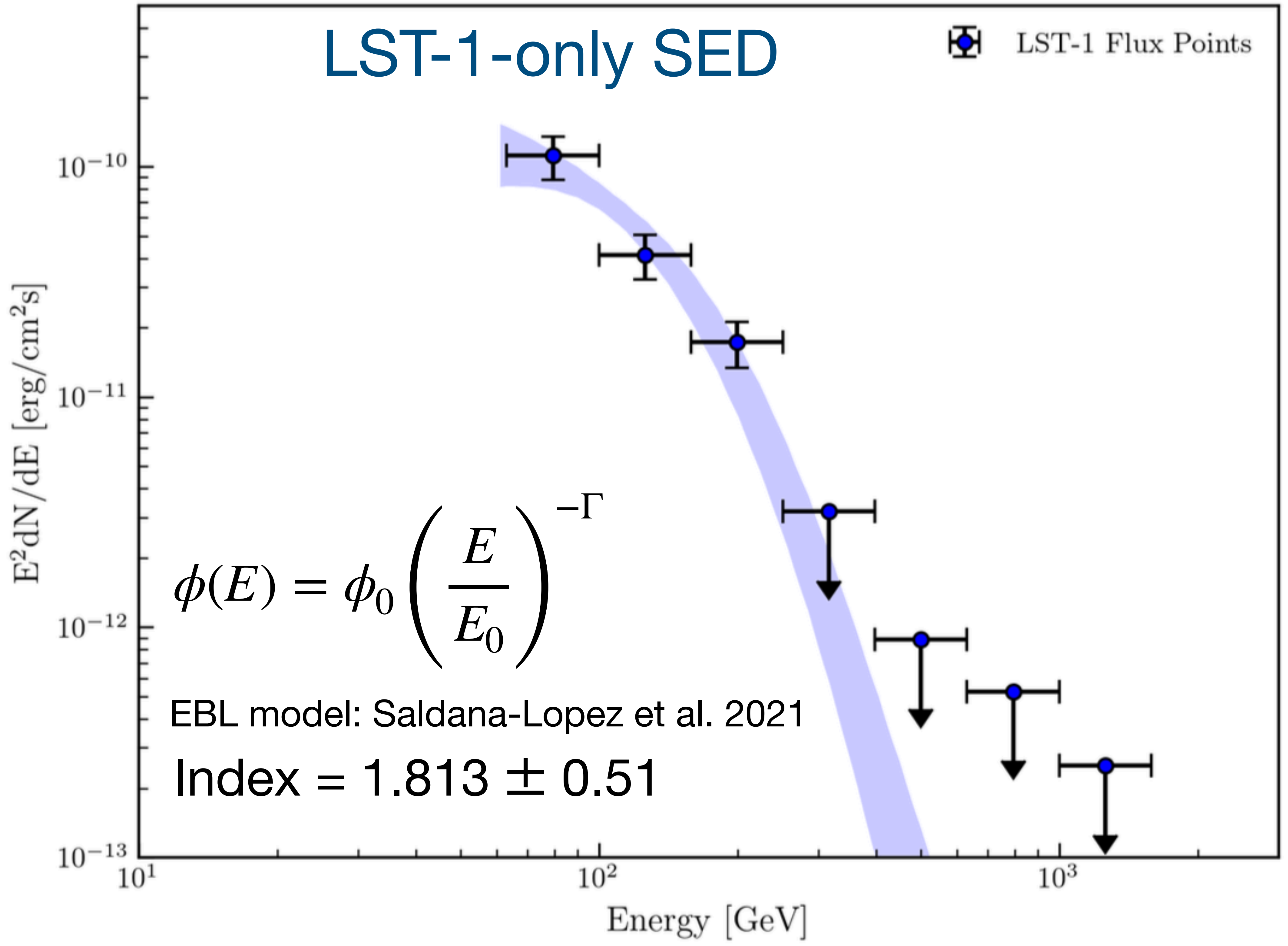
- LST-1 has demonstrated strong capabilities for AGN science through recent detections of distant blazars such as OP 313 and PKS 1725+123.
- The OP 313 flare provided the first clear VHE detection from a nearly z ~1 FSRQ and enabled detailed HE/VHE spectral modeling and EBL constraints.
- Multi-wavelength coverage, including X-ray, optical, and radio observations, played a central role in interpreting the flare behavior and testing emission scenarios.
- With the upcoming 4-LST era and strengthened ToO coordination in optical and X-rays, LST will further expand its contribution to blazar physics and time-domain AGN studies.
- **The deadline for LST-1 observing proposals is in January, so if there is any source you want to observe or any opportunity where coordinated observations would be useful, feel free to come talk to me.**

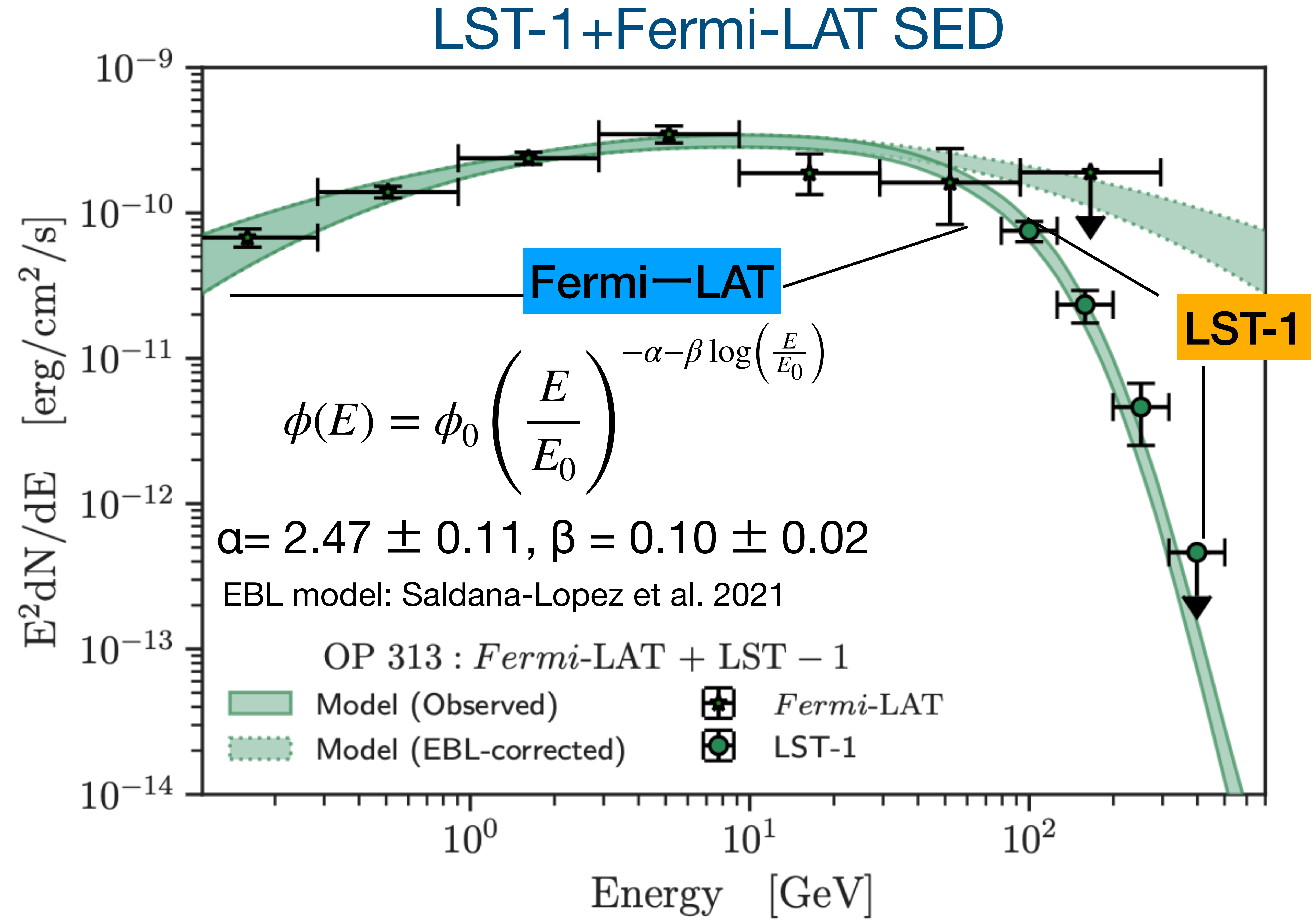
Backup

Flux Reconstruction of OP 313

We stacked the full 14 hours of observation data to reconstruct the SED and combined it with the quasi-simultaneous Fermi-LAT SED for a joint fit

- The LST-1 data provided flux points up to approximately 300 GeV.
- Fitted with $\left(\frac{d\phi}{dE}\right)_{\text{obs}} = \left(\frac{d\phi}{dE}\right)_{\text{int}} \cdot e^{-\tau_{\gamma\gamma}(E,z)}$, intrinsic model is assumed to be power law (LST-1), log-parabola (LST-1+Fermi-LAT).





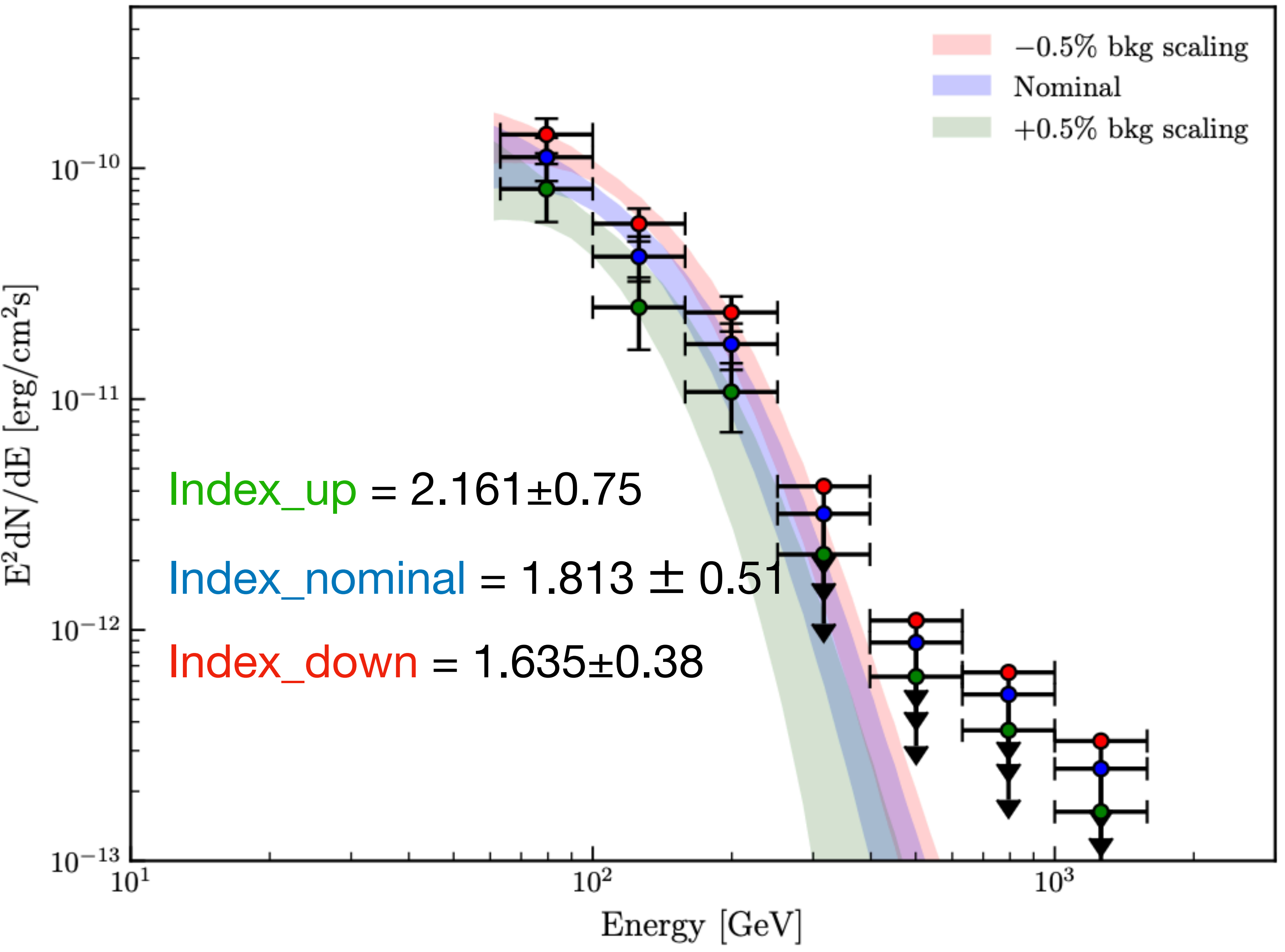
Systematic Uncertainties

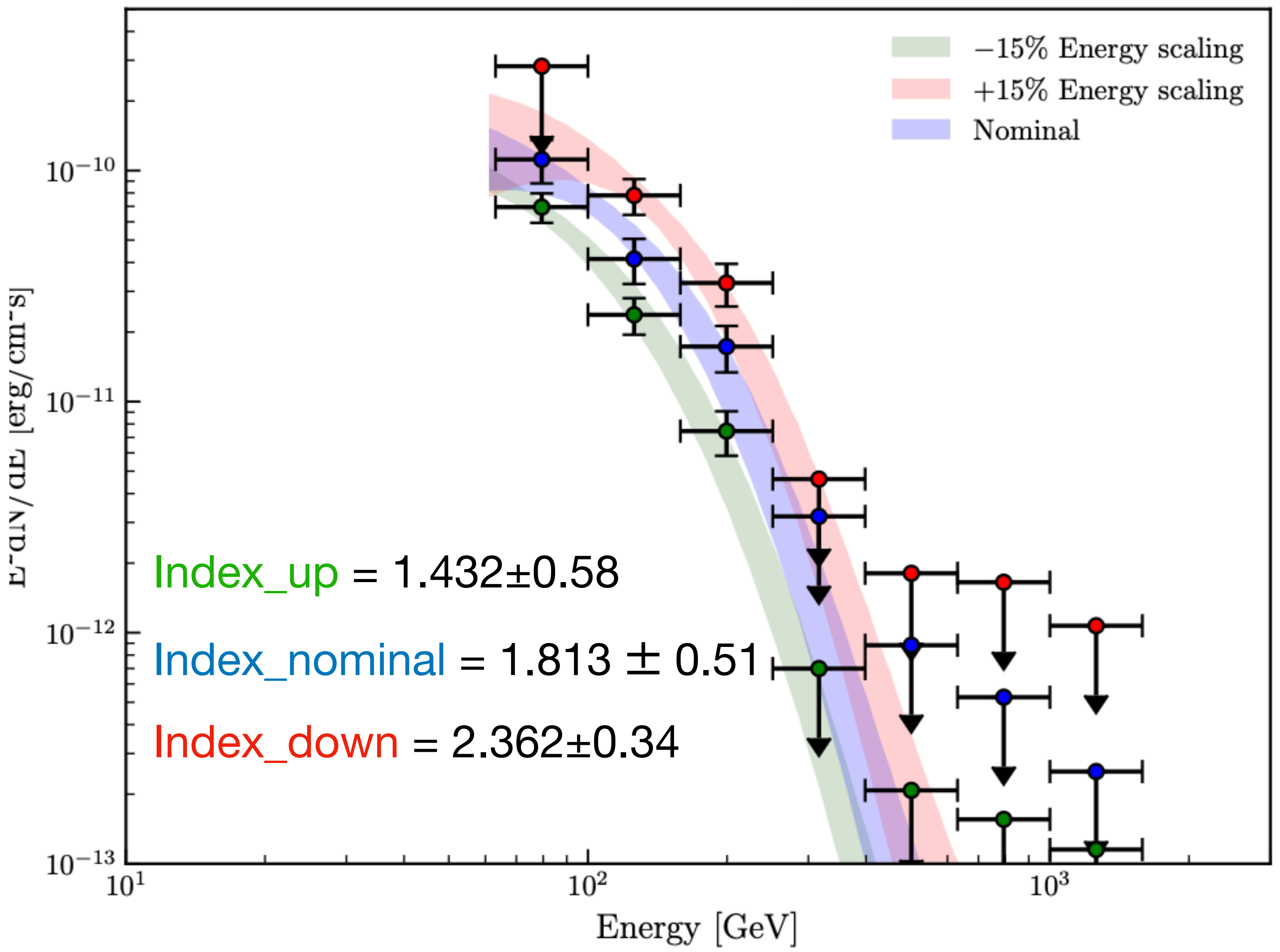
We considered three sources of systematic uncertainty in the SED

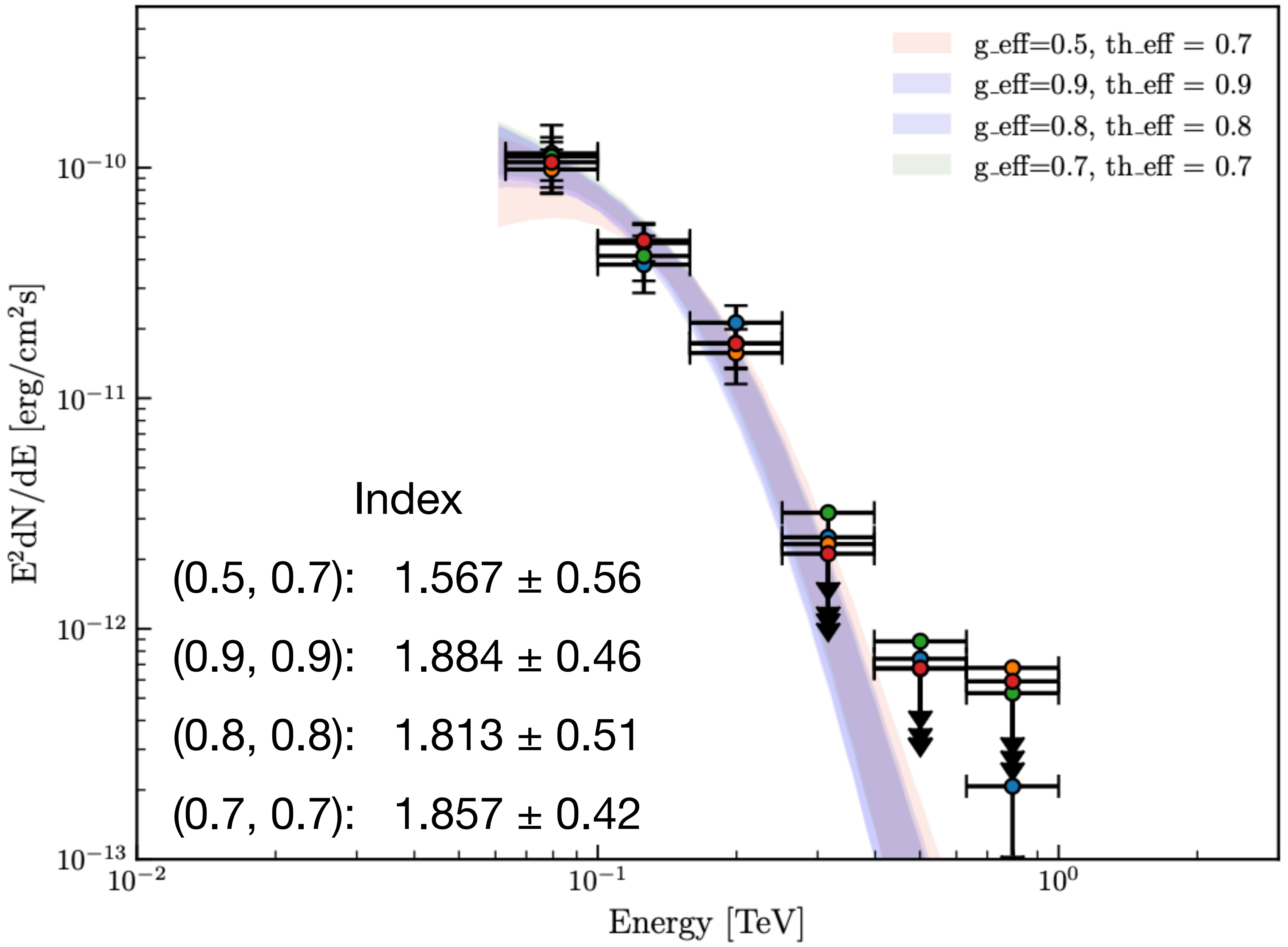
1. Energy Scale Shift (±15%)
   → Spectral index varies by ±0.55; flux normalization changes by up to 50%
   → Harder (softer) spectrum for higher (lower) energy scaling
2. Background Level (±0.5%)
   → Moderate effect: index shifts by up to 0.53; normalization changes ~30%
3. Event Selection Cuts
   → Index variation within ±0.32; amplitude changes ≤15%
   → Looser cuts slightly harden spectrum; tighter cuts steepen it

→ Combined Envelope (vs. Nominal Fit):

- Spectral index: **<u>Γ=1.43–2.36 (–21% to +30%)</u>**
- Normalization: **<u>A=(6.7–16.7)×10–9TeV^{-1}cm^{-2}s^{-1} (–40% to +51%)</u>**







Single-source Analysis: EBL Constraints from OP 313

Method for EBL Constraints from OP 313

- We modeled the observed spectrum as

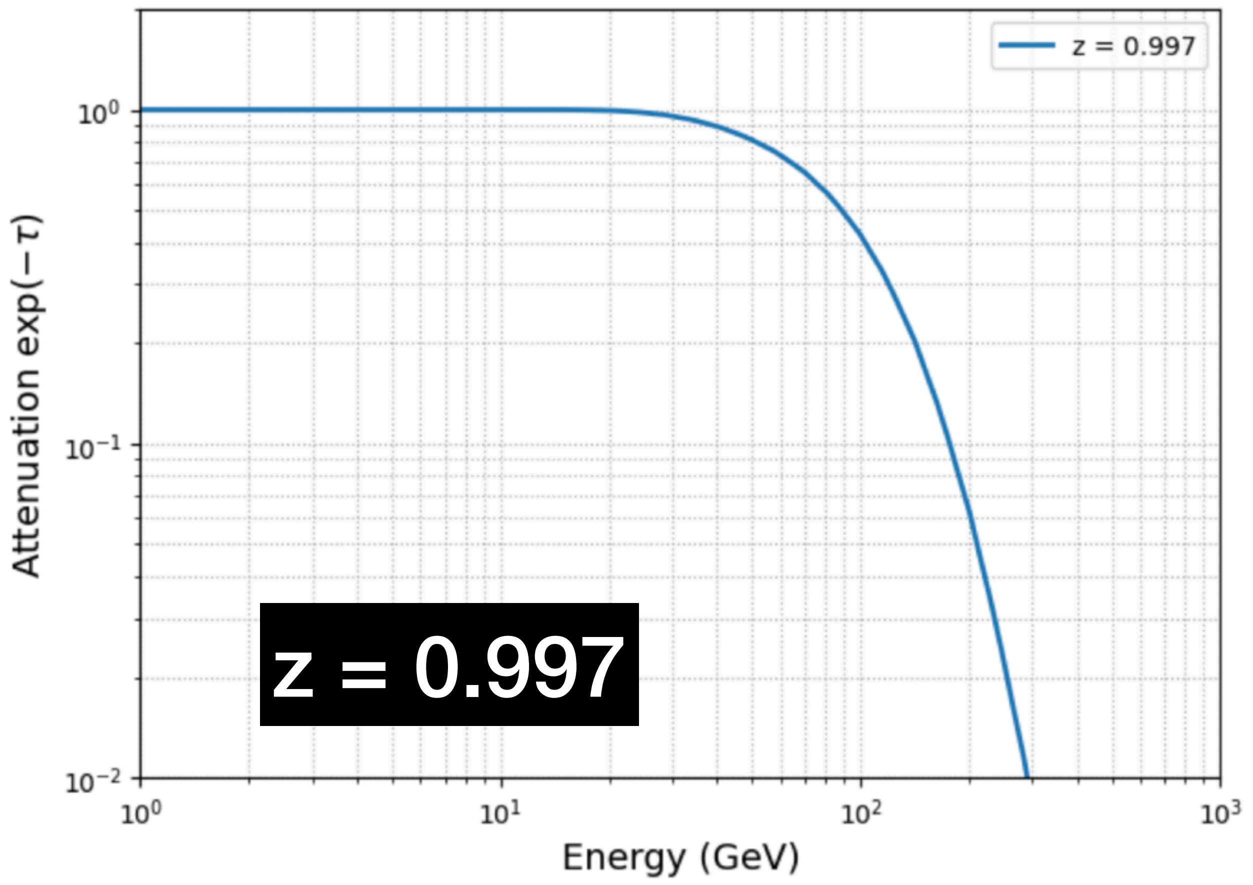
$$F_{\mathrm{obs}} = F_{\mathrm{int}} \cdot \exp\left[-\alpha\tau_{\gamma\gamma}\left(E_{\gamma}, z\right)\right]$$

  here, **<u>α is a scaling parameter</u>**

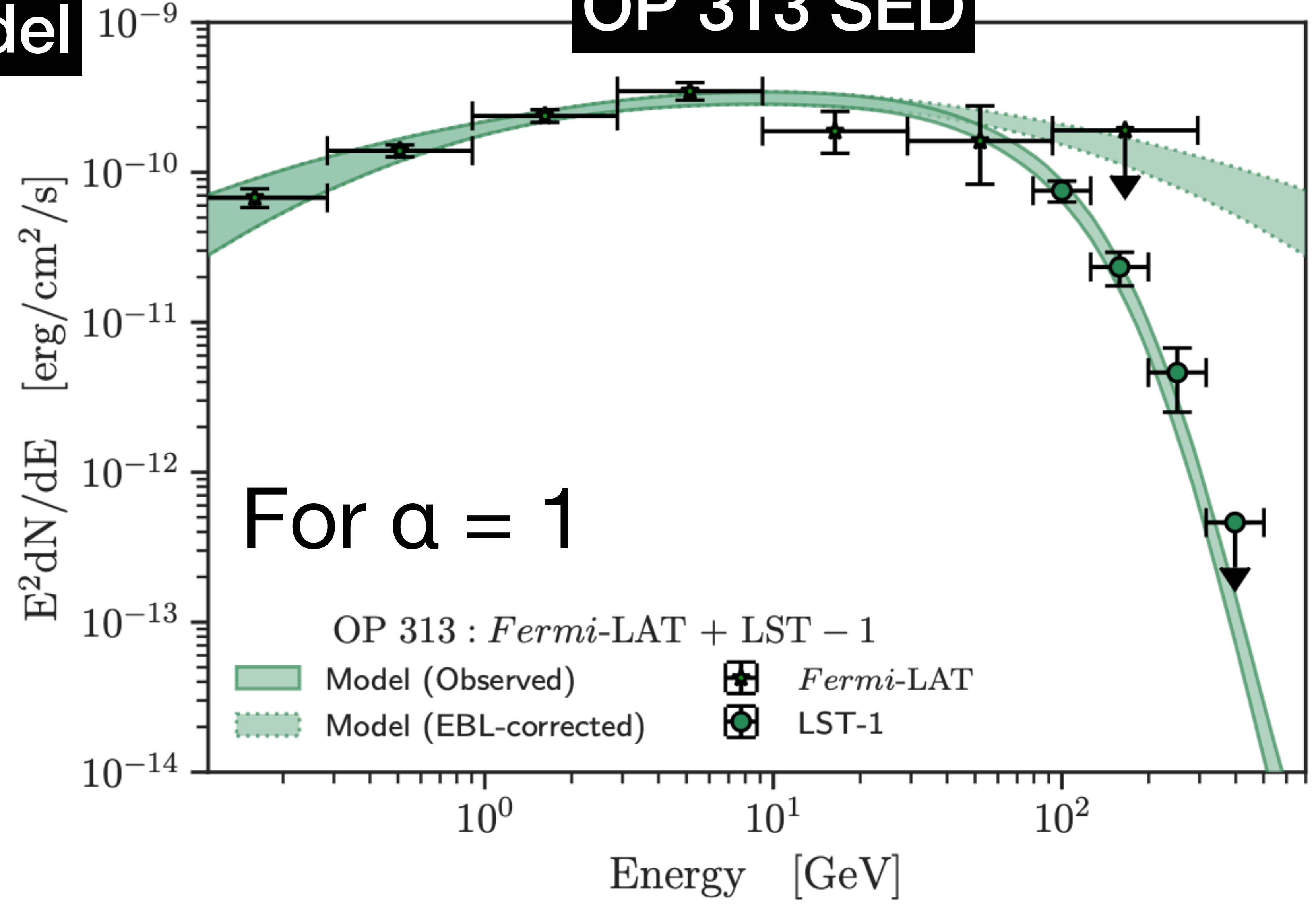
- The intrinsic spectrum F_{int} is assumed to follow smooth, concave forms (LP, PLEC, or LPEC)
  - Log-parabola, Pawer Law with exp cutoff, Log-parabola with exp cutoff
  - During the fit, the spectral parameters are free to vary.
  - Saldana-Lopez et al. (2021) EBL model assumed

- Performed a joint likelihood fit to LAT+LST-1, scanning over α, save each likelihood value

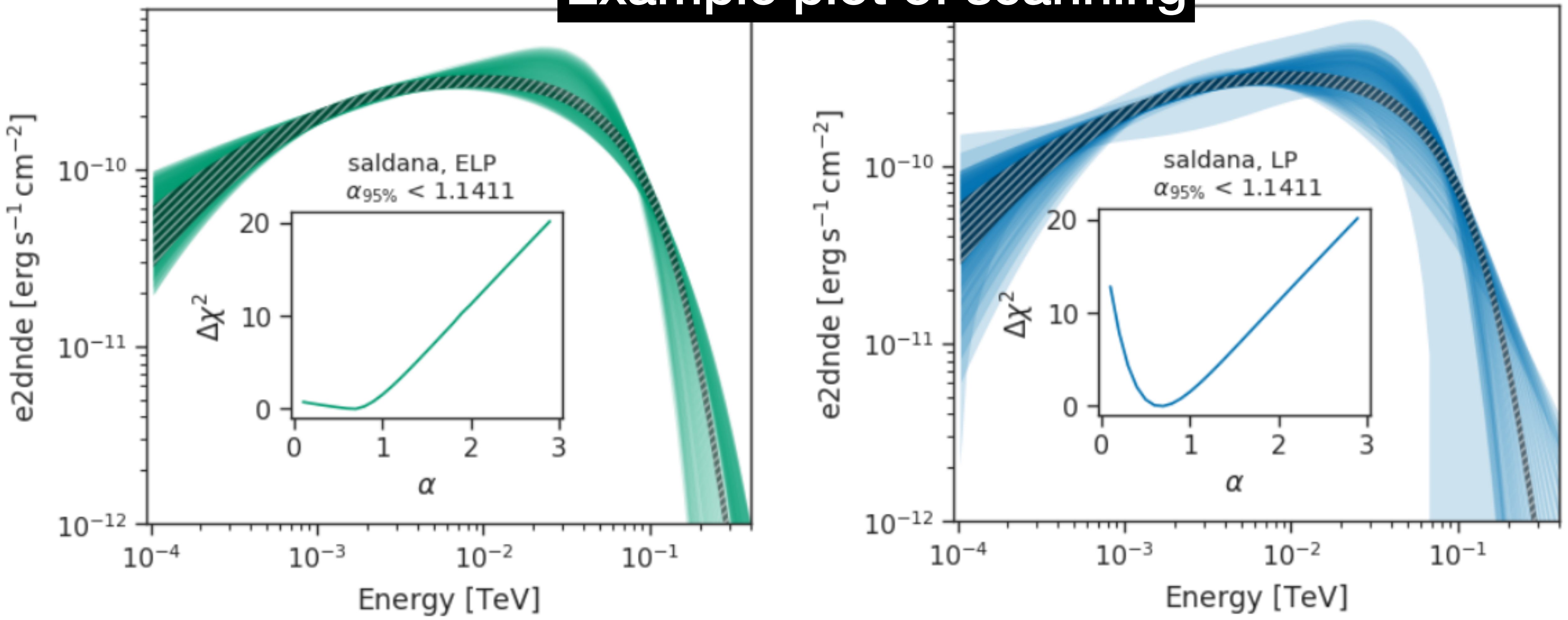
τ from Saldana-Lopez 2021 EBL model



OP 313 SED



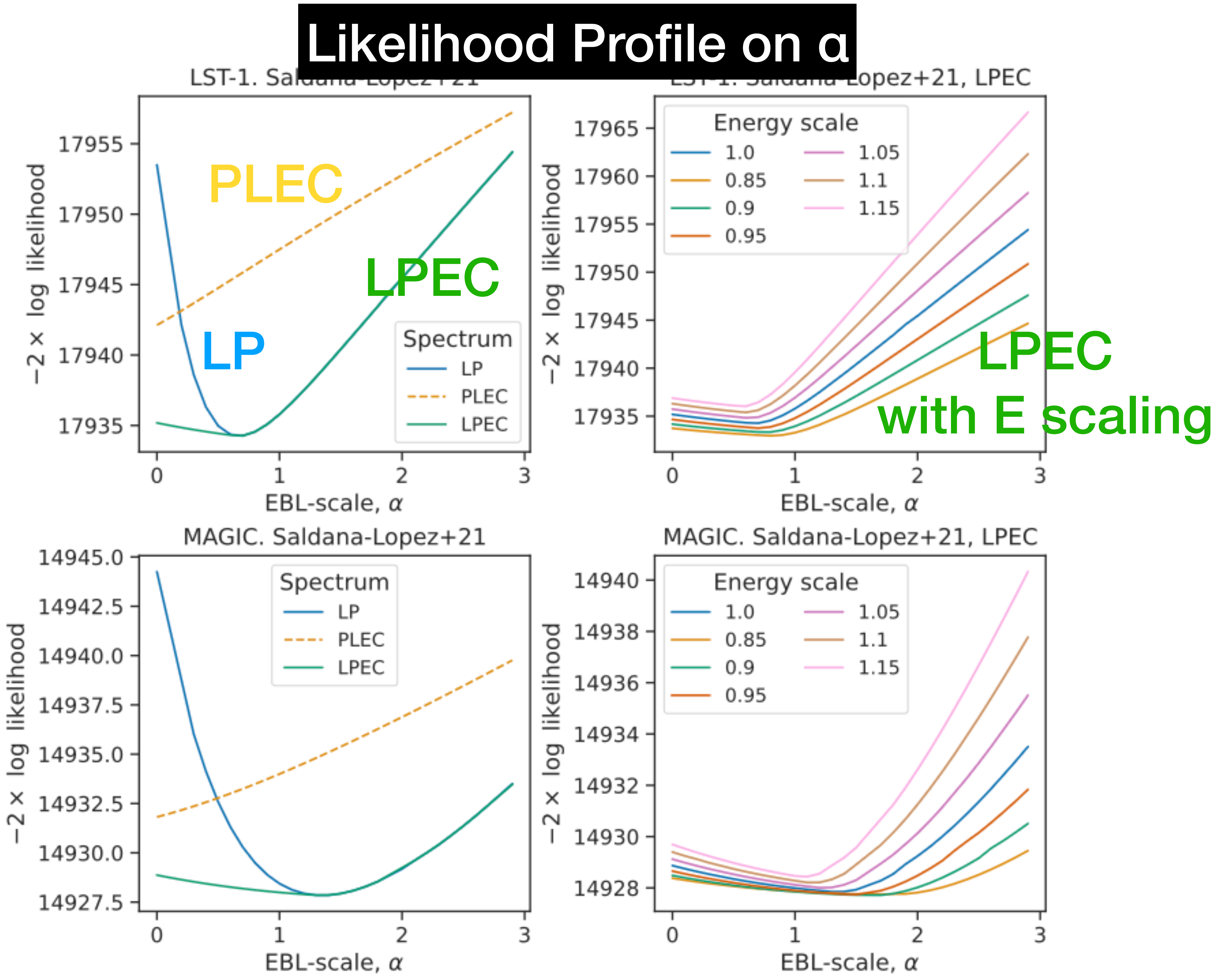
Example plot of scanning

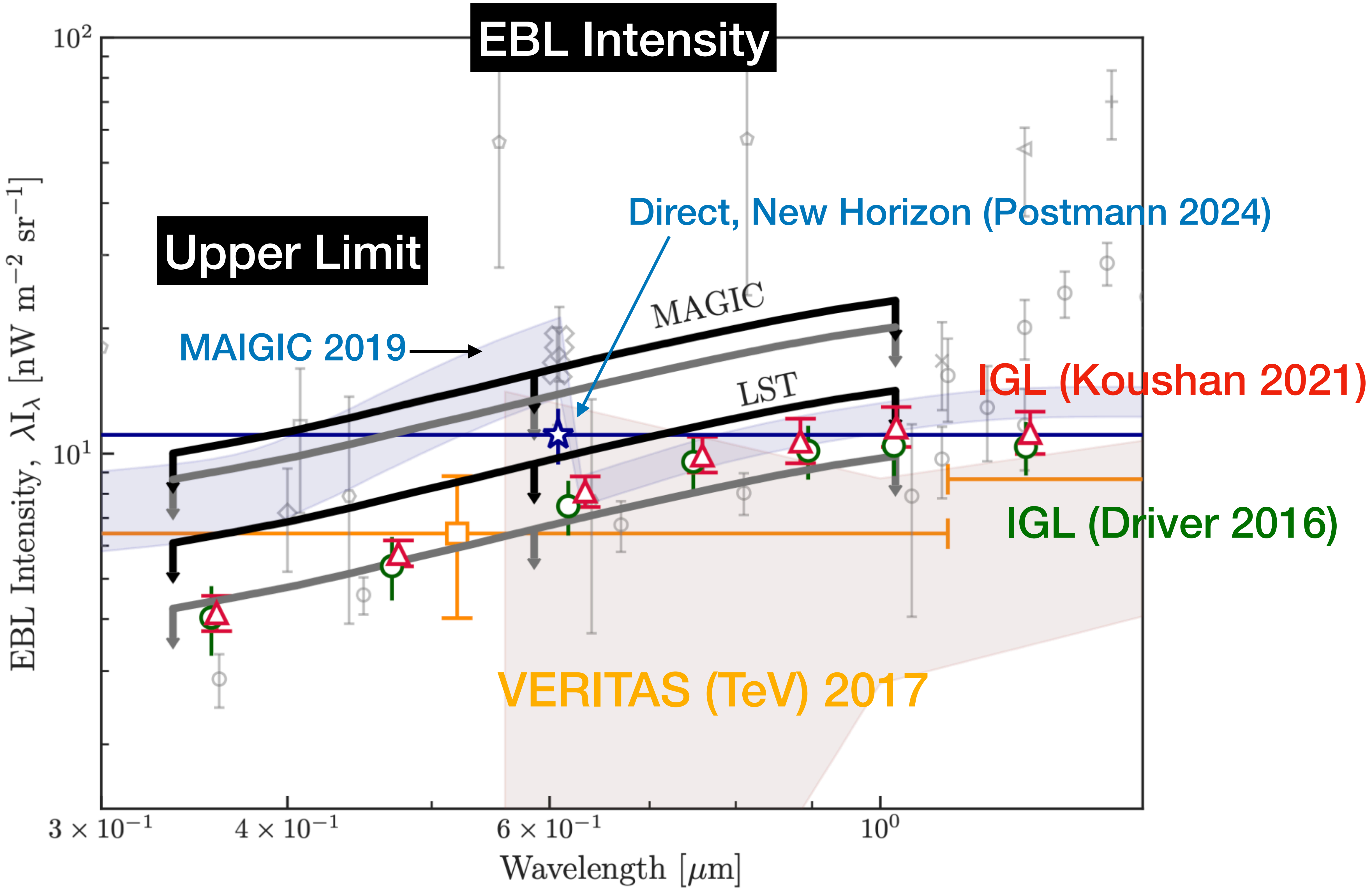


EBL Intensity Constraints from OP 313

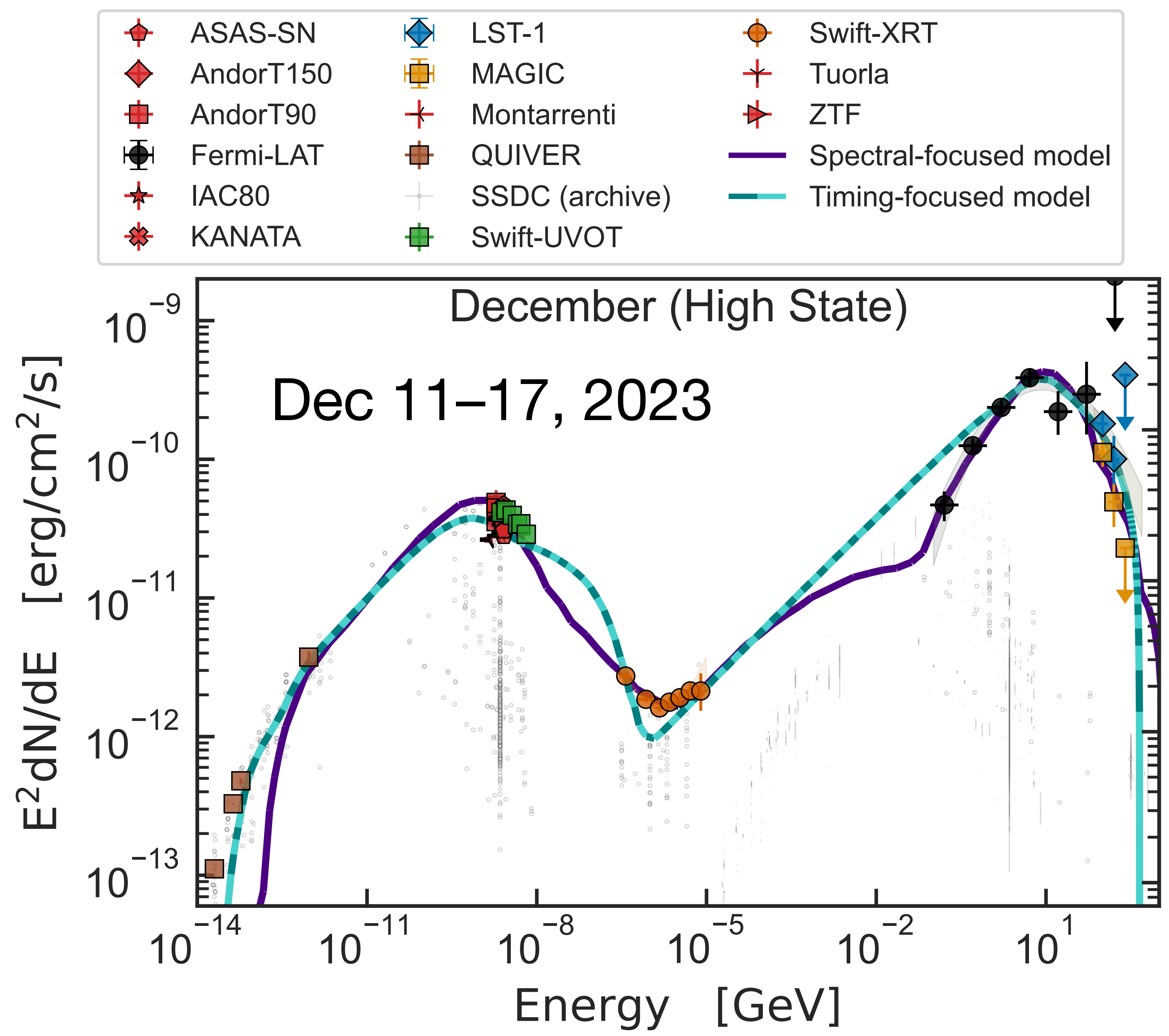
The HE and VHE observations allow us to set constrains to the EBL density, resulting in a upper limit at 0.6 µm of $\lambda I_\lambda < 8.74\ \mathrm{nWm^2sr^{-1}}$ with LST-1 data

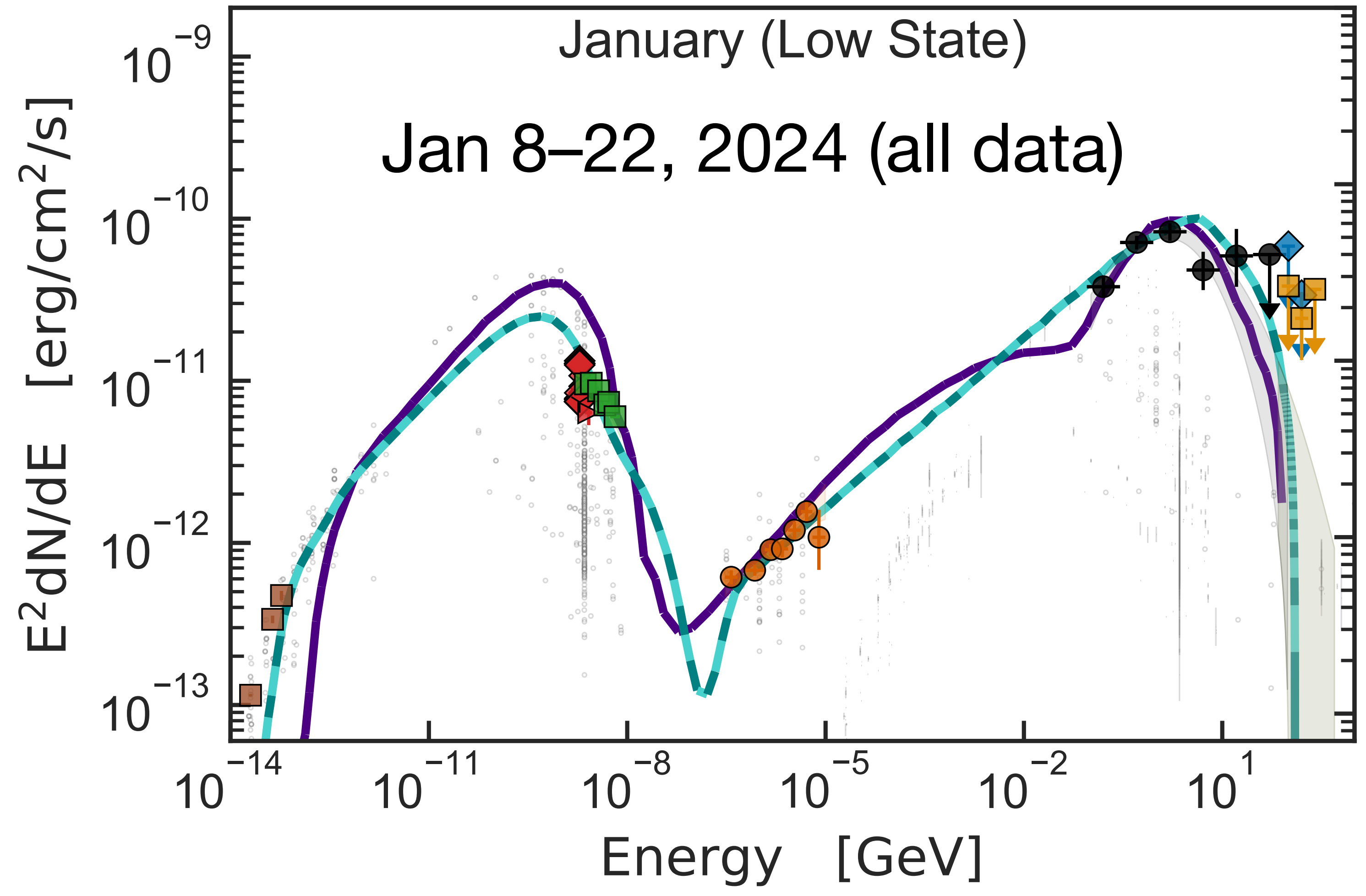
- The combined Fermi-LAT + LST-1/MAGIC spectra show strong intrinsic curvature. Power-law models (PWL) are excluded; LP and LPEC yield consistent likelihood shapes.
- The PLEC model prefers unphysical negative α, indicating a poor fit.
- We report conservative 95 % CL upper limits using the LP model: $\alpha < 1.14(\mathrm{LAT} + \mathrm{LST}-1), \quad \alpha < 2.33(\mathrm{LAT} + \mathrm{MAGIC})$





Broadband SED modeling





Parameters of the spectral-focused emission model

Parameters	"near zone" December 2023	"near zone" January 2024	"far zone"
B' $[10^{-2}\mathrm{G}]$	35	35	23
R' $[10^{16}\mathrm{cm}]$	1	1	20
δ	99	99	19
Γ	50	50	10
N_e $[10^{-5}\ \mathrm{cm}^{-3}]$	20	1.0	2.5
n_1	1.8	1.8	2.1
n_2	4.0	4.0	−−
γ'_{min}	3×10^2	3×10^2	1.0
γ'_{br}	3×10^3	1×10^3	−−
γ'_{max}	5×10^4	1×10^4	8×10^3
R_H $[10^{17}\mathrm{cm}]$	2.9	2.9	200

- we consider a two-zone leptonic scenario where the radiation produced by each emitting region is characterized by a set of physical parameters including its radius R, magnetic field B, bulk Lorentz factor Γ and Doppler factor δ.

$$N(\gamma) = \begin{cases} K(\gamma/\gamma_b)^{-n_1} : \gamma_{min} < \gamma < \gamma_b \\ K(\gamma/\gamma_b)^{-n_2} : \gamma_b > \gamma > \gamma_{max} \end{cases}$$