Astronomical Society of Japan

cherenkov telescope array

東京大学 THE UNIVERSITY OF TOKYO

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CTA大口径望遠鏡初号機によるブレーザーの観測：マルチメッセンジャー天文学時代のブレーザー観測戦略

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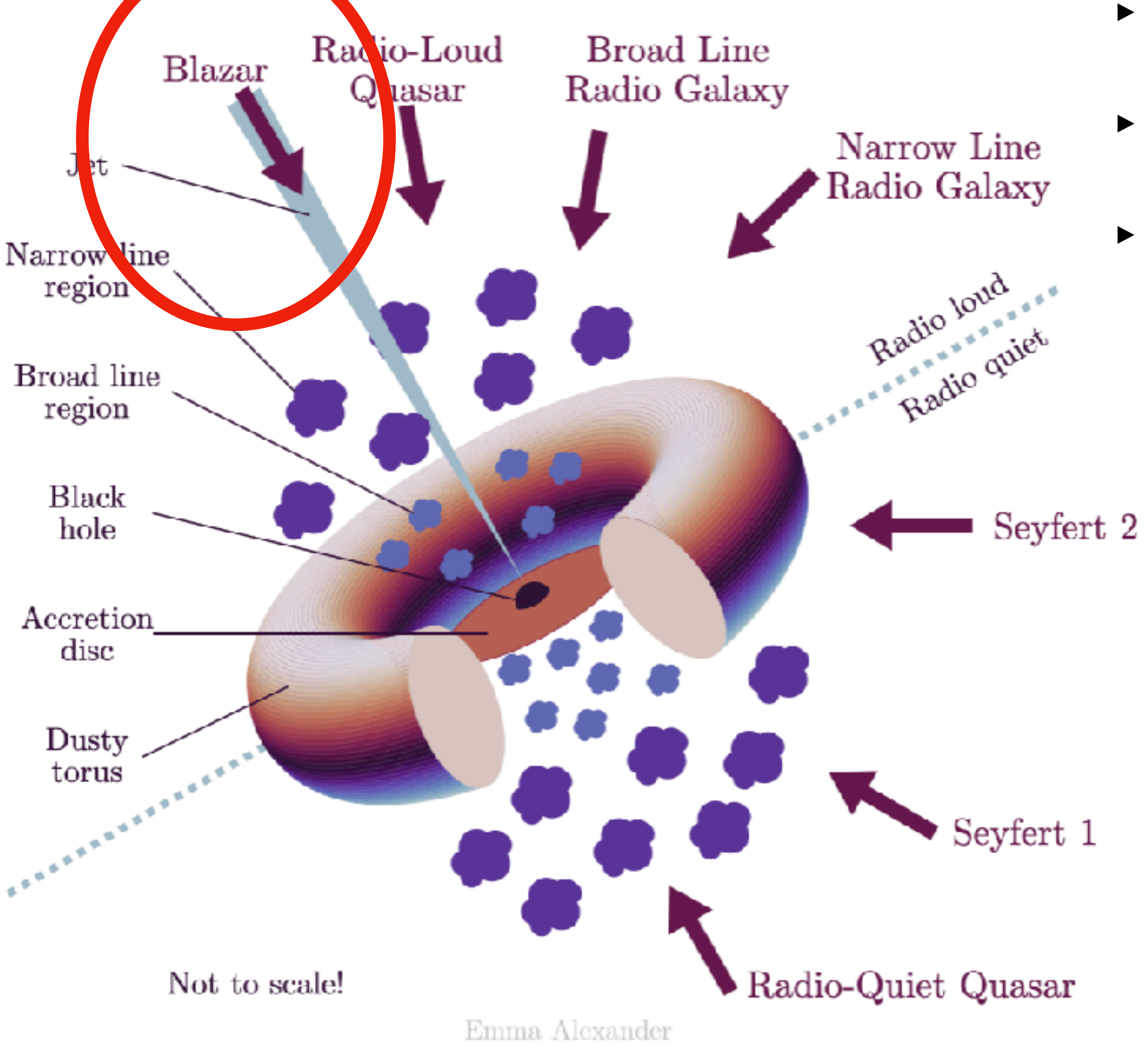
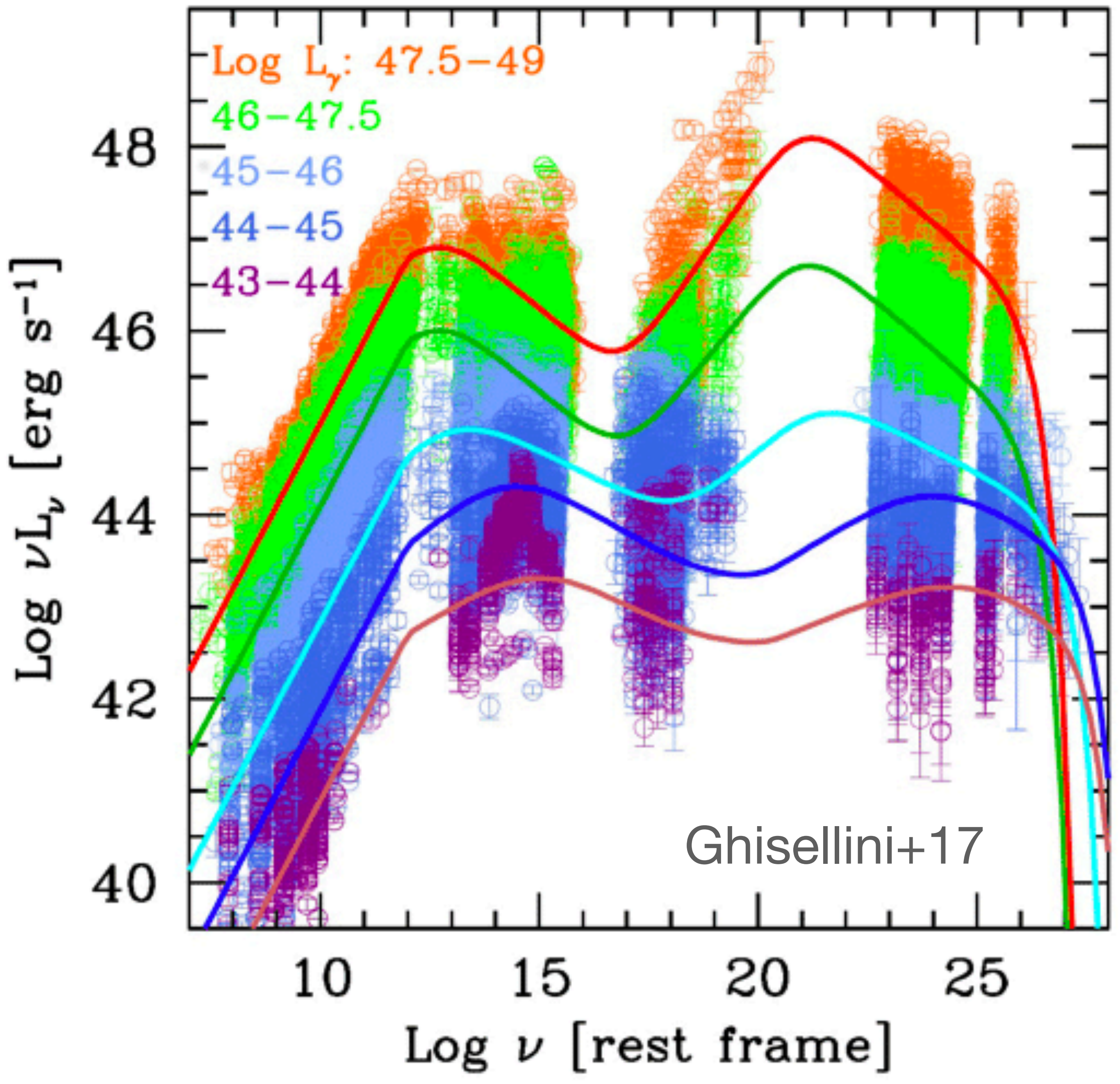
On Behalf of the CTA-LST Project

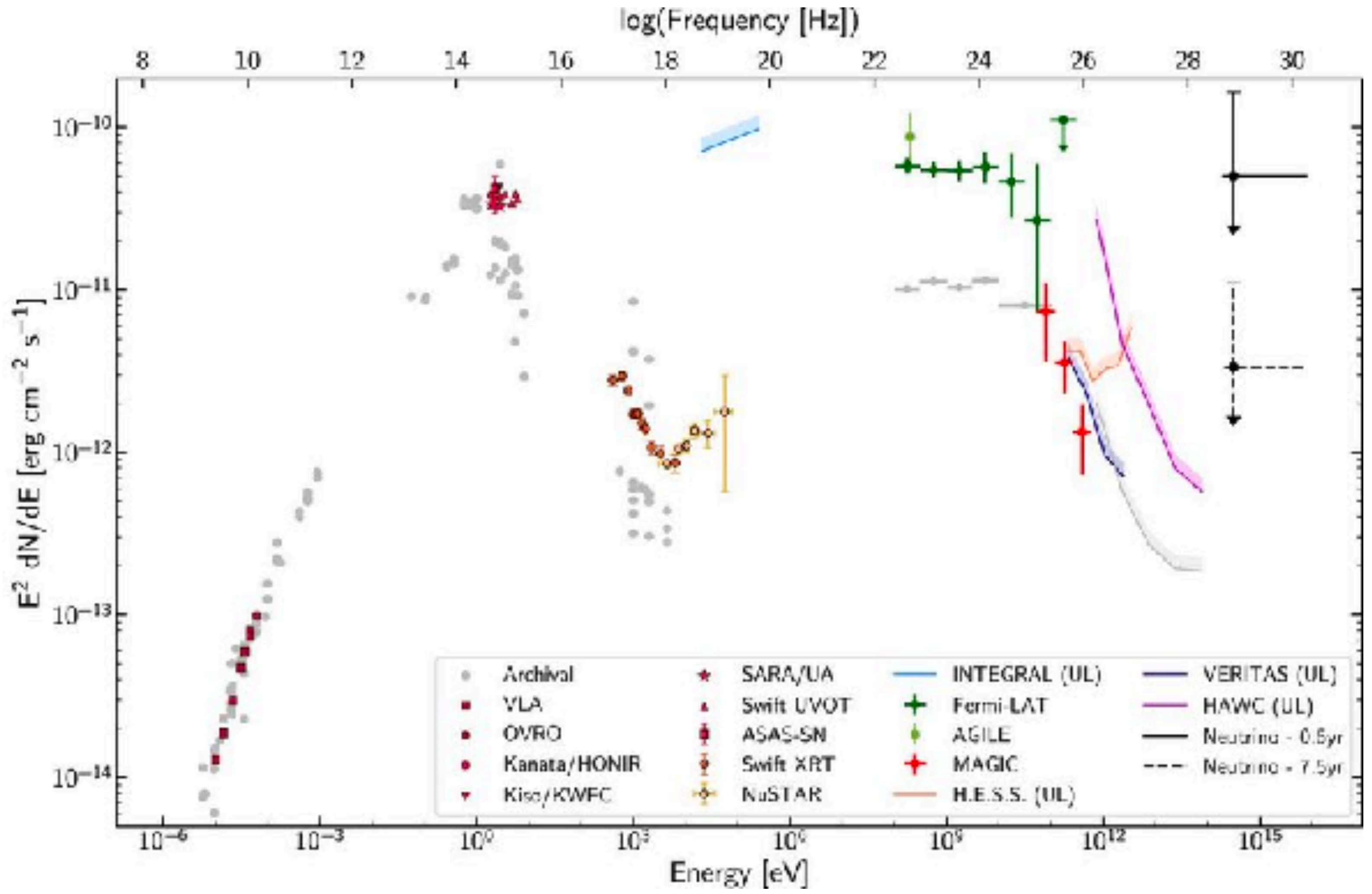
Blazars: Active Galactic Nuclei (AGN) jet pointing towards us

Only ~0.1% of all AGN



- Dominates the **HE/VHE extragalactic sky**
- **Significant variability** across the entire EM spectrum
- This talk will focus on **GeV-TeV** in particular as an individual engaged in VHE experiments (Cherenkov Telescope Array, CTA)



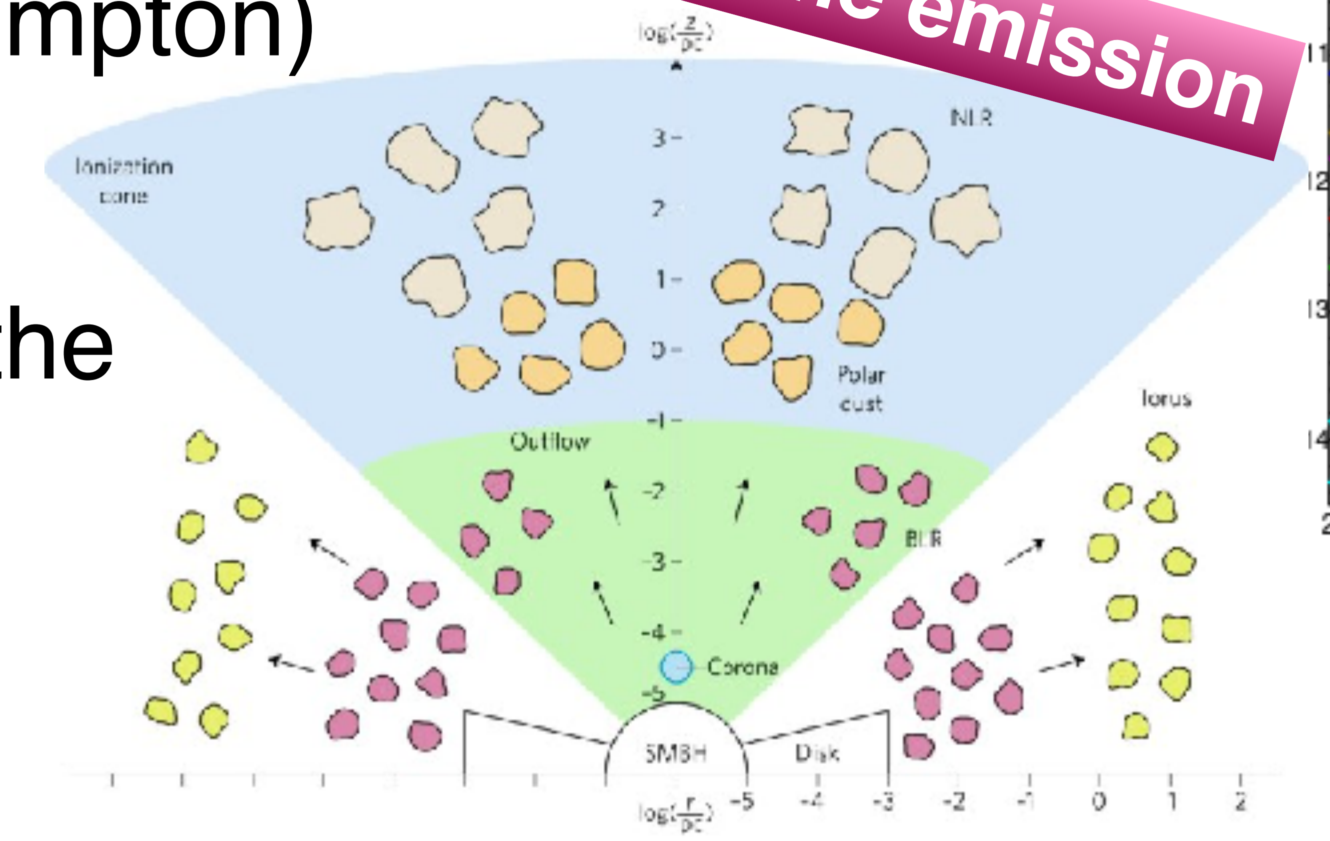


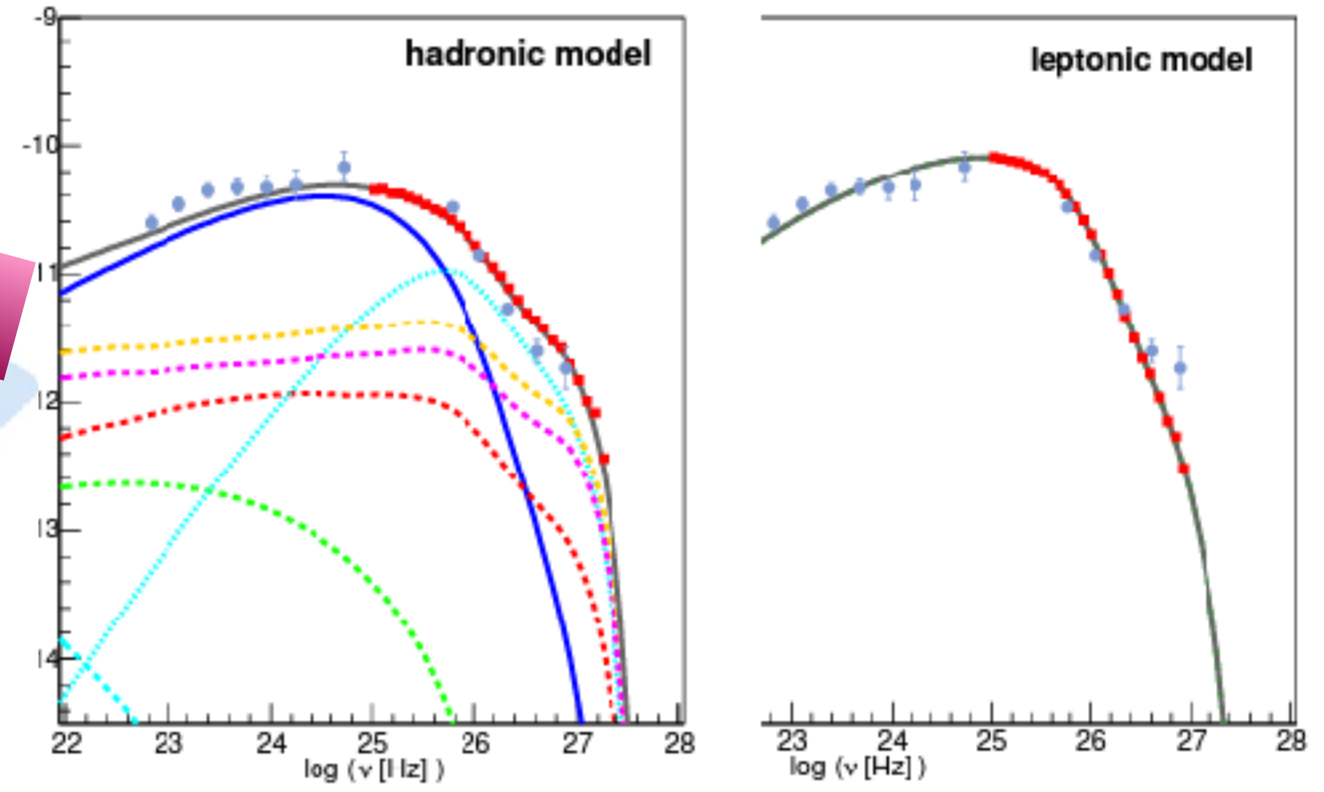
IceCube2018

What do we anticipate elucidating through the observation of blazars?

- **Astrophysical studies**:
  - Leptonic (Synchrotron Self-Compton, External Compton) or hadronic (Proton synchrotron, Photomeson...)?
  - What is the structure/role of the magnetic field in the jets?
  - Where along the jet HE/VHE emission produced?
- **Cosmological, fundamental physics**:
  - Validation of galaxy and star formation models in the universe
  - Does the intergalactic magnetic field exist?
  - Axion-Like Particle?
  - Towards the Hubble crisis; cosmological parameter measurement

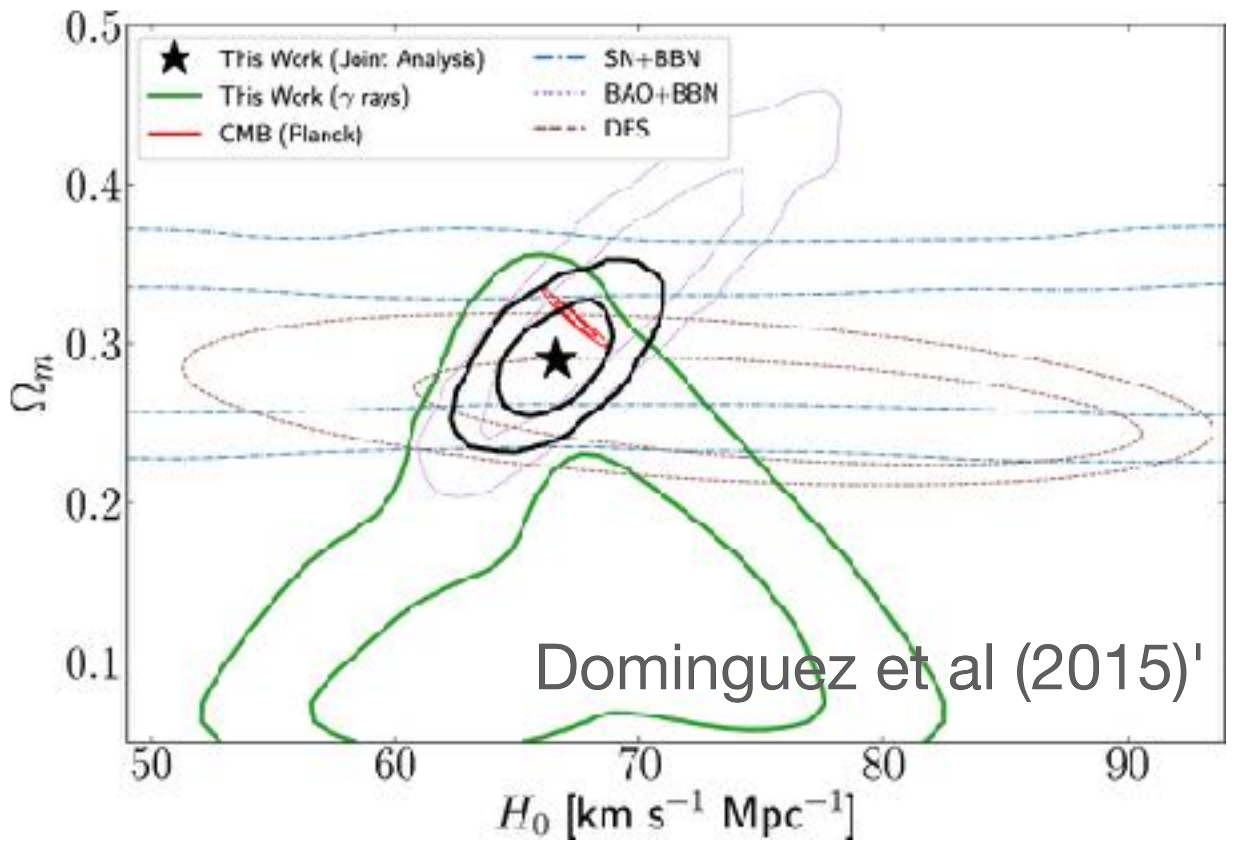
Location of the emission



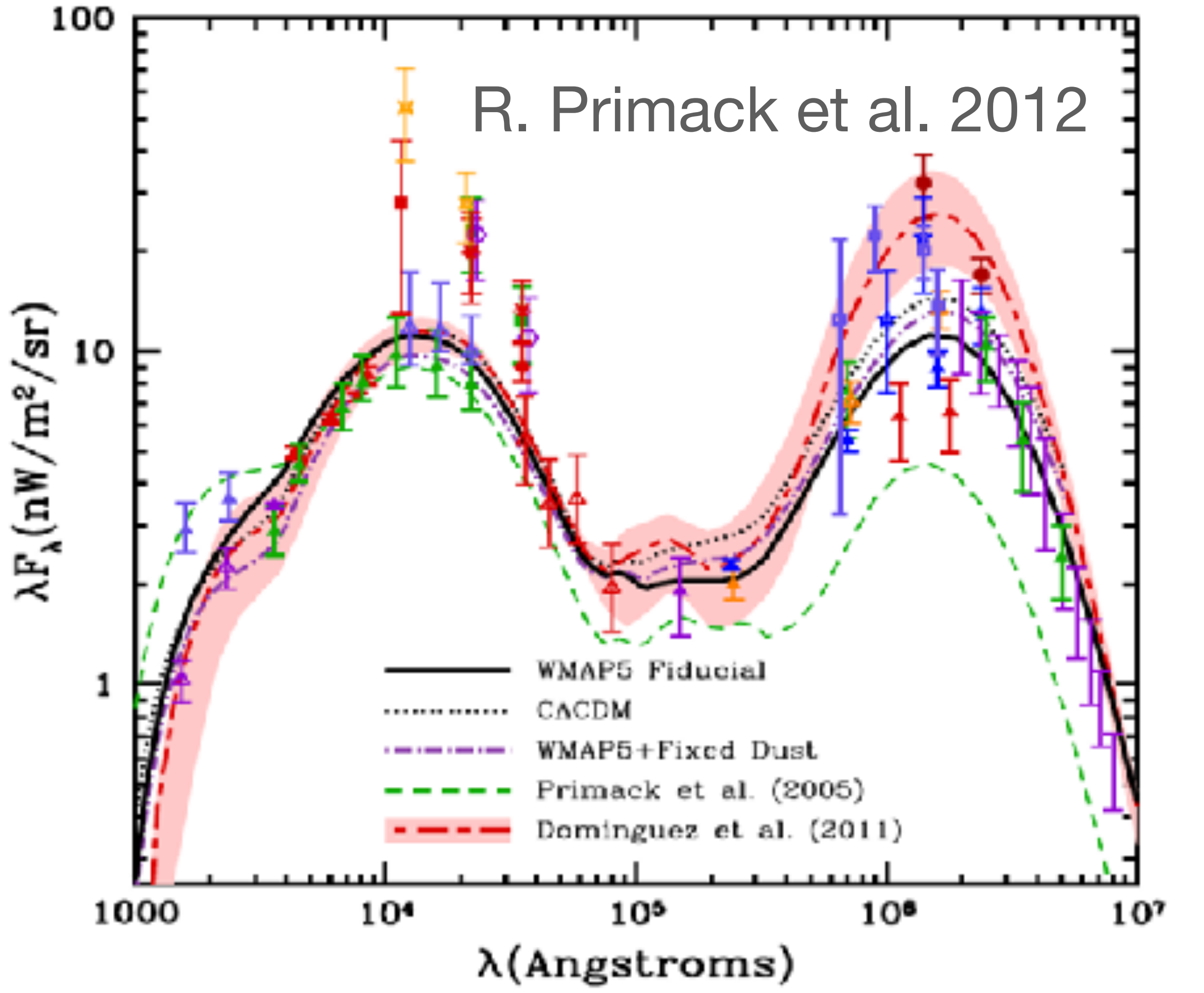


Hadronic vs Leptonic

Measurements of H0,Ωm



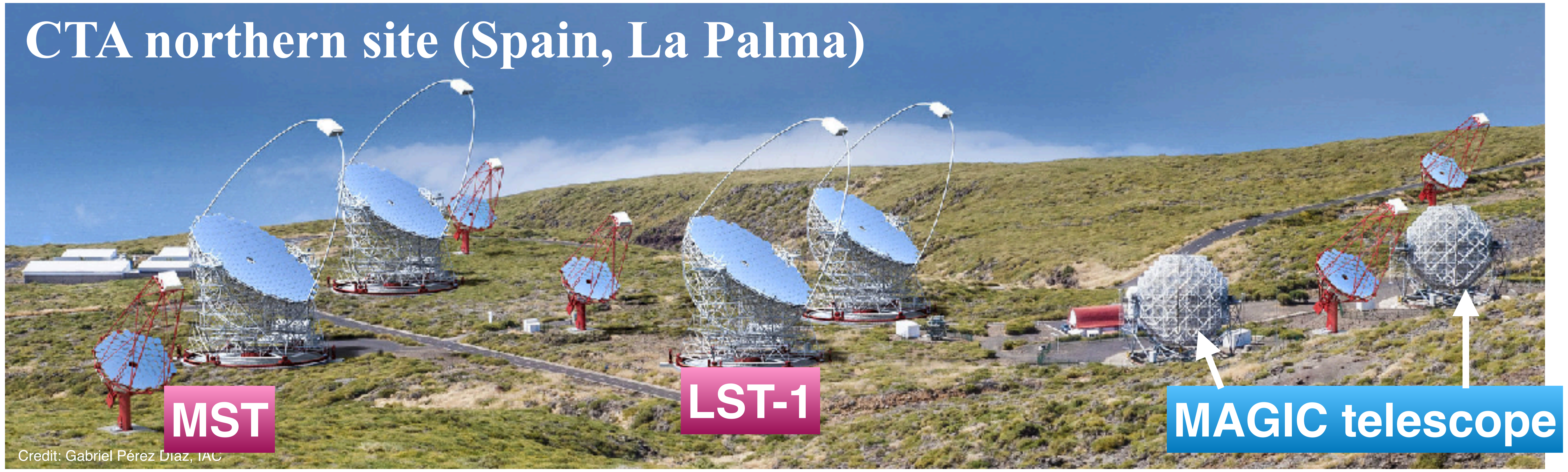
Measurements of EBL

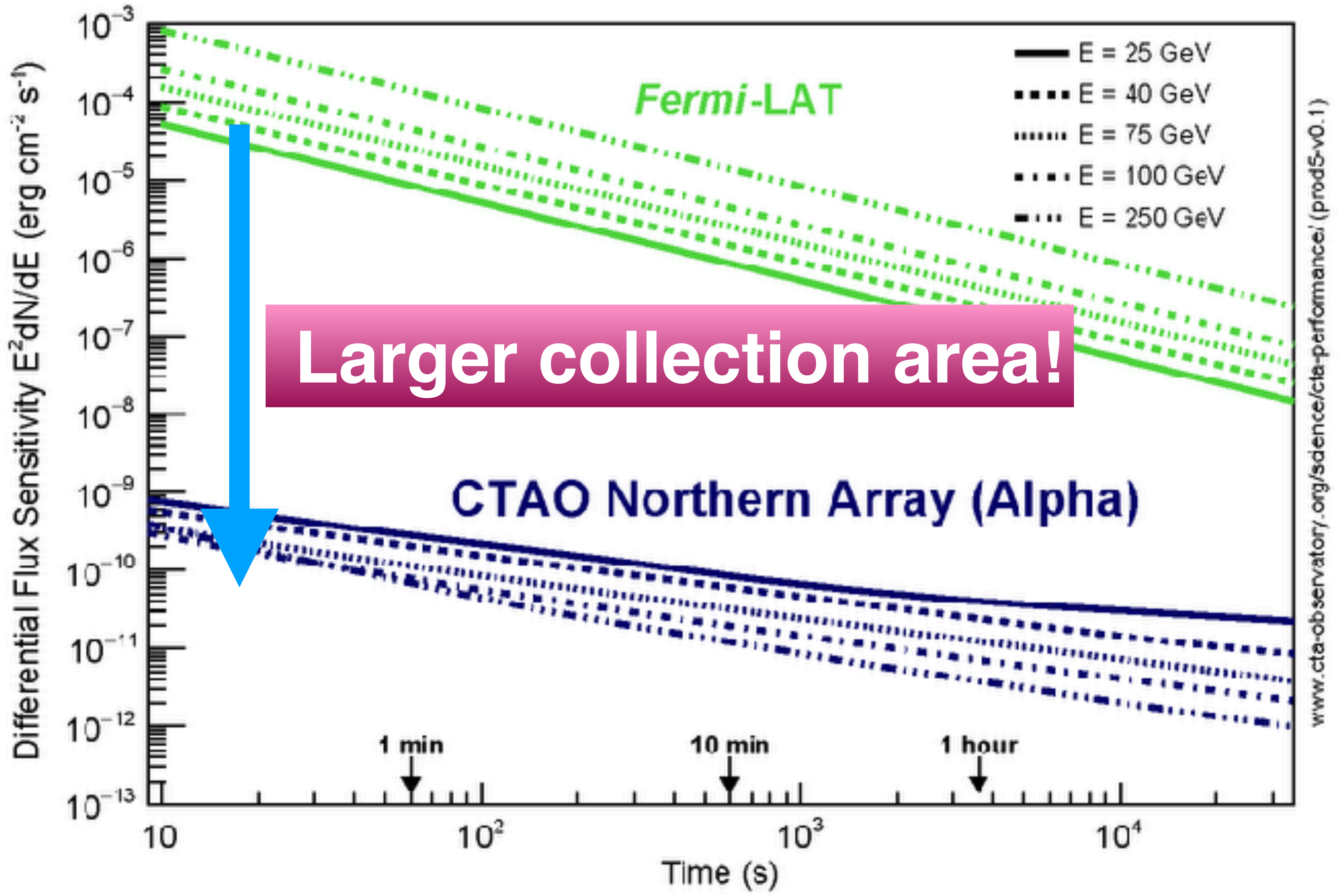


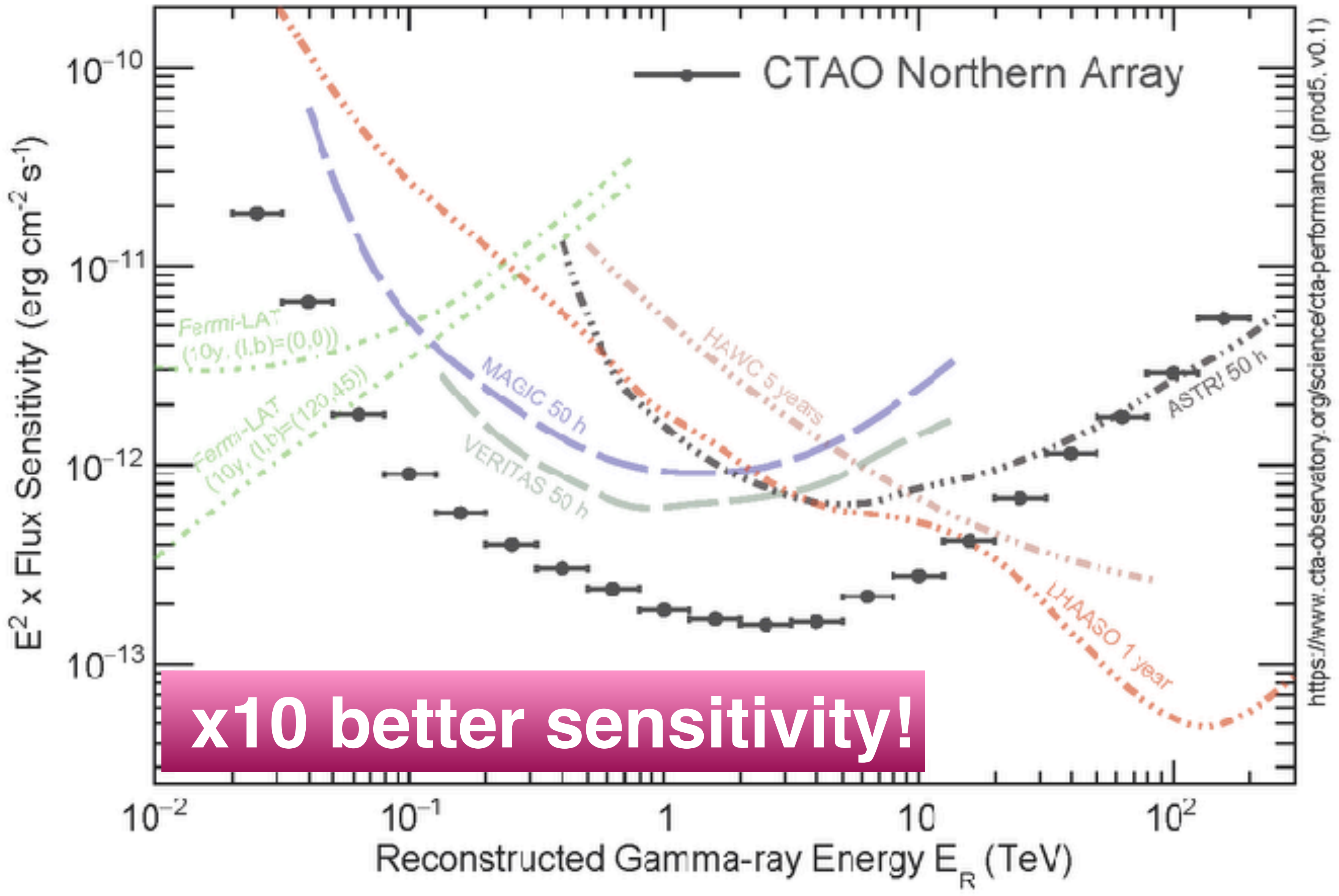
Cherenkov Telescope Array (CTA)

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

- Located in the northern and southern hemispheres with 71 telescopes
- Northern CTA: 4 Large-Sized Telescopes + 9 Medium-Sized Telescopes
- **x10 better sensitivity + wide energy coverage of 20 GeV-300 TeV**
- LST-1 started observation since 2020





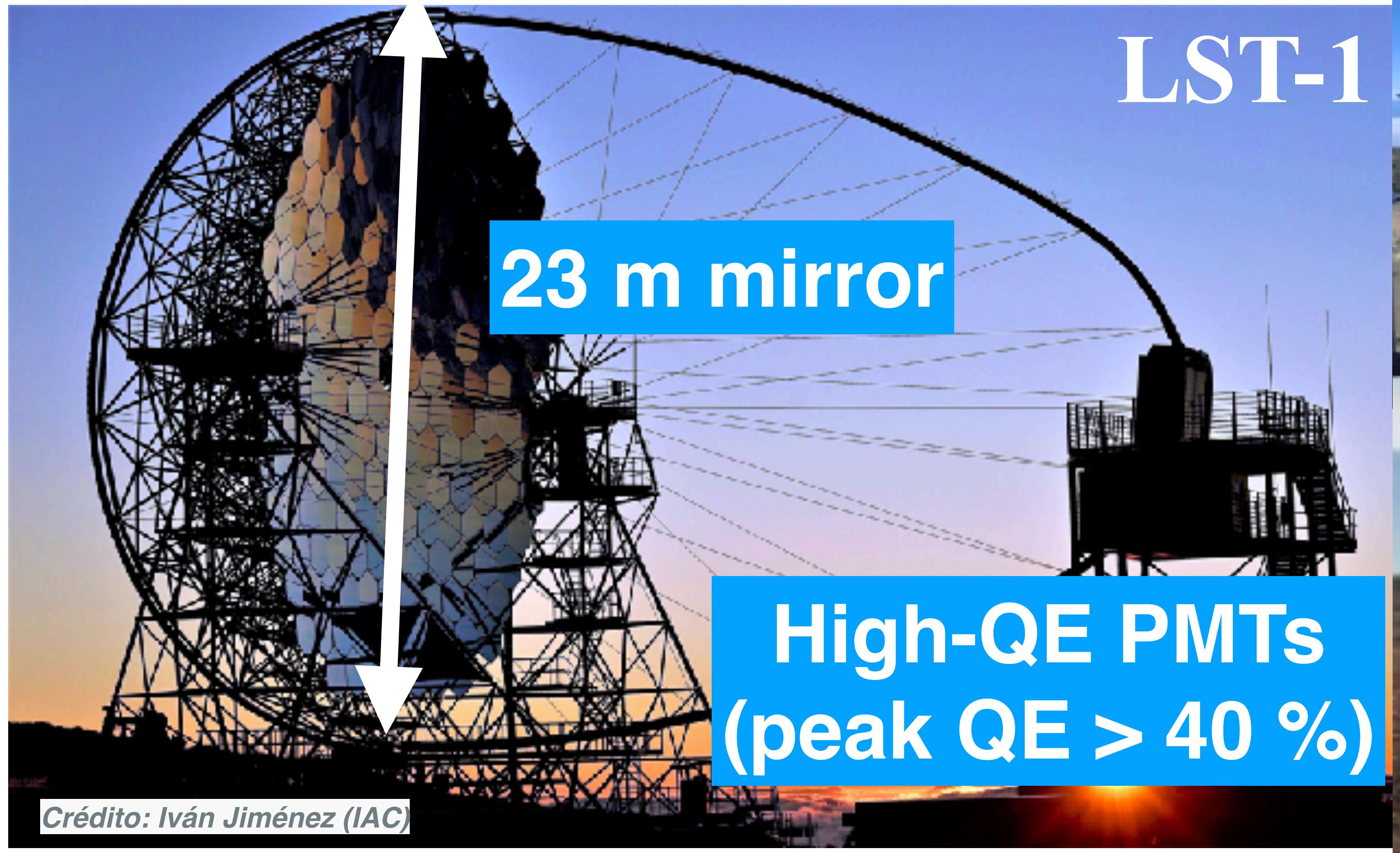


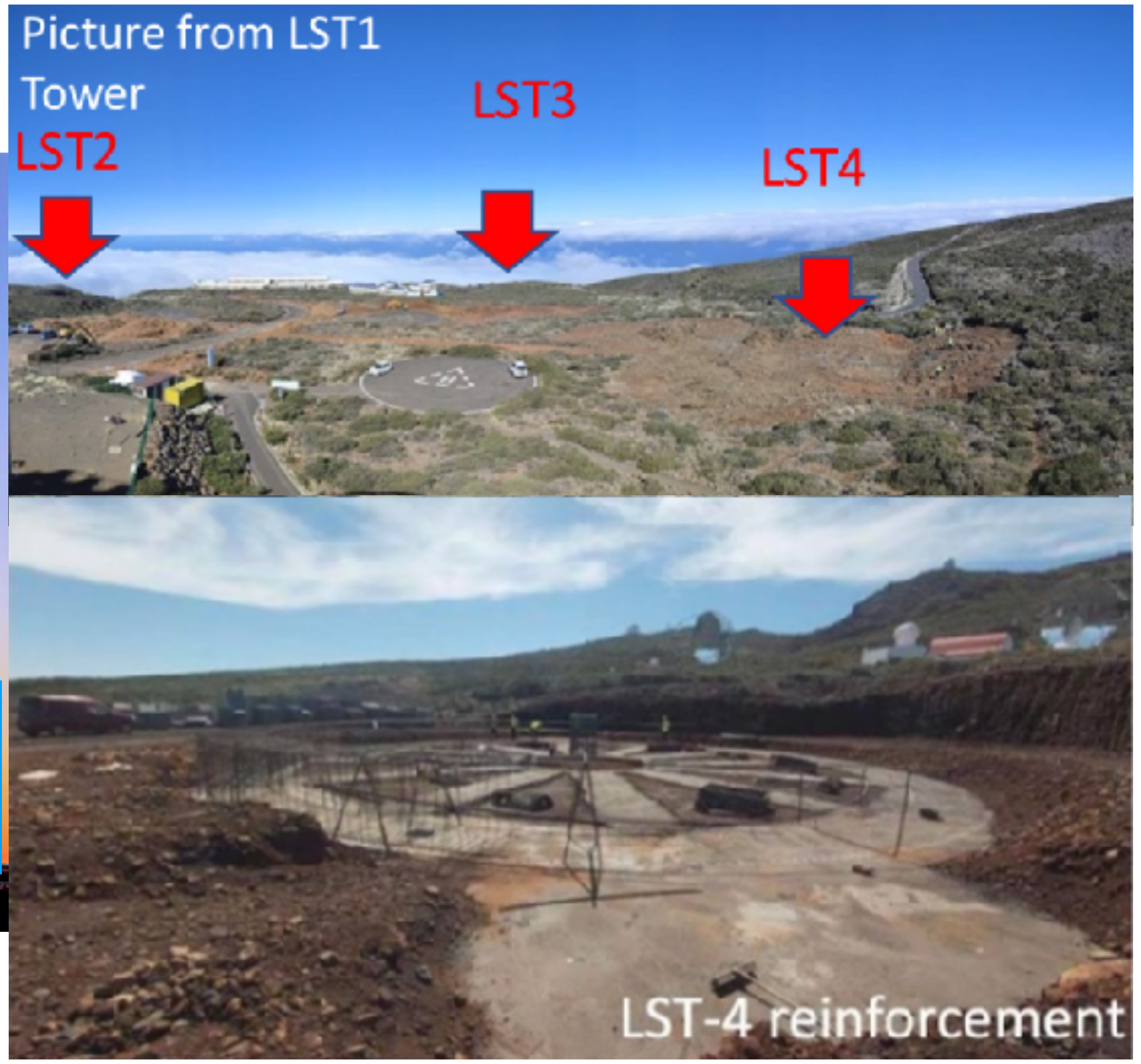
Large-Sized Telescope (LST)

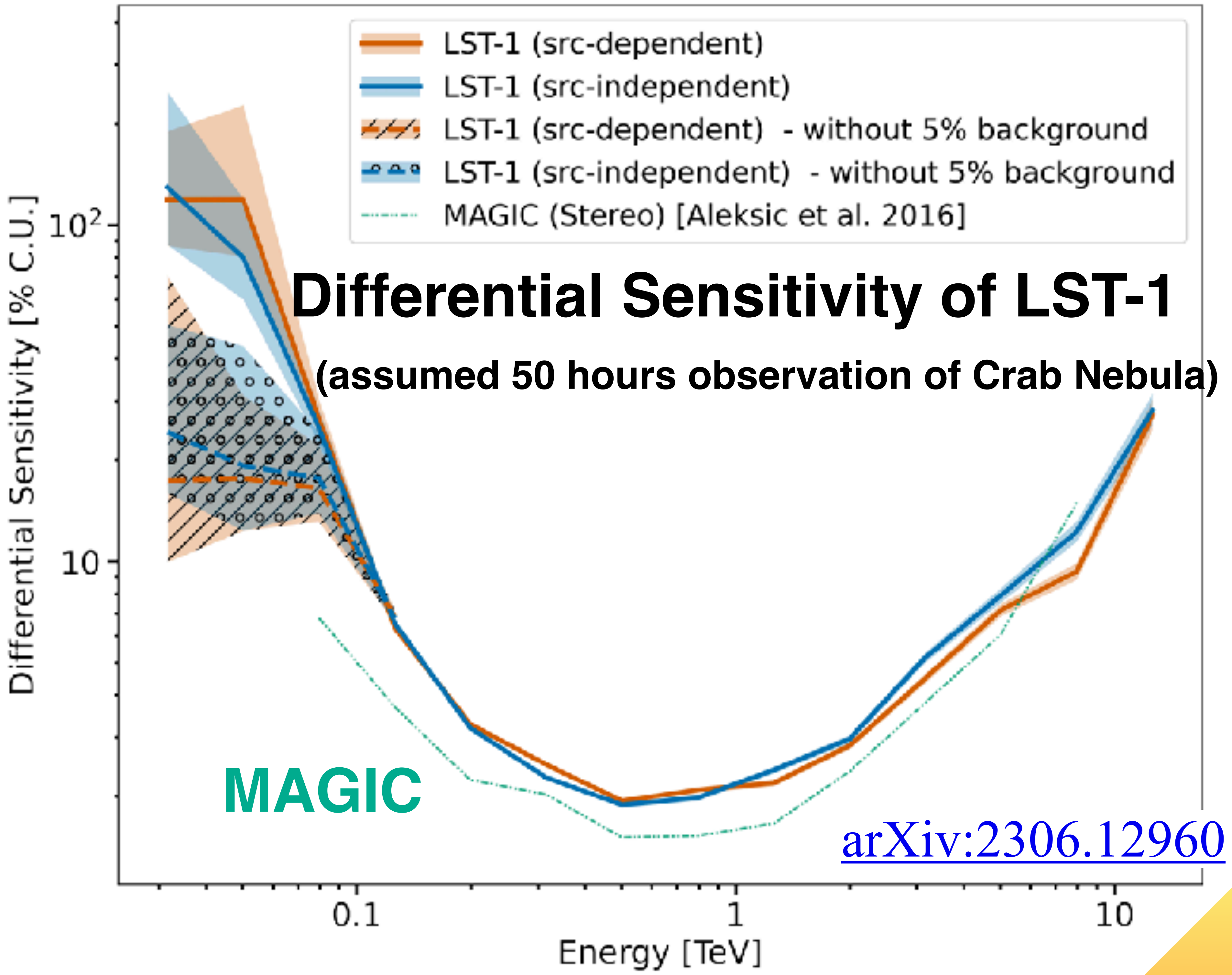
cherenkov telescope array

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**
- A performance paper on LST-1 was published based on the observational data of the Crab Nebula
  - The energy threshold at trigger level estimated to be **20 GeV**, increasing to ≃ **30 GeV after data analysis**
- Suitable for **transient/soft/distant** sources

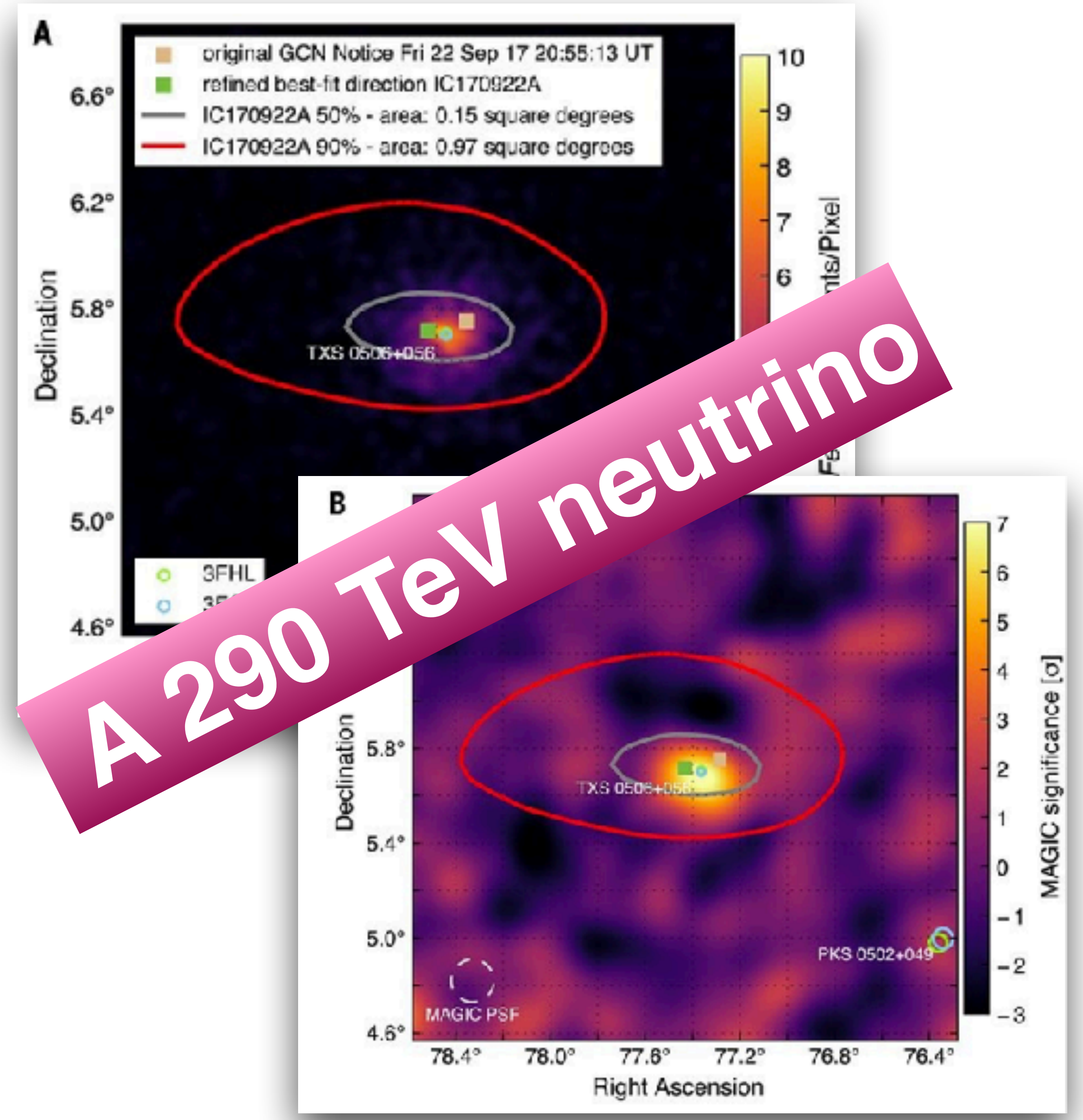


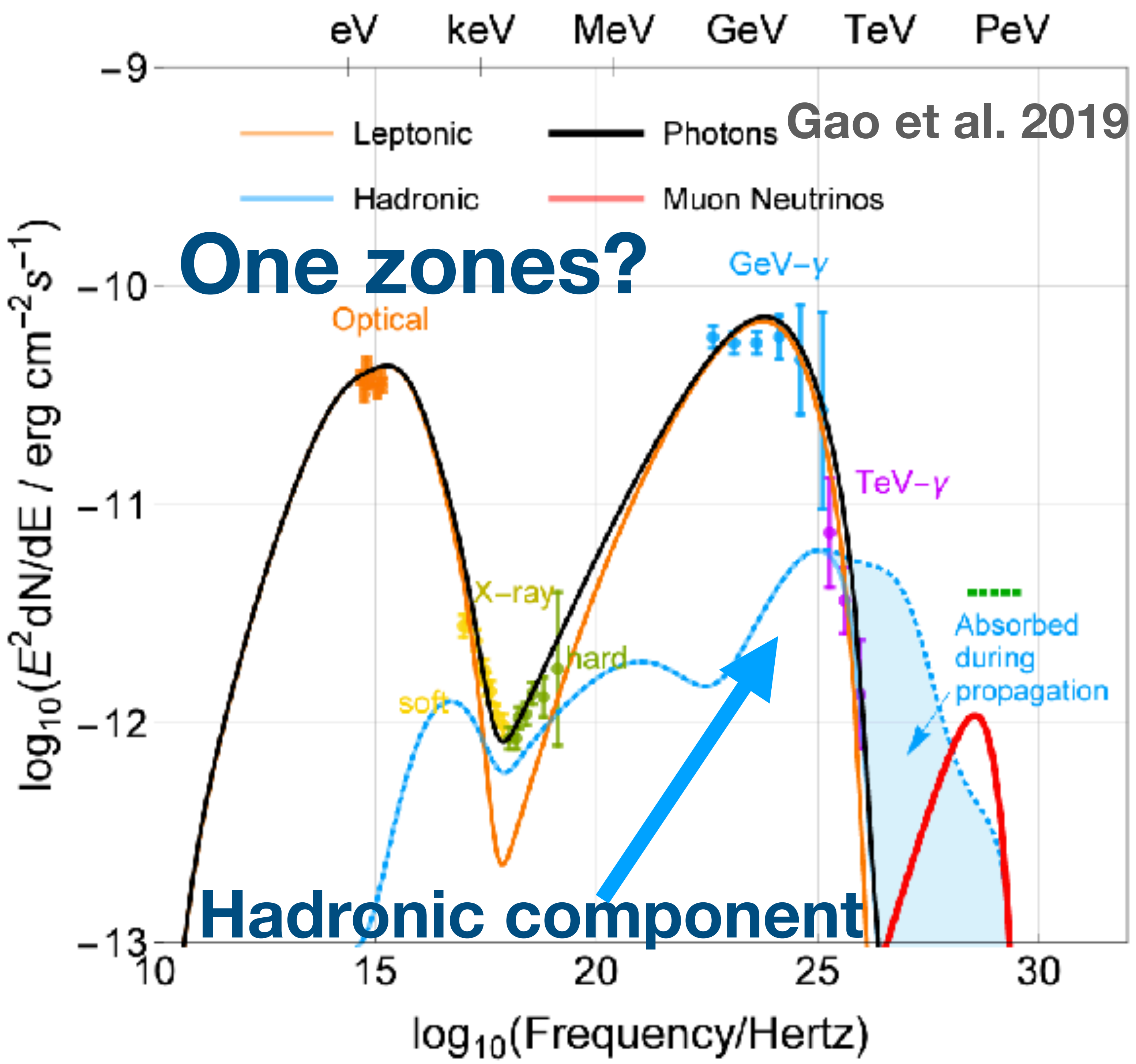




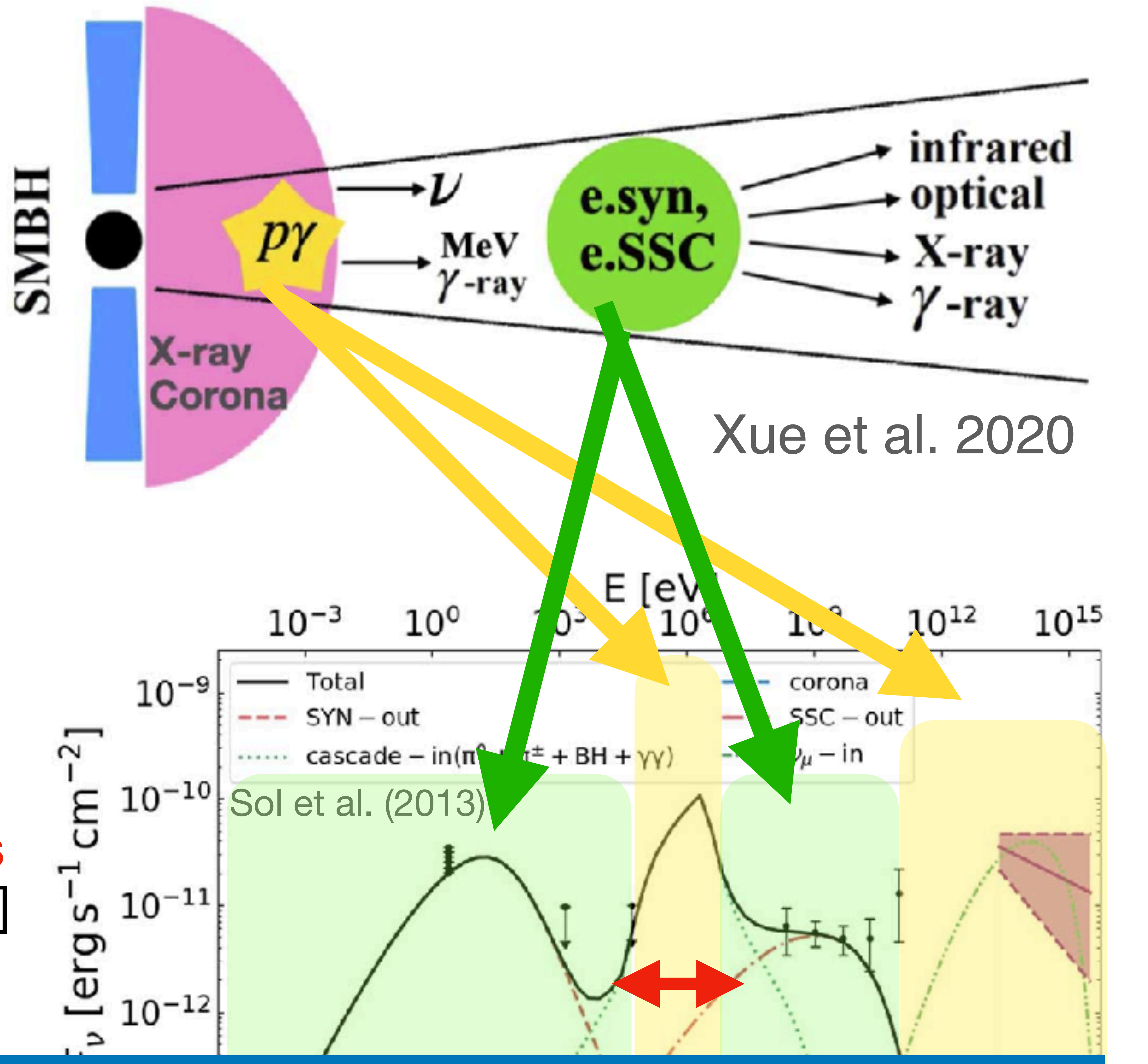
arXiv:2306.12960

Blazar Observation: Recent Trends in Astrophysics





two zones?



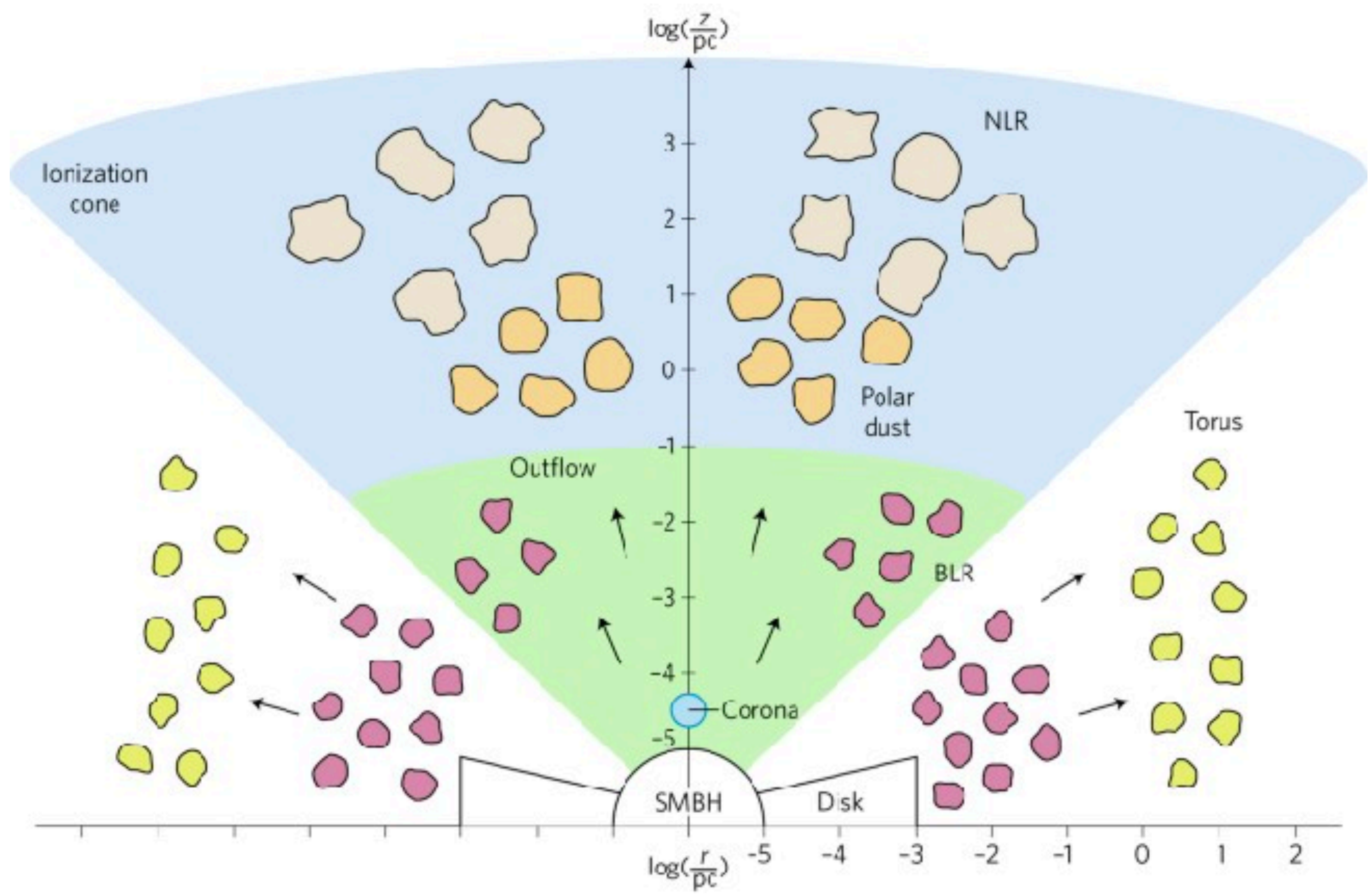
- Modeling TXS 0506+056/IC-170922A needs **a leptonic genesis for γ-rays** [Ansoldi et al. 2018, Keivani et al. 2018, Cerruti et al. 2019, Gao et al. 2019]
  - photo-hadronic cascades in jets should **manifest as X-ray/UV emissions**, potentially **a more reliable neutrino-activity indicator**

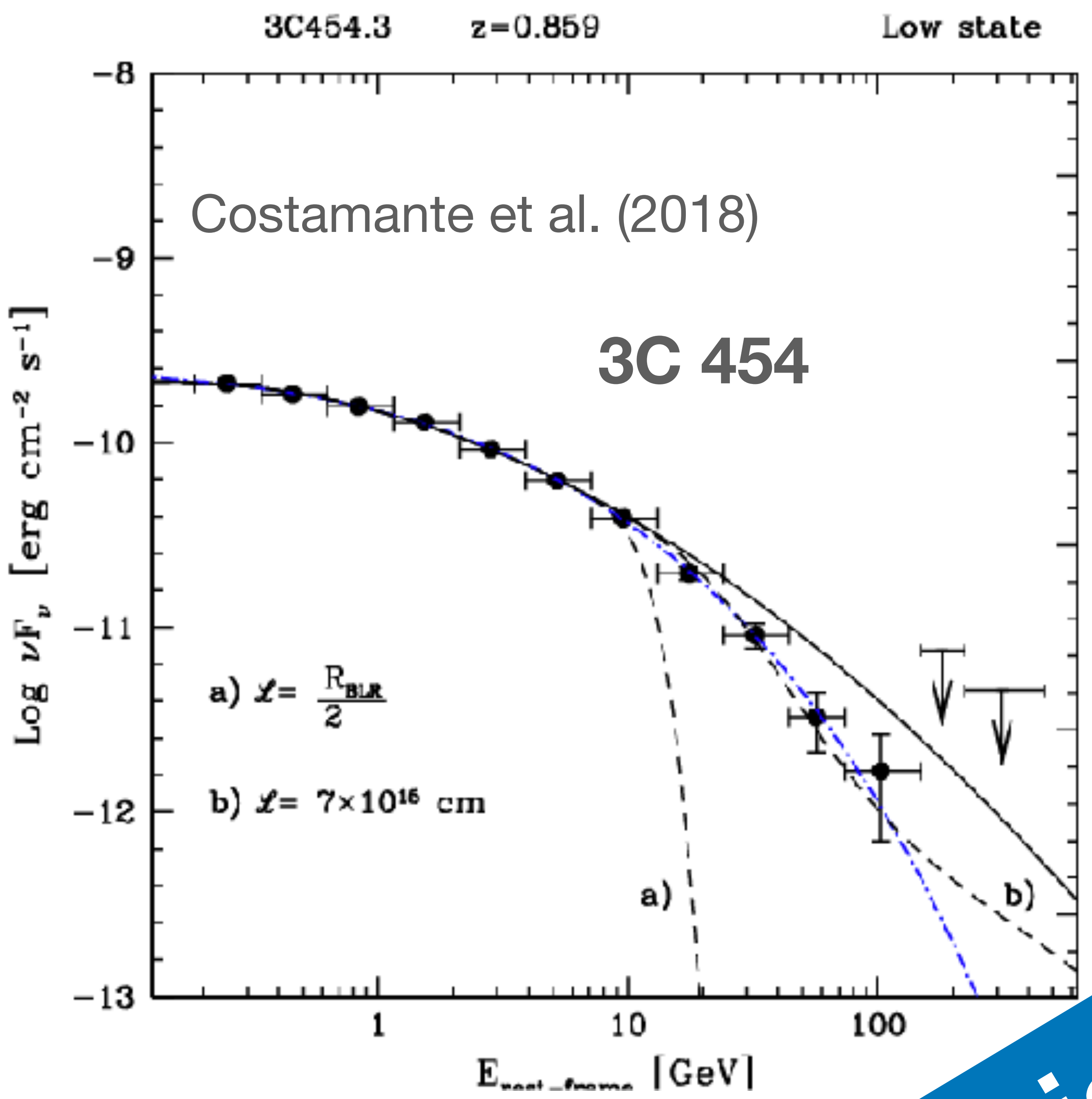
Observing a correlation between GeV-TeV gamma rays and neutrinos from the same blazar can be quite challenging!

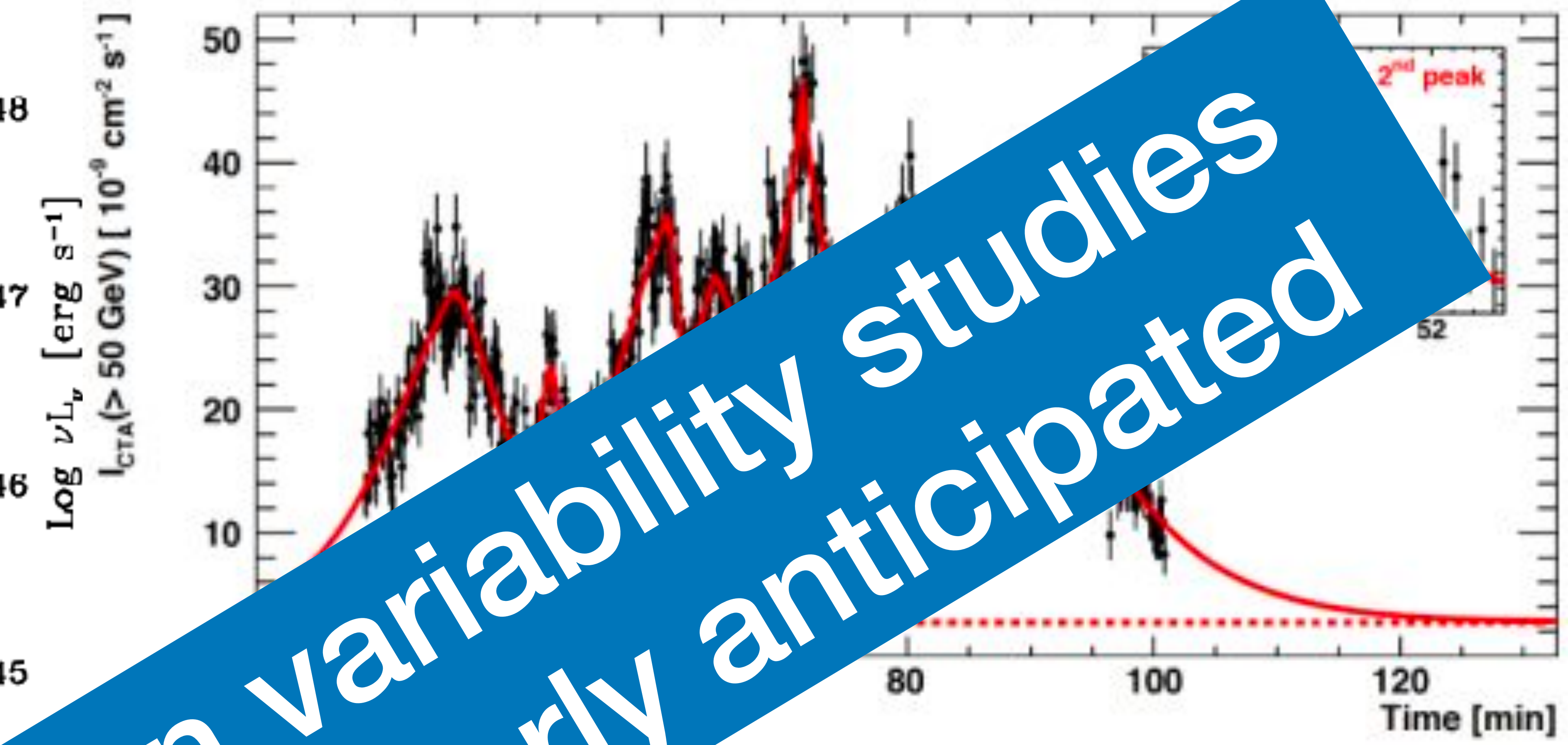
observations are awaited!

Blazar Observation: Recent Trends in Astrophysics

Where is the location of γ-ray emission region?



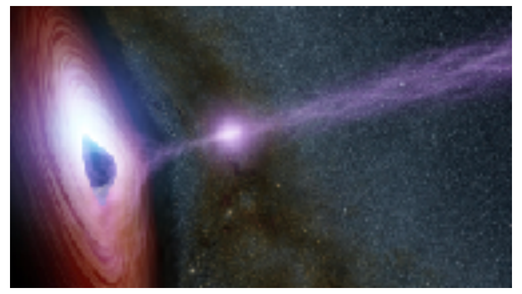




High-precision variability studies with CTA are eagerly anticipated

- Seeing **variability** helps us to constraints on Doppler factor, parti… identify the location of the emission from the causality, further challenging the blazar m…
- Gap of tens of pc between Radio and Optical Emissi… 279 show no γγ absorption by BLR
  -> Gamma rays from **sub-pc** regions?
- Blazars like PKS1504 exhibit minute time scale variab…
  -> Gamma-ray emission region **less than pc**? **How diverse are blazars**?

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

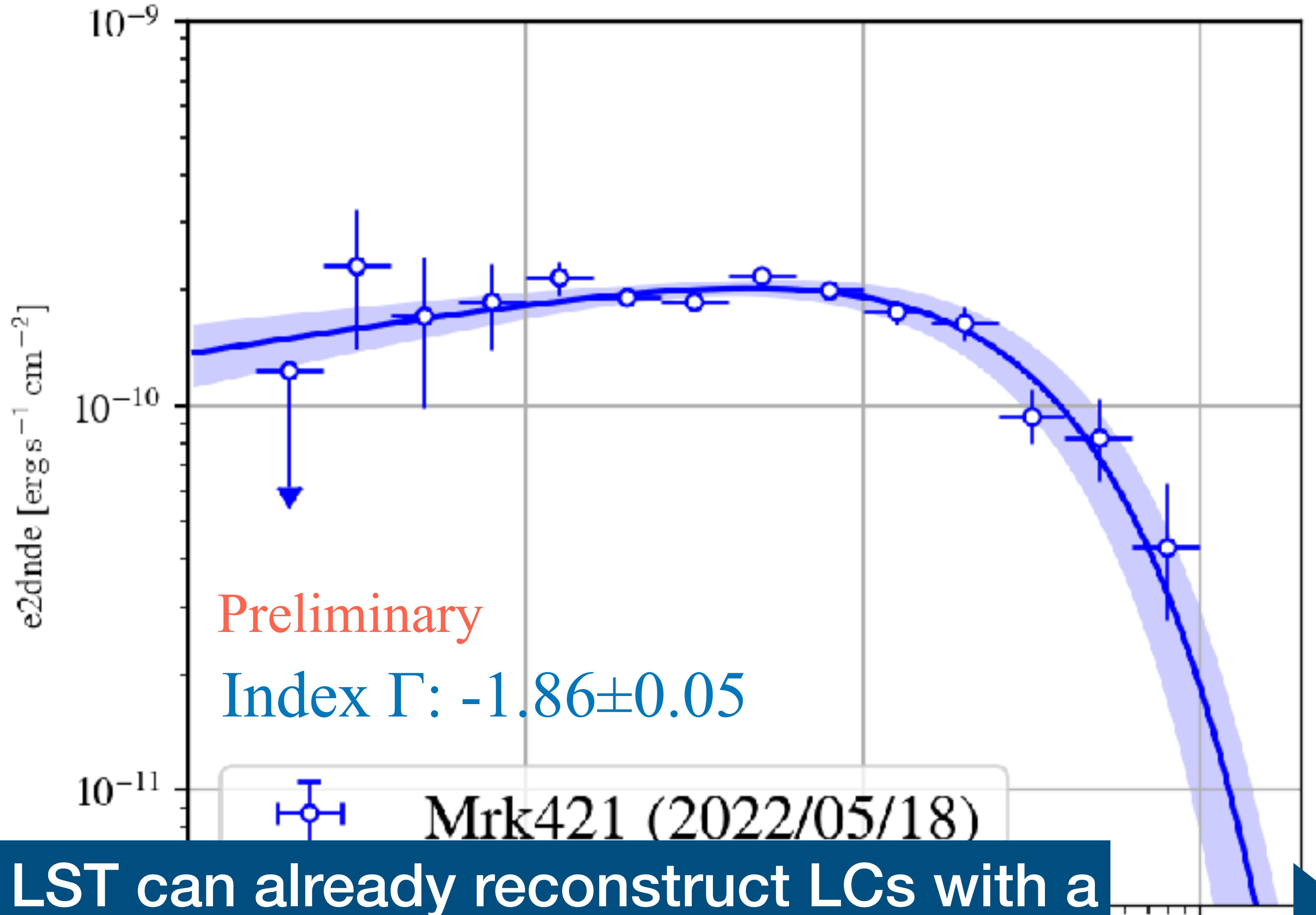
- A paper is slated for publication, along with simultaneous data acquired by the Fermi-LAT
- LST-1 detected a flare from BL Lac in 2021 [icrc2023_pos]. This is a separate project and will not be covered in this talk

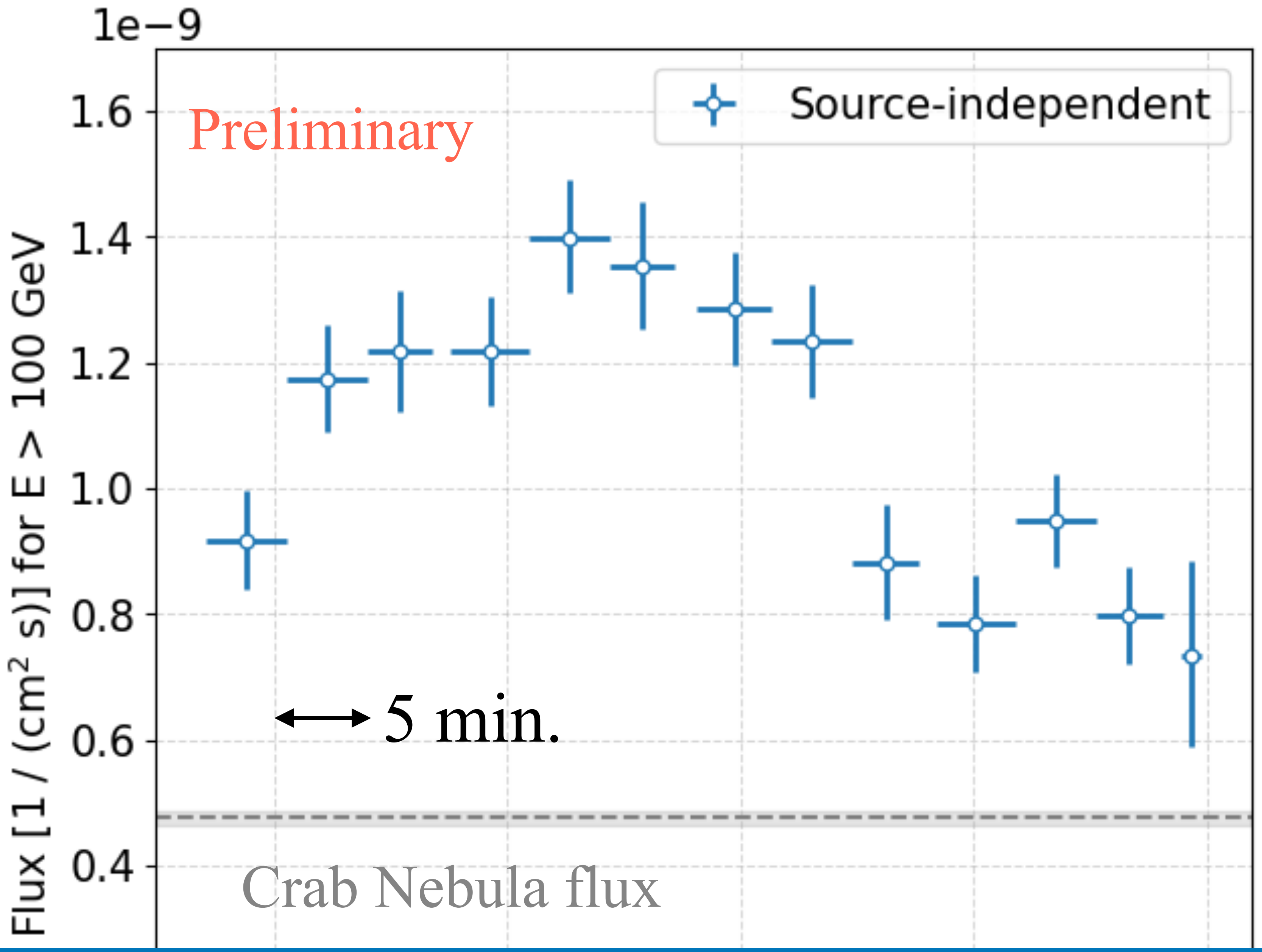
	Mrk421	Mrk 501	1ES1959+650	1ES0647+250	PG 1553+113
AGN type	HBL	HBL	HBL	HBL	HBL
Redshift	0.031	0.034	0.048	0.45±0.05	0.433
Obs. date	2020/12/12 -2022/05/23	2020/07/10 -2022/06/29	2020/07/11 -2022/05/05	2020/12/16 -2020/12/21	2021/04/08 -2022/05/23
Obs. time BF/AF cut (h)	68.5/32.4	67.2/39.7	21.3/11.8	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				

Seeing Variabilities: 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





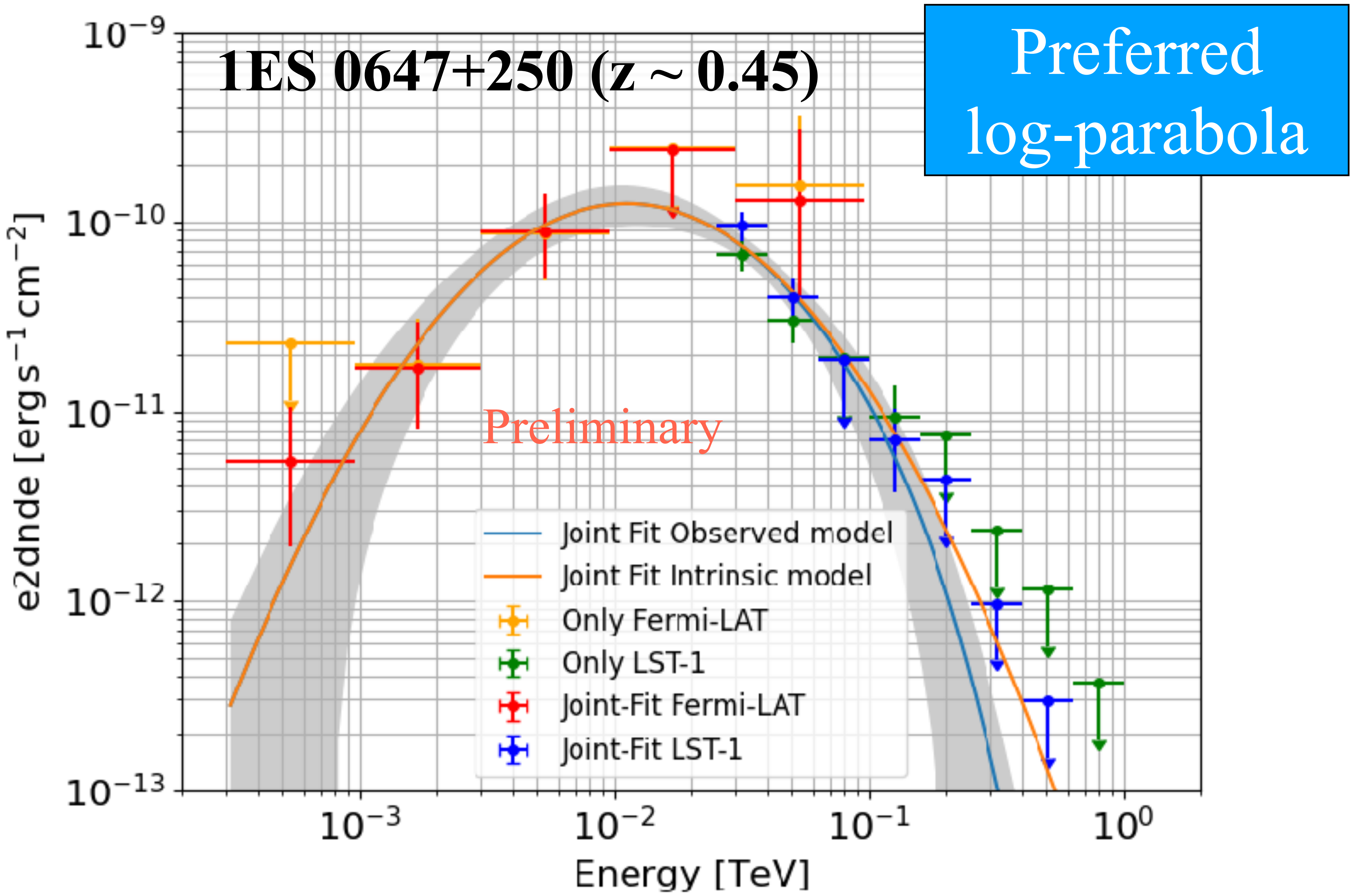
A single LST can already reconstruct LCs with a time-scale precision comparable to the current gamma-ray telescope MAGIC

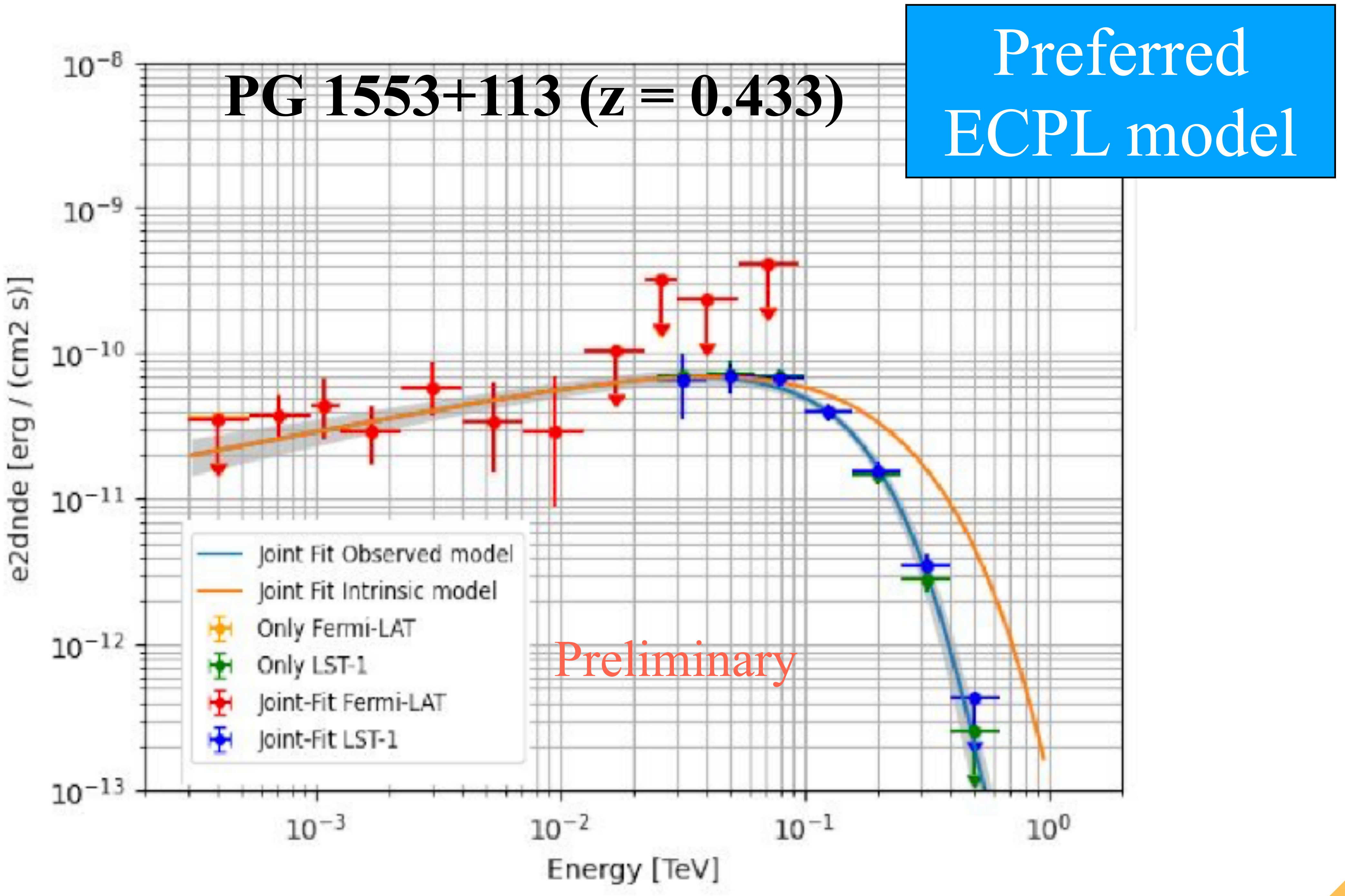
Upcoming minute-level variability studies by CTA could lead to locate the emission region, and further model constraints

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

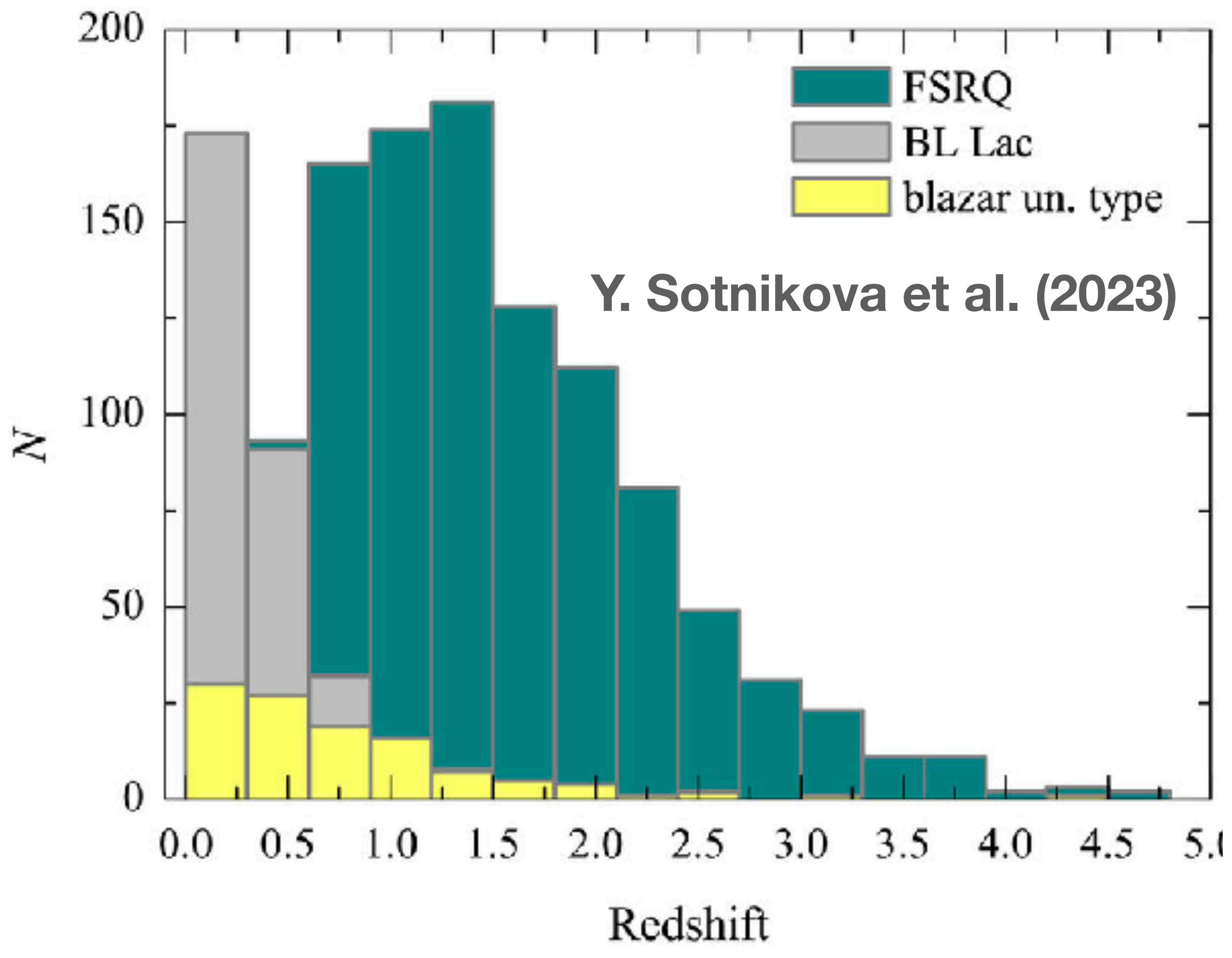
- Joint-fit with Fermi-LAT data using dedicated pipeline ***Asgardpy*** https://asgardpy.readthedocs.io/en/latest/
- Variability of these two sources is currently not confirmed by LST-1
  - The variation in PG 1553+113 has already been ascertained in Fermi-LAT observations, making it scientifically imperative to maintain ongoing surveillance through LST-1

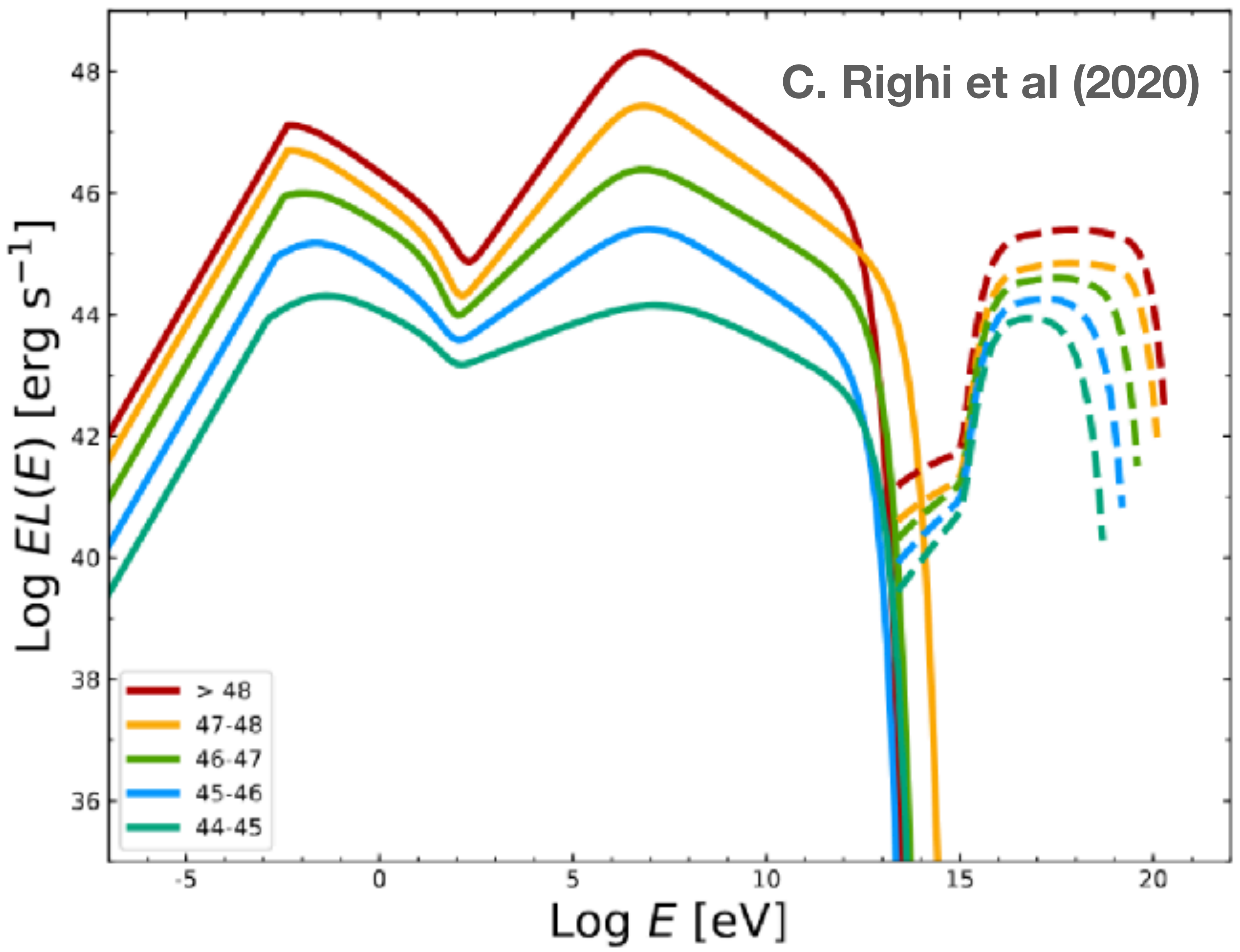


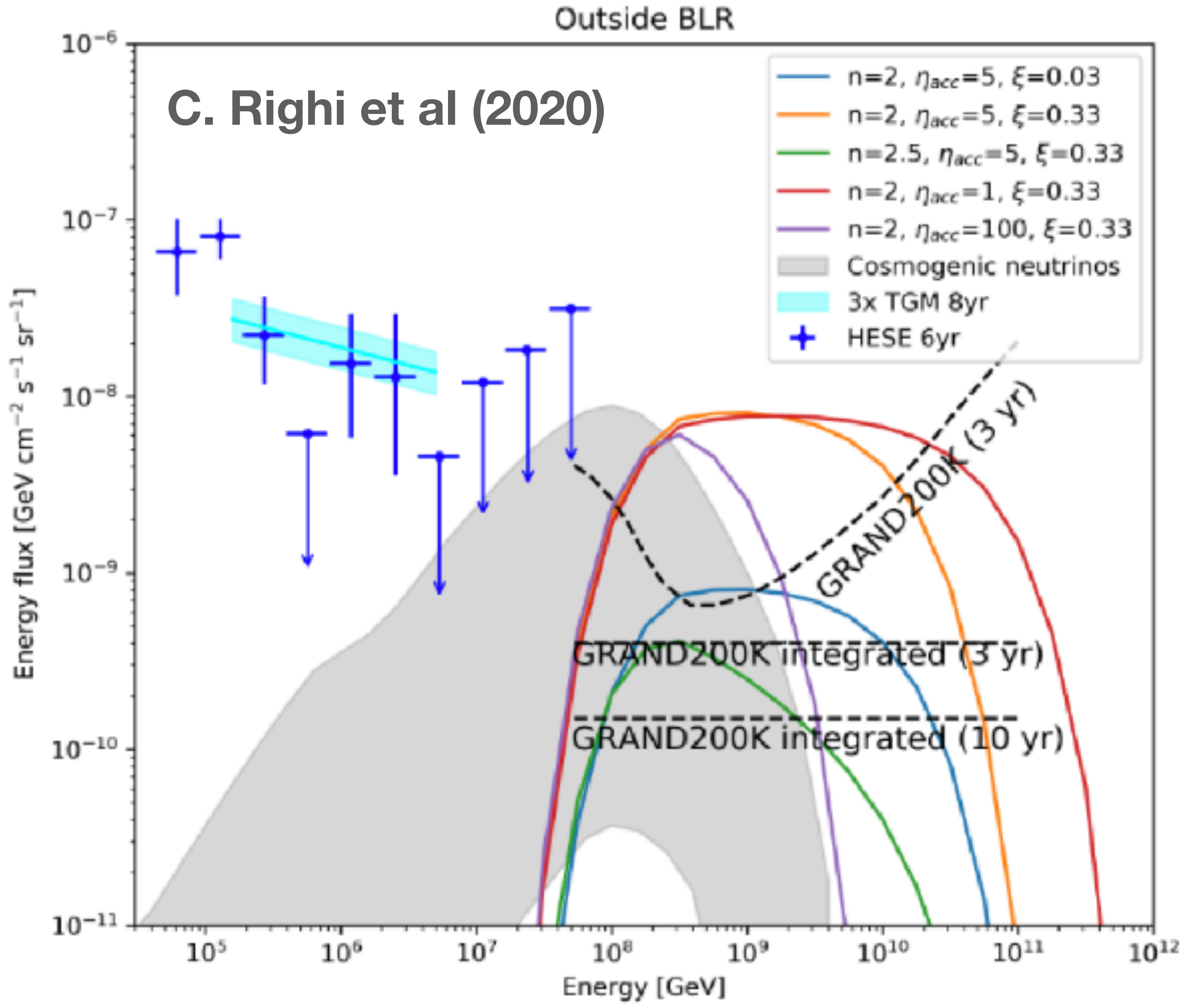


Why Distant VHE sources?

No detection of FSRQ by LST-1 so far, but...







- FSRQ is a promising candidate in producing neutrino, but **no significant detection of FSRQs** up to now
  - **EeV neutrino** production in FSRQs?
  - Simply gone unobserved due to the sensitivity-wise limitations of current neutrino detection facilities?
- Given FSRQs tend to be observed at **high redshifts** ($z > \sim 0.5$), employing **low-energy-threshold γ-ray telescope like LSTs** to increase FSRQ statistics is crucial

Summary

- MWL observations are essential for constraining blazar emission models
  - First neutrinos tied to a blazar observed: **TXS 0506+056/IC-170922A**
    - γ-rays likely of leptonic origin, **making γ-neutrino correlation challenging**
    - **UV/X-ray observations are awaited**
  - Monitoring variability crucial for pinpointing gamma-ray emission site
    $>$ pc or $<$ pc? Are blazars diverse? **Precise time-tracking by CTA is the key**
  - FSRQ may product **EeV neutrinos**
    - Given FSRQs tend to exist at high redshifts, using low-energy-threshold LSTs to increase FSRQ statistics is crucial

- LST-1 initiated scientific observations since 2020 and has already detected several known AGNs
  - Achieved reconstruction of minute-scale variability in blazars, and detection of sub-100 GeV γ-rays from distant blazars