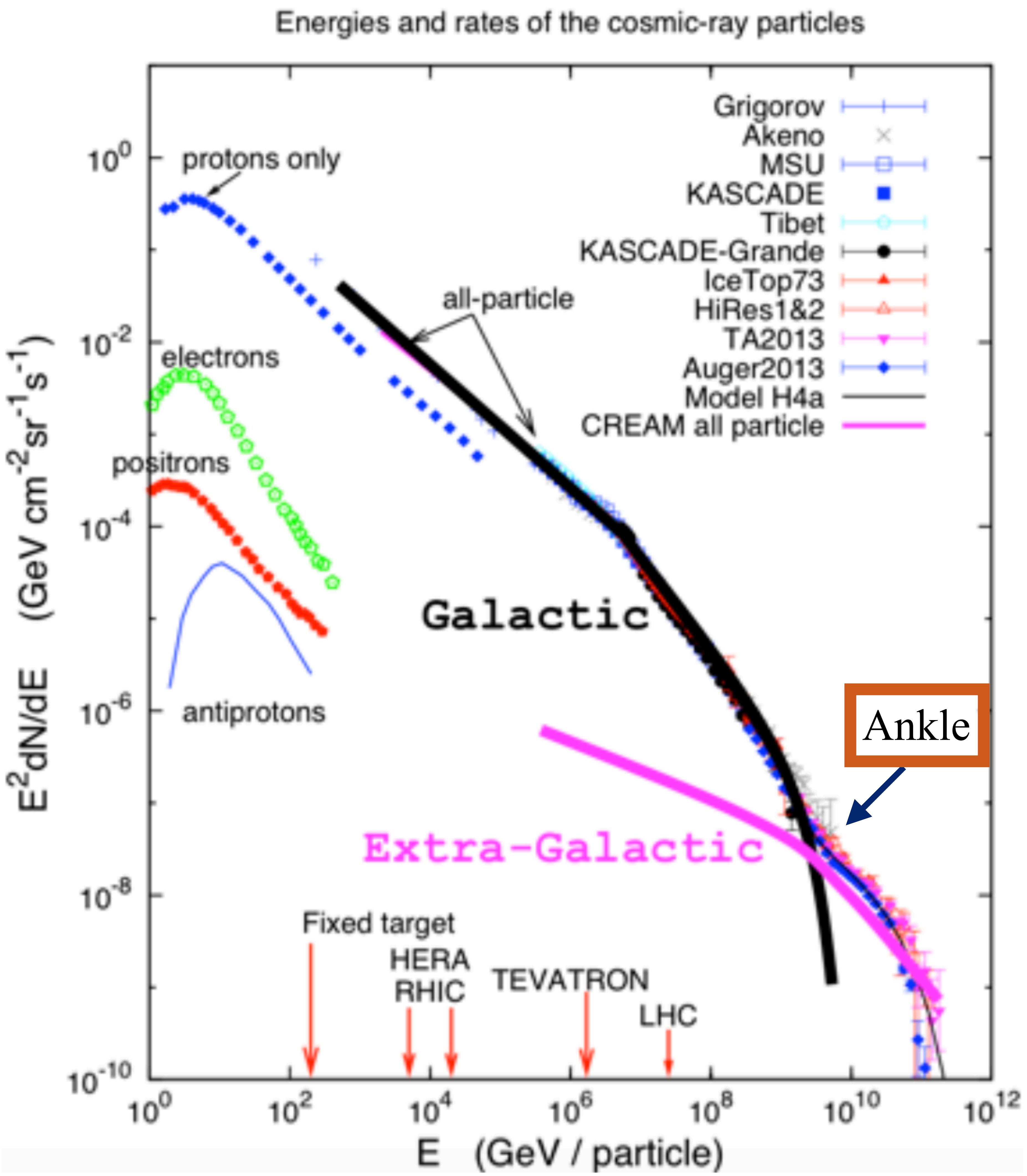
Investigating TeV Emissions from Simulated CTAO Data for the FSRQs 3C 279 & PKS 1510-089

Salma Ibrahim
Nevis Labs REU, Aug 1st, 2024

Why Study TeV Astronomy?

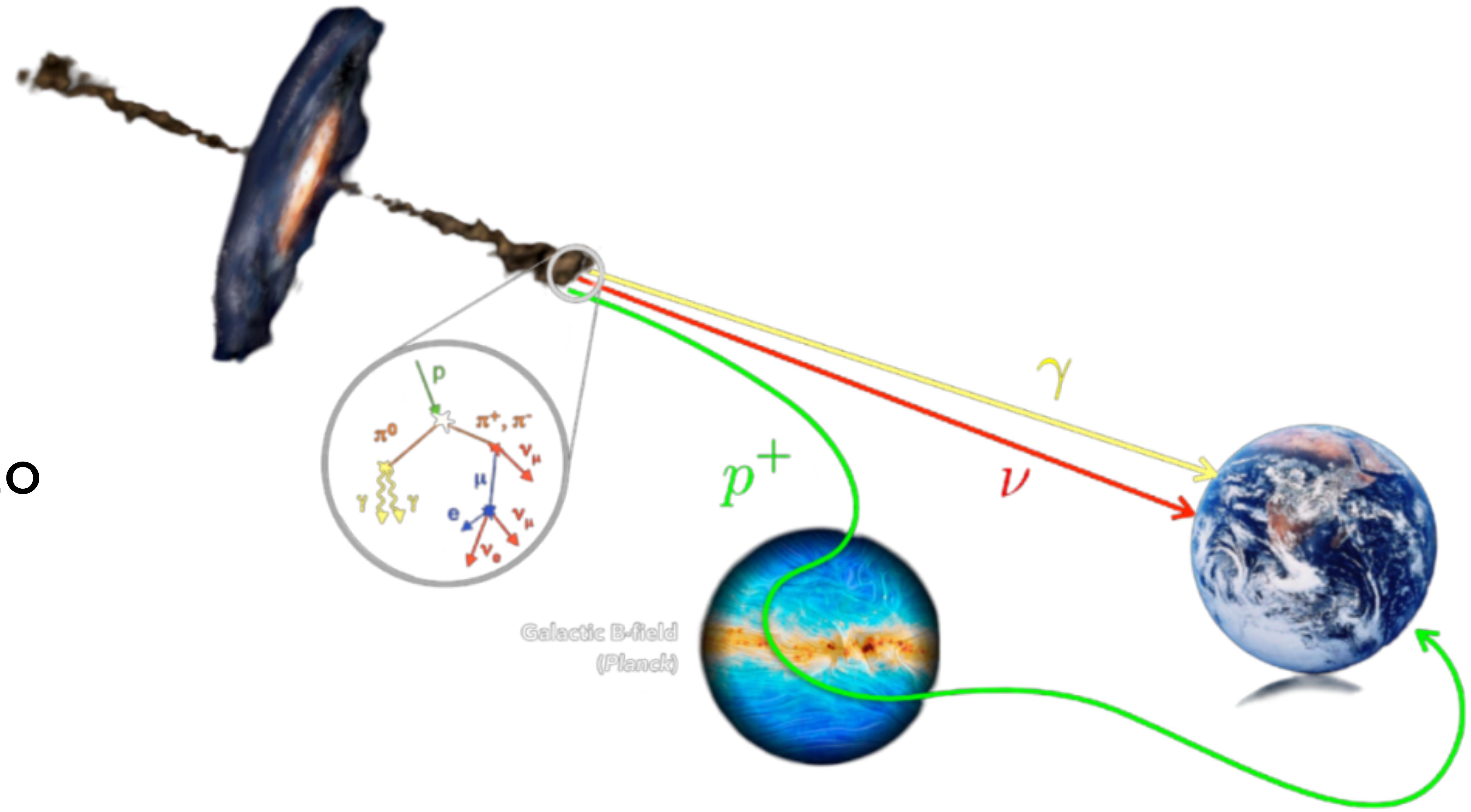
- Victor Hess discovered cosmic rays on a 5300 m balloon flight in 1912 during a solar eclipse
- Cosmic rays primarily consist of charged particles with a wide range of energies that can exceed 10^{20} eV and have near-light speeds
- The nature of these VHE cosmic rays is not entirely understood



Gaisser et al. (2016)

Multi-messenger Astronomy

- Since cosmic rays are deflected by magnetic fields, we search for the neutral VHE gamma-rays and neutrinos instead
- These neutral messengers point directly to the source and are products of the same non-thermal cosmic-ray accelerators



Santander (2016)

Gamma-ray Production

- Types of γ-ray sources:

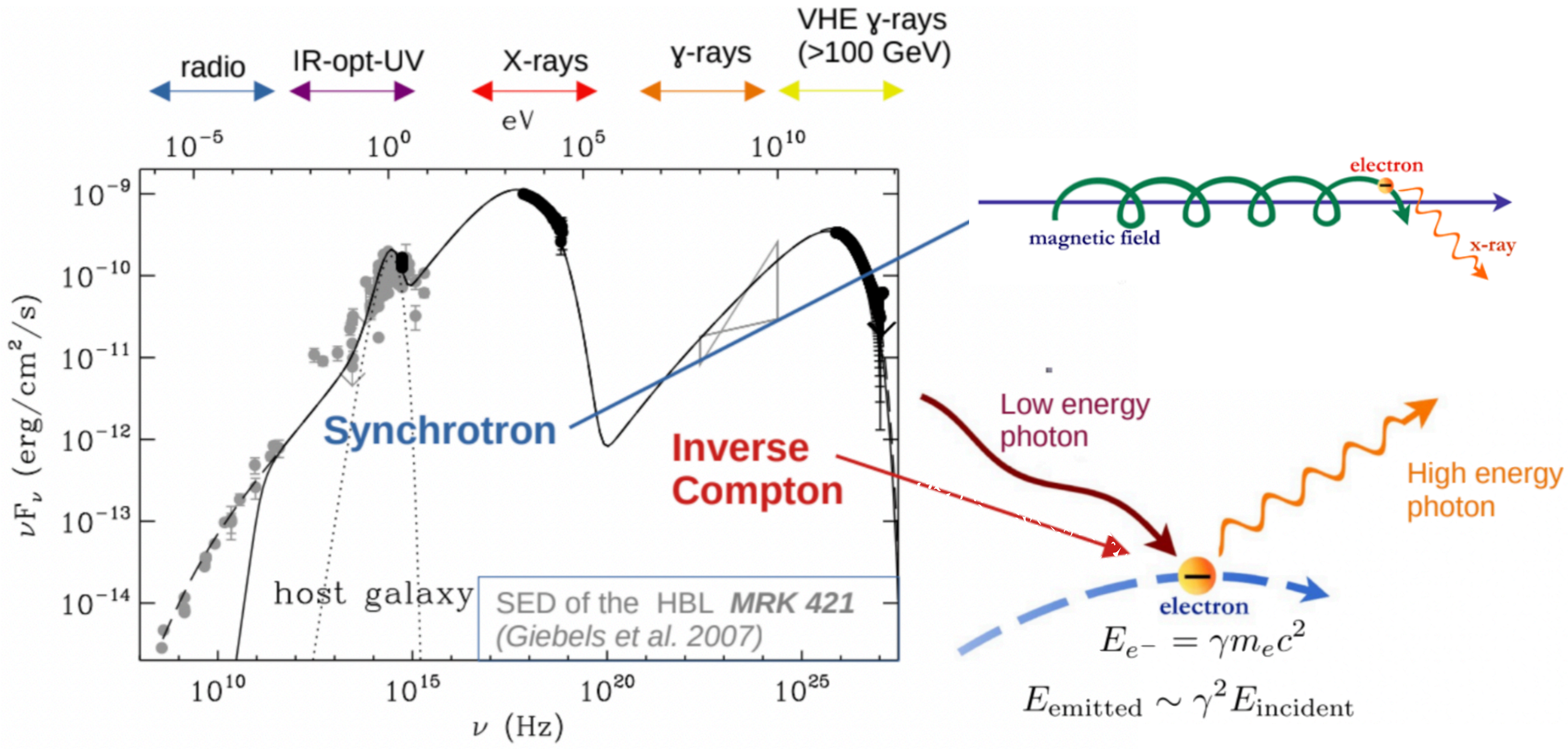
A. Electromagnetic:

Pulsars

B. Gravitational:

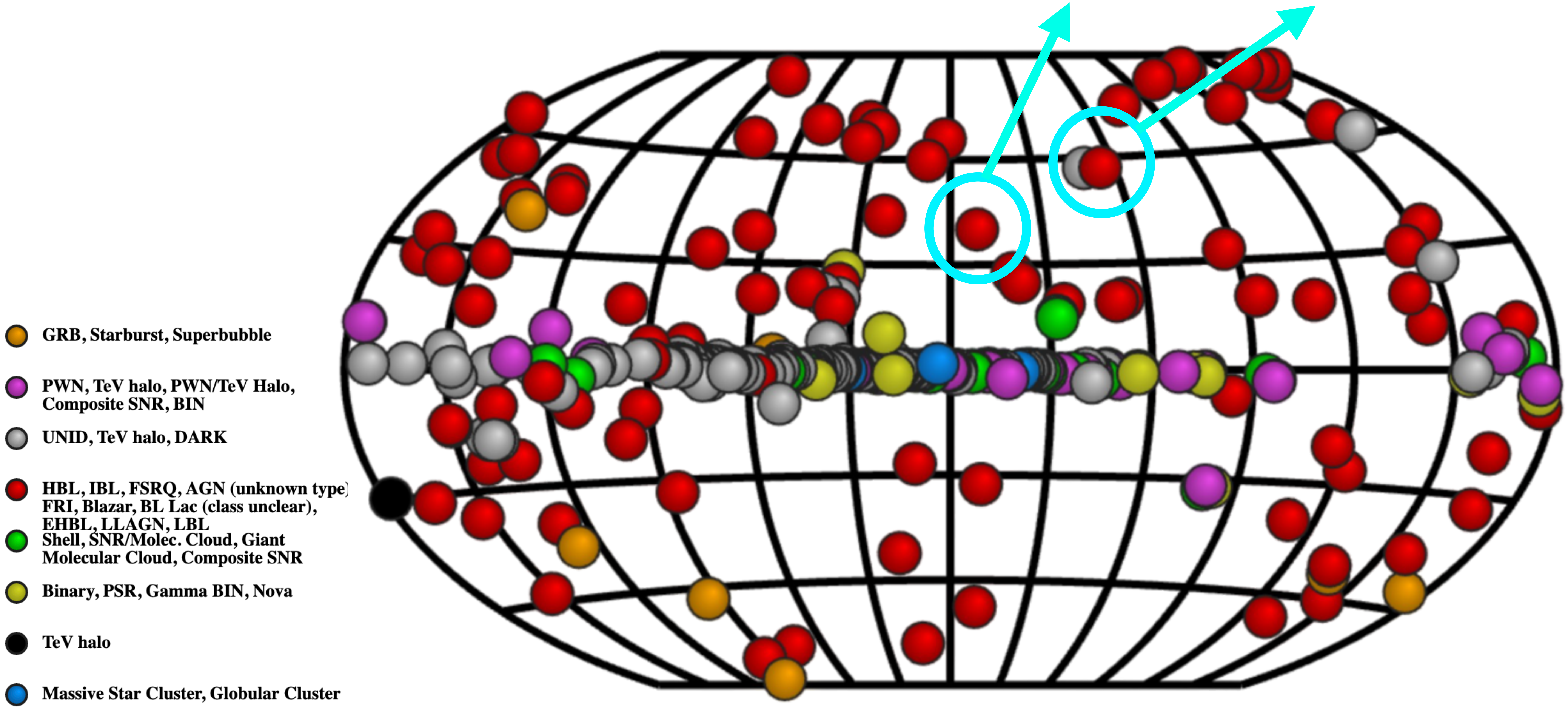
1- Supernova remnants, GRB

2- AGN, neutron stars



VHE γ-ray sources

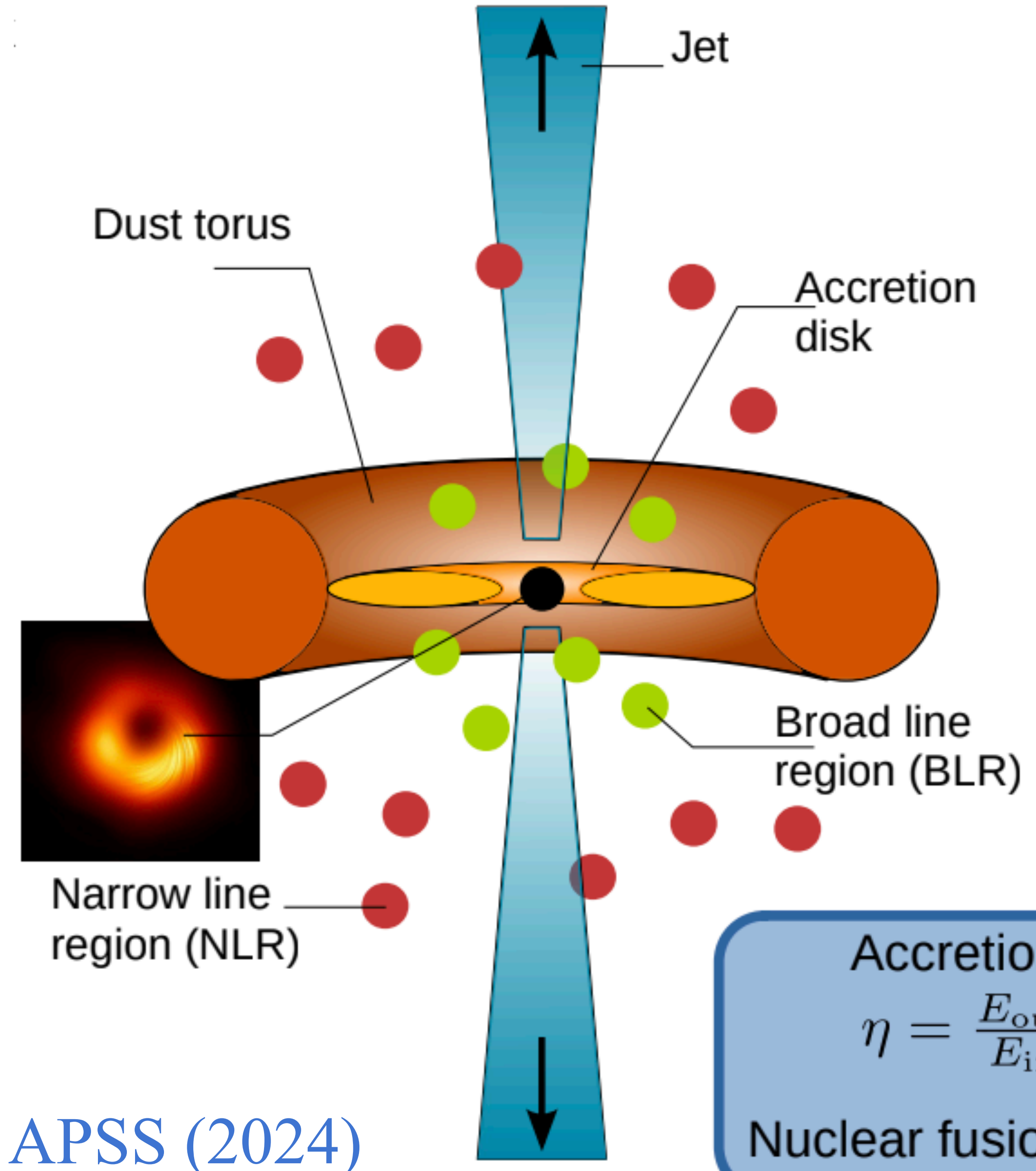
- Catalog currently consists of 308 total sources, 90 of which are AGN



TeVCat (2024)

AGN - Active Galactic Nuclei

- Accreting supermassive black holes that are among the most powerful particle accelerators in the universe

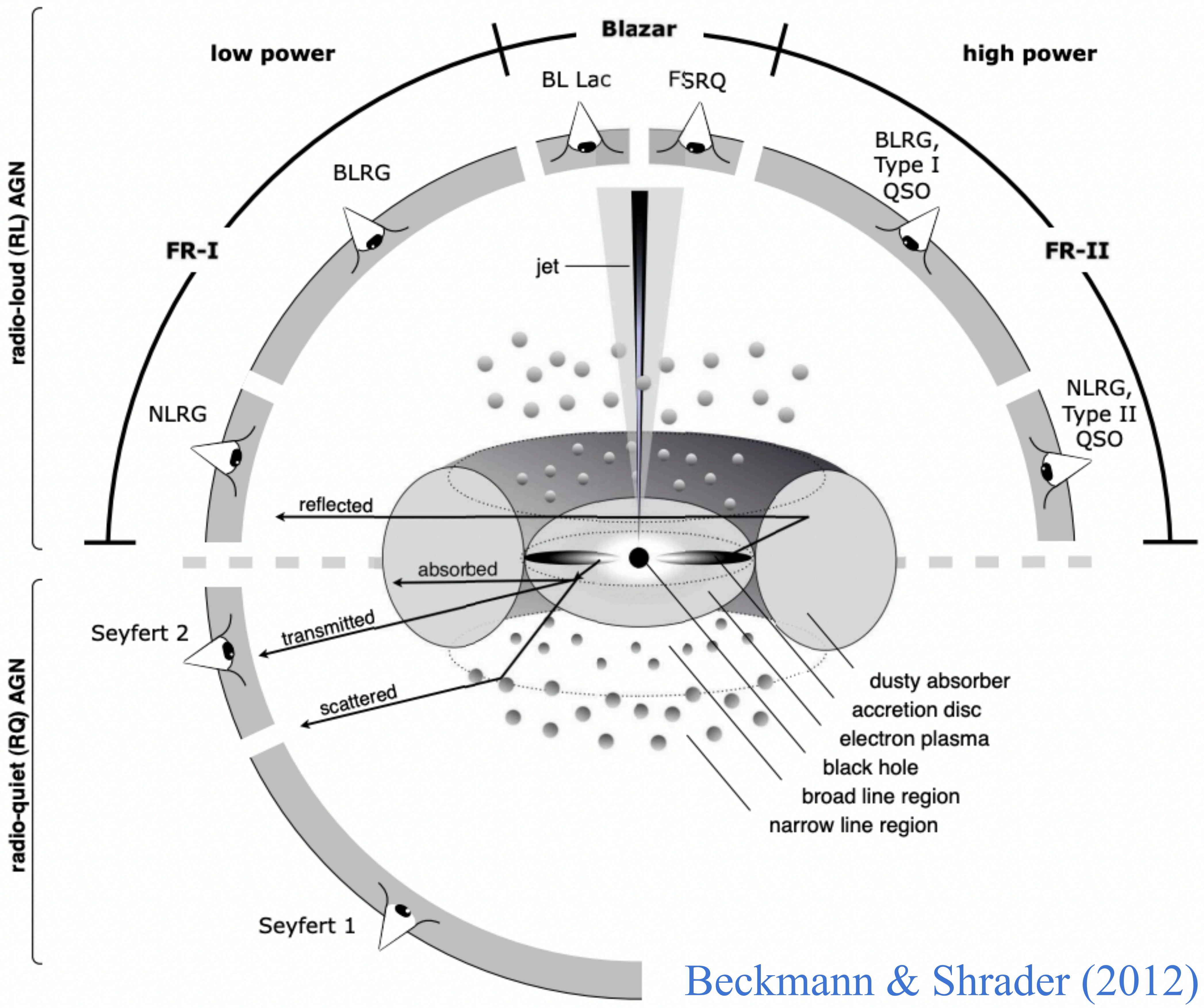


Accretion efficency

$$\eta = \frac{E_{\rm out}}{E_{\rm in}} \sim 0.1$$

Nuclear fusion: $\eta \sim 8 \times 10^{-4}$

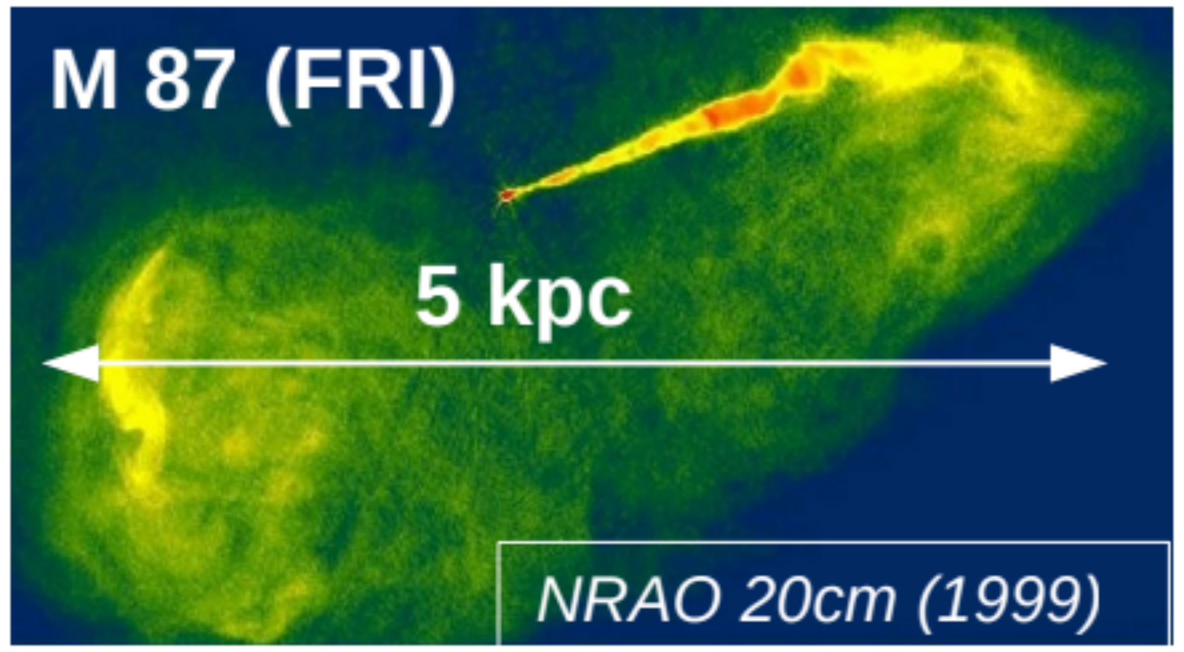
O. Hervet APSS (2024)

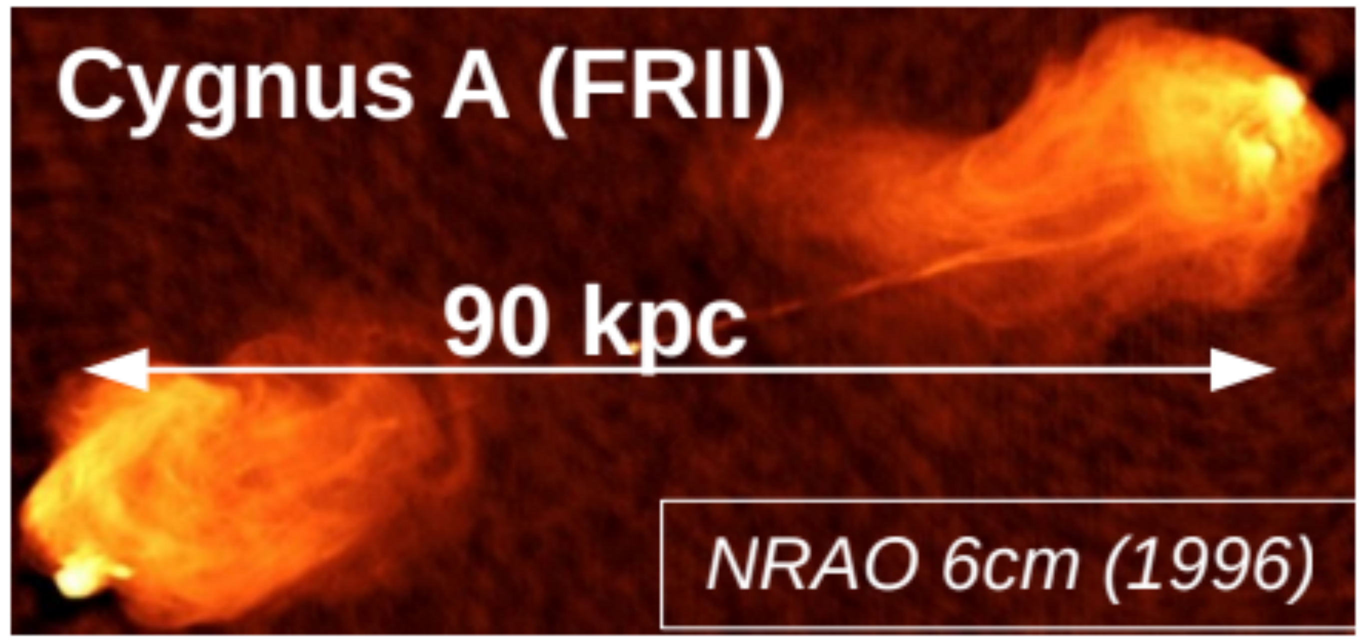


Beckmann & Shrader (2012)

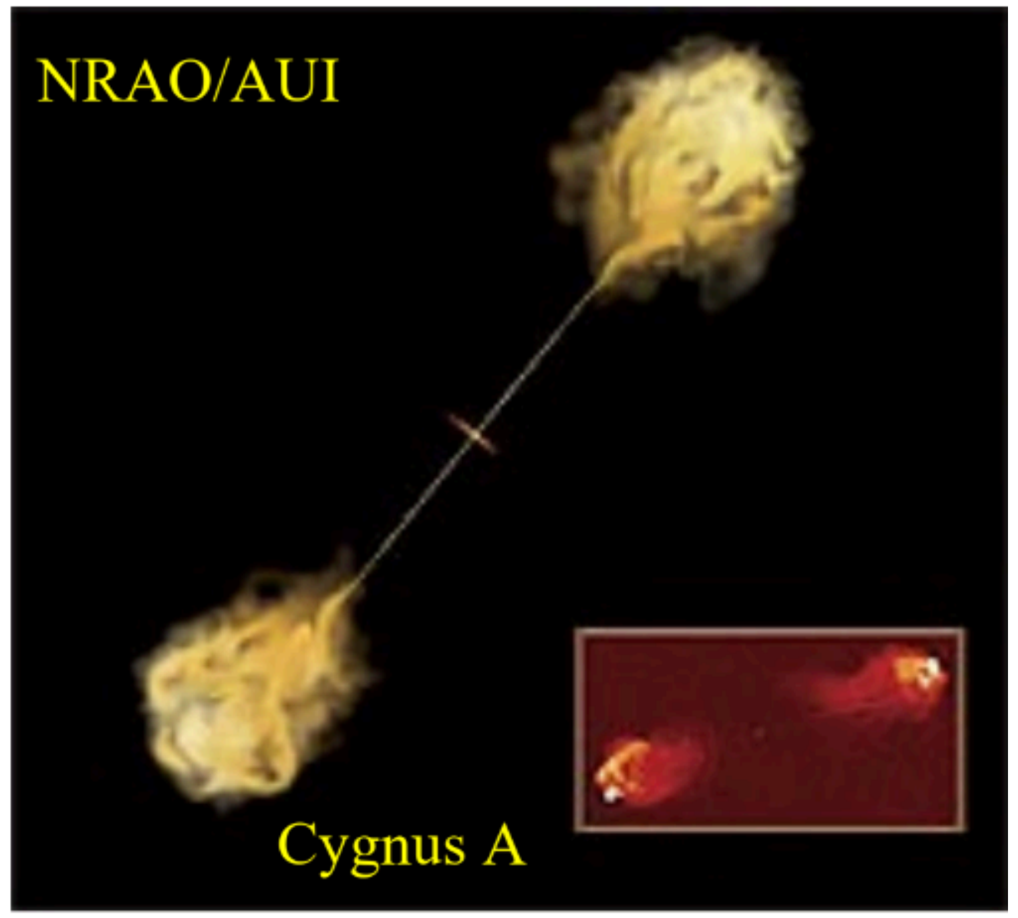
Blazars: Relativstic Jets

- Gamma rays typically originate from a region 1 to 10 pc away from the black hole, outside the BLR.
- It is unknown how such a huge amount of energy can be transported this far from the central engine

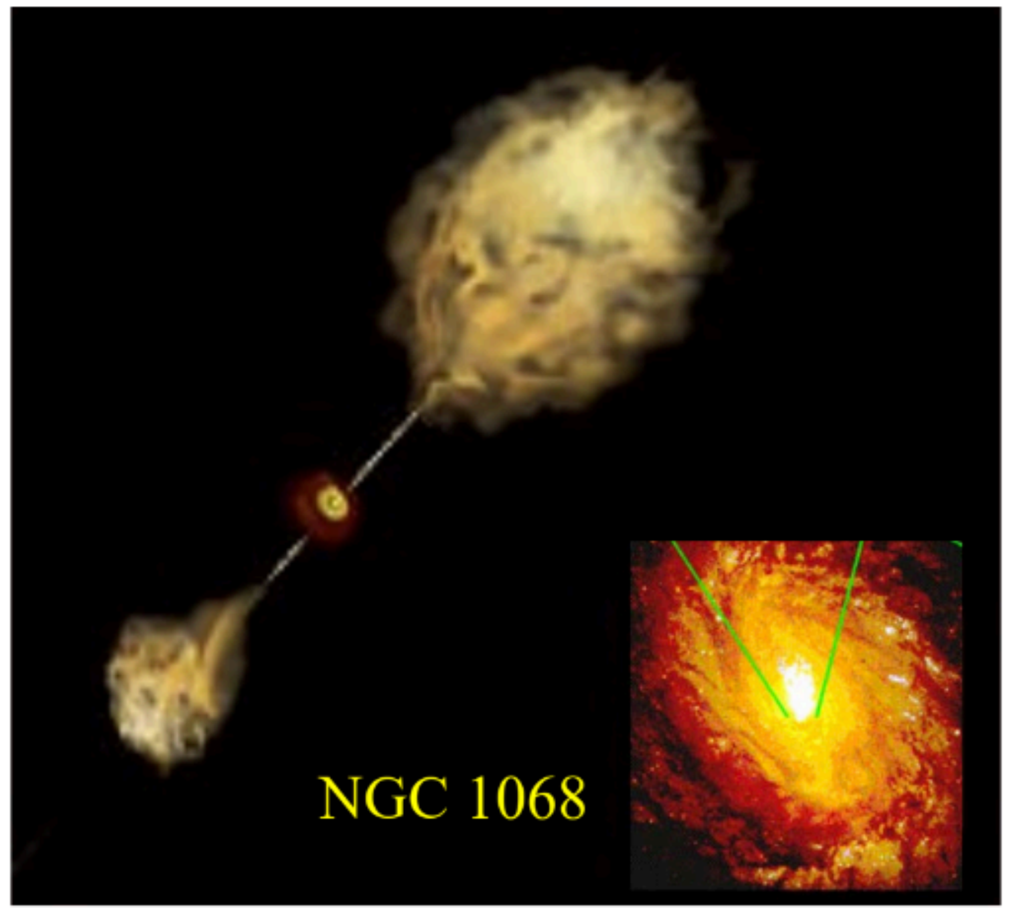




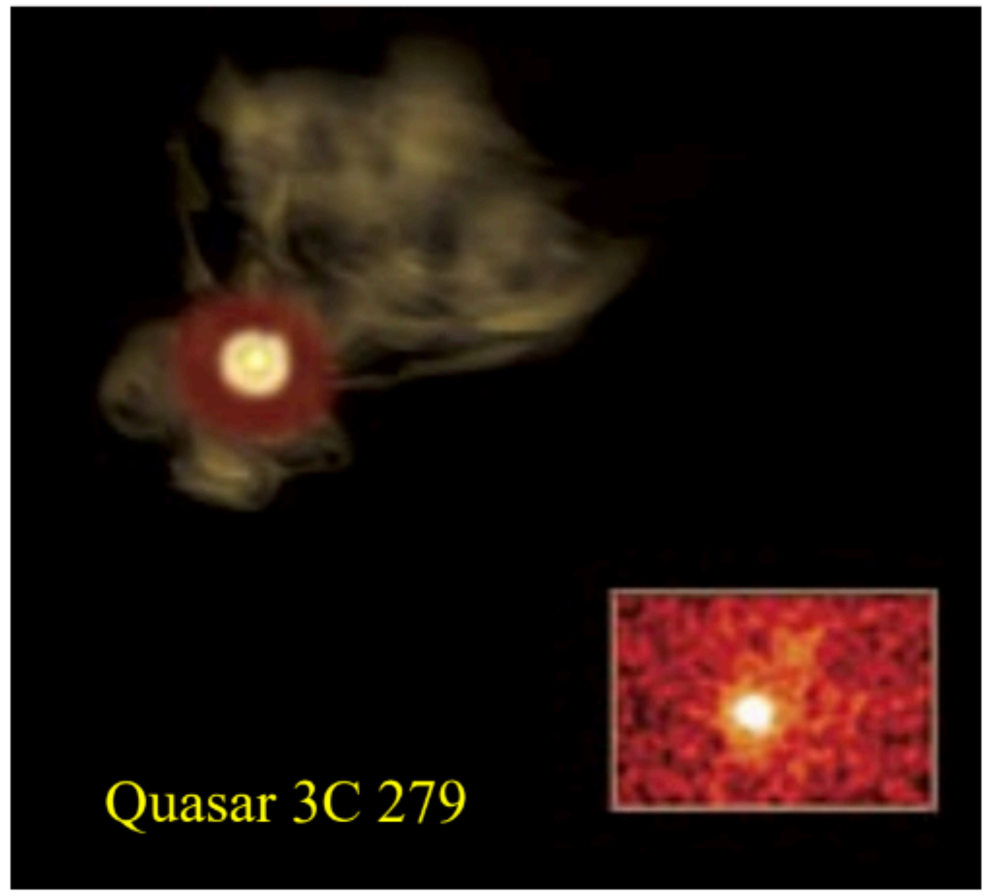
Images from Fermi/EPO



Radio Galaxy

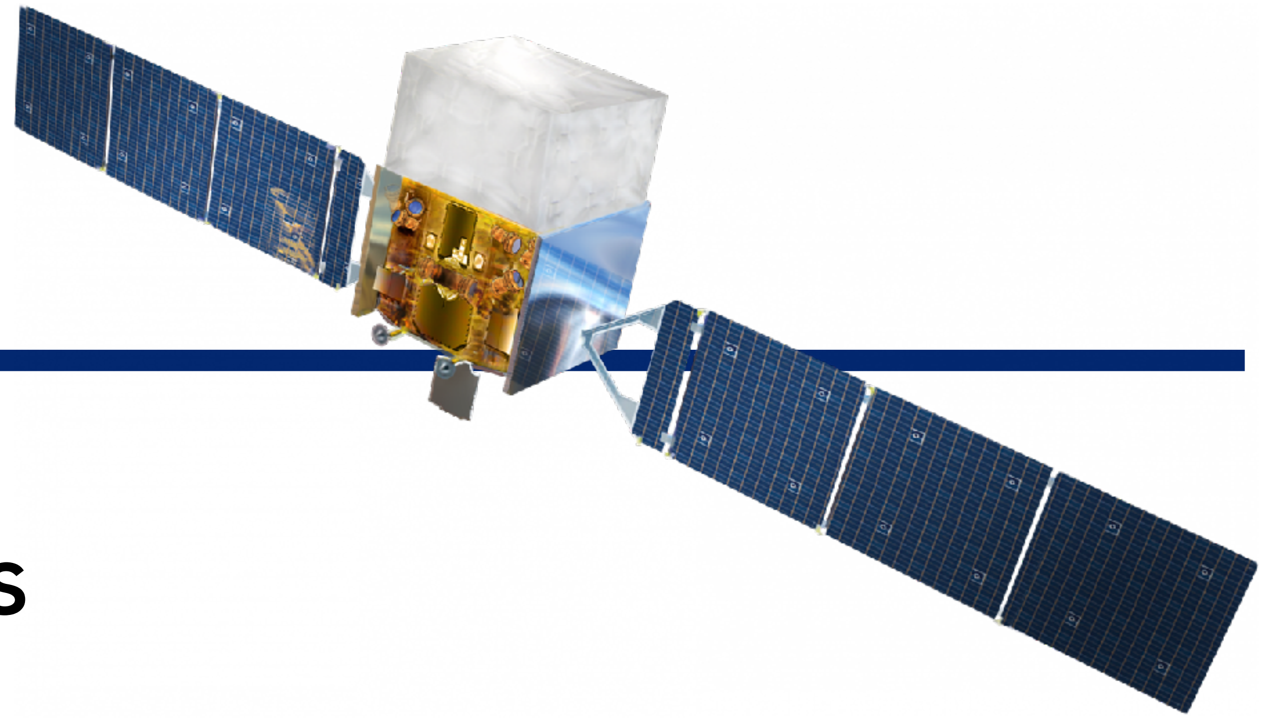


Seyfert Galaxy



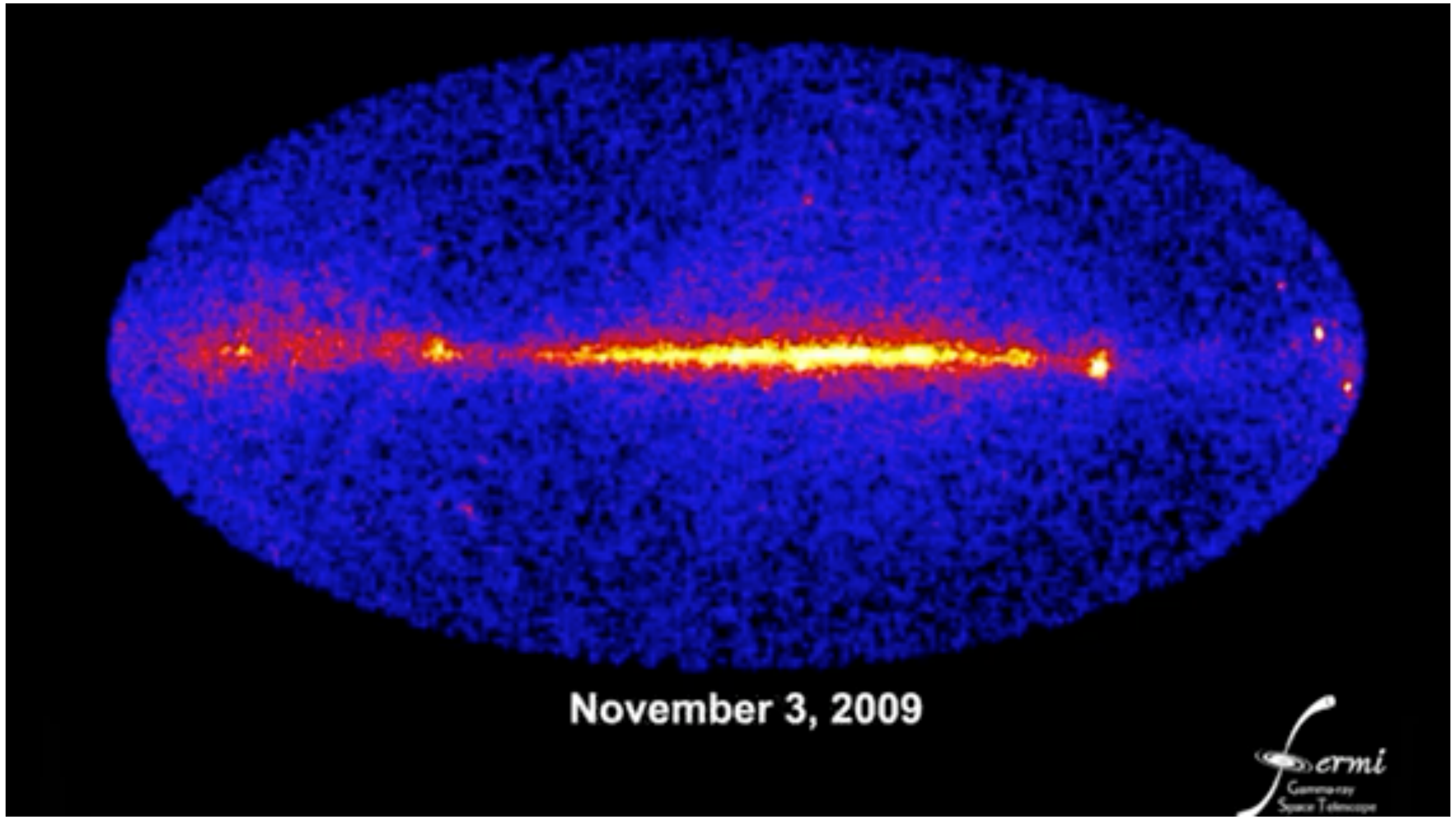
Blazar

FSRQs - Flat Spectrum Radio Quasars



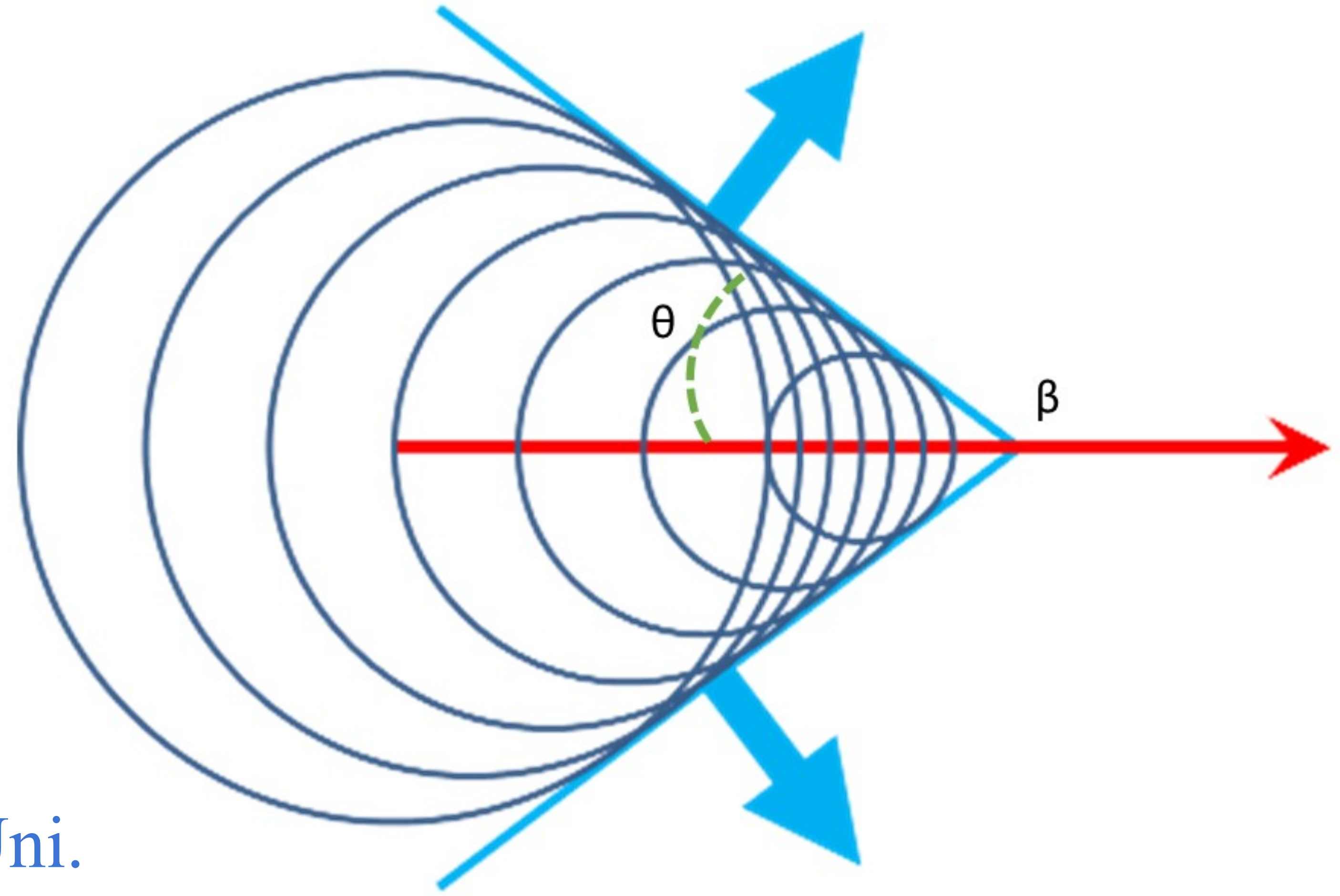
- Blazars typically exhibit variability scales as small as a few minutes
- Rarely detected at TeV energies
- Quasi-stellar sources

Source	z
GB6 J0043 1 3426	0.966
S3 02181 35	0.944
PKS 0256 1 075	0.893
PKS 0736 + 017	0.189
TON 599	0.729
4C 1 21.35	0.434
3C 279	0.536
B2 1420 I 32	0.682
PKS 1441 I 25	0.939
PKS 1510-089	0.361
3C 345	0.593
3C 454.3	0.859

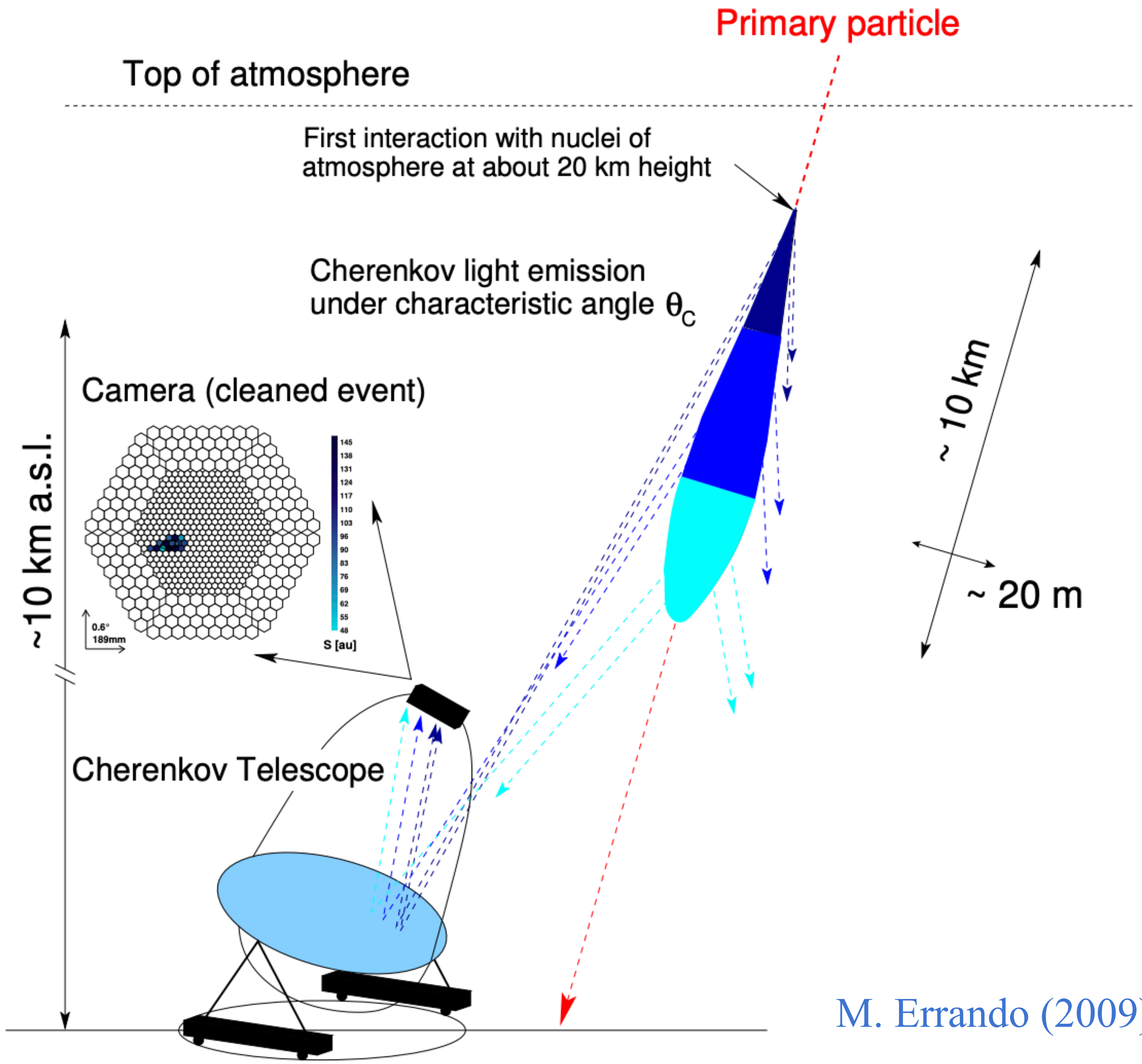


IACTs - Imaging Atmospheric Cherenkov Telescopes

- The atmosphere is opaque to gamma rays
- Indirect detections using the Cherenkov technique
- We can estimate the energy of the primary using the opening angle of the radiation cone, θ.



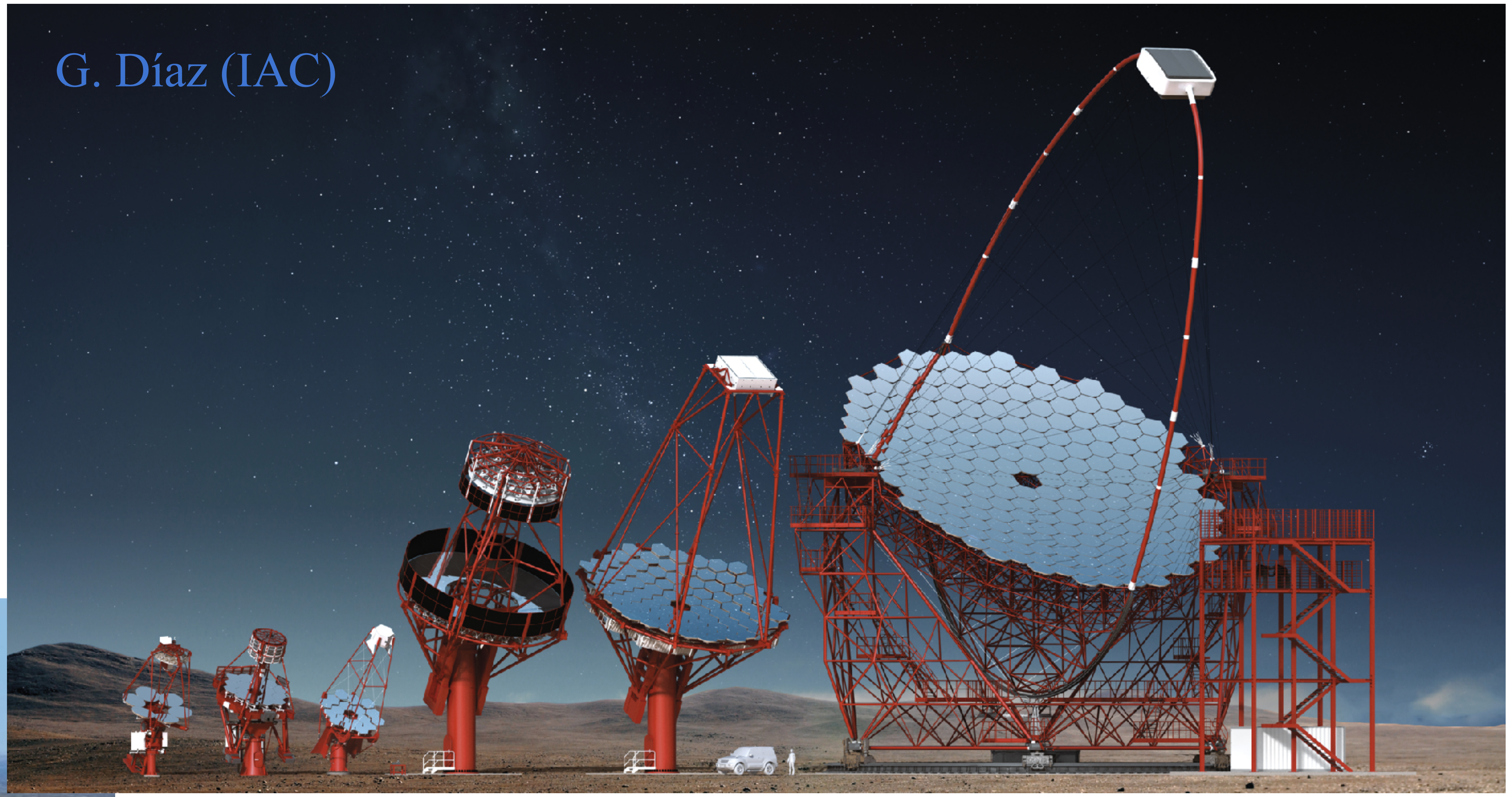
Sheffield Uni.



M. Errando (2009)

CTAO - Cherenkov Telescope Array Observatory

- New Generation of IACTs
- A state-of-the-art array with LSTs, MSTs, and SSTs to cover γ-rays in the range 20 GeV - 300 TeV
- 10 times more sensitive than existing instruments (VERITAS, H.E.S.S., MAGIC…)



CTAO

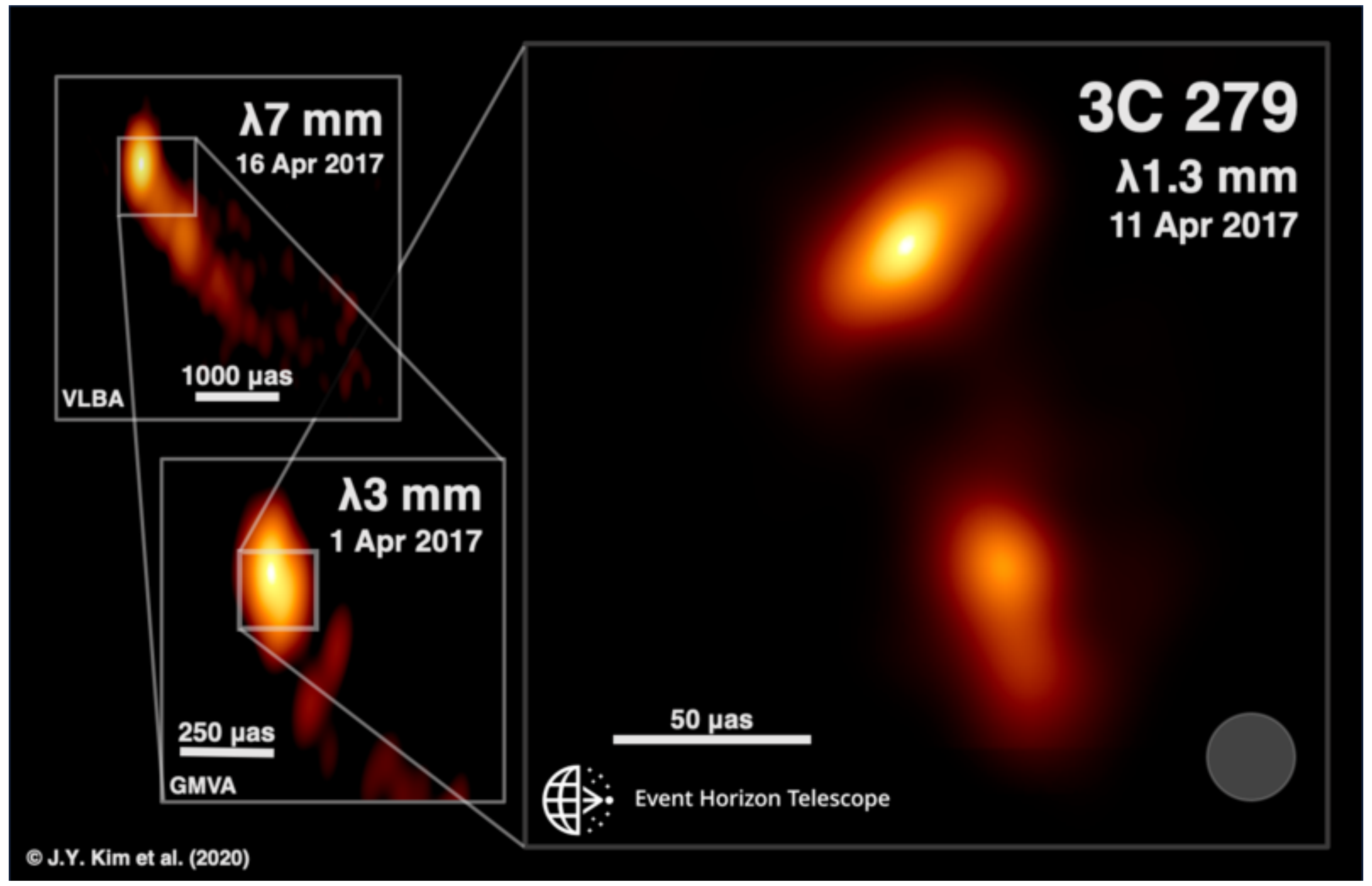

VERITAS

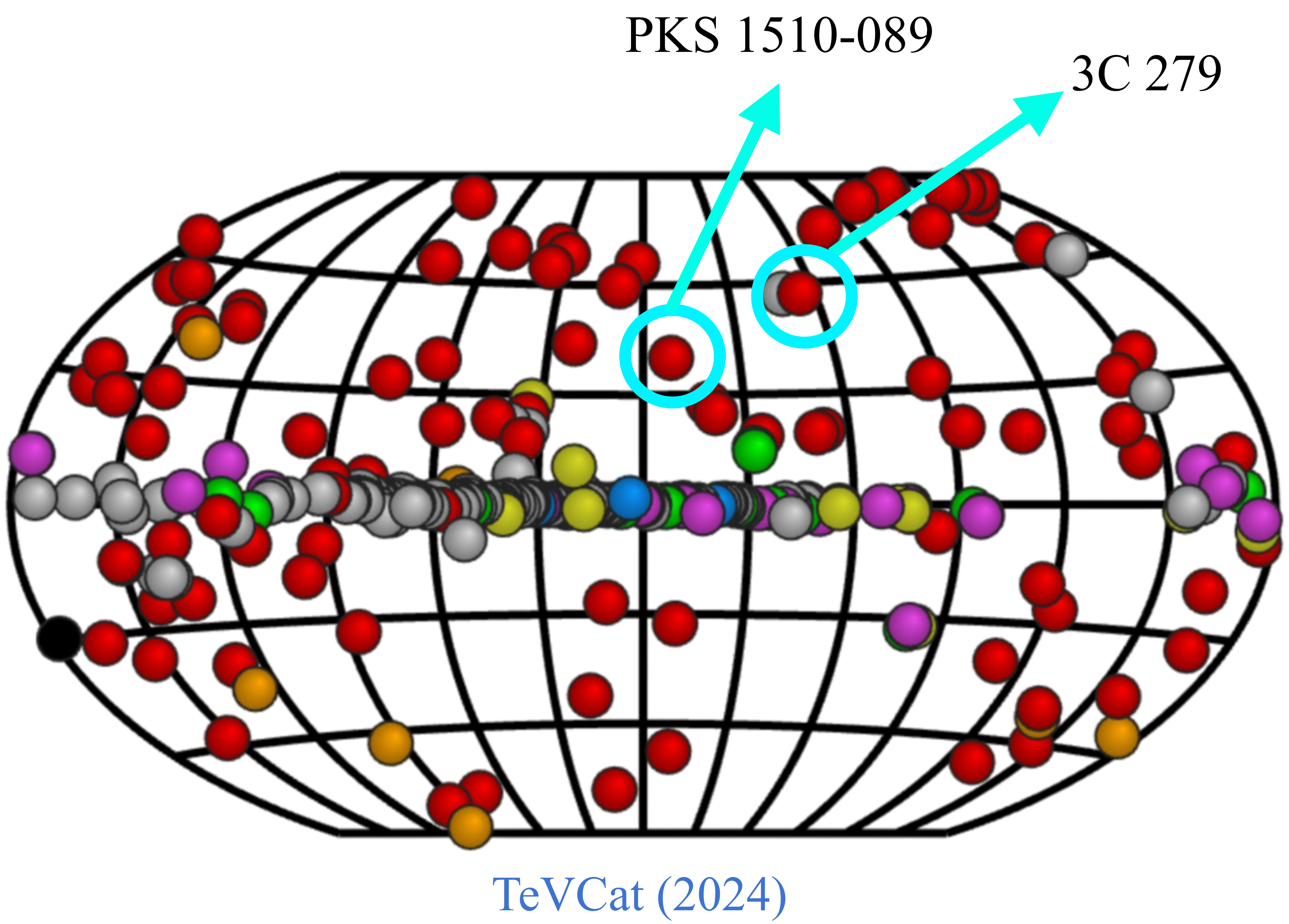

H.E.S.S.

- Expected to be fully operational by 2025
- Prepare by participating in the **CTAO Data Challenge (CDC)**

Source Selection: 3C 279 & PKS 1510-089

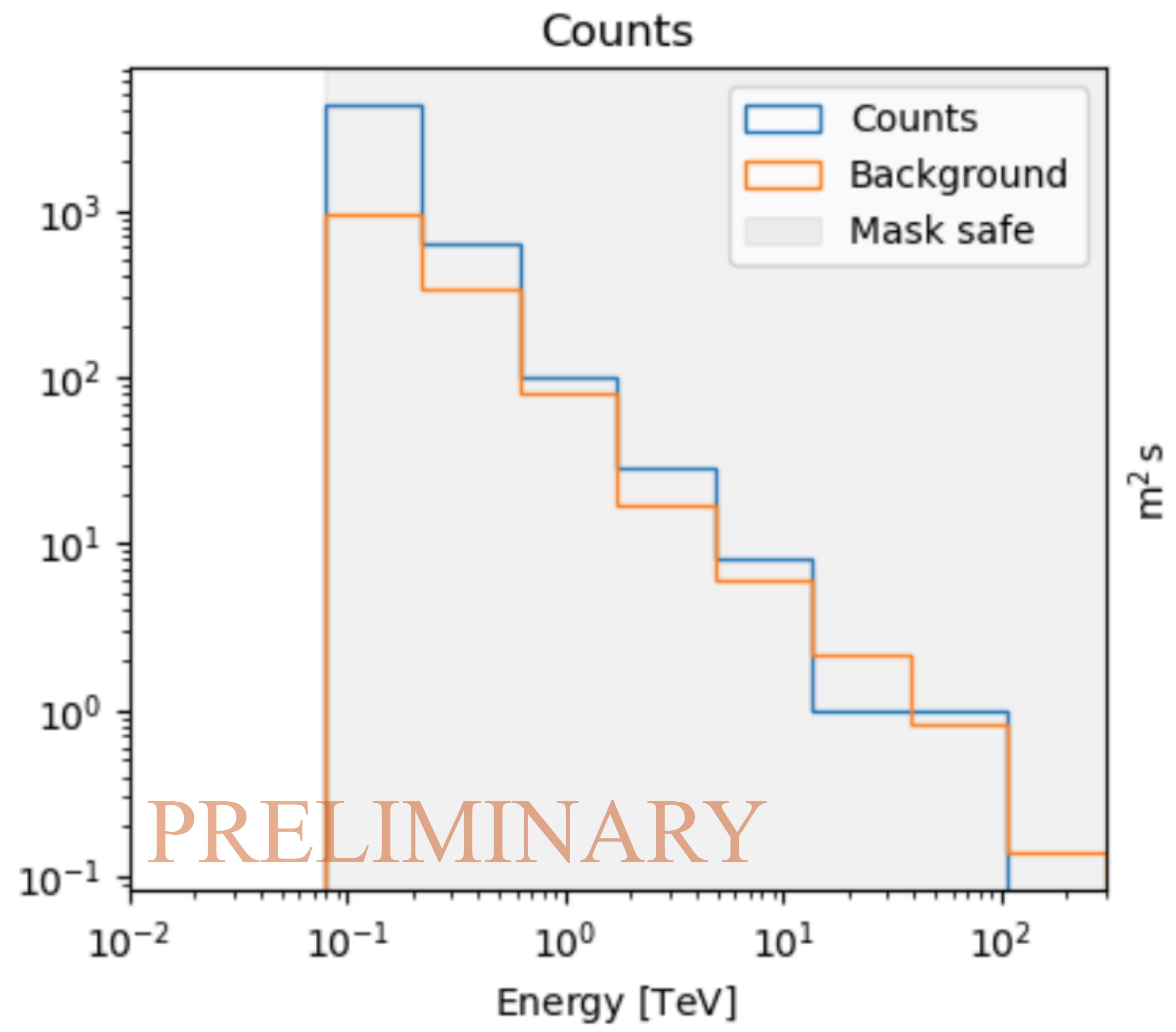
- Only FSRQs included in the simulated dataset
- PKS 1510-089: z = 0.361
- 3C 279: z = 0.5362
  - Flared in 2015
  - Well-studied source

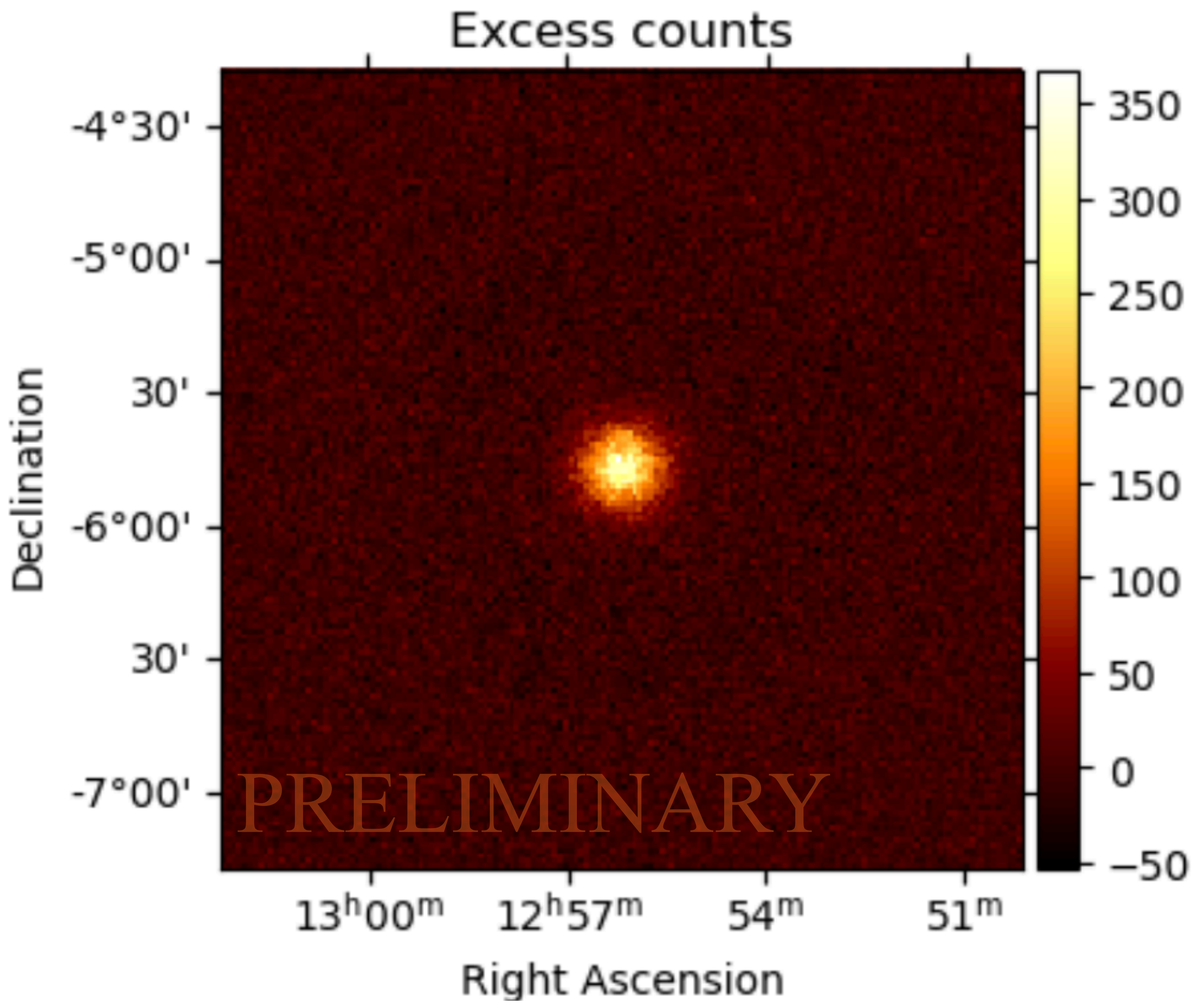




3C 279: Analysis Pipeline & Results

- ~15 hrs of simulated data
- Background subtraction models are applied to data
- Background Model: Reflected regions
- Exclusion radius: 0.1 deg

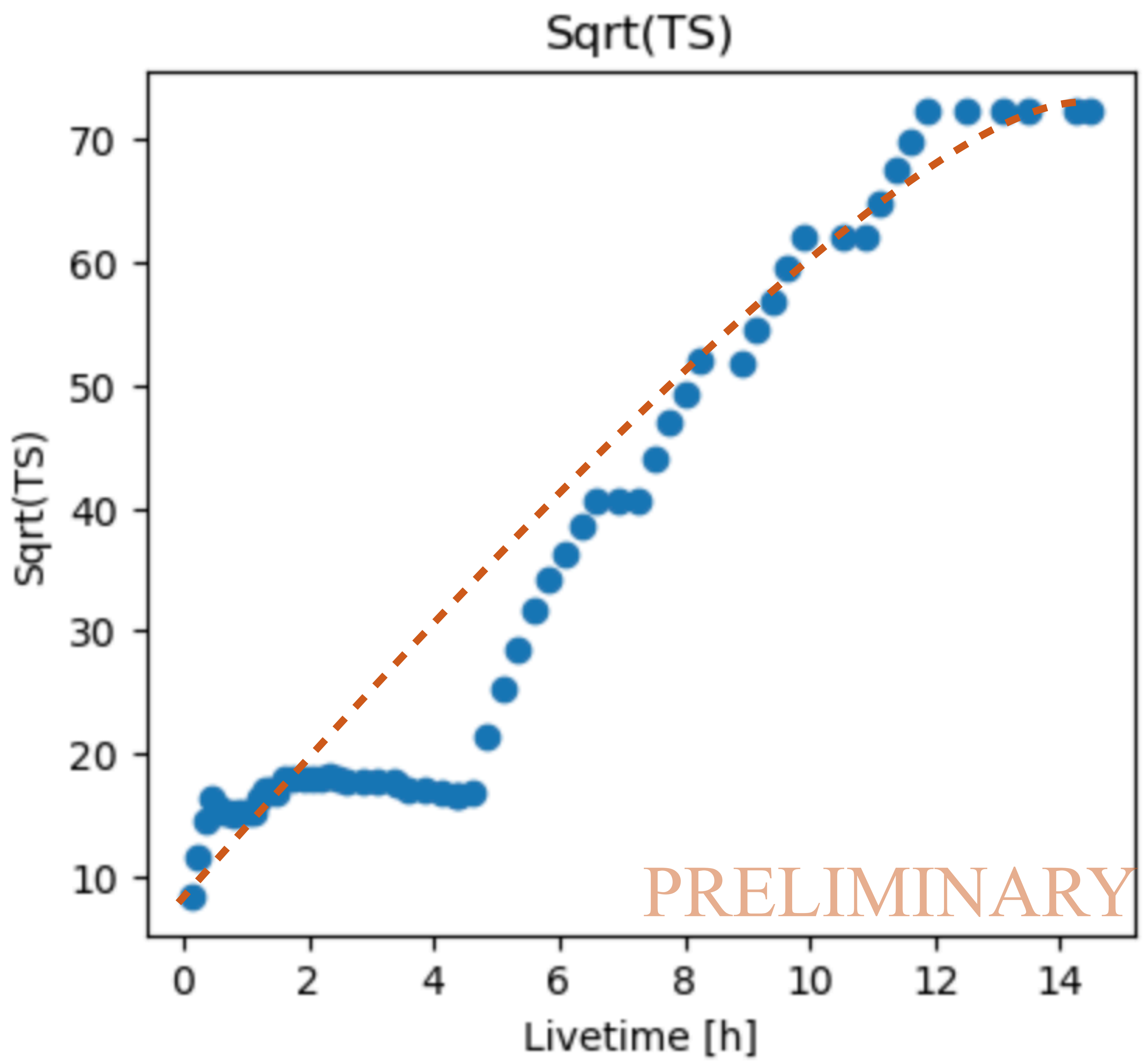




3C 279: Analysis Pipeline & Results

- Cumulative significance

- 74.6 σ detection for lowest energy bin (0.079 - 0.220 TeV)

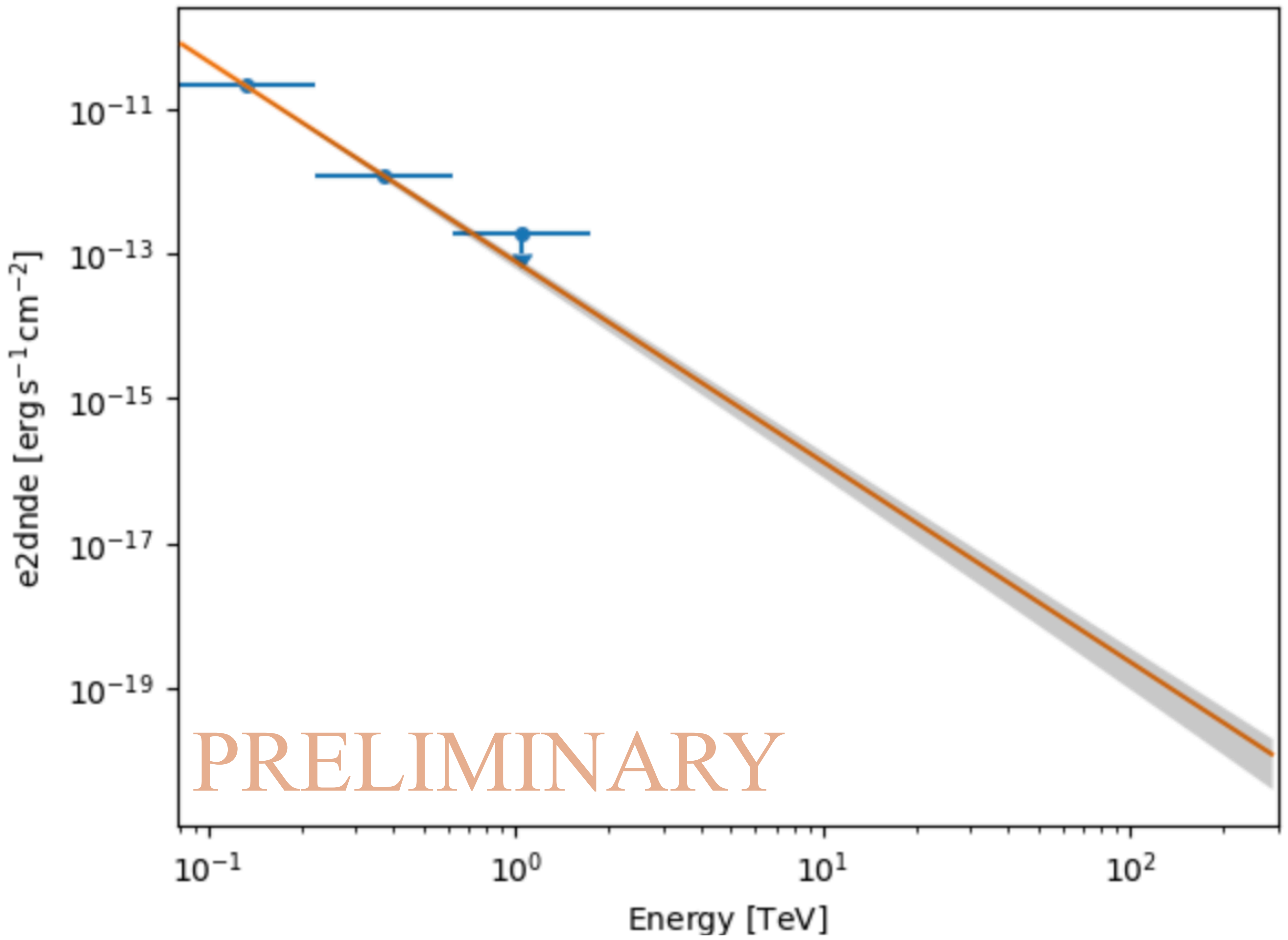


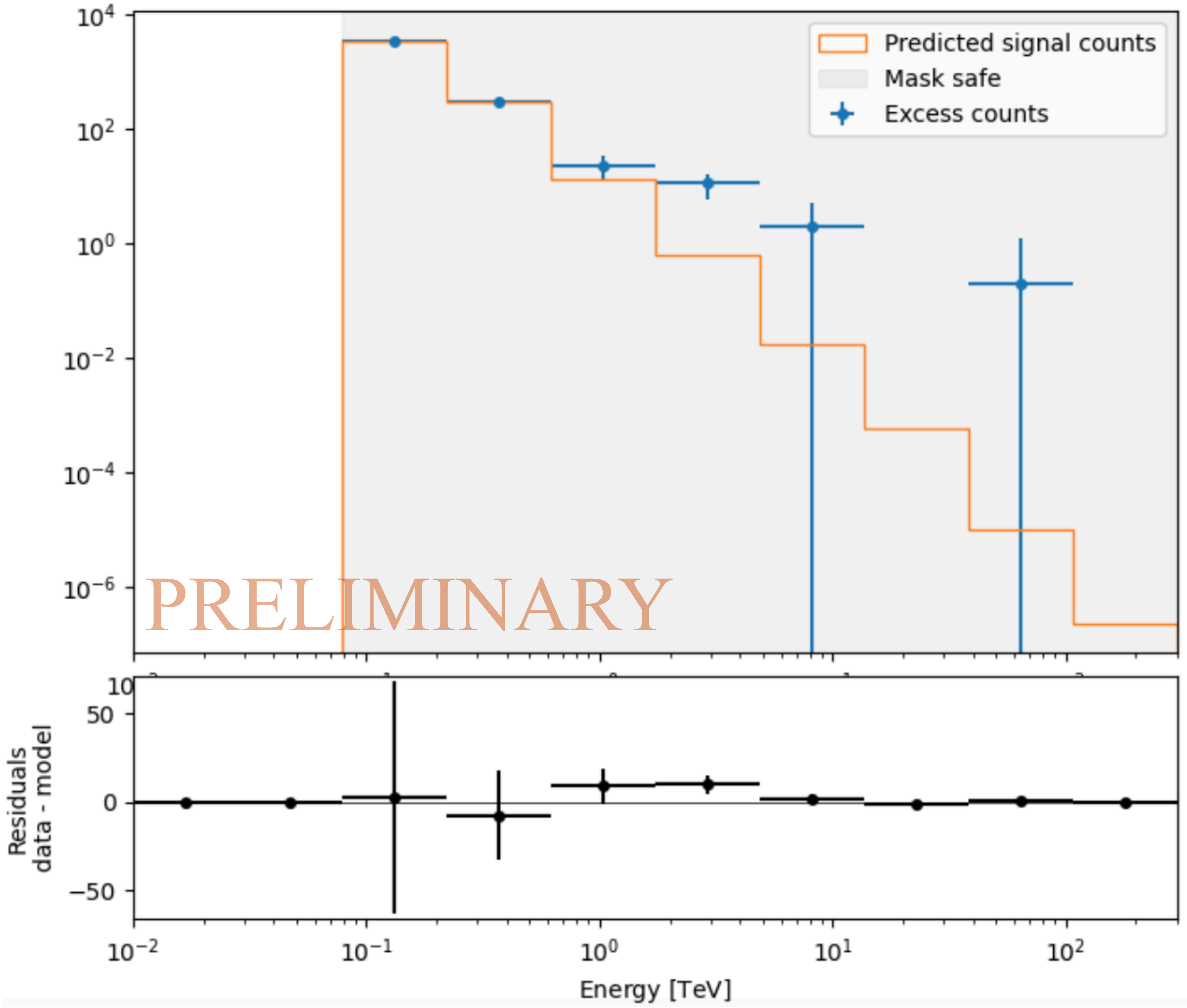
3C 279: Analysis Pipeline & Results

- Power law spectral model:

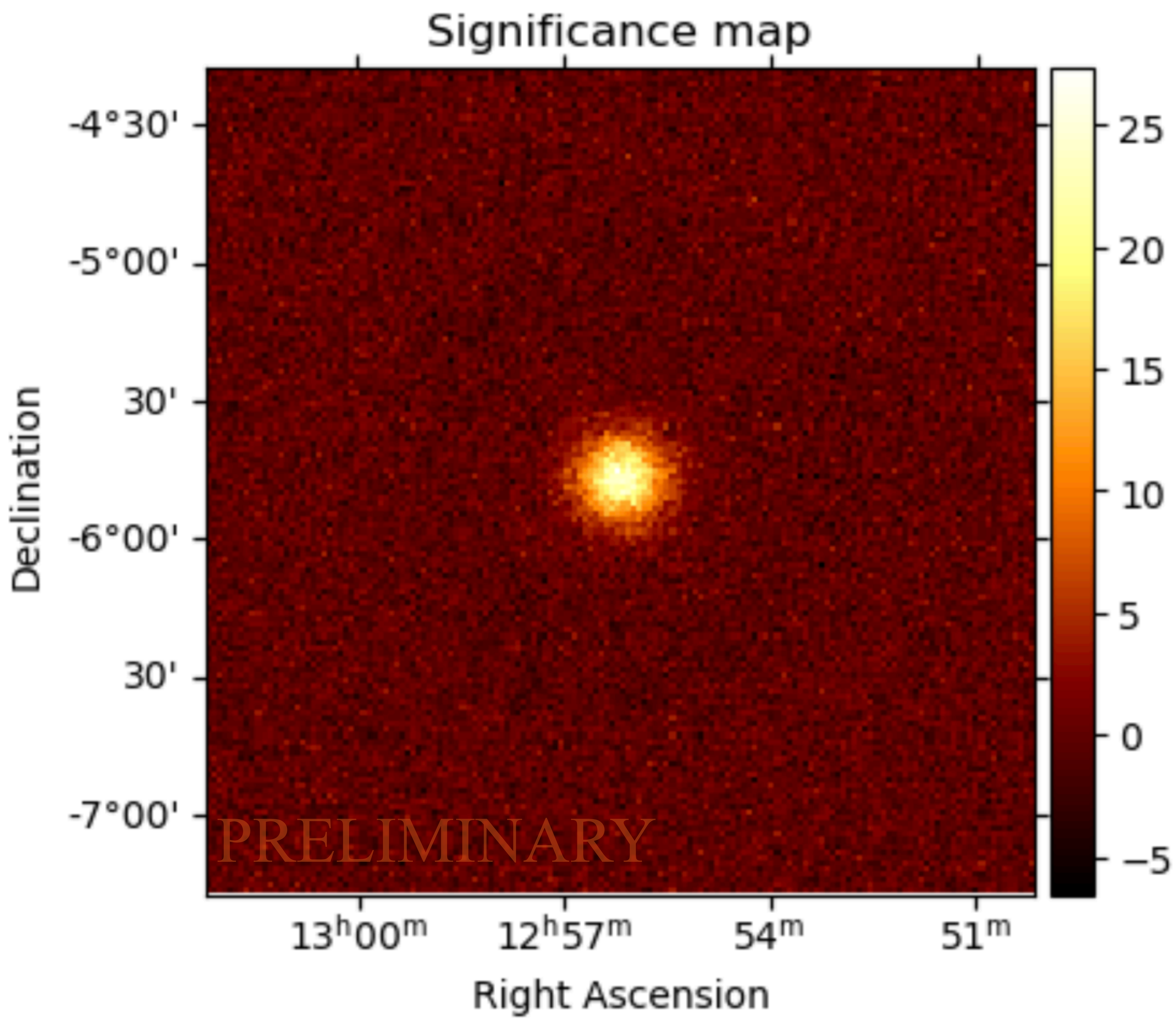
$$\boxed{\phi(E) = \phi_0 \cdot \left(\frac{E}{E_0}\right)^{-\Gamma}}$$

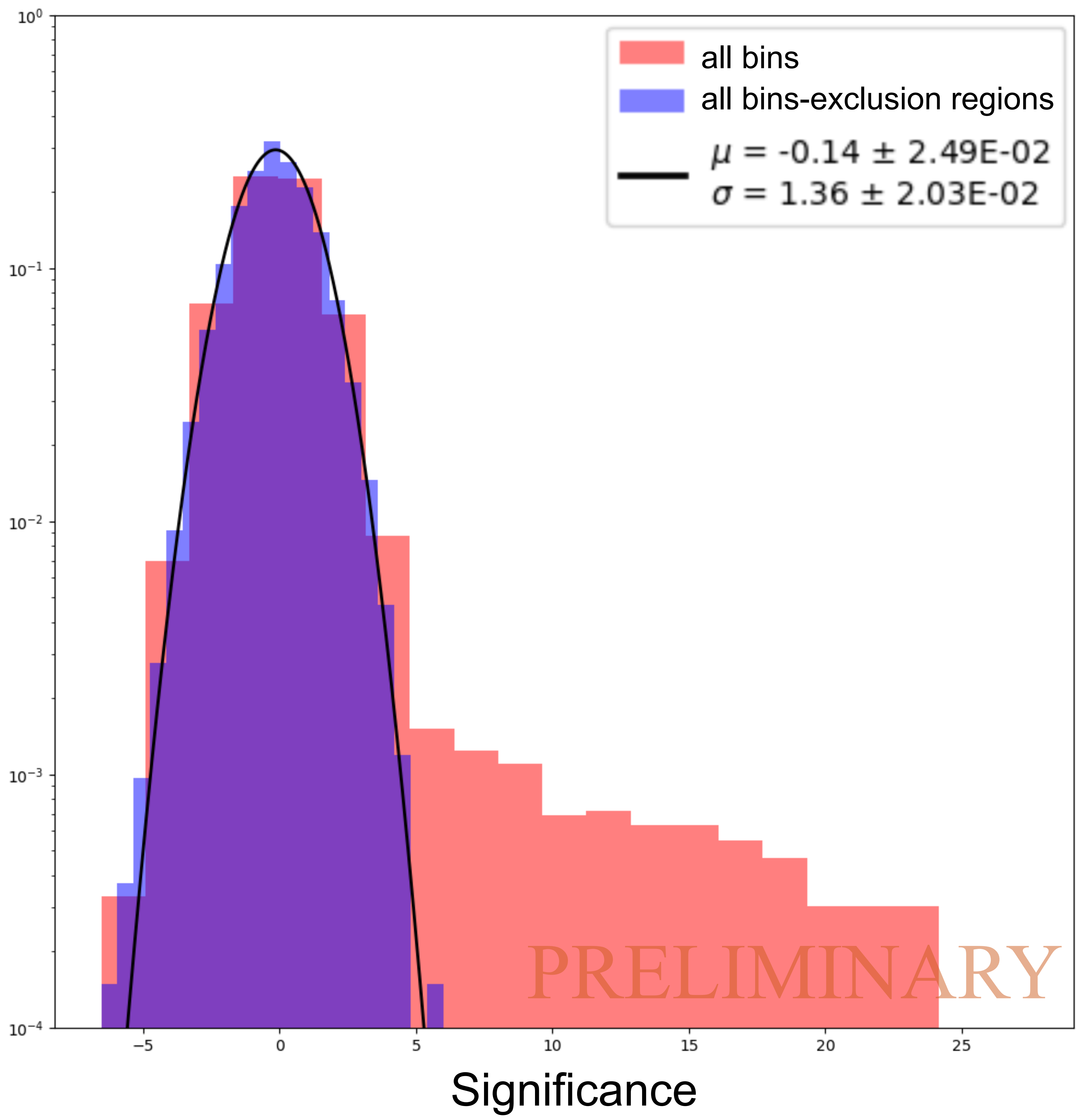
- After fit: -Γ = -4.77





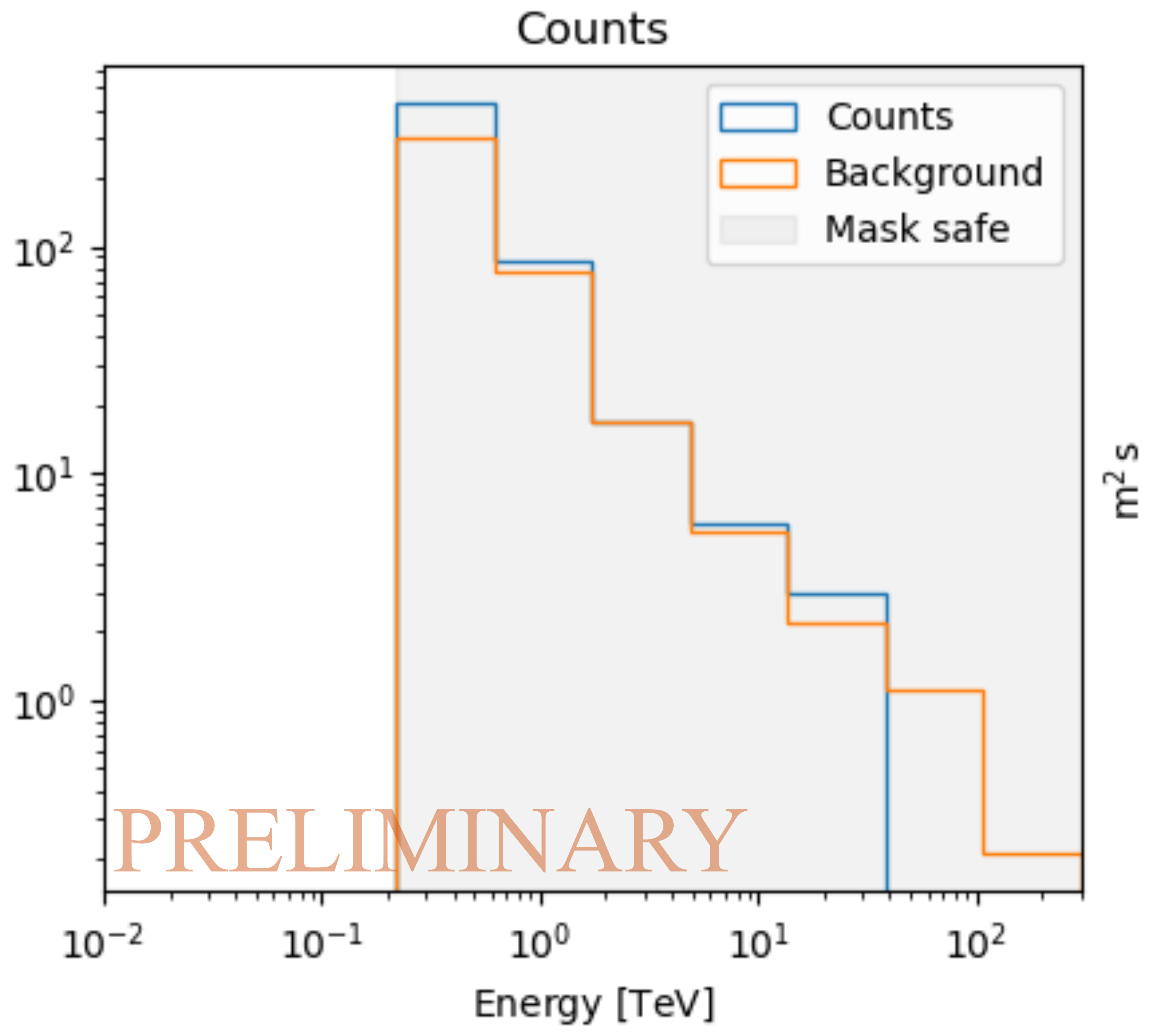
3C 279: Analysis Pipeline & Results

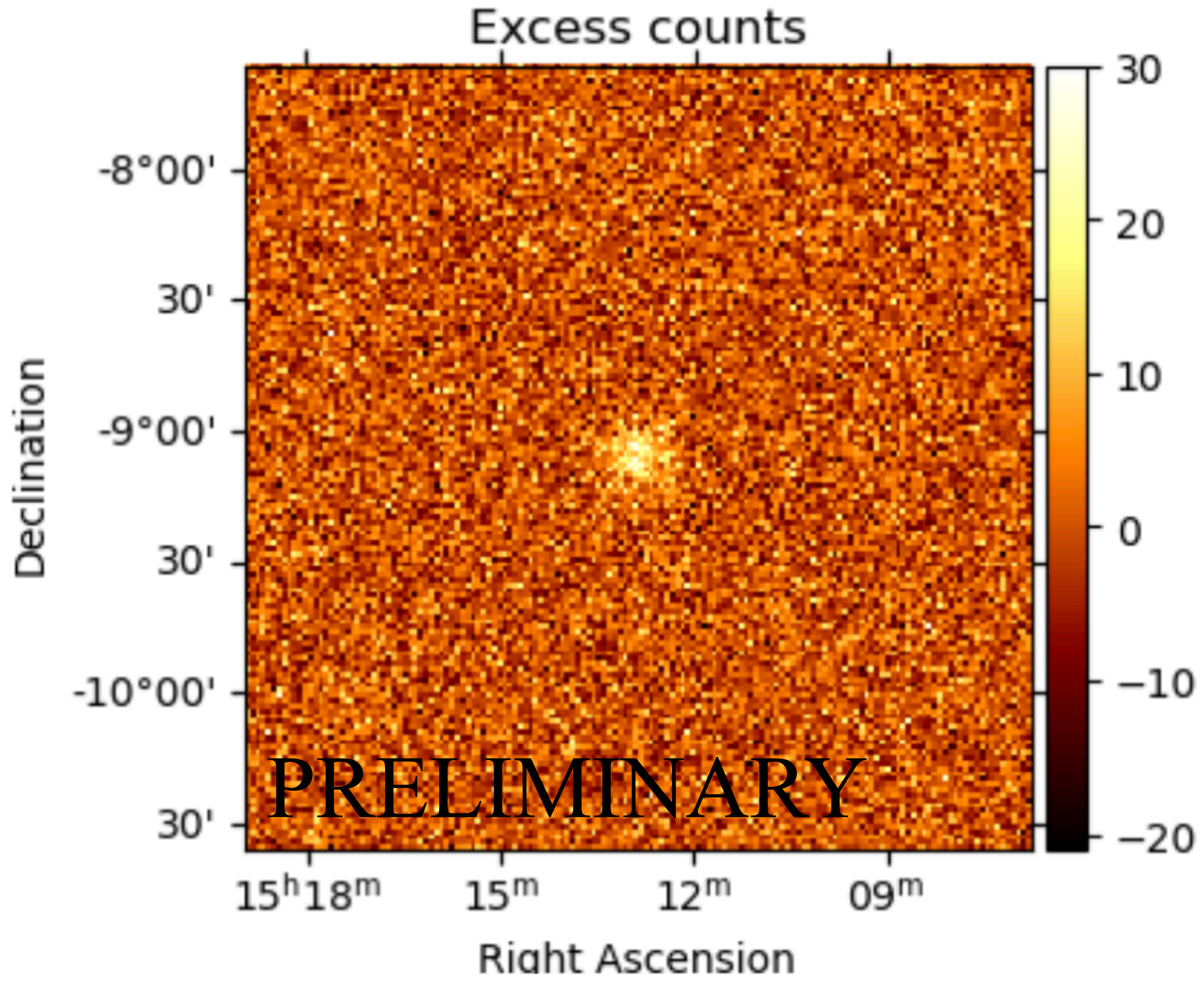




PKS 1510-089: Analysis Pipeline & Results

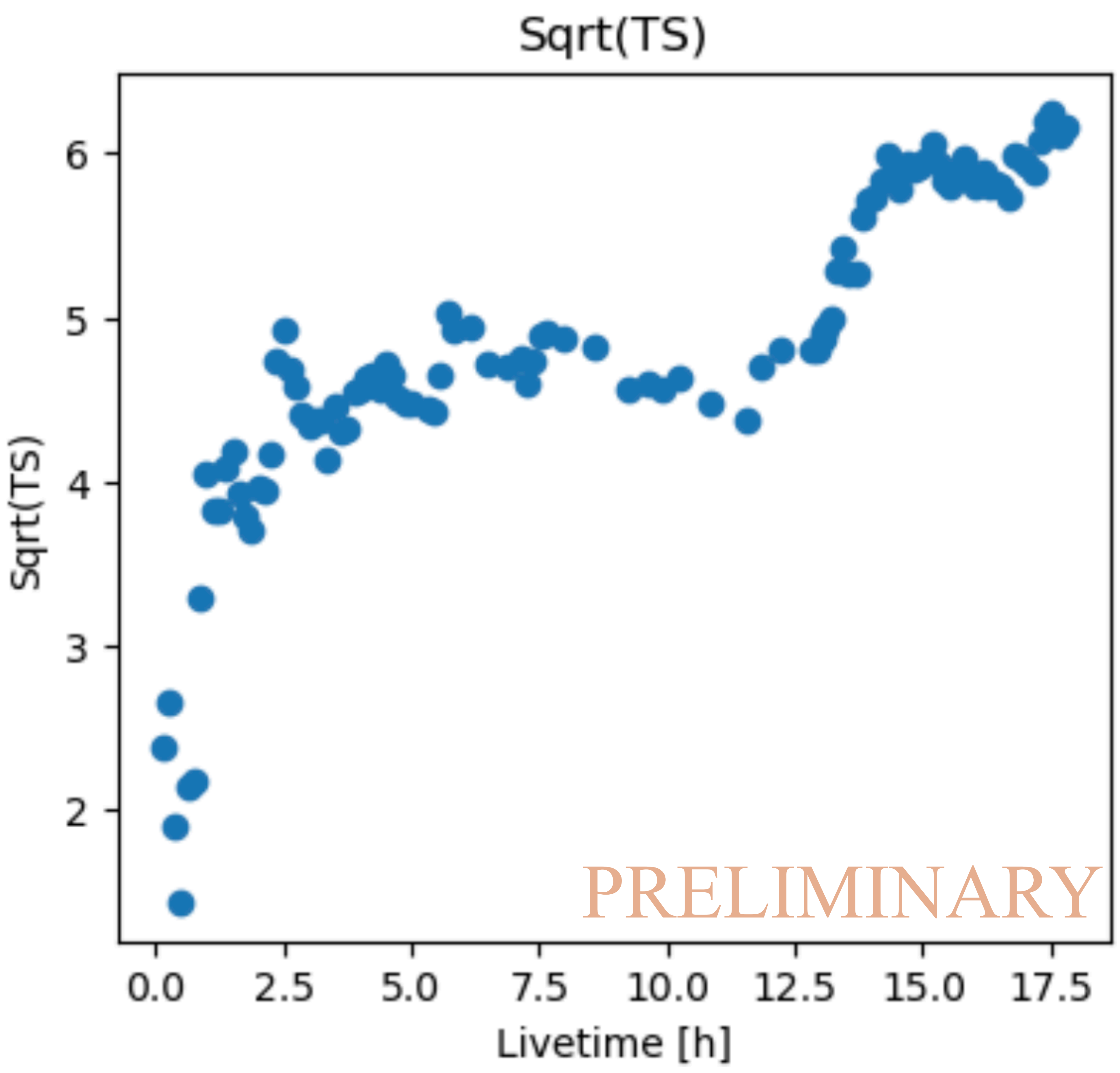
- ~18.5 hrs of simulated data
- Background subtraction models are applied to data
- Background Model: Reflected regions
- Exclusion radius: 0.1 deg





PKS 1510-089: Analysis Pipeline & Results

- Cumulative significance
- 38.4 σ detection for lowest energy bin (0.220 - 0.618 TeV)

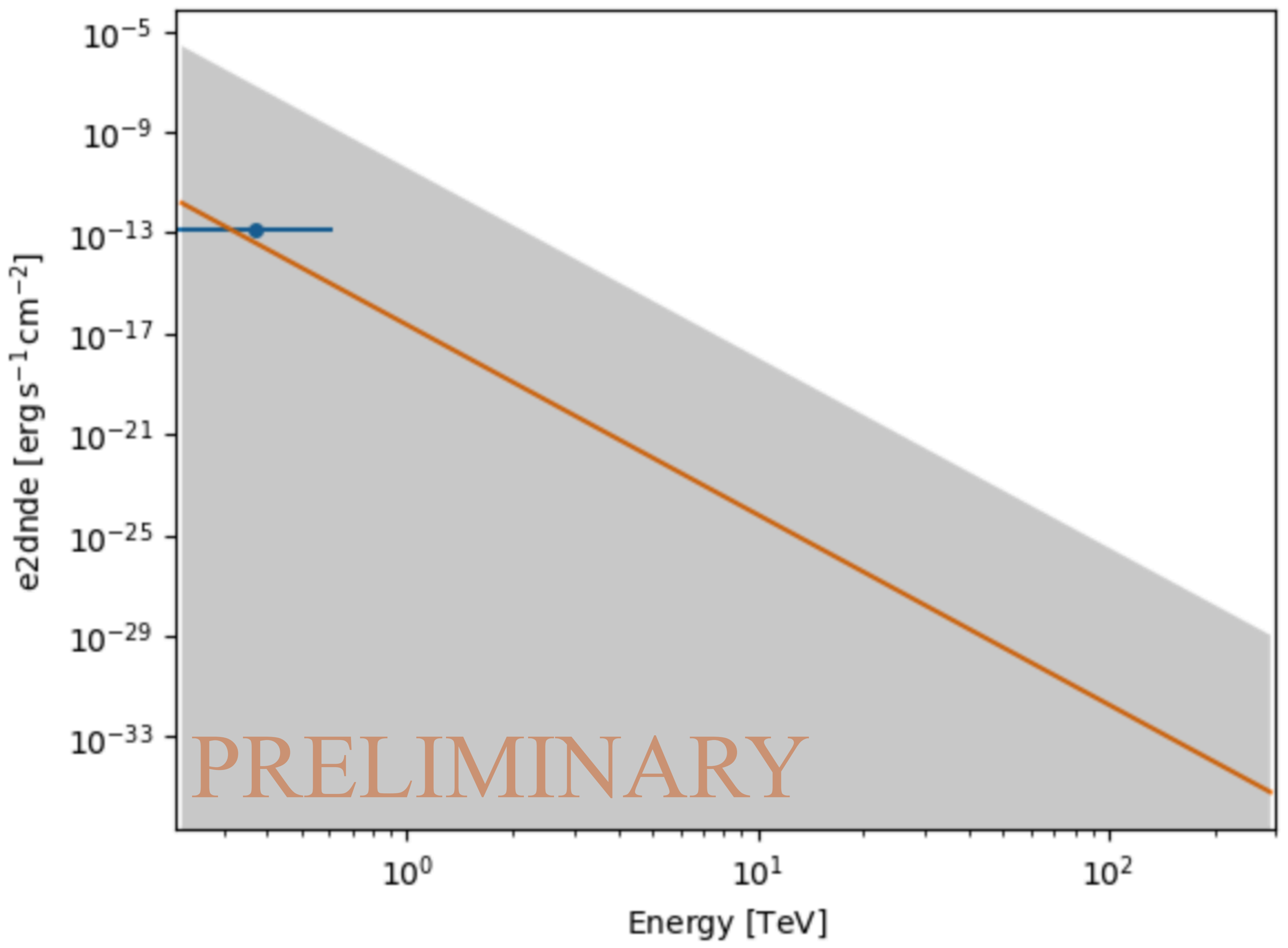


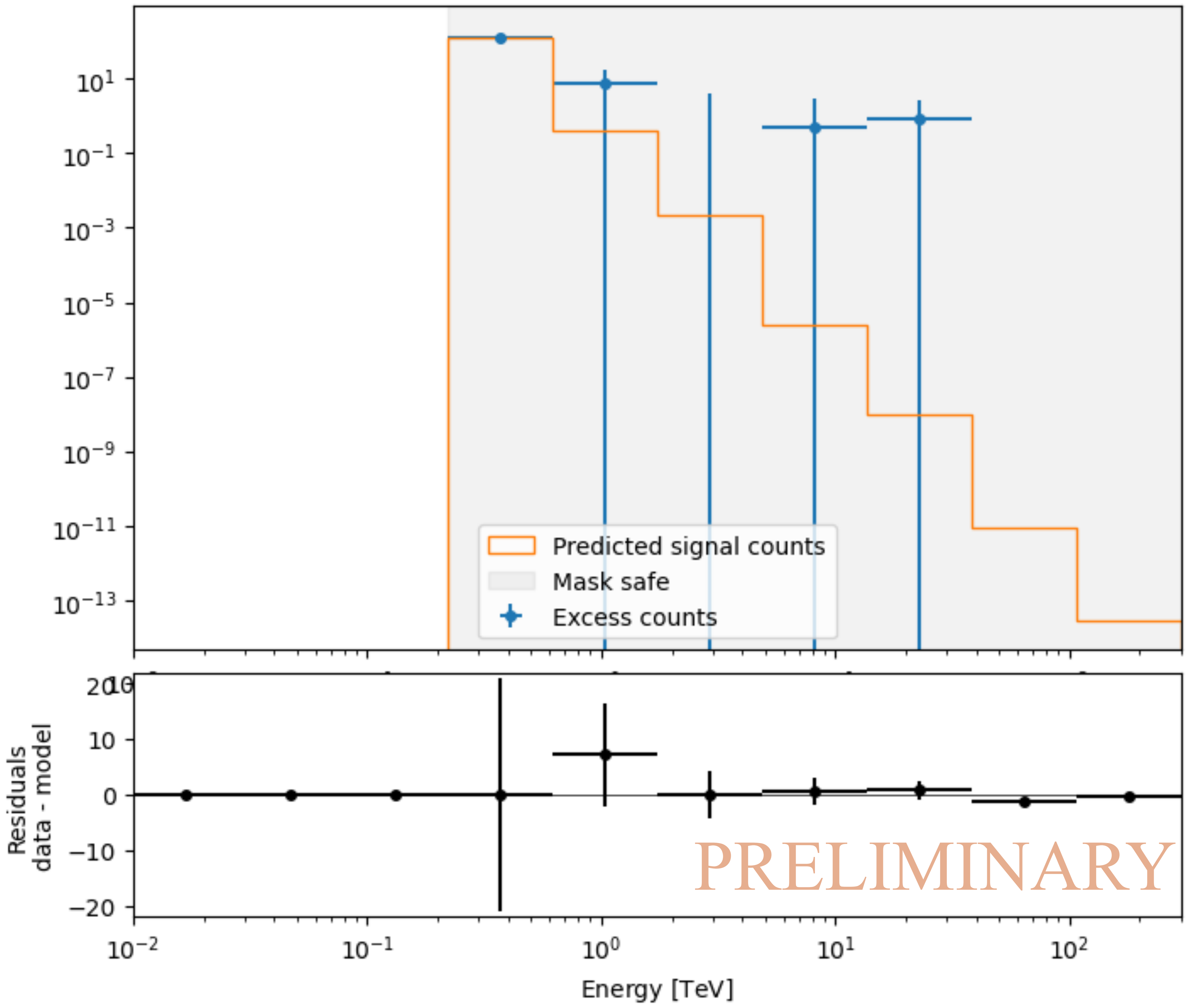
PKS 1510-089: Analysis Pipeline & Results

- Power law spectral model:

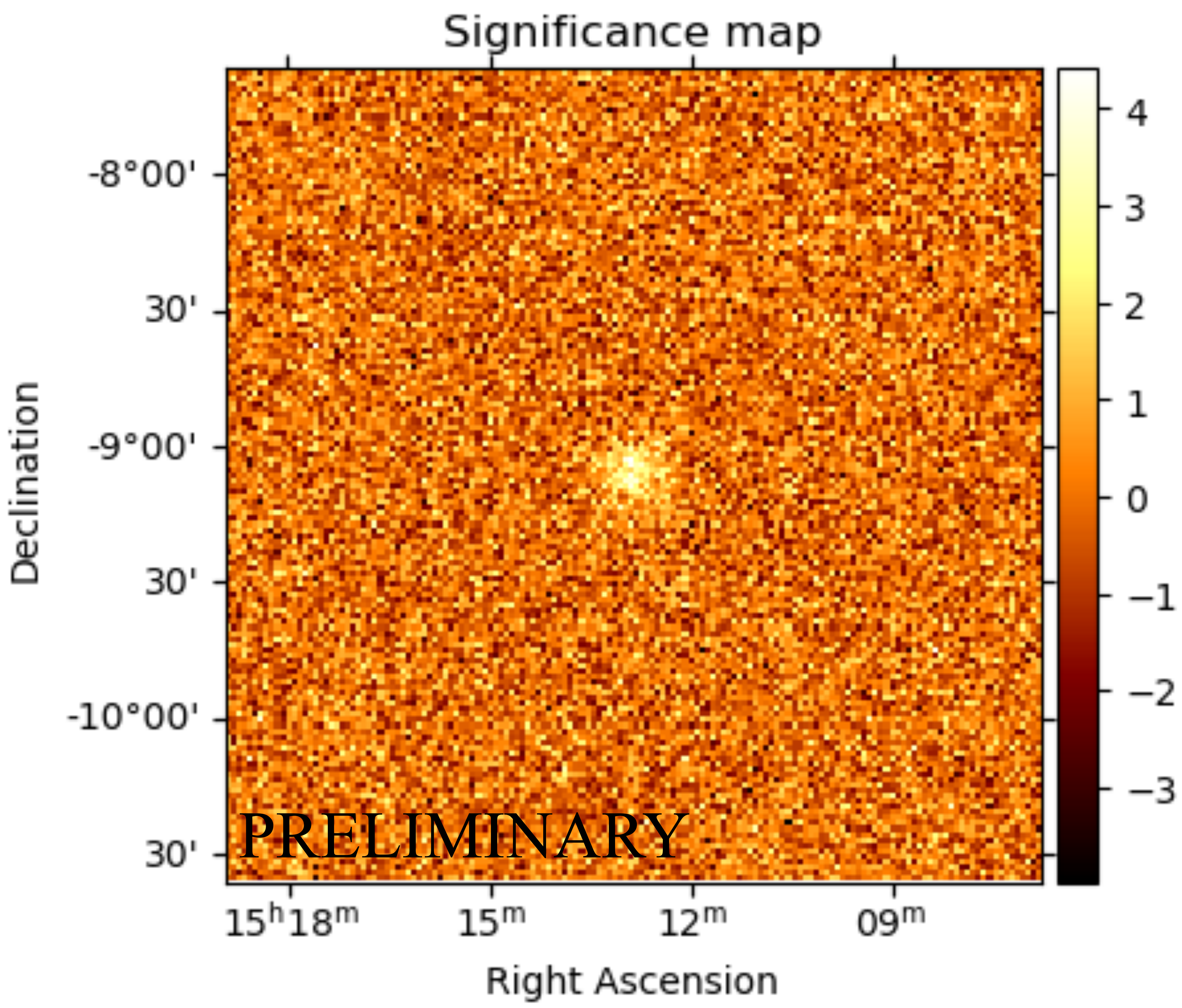
$$\boxed{\phi(E) = \phi_0 \cdot \left(\frac{E}{E_0}\right)^{-\Gamma}}$$

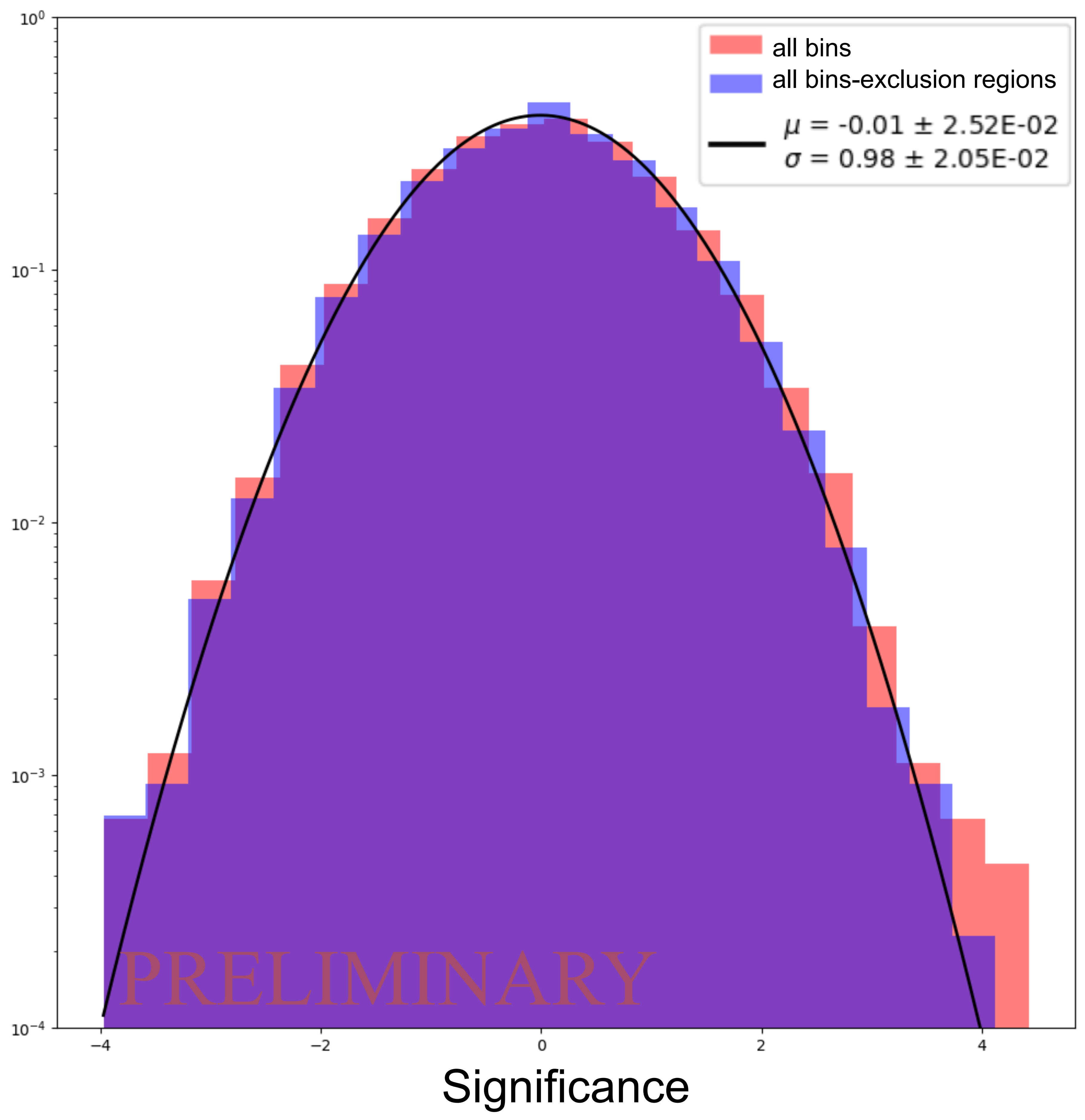
- After fitting: -Γ = -9.53





PKS 1510-089: Analysis Pipeline & Results

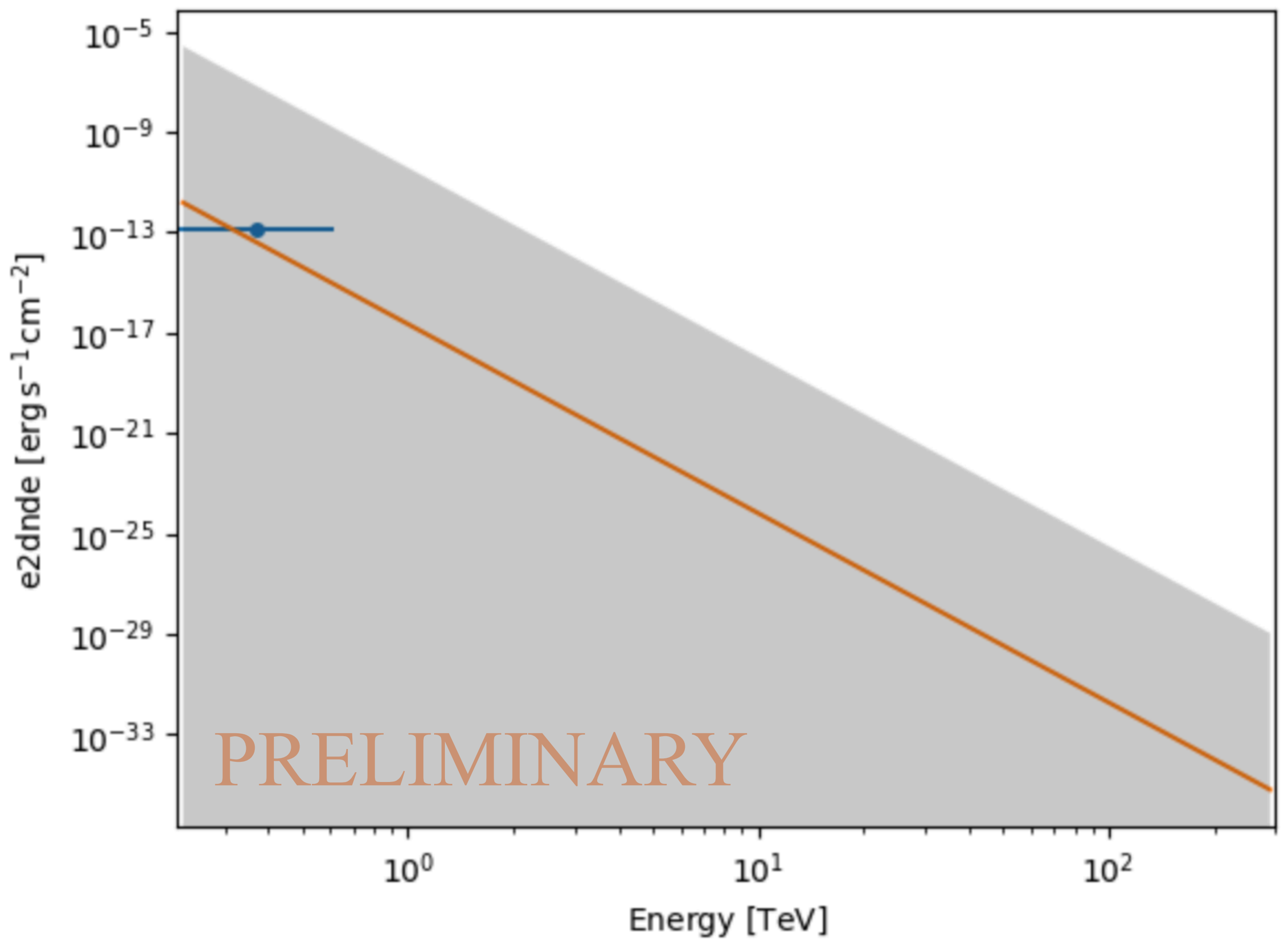




Conclusion & Next Steps

- Gammapy works!
- Provide feedback to improve open-access documentation & tutorials
- Test Gammapy EBL correction methods
- Test Gammapy's multi-instrument joint fitting analyses

- Collect more data (>20 hrs) on PKS 1510-089 to perform a more reliable spectral analysis



Acknowledgments

I want to thank Dr. Reshmi Mukherjee, Dr. Ruo-Yu Shang, and the entire VERITAS/CTA group at Columbia & Barnard for welcoming me into their group and for their continuous support.

Many thanks to Dr. Georgia Karagiorgi & Amy Garwood for organizing the REU program.

This material is based upon work supported by the National Science Foundation under Grant No. PHY-2349438.

NEVIS LABORATORIES

Thank You!

Questions?

Salma Ibrahim

Nevis Labs REU, Aug 1st, 2024