Prospects for the candidate PeVatron G106.3+2.7 with the ASTRI Mini-Array

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for the ASTRI Project

TeVPA 2023

Outline

Goal: Testing ASTRI Mini-Array's potential in understanding the complex morphology of LHAASO J2226+6057 and exploring potential improvements.

- The **ASTRI Mini-Array**: general information
- **LHAASO J2226+6057**: an interesting benchmark target
- **Simulations and Analysis** for the ASTRI Mini-Array:
  - morphological study
  - spectral study
- **Conclusions and outlooks**

The ASTRI Mini-Array project

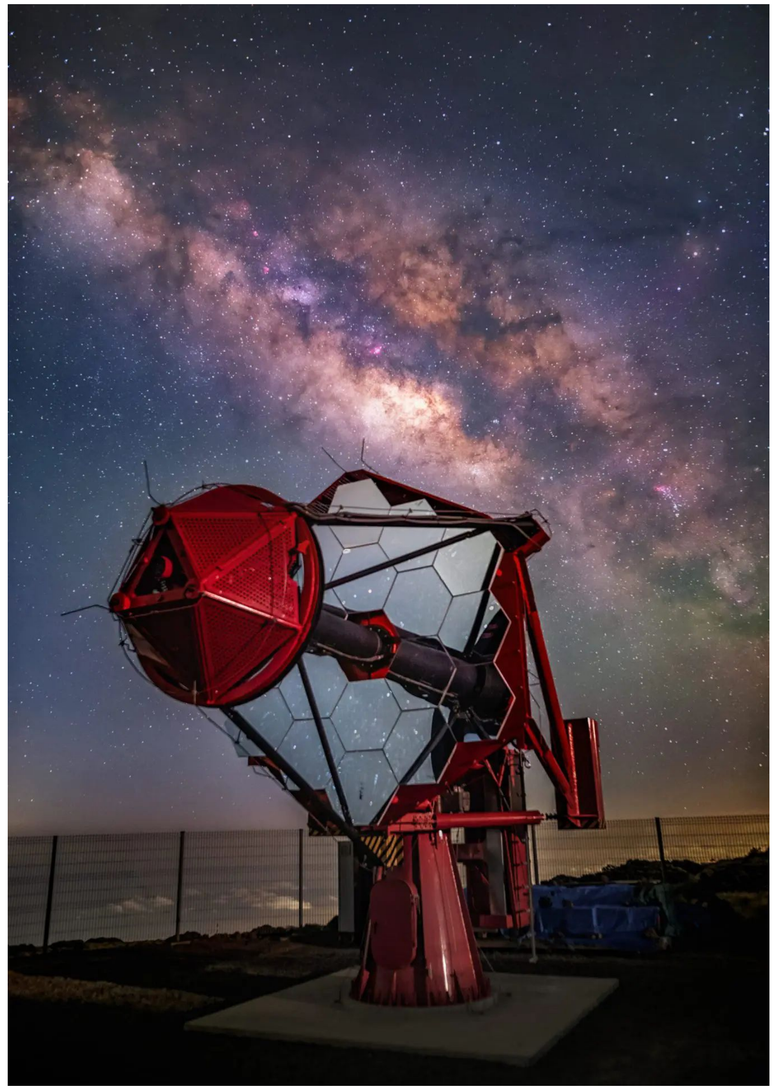
The ASTRI Mini-Array (MA) experiment will consist of **9 imaging Cherenkov telescopes** capable of detecting gamma-ray emission in the range 0.5-200 TeV.

Construction is underway at **Teide Observatory** site (Tenerife, Canary Islands), with the first telescope expected to be operational by the end of 2023 and two more by next year.

- More than 150 researchers belonging to:
  - INAF institutes
  - Italian Universities
  - International institutions

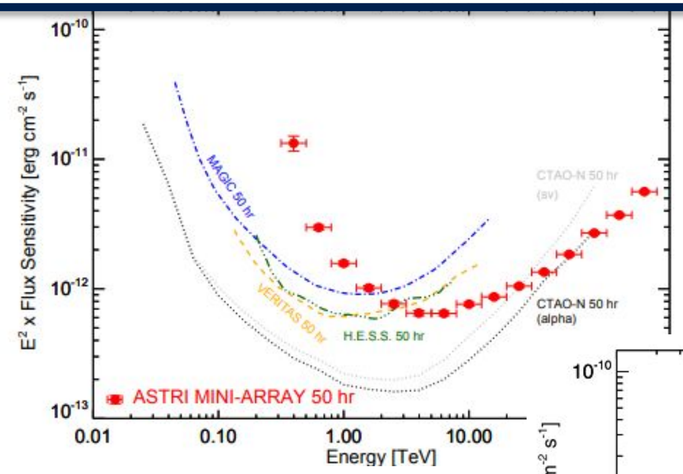
The ASTRI Mini-Array @ Teide Observatory

- Under construction at the Observatorio del Teide (Tenerife), in collaboration with IAC
- Unprecedented performance and wide FoV for observations at **multi-TeV energy scale**
- **Core Science Program** in the first 3 years
- **Important synergies** with other Northern ground-based gamma-ray facilities (LHAASO, HAWC, MAGIC, VERITAS, CTAO-N)

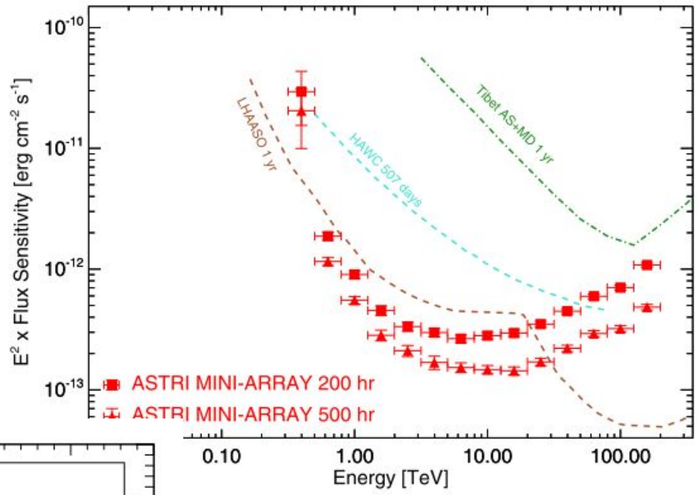


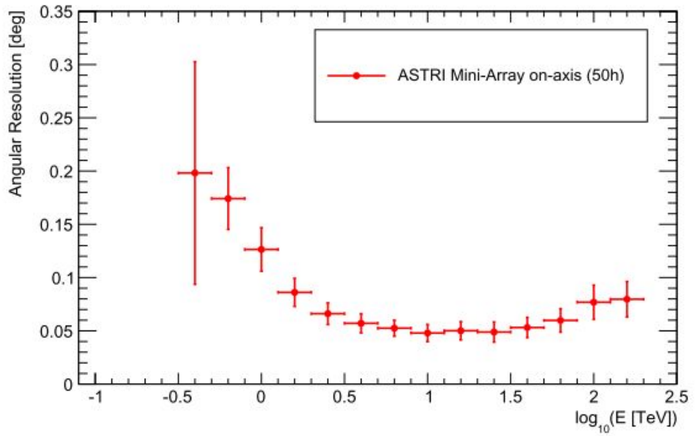
ASTRI Performances

- **Sensitivity: better than that of current IACTs (E>a few TeV)**
  - Extend the spectra and constraints on cut-offs
- **Energy/Angular resolution: ~10%/~3‘(E>a few TeV)**
  - Characterize the morphology @ VHE
- **Wide FoV (≥10°), with almost homogeneous off-axis acceptance**
  - Optimal for multi-target fields, surveys and extended sources
  - Enhanced chance for serendipity discoveries



ASTRI Sensitivity (Vercellone+2022)





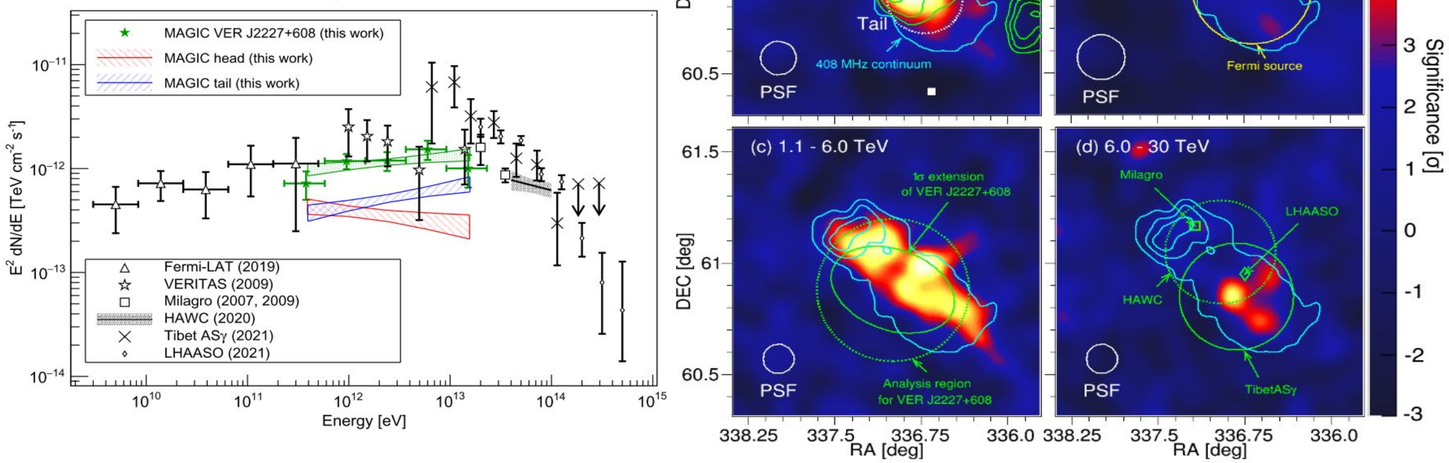
ASTRI Angular resolution (Vercellone+2022)

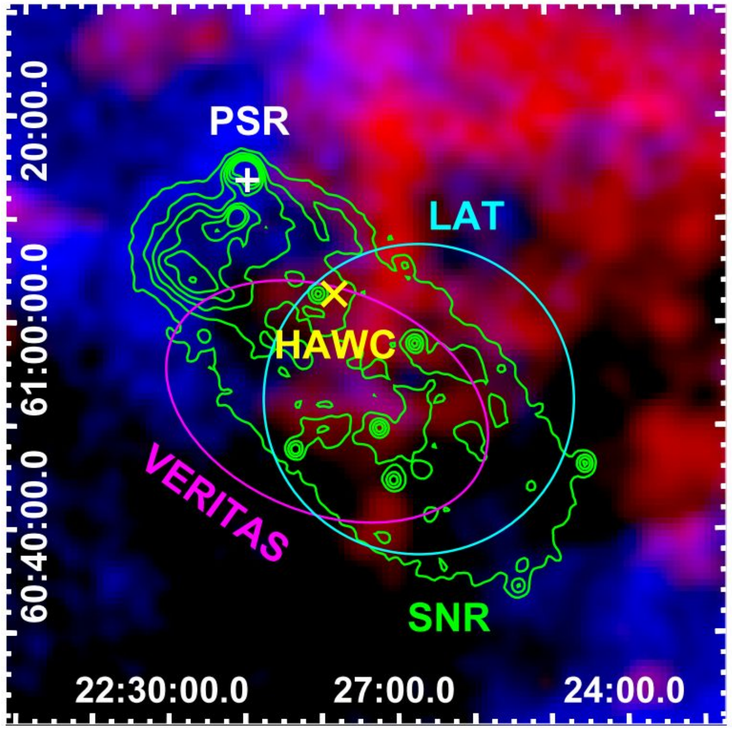
LHAASO J2226+6057

What we know:

- TeV emission extended (energy dependent)
- VHE ~0.4° from PSR J2229+6114
- Detected by FERMI, MAGIC, VERITAS, Milagro, HAWC, Tibet AS-γ, LHAASO
- Overlaps with region of high CO density
- Two sources could explain the emission: Boomerang PWN in the“Head” region SNR G106.3+2.7 in the “Tail” region

MAGIC results (MAGIC+2022)





Ge+2020

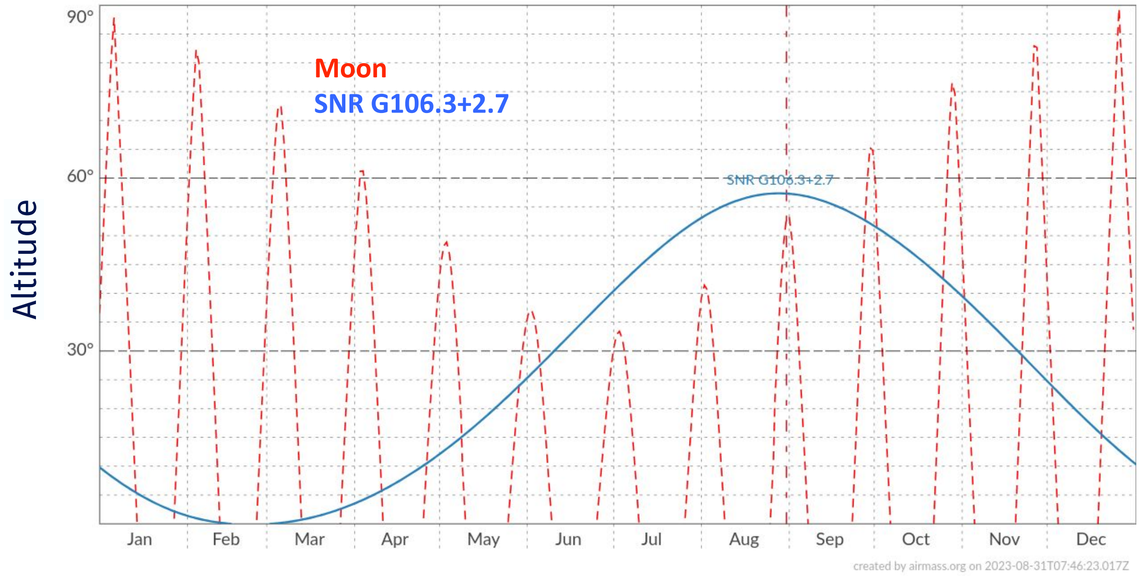
The ASTRI Mini-Array exceptional sensitivity and resolution will significantly contribute to understanding UHE emission.

Simulations

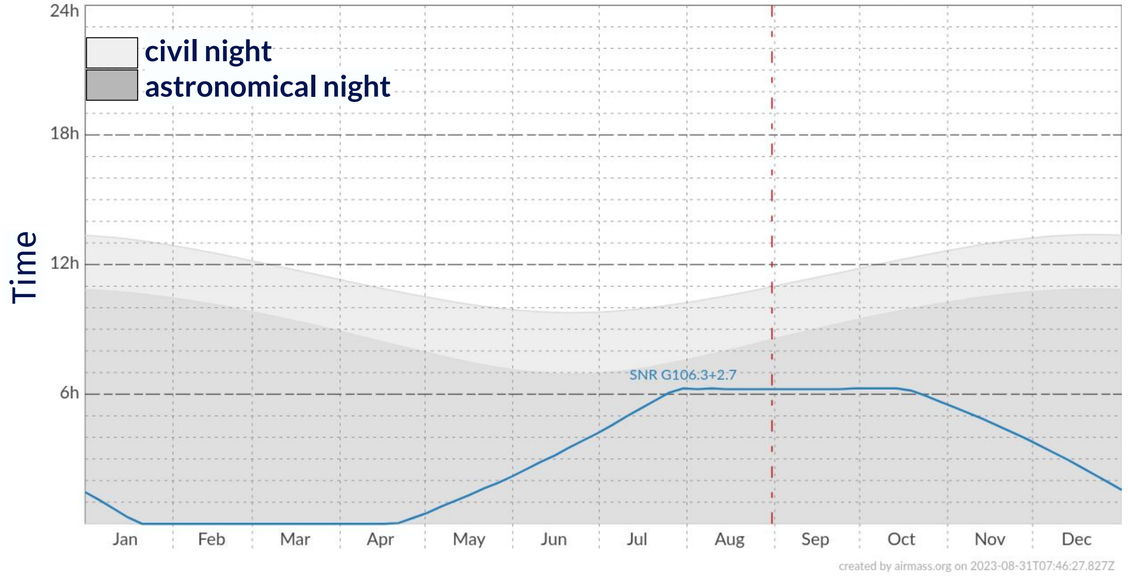
Simulations and Analysis were performed using **gammapy v1.1**

- The source is observable ~450 hr per year: we simulated **200 hr**
- The emission is studied in an energy range **1 – 300 TeV**
- Background:
  - Cosmic-ray background model (from IRFs)
  - **No diffuse emission** was considered
- To mitigate individual variations, we conducted 100 independent simulations, fitting each with the same model, and **averaging results** to statistically characterize source morphology and spectral features.

Altitude of SNR G106.3+2.7 at local midnight



Time above 45° altitude each day during night



Simulations

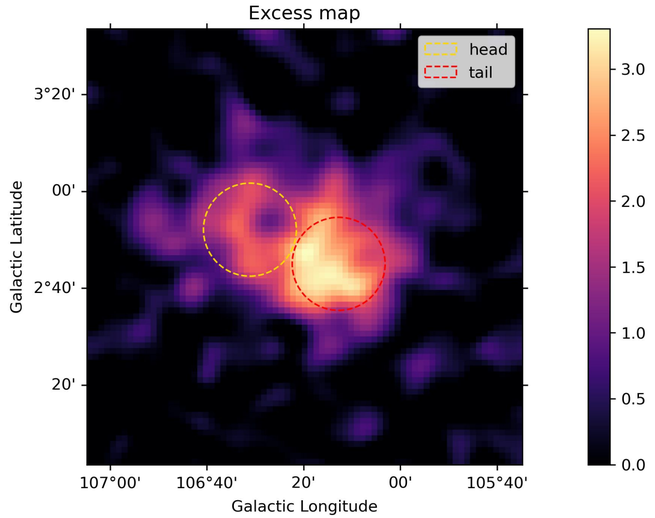
Simulations and Analysis were performed using **gammapy v1.1**

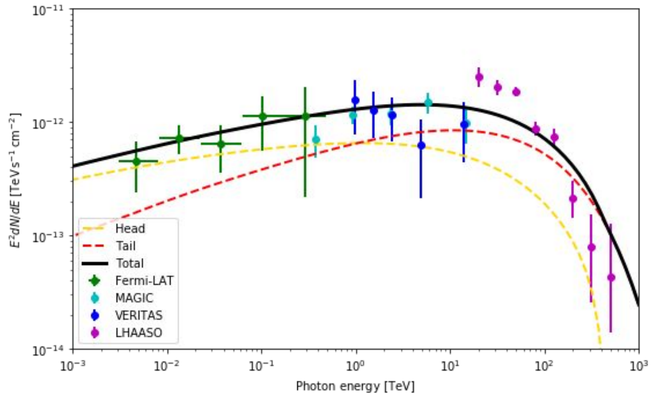
HEAD

Spatial shape: Symmetrical Gaussian
Coordinates-> *l*: 106.52° *b*: 2.87°
Radius-> 0.16°

Spectral model: Leptonic emission

- Distribution: PLEC
- index: 2.6
- cutoff: 360 TeV
- $W_e(E > 1\ GeV)$ 1.4×10^{47} erg





TAIL

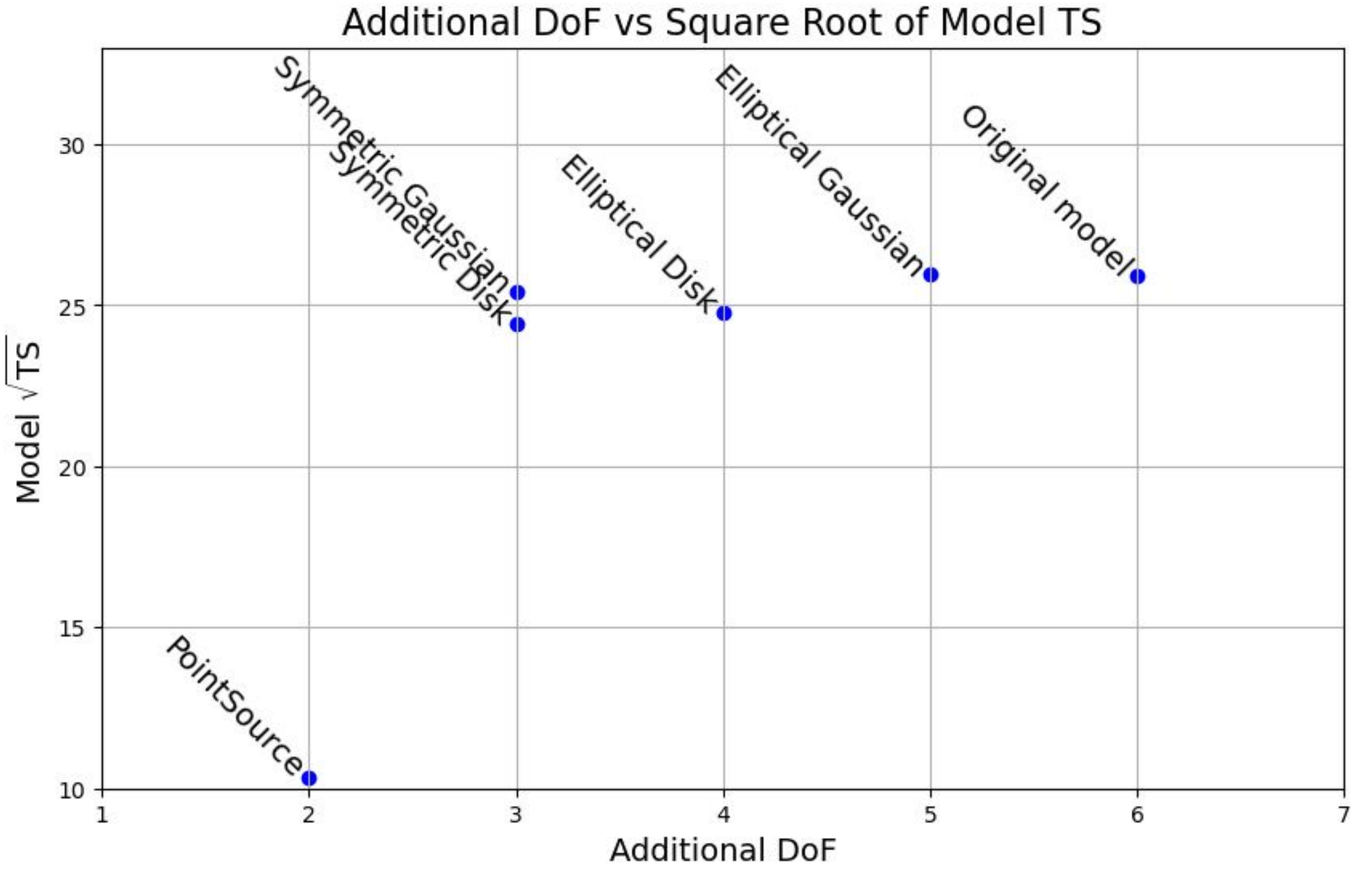
Spatial shape: Symmetrical Gaussian
Coordinates-> *l*: 106.21° *b*: 2.75°
Radius-> 0.16°

Spectral model: Hadronic+Leptonic emission

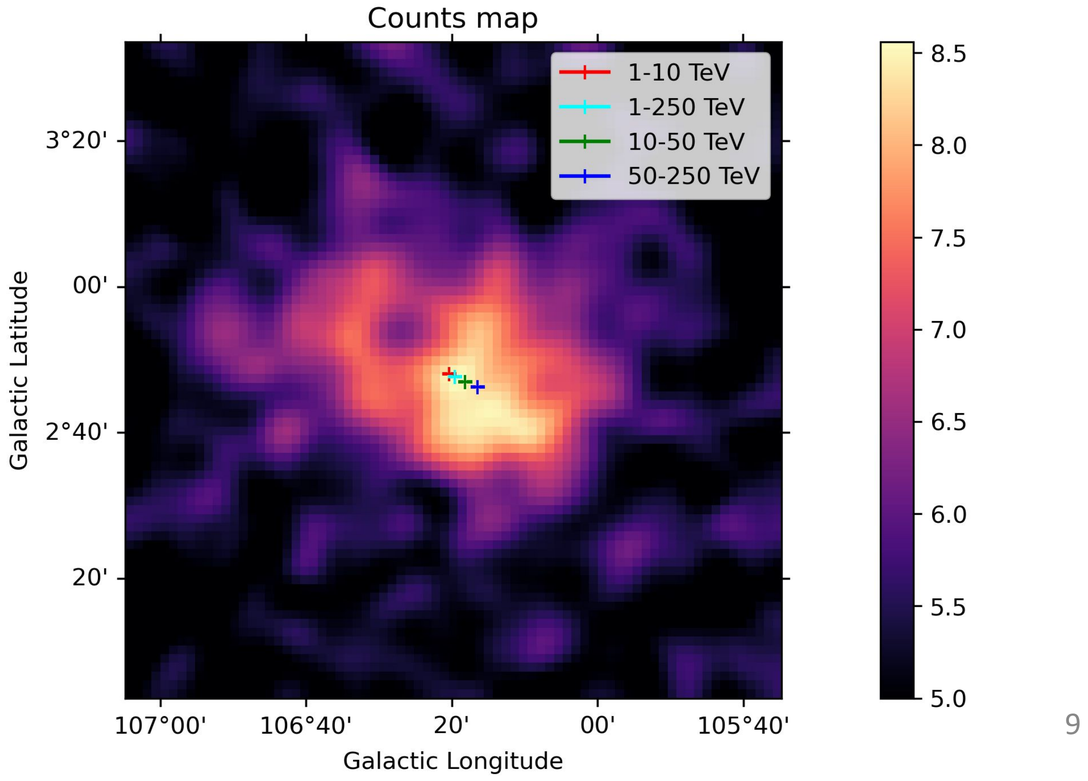
- **Leptonic**
  - Distribution: PLEC
  - index: 2.5
  - cutoff: 35 TeV
  - $W_e(E > 1\ GeV)$ 2×10^{46} erg
- **Hadronic**
  - Distribution: PLEC
  - index: 1.7
  - cutoff: 1000 TeV
  - $W_p(E > 1\ GeV)$ 8.2×10^{45} erg

Morphological Study

- Morphological investigation in the **entire energy range**
- Point source hypothesis is clearly excluded with a > 5σ confidence level



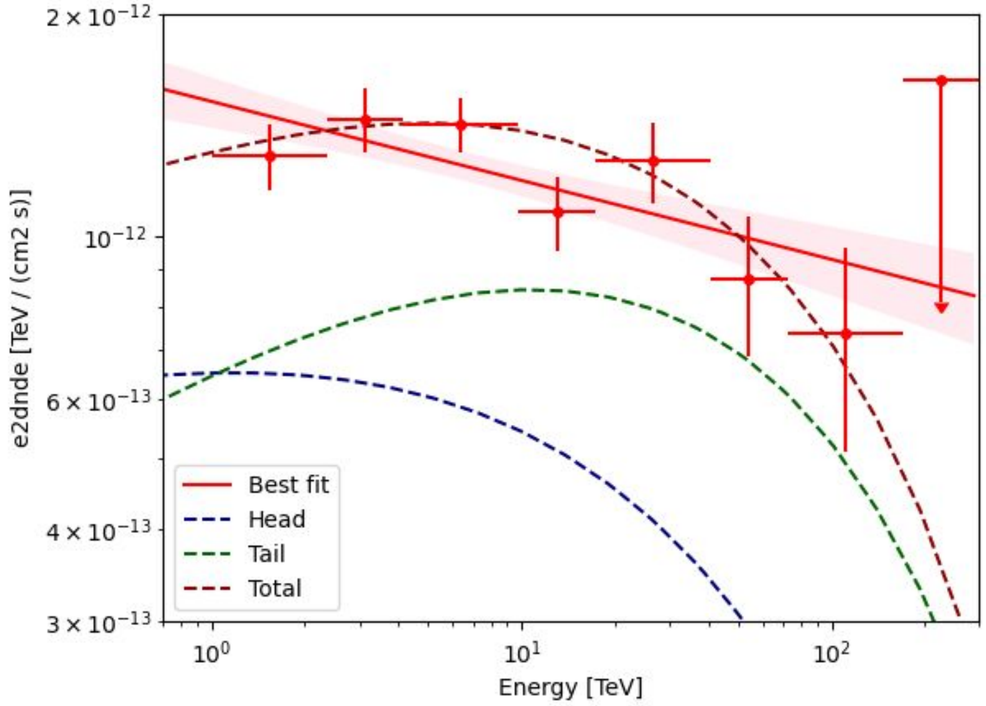
- Centroid position of the emission is **energy dependent**.
  - Fits were run in different energy bands. Results display γ-ray emission at higher energies shift towards the "tail", while lower energy emission extends nearer the "head".



Spectral Analysis - 1

- We used the **Elliptical Gaussian** spatial model for all tested spectral models.
  - A basic power law fits the data well, while including a cut-off or curved spectrum improves results by just under 3σ compared to the power law model.

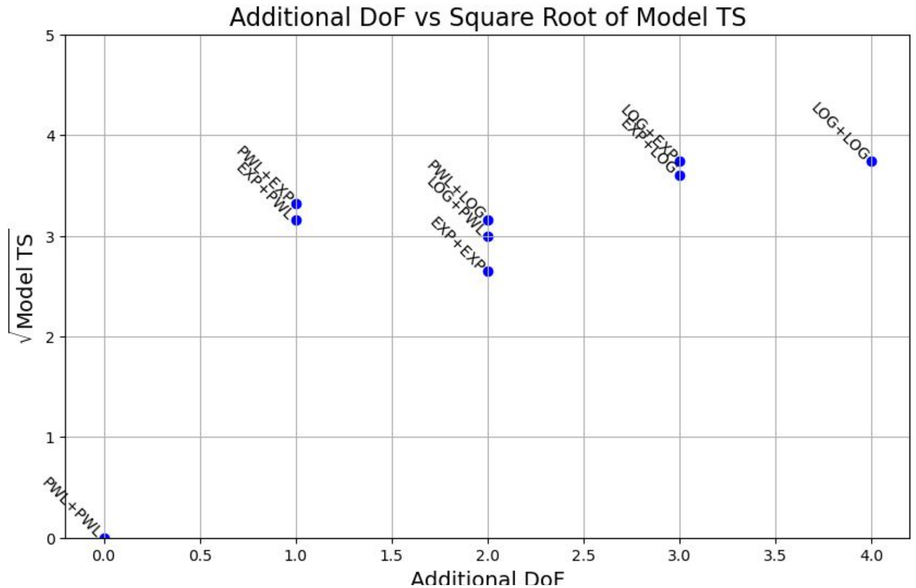
Model	Spectral Model	TS	Additional DoF
PowerLaw	$N_0 \cdot \left(\frac{E}{E_0}\right)^{-\gamma}$	0	0
ExponentialCutoff	$N_0 \cdot \left(\frac{E}{E_0}\right)^{-\gamma} \exp -\left(\frac{E}{E_{cut}}\right)$	6	1
LogParabola	$N_0 \cdot \left(\frac{E}{E_0}\right)^{-\alpha-\beta \log(E/E_0)}$	5	2

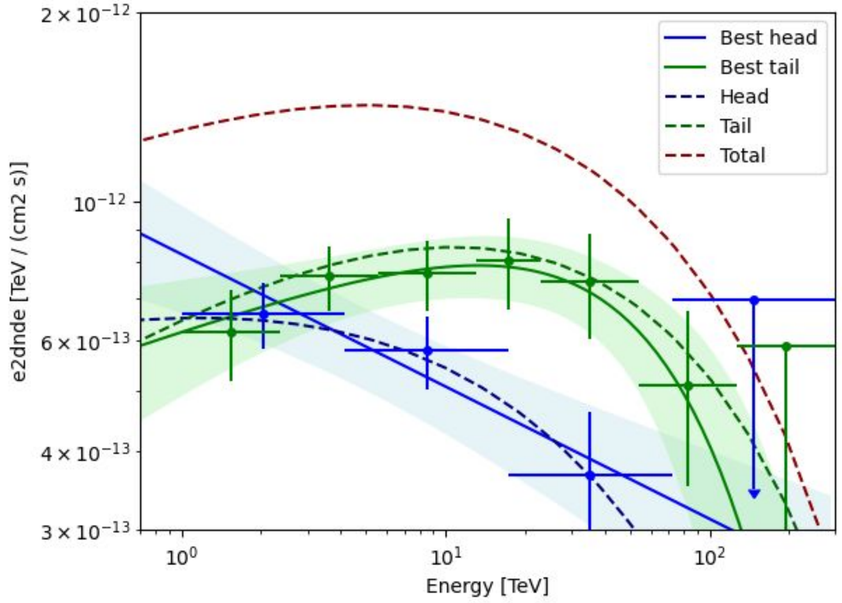


Spectral Analysis - 2

- Driven by the energy-dependent spatial emission pattern, we opted to separately analyze the emission spectrum in the **"head"** and **"tail"** regions.
- **“Head”** region:
  - no evident cut-off in the best-fit model for the emission it is subdominant with respect to the “tail” one
- **“Tail”** region:
  - cut-off in the γ-ray energy emission of 91 ± 6 TeV

implies a hadronic cut-off at about 1 PeV!





Conclusions

Goal: Testing ASTRI Mini-Array's potential in understanding the complex morphology of LHAASO J2226+6057 and exploring potential improvements.

- **Conclusions**
  - We have simulated the observation for the ASTRI Mini-Array of LHAASO J2226+6057 in the assumption that the source emission originates from two main regions, the “head” (leptonic) and "tail" (hadronic)
  - The ASTRI Mini-Array can verify the energy-dependent morphology by detecting the emission peak at low energies near the "head" and at higher energies near the "tail."
  - Compared to previous IACTs, the ASTRI Mini-Array spectral performances can uncover distinct spectral variations among source regions, providing a key tool for understanding the diverse PeVatronic emission nature.

1 telescope operative → by 2023
(already on-site!!)