PeVatrons with the ASTRI Mini-Array

A.Giuliani (INAF / IASF Milano)
for the ASTRI Project

CDHY PeVatron Workshop

The ASTRI Mini-Array

- The ASTRI Mini-Array is an array of 9 Cherenkov telescopes of the 4 meters class under construction at the **Observatorio del Teide** in Tenerife (Spain)

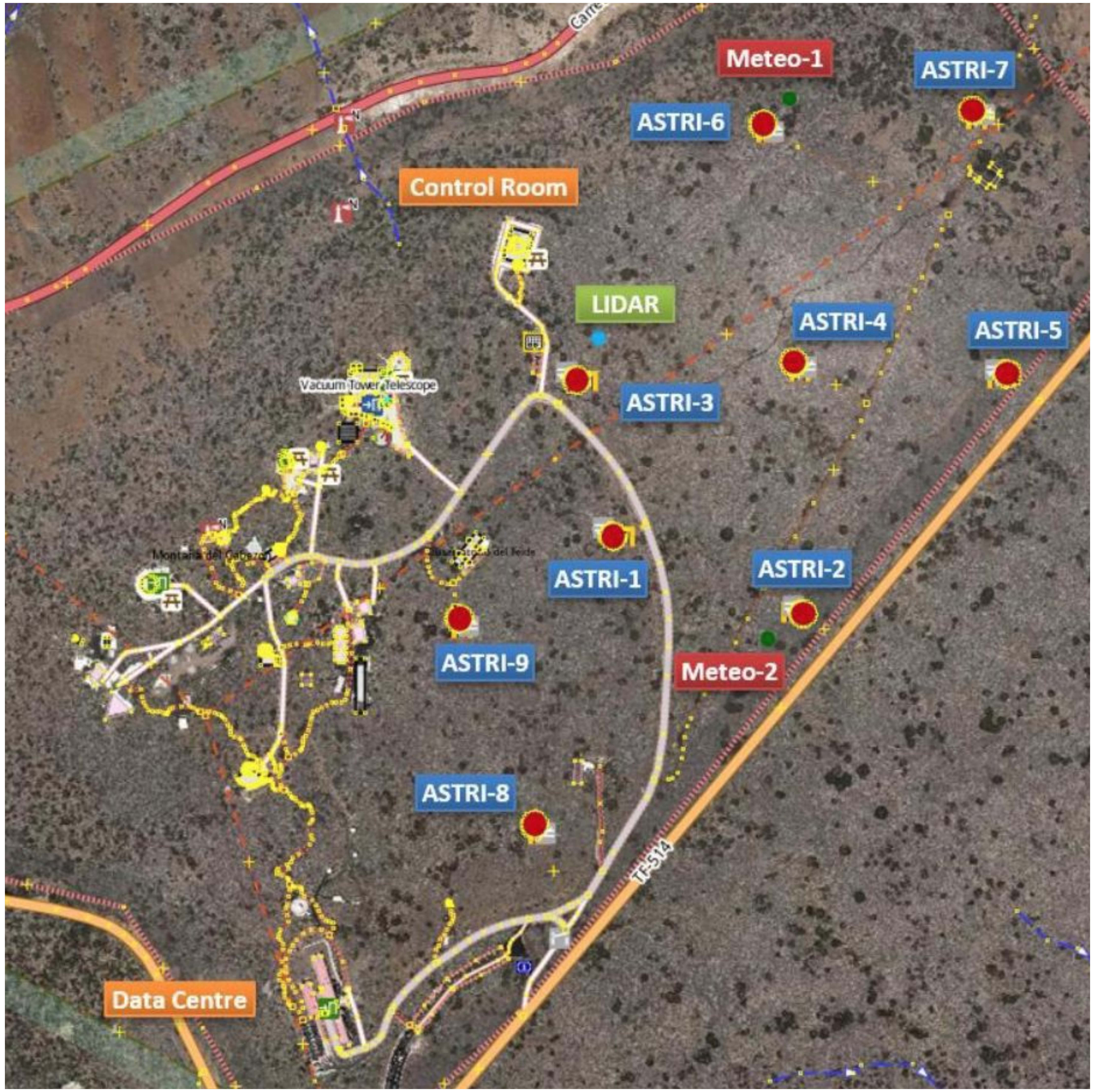
- About researchers belonging to **INAF** institutes (IASF-MI, IASF-PA, OAS, OACT, OAB, OAPD, OAR) Italian Universities (Uni-PG, Uni-PD, Uni-CT, Uni-GE, PoliMi), **INFN**, **Fundacion Galileo Galilei**, **IAC** (Spain), **University of Sao Paulo** (Brazil), **North-West University** (South Africa), **Université & Observatoire de Genève** (CH).

- End to end approach, from design/implementation of all HW/SW components to dissemination of final scientific products

- Unprecedented performance and wide FoV for observations at **multi-TeV energy scale**

- **Core Science Program** in the first 4 years

- **Important synergies** with other Northern ground-based gamma-ray facilities (LHAASO, HAWC, MAGIC, VERITAS, CTAO-N)



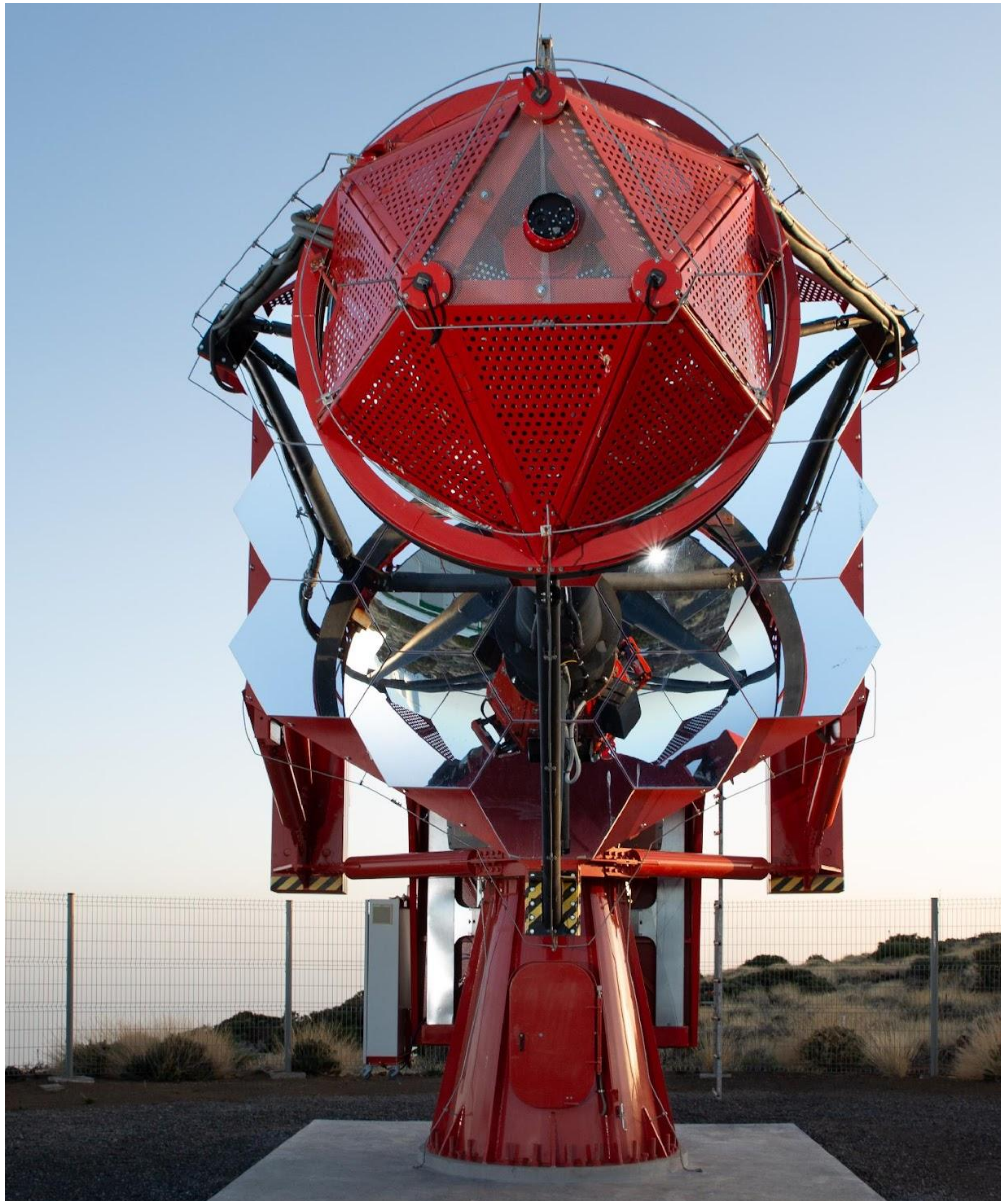
ASTRI Telescopes

The current ASTRI telescopes are an evolution of the ASTRI-Horn prototype telescope

The electromechanical structure was optimized in terms of mass, functionality and maintainability (mass has been reduced by 30%).

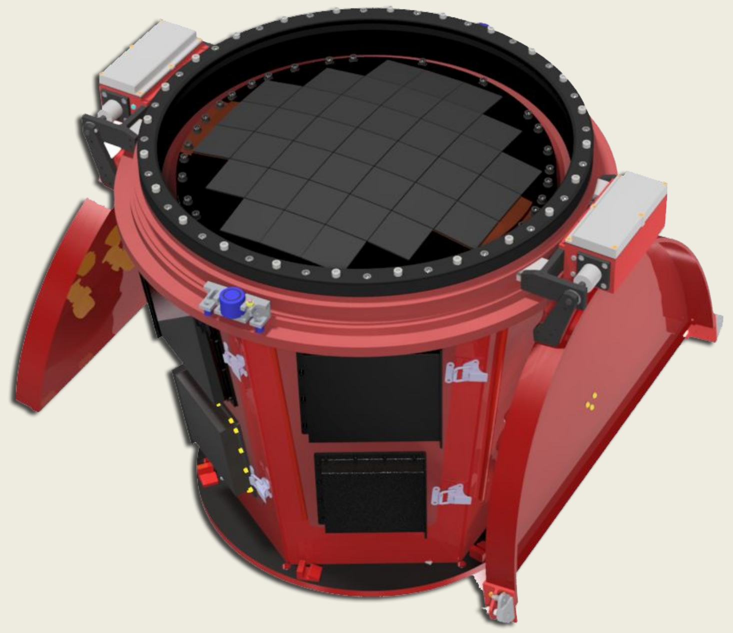
Dual-mirror optical layout (Schwarzschild-Couder)

- Optimal PSF across the entire FoV



ASTRI Silicon photomultipliers camera

- 37 (8x8) matrices are arranged to adapt to the curved focal plane of the telescope. ***Wide FOV (~10°)***
- Small pixel-size (0.19°)
- Work also with ***moonlight***

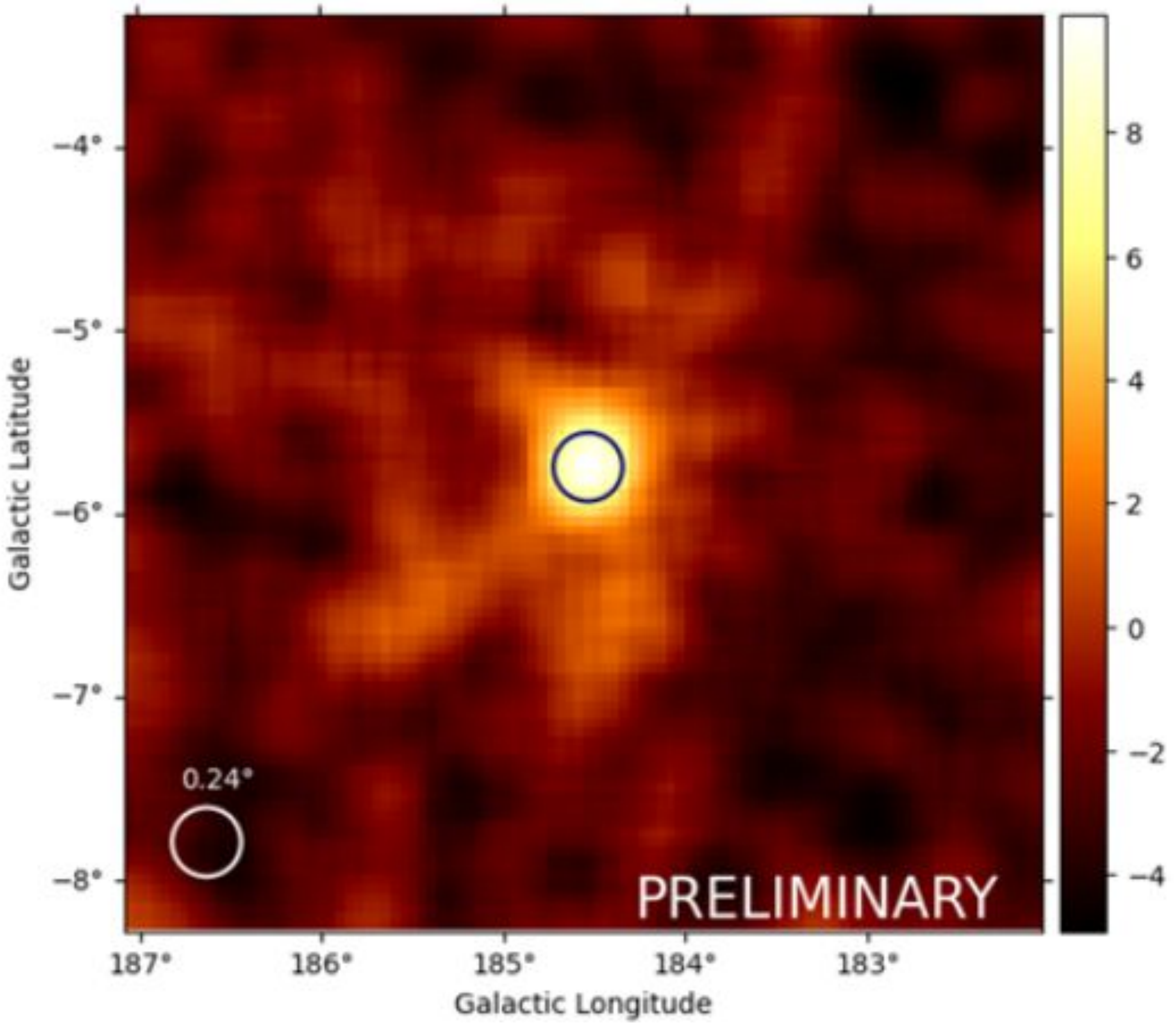


ASTRI Mini Array Status

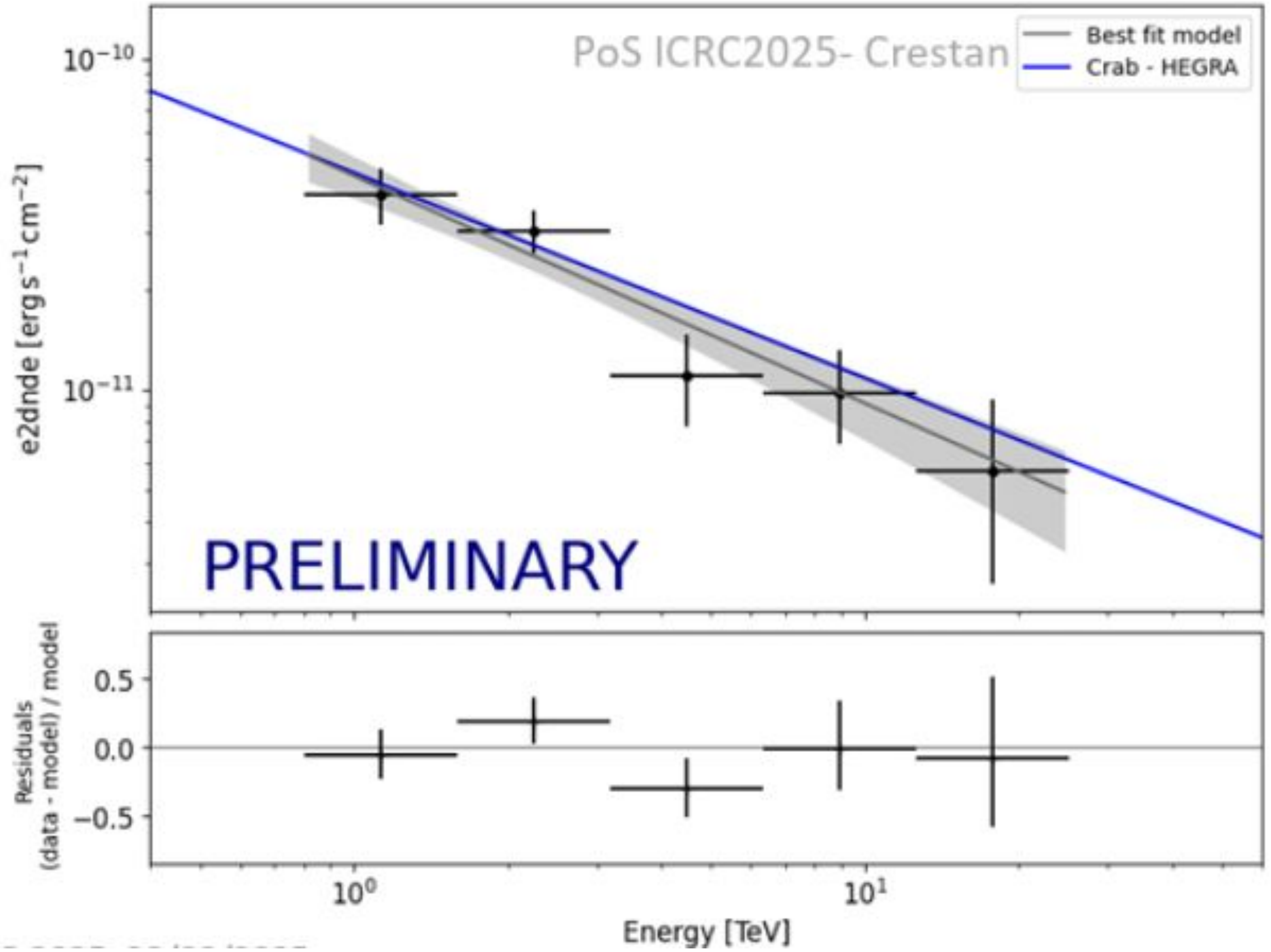
- 7 out of 9 telescopes fully assembled
- Remaining 2 telescopes to be delivered next year
- Second camera scheduled for installation next month
- Subsequent cameras to be deployed in the following months

ASTRI-1: Crab Spectrum

- Subsample of ~9 h of Crab data
- Detection at ~10σ
- RA/DEC = 83.65° , 22.05°
- 0.03°away from the position of Crab Nebula

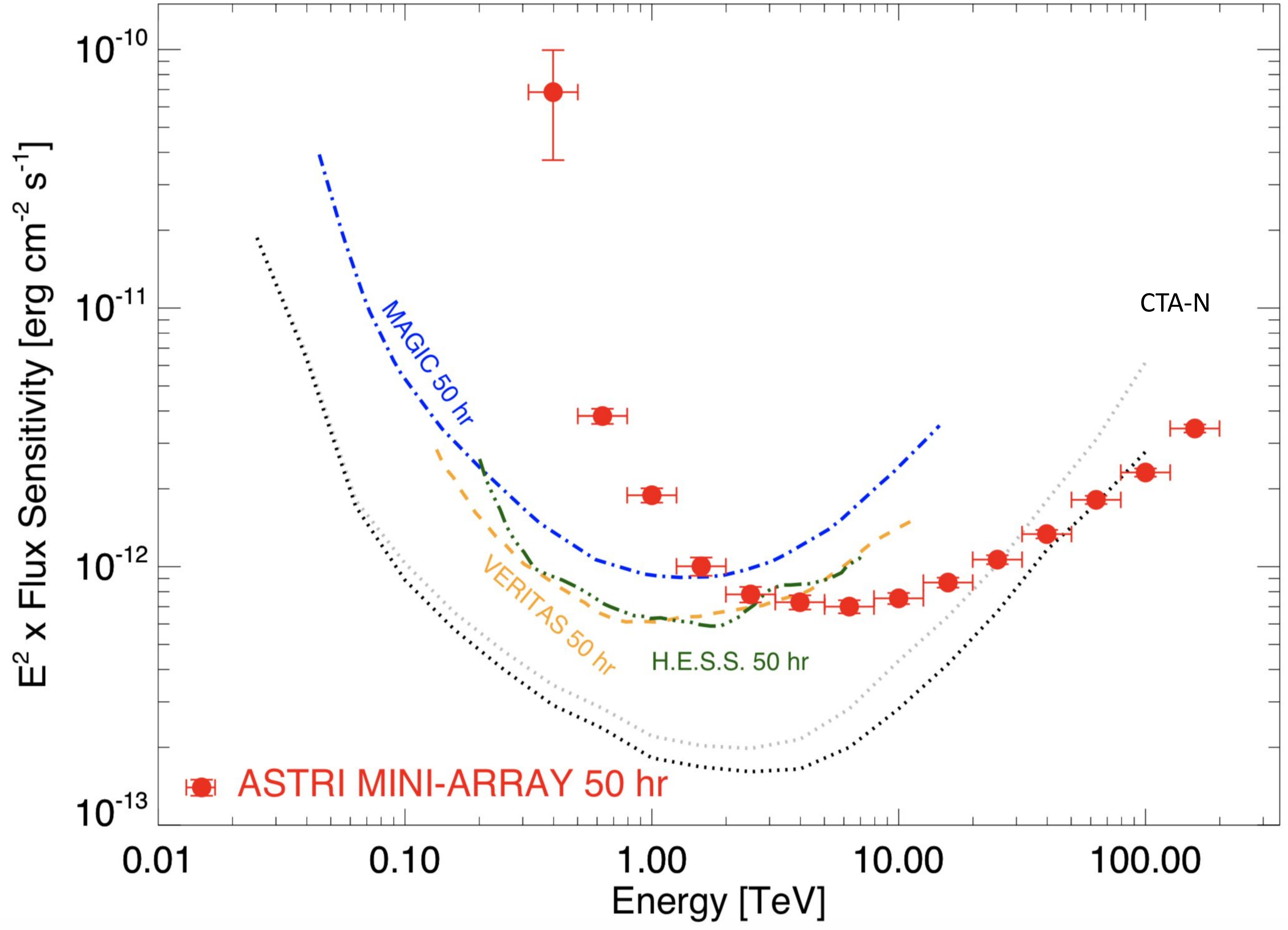


- Power-law fit in 1-30 TeV energy range: Index = 2.68 ± 0.13, N = 3.7 ± 0.5 TeV^{-1} cm^{-2} s^{-1}
- There is a good agreement!
- Spectral points up to ~20 TeV in 9 h



ASTRI Performance

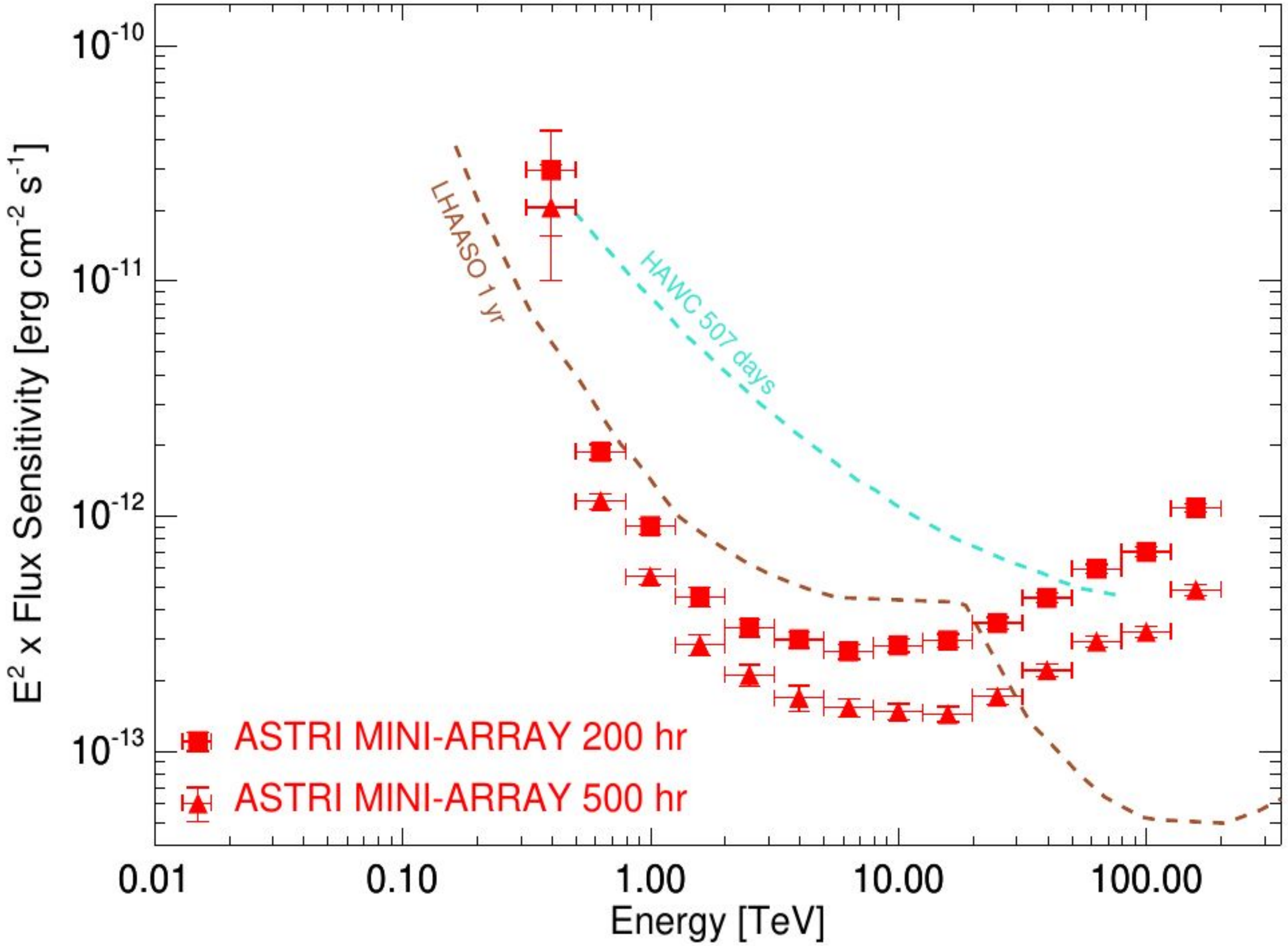
Expected performance



Sensitivity: better than that of current IACTs (E > a few TeV)

- Extend the spectra of already detected sources and/or measure cut-offs

ASTRI Performance

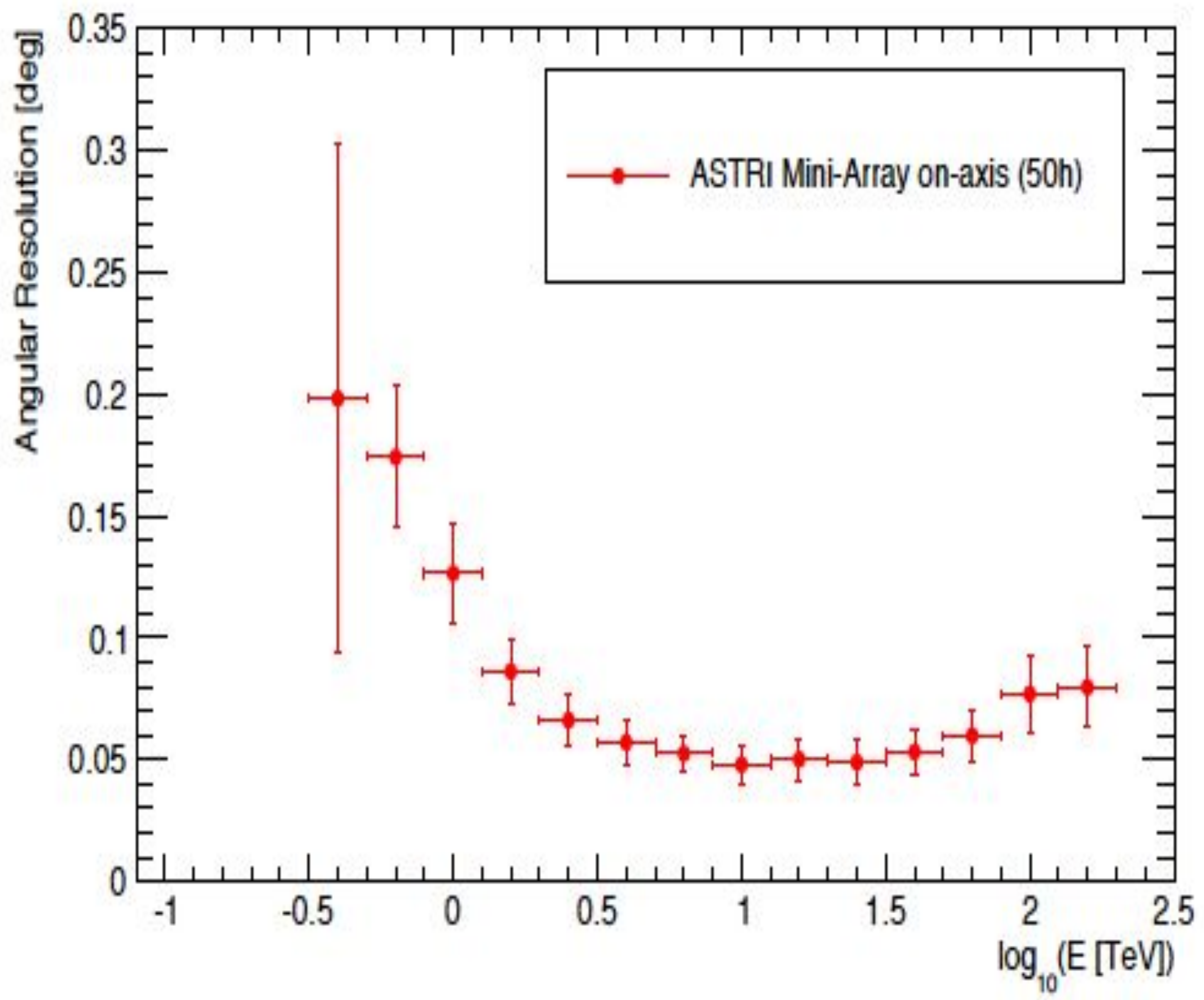


Expected performance

Sensitivity: better than that of current IACTs (E > a few TeV)

- Extend the spectra of already detected sources and/or measure cut-offs

ASTRI Performance



Expected performance

Sensitivity: better than that of current IACTs (E > a few TeV)

- Extend the spectra of already detected sources and/or measure cut-offs

Energy/Angular resolution: ~ 10% / ~ 3‘ (E > a few TeV)

- Characterize the morphology of extended sources at the highest VHE

Observing Strategy

ASTRI needs deep exposures

Strategy :

Focus on few sky fields in order to obtain long exposures

3 aces up the sleeve :

- Large FoV
    → Several sources in the FOV
- Observations with moonlight
    → Increases avail. time ~50-80%
- Large Z.A.
    → Increase Aeff @ high energies

Observing Strategy

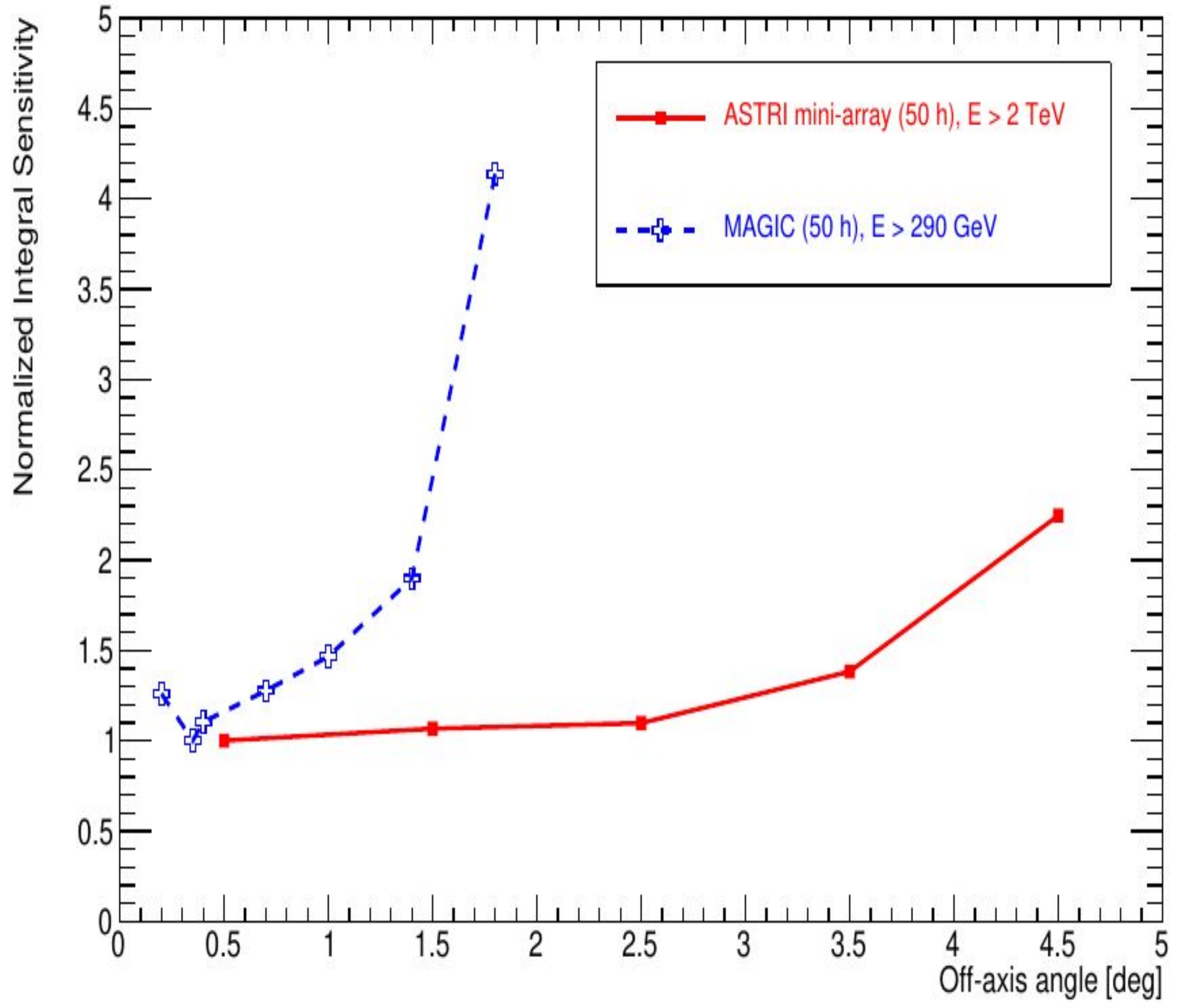
ASTRI needs deep exposures

Strategy :

Focus on few sky fields in order to obtain long exposures

3 aces up the sleeve :

- Large FoV
  - → Several sources in the FOV
- Observations with moonlight
  - → Increases avail. time ~50-80%
- Large Z.A.
  - → Increase Aeff @ high energies



Observing Strategy

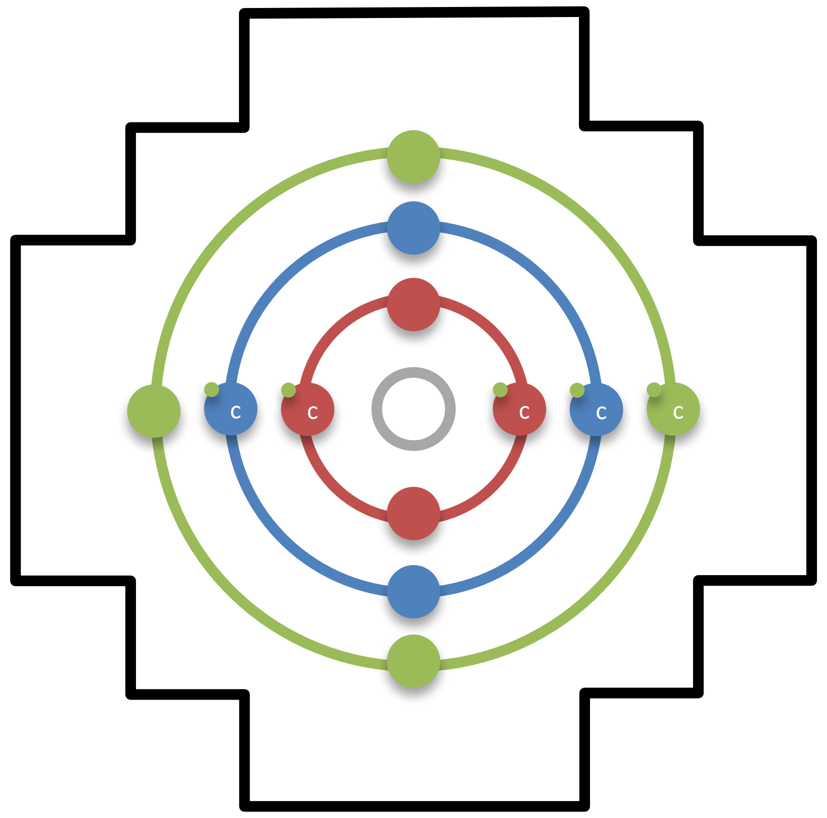
ASTRI needs deep exposures

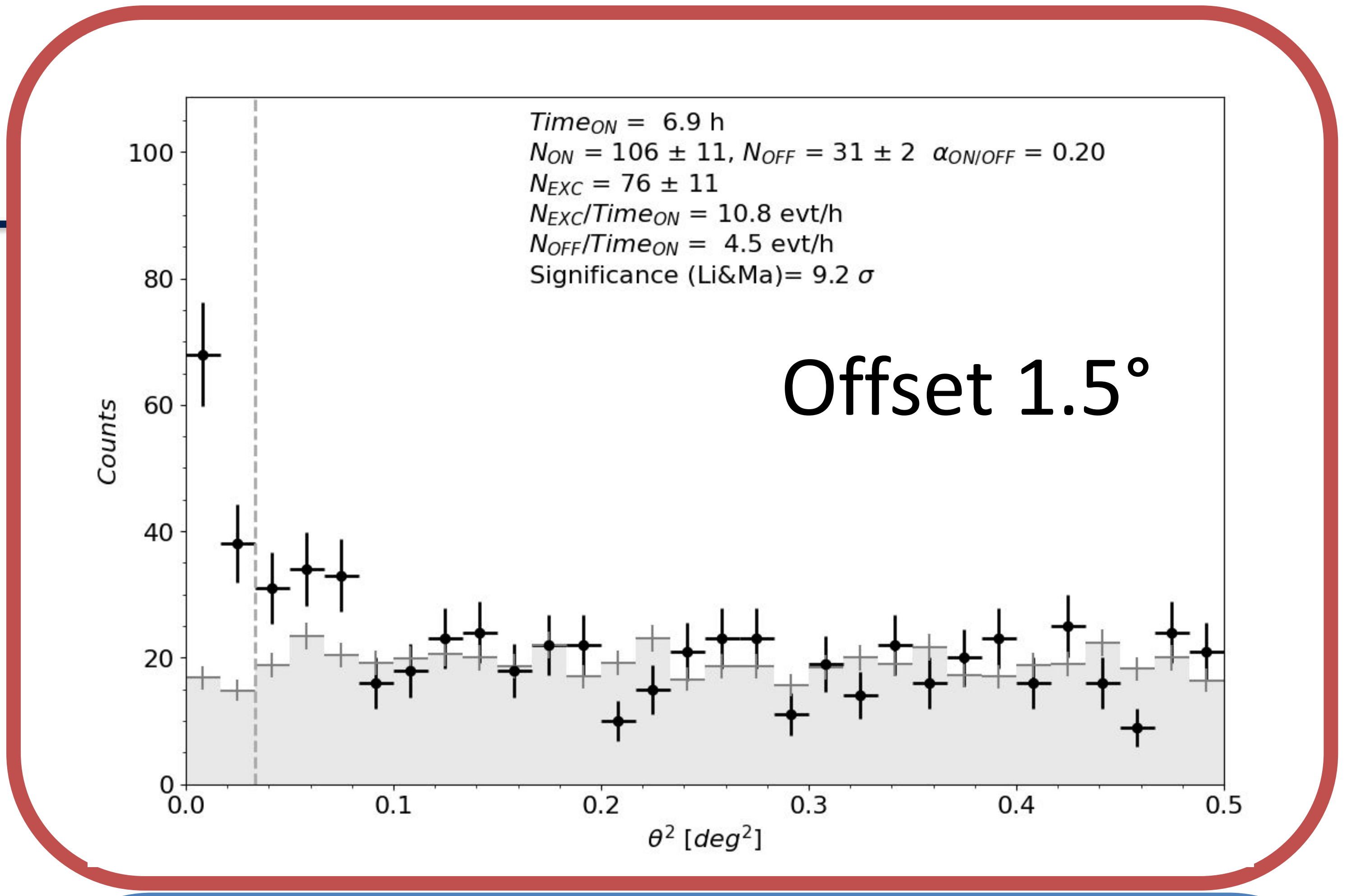
Strategy :

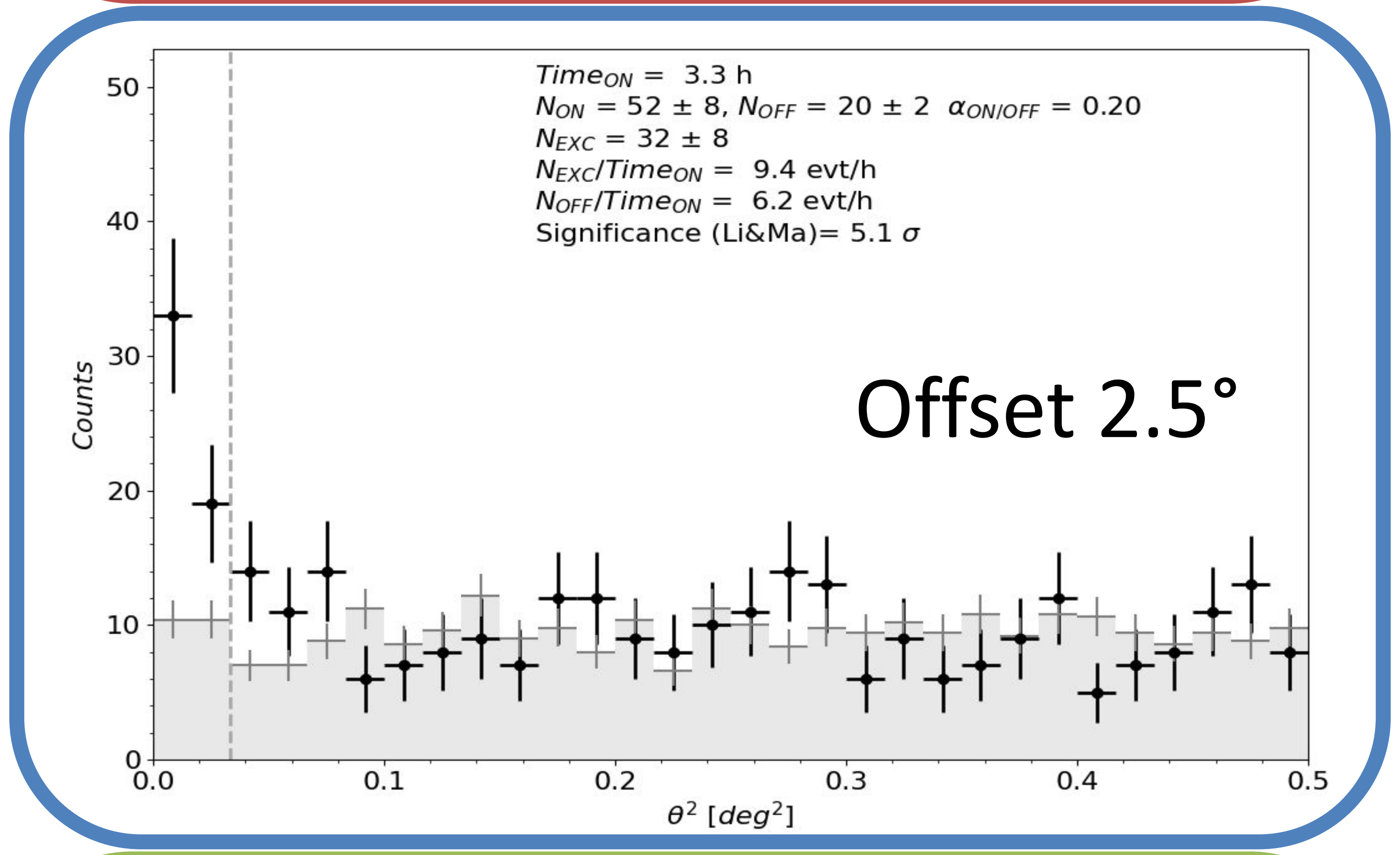
Focus on few sky fields in order to obtain long exposures

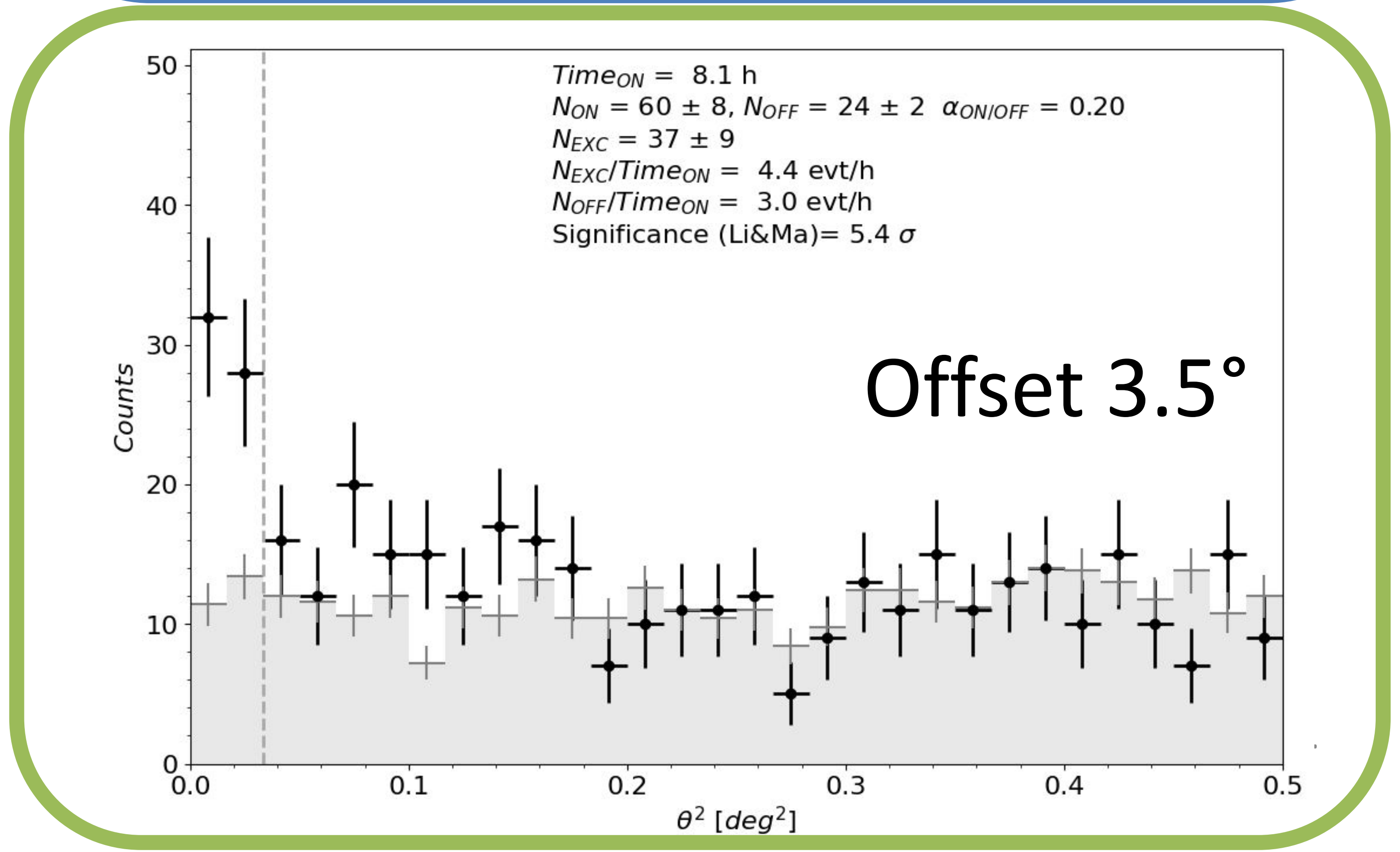
3 aces up the sleeve :

- Large FoV
  → Several sources in the FOV
- Observations with moonlight
  → Increases avail. time ~50-80%
- Large Z.A.
  → Increase Aeff @ high energies









Observing Strategy

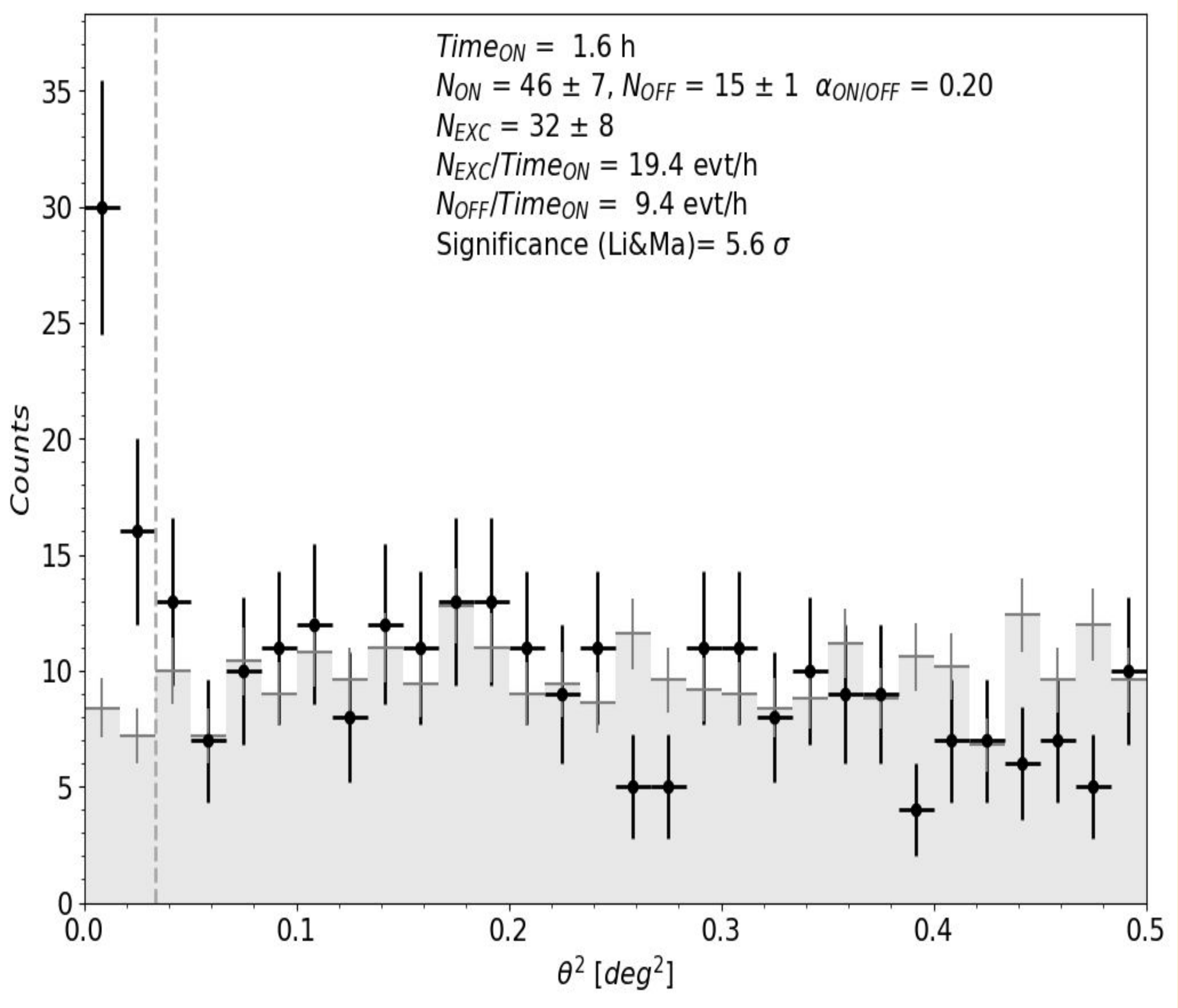
ASTRI needs deep exposures

Strategy :

Focus on few sky fields in order to obtain long exposures

3 aces up the sleeve :

- Large FoV
  → Several sources in the FOV
- Observations with moonlight
  → Increases avail. time ~50-80%
- Large Z.A.
  → Increase Aeff @ high energies



Crab runs taken during the first night:
- 4 in moonlight condition
- Offset angle: 0.5°

Observing Strategy

ASTRI needs deep exposures

Strategy :

Focus on few sky fields in order to obtain long exposures

3 aces up the sleeve :

- Large FoV
  → Several sources in the FOV
- Observations with moonlight
  → Increases avail. time ~50-80%
- Large Z.A.
  → Increase Aeff @ high energies

ASTRI Science : overview

ASTRI Mini-Array

Origin of Cosmic Rays

- PeVatrons
- CRs Acceleration and Propagation
- Pulsar Wind Nebulae and TeV Halos

Fundamental Physics

- Intergalactic fields
- Blazars
- LIV, ALP and DM

Transient Follow-Up

Non gamma-ray science

The ASTRI Mini-Array of Cherenkov Telescopes at the Observatorio del Teide

JHEAP, 2022, 35, 52

ASTRI Mini-Array Core Science at the *Observatorio del Teide*

JHEAP, 2022, 35, 1

Galactic Observatory Science with the ASTRI Mini-Array at the *Observatorio del Teide*

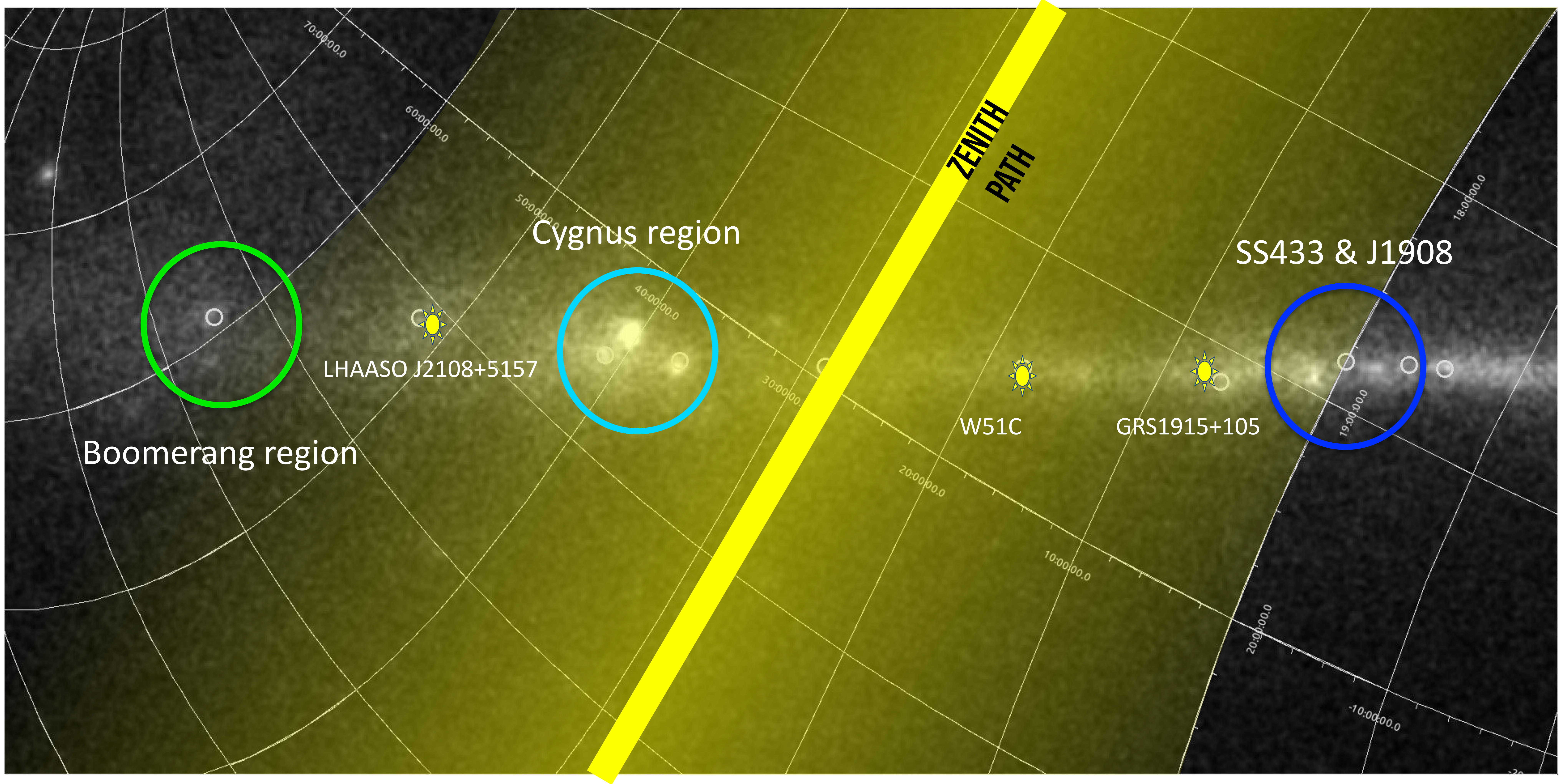
JHEAP, 2022, 35, 39

Extragalactic Observatory Science with the ASTRI Mini-Array at the *Observatorio del Teide*

JHEAP, 2022, 35, 91

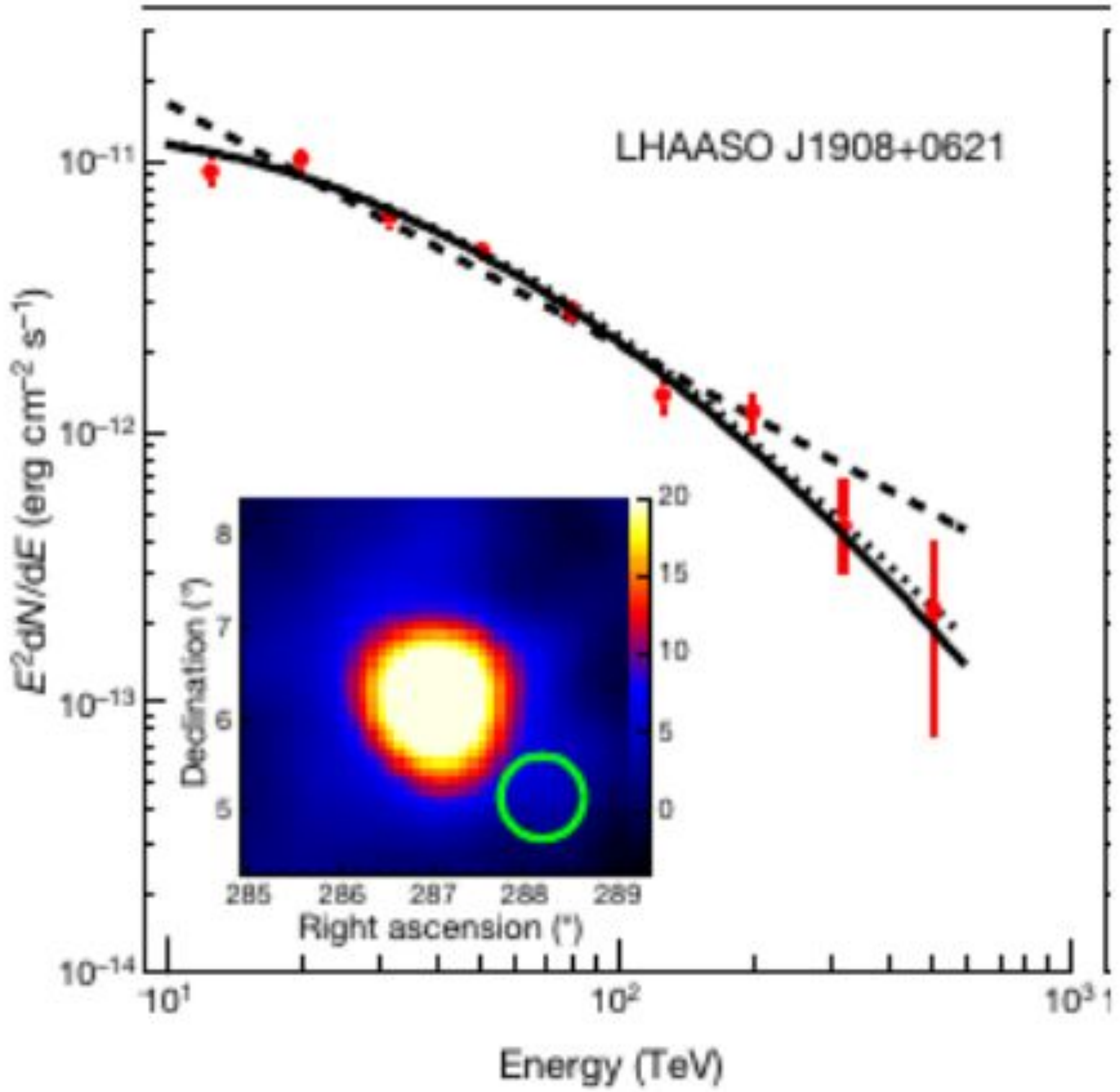
F. G. Saturni[a,b,*], C. H. E. Arcaro[c,d,e,f], B. Balmaverde[g], J. Becerra González[h,i], A. Caccianiga[j], M. Capalbi[k], A. Lamastra[a], S. Lombardi[a,b], F. Lucarelli[a,b], R. Alves Batista[l], L. A. Antonelli[a,b], E. M. de Gouveia Dal Pino[m], R. Della Ceca[j], J. G. Green[a,b], A. Pagliaro[k], C. Righi[n], F. Tavecchio[n], S. Vercellone[n], A. Wolter[j], E. Amato[o], C. Bigongiari[a,b], M. Böttcher[d], G. Brunetti[p], P. Bruno[q], A. Bulgarelli[r], M. Cardillo[s], V. Conforti[r], A. Costa[q], G. Cusumano[k], V. Fioretti[r], S. Germani[t], A. Ghedina[u], V. Giordano[q], A. Giuliani[v], F. Incardona[q], A. La Barbera[k], G. Leto[q], F. Longo[w,x], G. Morlino[o], B. Olmi[y], N. Parmiggiani[r], P. Romano[n], G. Romeo[q], A. Stamerra[a], G. Tagliaferri[n], V. Testa[a], G. Tosti[j,t], P. A. Caraveo[v] and G. Pareschi[n]

ASTRI Early Science



LHAASO Sources

LHAASO J1908+0621

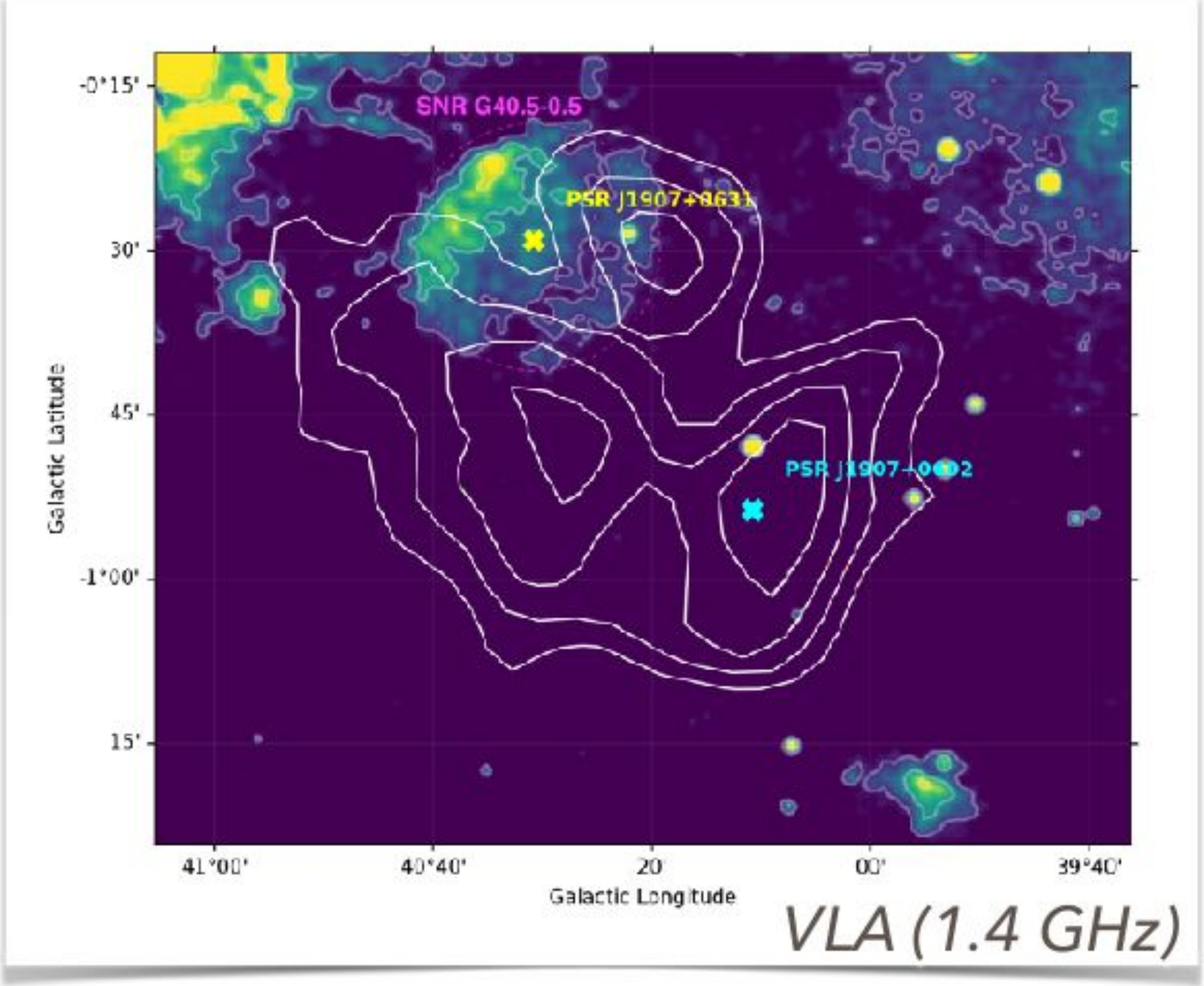


source	Number of on-source events	number of background events	exposure (hr)
LHAASO J0534+2202	67	5.5	2236.4
LHAASO J1825-1326	61	3.2	1149.3
LHAASO J1839-0545	26	4.2	1614.5
LHAASO J1843-0338	30	4.3	1715.4
LHAASO J1849-0003	36	4.8	1865.3
LHAASO J1908+0621	74	5.1	2058.0
LHAASO J1929+1745	29	5.8	2282.6
LHAASO J1956+2845	34	6.1	2461.5
LHAASO J2018+3651	42	6.3	2610.7
LHAASO J2032+4102	45	6.7	2648.2
LHAASO J2108+5157	30	6.4	2525.8
LHAASO J2226+6057	60	6.2	2401.3

Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 Î³-ray Galactic sources (LAHAASO coll.Â Nature, 2021)

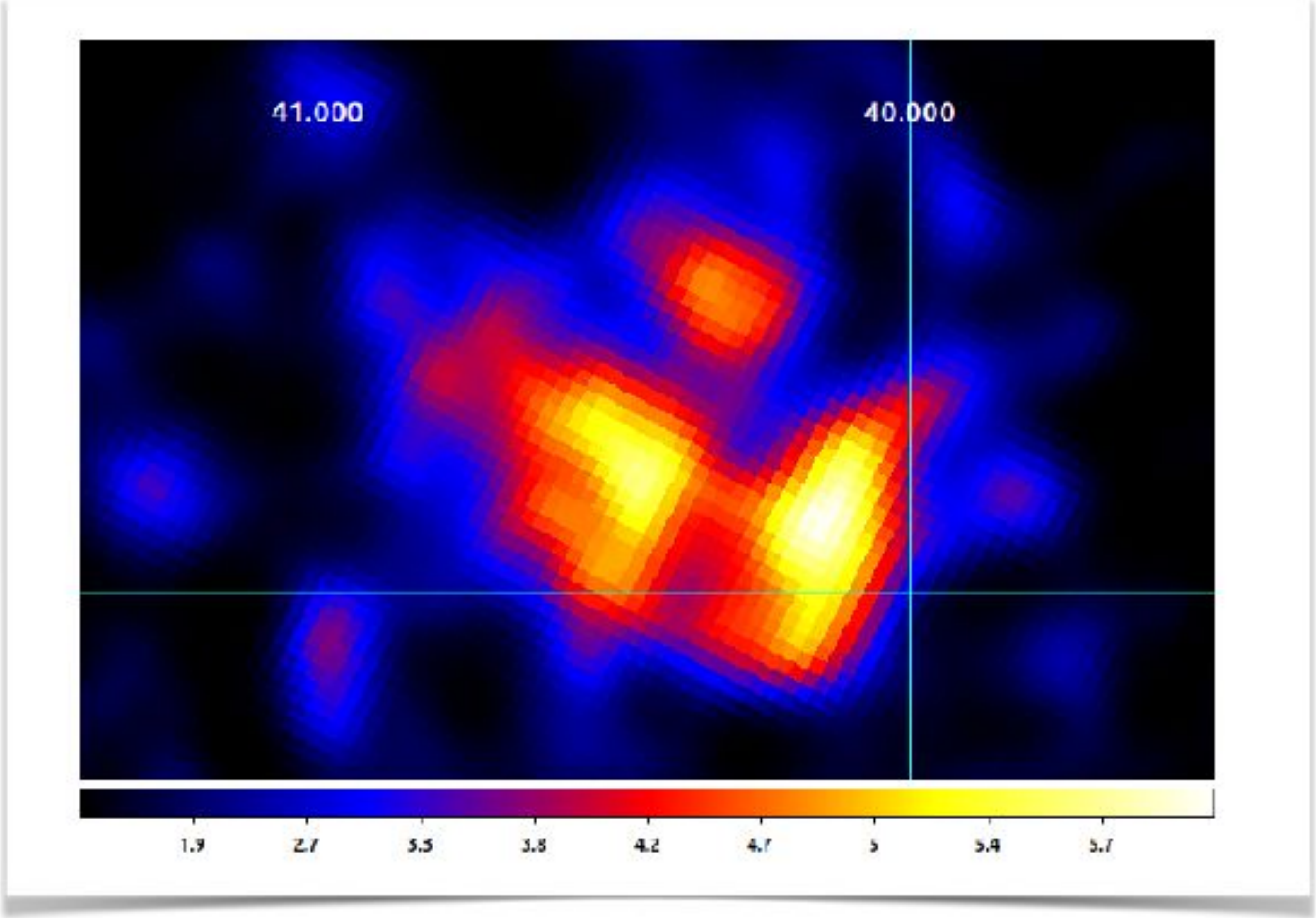
LHAASO J1908+0621

Source counterparts



VLA (1.4 GHz)

VERITAS (E>200 GeV)

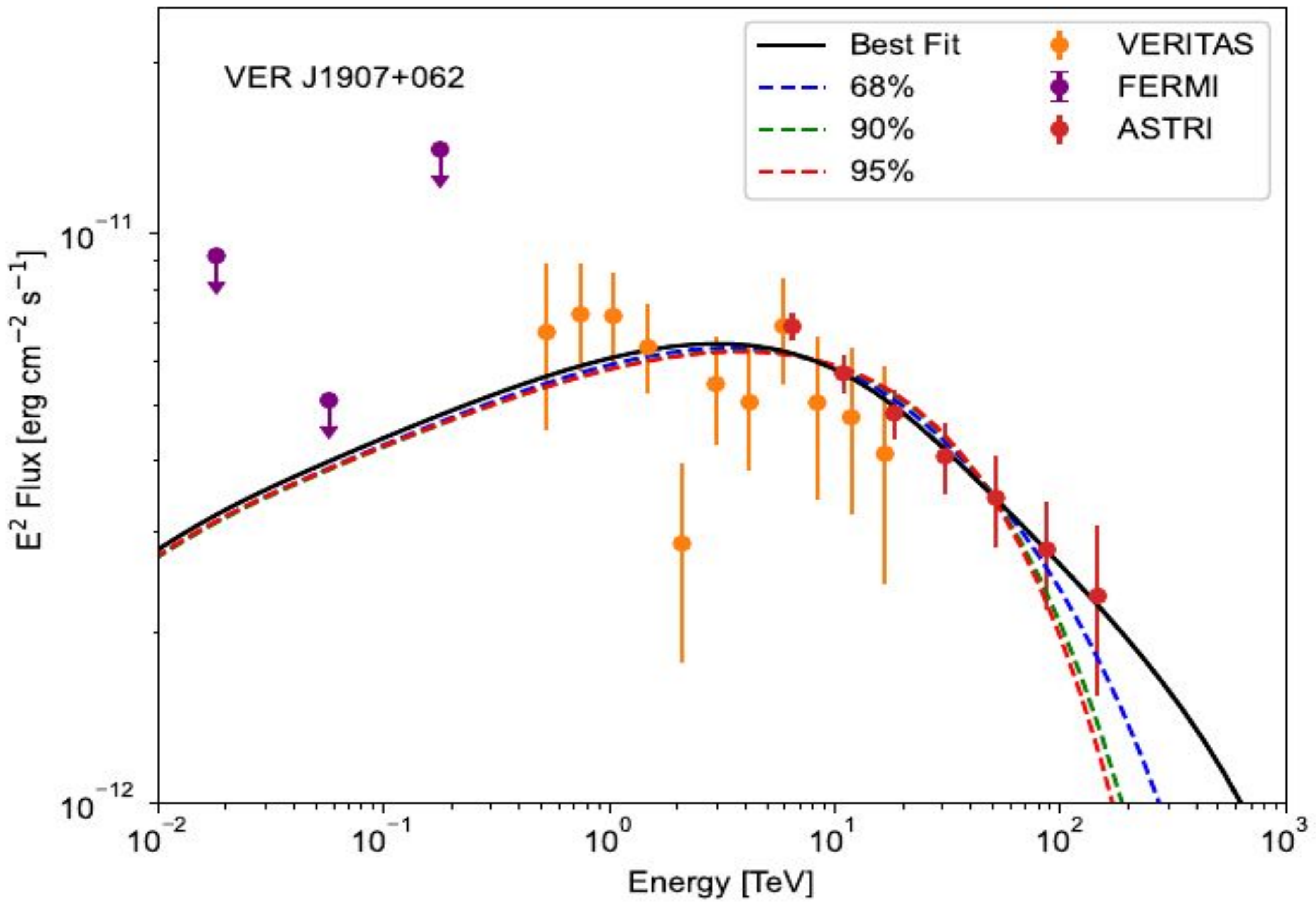


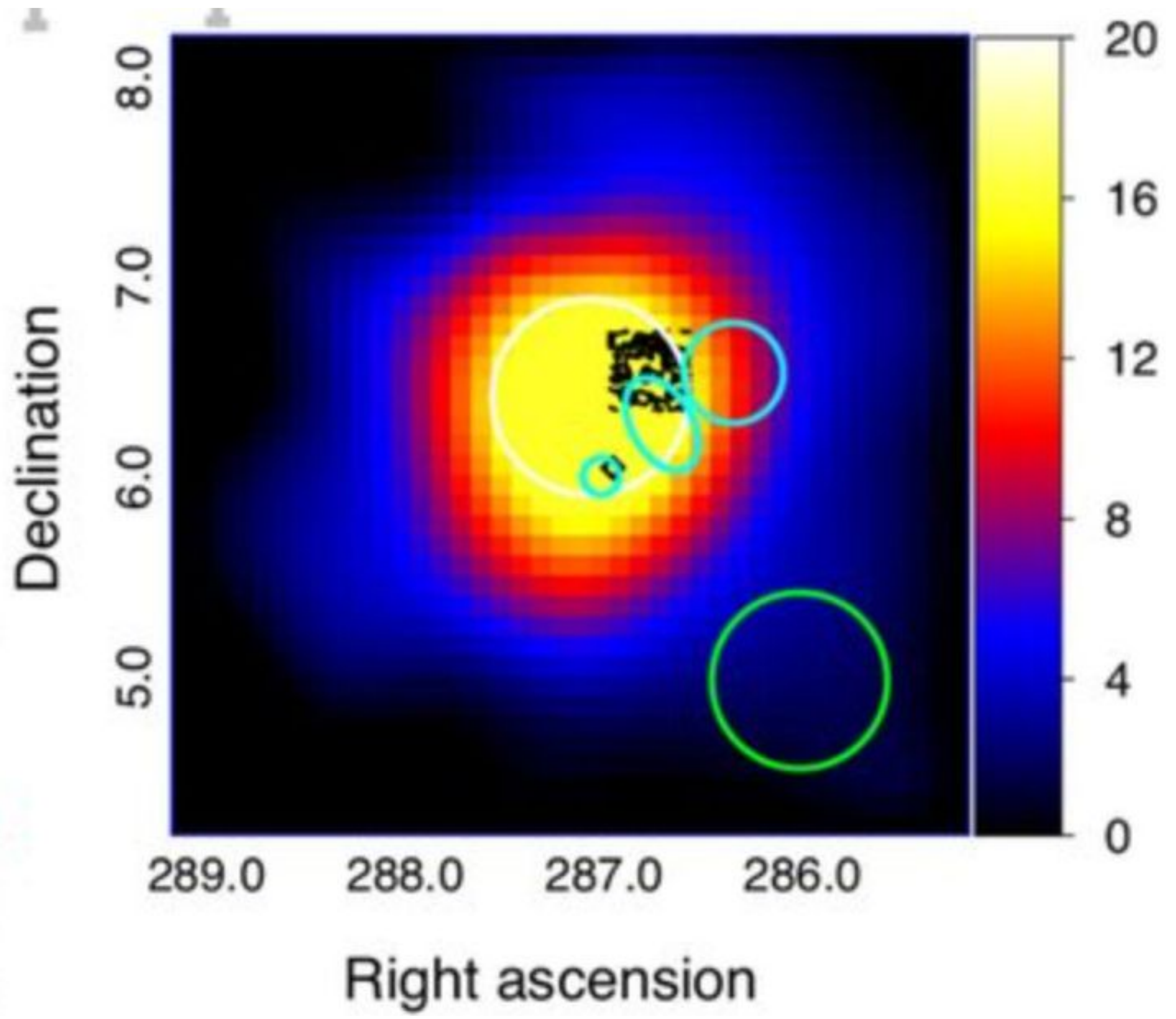
Follow up of LHAASO sources : the case of J1908+0621

ASTRI Mini-Array **200 hr simulation**

(up to E~200 TeV)

of [2HWC J1908+063]()





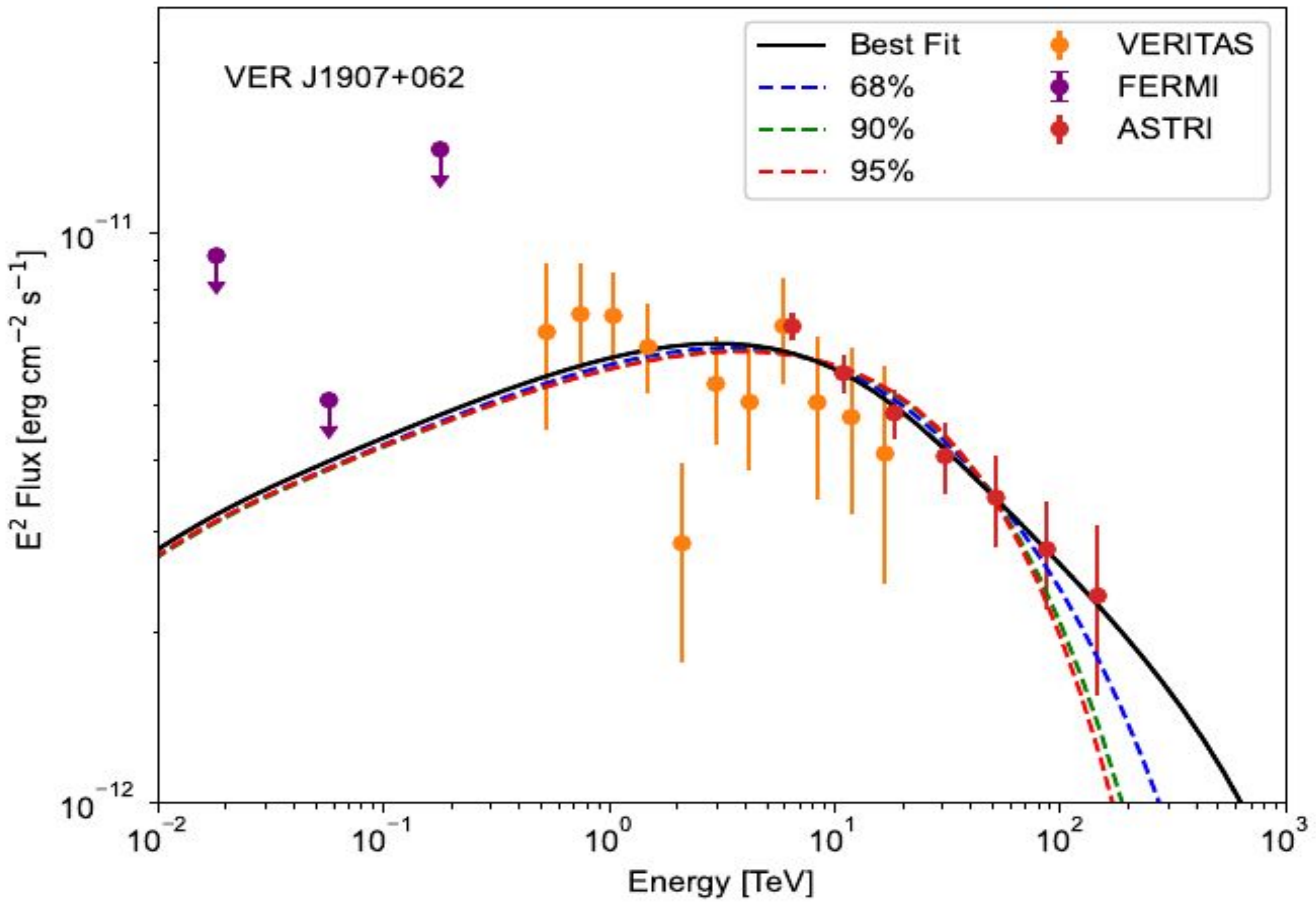
Follow up of LHAASO sources : the case of J1908+0621

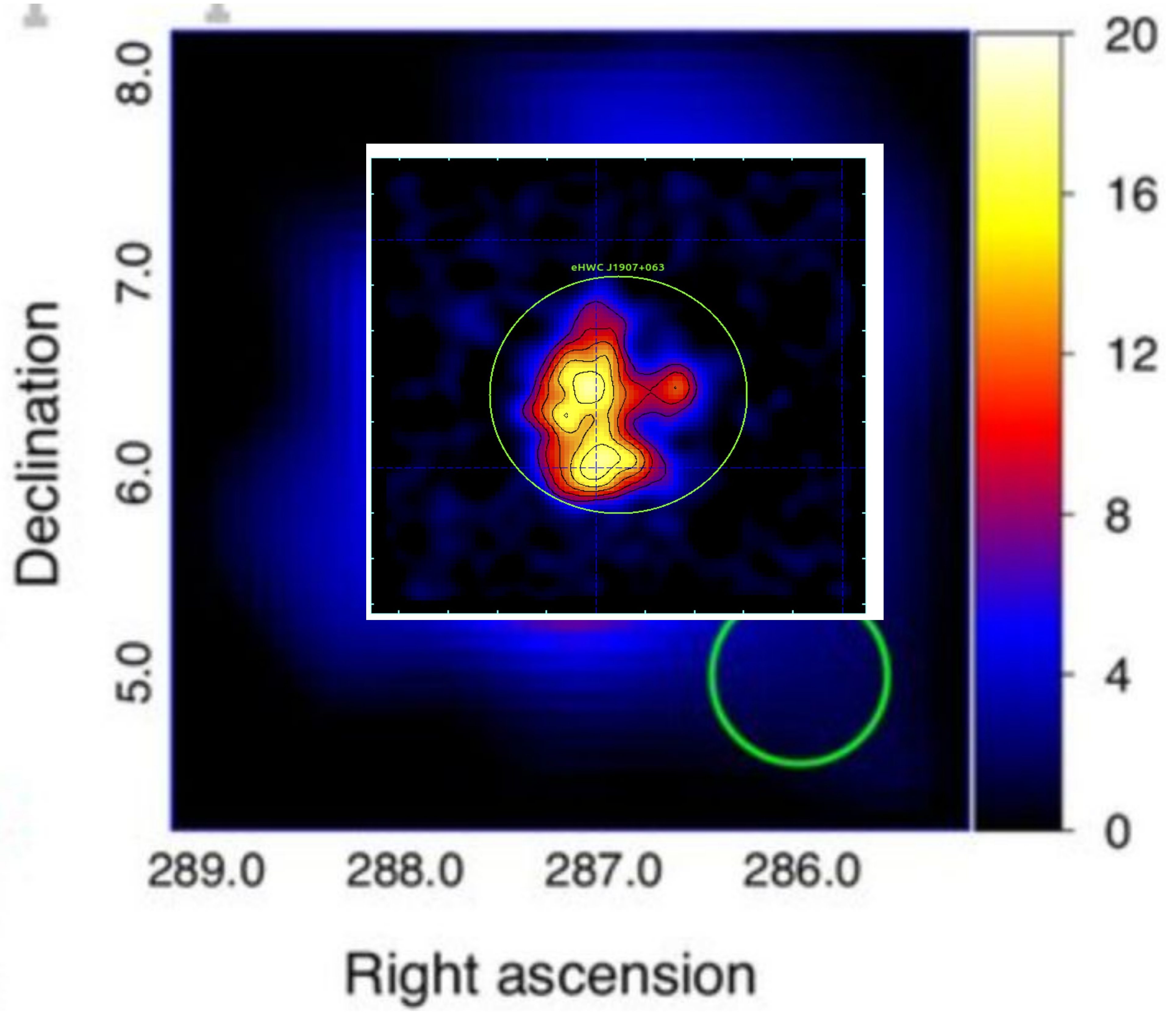
Mini-Array

ASTRI Mini-Array **200 hr simulation**

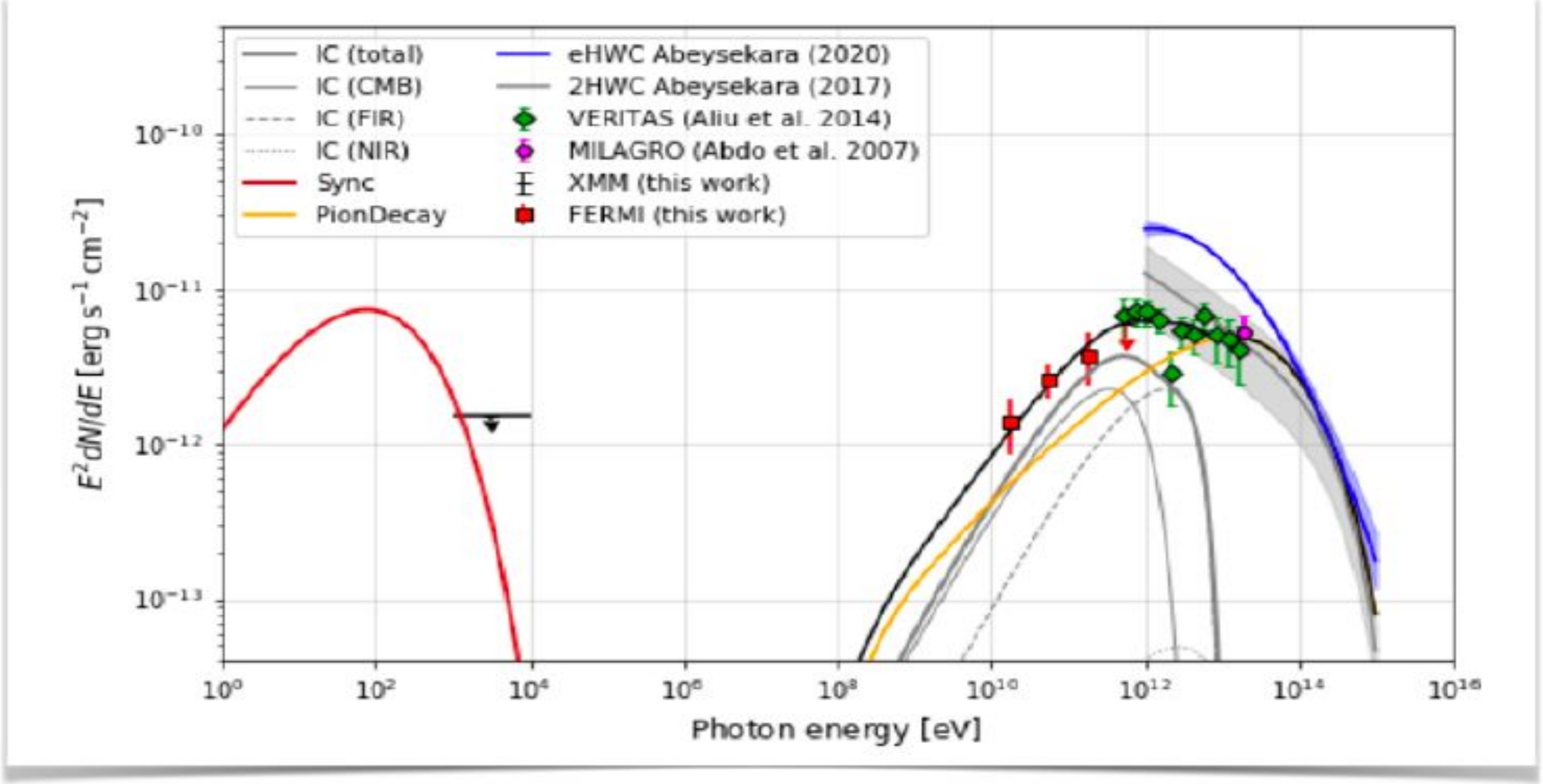
(up to E~200 TeV)

of [2HWC J1908+063]



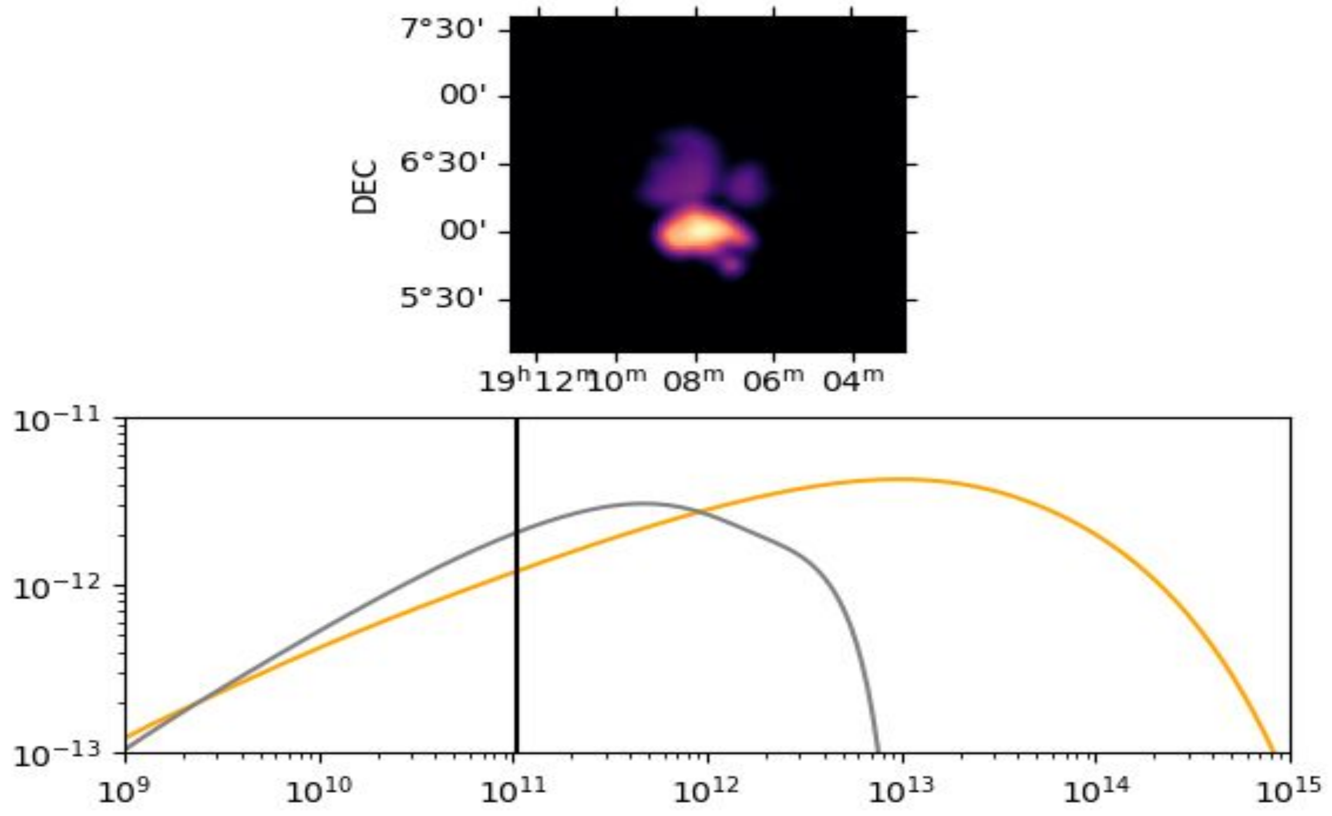


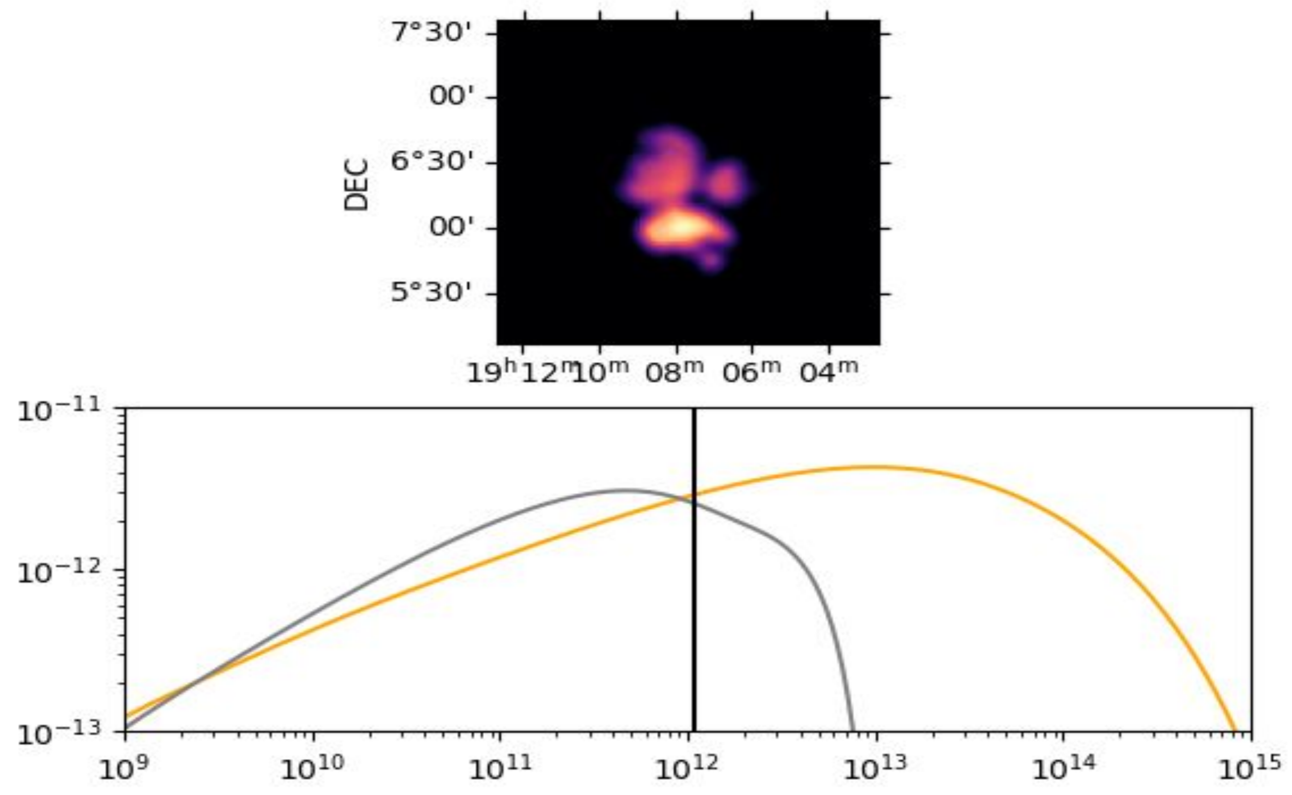
Follow up of LHAASO sources : the case of J1908+0621

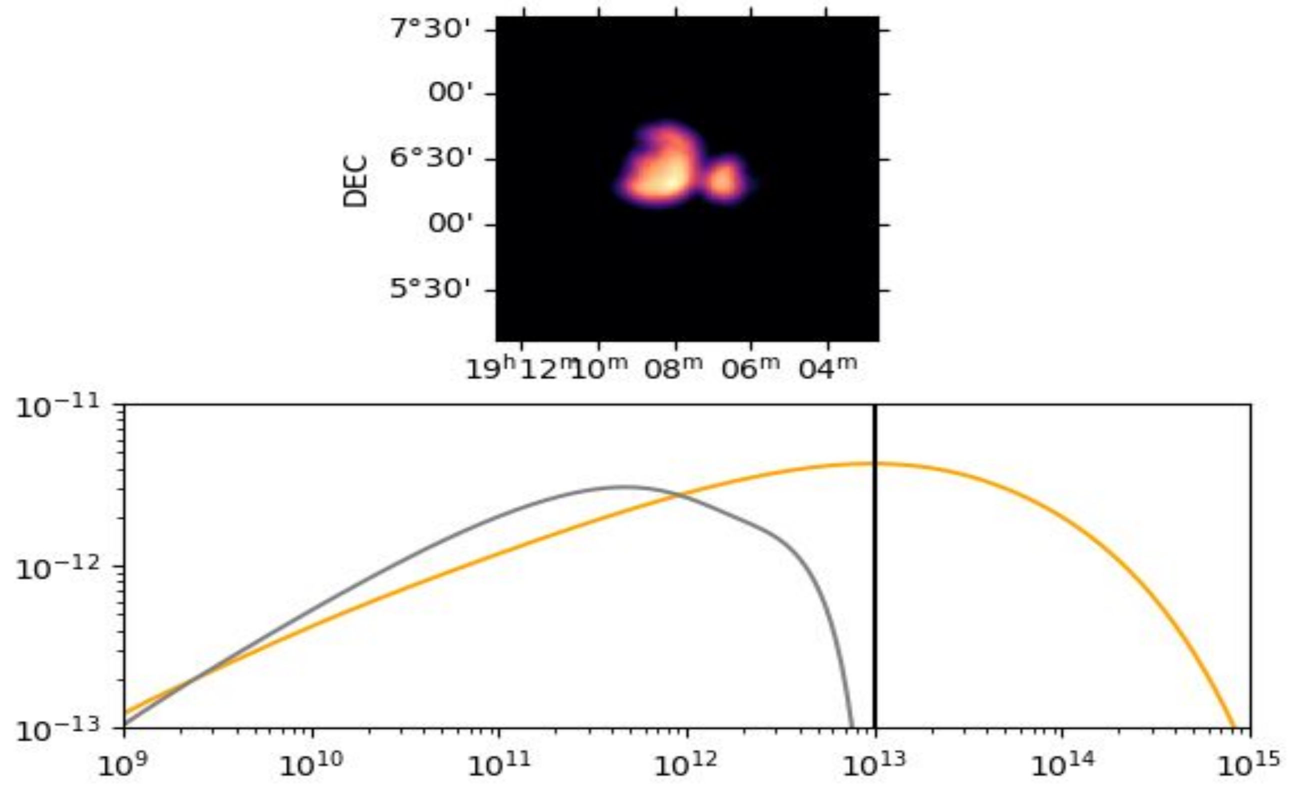


Model	Component	d (kpc)	Γ_1	Γ_2	W (erg)	E_0 (TeV)	E_b (TeV)	E_c (PeV)
1-zone	Leptonic	3	1.0 ± 0.4	2.6 ± 0.1	2×10^{47}	10	2.7 ± 0.7	7.1 ± 6.0
1-zone	Hadronic	3	1.0 ± 0.1	2.1 ± 0.1	7×10^{47}	30	2.8 ± 0.8	3.0 ± 0.9
1-zone	Hadronic	9	1.1 ± 0.2	2.1 ± 0.1	2×10^{49}	30	3.4 ± 1.2	1.9 ± 0.5
2-component	Leptonic	3	1.2	1.2	9×10^{46}	10	0.2	0.011
	Hadronic	3	1.6	2.0	4×10^{47}	30	200	>1
	Hadronic	9	1.6	2.0	1×10^{49}	30	200	>1

Crestan et al. MNRAS, 2021

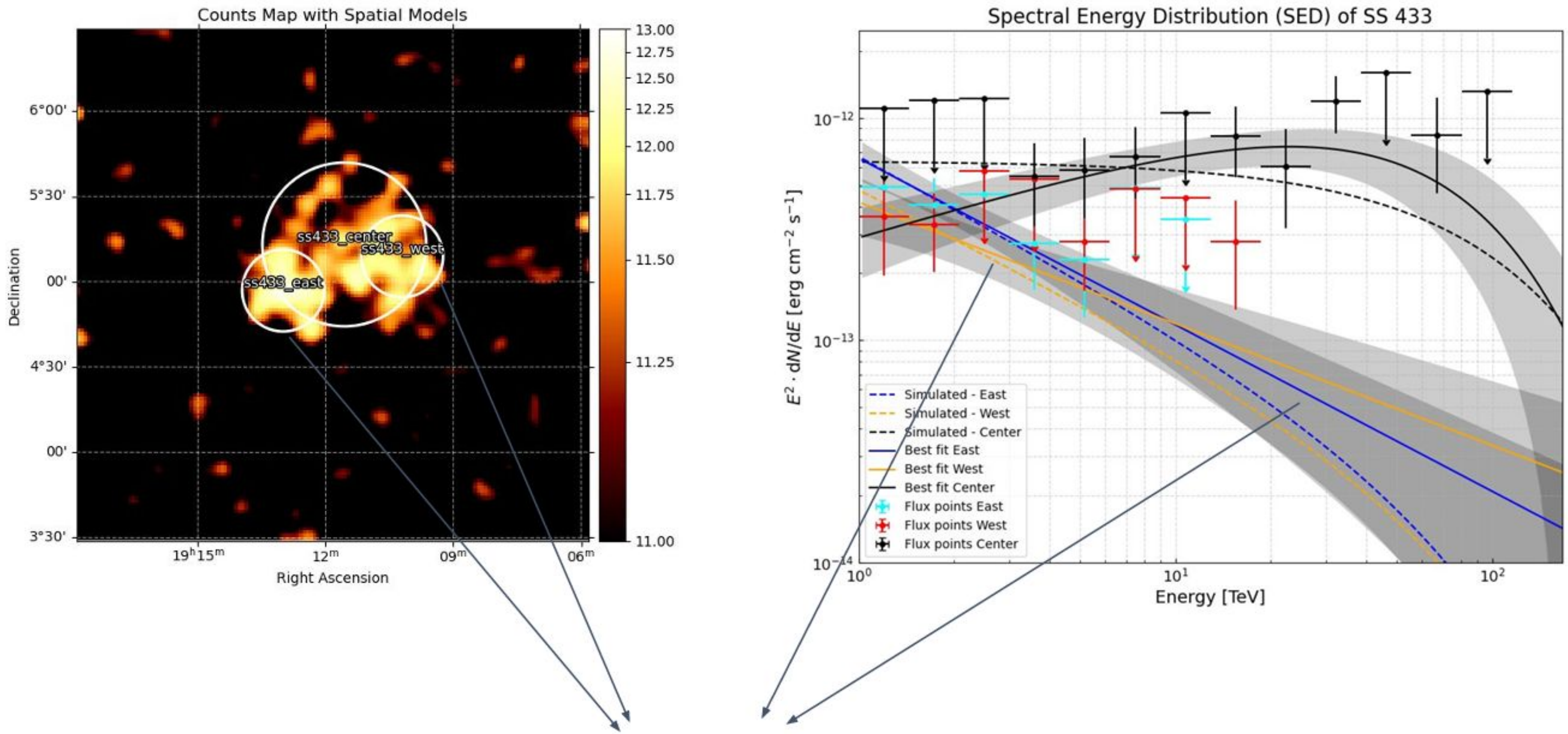






An Energy-dependent morphology (2 zone model)
can be **resolved by the ASTRI observations**

SS 433



Extended East/West lobes (both 0.16°σ Gaussian spatial model) with soft ECPL spectral shapes (Γ=2.8, E_{cut} = 80 TeV).

G 106.3+2.7

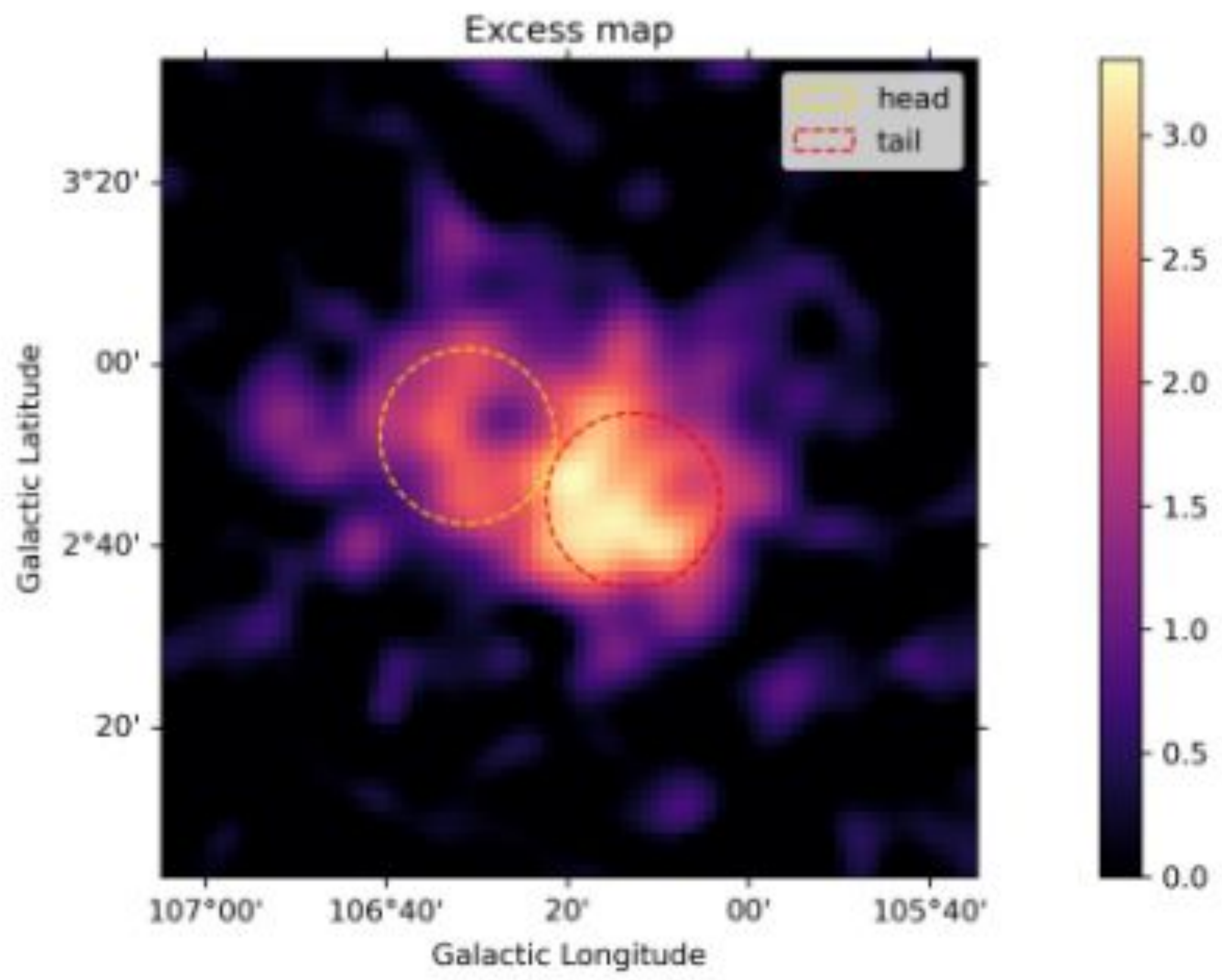
Simulations and Analysis were performed using **gammapy v1.1**

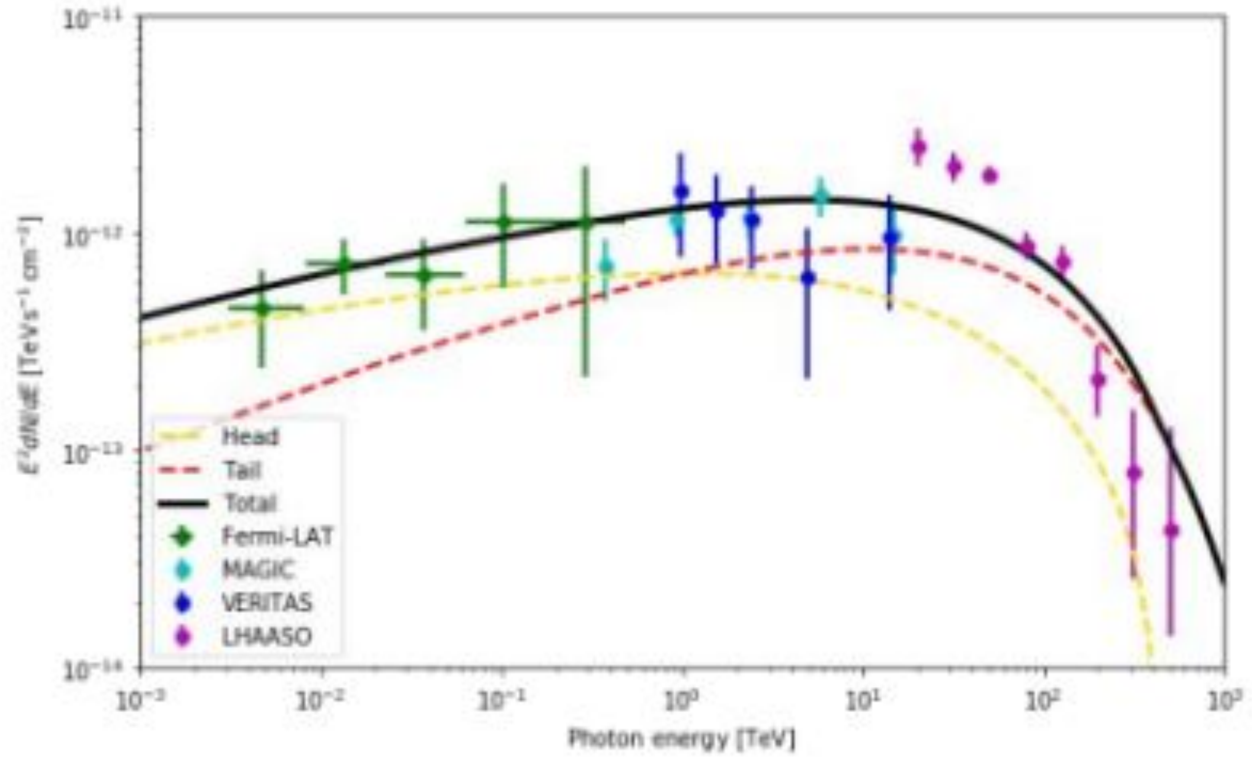
HEAD

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
- $W_e(E > 1\ \mathrm{GeV})$ 1.4×10^{47} erg





TAIL

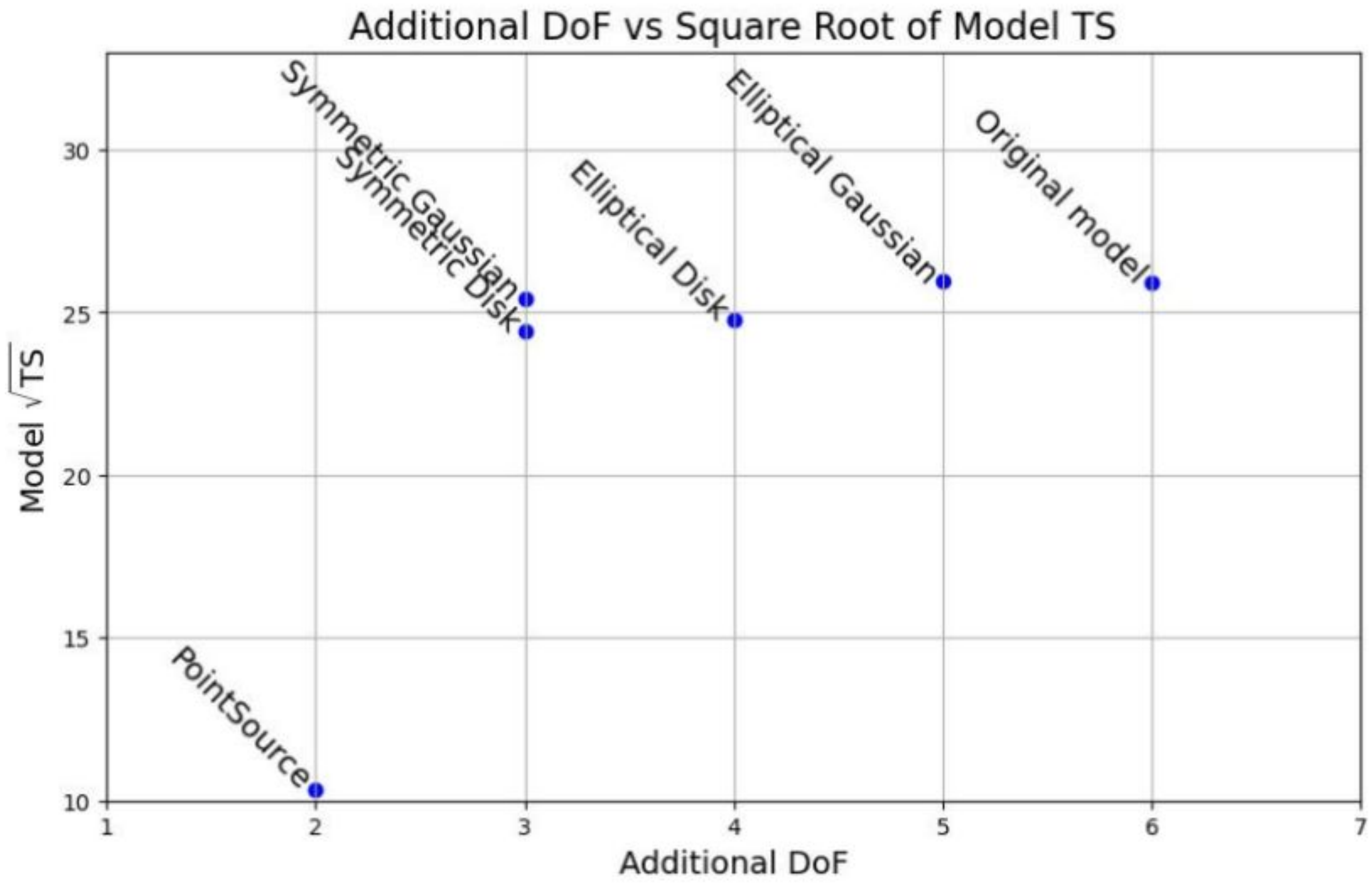
Spatial shape: Symmetrical Gaussian
Coordinates-> *l*: 106.21° *b*: 2.75°
Radius-> 0.16°

Spectral model: Hadronic+Leptonic emission

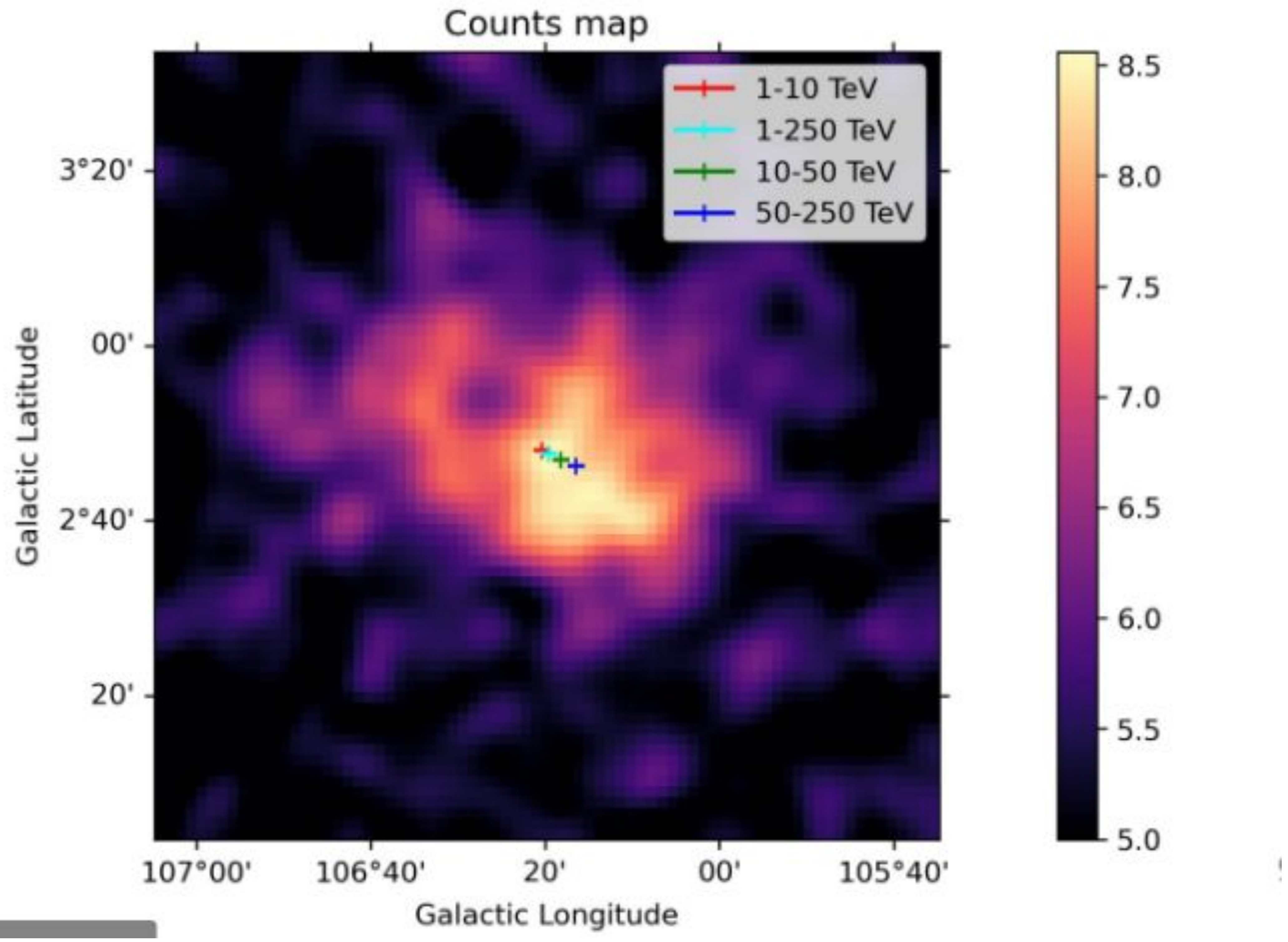
- **Leptonic**
  - Distribution: PLEC
  - index: 2.5
  - cutoff: 35 TeV
  - $W_e(E > 1\ \mathrm{GeV})$ 2×10^{46} erg
- **Hadronic**
  - Distribution: PLEC
  - index: 1.7
  - cutoff: 1000 TeV
  - $W_p(E > 1\ \mathrm{GeV})$ 8.2×10^{45} erg

G 106.3+2.7

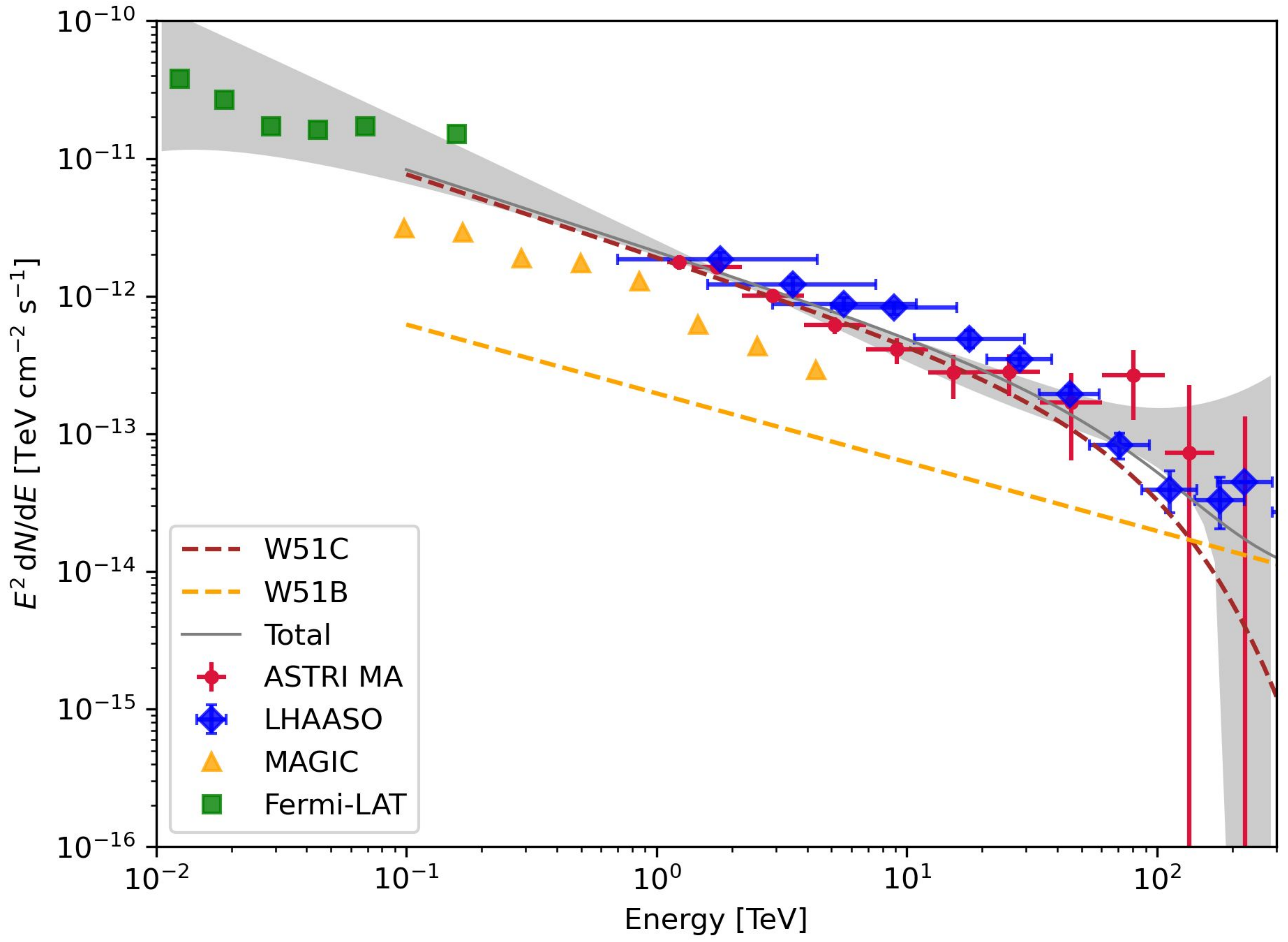
- Morphological investigation in the **entire energy range**
- Point source hypothesis is clearly excluded with a > 5σ confidence level



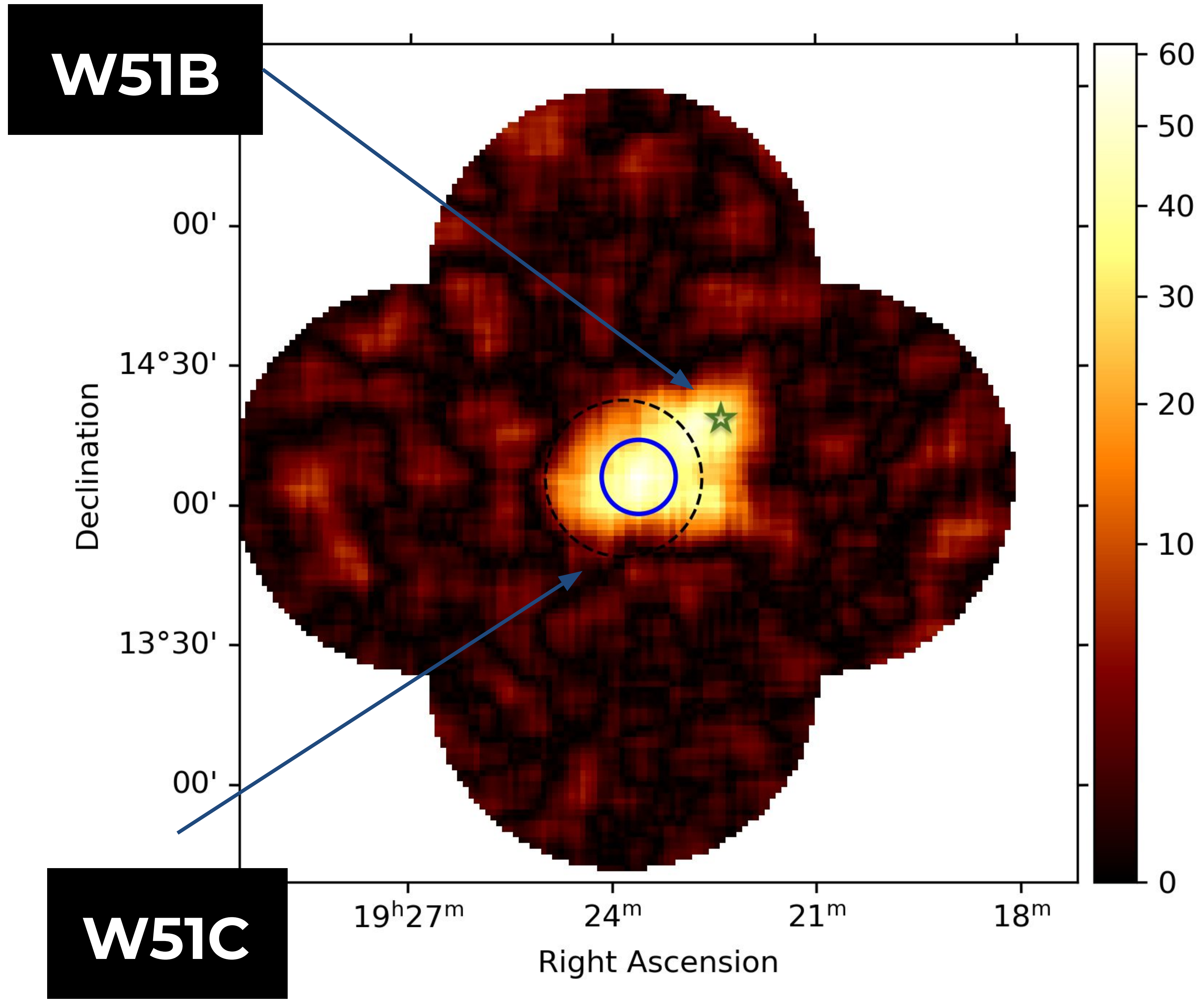
- Centroid position of the emission is **energy dependent**.
  - Fits were run in different energy bands. Results display γ-ray emission at higher energies shift towards the "tail", while lower energy emission extends nearer the "head".



SNR W51 C



$E^2\,dN/dE$ [TeV cm^{-2} s^{-1}]
Energy [TeV]
W51C
W51B
Total
ASTRI MA
LHAASO
MAGIC
Fermi-LAT



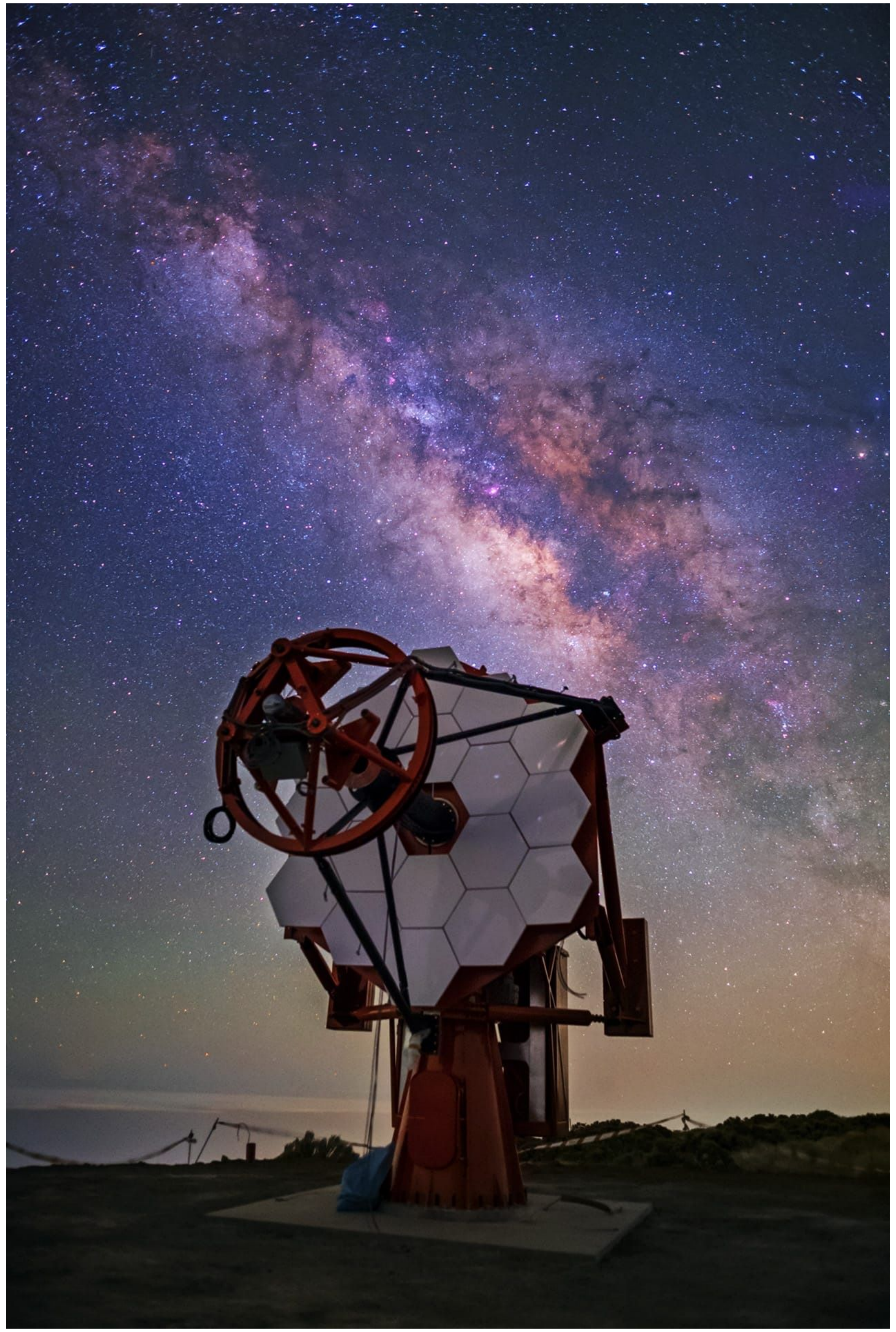
W51B
W51C
Declination
Right Ascension
14°30'
13°30'

More at..

Astri web site : **http://www.astri.inaf.it/**

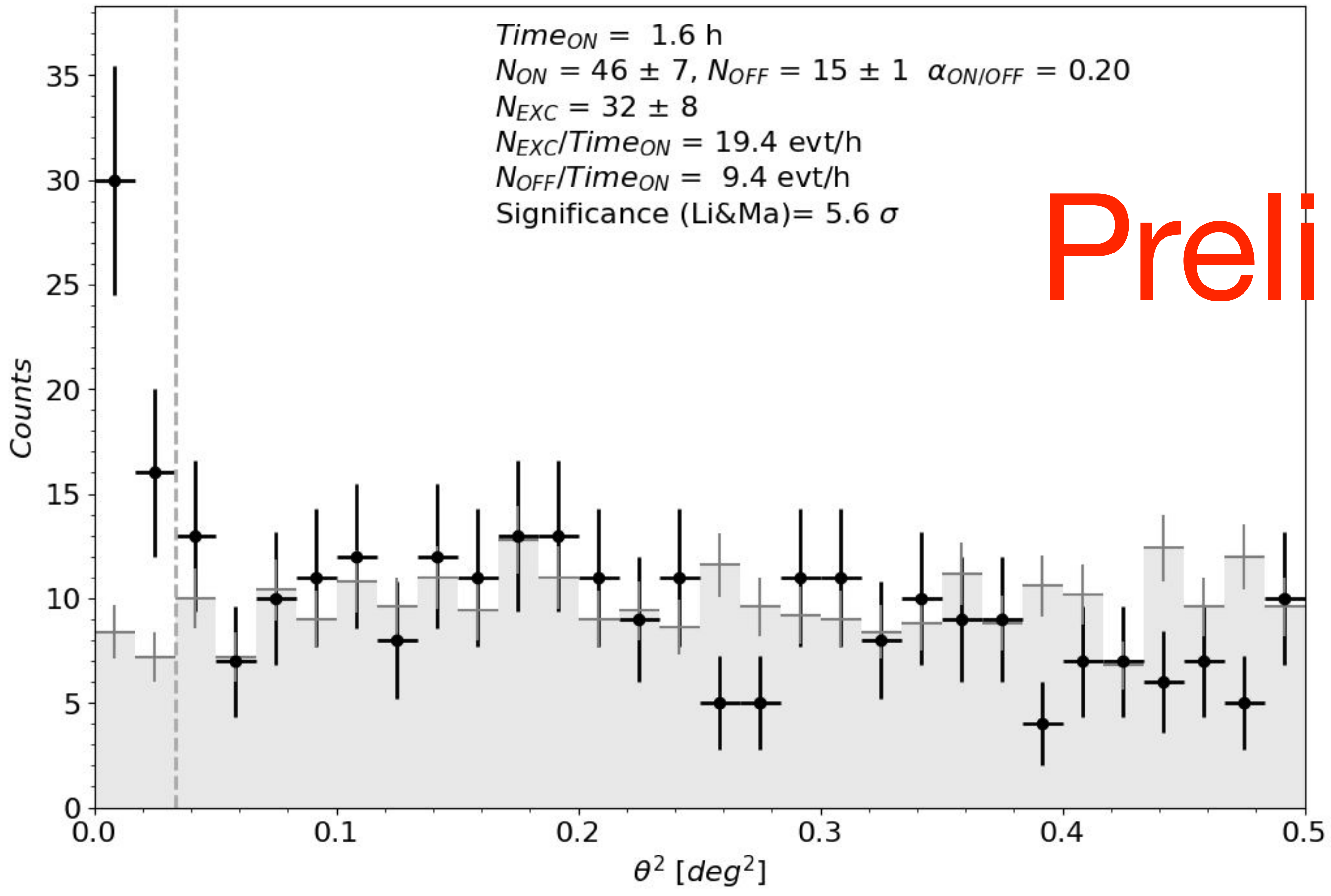
On socials, search for ***ASTRIgamma*** (FB and Instagram)

IRFs (gammapy compatible) available at :
https://zenodo.org/record/6827882

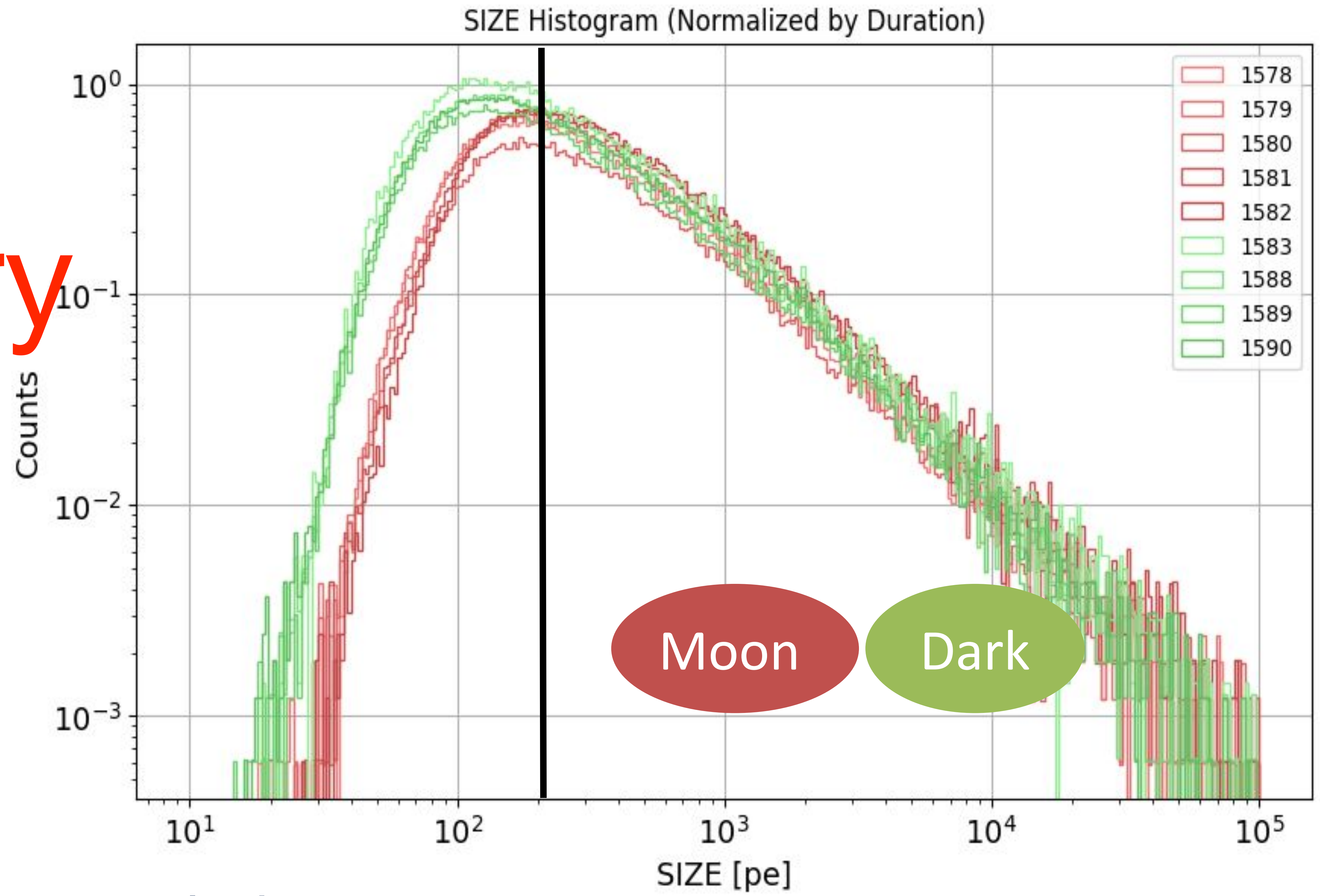


Backup slides

ASTRI-1 detection with the Moon



Preliminary



Crab runs taken during the first night:

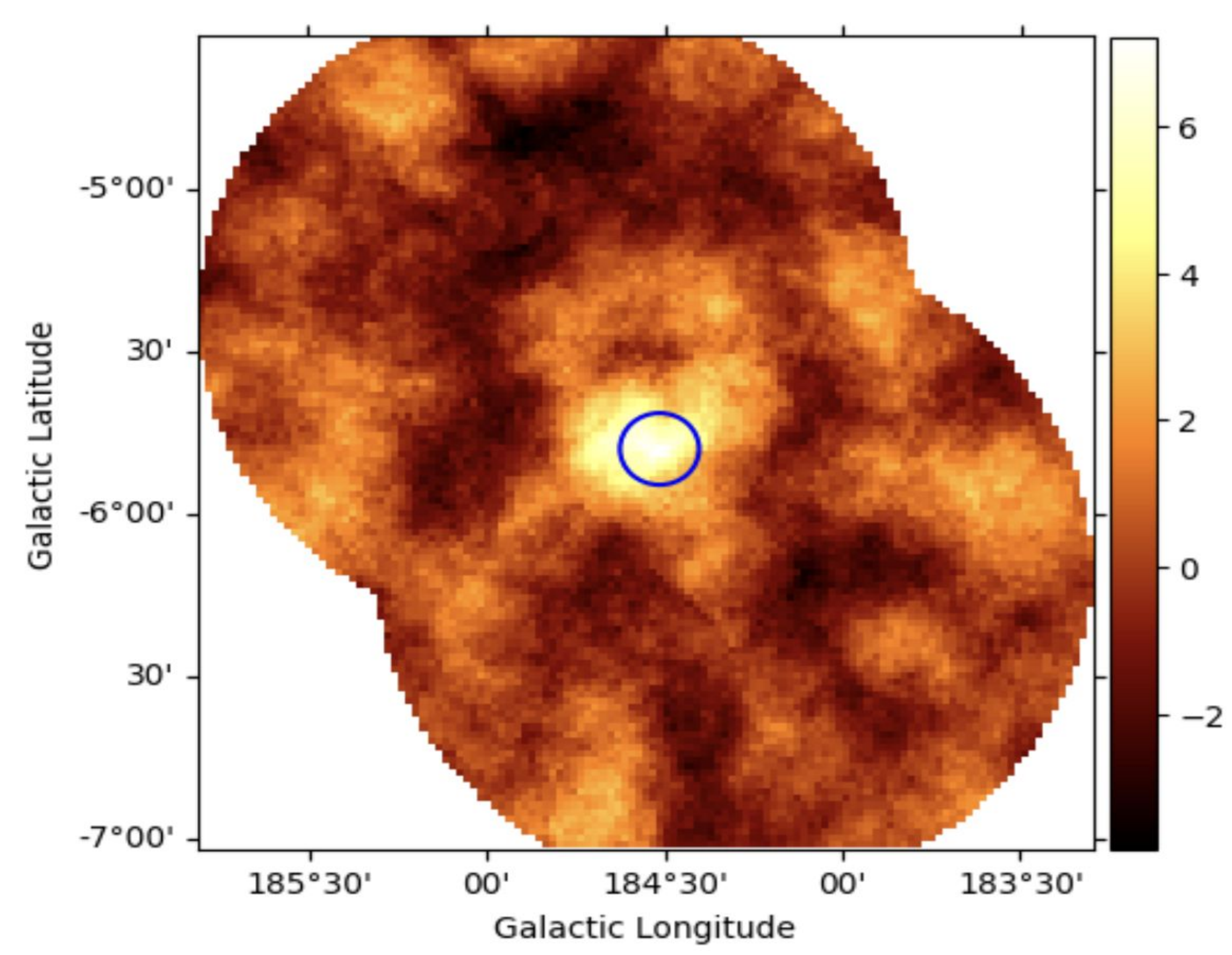
- 4 in moonlight condition
- Offset angle: 0.5°

Analysis :

- Baseline analysis configuration
- Not-yet fine-tuned Monte Carlo simulation
- Applied cuts: Size>150 , Leakage=0, Numisland=1, ZD<30°, Gammaness>0.85, Th2<0.034 deg^2

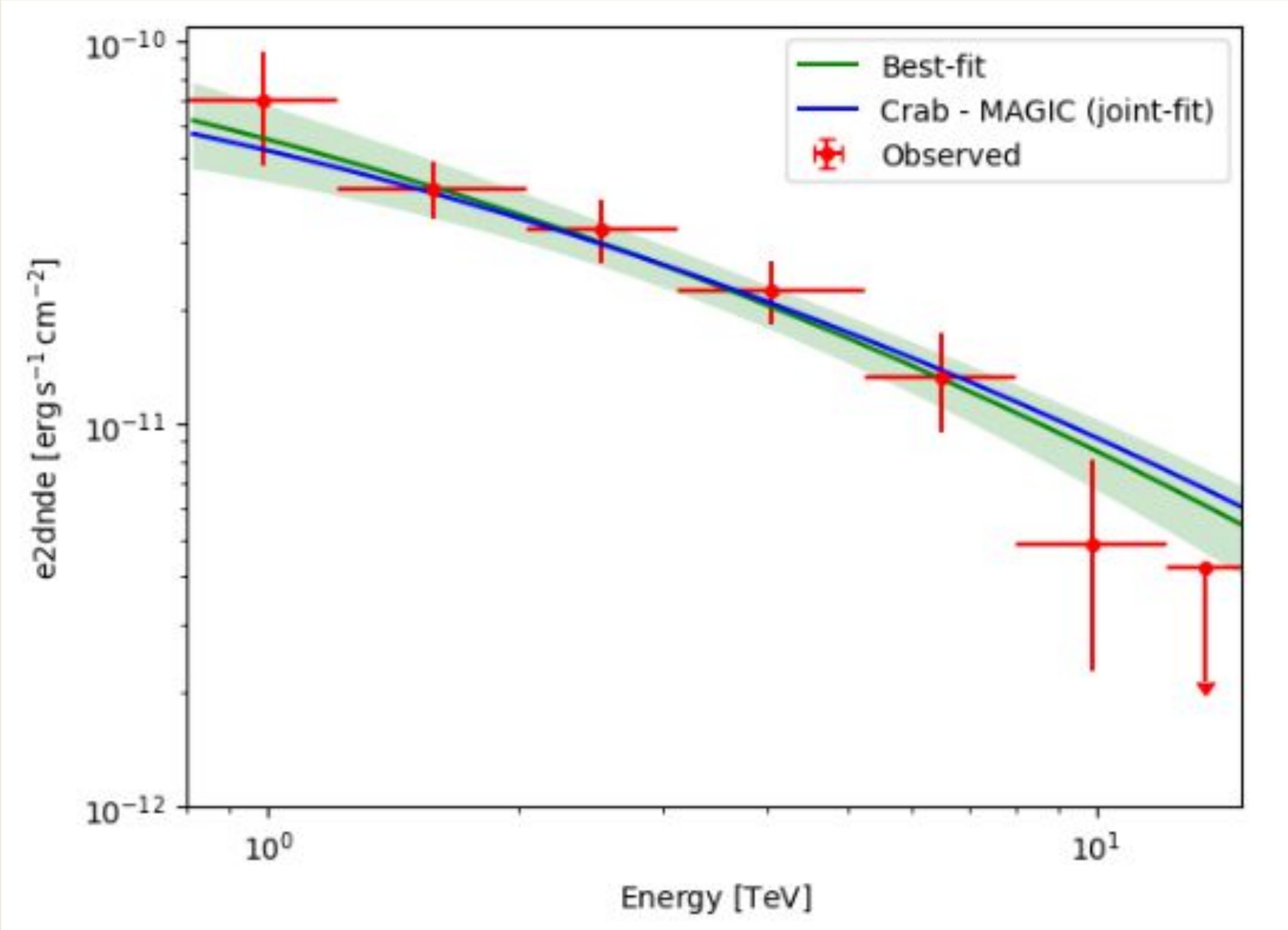
ASTRI HORN

ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) was born as “Progetto Bandiera” funded by MIUR with the initial aim to design and realize an innovative end-to-end prototype of the 4 meters class telescopes in the framework of the CTA observatory



Crab Observations in 2022-2023

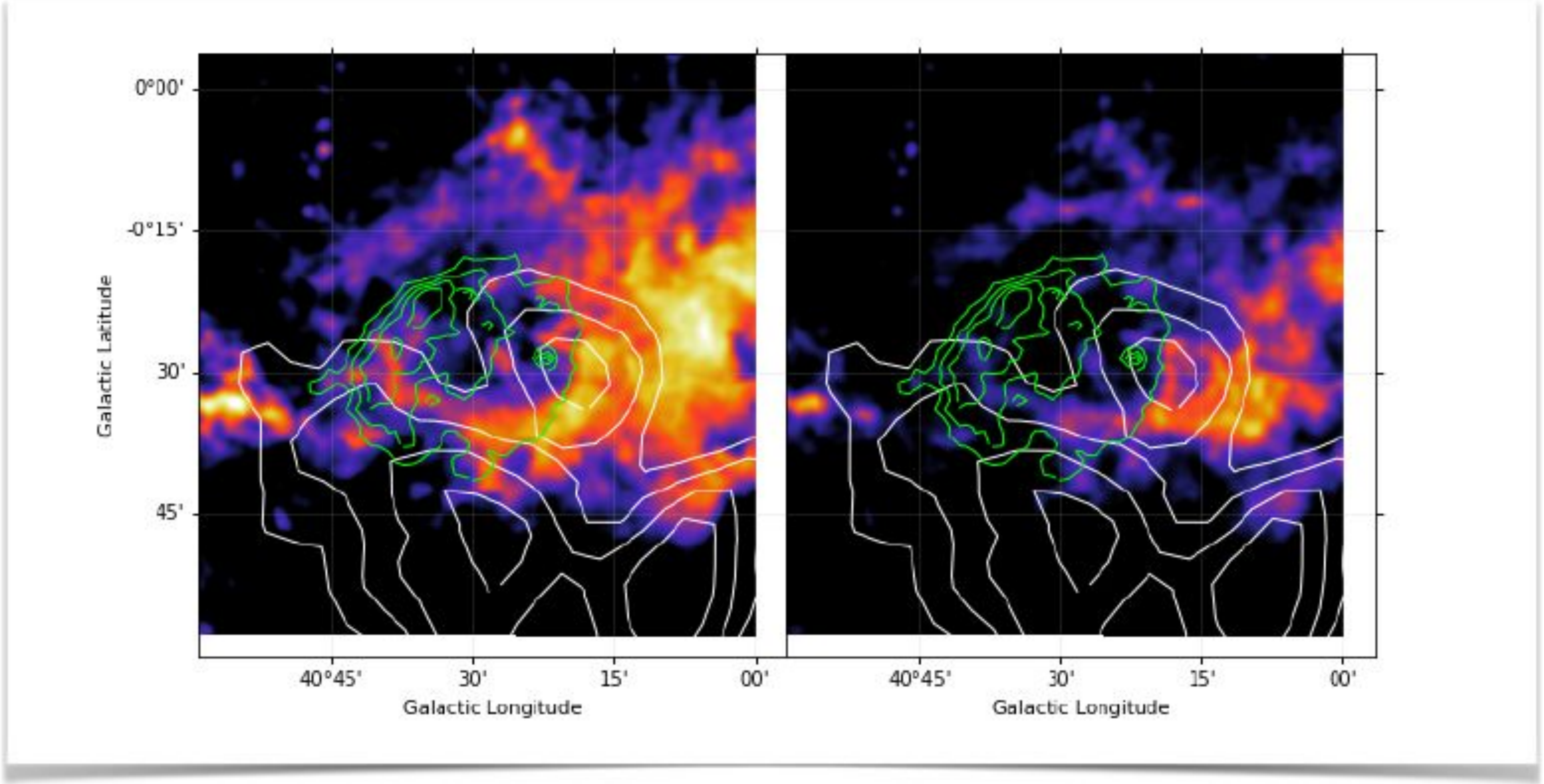
- Detection at ~7.2σ in ~22.6 hr
- 0.05° location accuracy
- Spectrum in 0.8-10 TeV energy range well modeled by a log-parabola



Leto et al., in preparation

LHAASO J1908+0621

CO emission



Maps of the 12CO (left) and 13CO (right) emission in the region integrated between 58 - 62 km s-1

Crestan et al. MNRAS, 2021

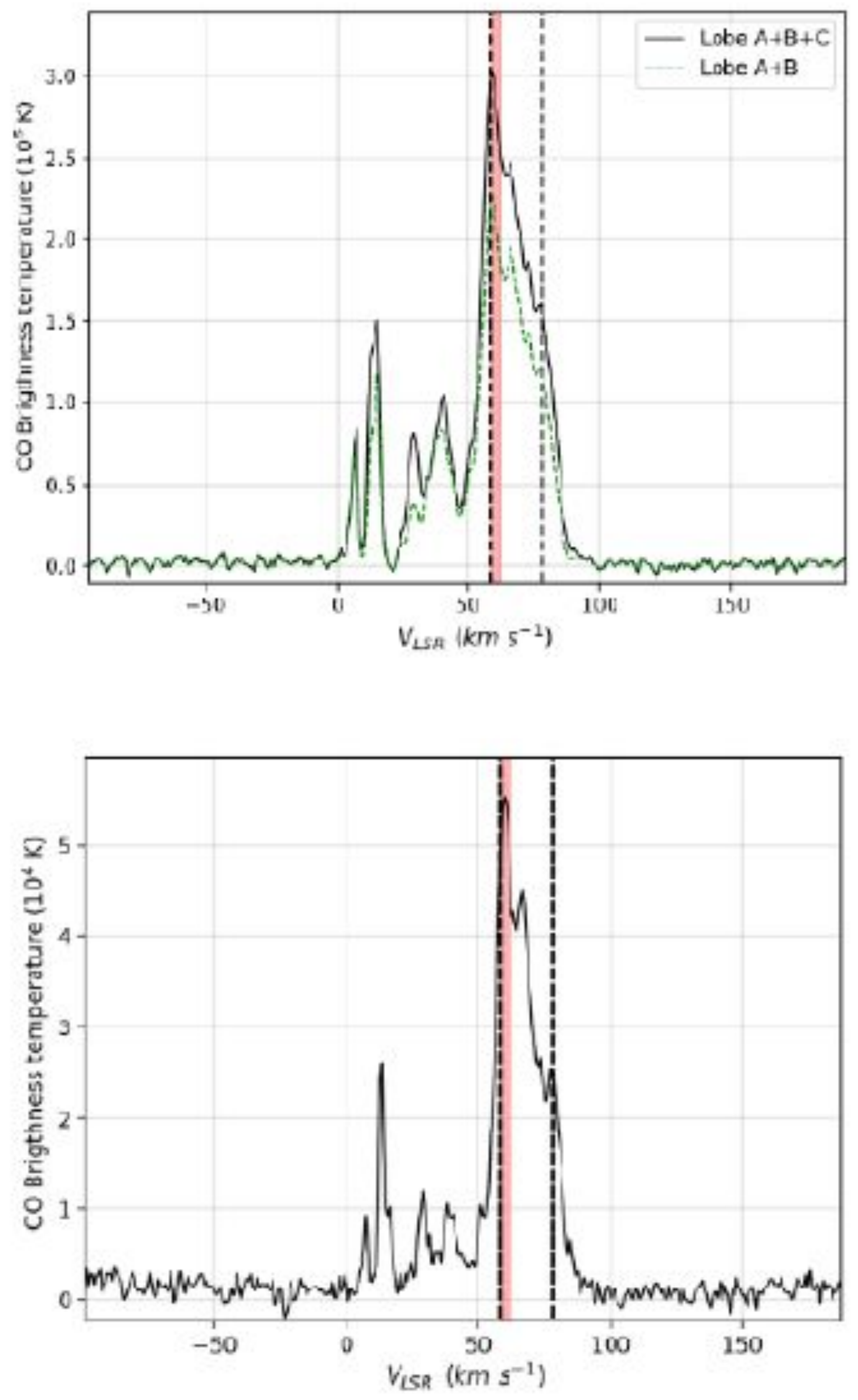


Figure 2. The ^{12}CO (top) and ^{13}CO (bottom) summed spectra in the region of MGRO J1908+06. The velocity interval between the two dashed lines (58–78 km s^{-1}) represents the bulk of the emission, while the red zone marks the velocity range between 58 and 62 km s^{-1} (shown in Fig. 3) that is the velocity range considered for the molecular cloud analysis (section 3.1).