Observation of the MGRO J1908+06 region

Sha Wu、Shicong Hu、 Khangulyan Dmitriy and Ruoyu Liu
on behalf of the LHAASO Collaboration

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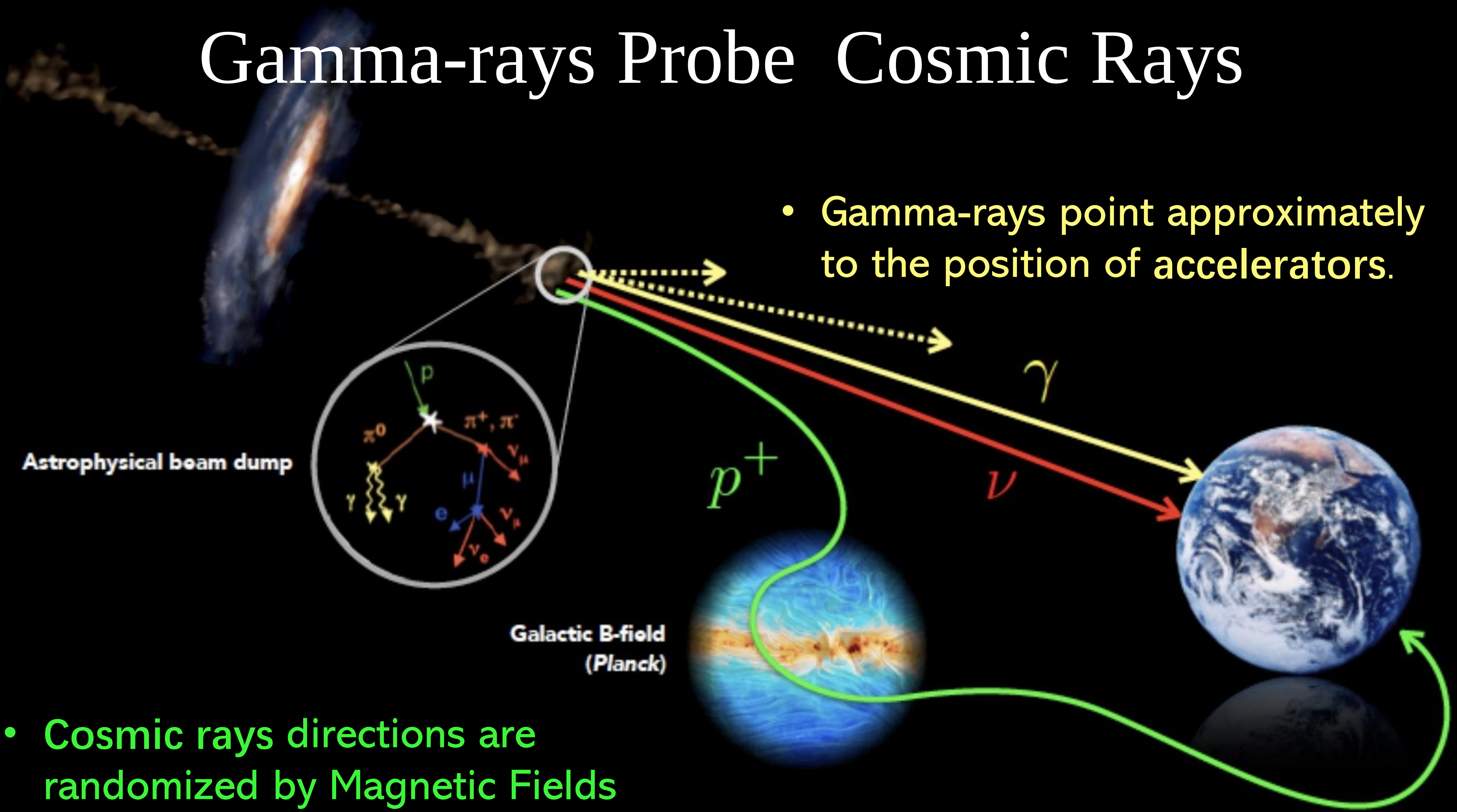
Gamma-rays Probe Cosmic Rays

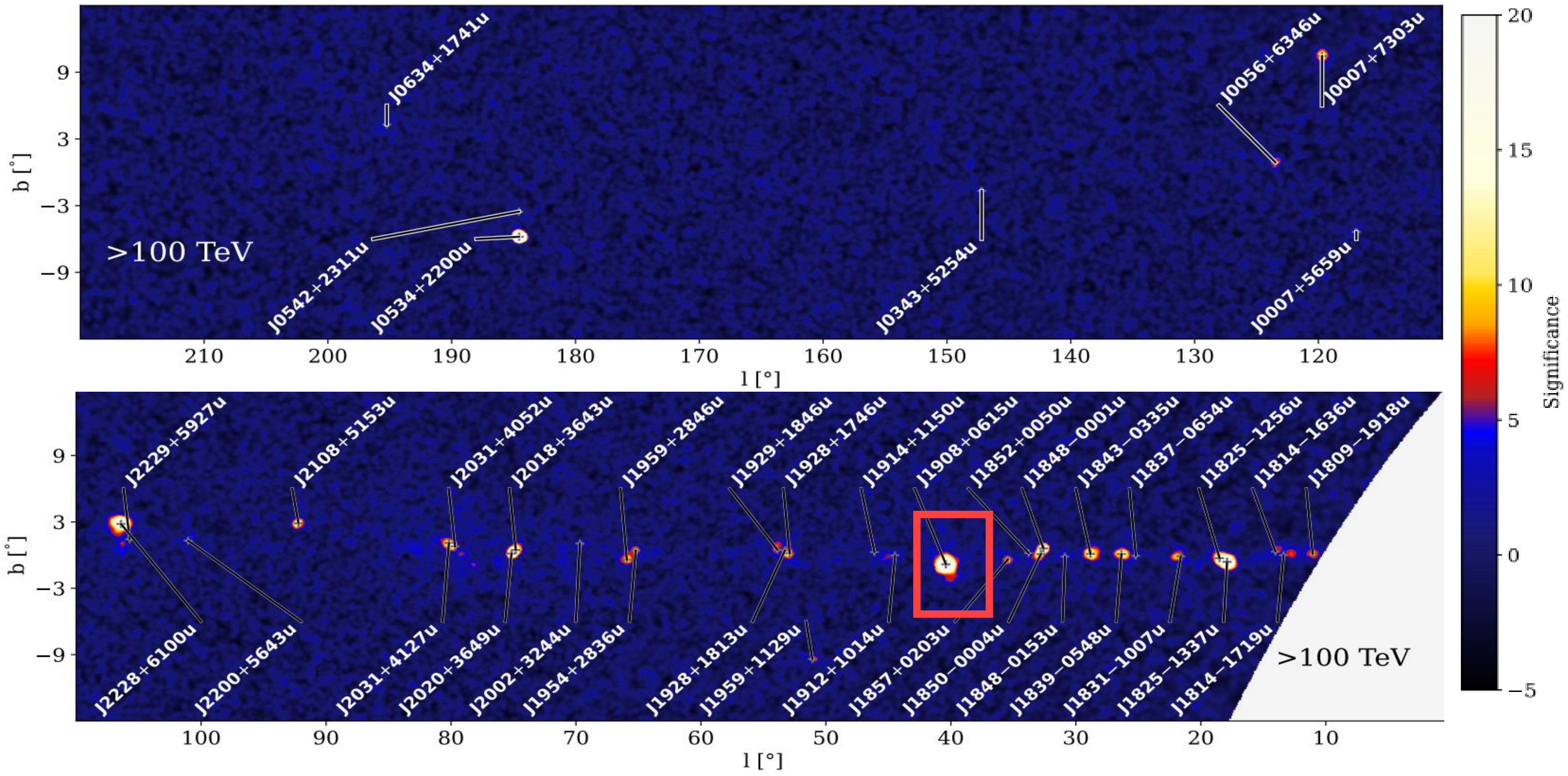
- Gamma-rays point approximately to the position of accelerators.



- Cosmic rays directions are randomized by Magnetic Fields in the Universe.

UHE Gamma-ray Sources

Cao et al., DOI: 10.48550/arXiv.2305.17030.



- E>100 TeV, **43** sources were detected with significance above 4σ.
- MGRO J1908+06 is a strong contender for a Pevatron.

Introduction of the MGRO J1908+06 region

- **SNR G40.5−0.5:**

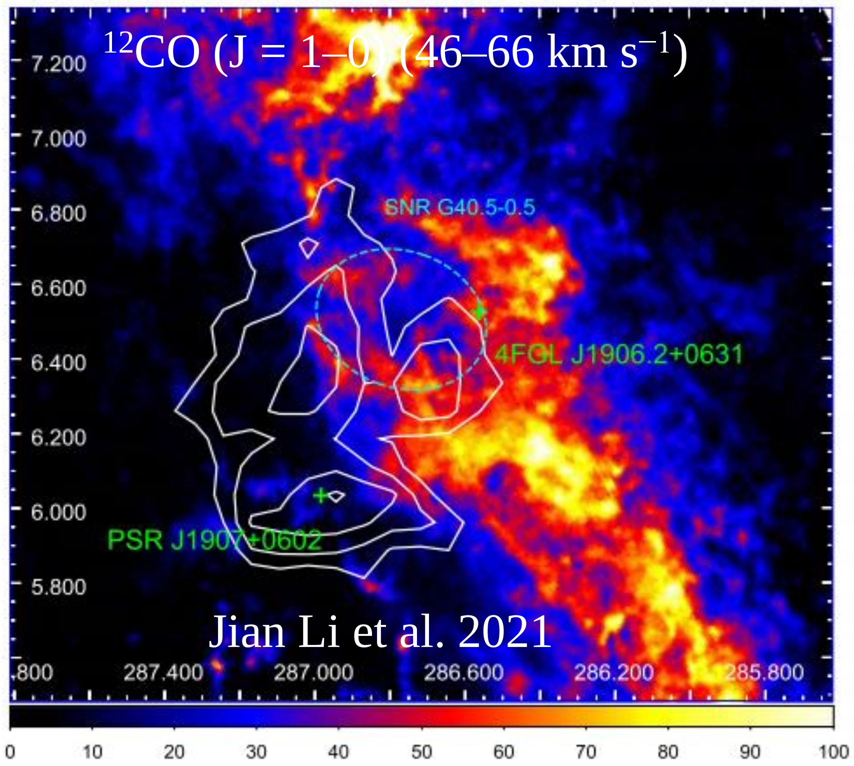
diameter,40-65pc; distance,5.5-8.5kpc; age (20–40)kyr.

- **PSR J1907+0631**

5×10^{35}erg/s, 11 kyr, 7.9kpc

- **PSR J1907+0602 :**

2.8×10^{36}erg/s, 19.5kyr, 3.2kpc

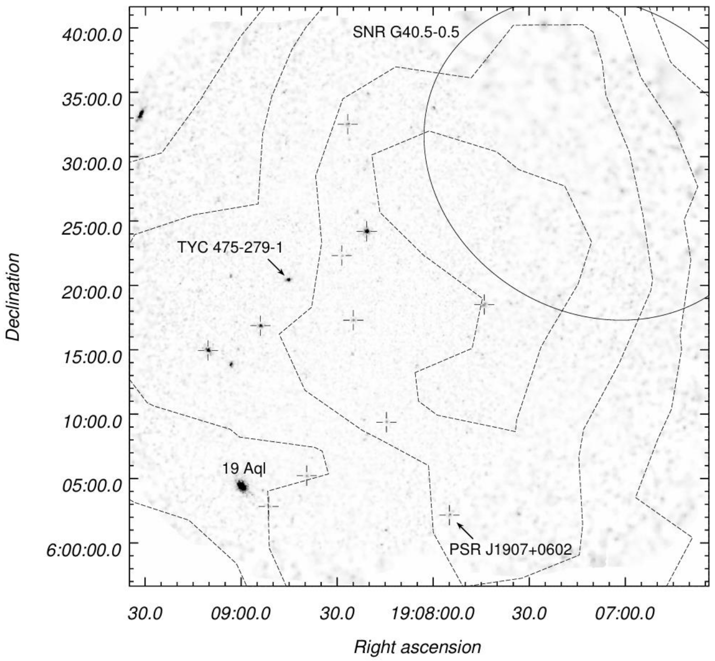


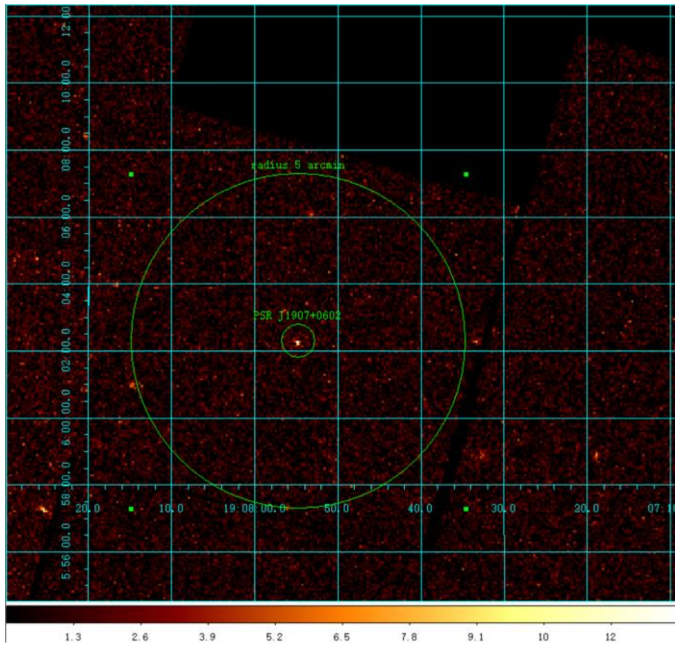
◆ The TeV emission has been attributed to this pulsar, but other objects could also contribute to the emission.

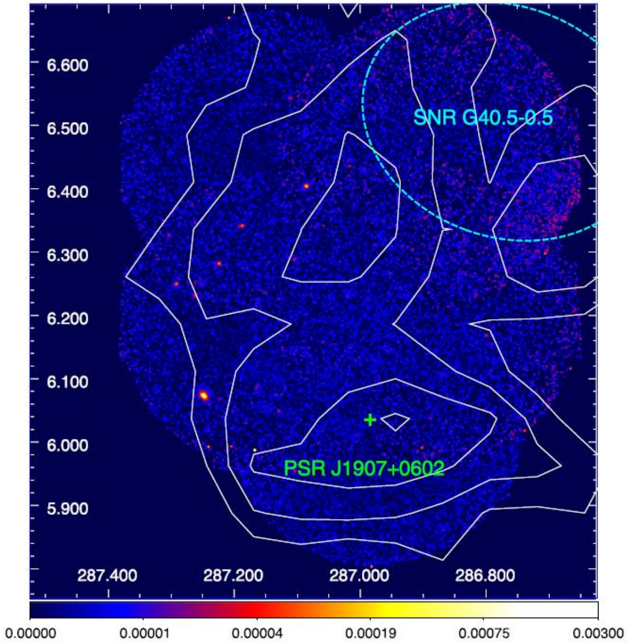
X-ray observations

Paper	Data	Exposure times [ks]	Radius of ROI	Energy range [keV]	95% UL
Dirk Pandel, ICRC 2015	**XMM-Newton EPIC MOSs and PN**	**56.4**	**45'** **(VERITAS 2014, 286.84, 6.22)**	**1-10**	**7.1e-12 erg/cm2/s** $L_X \leq 8.7e33$ **erg/s**
S. Crestan, et al., MNRAS, May 2021.	XMM-Newton EPIC MOSs and PN	~40	5' (PSR J1907+0602)	1-10	1.5e-12 erg/cm2/s
Jian Li, et al., APJL, June 2021.	XMM-Newton EPIC MOSs and PN	109	20' (H.E.S.S. 2009, 286.97, 6.26)	0.2-10	1.2e-10 erg/cm2/s

Coverage





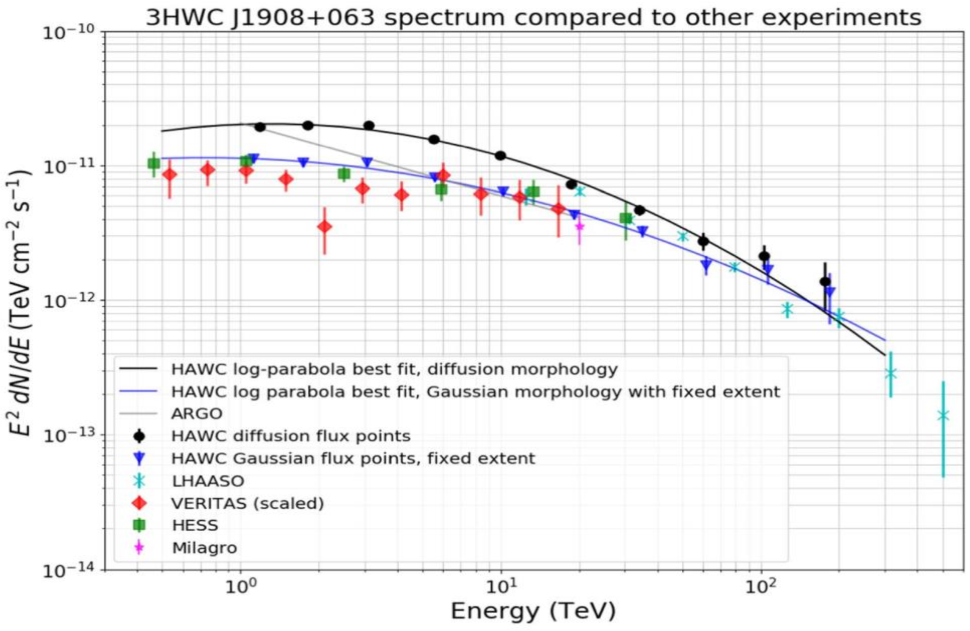


Previous TeV Observation

	VERITAS_2014	HESS_2009	ARGO_2012	HAWC_2022	LHAASO_2021
Erange	100 GeV -30 TeV	300 GeV-30 TeV	1-20TeV	470 GeV-213 TeV	10-500 TeV
Position(°)	286.84± 0.02 6.22 ± 0.02	286.98 ± 0.04 6.27± 0.04	287.0±0.2 6.4±0.2	287.05, 6.39 Fix 3HAWC	287.05,6.35
Extension(°)	0.44 ± 0.02	0.34+0.04 -0.03	0.49 ±0.22	1.78±0.08 (θ_d)	0.58±0.04
Alp	2.20±0.10±0.2	2.10±0.07±0.2	2.54±0.36	2.545 ± 0.026(α) 0.134 ± 0.018(β)	2.27(α) 0.46(β)

- The position and extension of the gamma-ray emission is consistent within uncertainties.

- The spectrum shows a gradual steepening as the energy increases.



Results in ICRC 2023

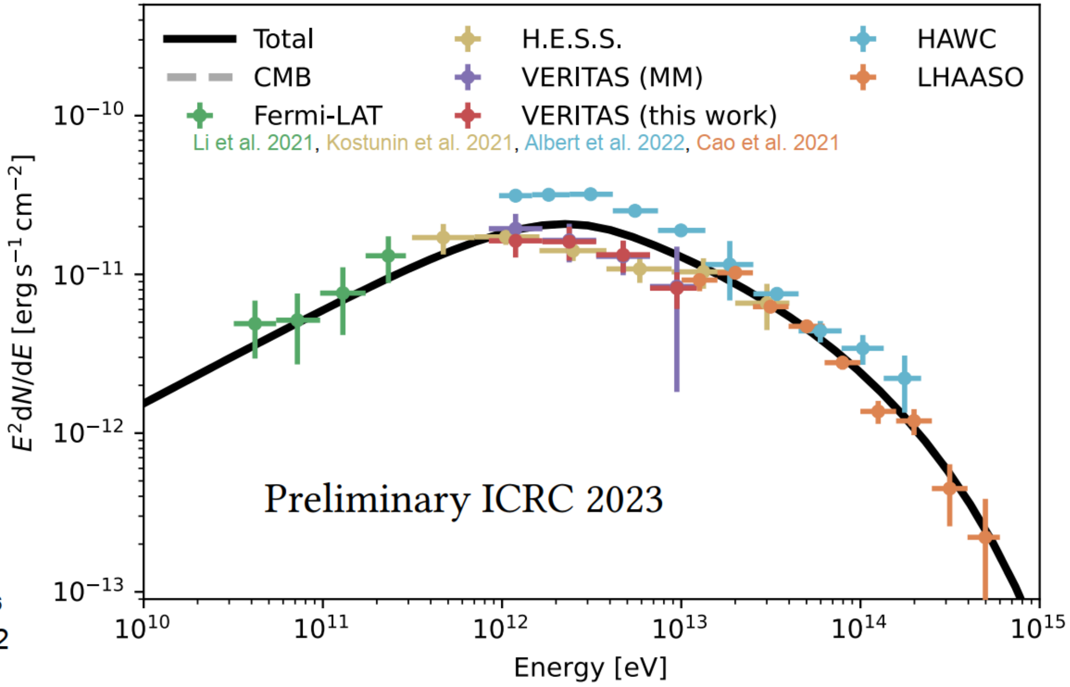
- Closer to the pulsar location & a softening of the spectral index

Energy range (TeV)	Right ascension (deg)	Declination (deg)	Extension $1\,\sigma$ (deg)	Γ	ϕ_0 $1/(\mathrm{cm^2 s TeV})$
(0.8 – 3.05)	286.98 ± 0.03	6.44 ± 0.03	0.47 ± 0.02	2.19 ± 0.12	$(9.61 \pm 0.74) \cdot 10^{-12}$
(3.05 – 12.3)	286.95 ± 0.04	6.28 ± 0.04	0.48 ± 0.03	2.63 ± 0.2	$(1.58 \pm 0.51) \cdot 10^{-11}$

Best fit parameters of the model:

Parameter	Value
A	$4^{+4}_{-2} \cdot 10^{34}$ 1/eV
E_{break}	19 ± 3 TeV
α_1	$1.8^{+0.3}_{-0.5}$
α_2	$3.36^{+0.11}_{-0.15}$
E_{cutoff}	800^{+4000}_{-400} TeV
B	5^{+5}_{-4} μG

W_e(>0.511 MeV) = 6 · 10^{47} erg consistent with Abdo et al. 2009 2.84 · 10^{36} erg/s spin down power of PSR J1907+0602 for a pulsar age estimate of ~ 20 kyr.

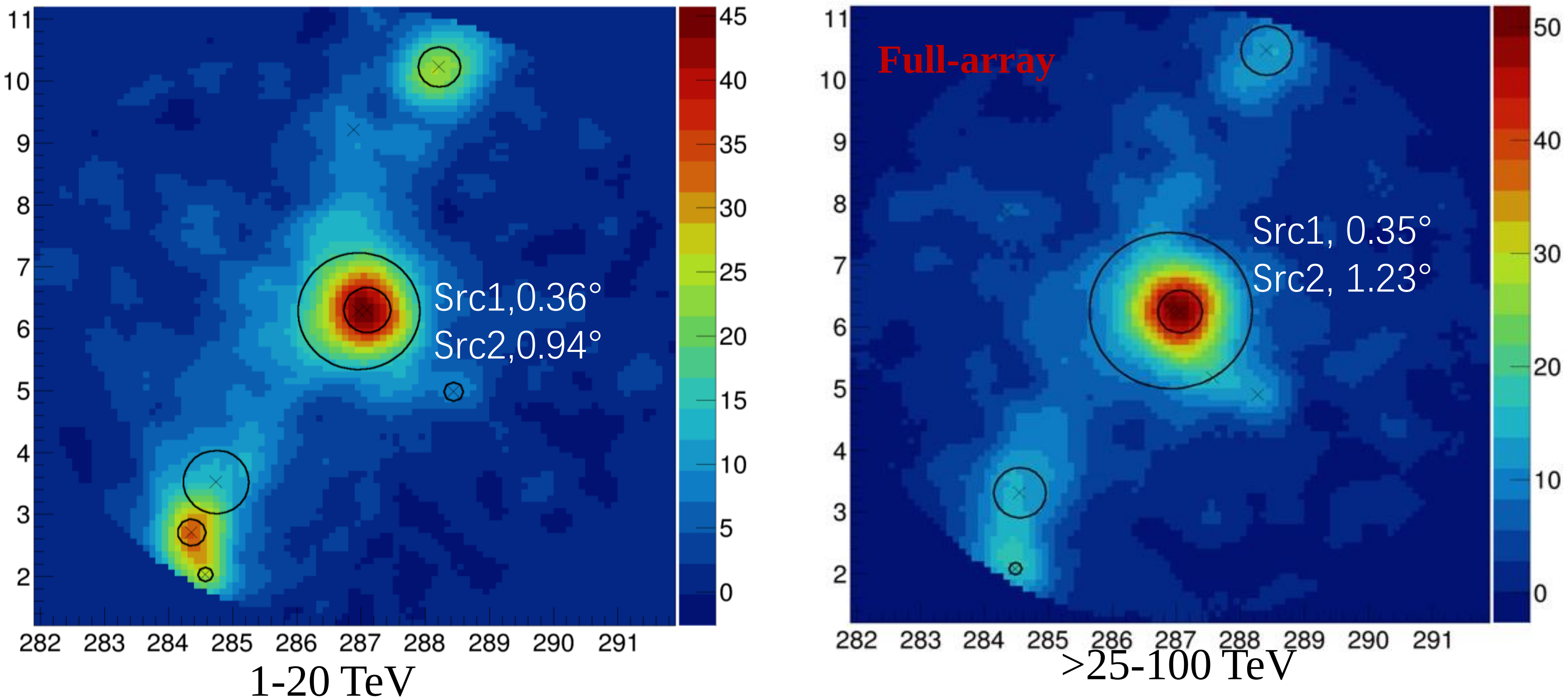


3D analysis-> the spectral does not require containment correction.

LHAASO Results

- **Selection:** Same as Crab (CPC)
- **Background estimation:** direct integration method
- **Method:** 3DLikelihood analysis
- **GDE:** Dust model. free the flux.

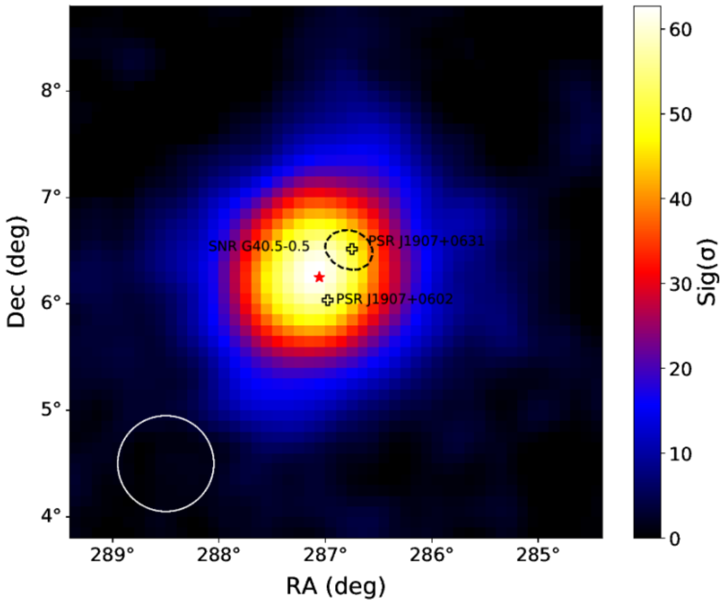
- **Distance of Src1 and Src2:** 0.1 deg
- The extension of Src2 in KM2A is larger than that of WCDA by 3σ.

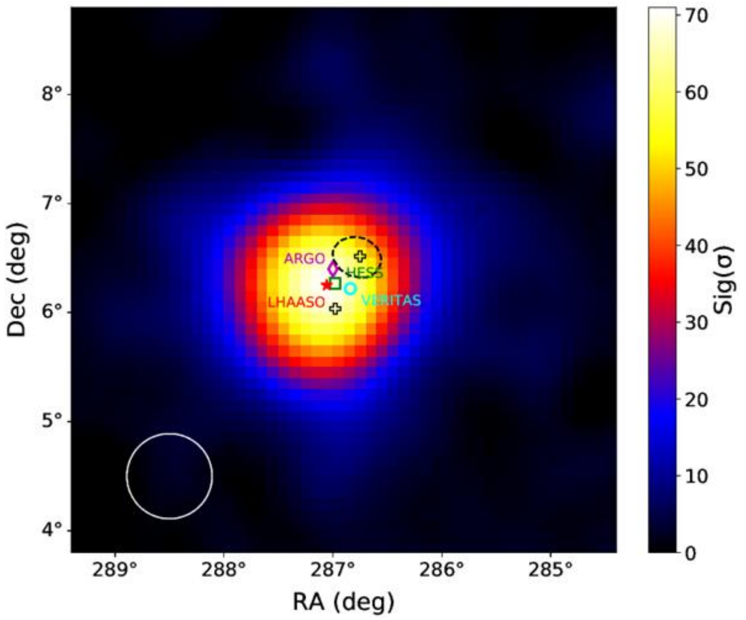


Test the Templet

- It appears that Src1 and Src2 together contribute to the emission of MGRO J1908+06
- The gamma-ray morpholoy may be non-Gaussian. $f(\theta) \propto \frac{1}{\theta_d(\theta + 0.085\theta_d)} \exp[-1.54(\theta/\theta_d)^{1.52}]$

Energy	Model	R.A. [deg.]	Dec. [deg.]	θ_d [deg.]	ΔBIC（vs Two Gaus）
1-20 TeV	**Diffuse**	287.072 0.011	6.279 0.010	1.547 0.047	**-41.7**
>25 TeV	**Diffuse**	287.058 0.011	6.234 0.012	1.150 0.039	**4.1**





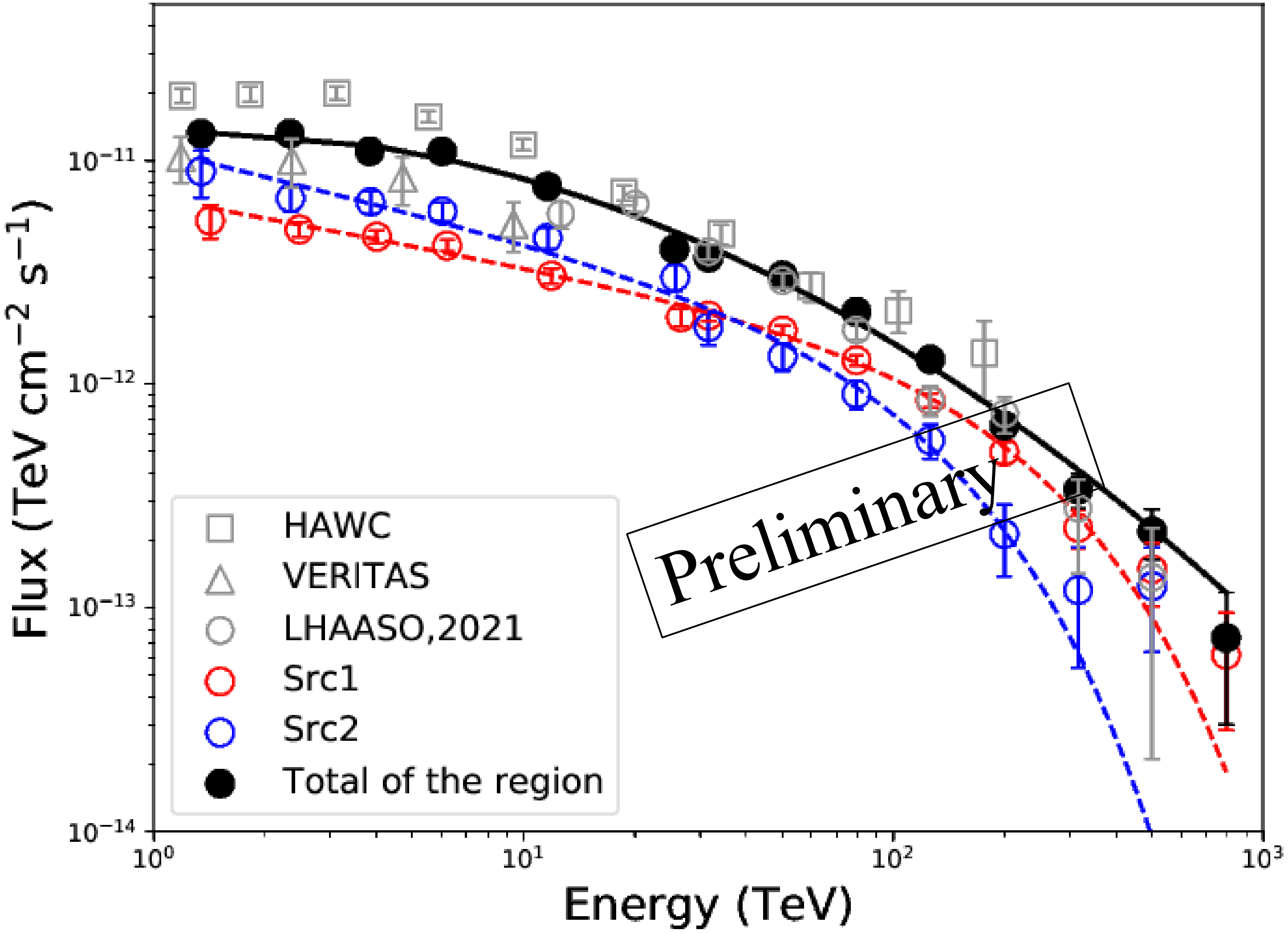
SED

Total of the region:

- **From 1 TeV to 10 TeV:** slightly higher than VERITAS but consistent within 1σ.

- **Above 10 TeV:** in good agreement with the data reported by LHAASO in 2021 and HAWC.

$$\frac{dN}{dE} = E^2 \times N_0\left(\frac{E}{20\ \text{TeV}}\right)^{-\alpha-\beta\times lg\left(\frac{E}{20\ TeV}\right)}$$



Leptonic Model

- **Photon seeds**

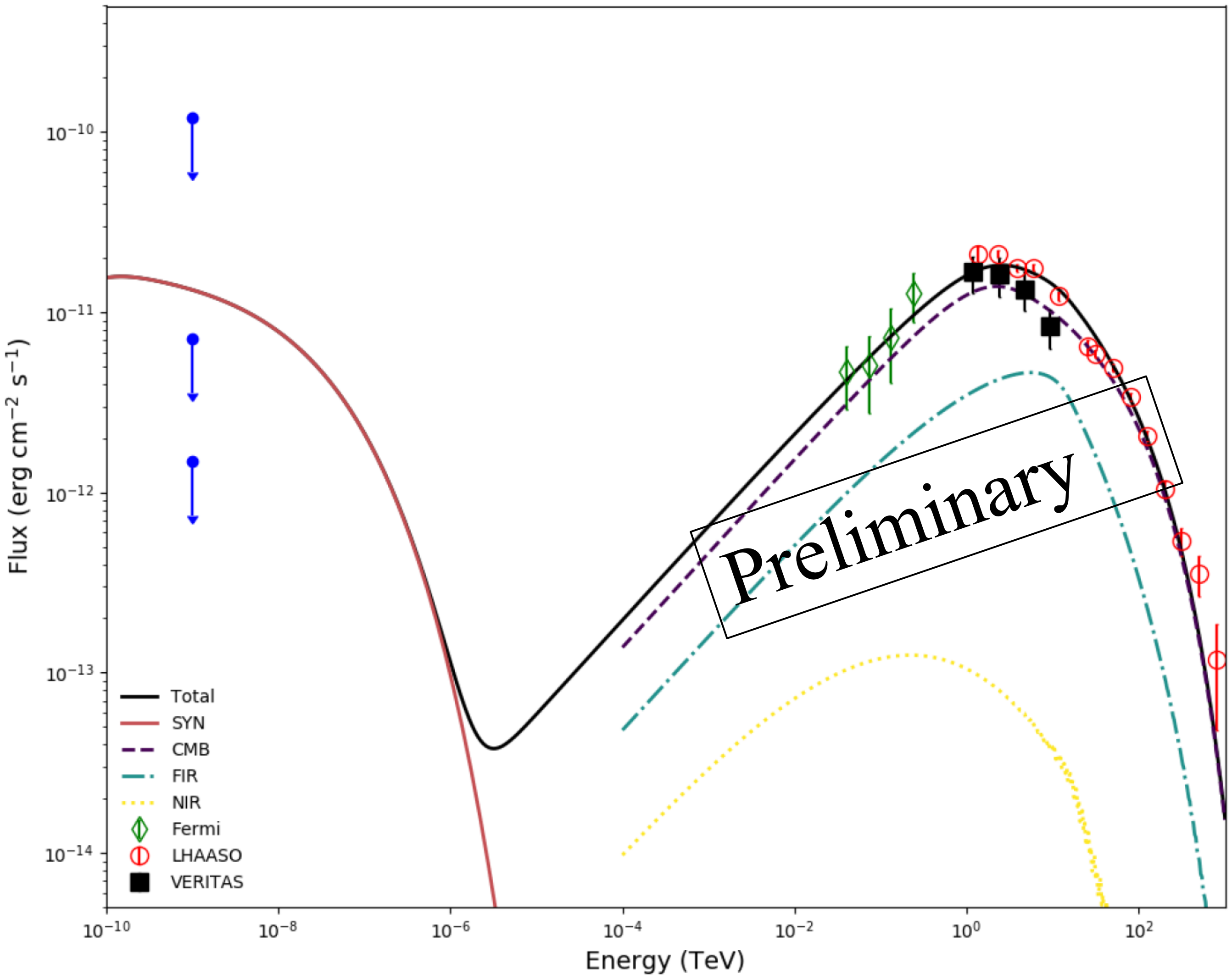
CMB: 0.261 ev cm^{-3}
FIR dust emission: 0.5 ev cm^{-3} 70k
NIR stellar emission: 1.0 ev cm^{-3} 5000k

(Same with the model of Crab)

- **Best fit parameters of the moc**

Parameter	Value
A	$5.1 \pm 1.5 \times 10^{34}$
E_{break}	18.6 ± 1.8
α_1	1.95 ± 0.12
α_2	3.05 ± 0.06
E_{cutoff}	358±74TeV
B	3uG

- $W_e(>100\ \text{GeV}) = 5. \times 10^{47}$ erg

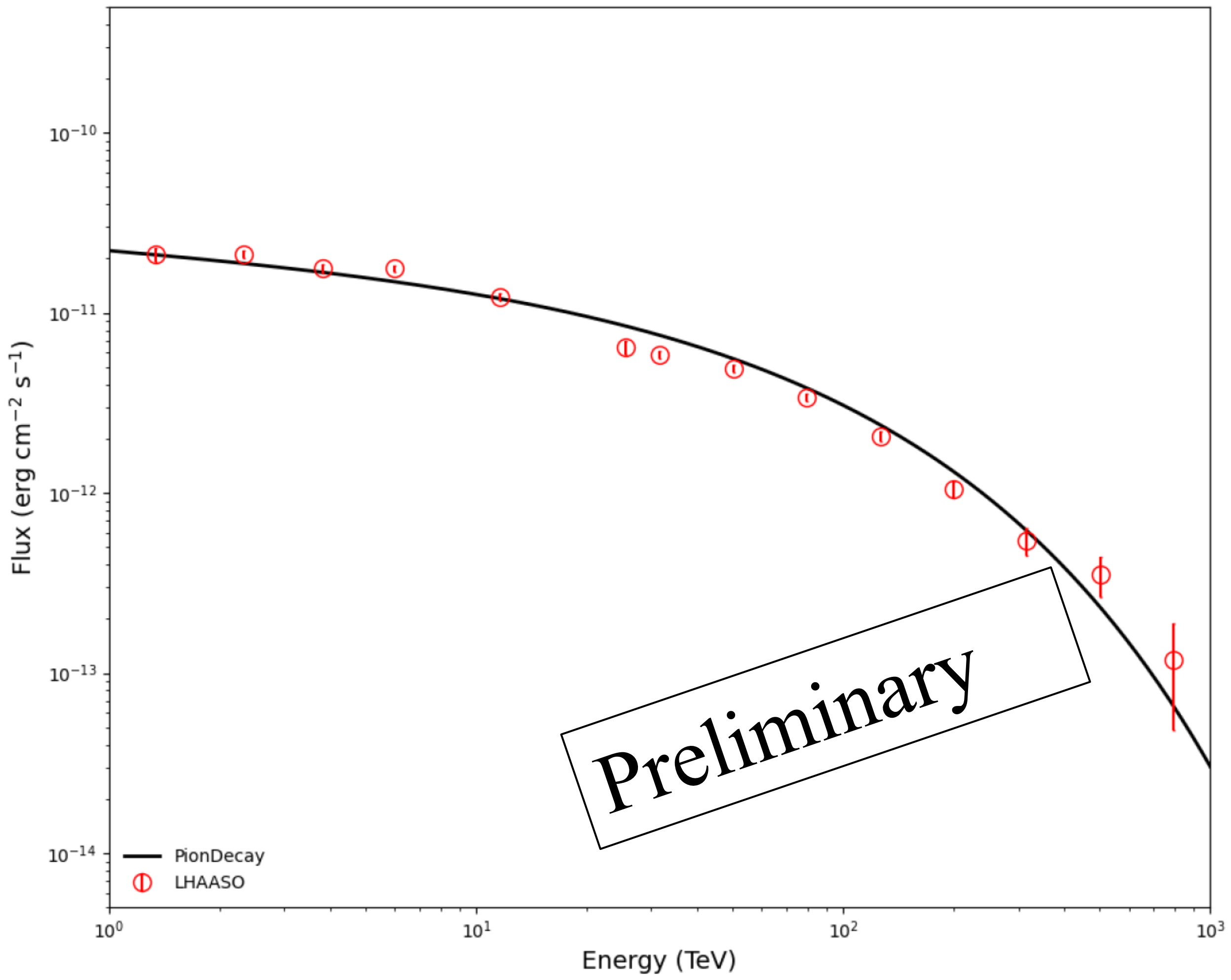


Hadronic Model

- A power-law spectrum with an exponential cutoff:

a= 2.2; Ec~700TeV;

W_p=4.4×10^{49}erg



Conclusion

- The results from LHAASO are consistent with other observations.
- Both leptonic and hadronic models are capable of explaining the observed gamma-ray emission.
- A more detailed analysis investigating the energy-dependent morphology is in progress.

Thank you!