Gamma-ray astronomy results from LHAASO

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Outline

- LHAASO experiment
- Data and analysis method
- Gamma-ray astronomy results
- Summary

We are in Multi-Messenger Astronomy era

Gamma-ray is a powerful probe for astrophysics and fundamental physics under extreme conditions

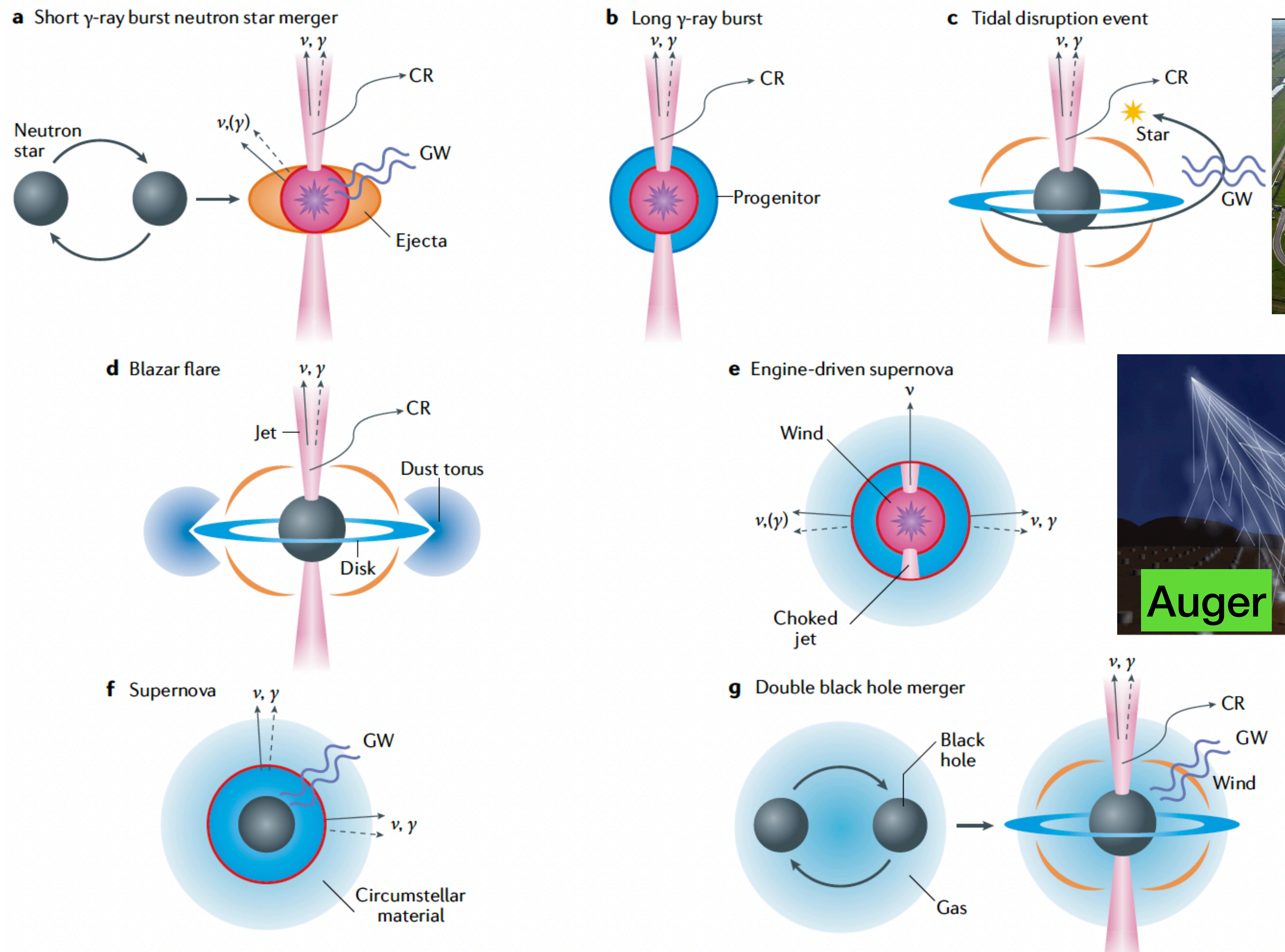
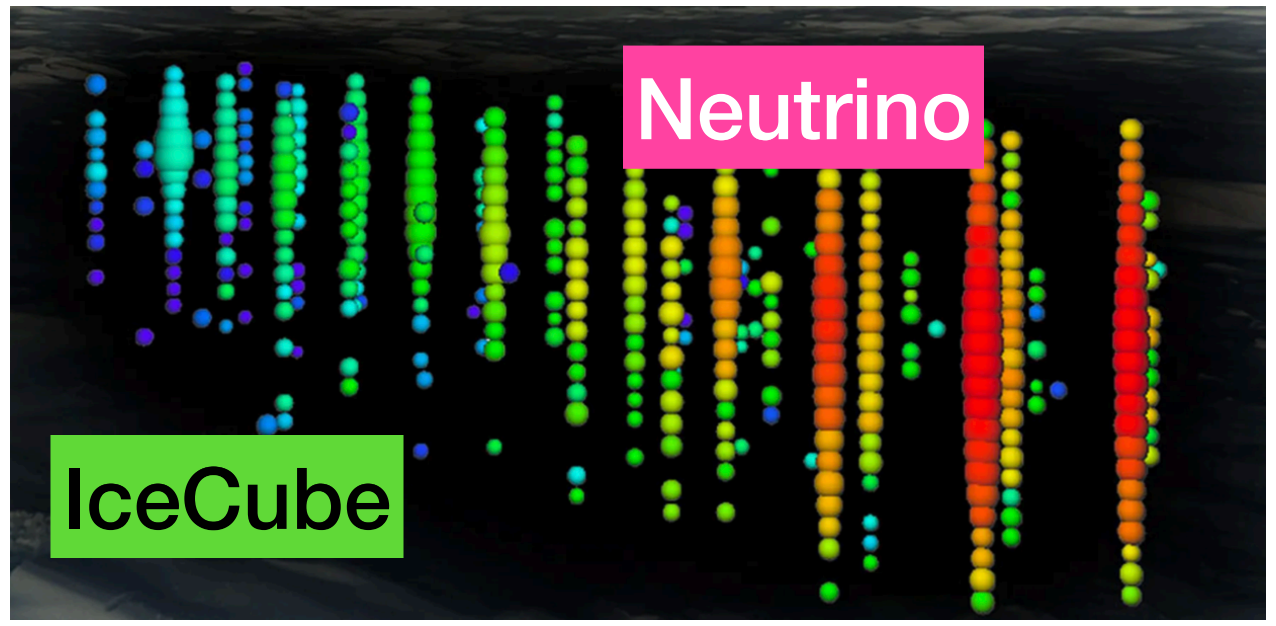
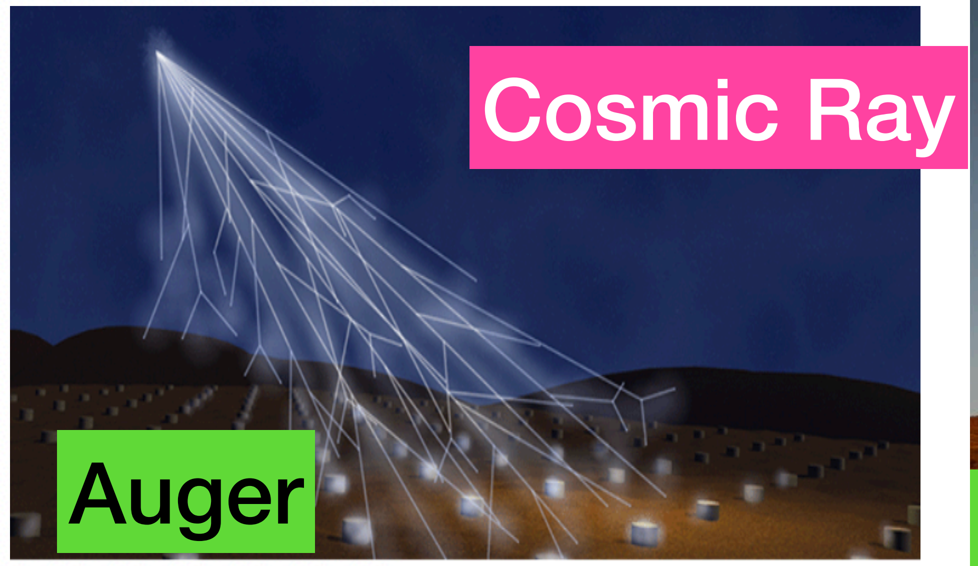
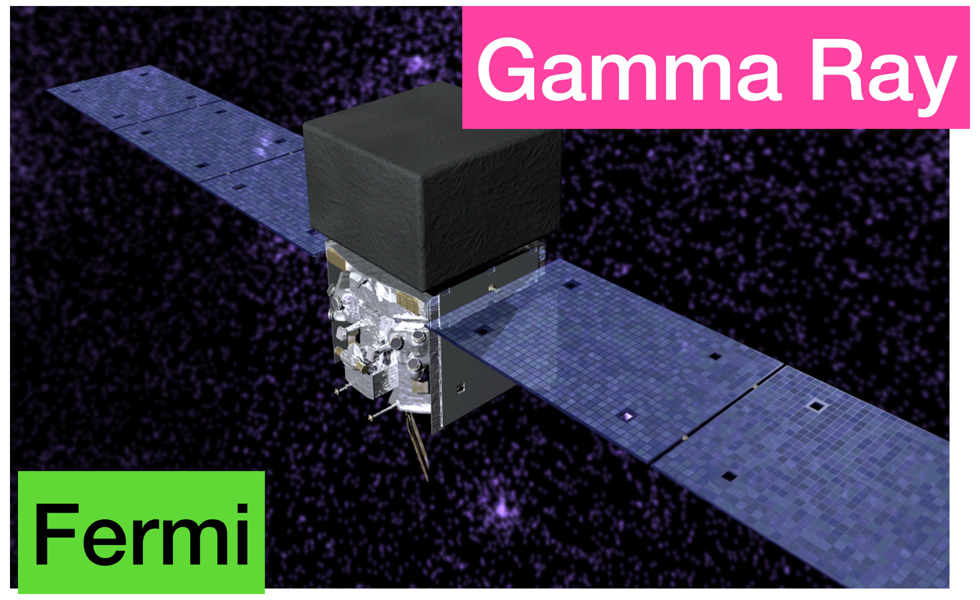
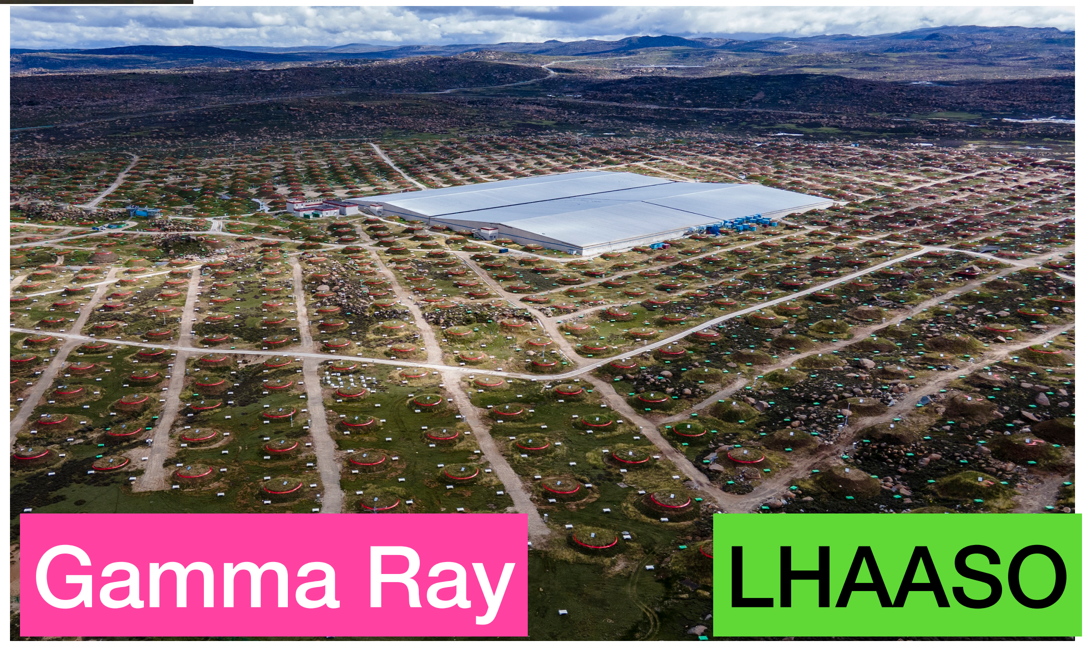


Figure adapted with permission from REF.[174], Annual Reviews.







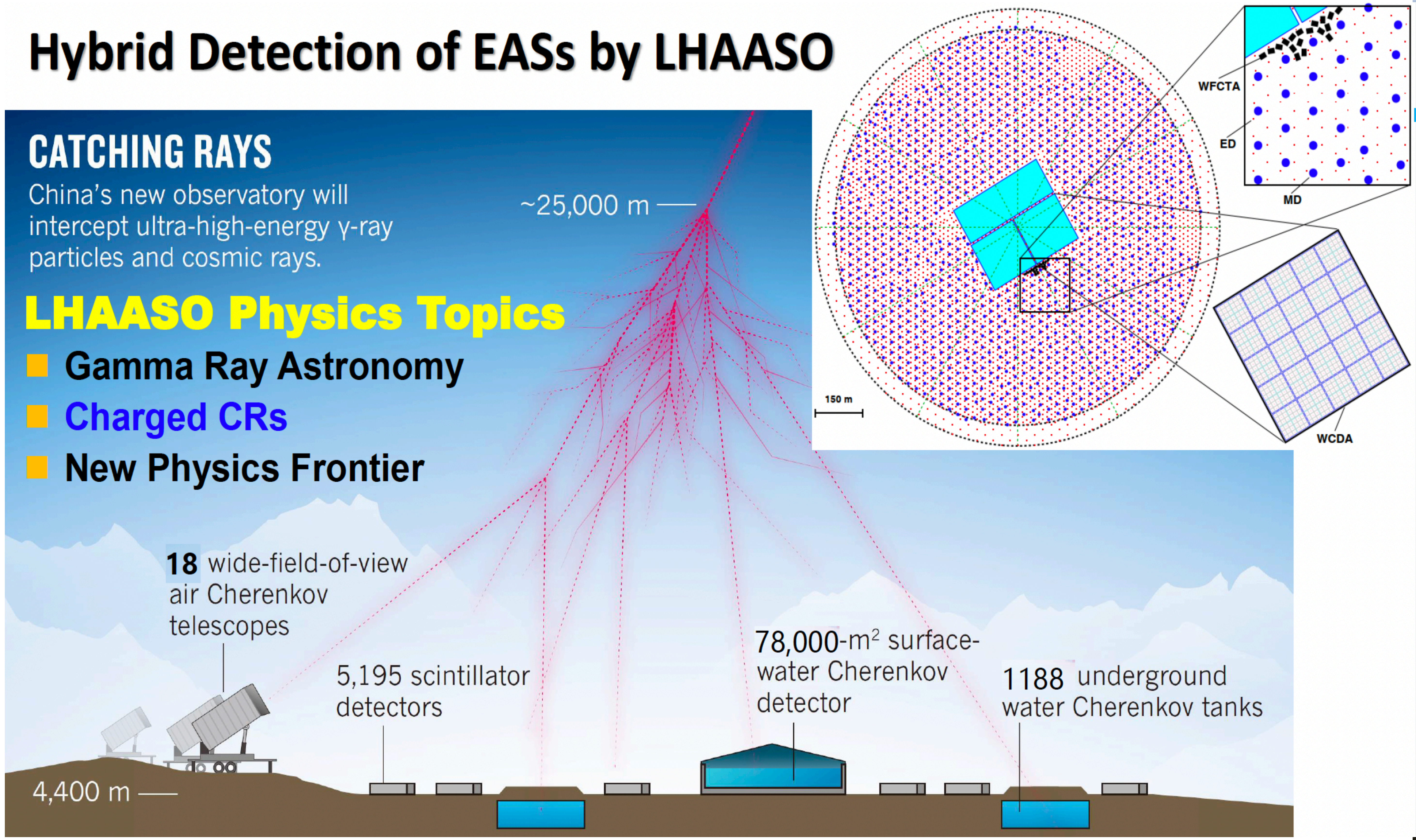


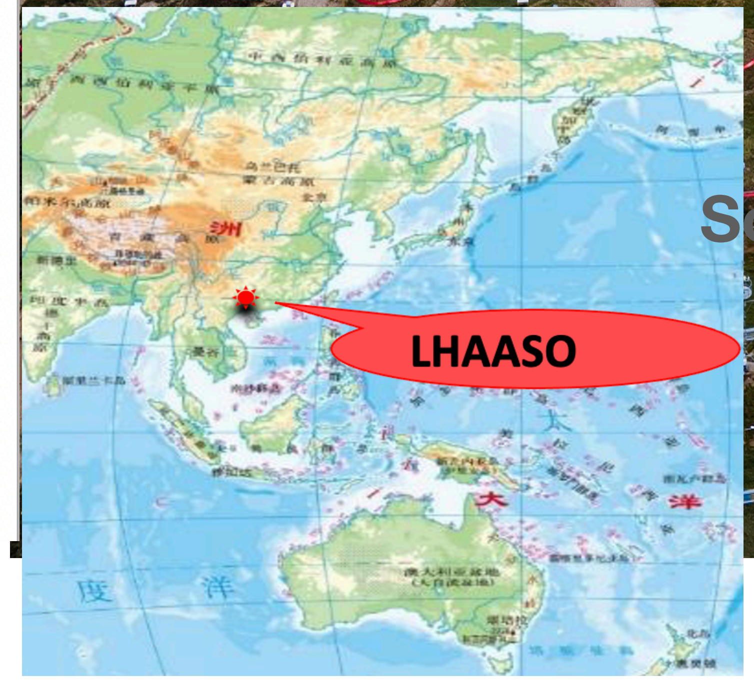
2019,Péter Mészáros, et al., Nature Review

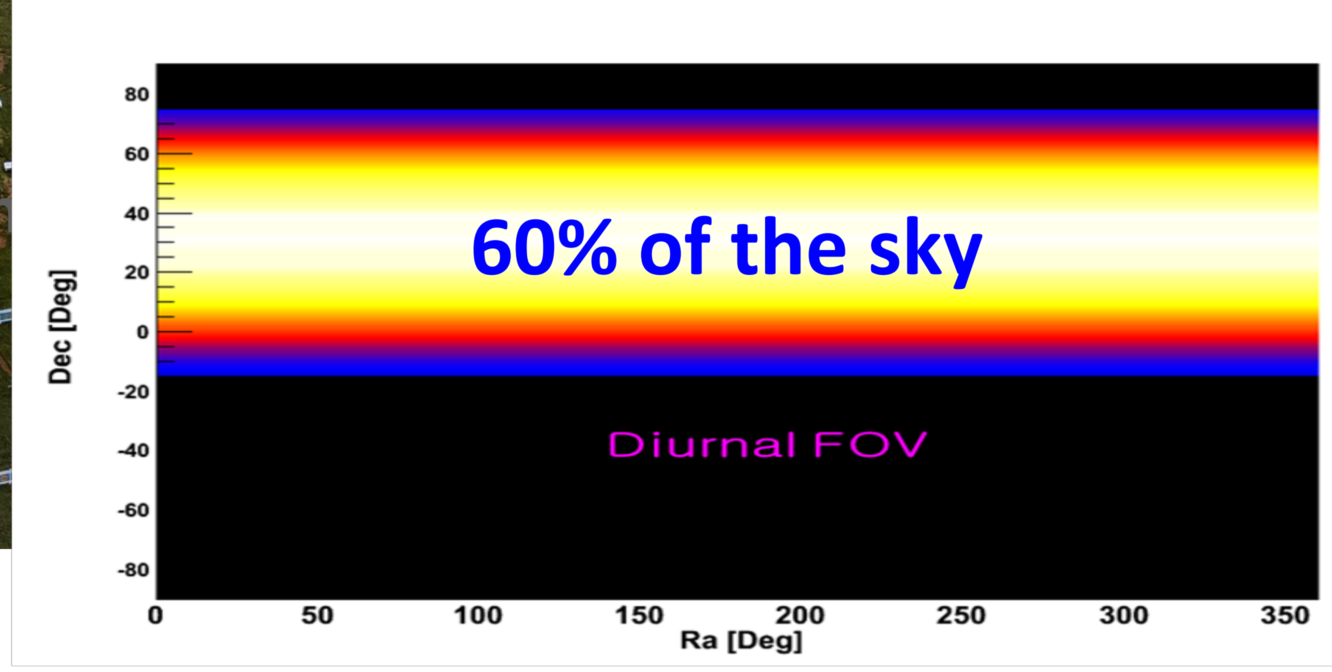
1. LHAASO experiment

- **Haizi Mountain 4410 m a.s.l. , Sichuan province, China**
- **Location：29°21′ 27.6″ N, 100°08′ 19.6″ E.**

Hybrid Detection of EASs by LHAASO

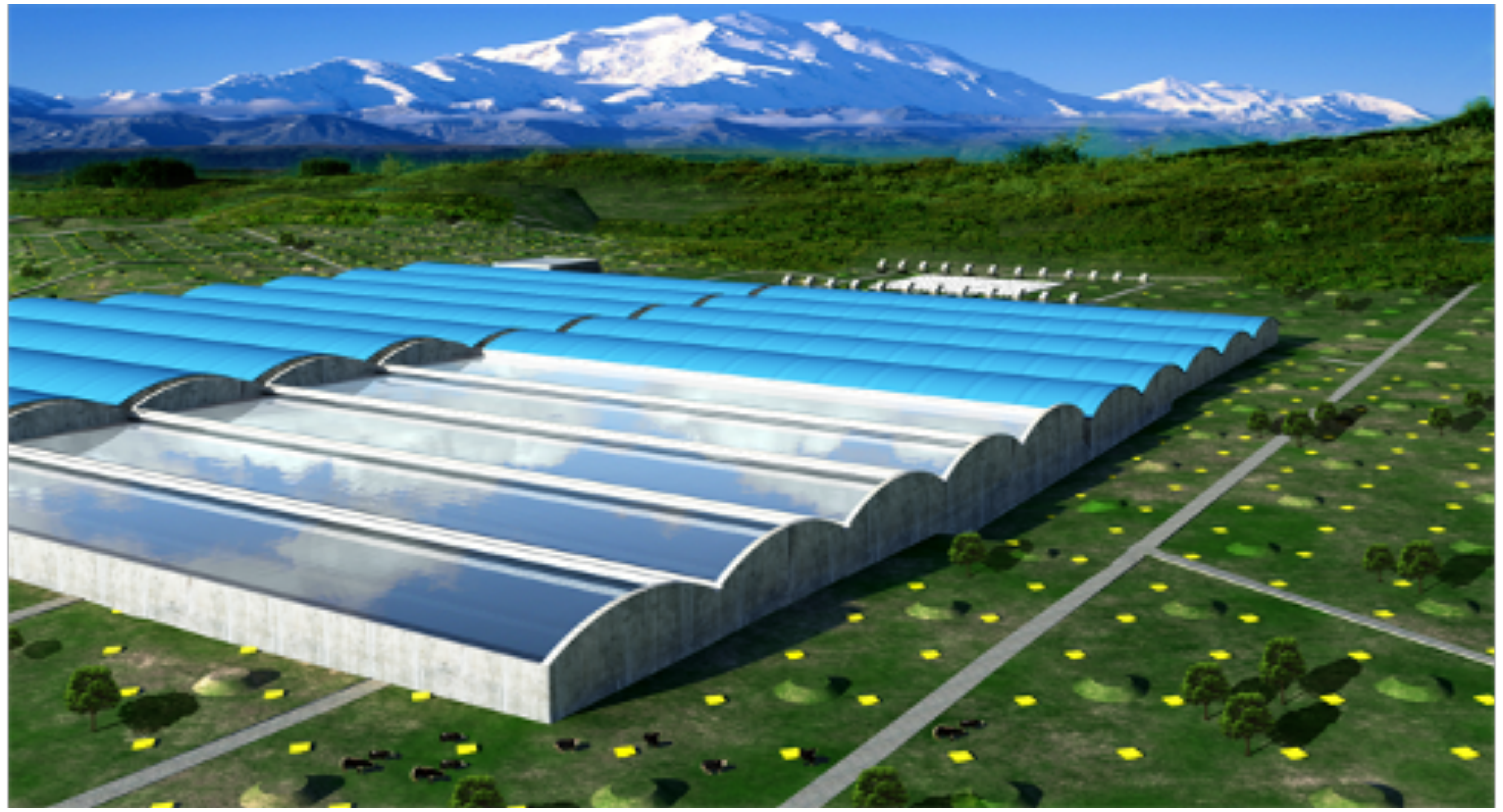




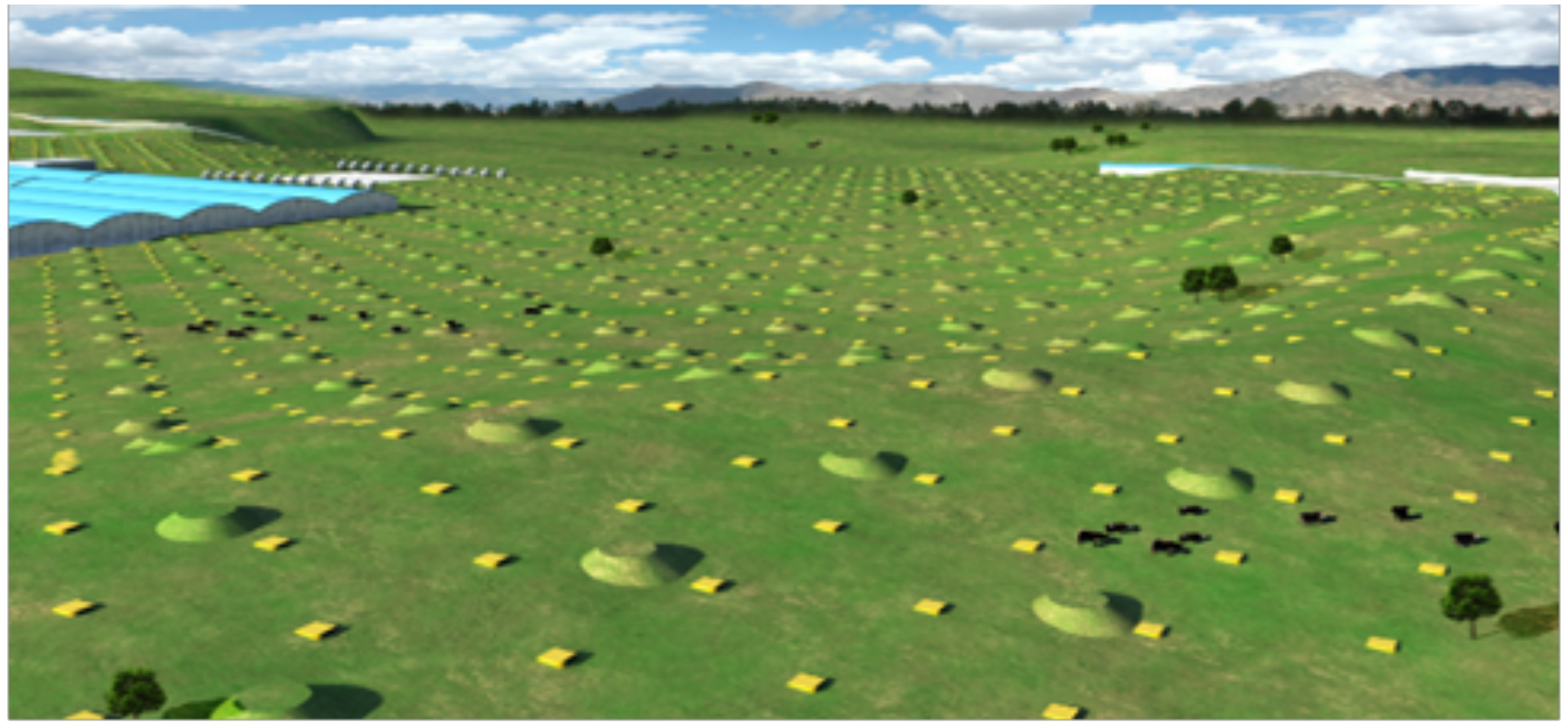


1. LHAASO experiment

- **WCDA (100 GeV-30 TeV)**
  - VHE gamma-ray astronomy
- **KM2A (10 TeV-10 PeV)**
  - UHE gamma-ray astronomy
- **WFCTA (10TeV to 1 EeV)**
  - Combined with WCDA, and KM2A
  - Individual Cosmic ray nuclei spectra



WCDA

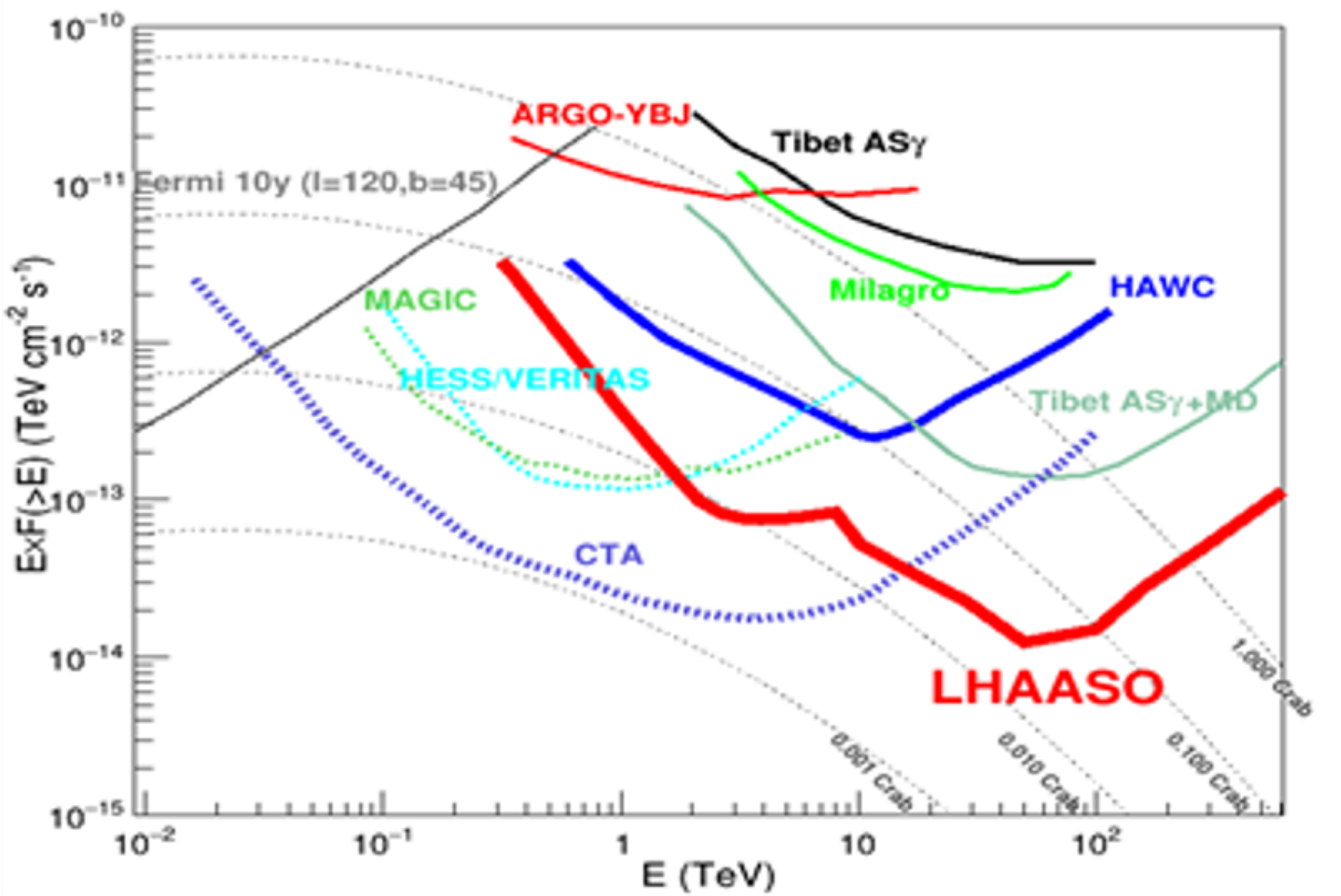


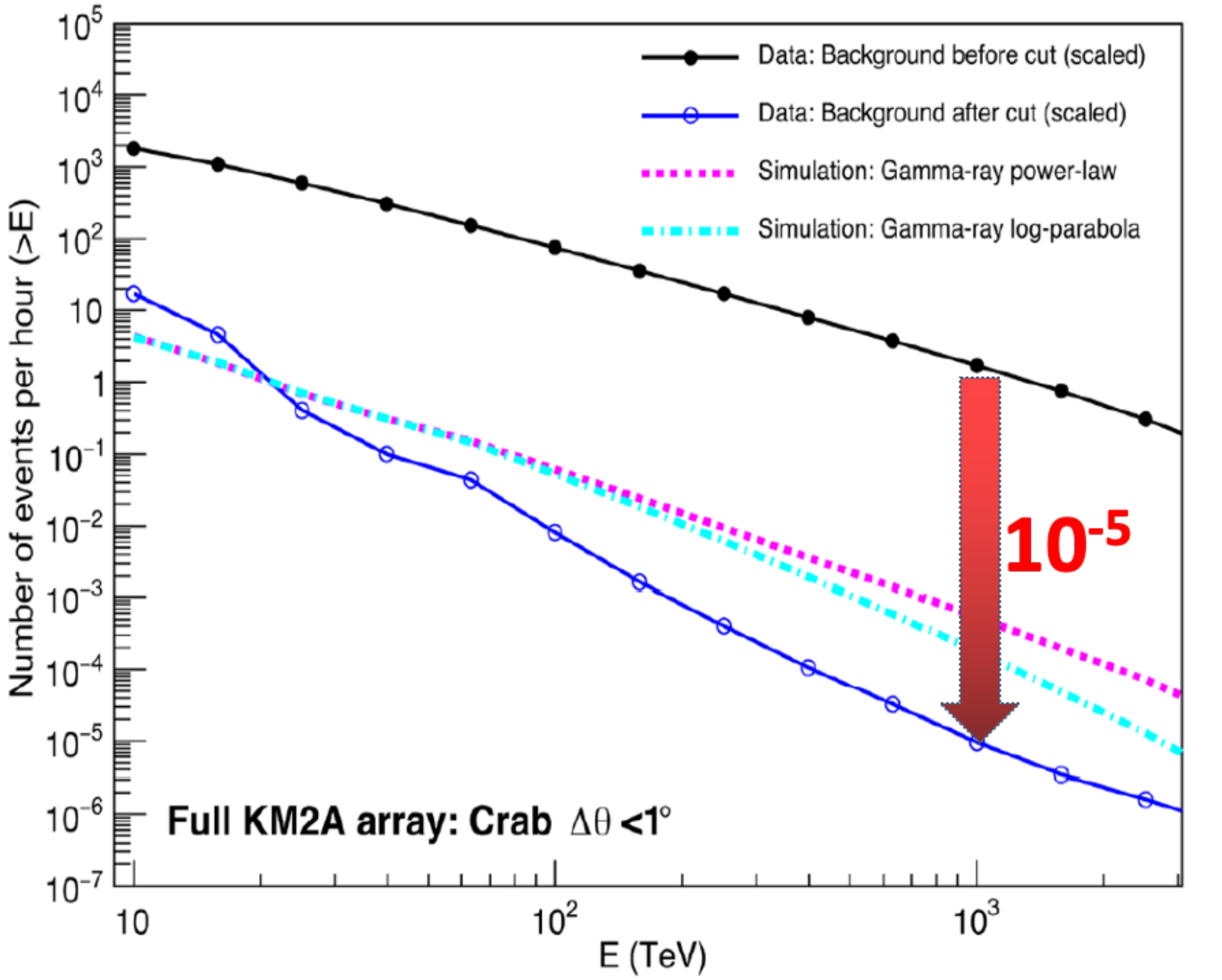
KM2A

WFCTA

1. LHAASO experiment

With large FOV and high sensitivity, LHAASO is an ideal detector for sky survey to search VHE and UHE sources!

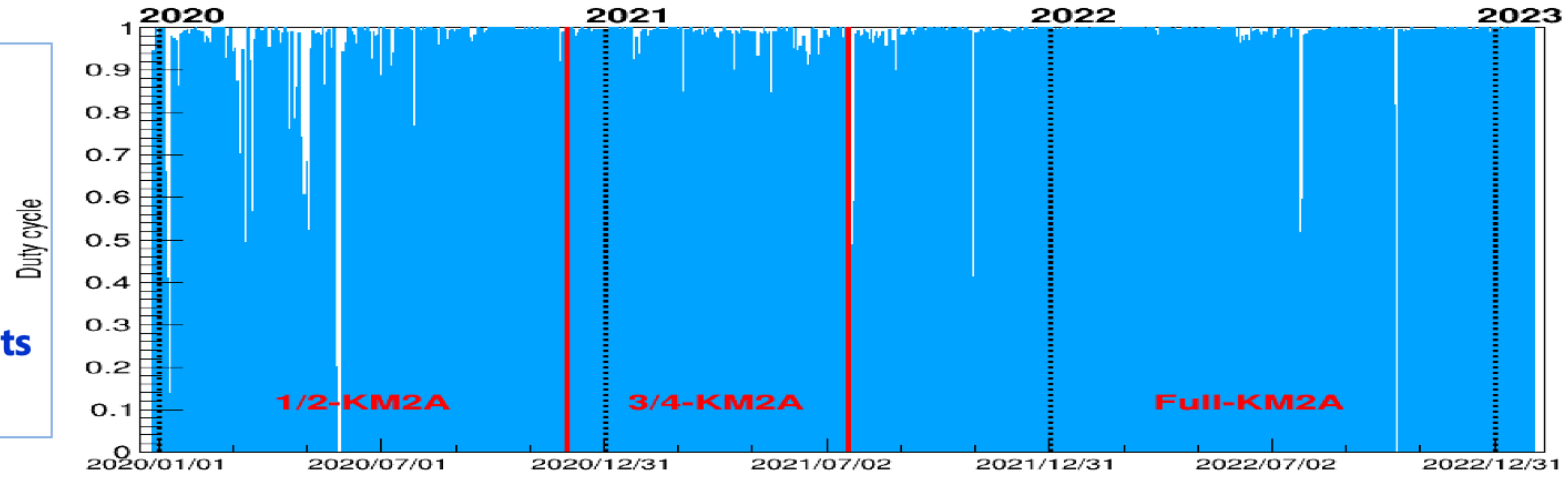




2. Data and analysis method

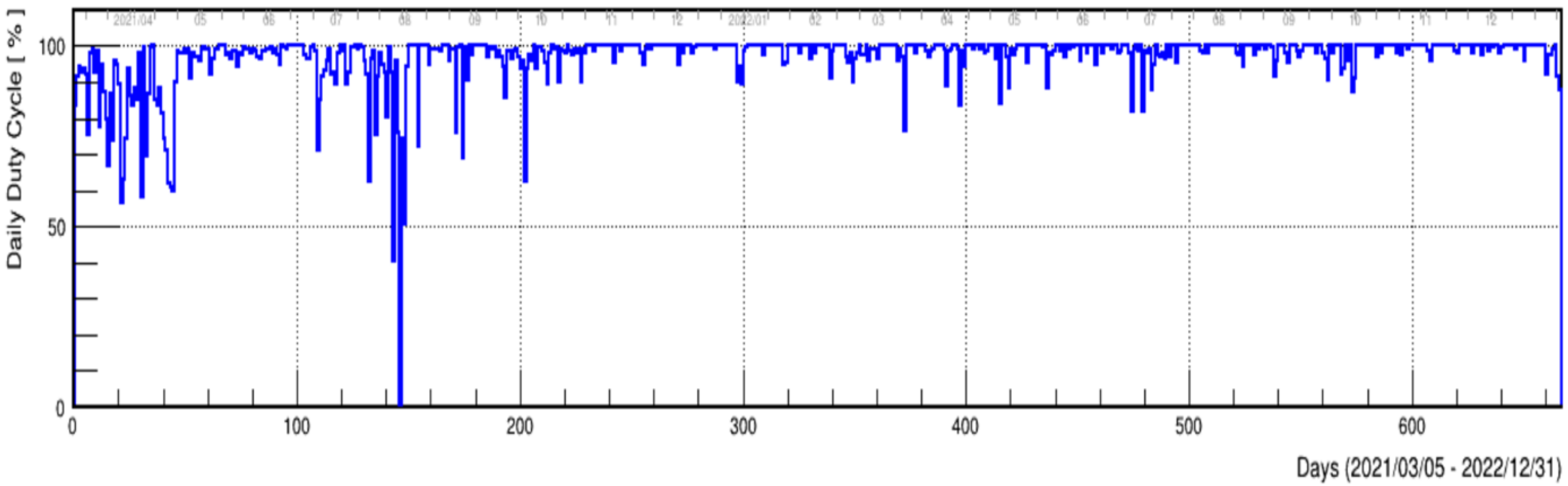
KM2A

- 2019-12 to 2022-09
- 933 days (~730 days full array)
- 1.3×10^7 gamma-like events



WCDA

- 2021-03 to 2022-09
- 508 days
- 1.3×10^9 gamma-like events



2. Data and analysis method

- **Space bin:** 0.1°x0.1° for Ra:0°-360°, Dec:-20°-80°
- **WCDA energy bin:** N_{hit}100-200, 200-300, 300-500, 500-800, ≥800
- **KM2A energy bin:** E_{rec} 25-40, 40-63, 63-100, 100-160, 160-250, 250-400, 400-630, 630-1000, 1000-1600, >1600 TeV

$$P(N_{i,j}^{\text{on}}|\lambda_{i,j}) = \frac{\lambda_{i,j}^{N_{i,j}^{\text{on}}} e^{-\lambda_{i,j}}}{N_{i,j}^{\text{on}}!}$$

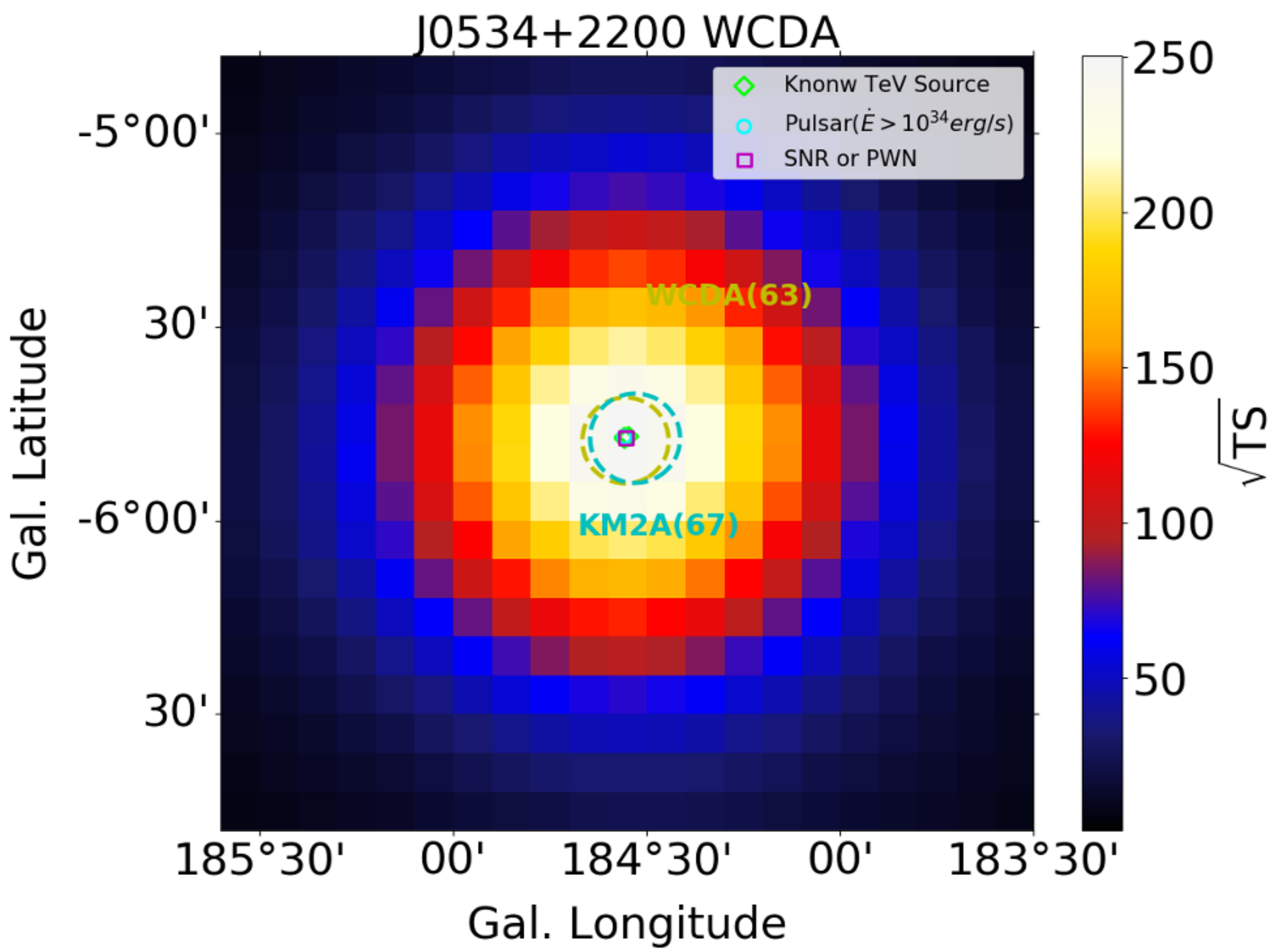
$$\lambda_{i,j} = N_{i,j}^{\text{bk}} + \sum_{k}^{N_{\text{src}}} N_{k,i,j}^{\text{s}}$$

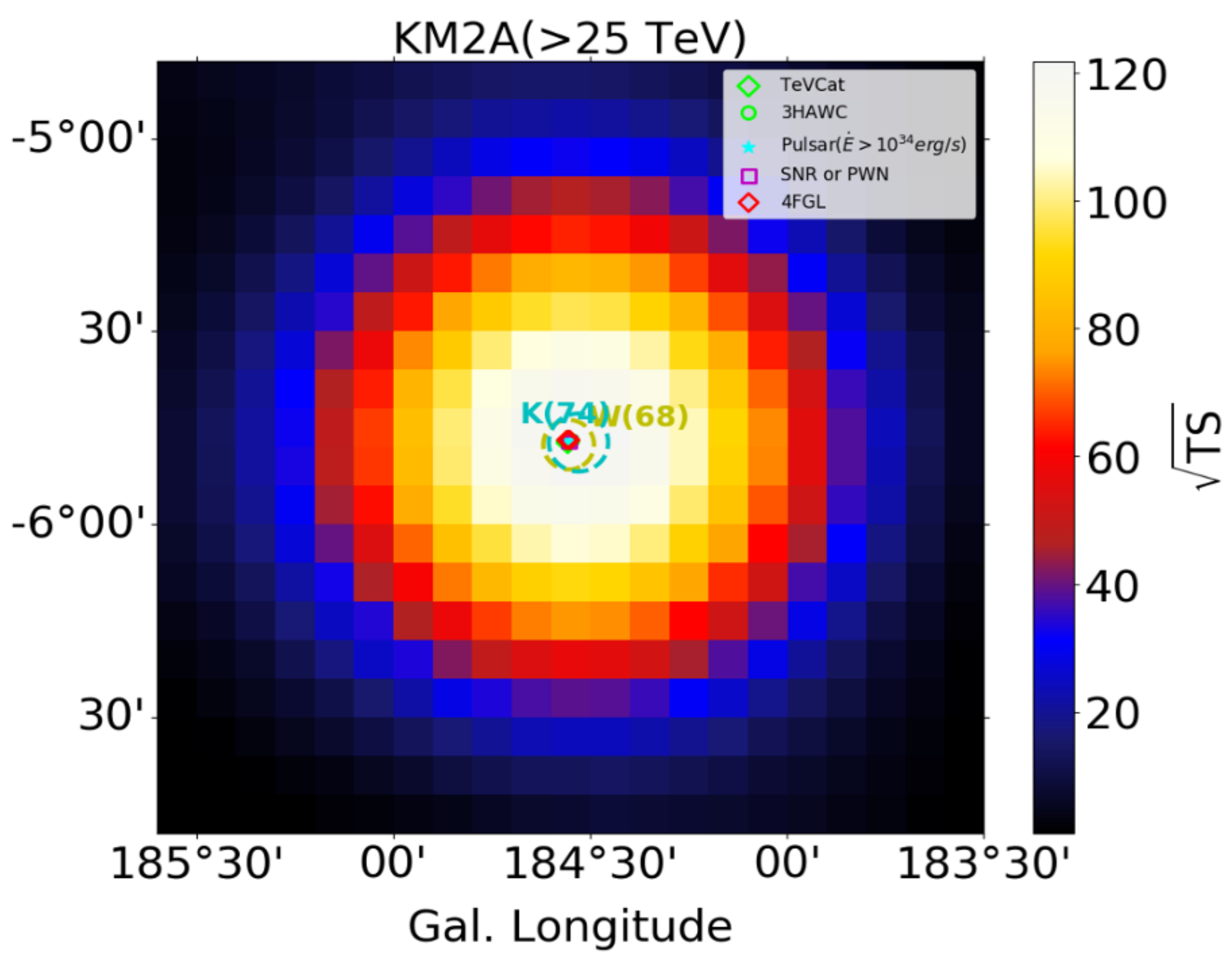
$$\ln L(\Theta|N_{\text{on}}) = \sum_{i}^{N_{\text{bins}}} \sum_{j}^{\text{ROI}} \left(N_{i,j}^{\text{on}} \ln\lambda_{i,j} - \lambda_{i,j} - \ln N_{i,j}^{\text{on}}!\right)$$

$$TS = -2\left(\ln L_0 - \ln L_1\right)$$

- **The position, SED and extension for each seed are fitted simultaneously.**

2. Data and analysis method

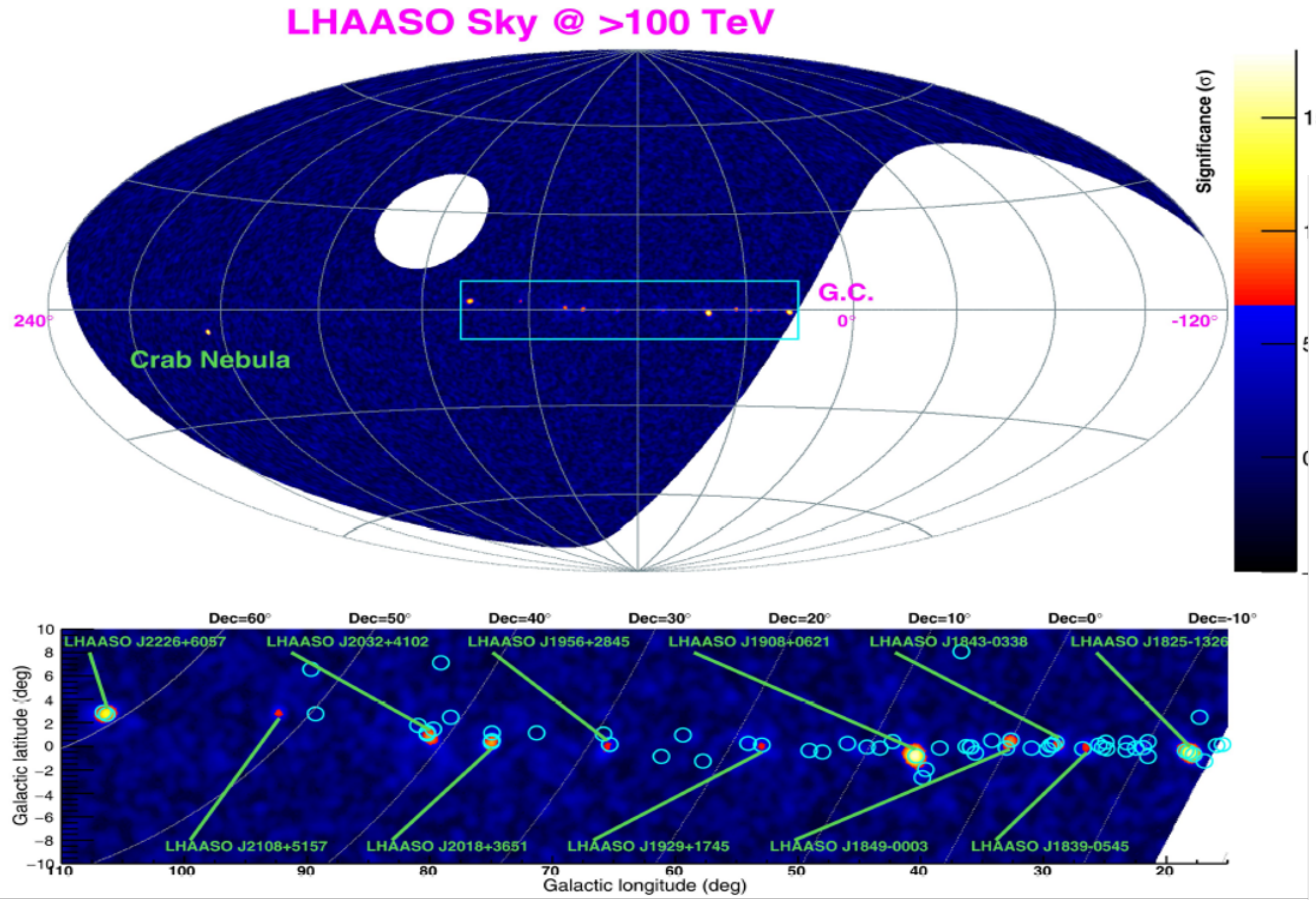




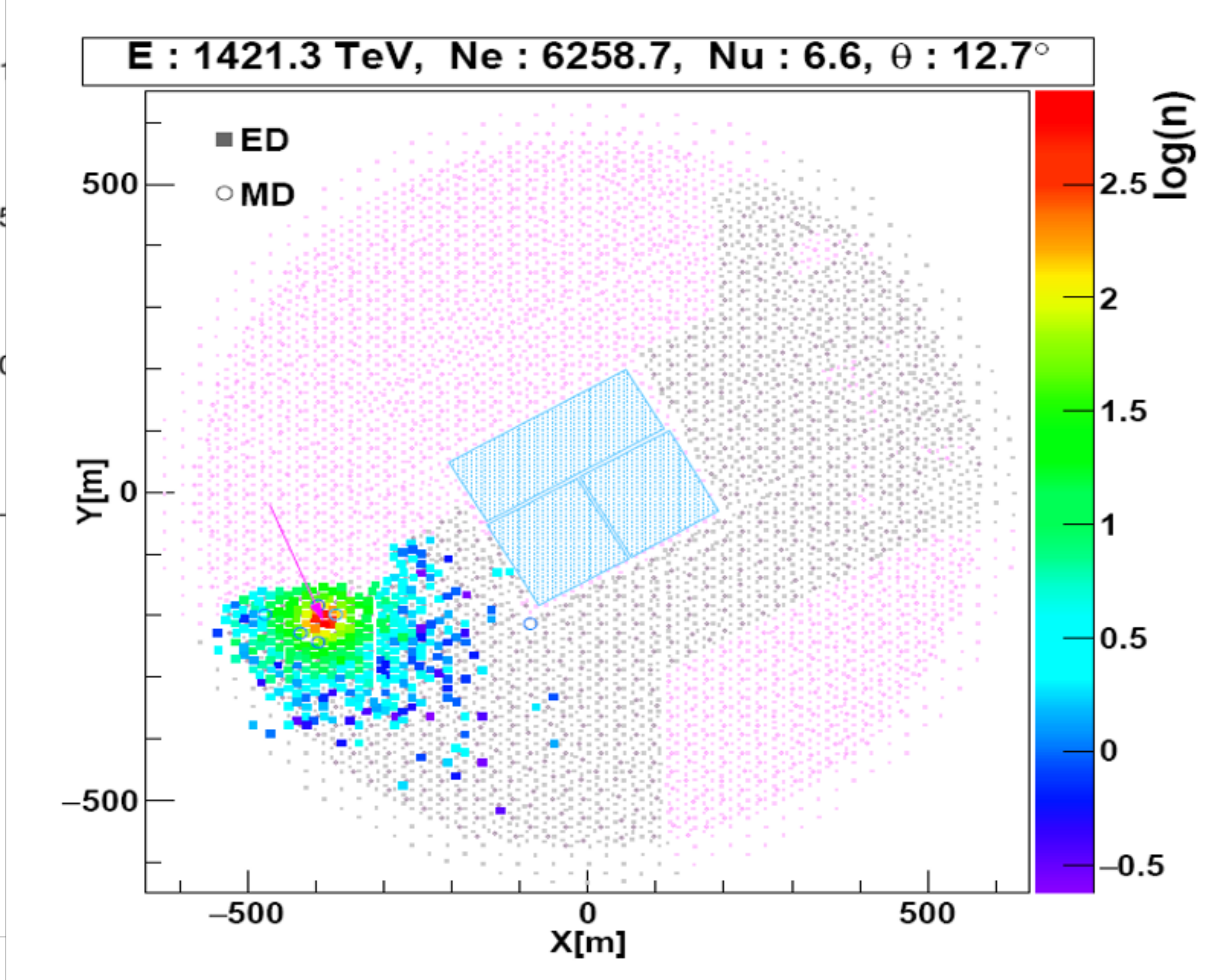
TS_{WCDA}=73603.7

TS_{KM2A}=14328.1

3. Gamma-ray astronomy results



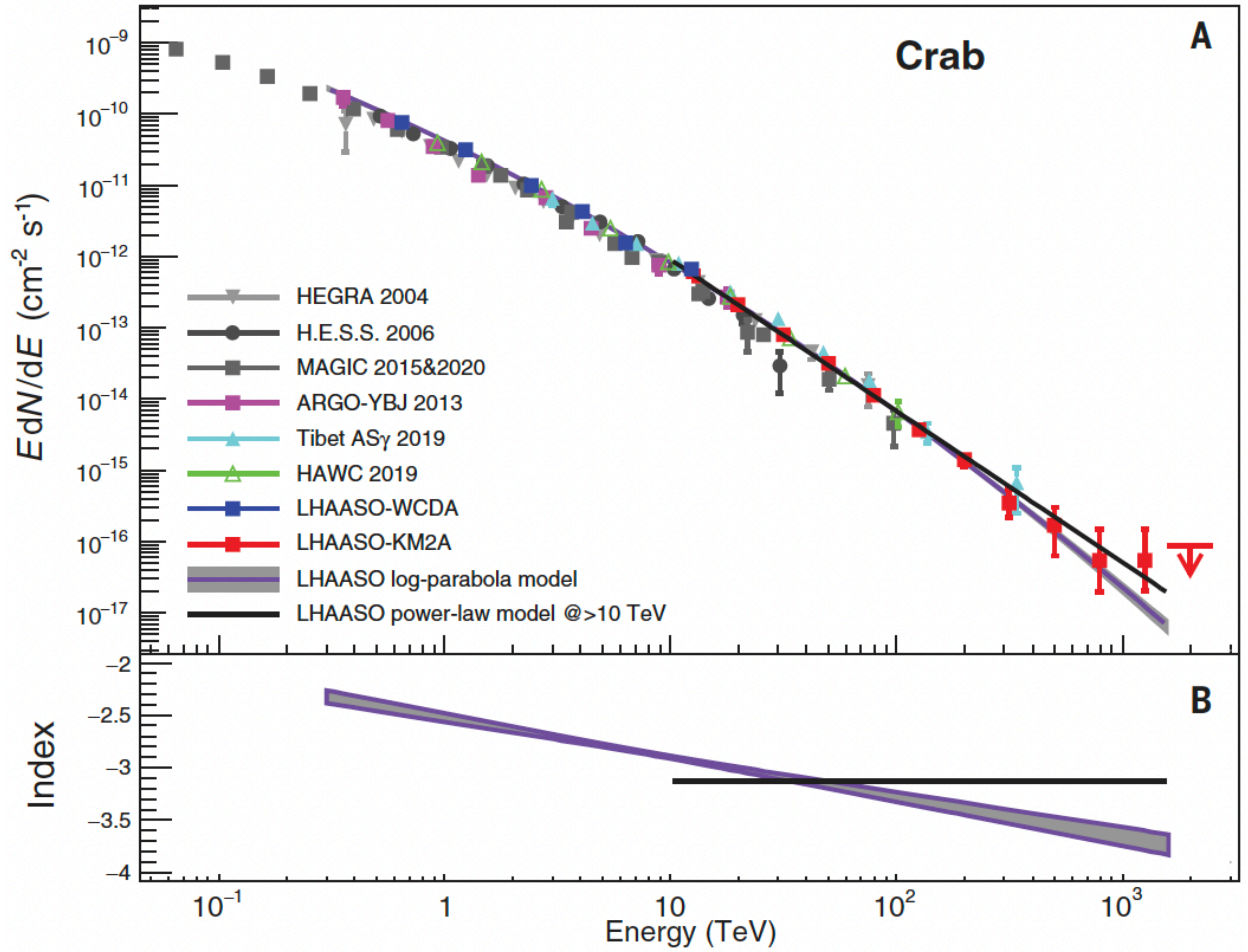
- 1.42±0.13 PeV from the Cygnus region, the hottest PeV CR accelerator

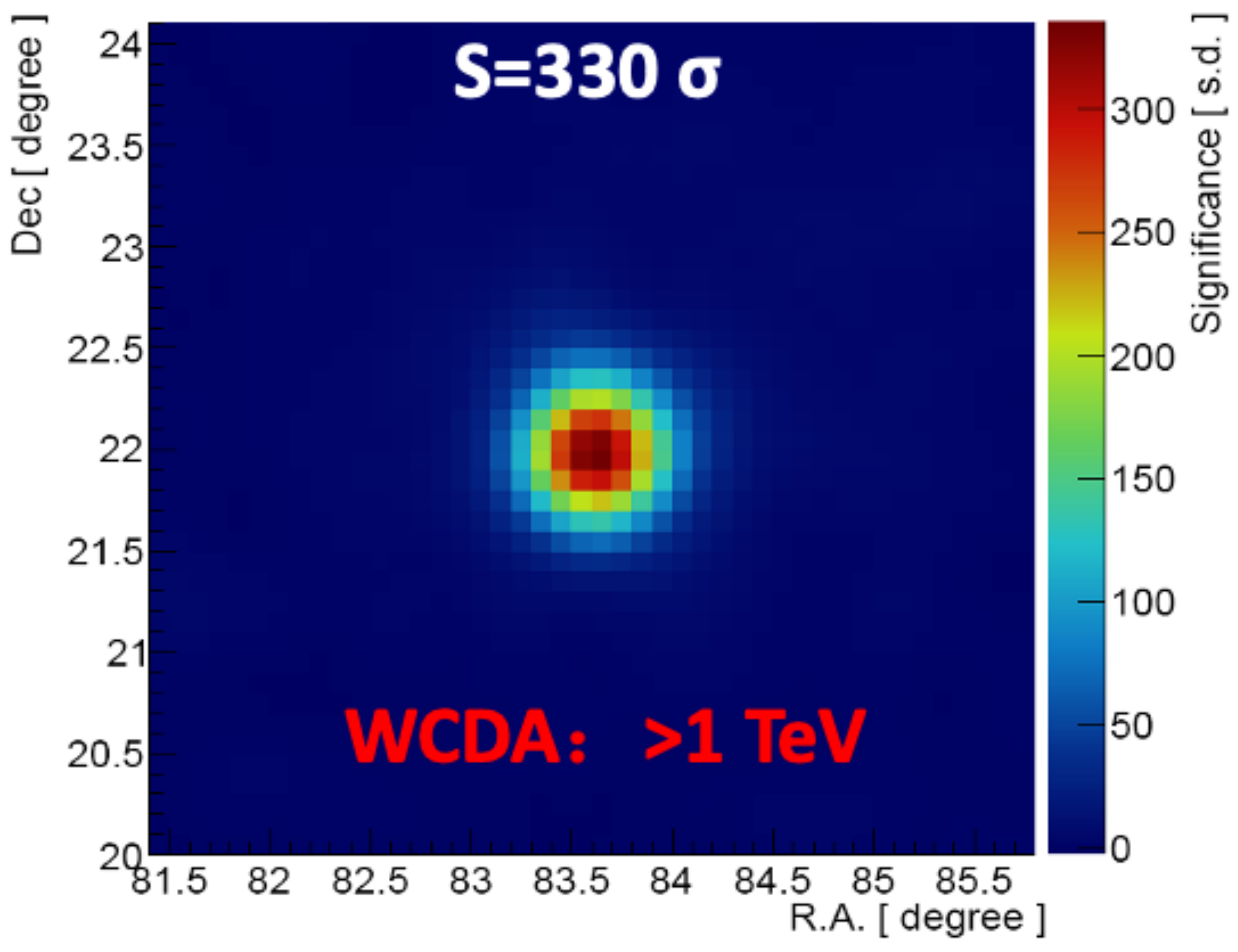


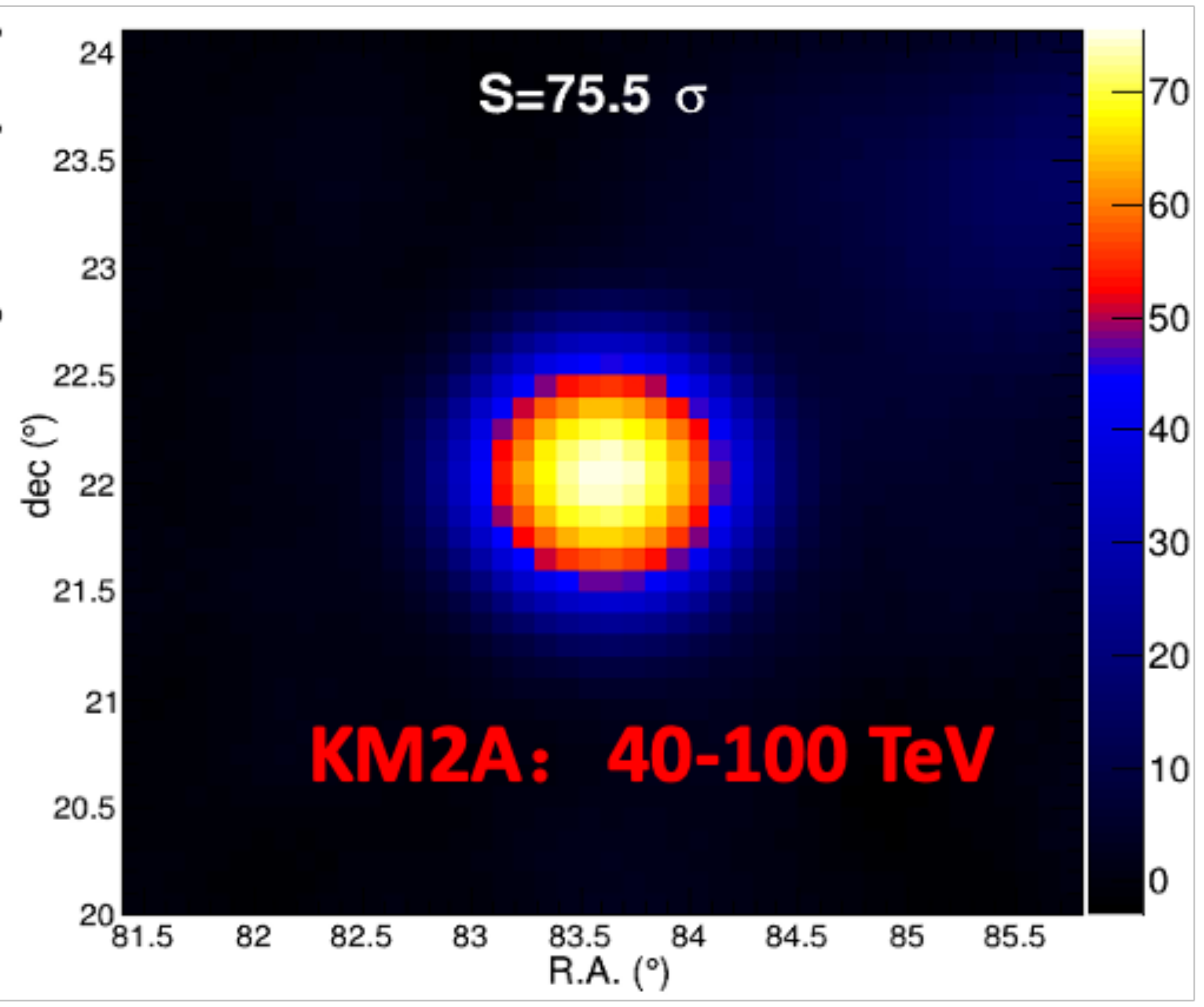
LHAASO coll. 2021 (Nature 594:33-36)

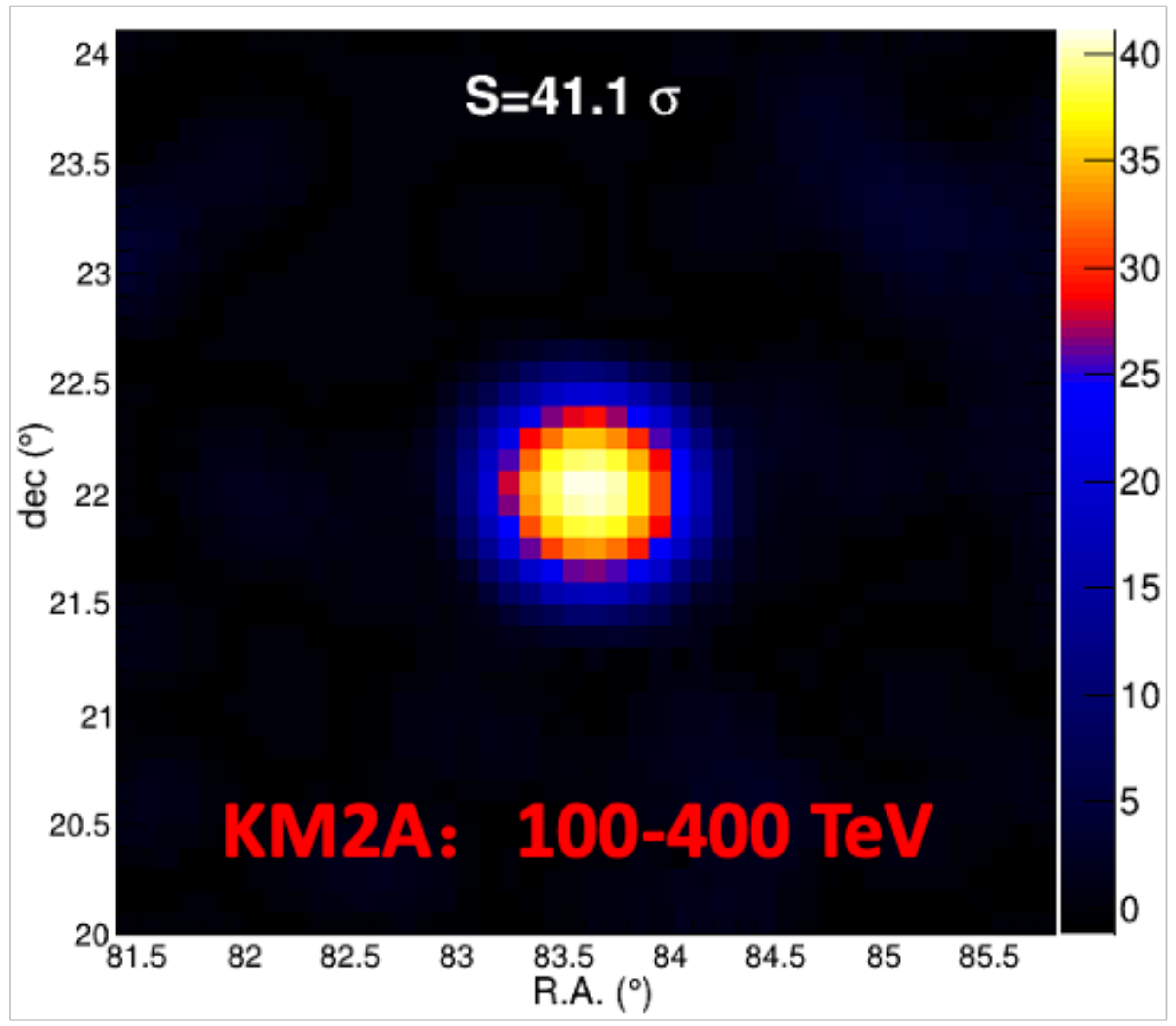
3. Gamma-ray astronomy results

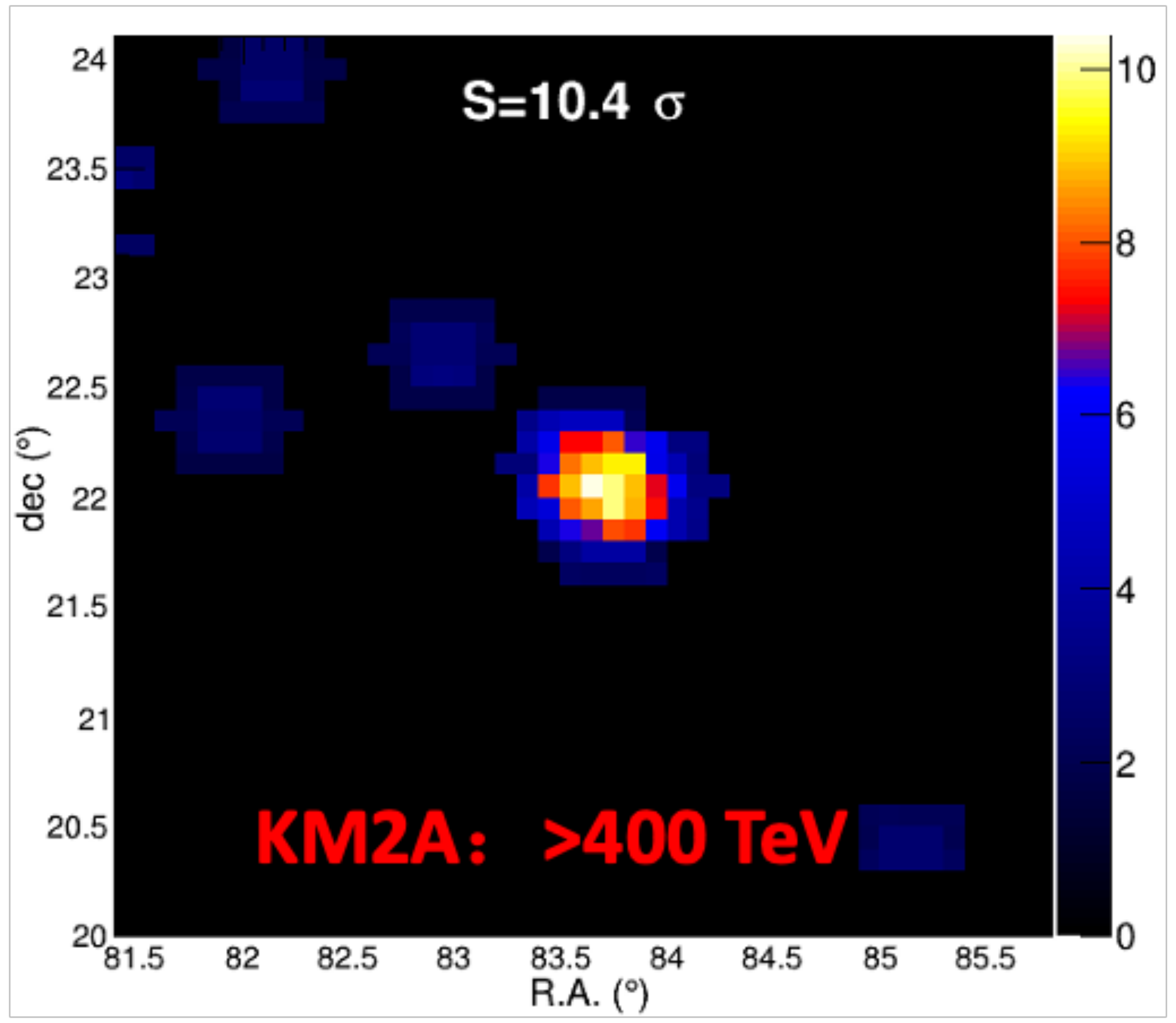
- **Unique UHE SED**
- **A PeVatron without ambiguity**
- **Clear origin: a well-known PWN**
- **An extreme e-accelerator:**
  - **2.3 PeV electrons**
  - **in ~0.025 pc compact region**
  - **accelerating efficiency of 15% (1000× better than SNR shock waves)**







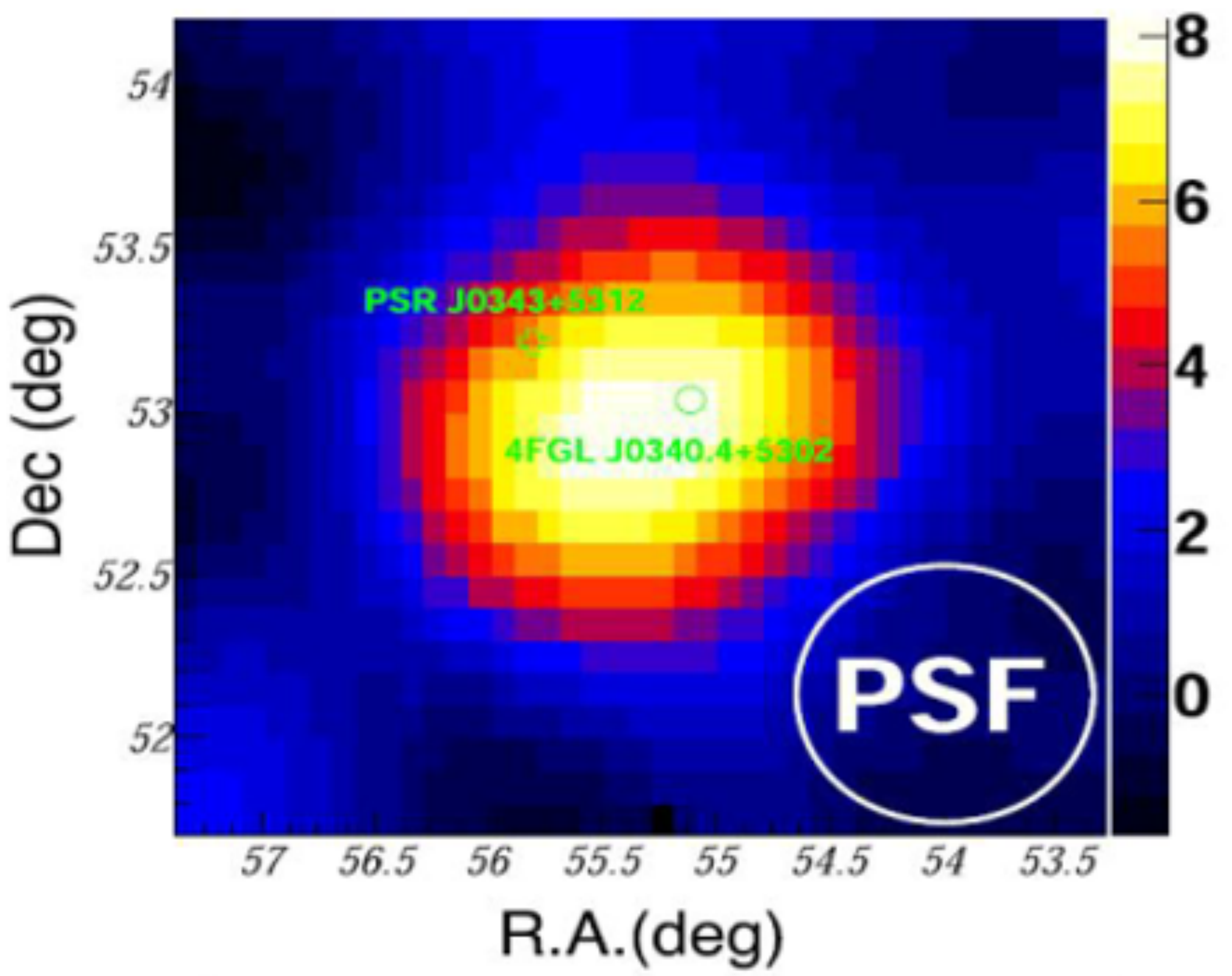


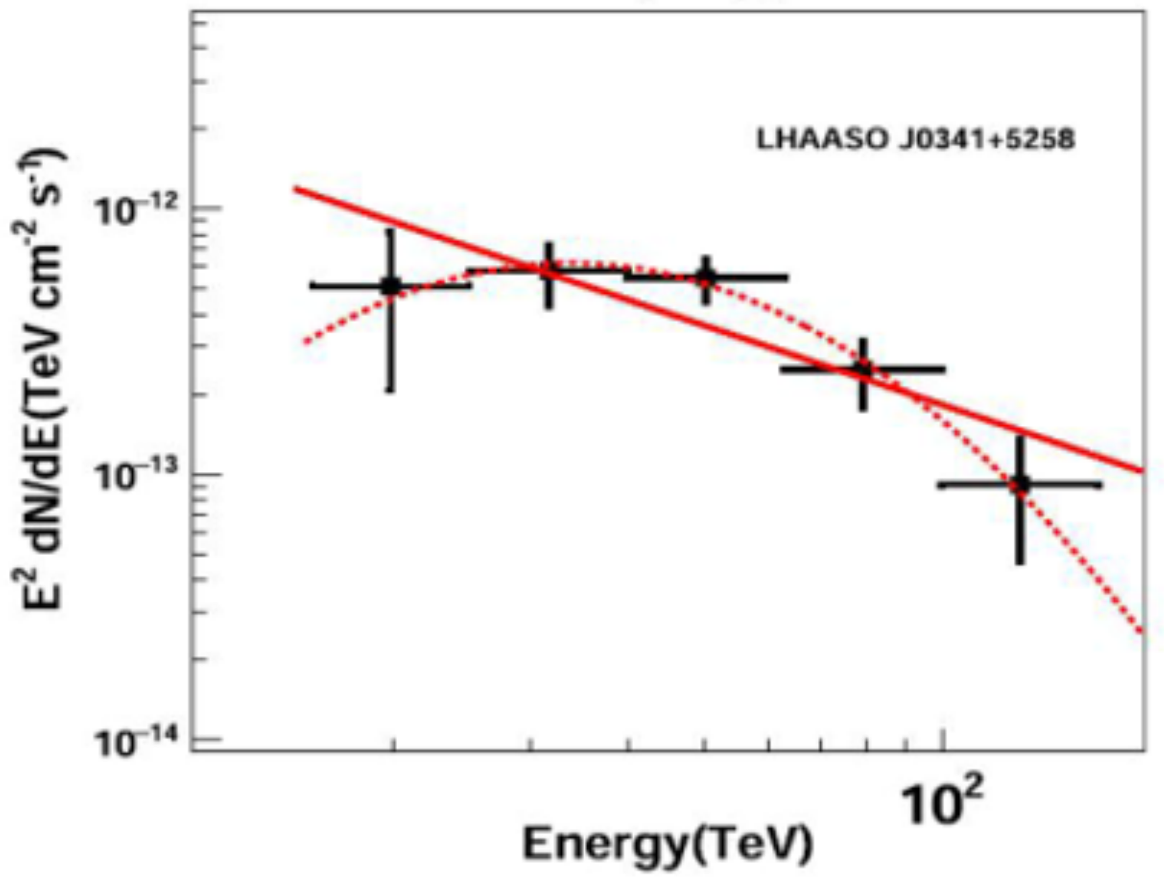


LHAASO Coll, 2021, (Science, 373,425-430)

3. Gamma-ray astronomy results

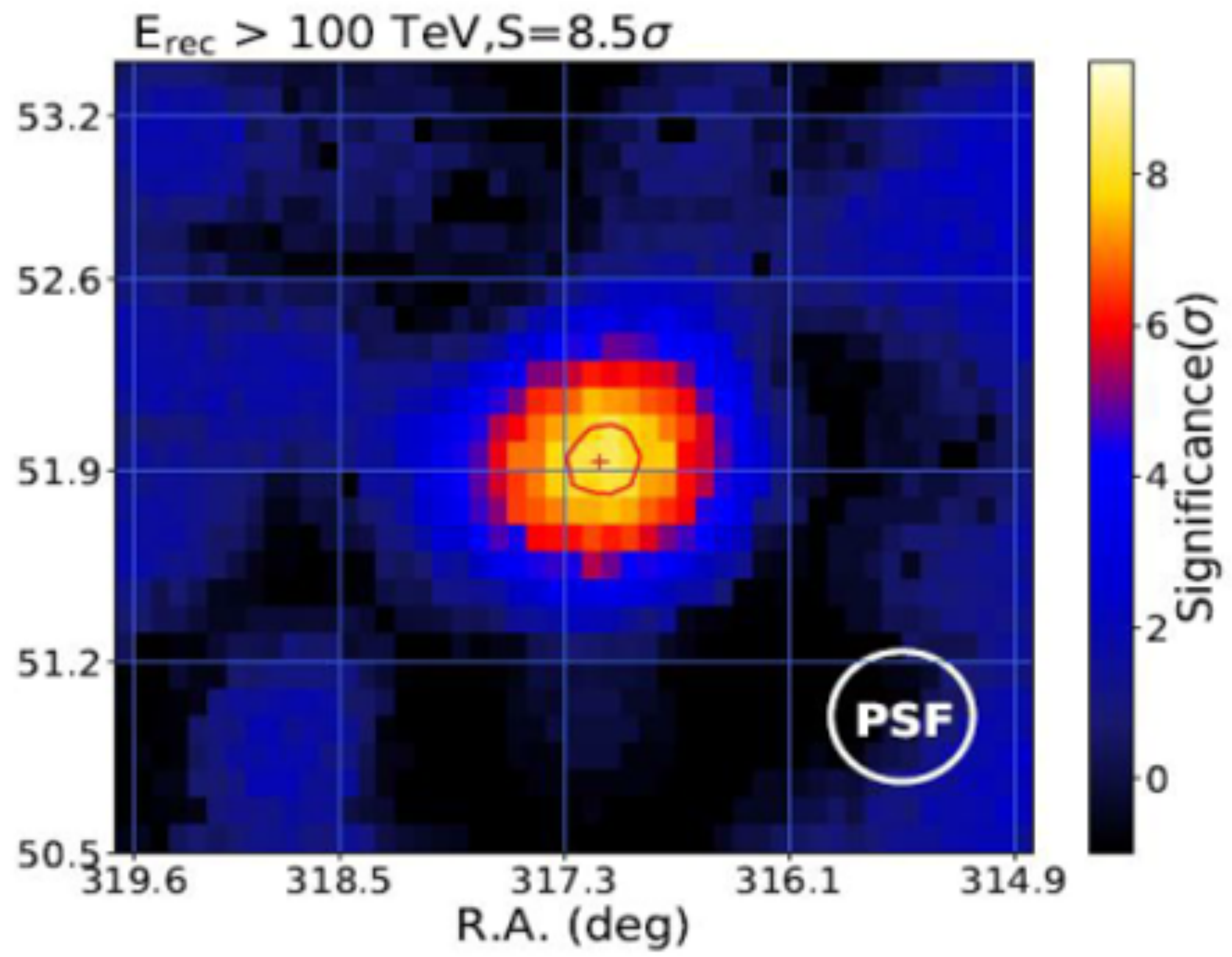
LHAASO J0341+5258

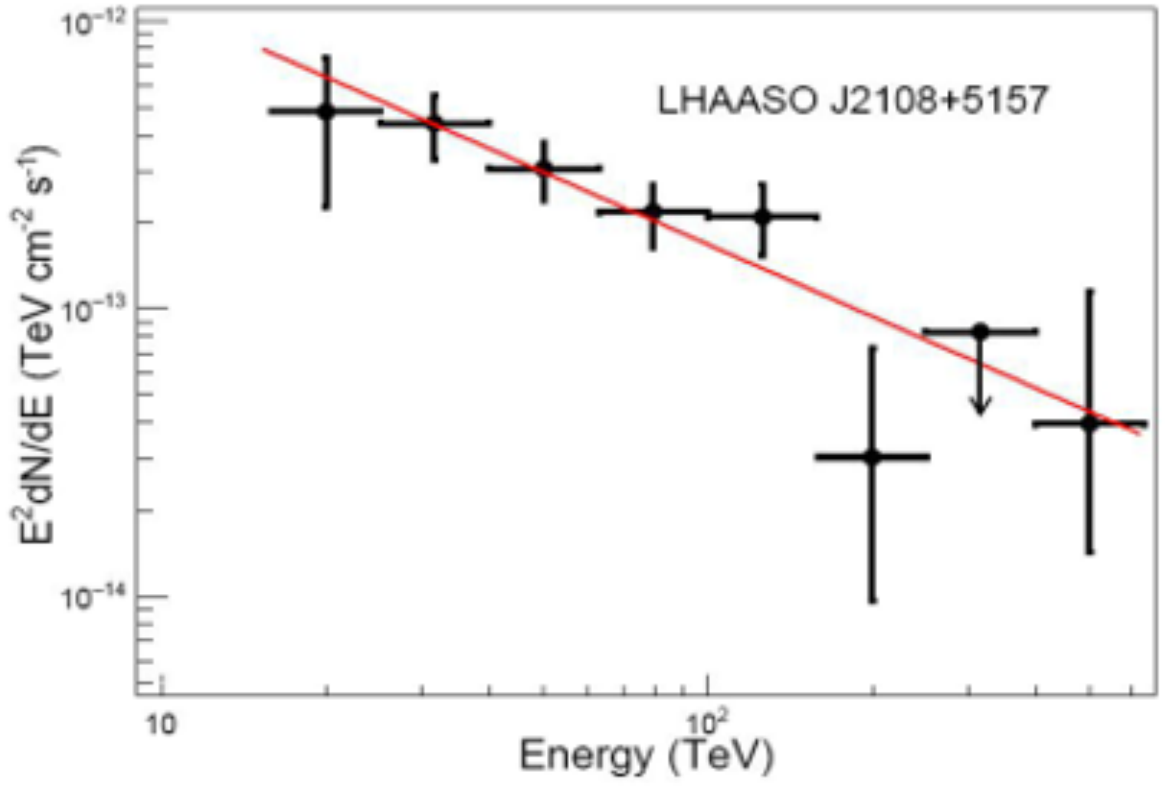




ApJL 917:L4 (2021)

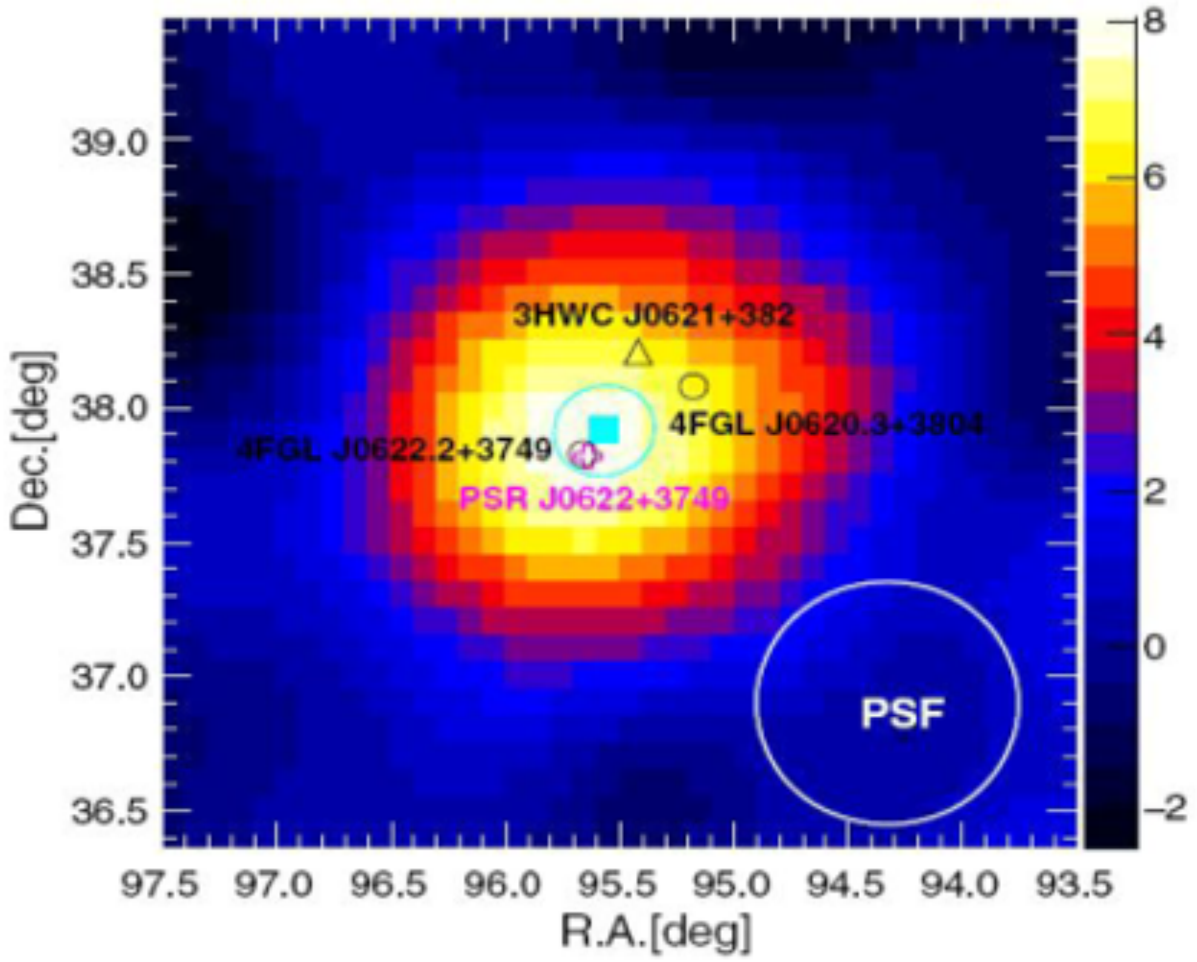
LHAASO J2108+5157

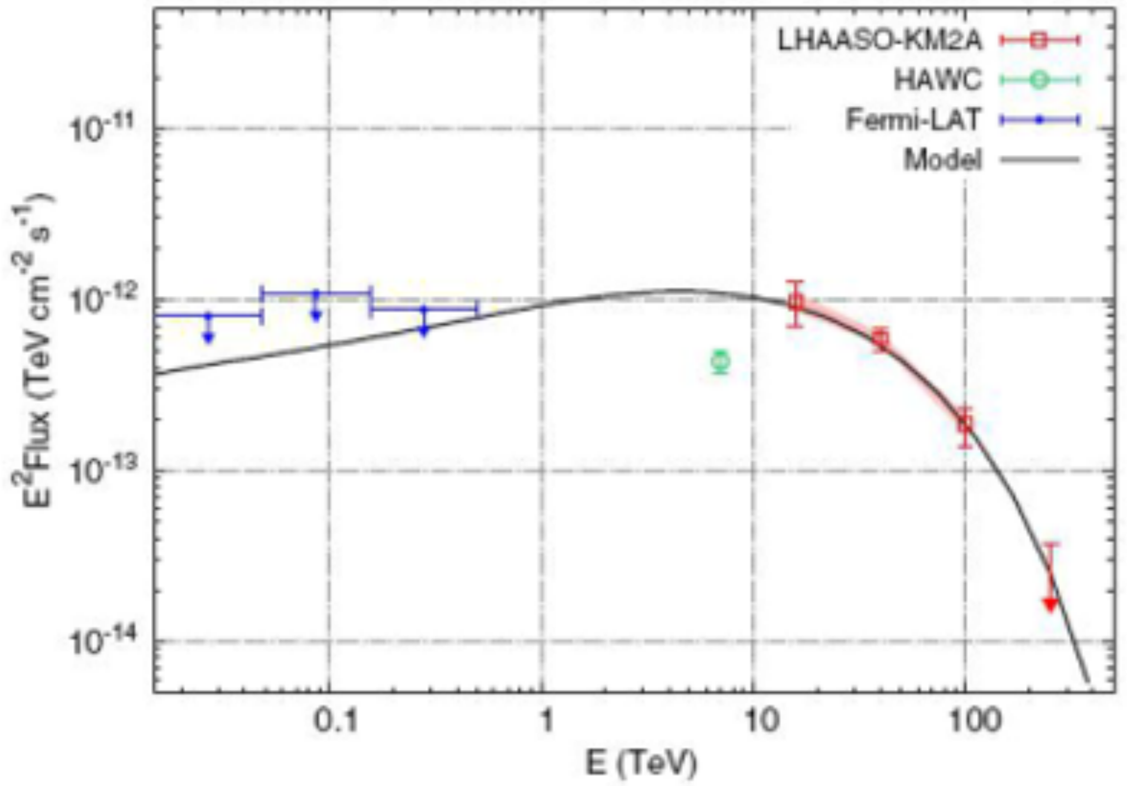




ApJL 919:L22 (2021)

Halo of PSR J0622 + 3749

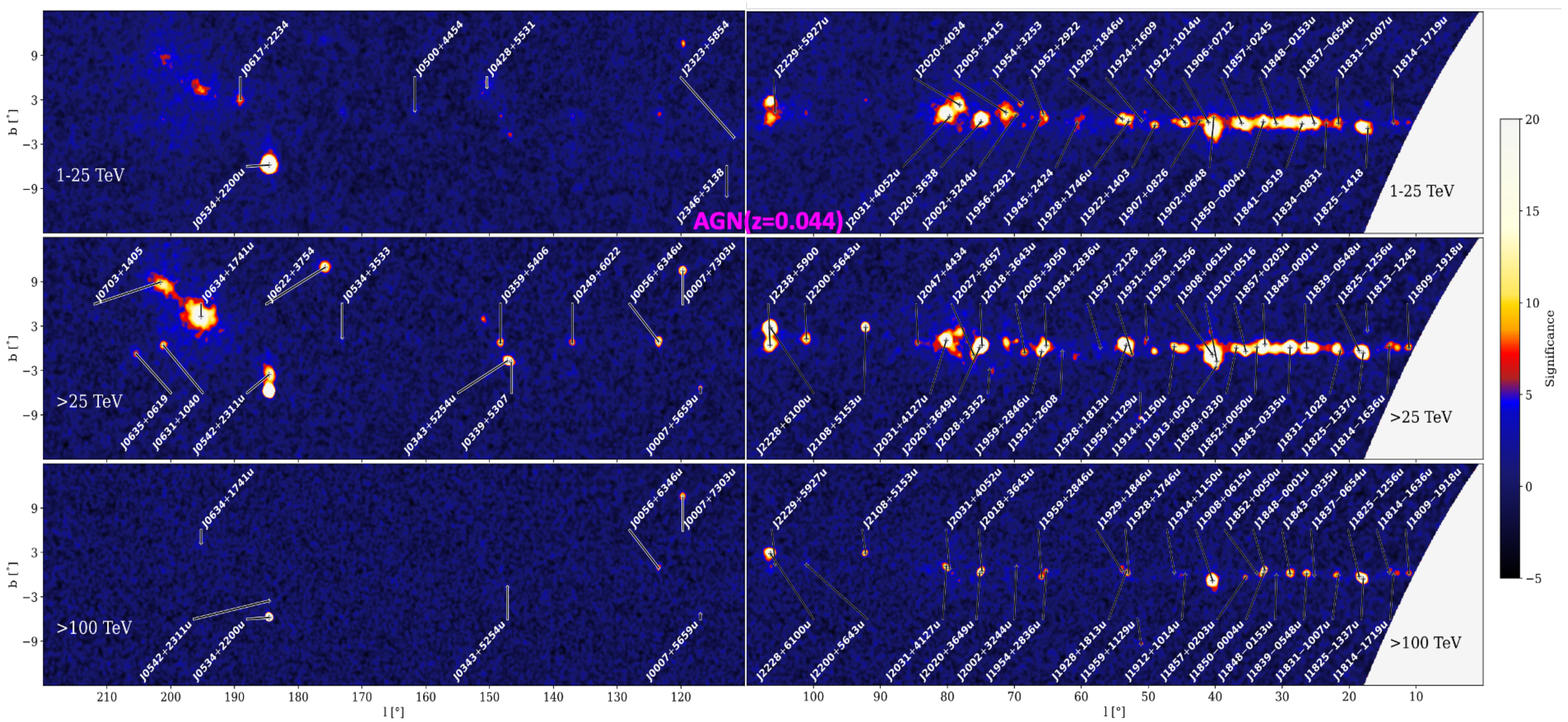




PRL 126:241103 (2021)

3. Gamma-ray astronomy results

82 sources with the Galactic latitude |b|<12°



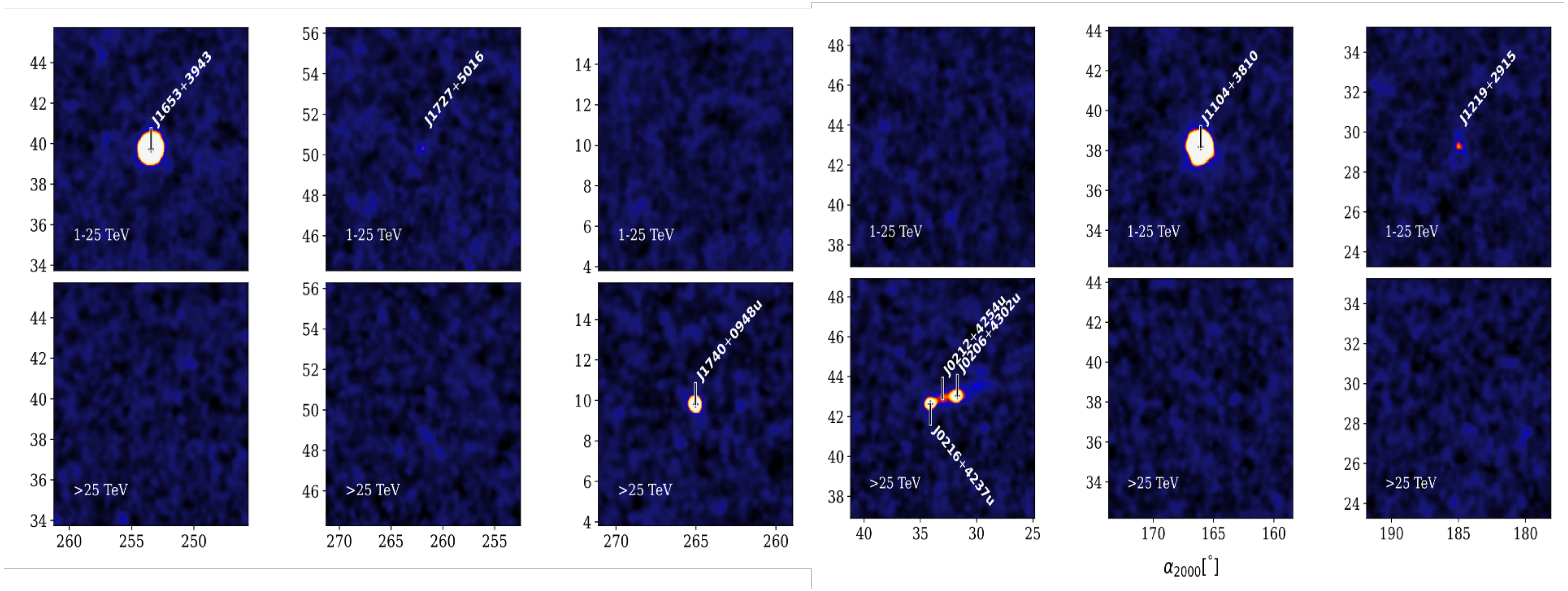
LHAASO's first catalog

LHAASO Coll, 2023, arXiv:2305.17030

3. Gamma-ray astronomy results

8 sources with the Galactic latitude |b|>12°

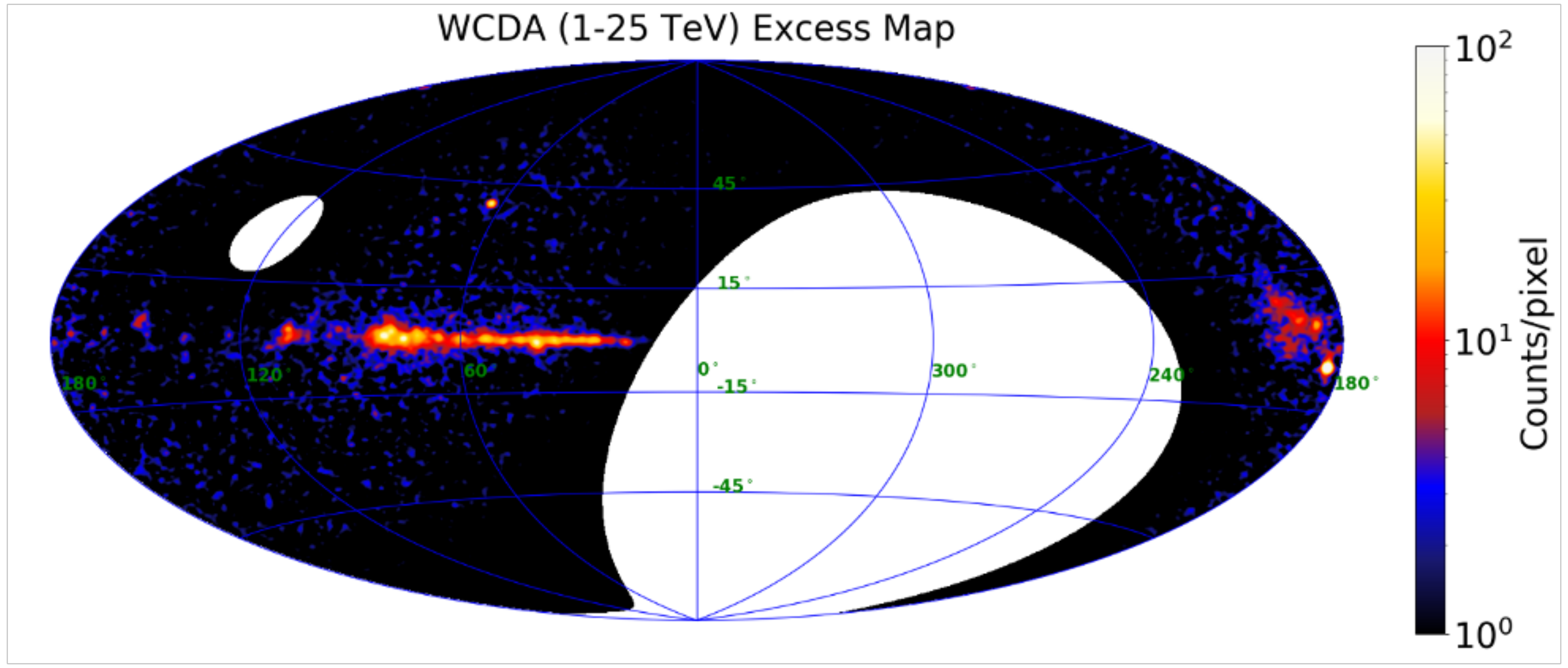
Mrk 421 $z=0.031$ **1ES 1727+502** $z=0.055$ **4 AGNs** **Mrk 501** $z=0.034$ **NGC 4278** $z=0.002$

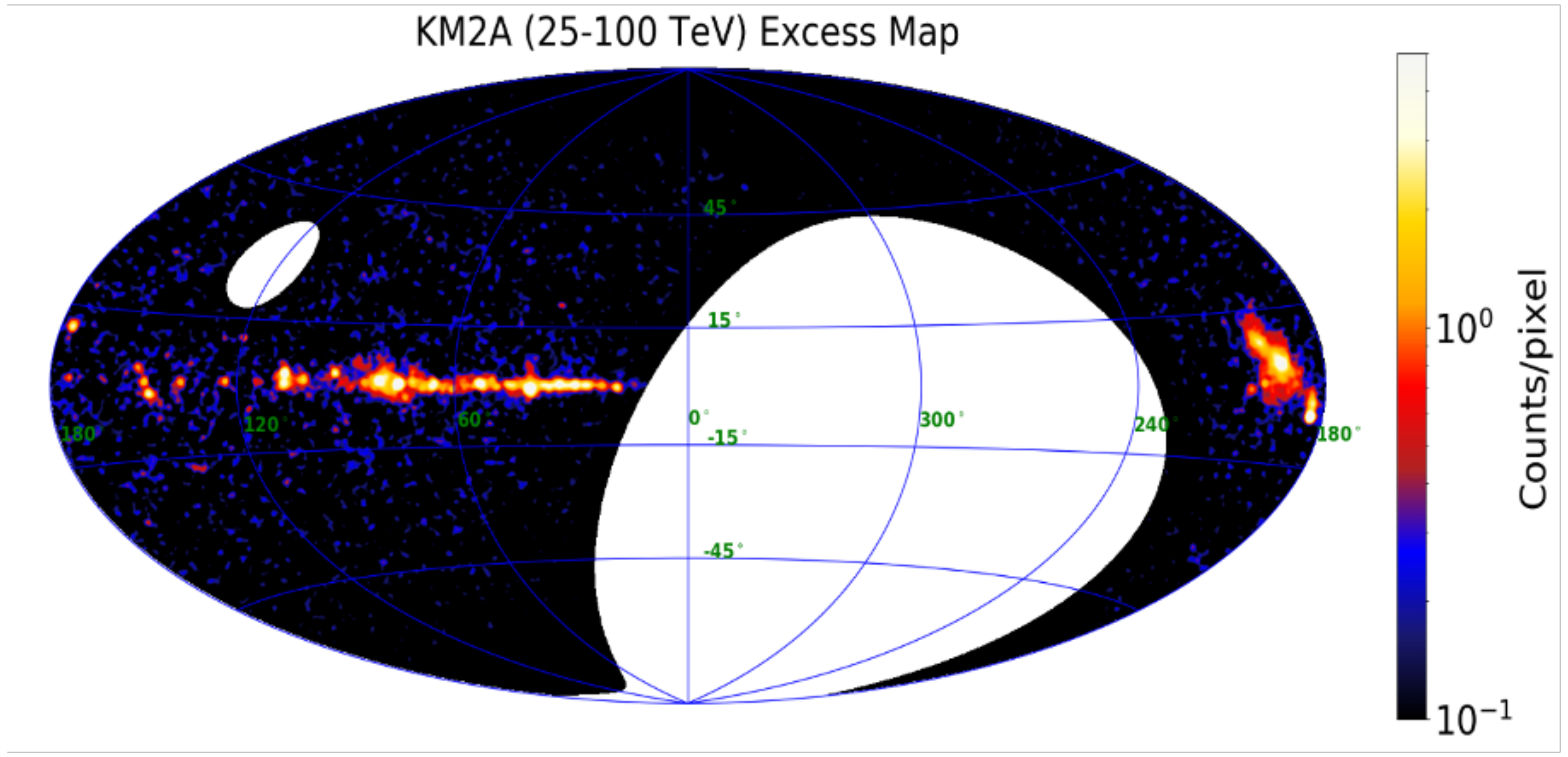


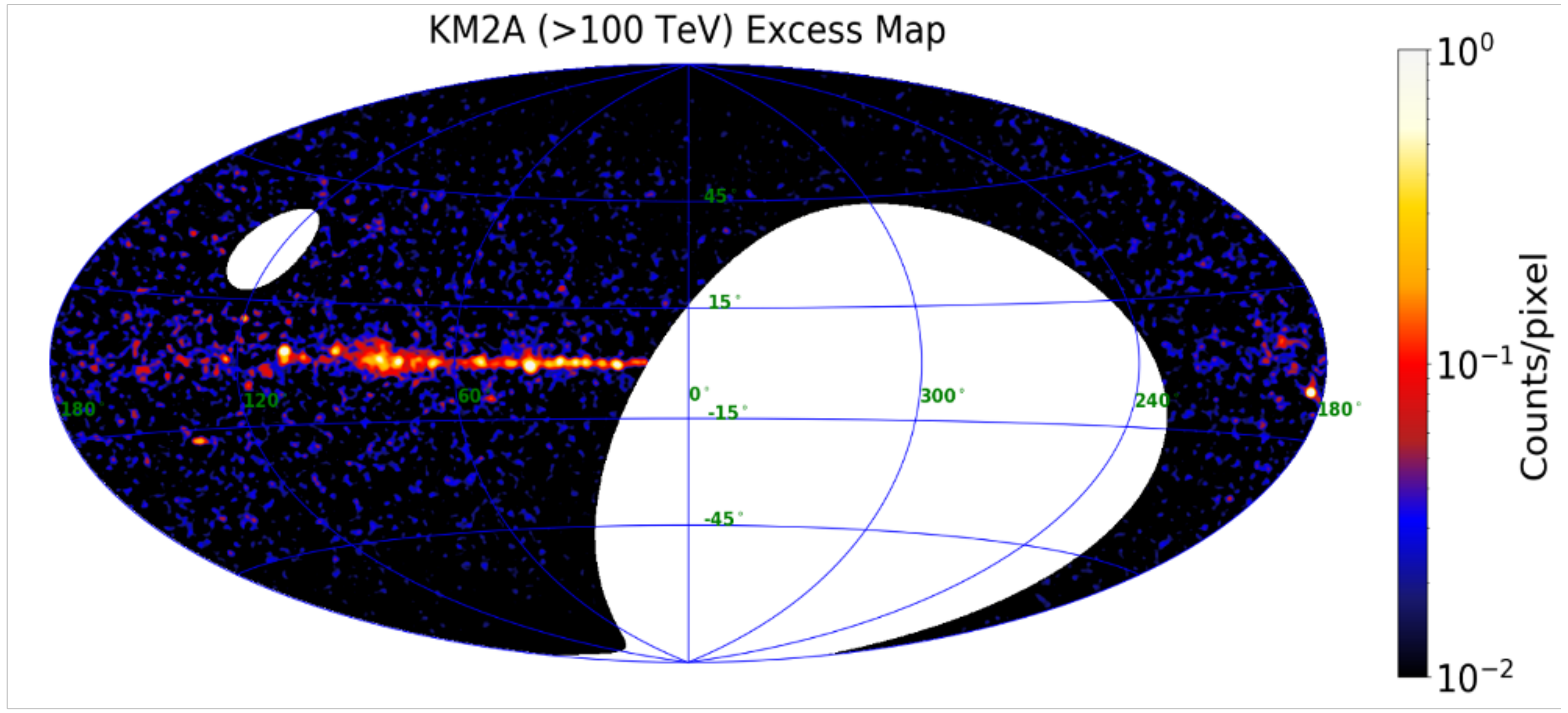
LHAASO Coll, 2023, arXiv:2305.17030

3. Gamma-ray astronomy results

- **90 in 1st LHAASO sources.**
- **32 new discoveries**
- **43 UHE**



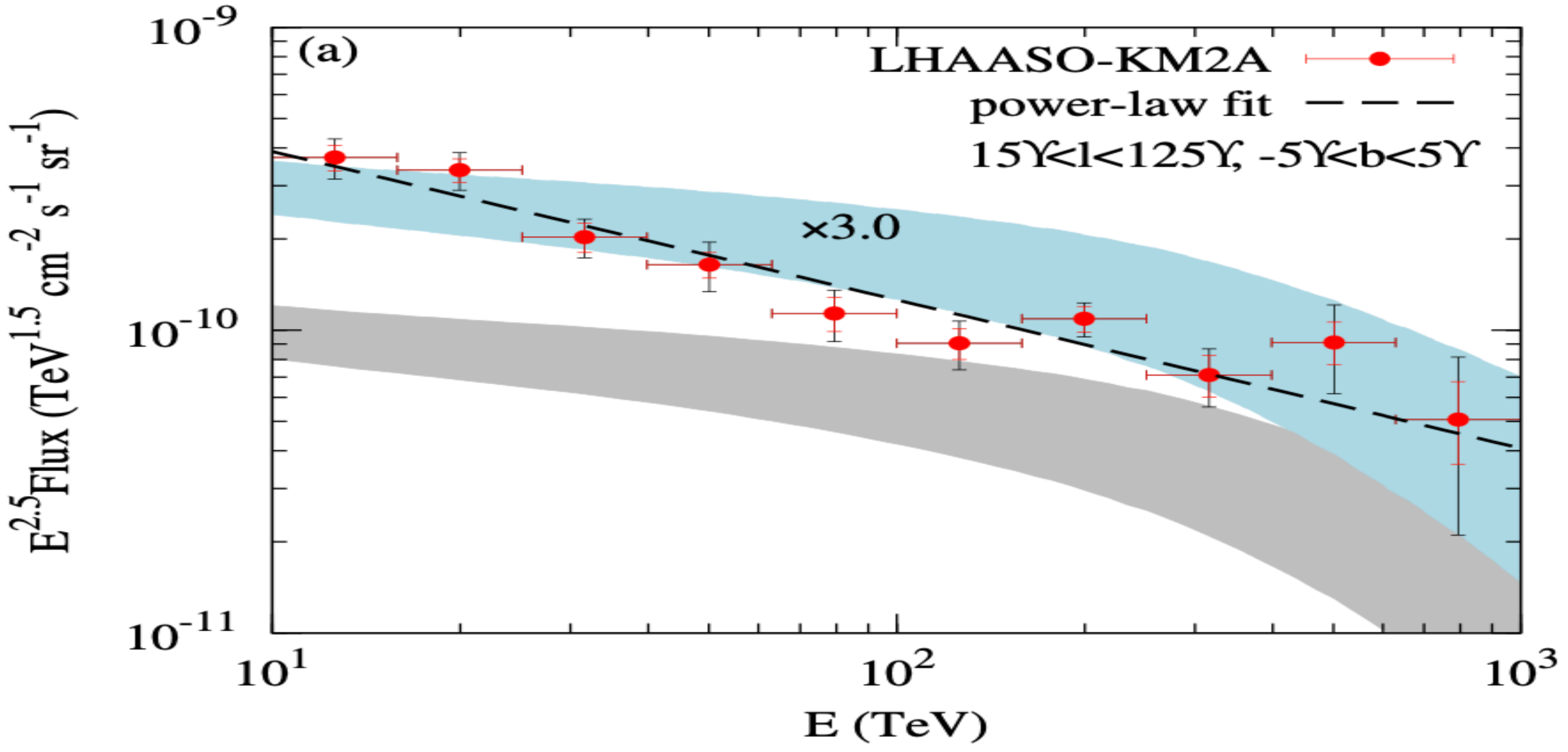


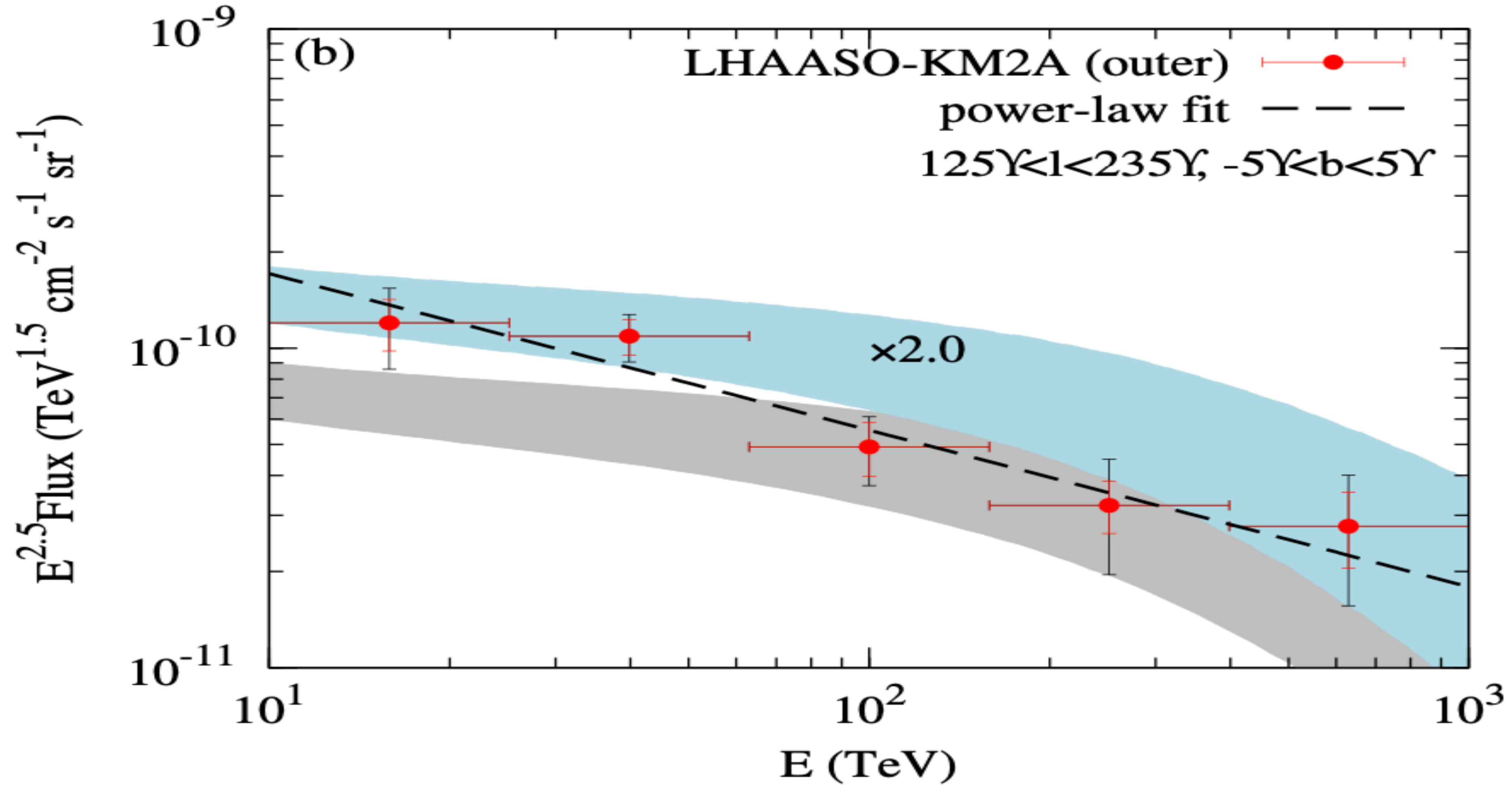


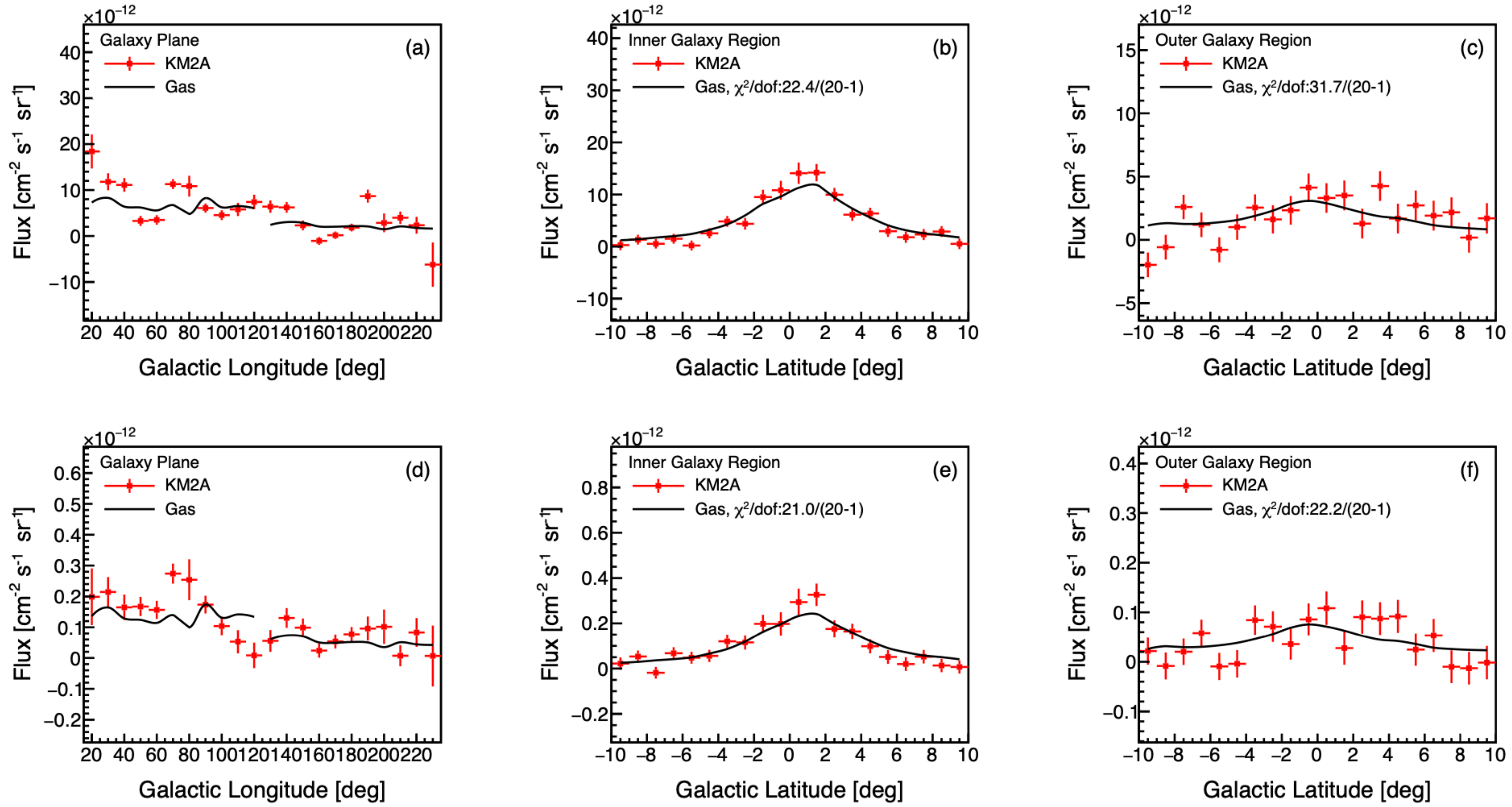
LHAASO Coll, 2023, arXiv:2305.17030

3. Gamma-ray astronomy results

Diffuse gamma-ray emission of the Galactic plane from 10 TeV to 1 PeV





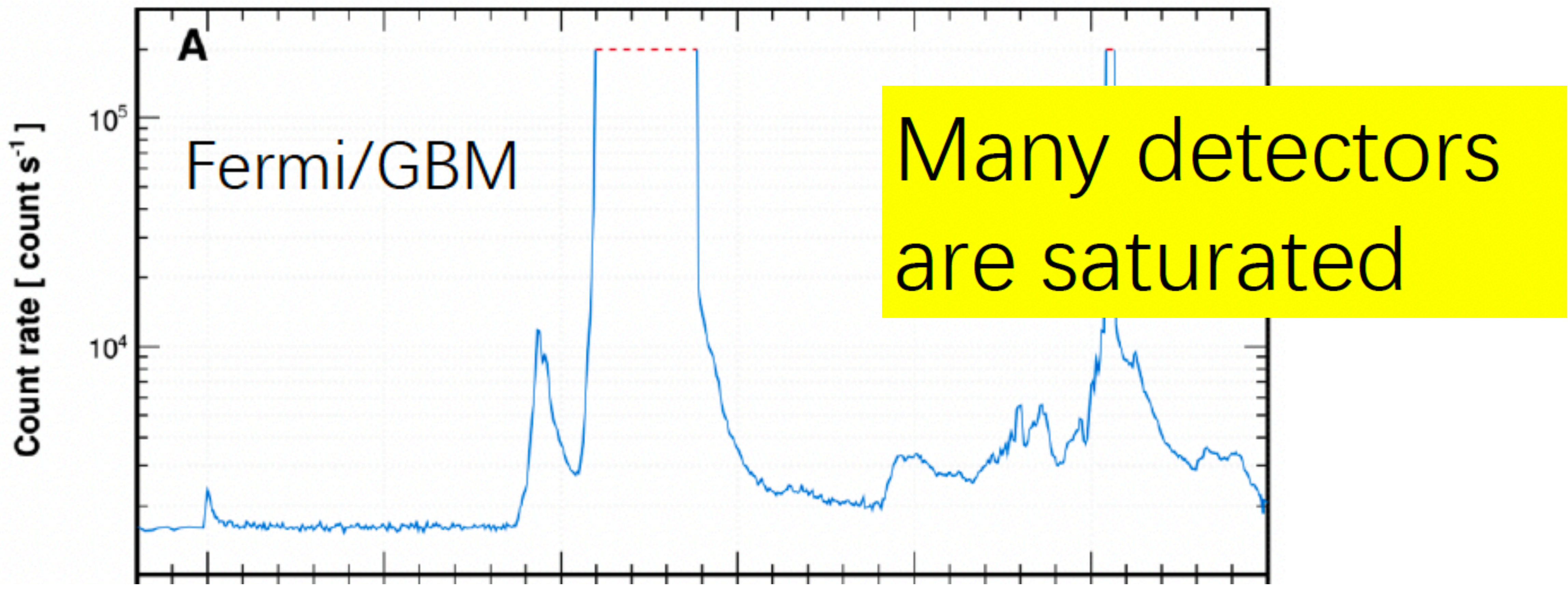


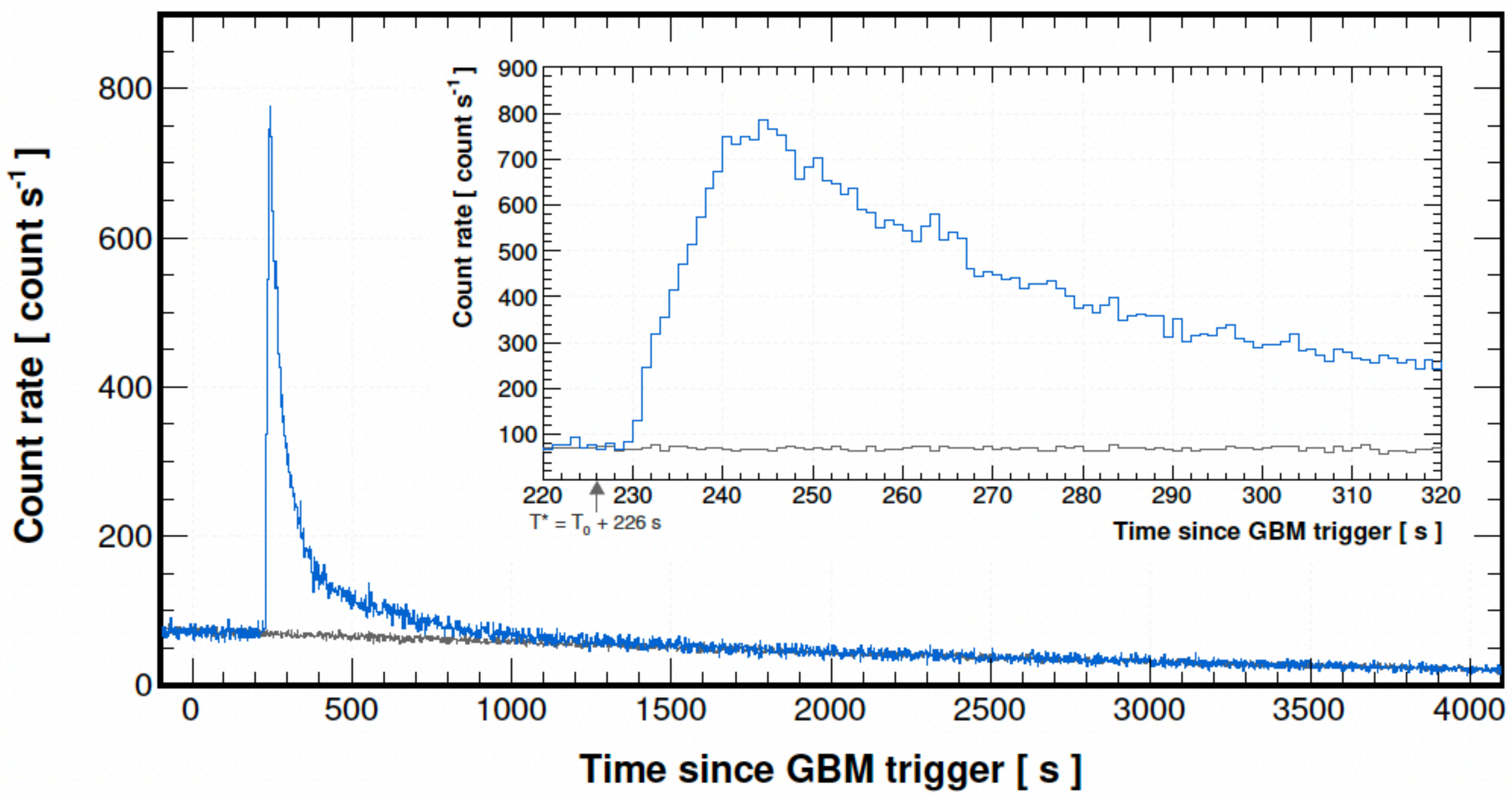
- Spectral indices of both inner and outer regions are about -3; deviation from single power-law is not evident by the current data
- The latitude distributions are consistent with the gas template, and more complicated structures in the longitude distributions

LHAASO Coll, 2023, arXiv:2305.05372

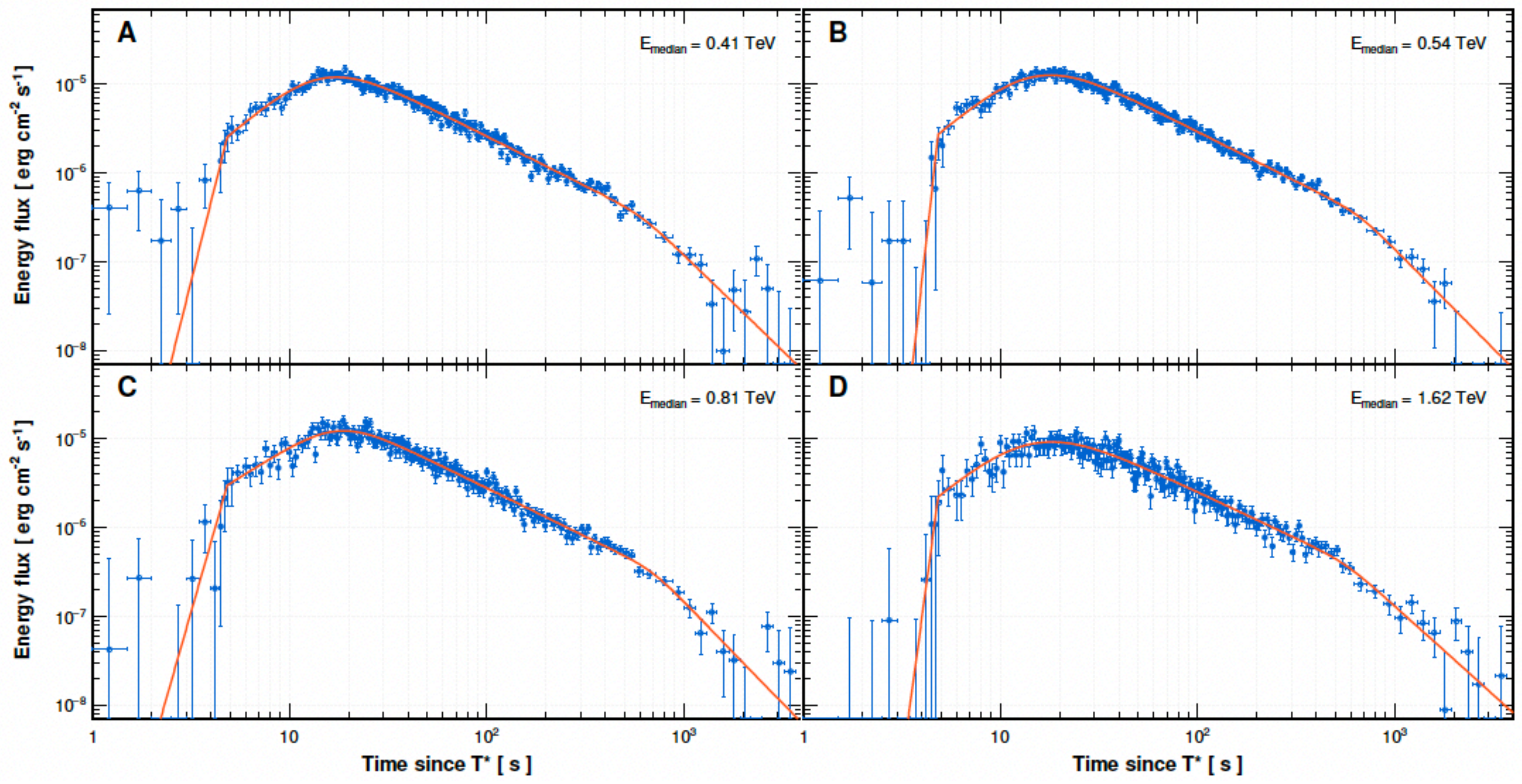
3. Gamma-ray astronomy results

A Teraelectronvolt afterglow from a narrow jet in the extremely bright GRB 221009A





More than 64,000 photons were detected within the first 3000 seconds.



LHAASO Coll, (Science,8 Jun 2023)

Jet model could explain the high isotropic energy of this GRB.

3. Gamma-ray astronomy results

Constraints on LIV using PeV photons

In the superluminal LIV

$$\gamma \rightarrow e^- e^+$$

$$\alpha_0 \leq \frac{4m_e^2}{E_\gamma^2 - 4m_e^2},$$

$$E_{LIV}^{(1)} \geq 9.57 \times 10^{23}\text{eV}\left(\frac{E_\gamma}{\text{TeV}}\right)^3,$$

$$E_{LIV}^{(2)} \geq 9.78 \times 10^{17}\text{eV}\left(\frac{E_\gamma}{\text{TeV}}\right)^2.$$

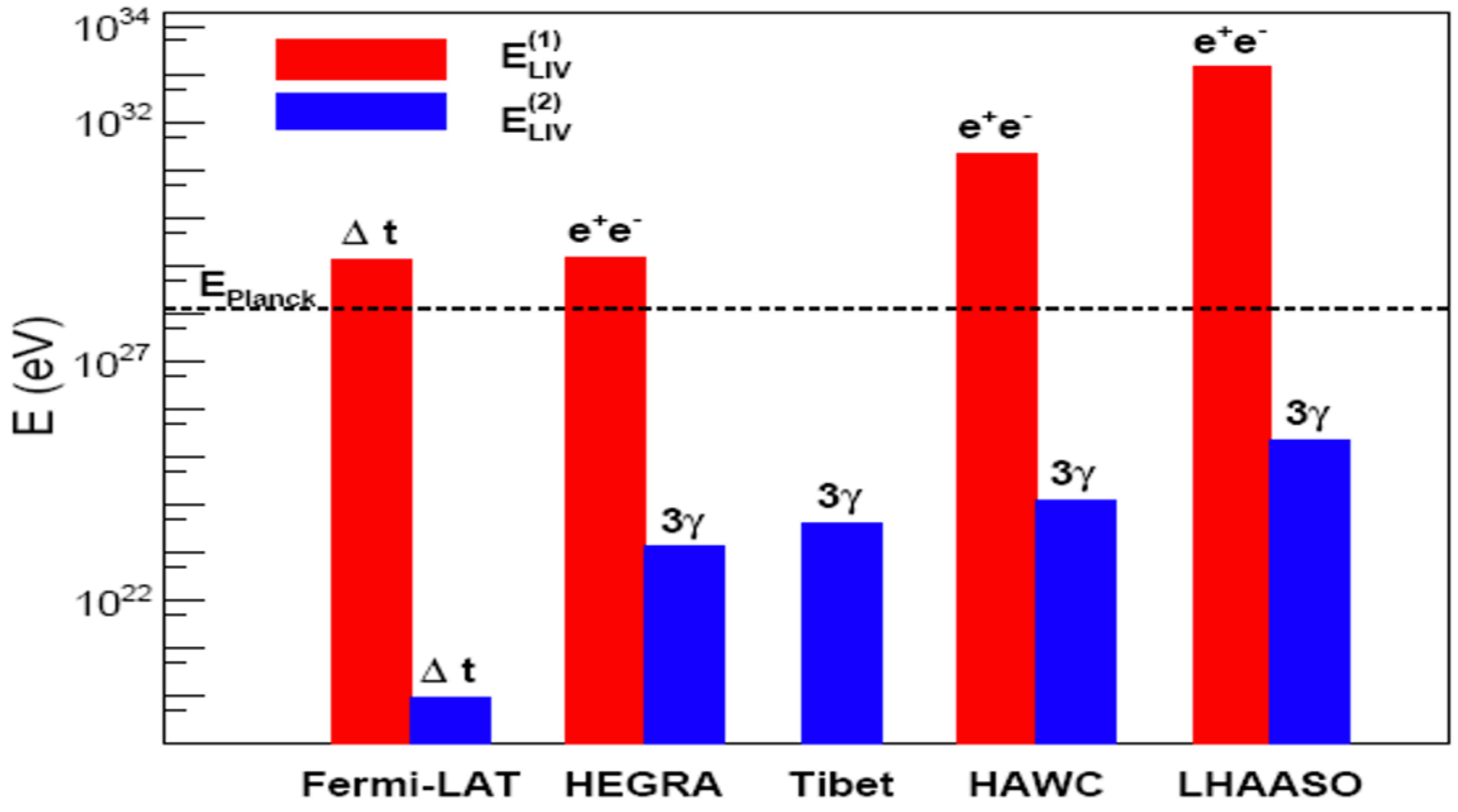
$$\gamma \rightarrow 3\gamma$$

$$\Gamma_{\gamma\rightarrow 3\gamma} = 5 \times 10^{-14}\frac{E_\gamma^{19}}{m_e^8 E_{LIV}^{(2)10}},$$

$$E_{LIV}^{(2)} > 3.33 \times 10^{19}\text{eV}\left(\frac{L}{\text{kpc}}\right)^{0.1}\left(\frac{E_\gamma}{\text{TeV}}\right)^{1.9}.$$

New CLs method

Source	L (kpc)	$E_{\max}$ (PeV)	$E_{\text{cut}}^{95\%}$ (PeV)
J0534+2202	2.0	0.88	$0.75^{+0.043}_{-0.043}$
J2032+4102	1.4	1.42	$1.14^{+0.06}_{-0.06}$



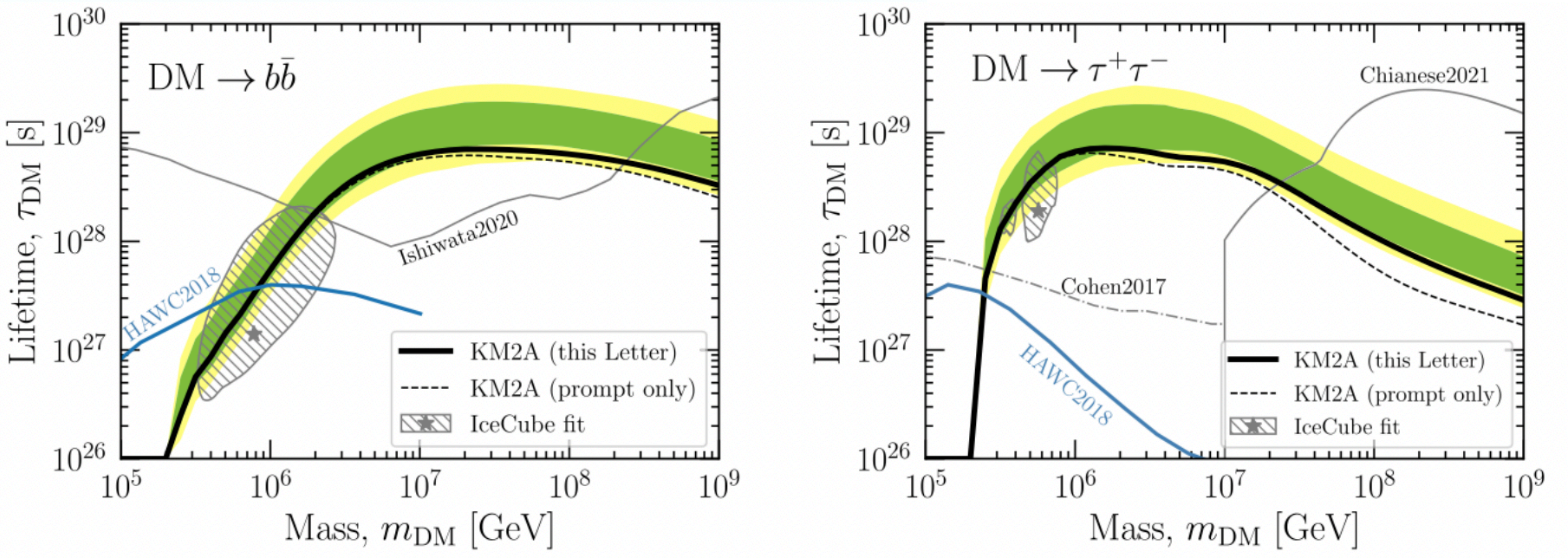
LHAASO coll. 2022 (PRL 128:051102)

3. Gamma-ray astronomy results

Results

Constraints on Heavy Decaying Dark Matter

- We do not see significant level of detection
- (most significant fit is 1.4σ at 8PeV dark matter mass, for tau channel)
- Find the lower limit of decay lifetime
- $$-2\ln\frac{L(\tau_{95})}{\max(L)} = 2.71$$
- highly constrain the hypothesis of decaying DM as a source of high energy neutrinos.



LHAASO Coll, and Marco Chianese, Kenny C.Y.Ng, et al., (PRL,2022,129:261103)

LHAASO
高海拔宇宙线观测站

4. Summary

- LHAASO onset of the UHE γ–ray astronomy, and some distinct science results about the UHE universe have been achieved;
- LHAASO is a powerful tool to probe the non–thermal universe with VHE and UHE γ–ray emissions;
- LHAASO will contribute more in the multi–messenger astronomy era to understand the fundamental physics.

Thanks!