



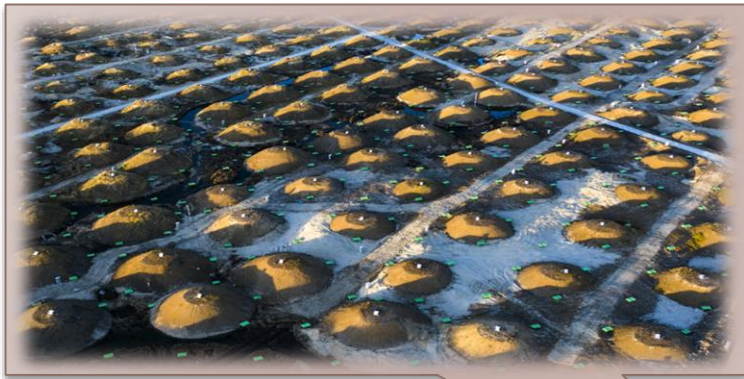
Recent results on Gamma astronomy from LHAASO

TeVPA 2023, Napoli

Zhiguo Yao
On behalf of LHAASO Collaboration
2023/09/11

Outline

- ◆ **Brief introduction to LHAASO**
- ◆ **1st Catalogue**
- ◆ **GRB 221009A**
- ◆ **Galactic diffuse Gamma rays**
- ◆ **Selected new results**
- ◆ **Summary**



LHAASO



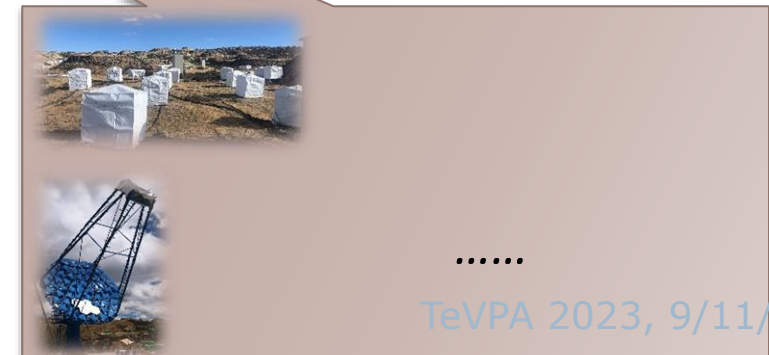
KM2A:
5216 scintillators (ED)+
1188 muon detectors

WCDA:
3 pools, 3120 cells,
area 78,000 m²



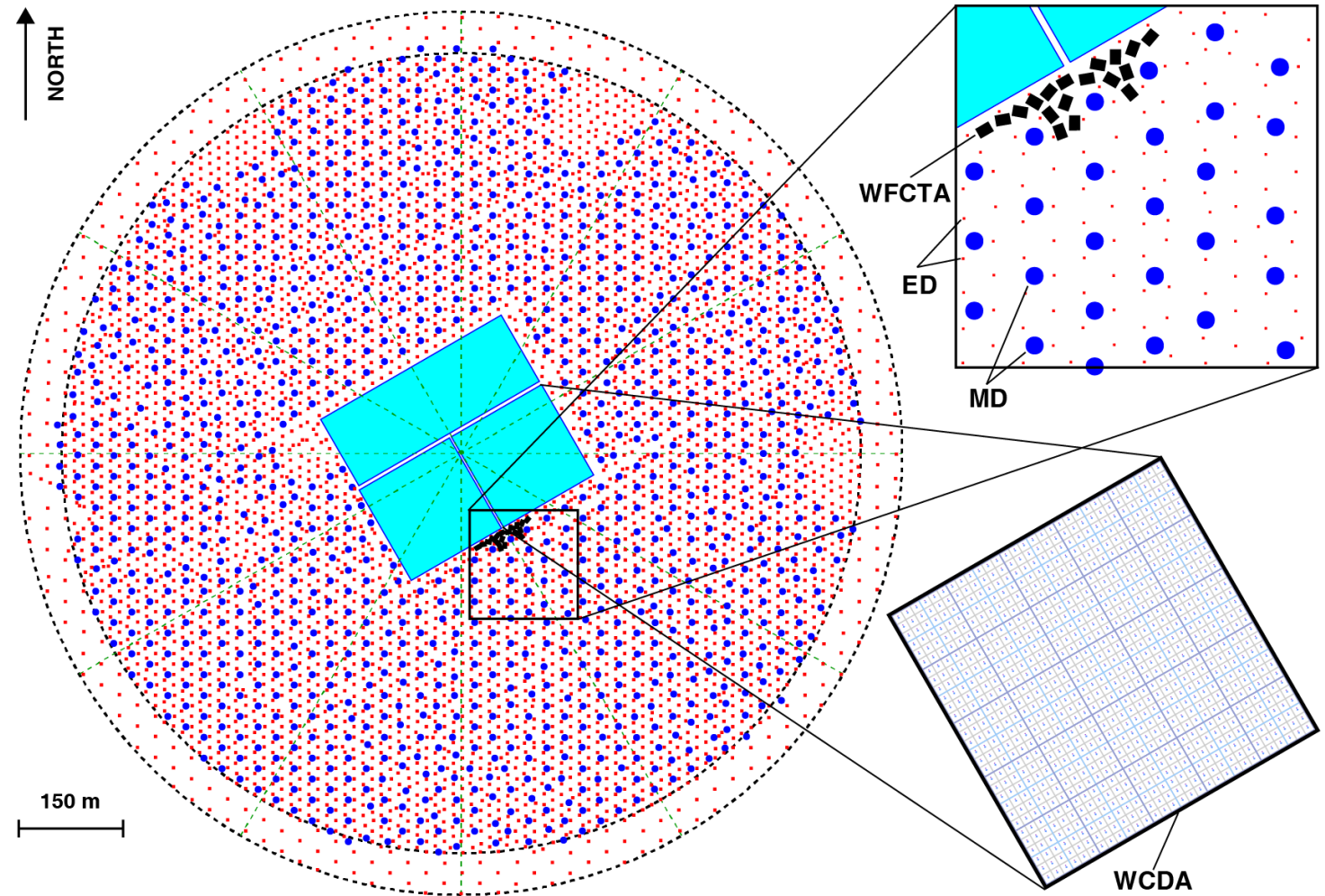
WFCTA:
18 wide FOV telescopes

Some planned addons:
Neutron detectors
High energy IACTs
...



Layout of LHAASO Detectors

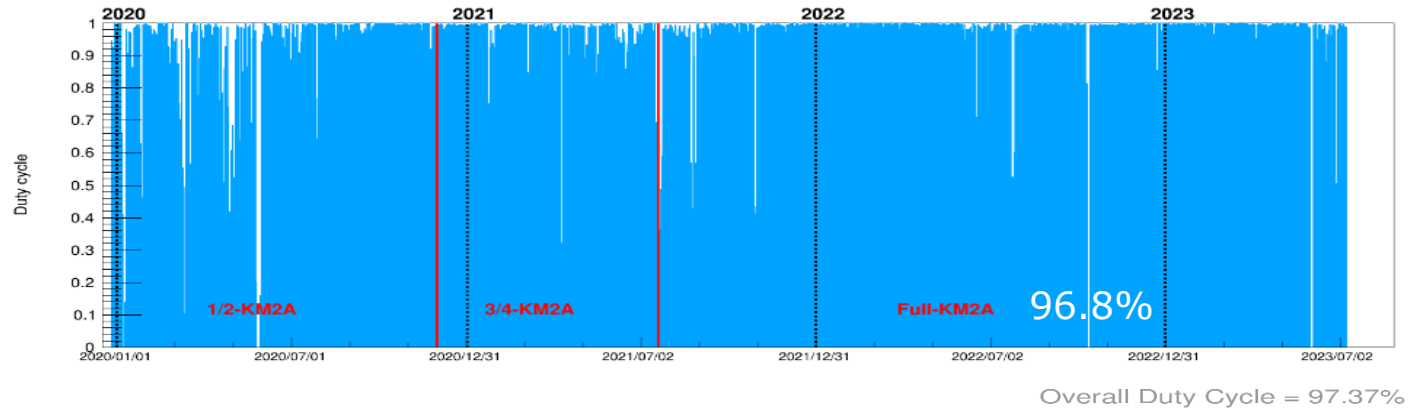
- Site: Mt. Haizishan, Daocheng, Sichuan Province
- Location: $29^{\circ}21'27.6''\text{N}$, $100^{\circ}08'19.7''\text{E}$
- Altitude: 4410 m a.s.l.
- Overall Coverage: 1.3 km^2



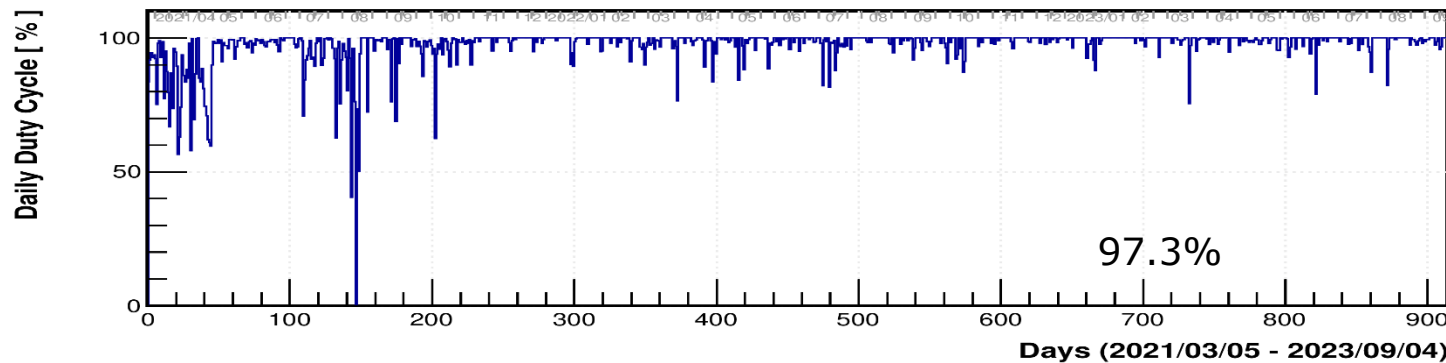
Features: full duty cycle

No interference from celestial bodies like the Sun and the Moon, as well as meteorological conditions such as clouds, rain, or snow, ensures the feasibility of detecting **transients** and allows for continuous monitoring of frequently **flaring sources**.

Data-taking:
24 hour × 360 days
duty cycle >95%



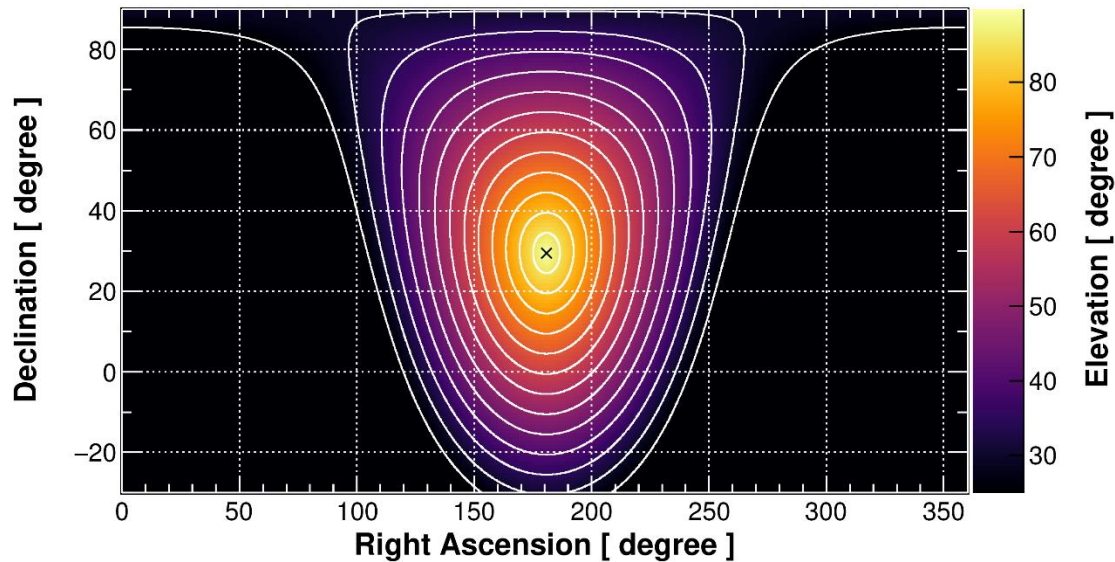
KM2A



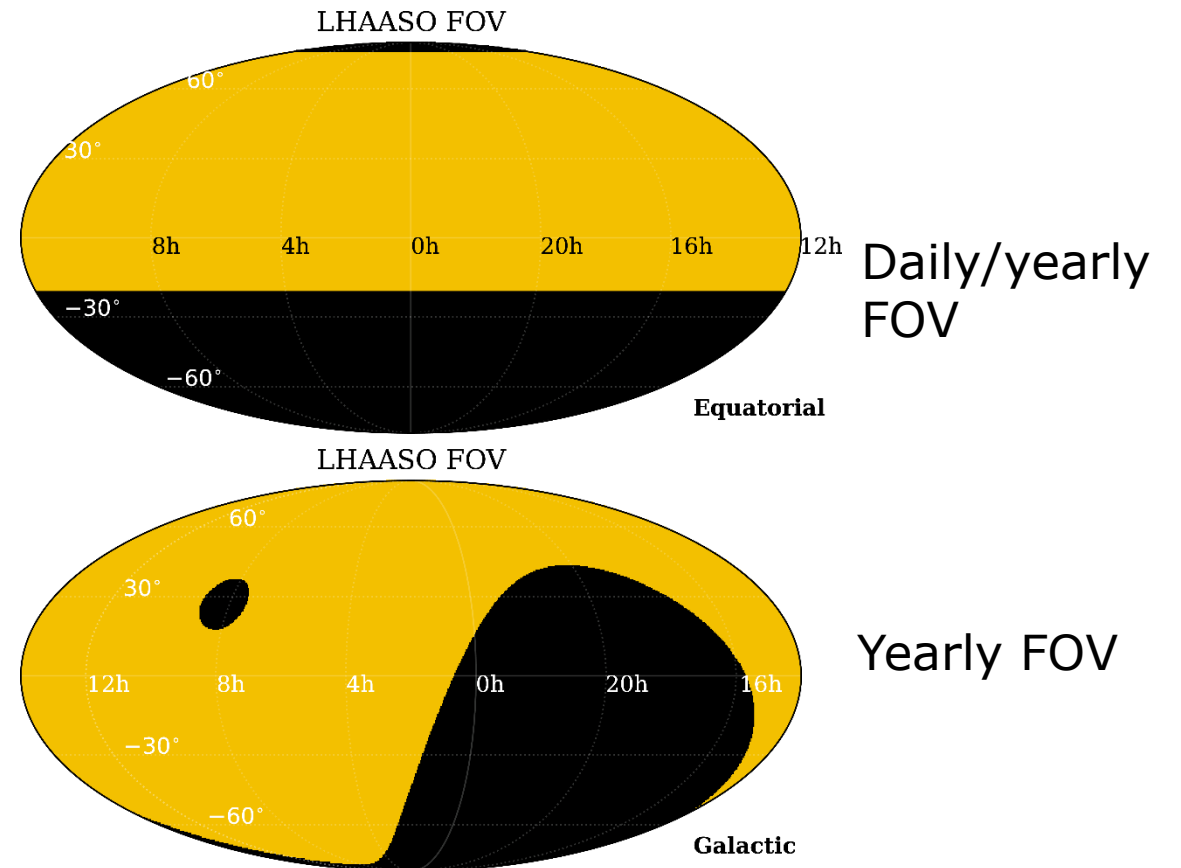
WCDA

Features: wide field of view

It can observe **1/6** of the entire sky at any given moment. The Earth's rotation further enables a **3/4** sky coverage, including the entire northern sky. This is particularly crucial for studying **extended sources** and resolving **vicinity pileup sources**.

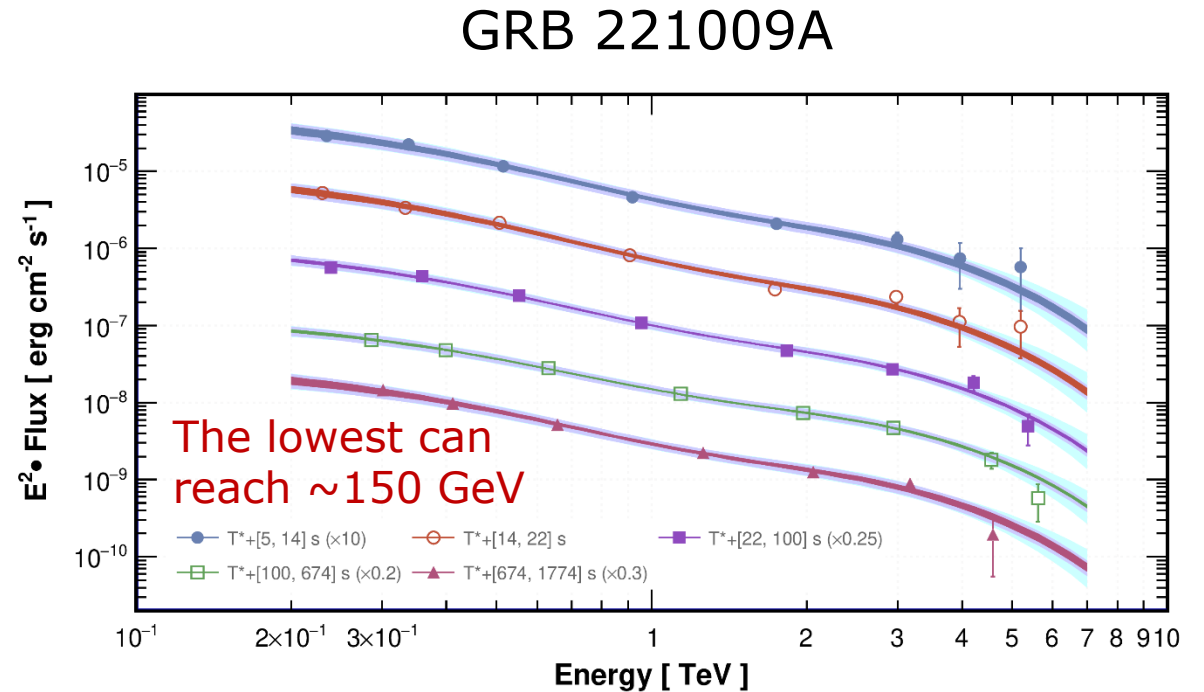
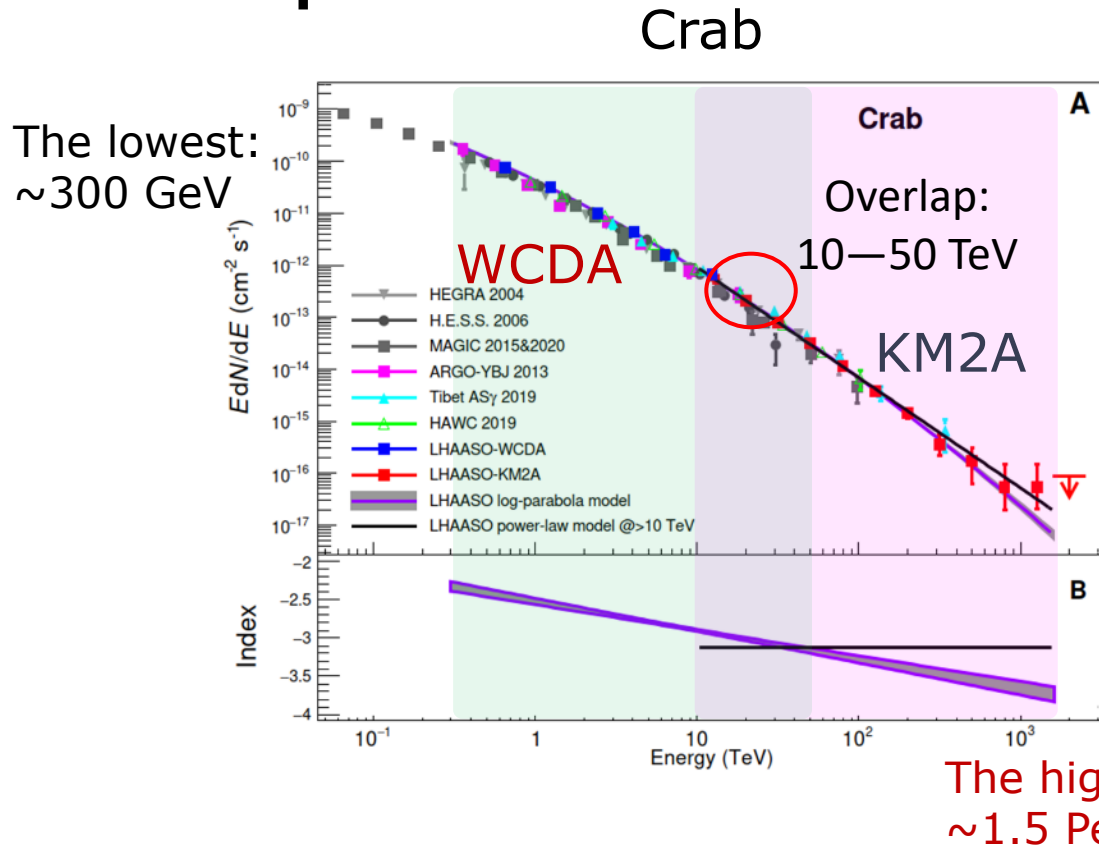


Instant FOV



Features: wide energy range coverage

The energy range spans nearly **four orders** of magnitude, ranging from **several hundred GeV** to **several PeV**, enabling broad band spectrum measurement. The two detector arrays provide a valuable cross-check with a reasonably **large energy overlap**.

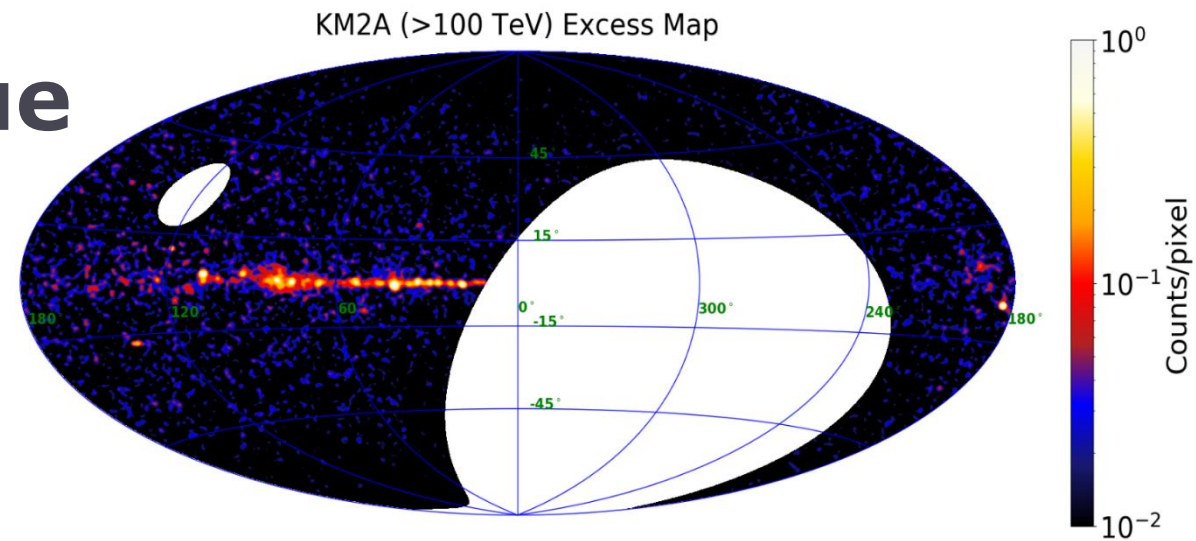


The 1st LHAASO Catalogue

KM2A: 933 days (~ 730 days full array)

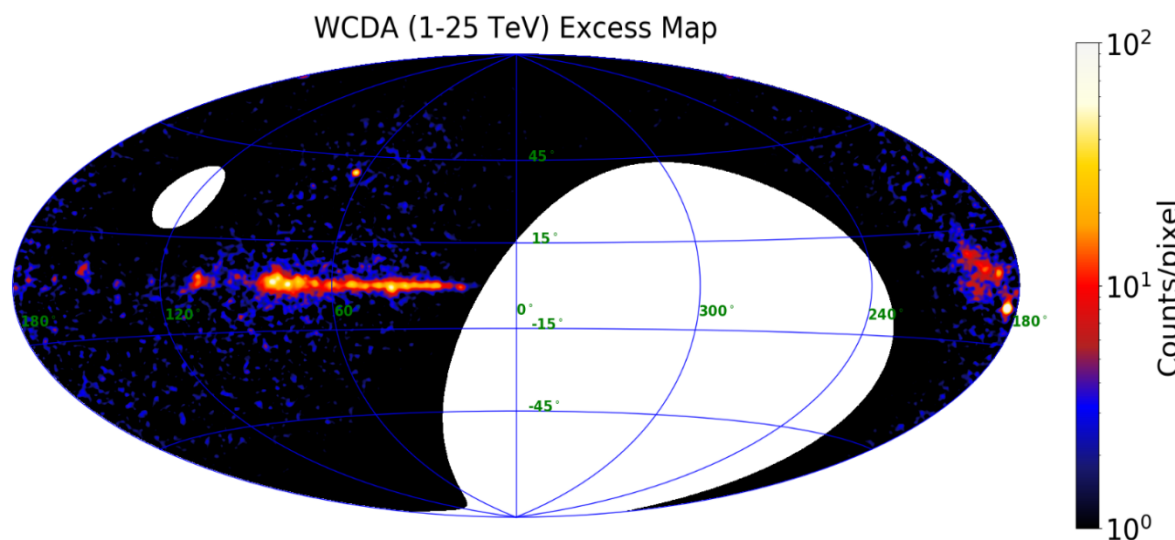
WCDA: 508 days (full array)

Released: May 2023: [arXiv.2305.17030](https://arxiv.org/abs/2305.17030).

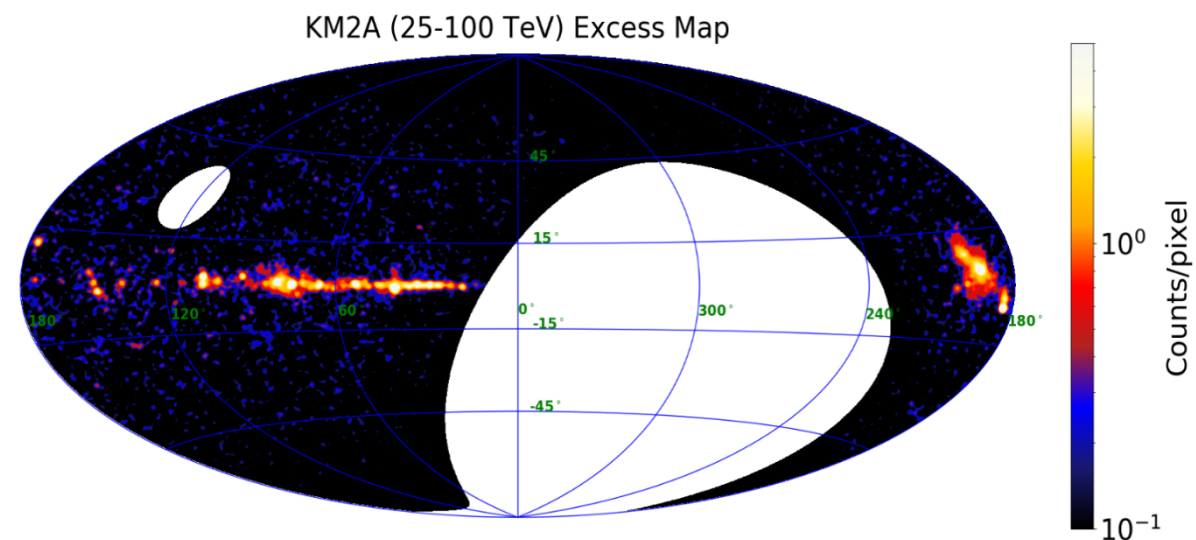


Pixel size: $0.1^\circ \times 0.1^\circ$

> 100 TeV (KM2A)



1–25 TeV (WCDA)



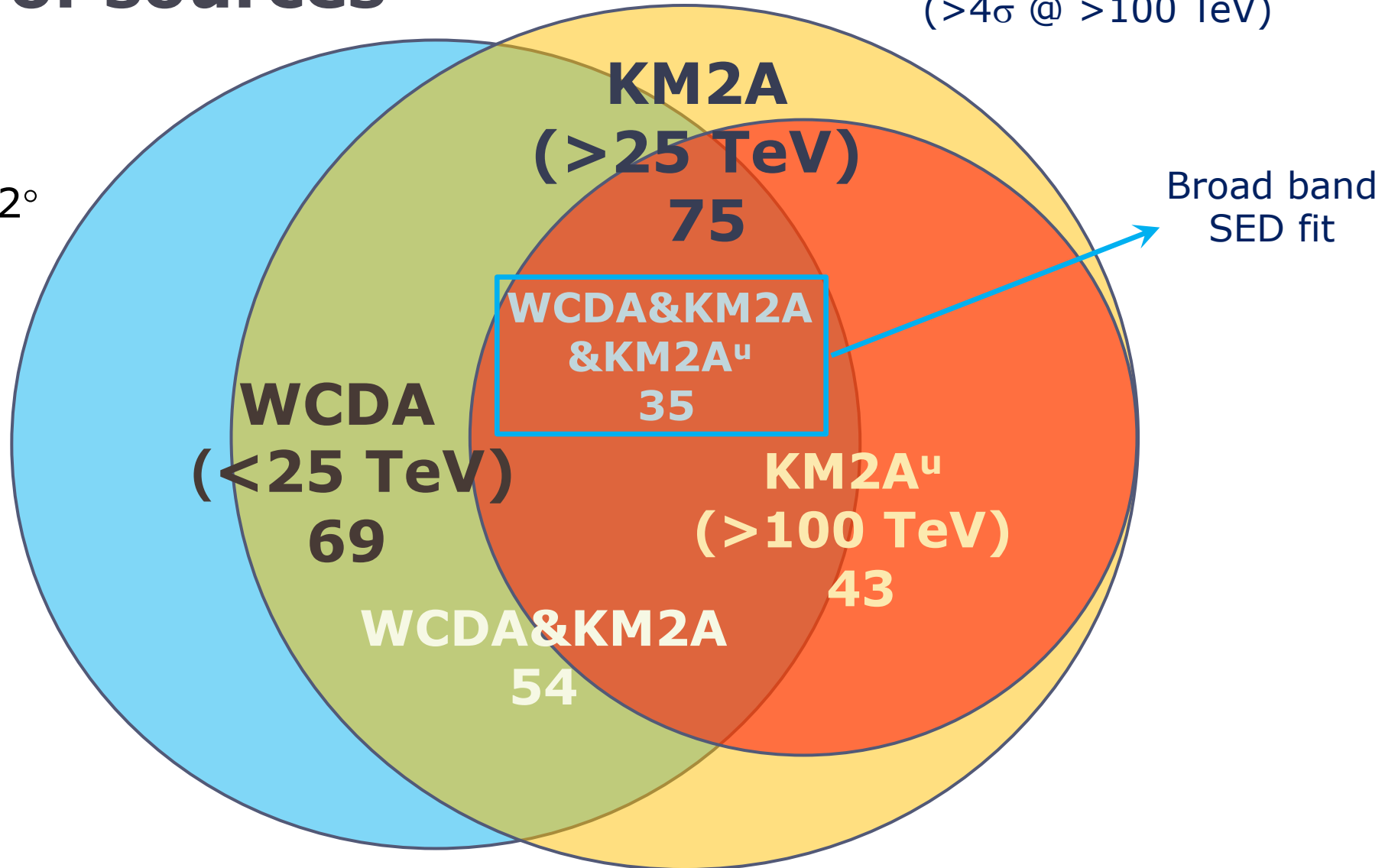
25–100 TeV (KM2A)

Number of sources

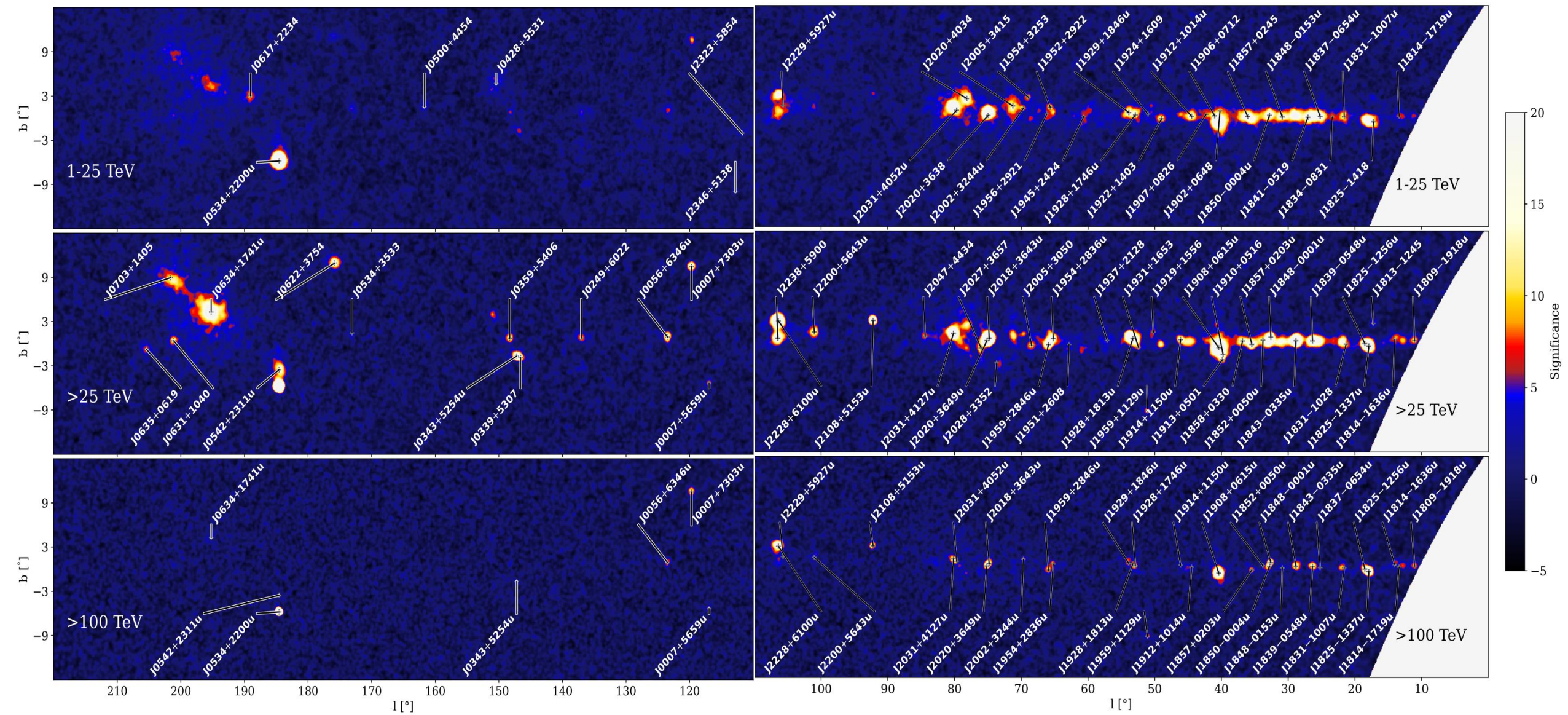
90 sources

- ◆ >1 TeV
- ◆ Extension $< 2^\circ$

KM2A^u → KM2A UHE
($>4\sigma$ @ >100 TeV)

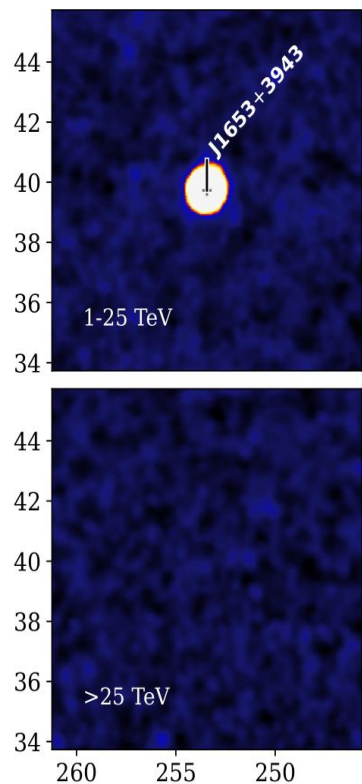


Sources in galactic plane

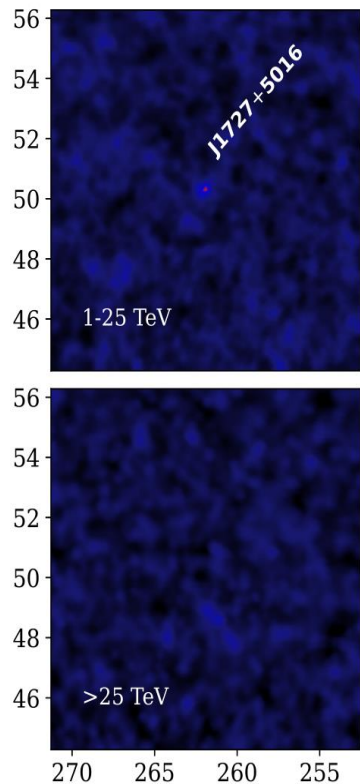


Sources off-galactic plane

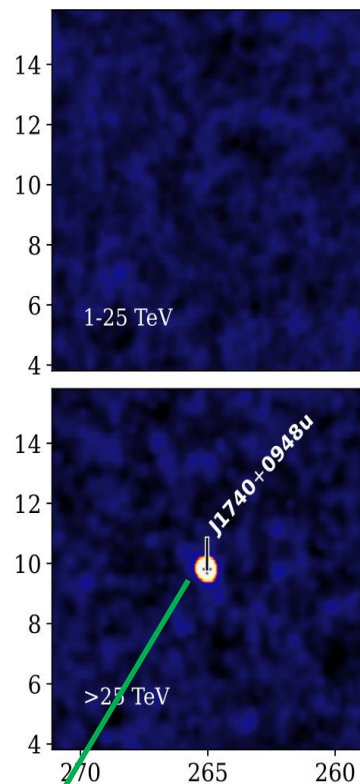
Mrk 421
z=0.031



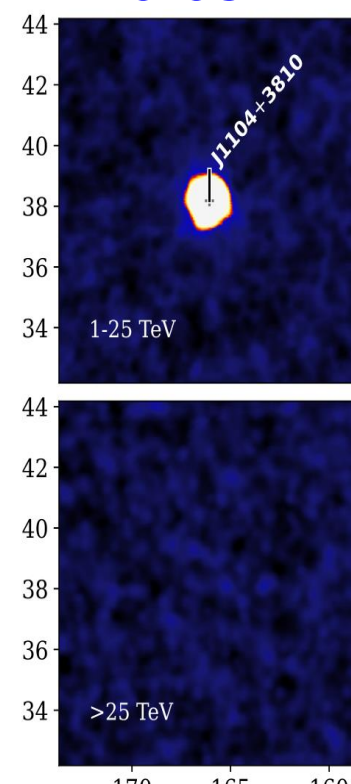
1ES 1727+502
z=0.055



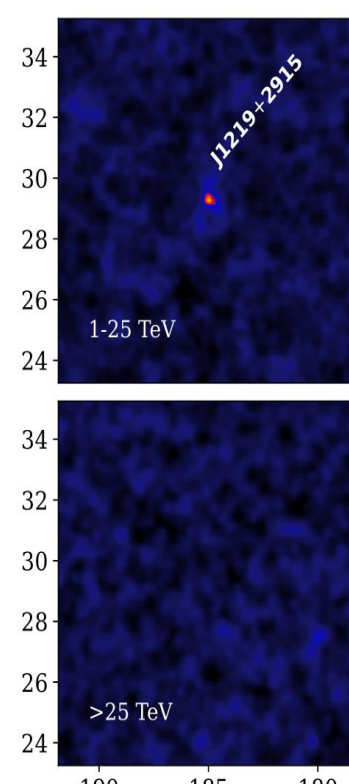
4 UNID (>25 TeV)



Mrk 501
z=0.034



NGC 4278
z=0.002



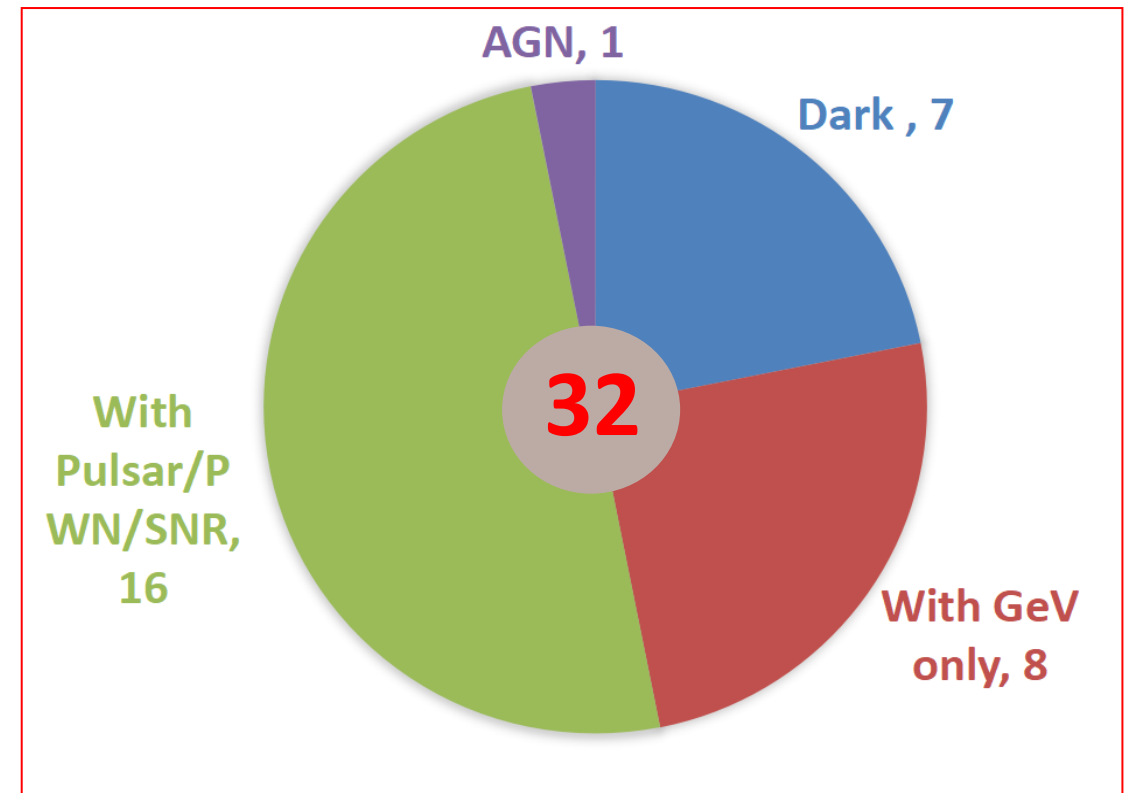
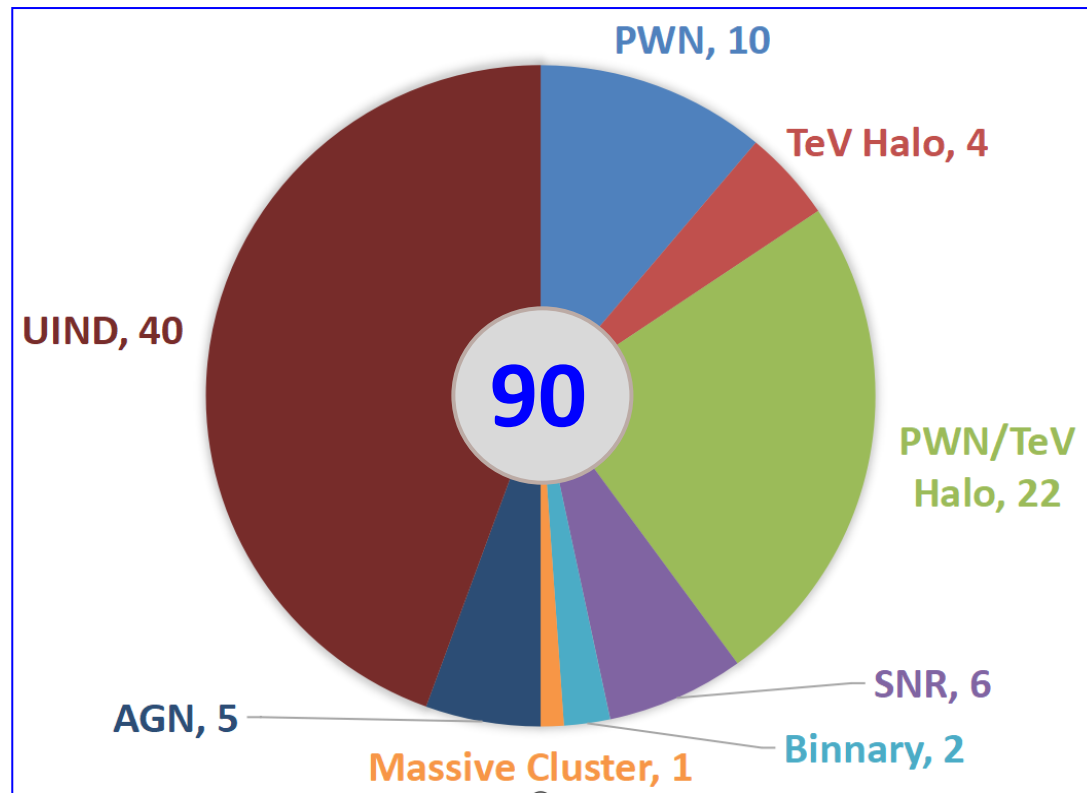
PWN?

α_{2000} (deg)

LHAASO
"Peanut"

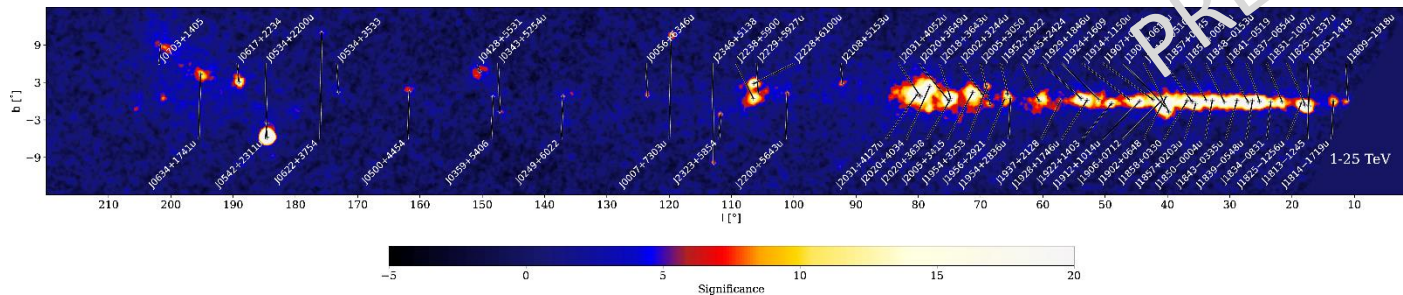
Associations (quite rough ...)

- ◆ 58 sources with TeVCat+3HAWC association
- ◆ **32 new sources** in TeV band!



New updates from WCDA

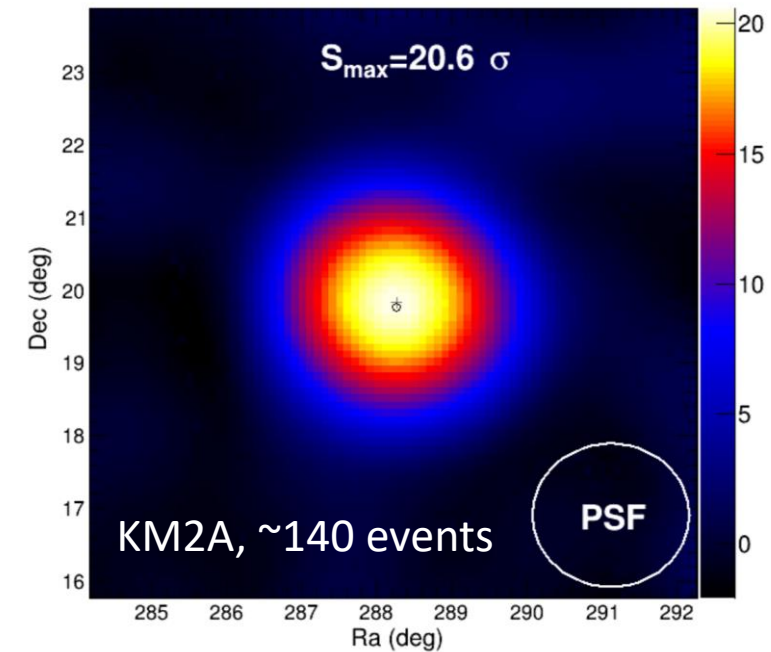
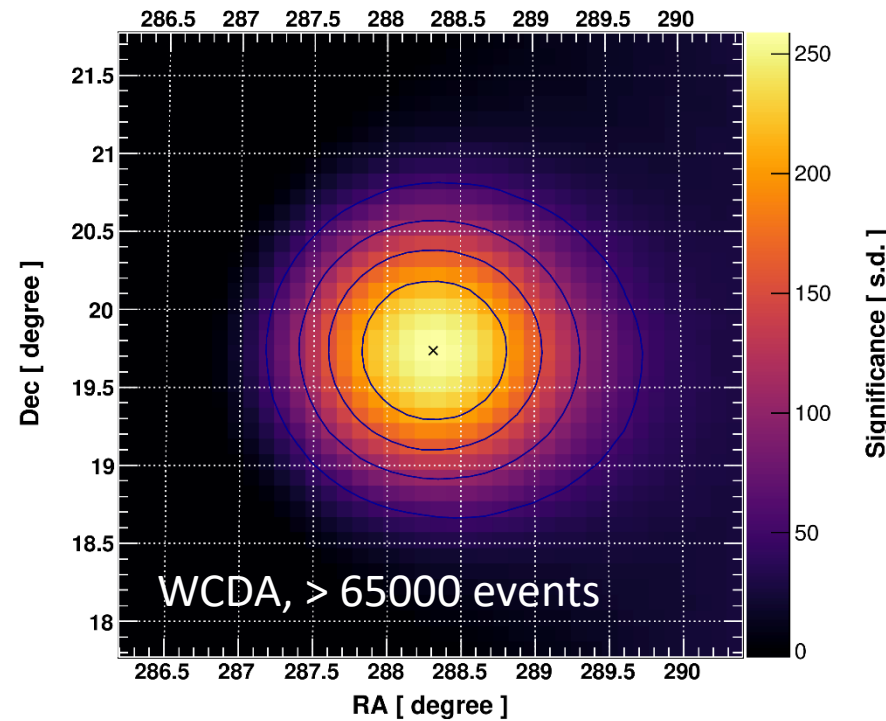
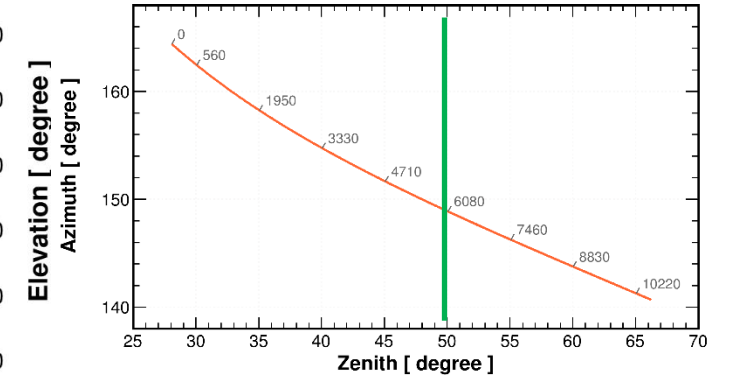
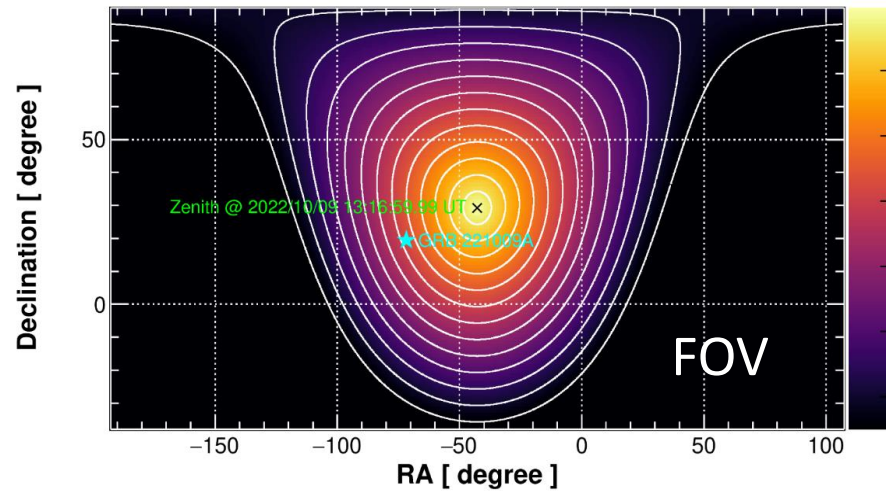
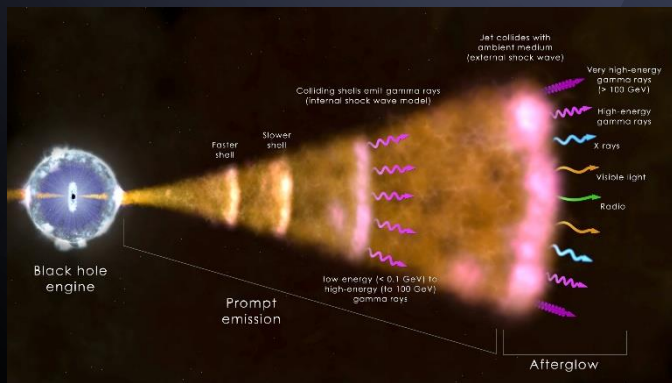
- ◆ Improved the angular resolution, and extended the low energy SED.
- ◆ Number of sources: 69 → ~100.
- ◆ Number of extra-galactic sources: 6 → 15



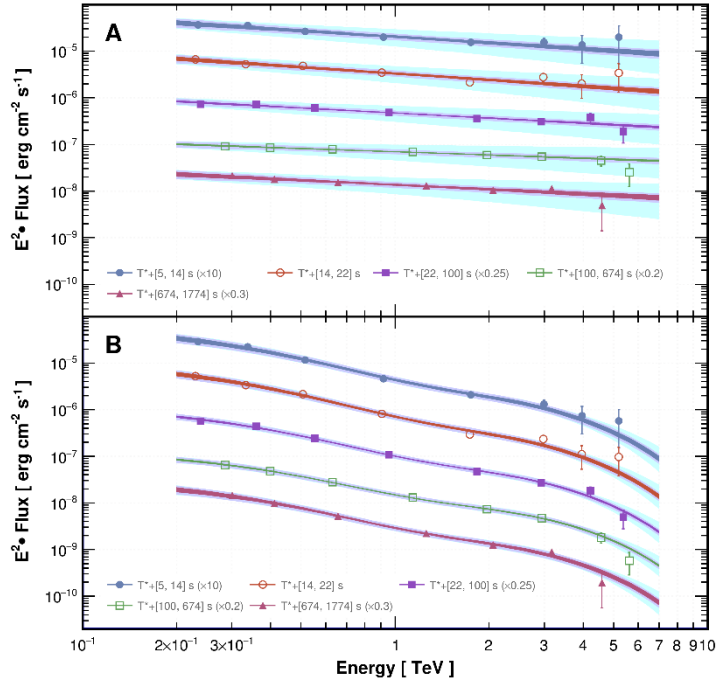
Extragalactic sources

	Name	RA [°]	Dec [°]	Significance [s.d]	Separation [°]
1	Mkn421	166.05	38.15	70.8 → 110	0.05
2	Mkn501	253.45	39.75	64.0 → 85	0.02
3	1ES2344+514	356.75	51.65	6.8 → 9.3	0.06
4	LHAASO J1219+2916 (NGC 4278)	184.95	29.25	6.7 → 9.6	0.04
5	1ES1727+502	261.95	50.25	6.5 → 8.6	0.09
6	RXJ0648.7+1516	102.15	15.35	5.1 → 5.1	0.09
7	M87	187.75	12.45	5.1 → 7.5	0.07
8	TXS0210+515	33.65	51.75	5.0 → 4.4	0.05
9	1ES1741+196	265.85	19.55	4.4 → 6.3	<0.1
10	BL Lacertae	330.67	42.27	4.4 → 5.6	<0.1
11	VER0521+211	80.55	21.05	4.2 → 5.7	<0.1
12	1ES1959+650	299.65	65.05	4.2 → 8.7	<0.1
13	RGB J2056+96	313.75	49.75	<4 → 5.3	<0.1
14	H1426 + 428	217.25	42.55	<4 → 5.3	<0.1
15	1ES 1218+304	185.55	30.15	<4 → 5.4	<0.1

BOAT: GRB 221009A

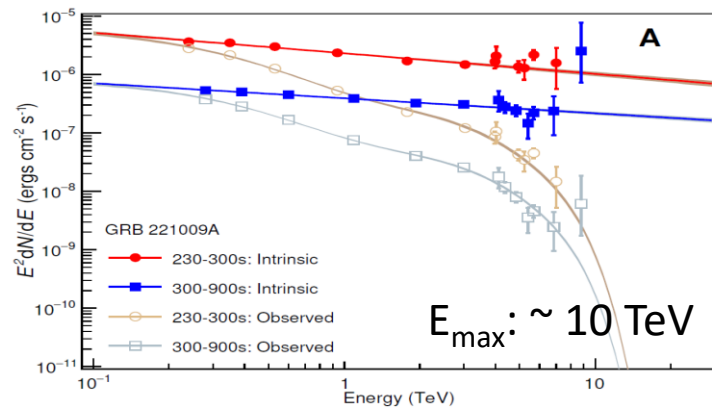


GRB 221009A

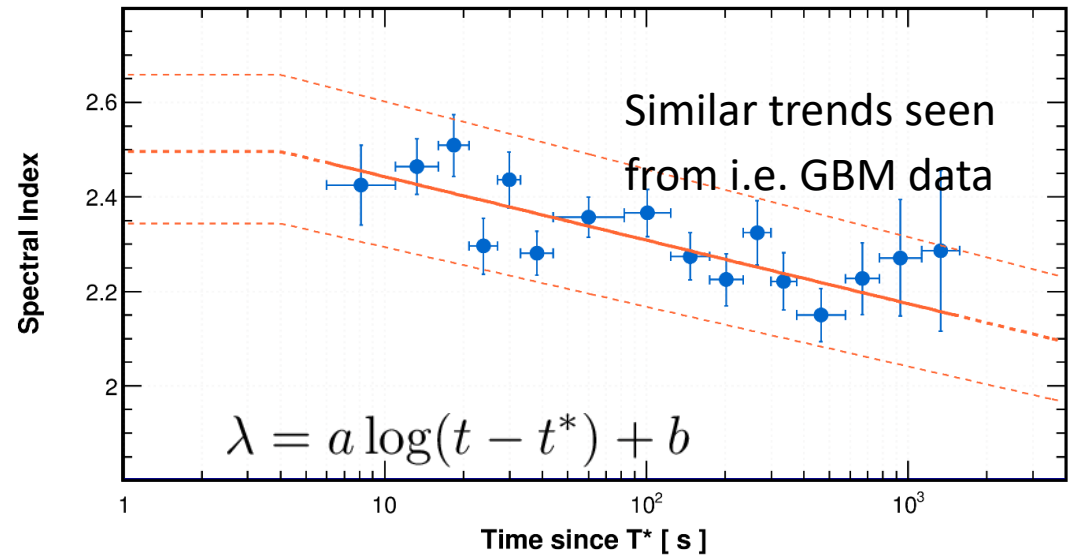
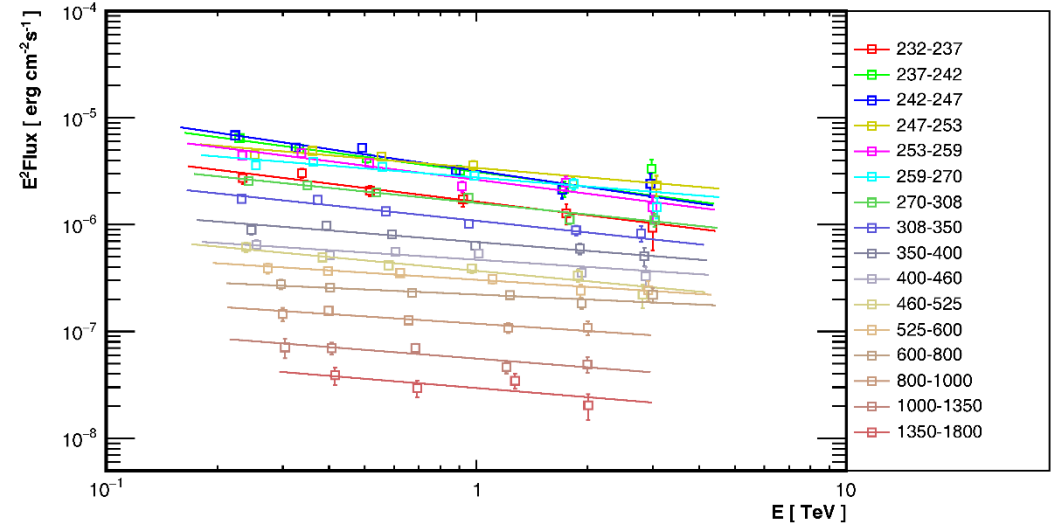


WCDA
intrinsic

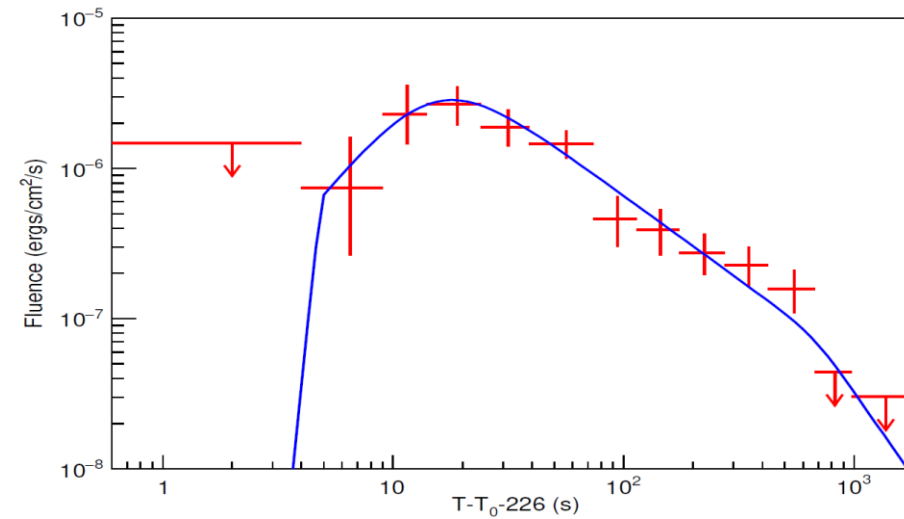
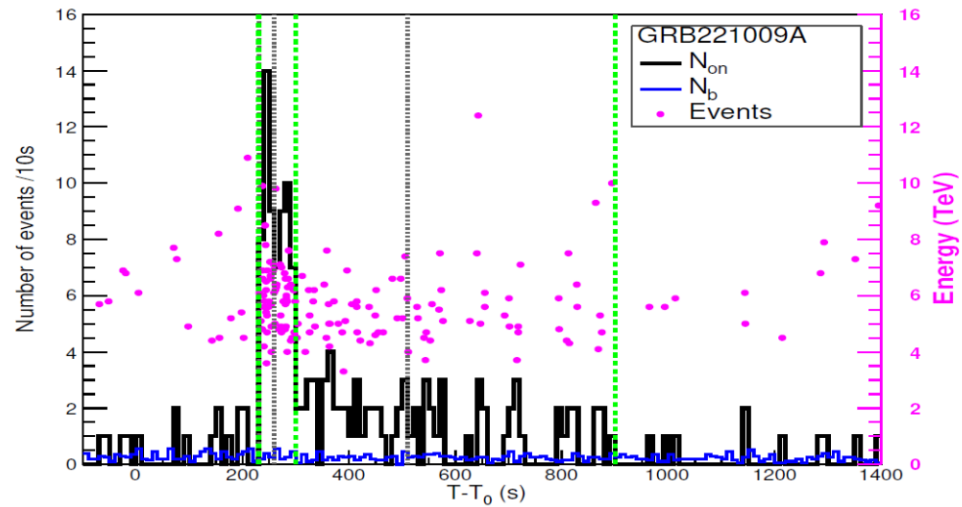
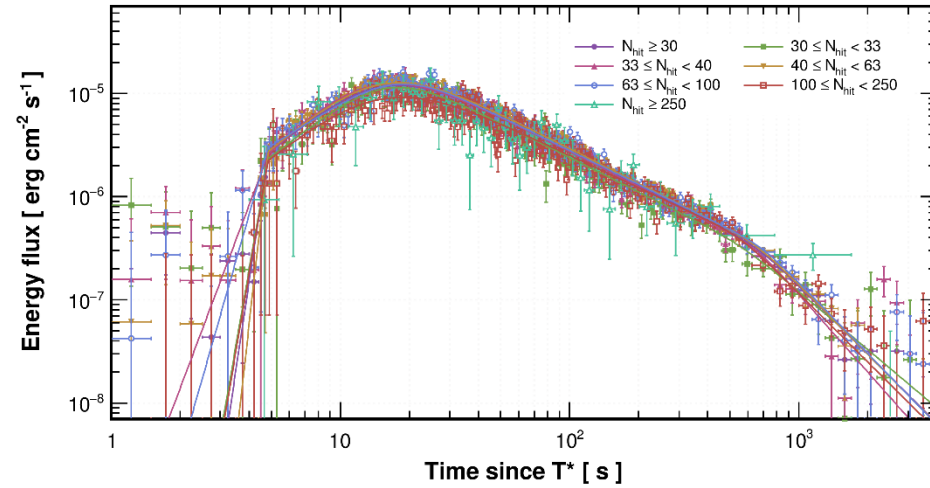
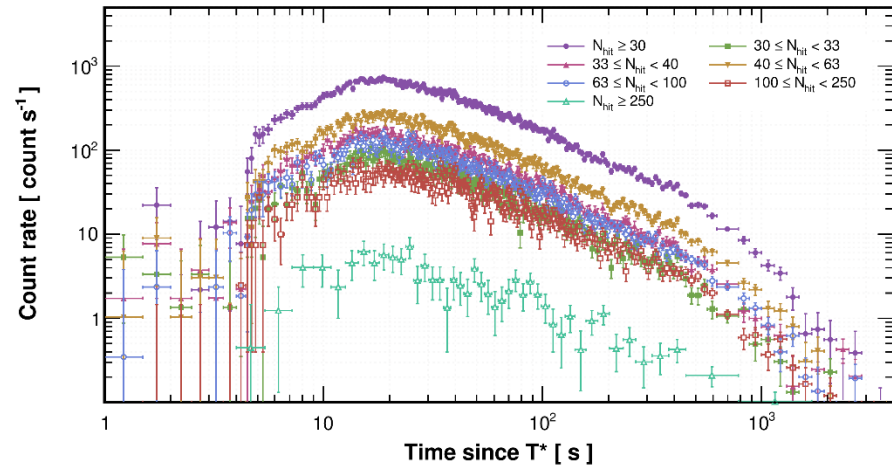
WCDA
observed



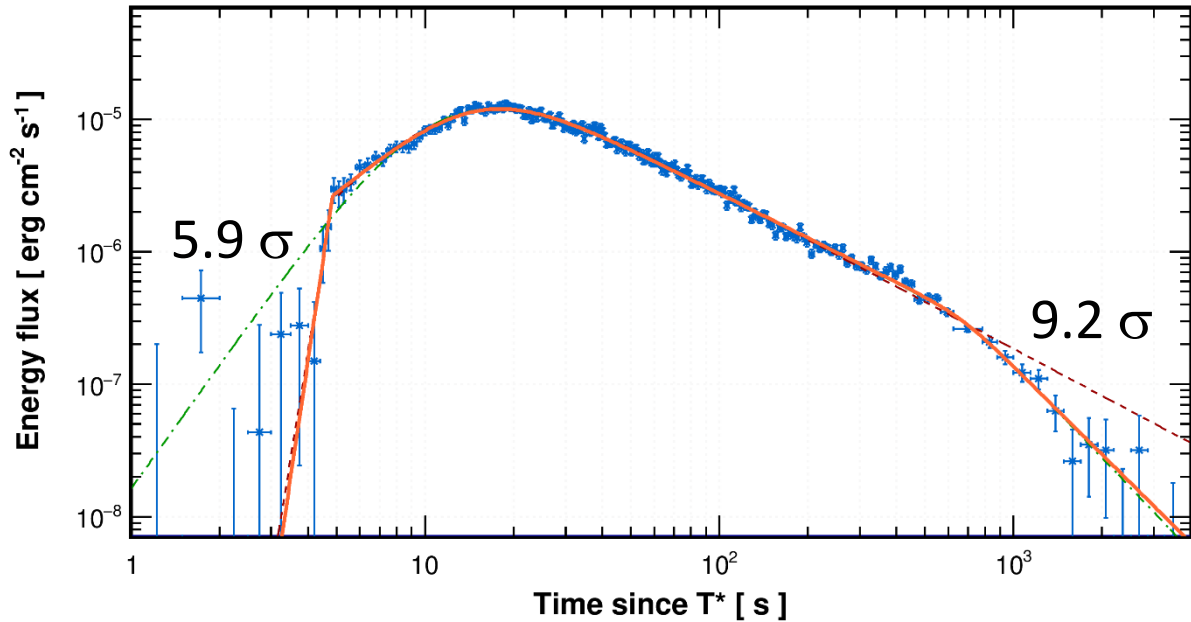
WCDA +
KM2A



GRB 221009A

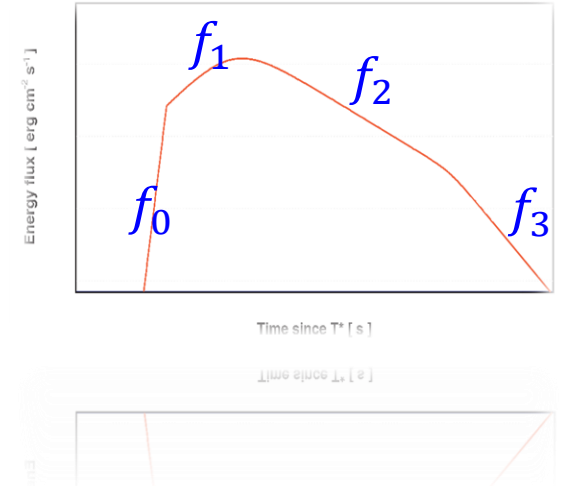


GRB 221009A



Four stages:

- rapid rise;
- slow rise;
- slow decay;
- steep decay.

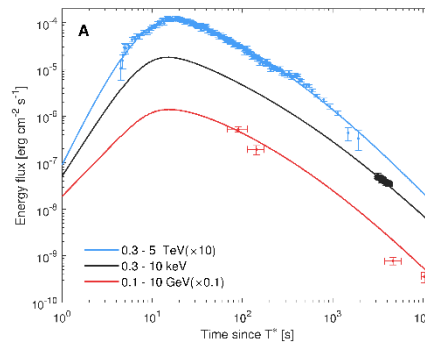
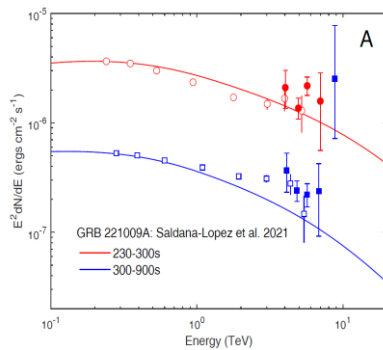
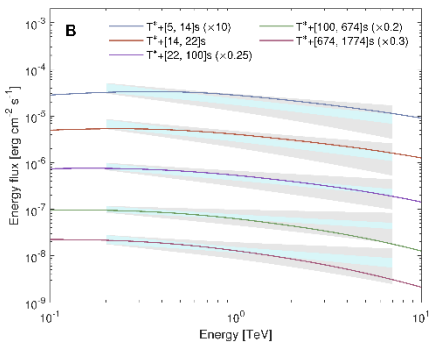


Jet break:

- structured jet;
- explained the BOAT nature of the GRB;

Rapid rise:

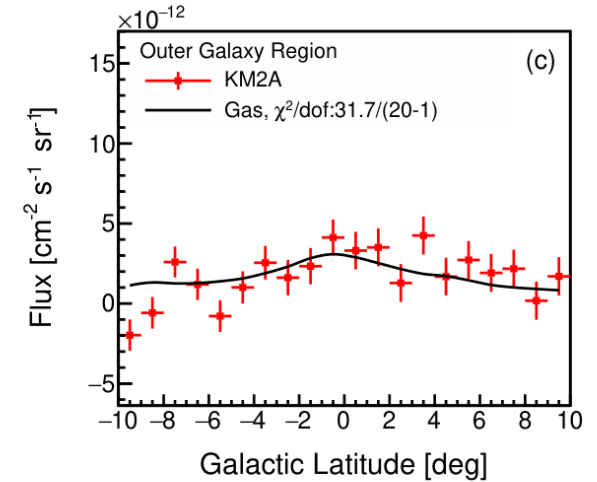
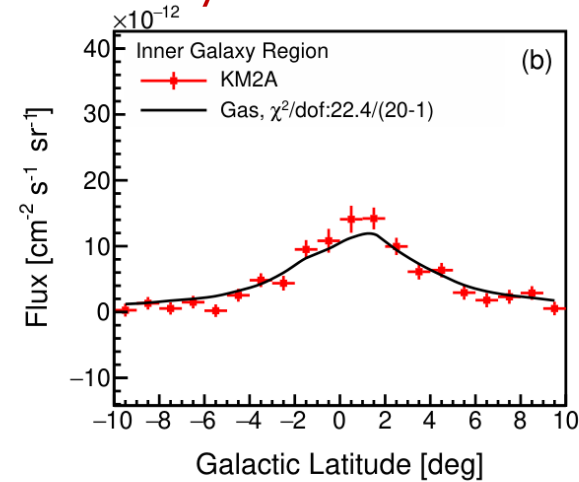
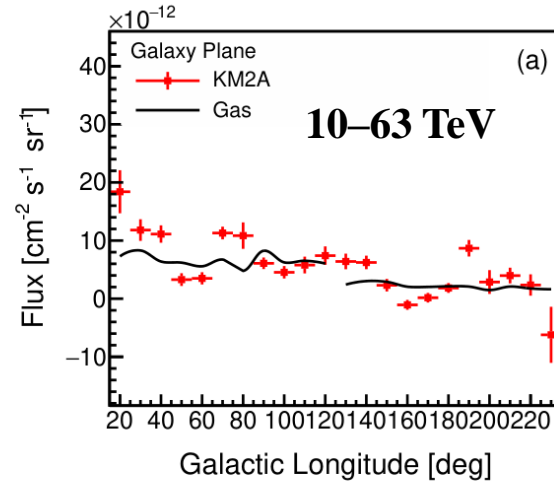
- unclear, probably related to energy injection.



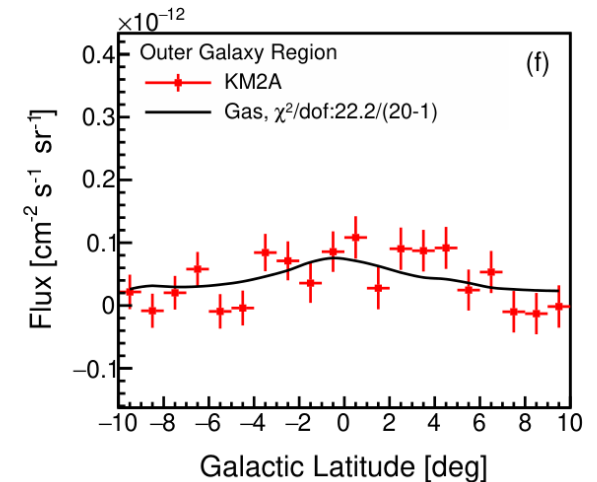
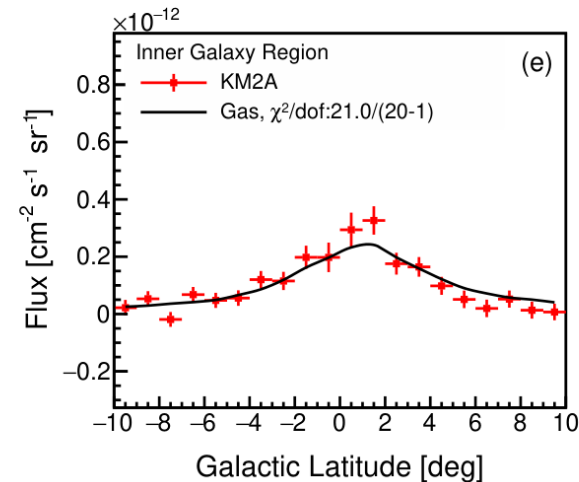
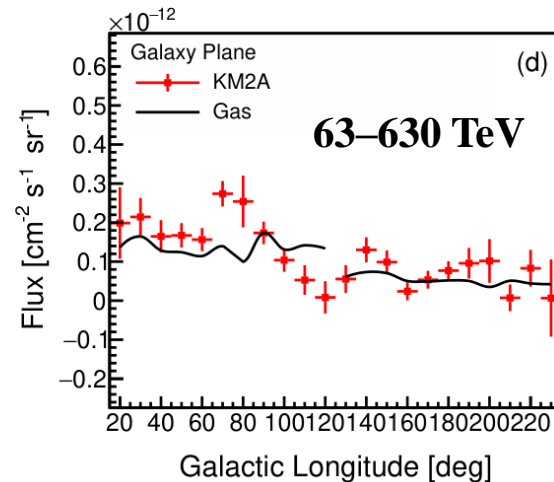
Galactic diffuse emission (GDE)

KM2A only: arXiv:2305.05372

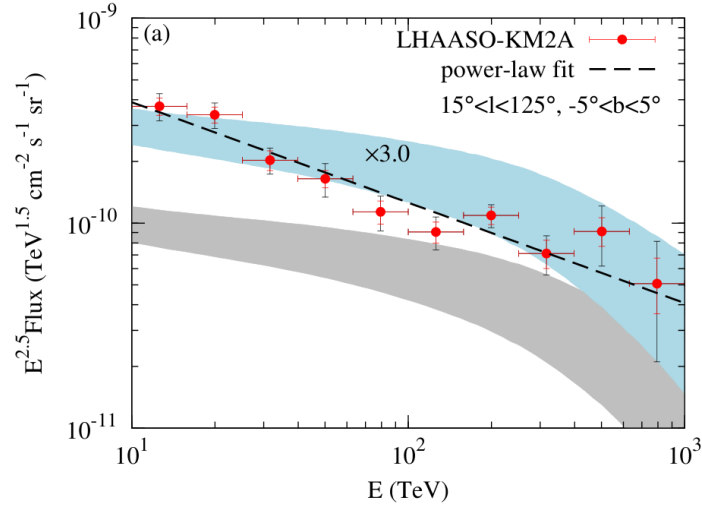
The longitude distributions: slight deviation from the gas distribution.



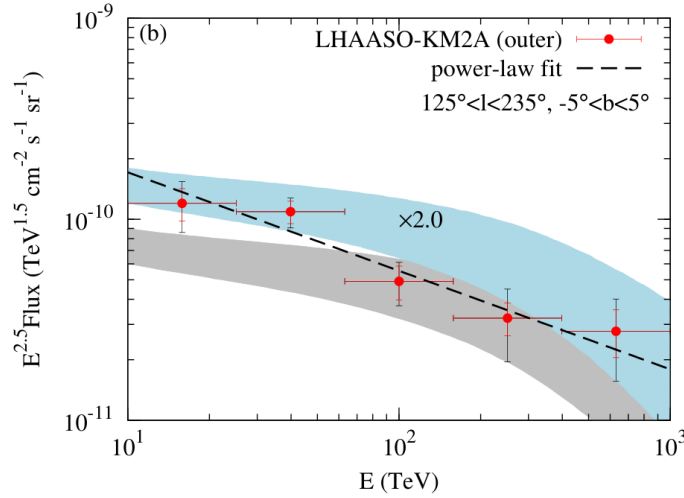
The latitude distributions: consistent with the gas distribution.



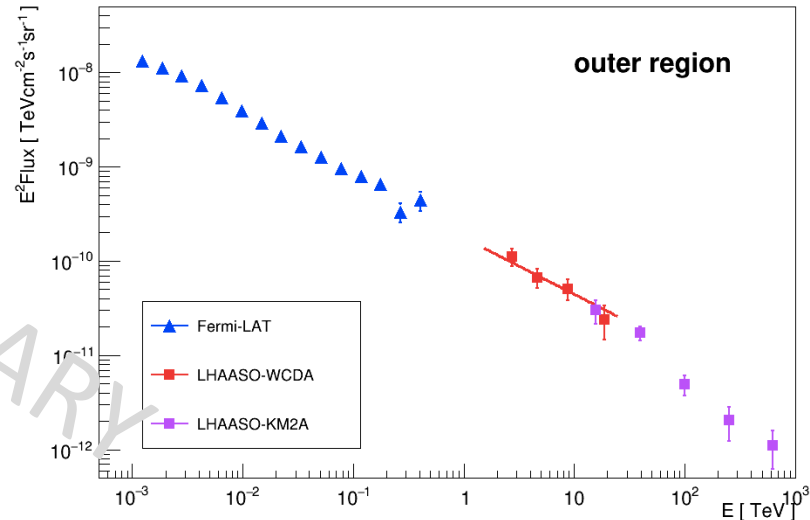
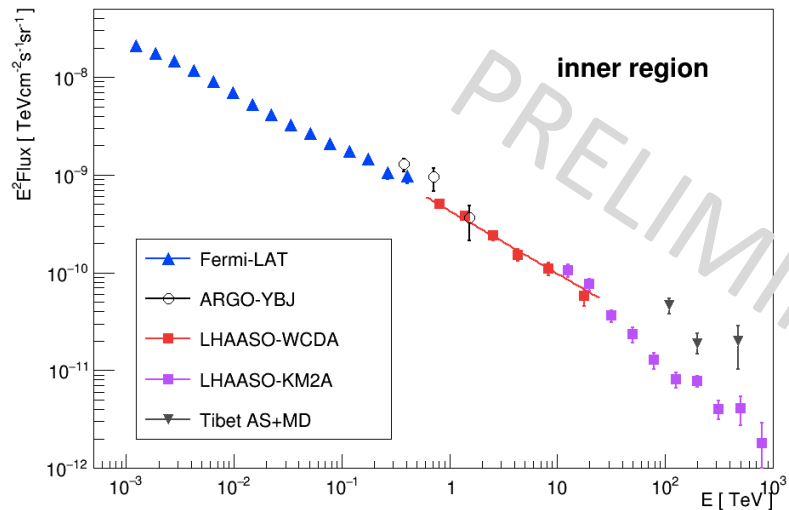
GDE spectrum



KM2A only: arXiv:2305.05372

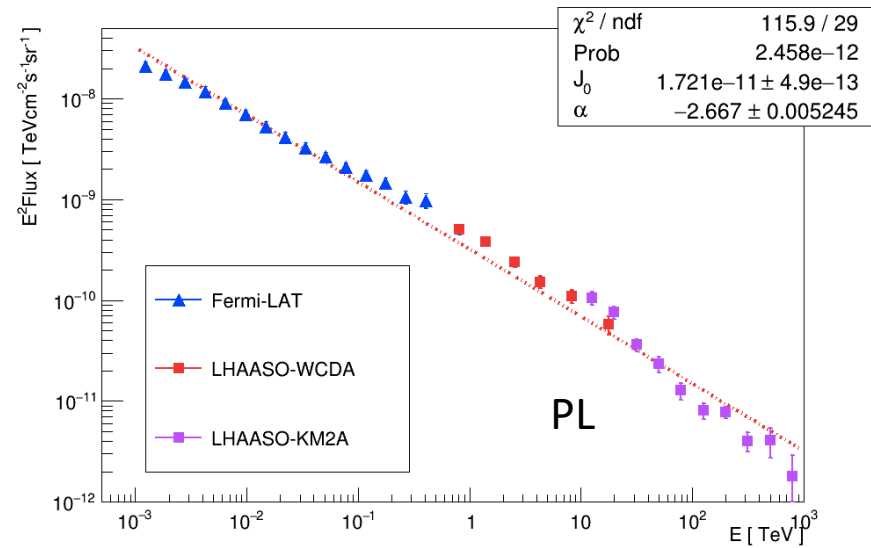
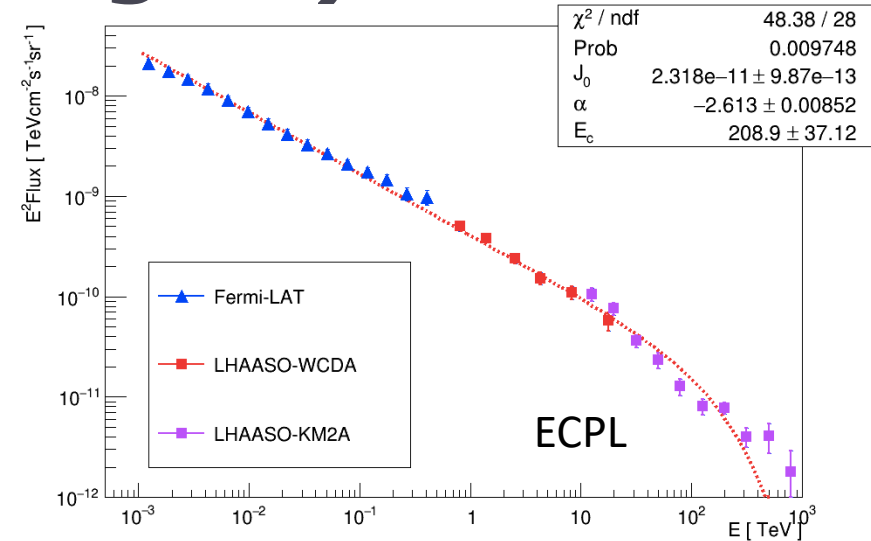
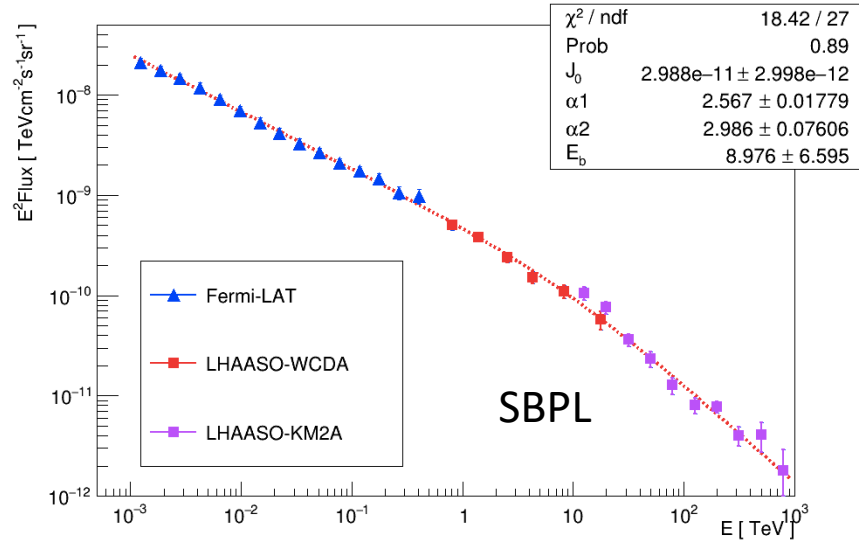


Fluxes higher than predictions (local CR flux \times gas column) by a factor of 2–3: additional diffuse source exist or propagation effect, or contributions from sub-threshold sources.



New from WCDA

Broad band fitting (inner region)



Spectral Model	Formula	Parameter values	χ^2 / ndf
SBPL	$N_0(E/E_0)^{-\gamma_1} (1 + (E/E_b)^{\frac{\gamma_2-\gamma_1}{\beta}})^{-\beta}$	$\gamma_1 = 2.57 \pm 0.02$ $\gamma_2 = 2.99 \pm 0.08$ E_b (TeV) = 9.0 ± 6.6	18.4/27
ECPL	$N_0(E/E_0)^{-\gamma} \exp(-E/E_c)$	$\gamma = 2.61 \pm 0.008$ E_c (TeV) = 208.9 ± 37.1	48.4/28
PL	$N_0(E/E_0)^{-\gamma}$	$\gamma = 2.67 \pm 0.005$	115.9/29

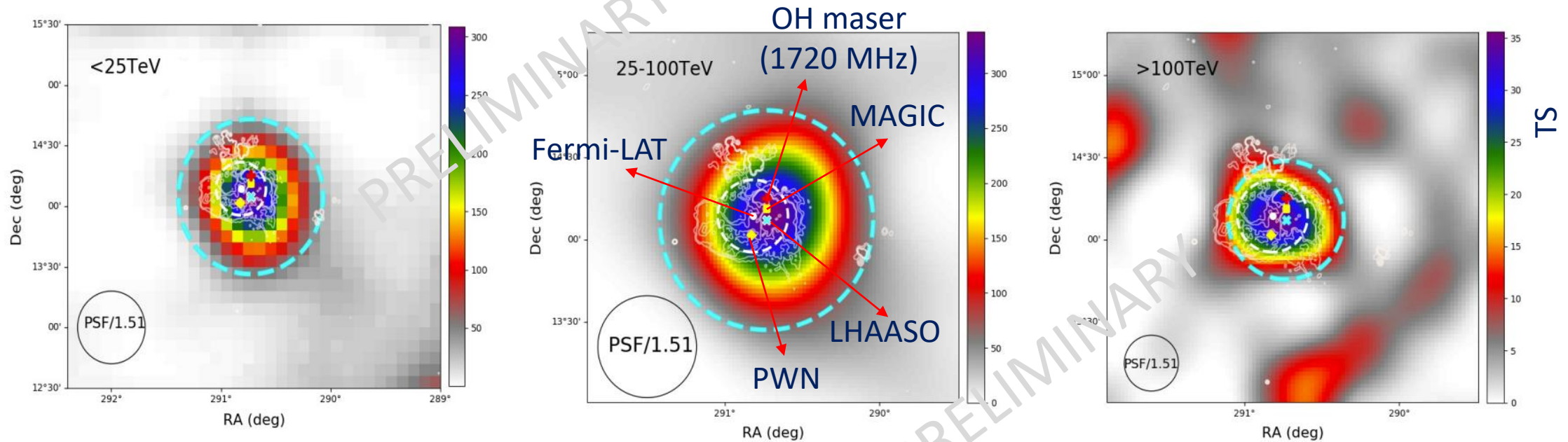
The SBPL model is favored!

Selected new results

*Arbitrary selection, still preliminary
Based on personal preference*

W51C

π^0 bump was detected by Fermi;
An interacting SNR (W51C) with MC (associated with W51B);
Distance: ~ 4.3 kpc, age: ~ 30 kyr.



Center position: (WCDA: 290.73, 14.08); (KM2A: 290.73, 14.10).
Extension: 0.17° (< 25 TeV); $< 0.19^\circ$ (90% CL, > 25 TeV)

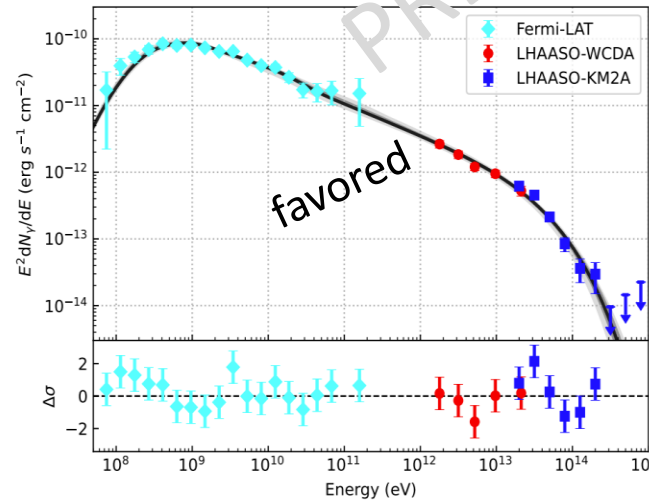
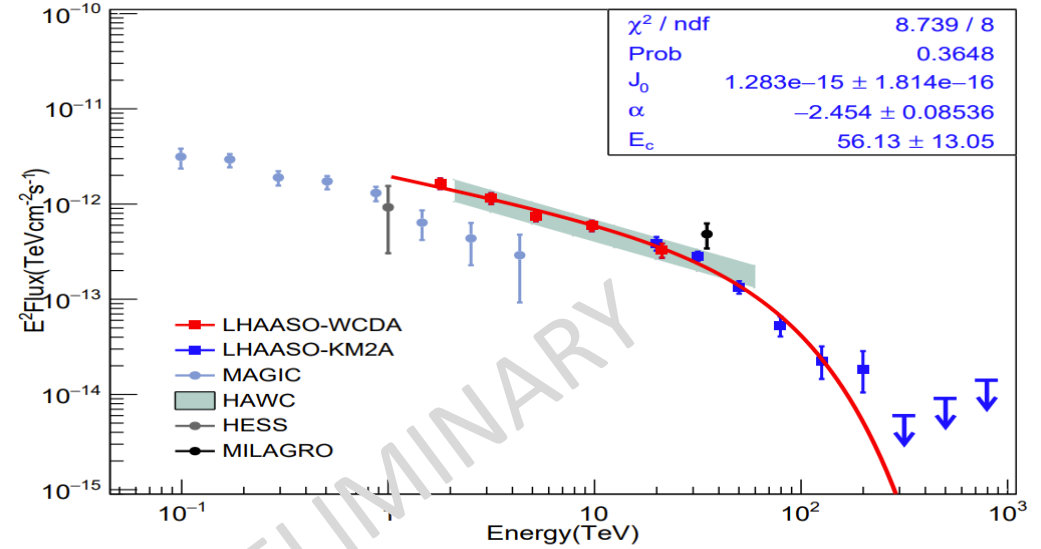
W51C

The SED at 1–300 TeV can be well fitted with power-law \oplus Exp-cut model:

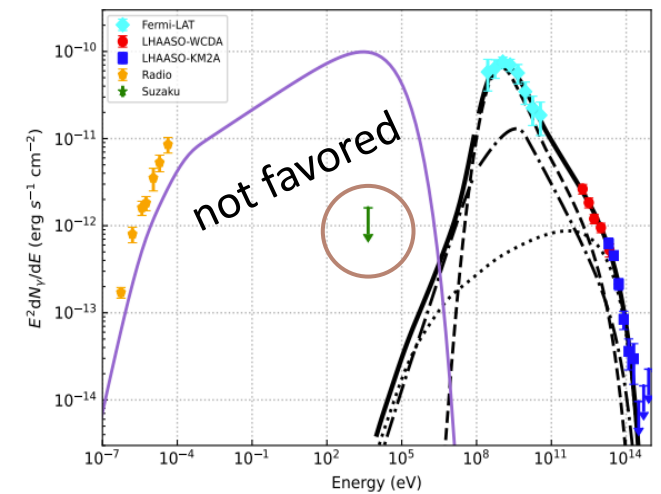
$$dN/dE = J_0 (E/E_0)^{-\alpha} \exp(E/E_c)$$

The gamma-ray spectrum of W51C detected by LHAASO extends to ~ 300 TeV.

The hadronic emission model is favored and the maximum proton energy up to PeV.



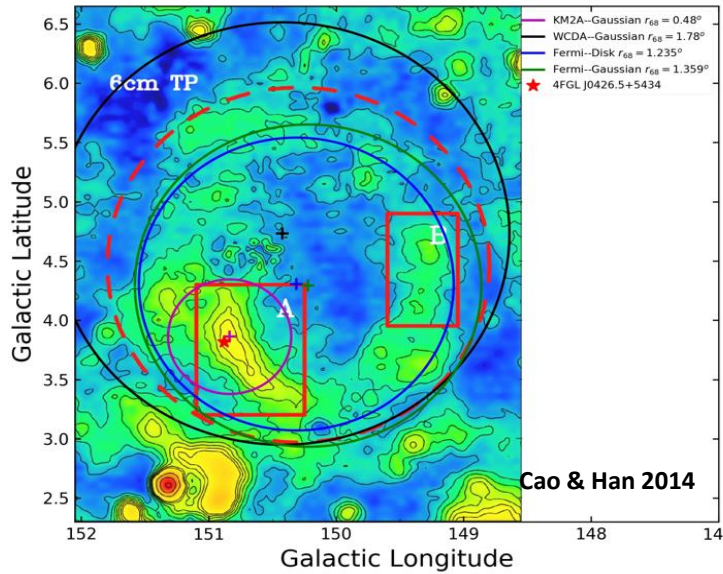
Hadronic model



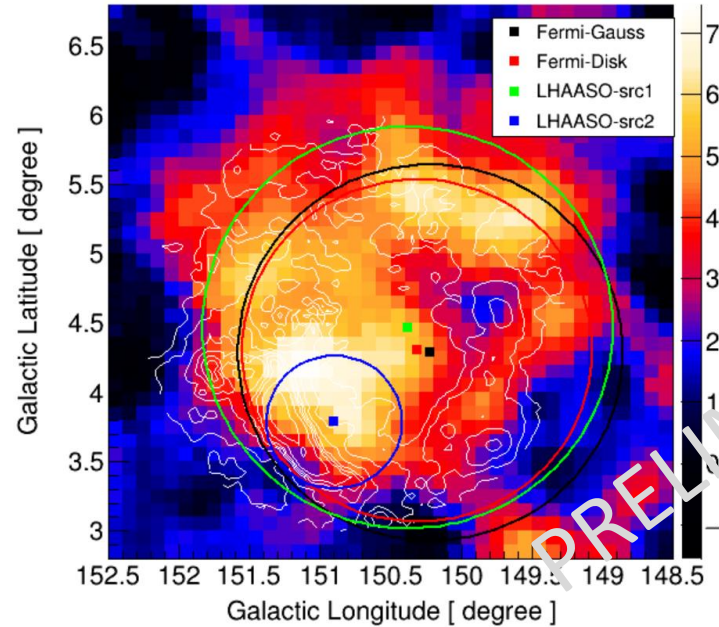
Leptonic model

G150.3+4.5

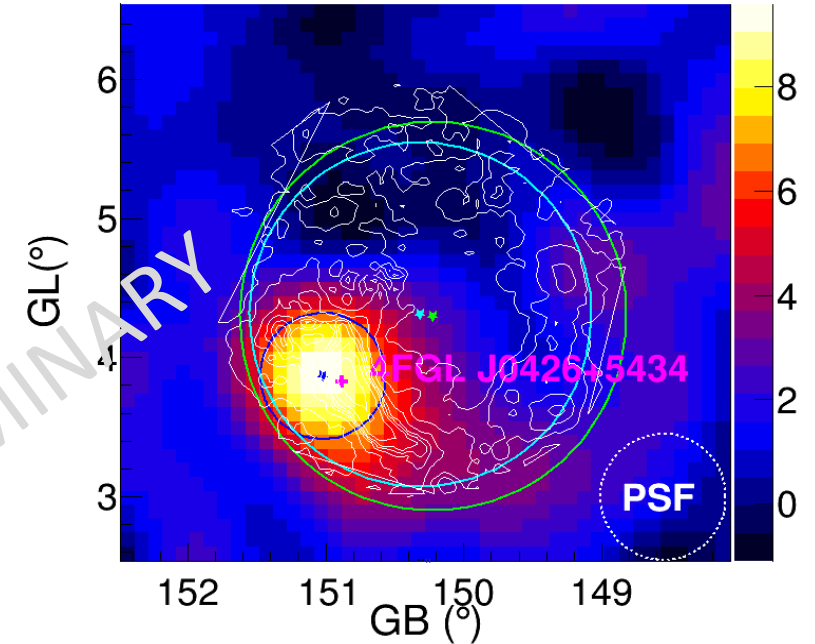
CO map



<25 TeV



>25 TeV



Fitted with two Gaussians: One is spatially coincident with the radio and Fermi-LAT observation (G150.3+4.5); another is very close to the unidentified source 4FGL J0426.5+5434.

(150.38, 4.47), extension = 1.45; (150.9, 3.79), extension = 0.26

The distance of CO emission (MWISP): 0.8 kpc, and a uniform density: $\sim 1.0 \text{ cm}^{-3}$, with an age: $\leq 1.3 \times 10^4 \text{ yr}$.

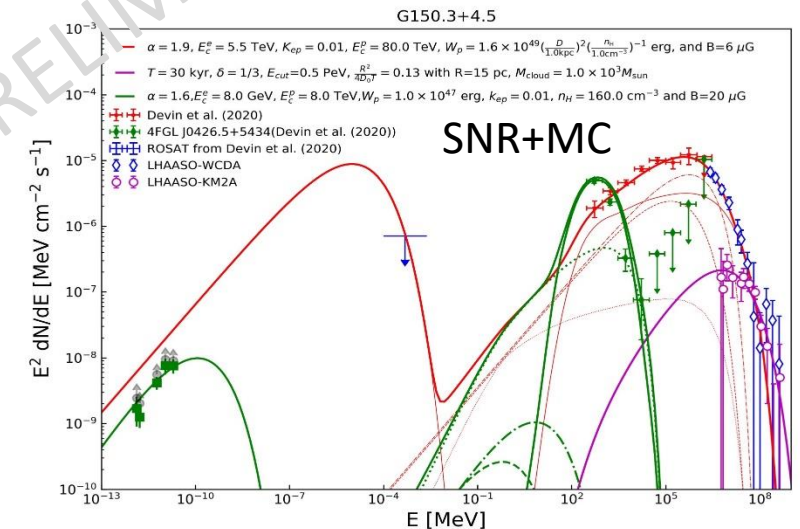
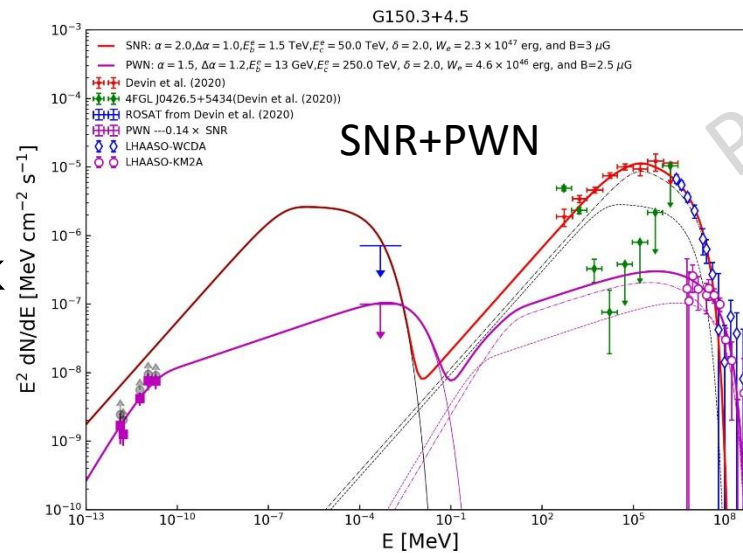
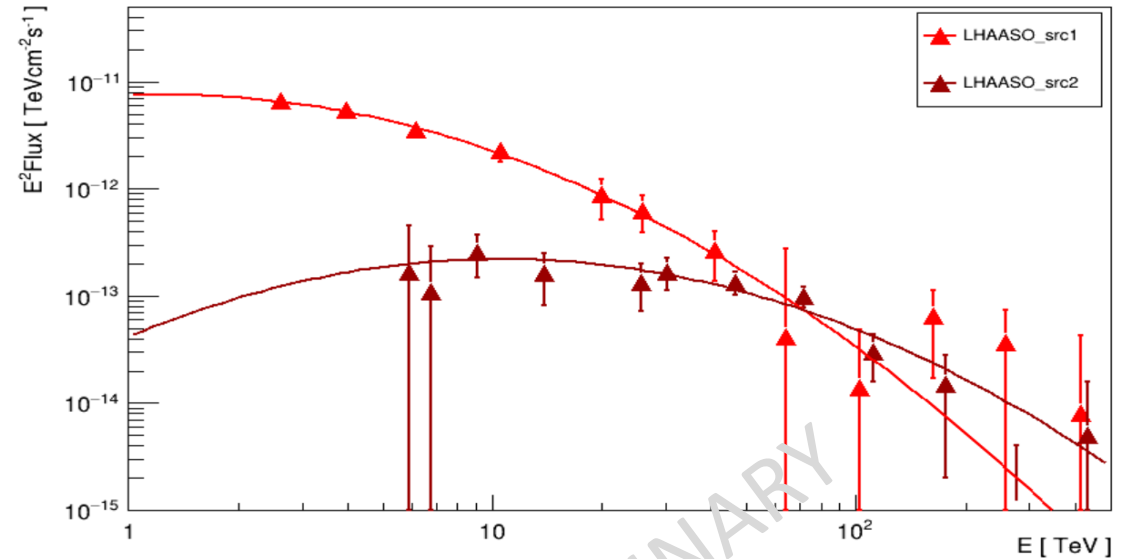
G150.3+4.5

The SEDs at 1–400 TeV can be fitted with log-parabola models.

$$dN/dE = J_0 (E/E_0)^{-\alpha-\beta \log(E/E_0)}$$

Scenario A: sync.+ SSC from SNR G150.3+4.5 and PWN, respectively.

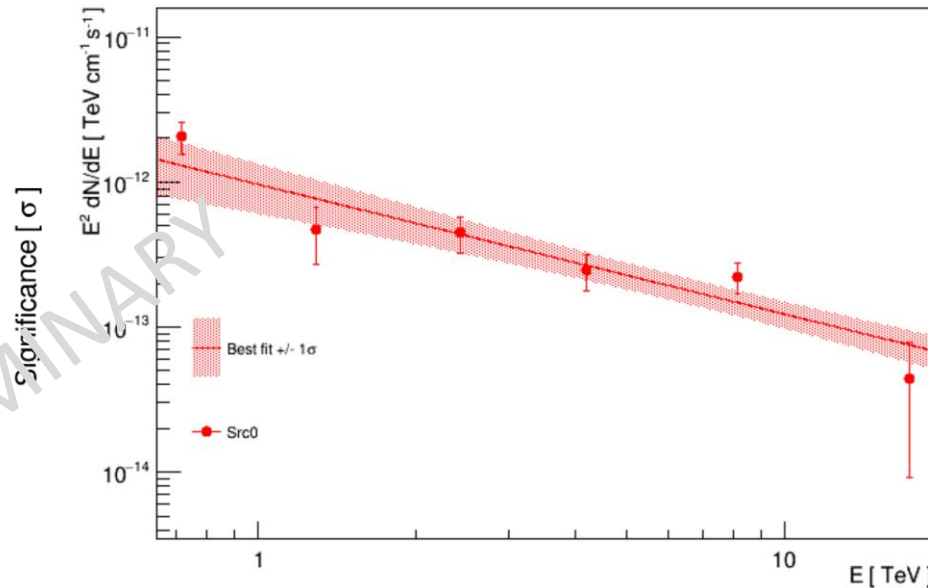
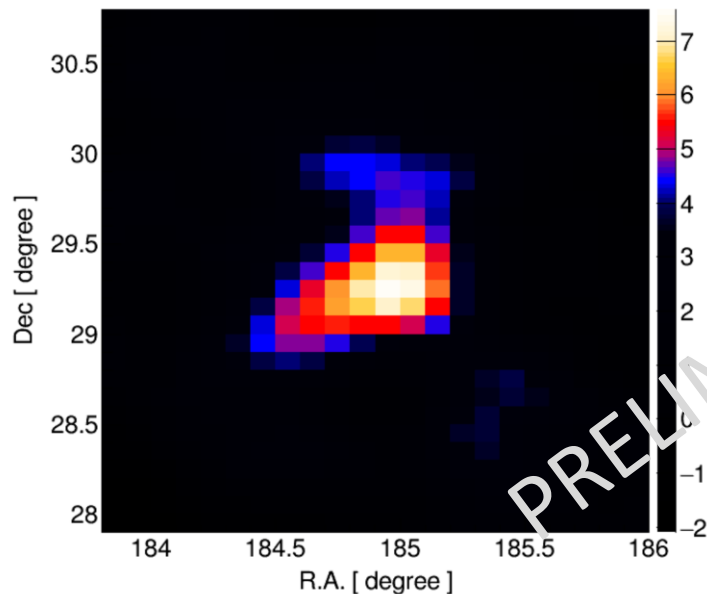
Scenario B: sync. + SSC from SNR G150.3+4.5; Escaped CR interacting with MC, and shock colliding with MC.



NGC 4278

- NGC 4278 is a very young radio galaxy, a **CSO** (compact symmetric object);
- Weak radio emission ($\sim 10^{38}$ - 10^{39} erg s $^{-1}$), small jet size (~ 3 pc);
- Distance: 16.1 Mpc, kinematic age (< 100 yr!).
- **A new type of TeV extra-galactic source?**

TS Map, index=-2.60,sigma=0.00



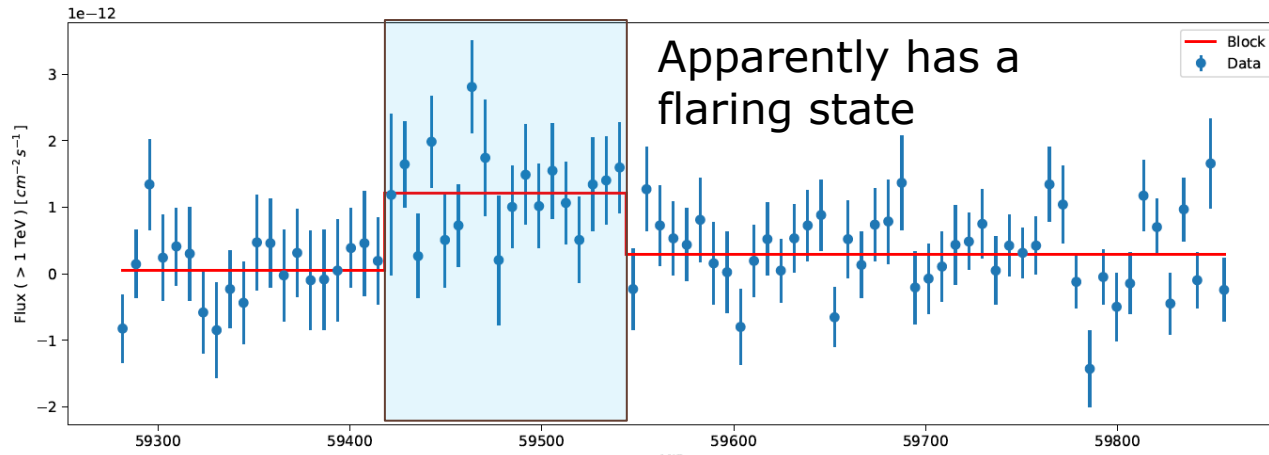
508 days' observation

Position: (184.98, 29.25)

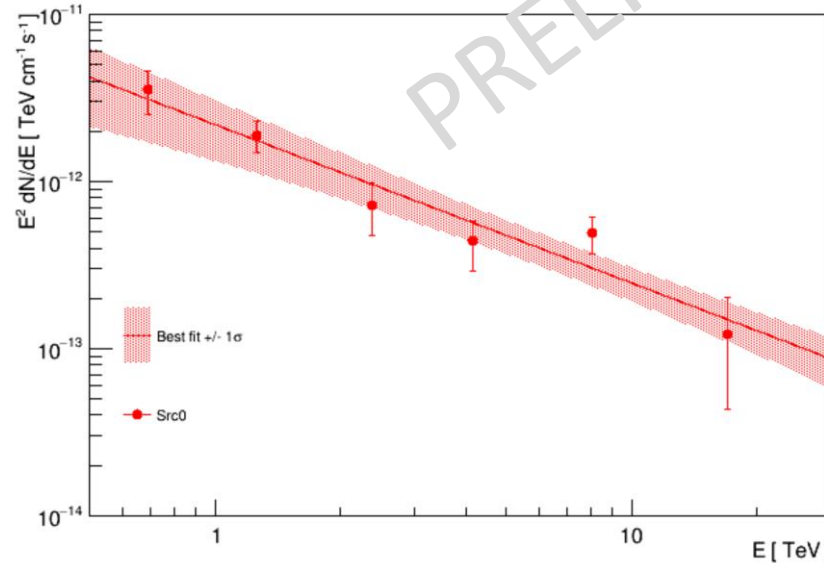
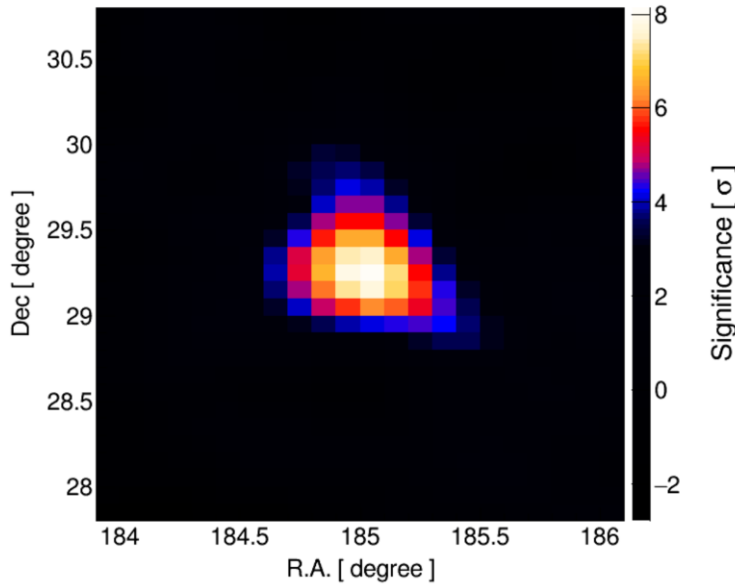
Spectrum index: -2.90

E_{max} : up to ~ 20 TeV

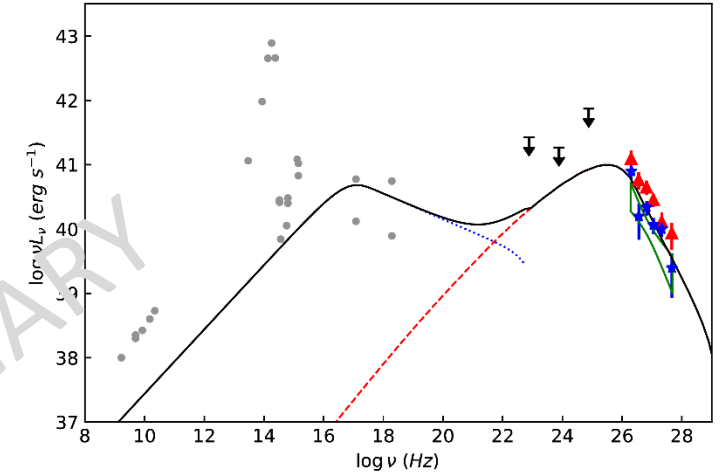
NGC 4278



TS Map, index=-2.60, sigma=0.00



Modeling: Sync. + SSC



159 days' flaring period

Spectrum index: -2.95, a little bit softer but insignificant.

SS 433

- ◆ A microquasar in SNR W50 - a black hole orbiting a supergiant companion;
- ◆ Distance: 5.5 kpc;
- ◆ Orbital period: 13.082 days;
- ◆ Precession period: 162.250 days;
- ◆ Jet termination lobes.

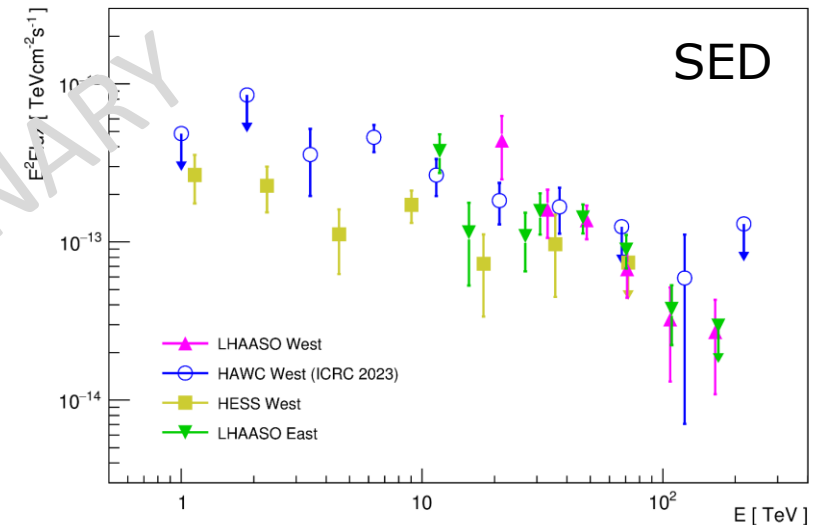
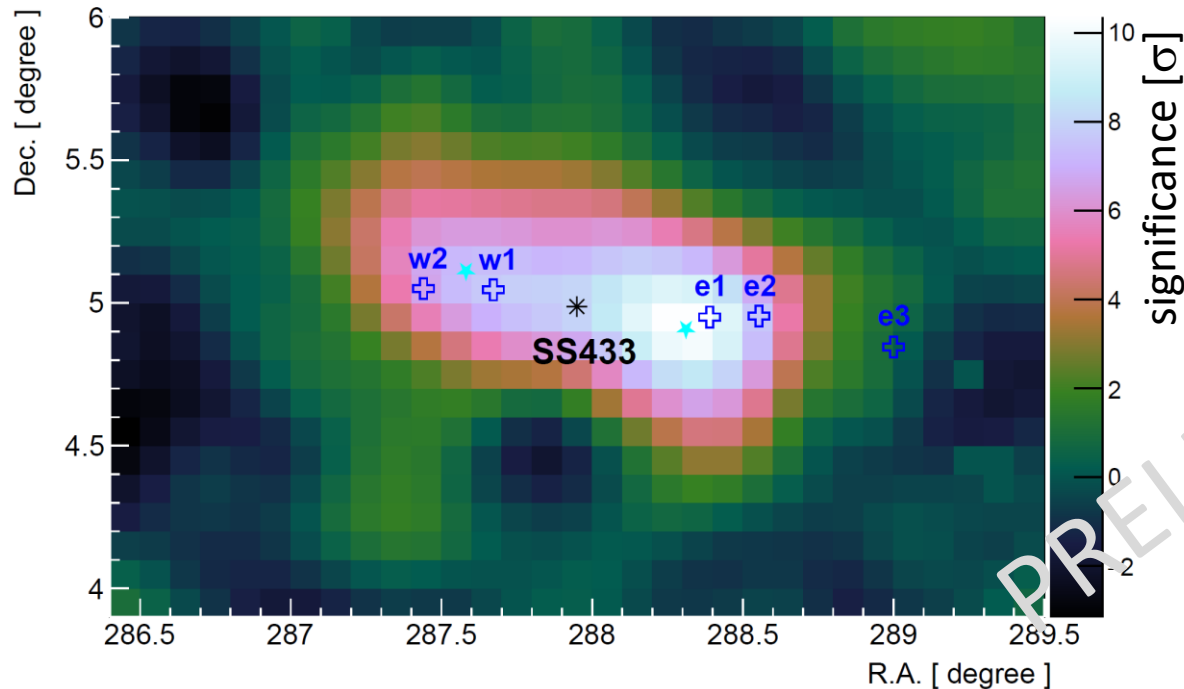
LHAASO observations (Cyan stars)

- West lobe

- R.A.: 287.581 ± 0.050
- Dec: 5.112 ± 0.039

- East lobe

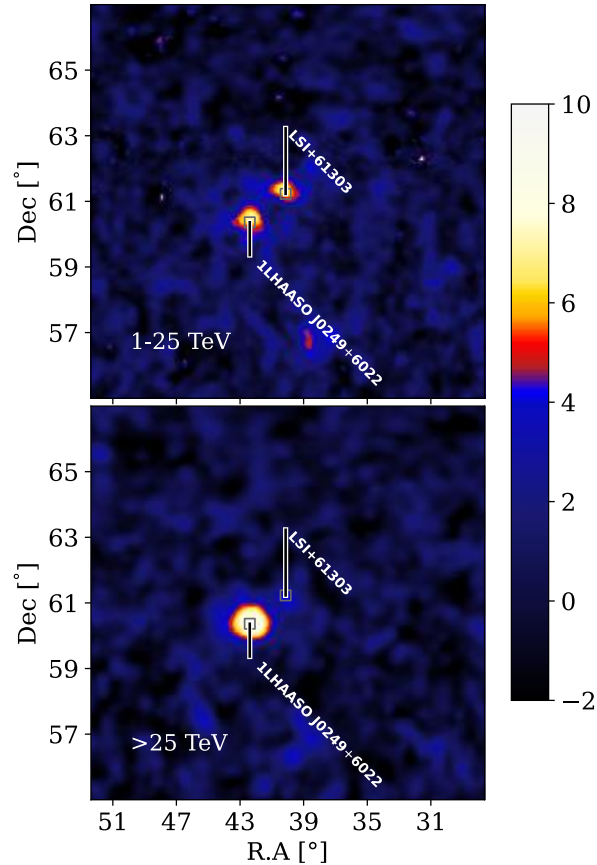
- R.A.: 288.3114 ± 0.031
- Dec.: 4.908 ± 0.026



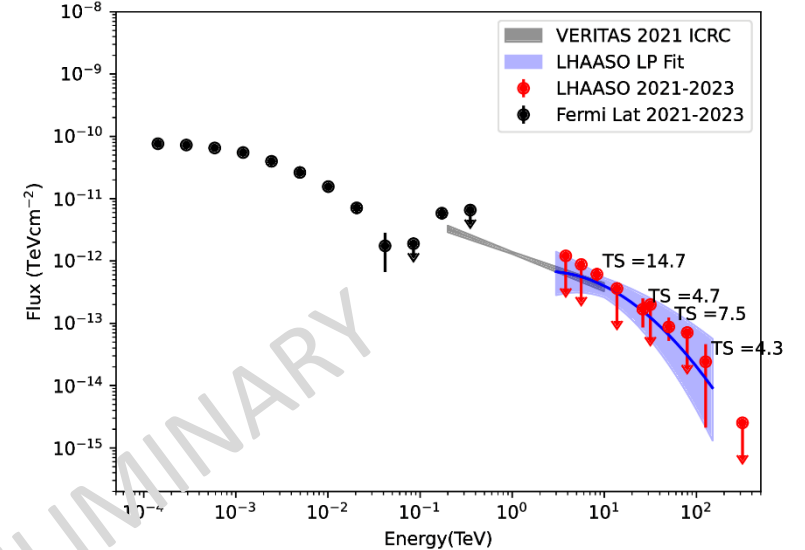
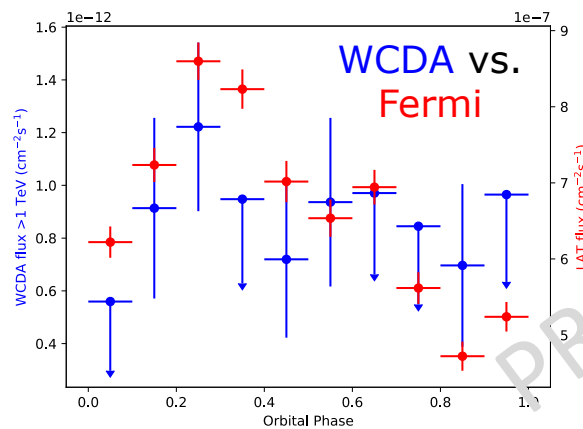
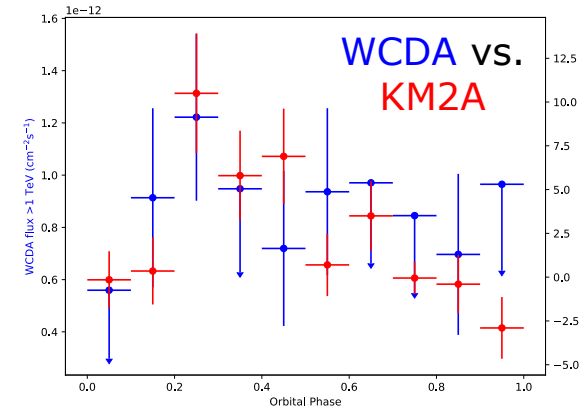
LS I+61 303

- Gamma-ray binary that consists of a Be star and a compact object (BH or NS)
- Distance: 2 kpc, period: 26.5 da

WCDA: 6.7σ



KM2A: 3.5σ



Other sources under active analysis

◆ SNR

- γ -cygni
- IC443
- W44
- Cas A
- J2002/SNR
G069.7+01.0
- SNR G106.3
- ...

◆ Young star cluster

- Cygnus
(cocoon)
- W43
- ...

◆ KM2A only

- LHAASO
peanut
- 1LHAASO
J1740+0948u
- J1740+1000
- 1LHAASO
J1959+1129u
- ...

◆ PWN/Pulsar halo

- Geminga
- CAT 1
- J1825
- ...

◆ Dark sources

- 1LHAASO
J0343+5254u
- 1LHAASO
J2108+5153u
- 1LHAASO
J2200+5643u
- ...

◆ Extragalactic

- Mrk 421
- Mrk 501
- NGC 1275
- M87
- ...

◆ Unidentified

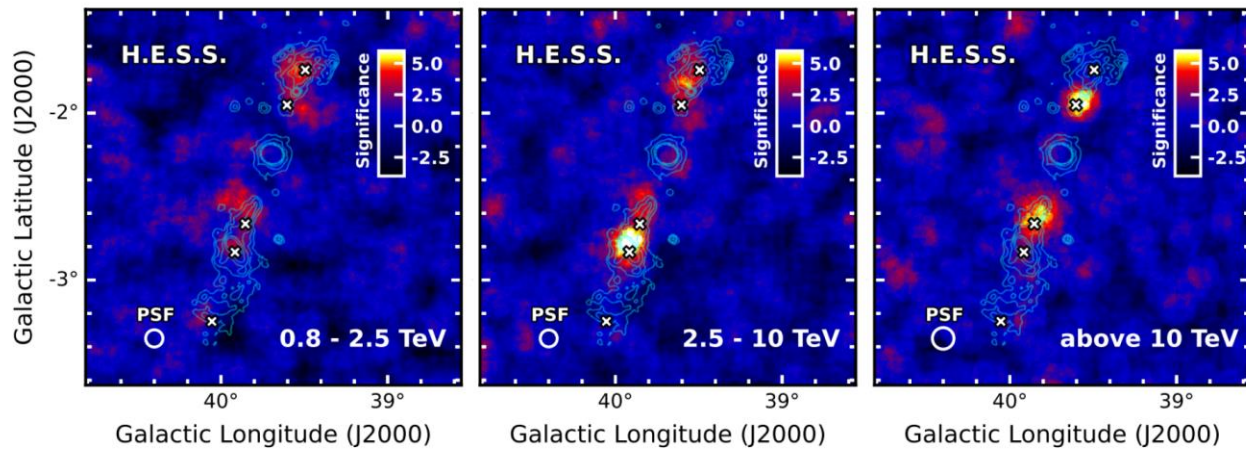
- 1LHAASO
J1809–1918u
- 1LHAASO
J1908+0615u
- 1LHAASO
J2018+3643u
- ...

Summary

- ◆ LHAASO has been in full-scale operation for more than two years.
- ◆ We are pleased to announce the release of our 1st Catalogue, which includes 90 sources.
- ◆ LHAASO collaboration is currently conducting analyses on these sources, and we anticipate unveiling more exciting results soon. **Stay tuned for updates!**
- ◆ **Thank you for your attention!**

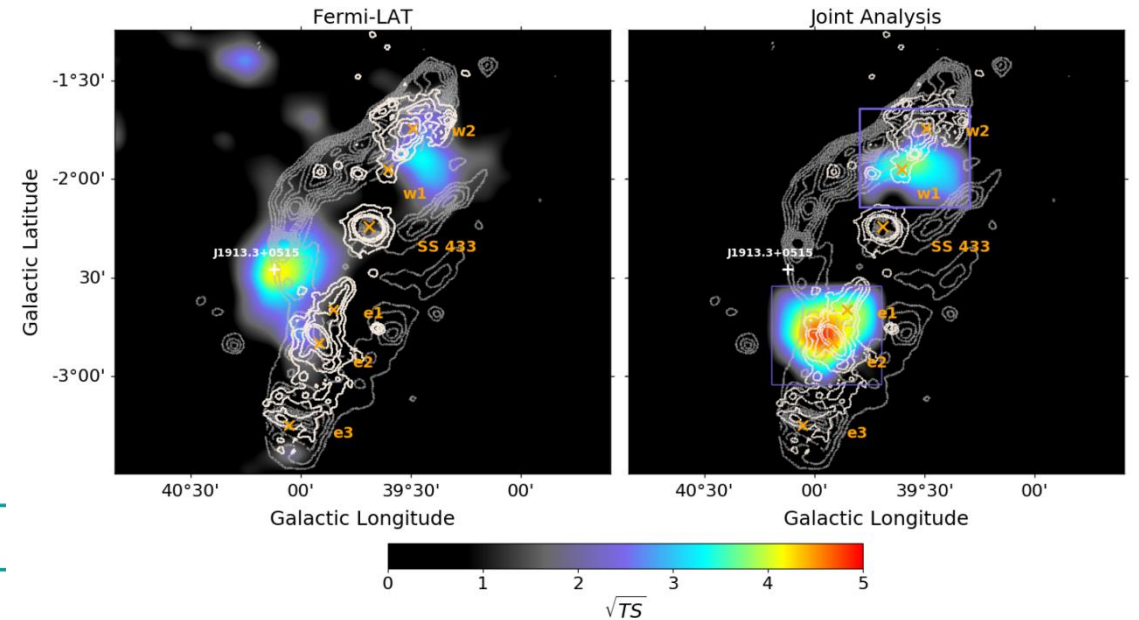
SS 433

Energy-dependent morphology in the TeV emission



first observation of energy-dependent morphology in TeV emission of a jet!

HESS



FERMI + HAWC

LS I+61 303

