Recent results from LHAASO

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On behalf of LHAASO Collaboration
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Large High Altitude Air Shower Observatory (LHAASO)

Haizi Mountain 4410 m a.s.l. Daocheng, Sichuan Province, China

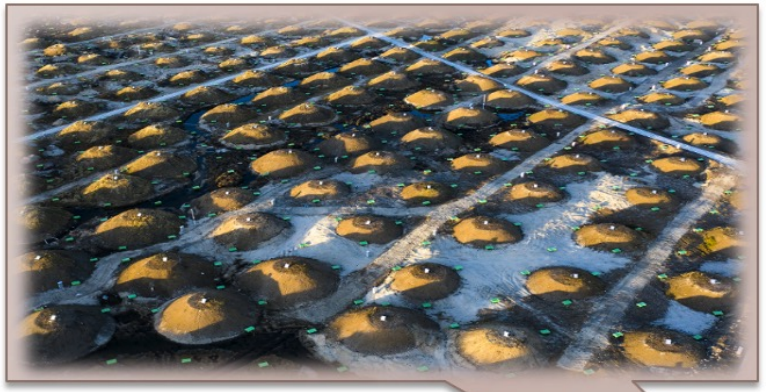
Location: 29°21′ 27.6″ N , 100°08′19.6″ E

2021-07 completed built and in full array operation

LHAASO collaboration

318 researchers from 30 institutes of 5 countries

LHAASO

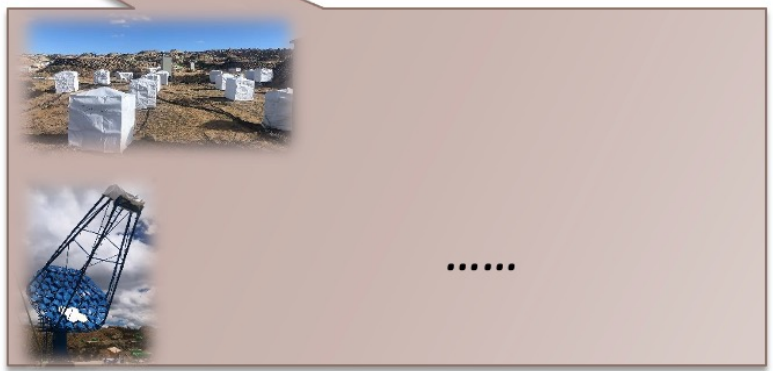


KM2A:
5216 scintillators (ED)+
1188 muon detectors

WCDA:
3 pools, 3120 cells,
area 78,000 m^2

WFCTA:
18 wide FOV telescopes

Some planned addons:
Neutron detectors
High energy IACTs
…

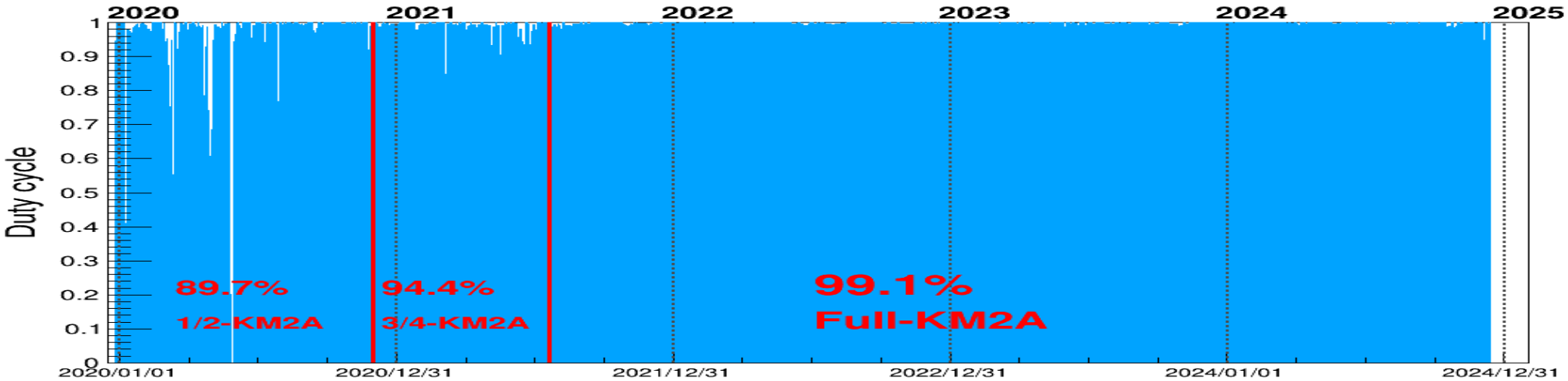


……

Features: full duty cycle

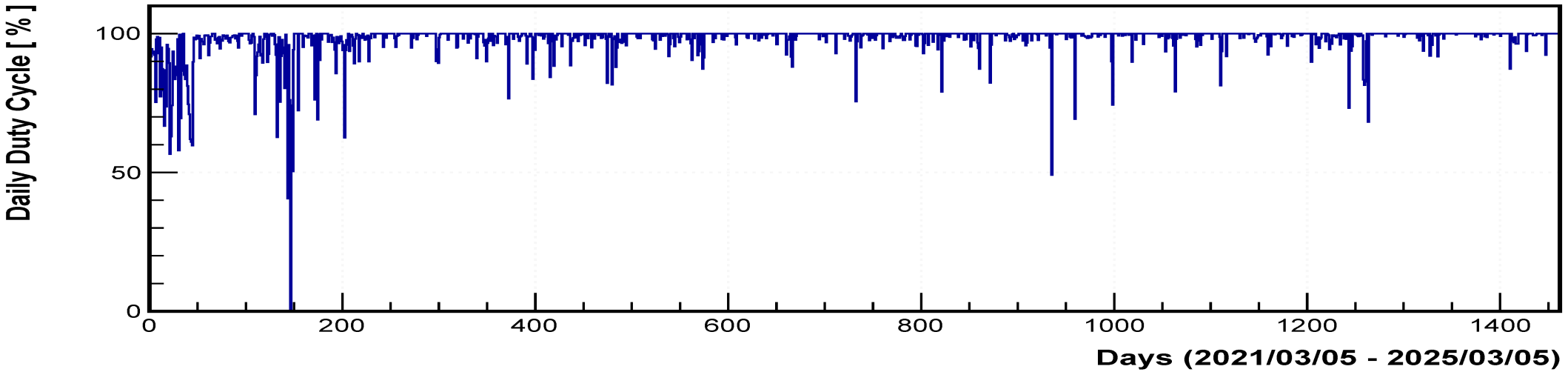
Yearly-Data-taking:

~ 24 hour × 360 days



KM2A

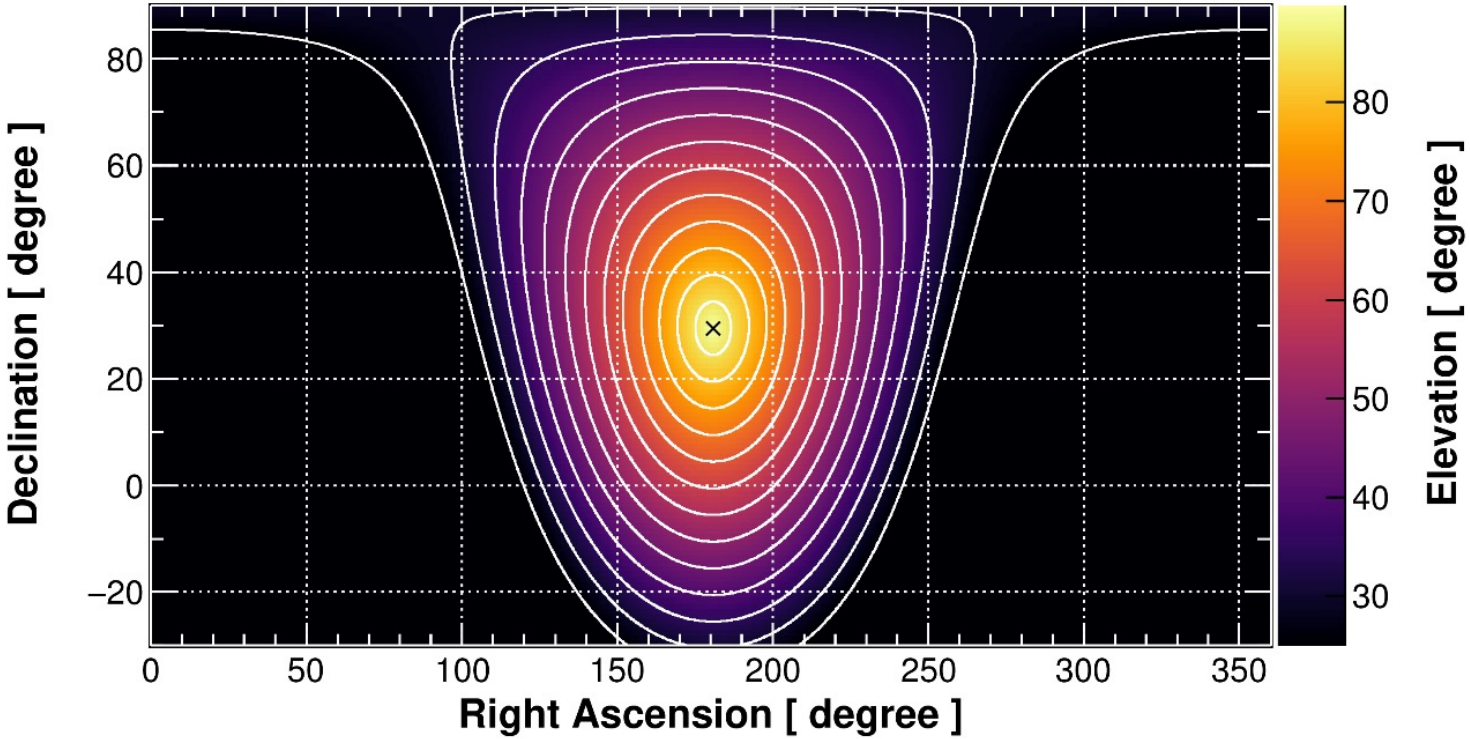
Overall Duty Cycle = 97.96%



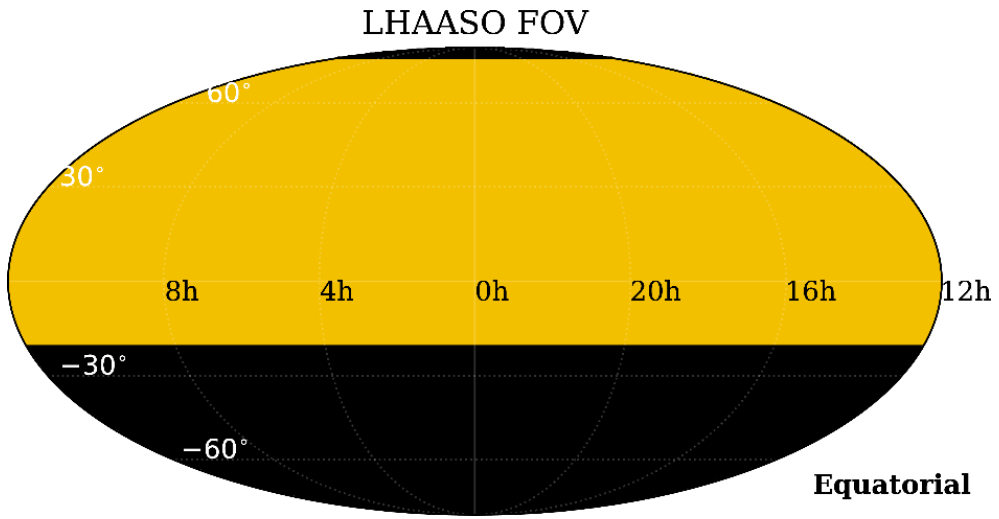
WCDA

Features: wide field of view

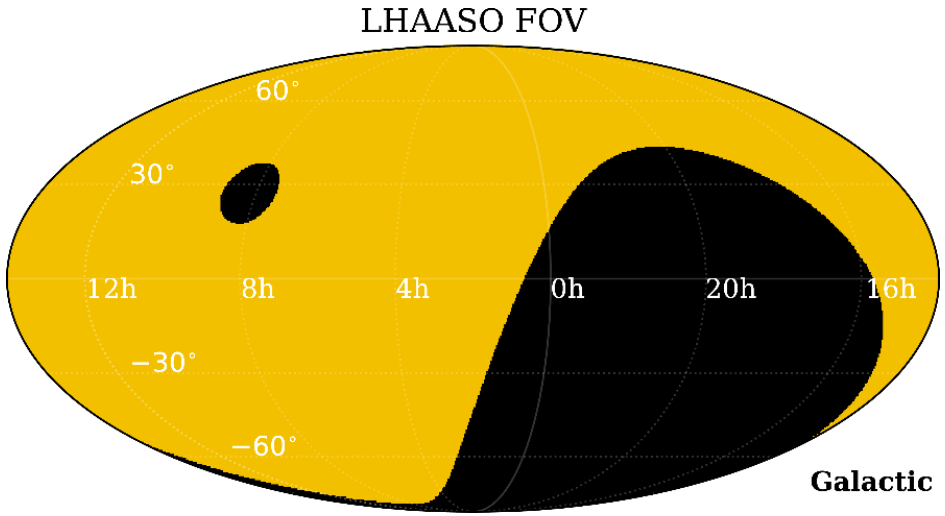
Instant FOV



Daily/yearly FOV

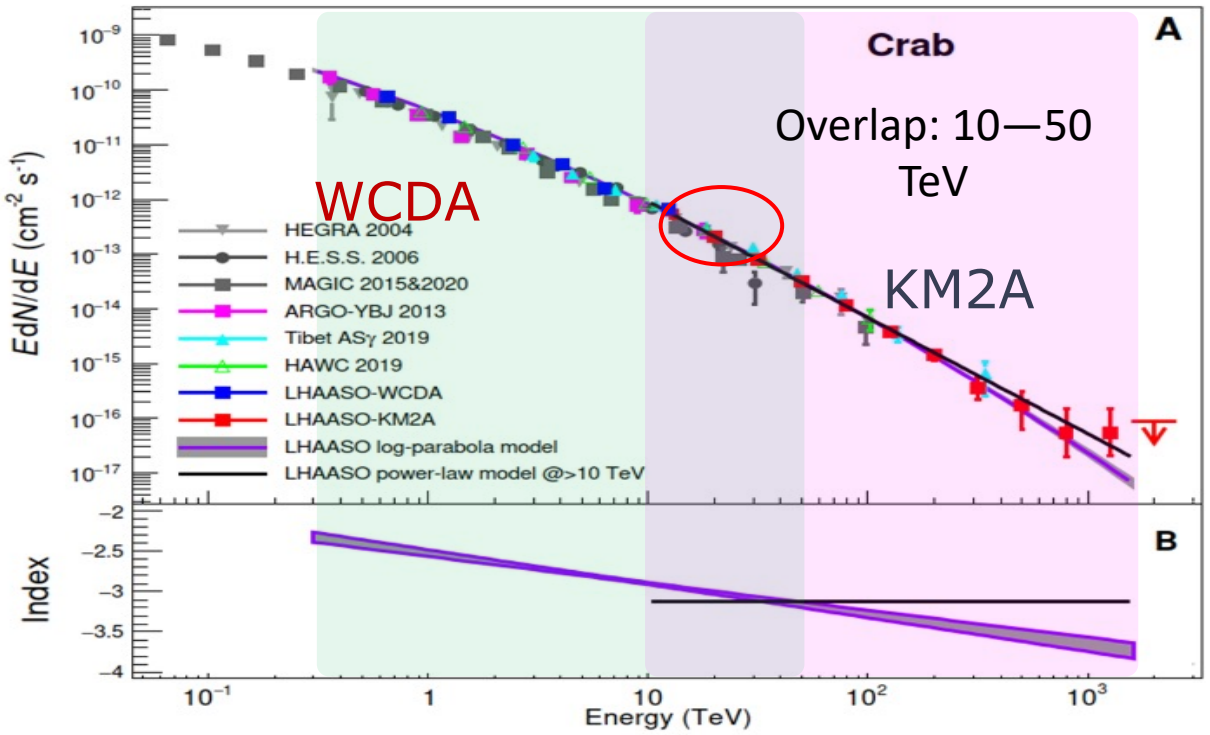


Daily/Yearly FOV

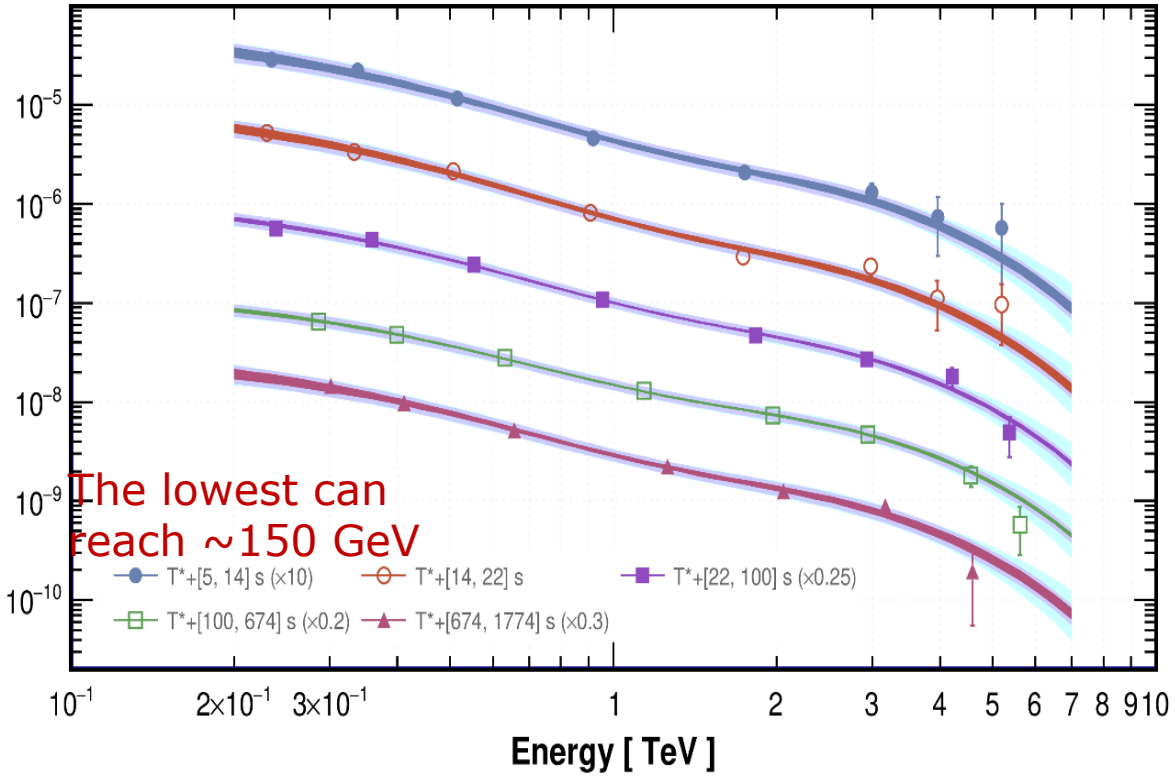


Features: wide energy range coverage

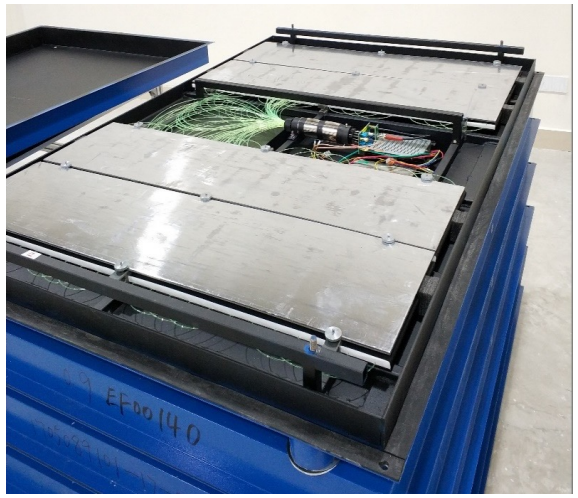
Crab

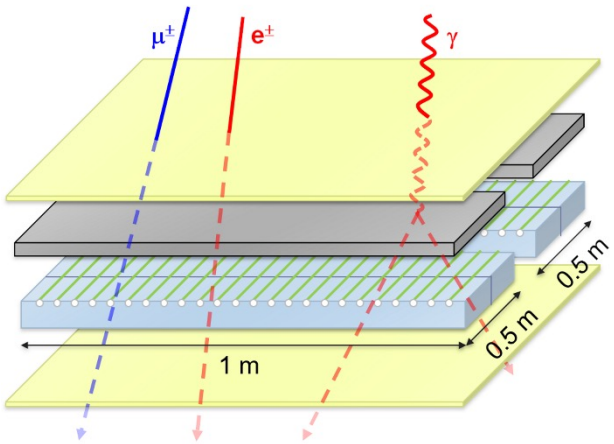


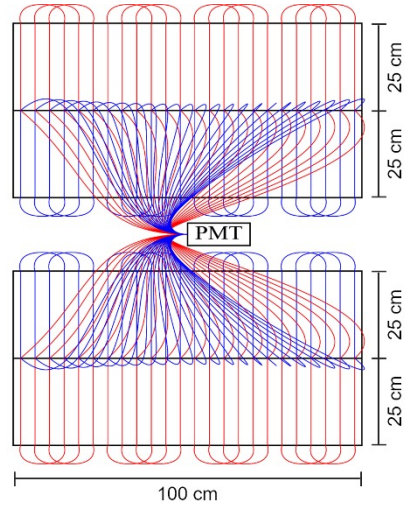
GRB 221009A



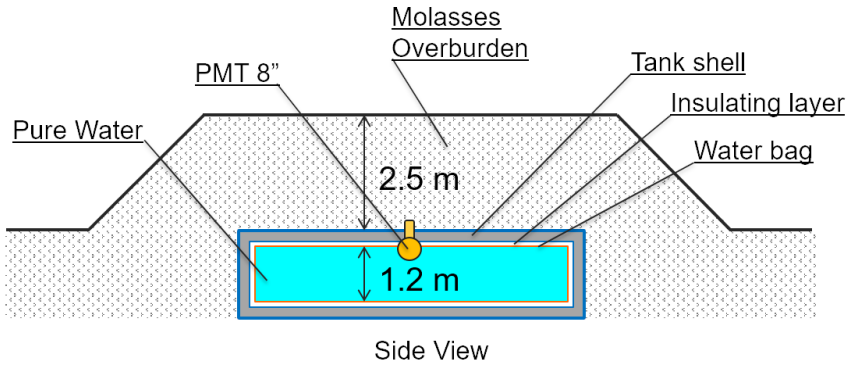
Electromagnetic Detector (ED)



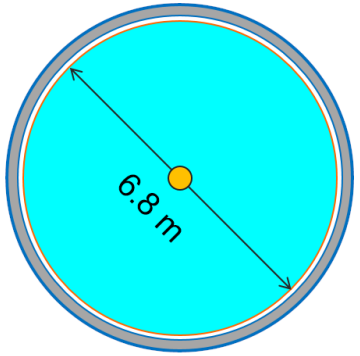




Muon Detector (MD)

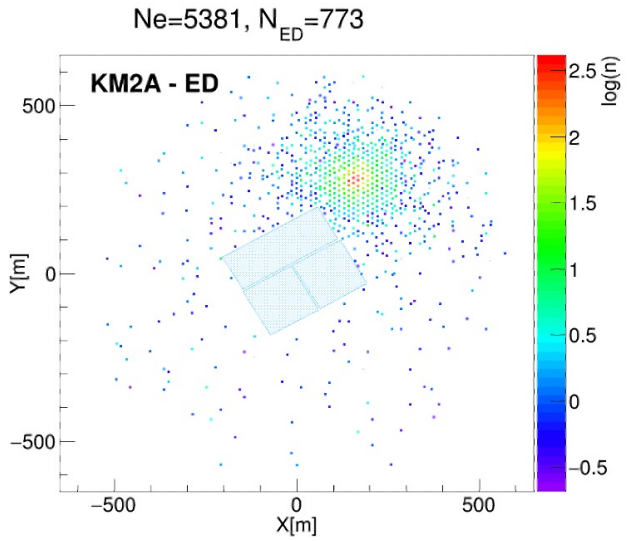


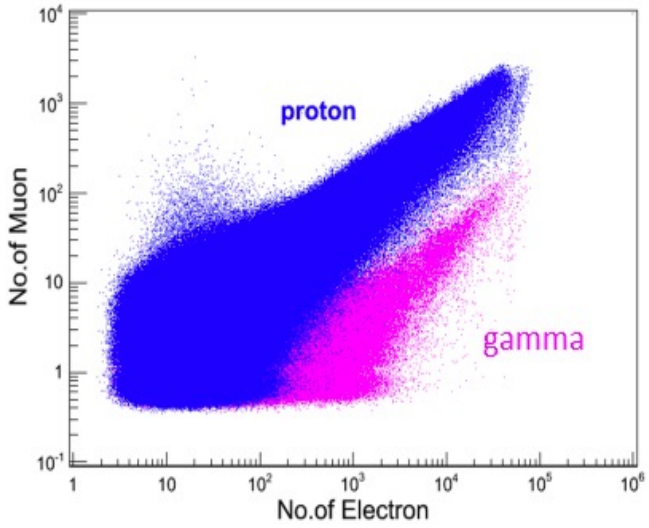
Side View

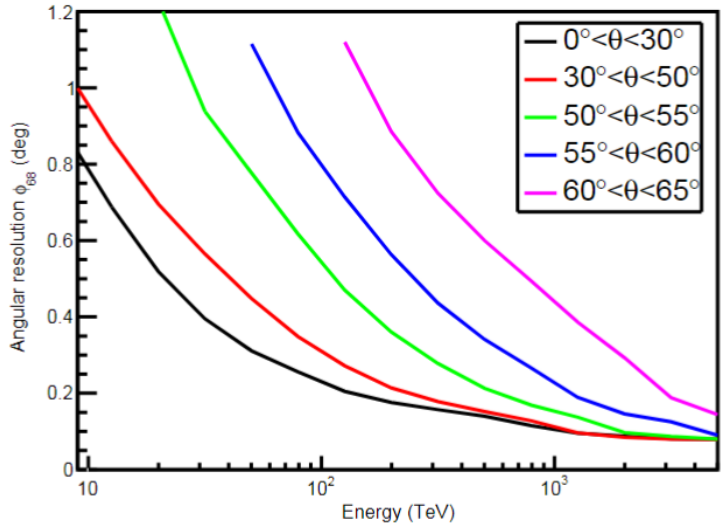


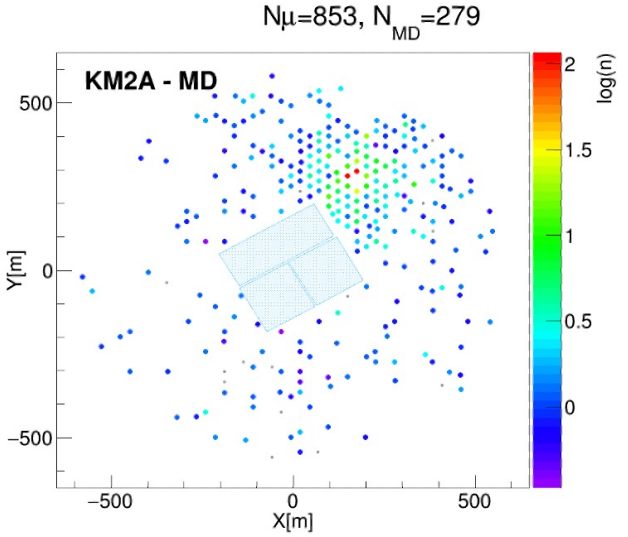
Top view

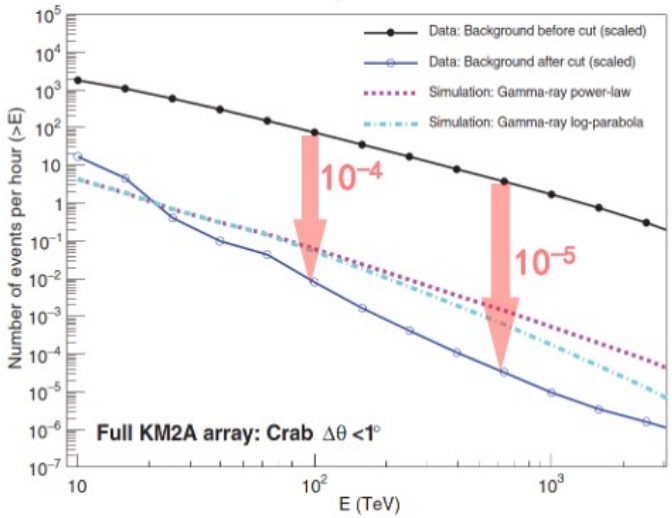
KM2A Performance

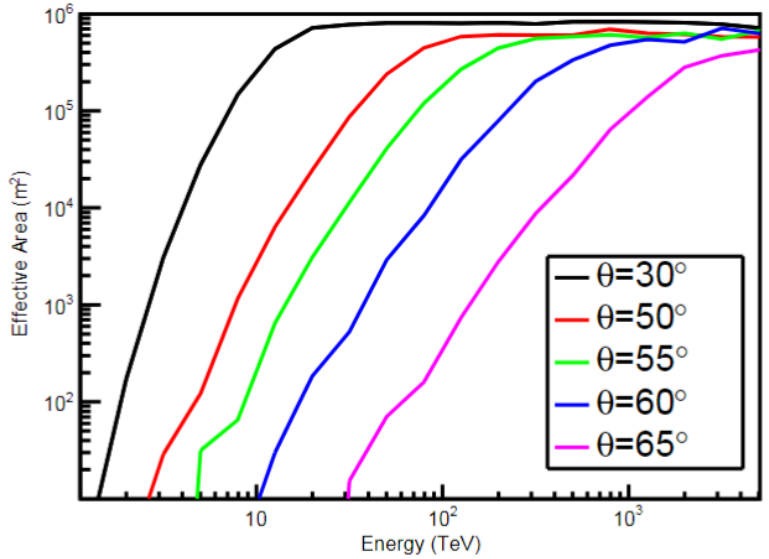




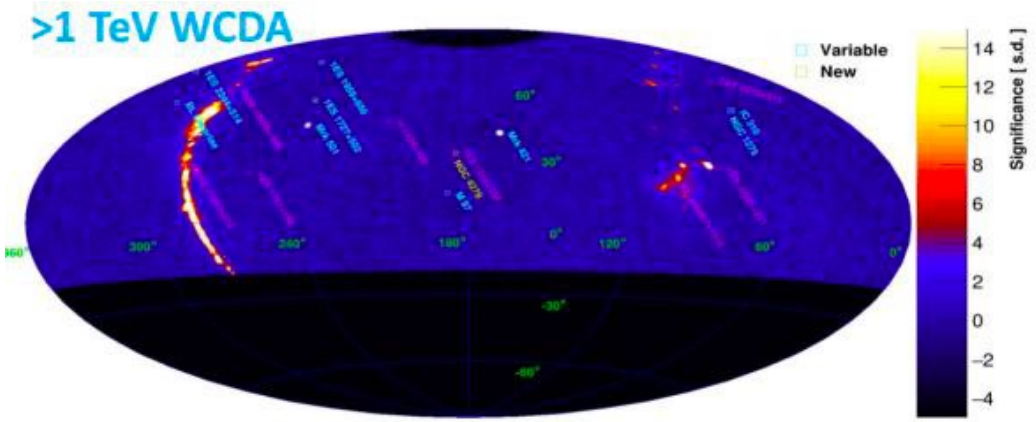


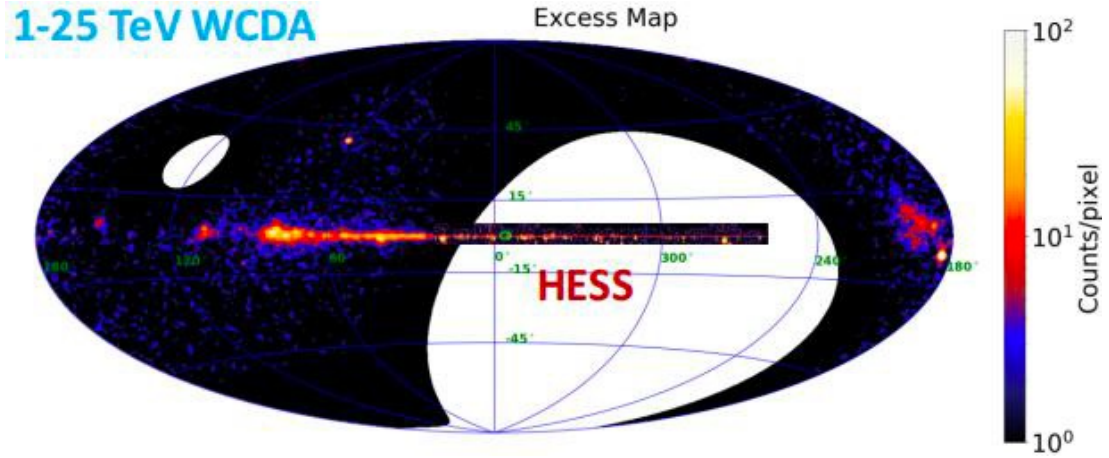


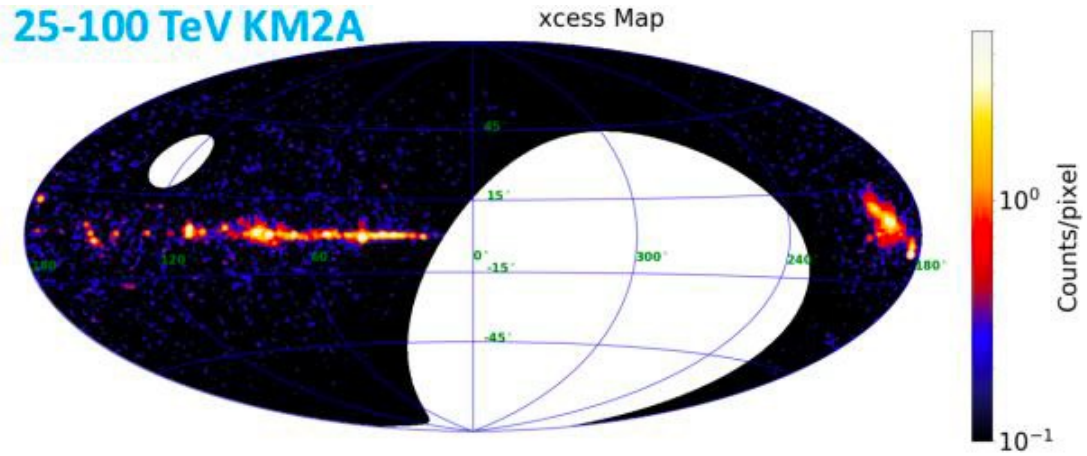


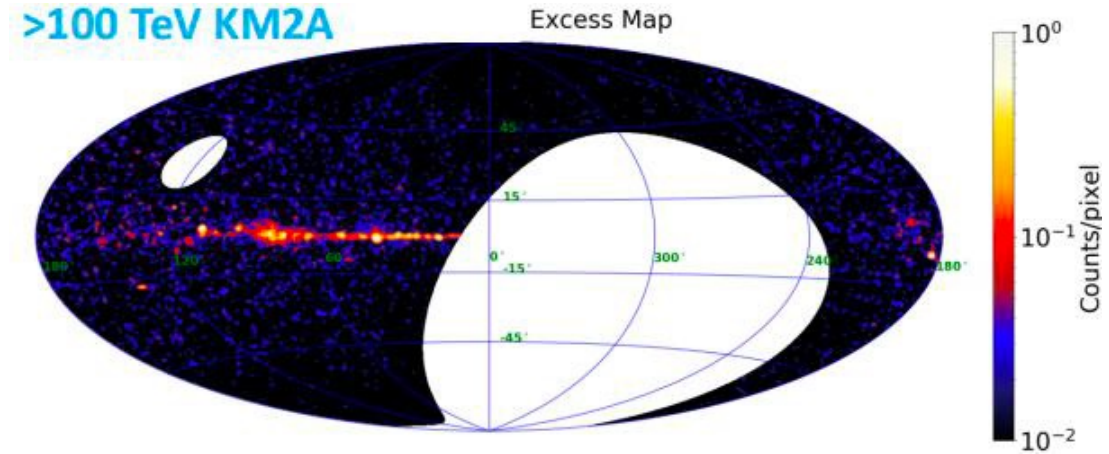


VHE-UHE source @ LHAASO





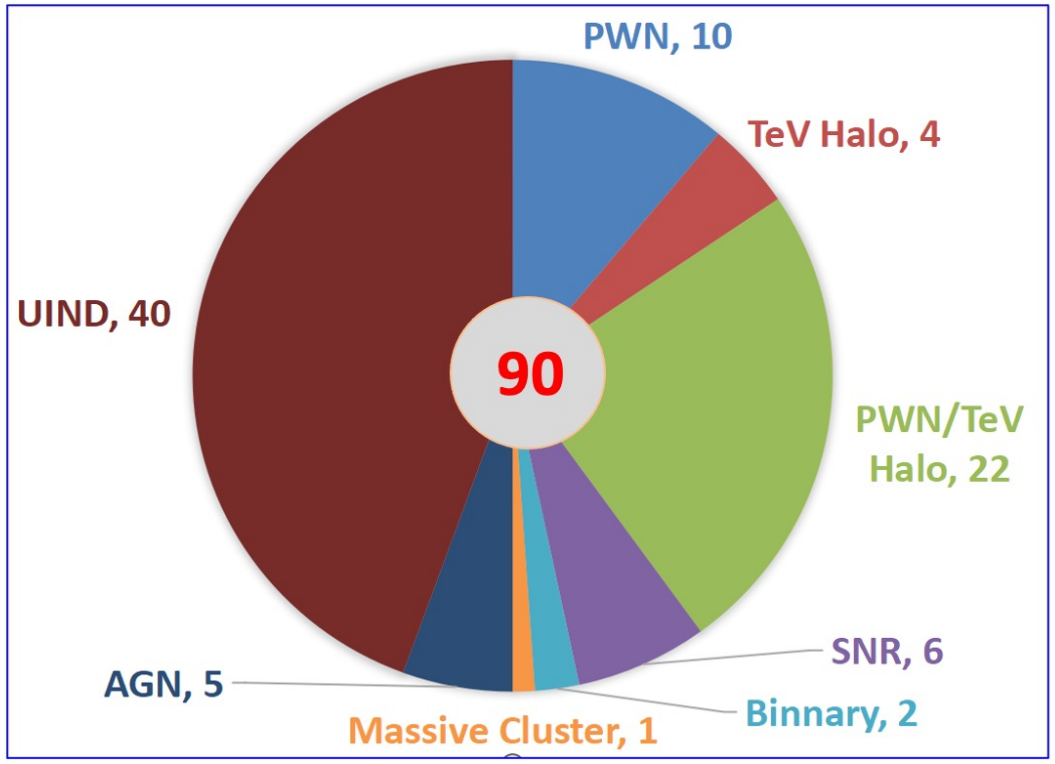




Released by LHAASO coll. arXiv.2305.17030.

1st LHAASO catalog source type

- 90 VHE sources with 32 new discoveries.
- 43 UHE (>100 TeV) sources
- 77% by WCDA, 83% by KM2A, 61% by both



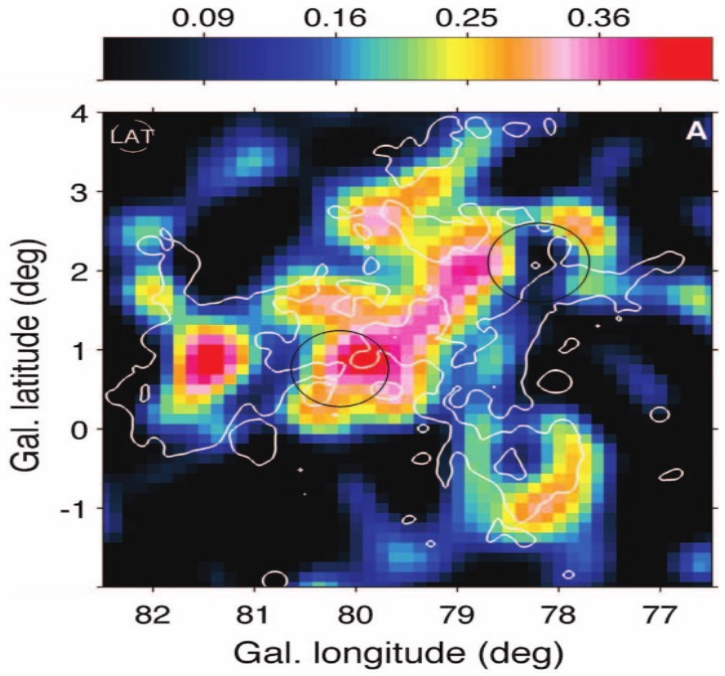
- KM2A: 933 days (~730 days full array)
- WCDA: 508 days (full array)

- Galactic sources
  - SNR
  - Pulsar wind nubula/TeV halo
  - Binnary (microquasar)
  - Massive Cluster
- Pevatron
  - Massive Star Clusters
  - Supernova Remant
  - Pulsa Wind Nebulae
  - New type sources

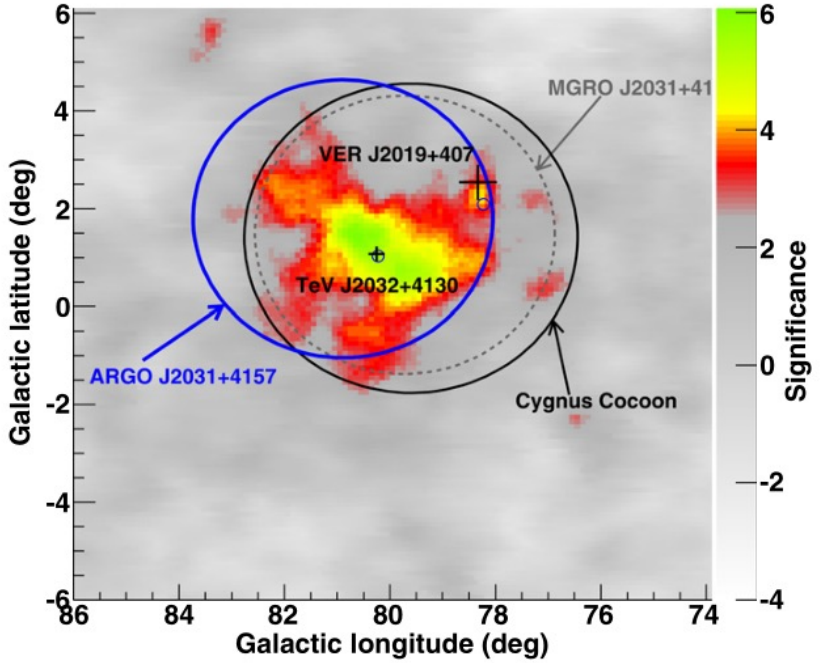
Super Pevatron: cygnus region

Cygnus X region (~1.4 kpc) is rich with potential particle accelerators.

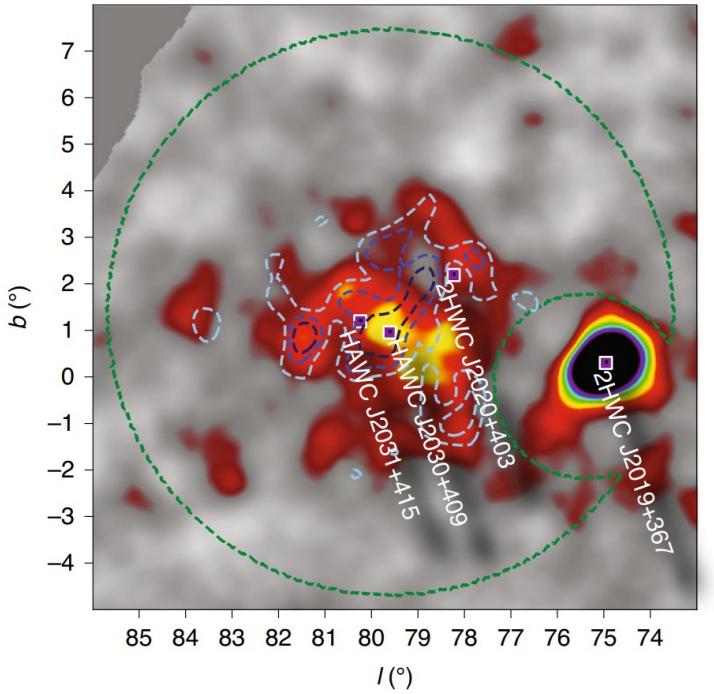
Extended (σ~ 2°) gamma-ray emission revealed in GeV-TeV



Fermi-LAT coll. 2011



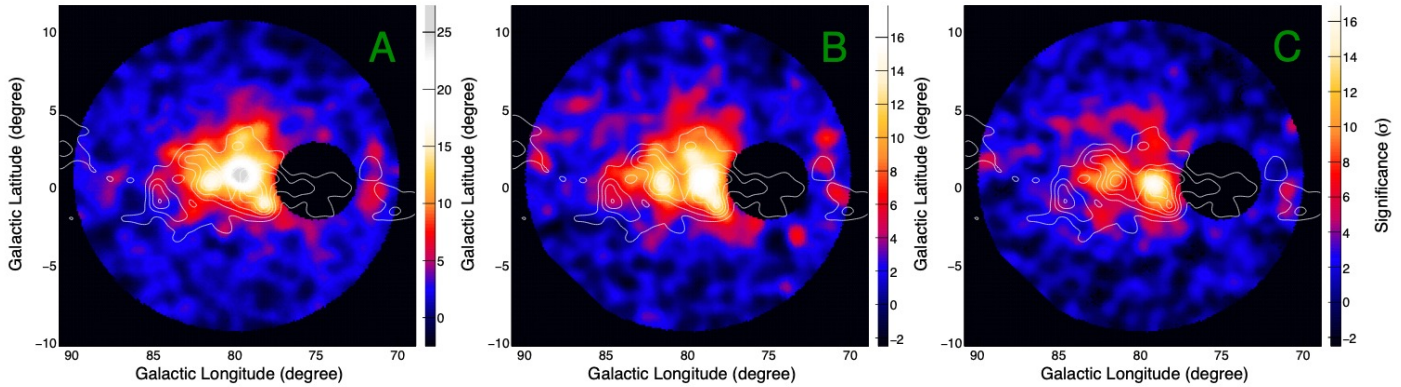
ARGO-YBJ coll. 2014

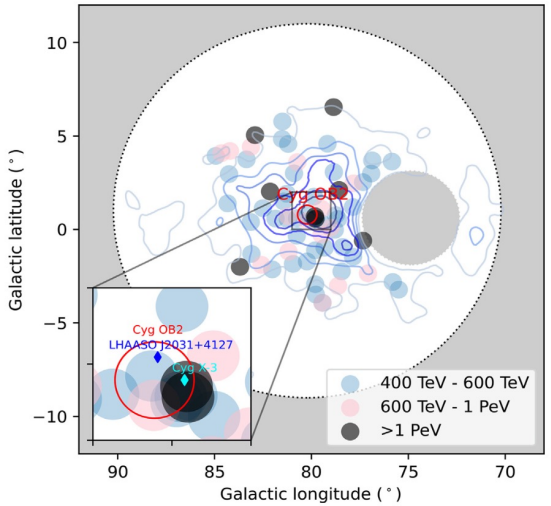


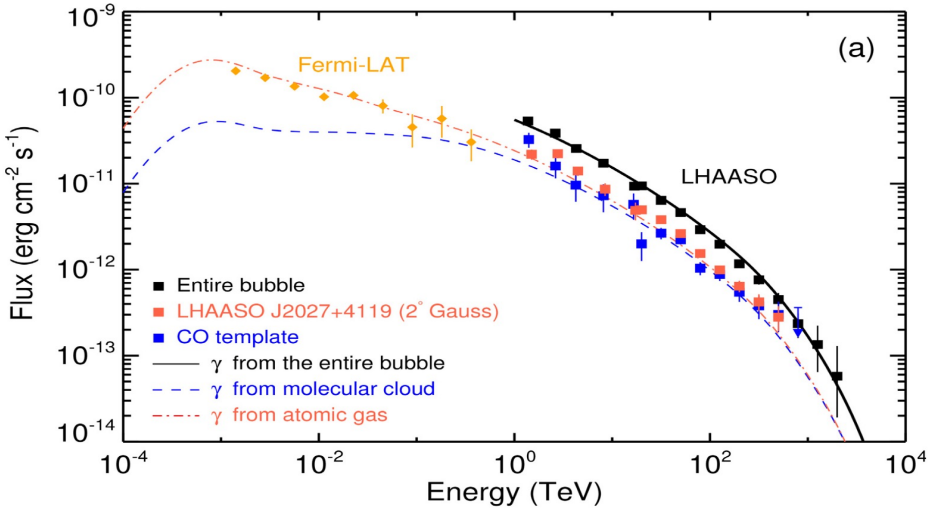
HAWC coll. 2021

LHAASO identify A super PeVatron

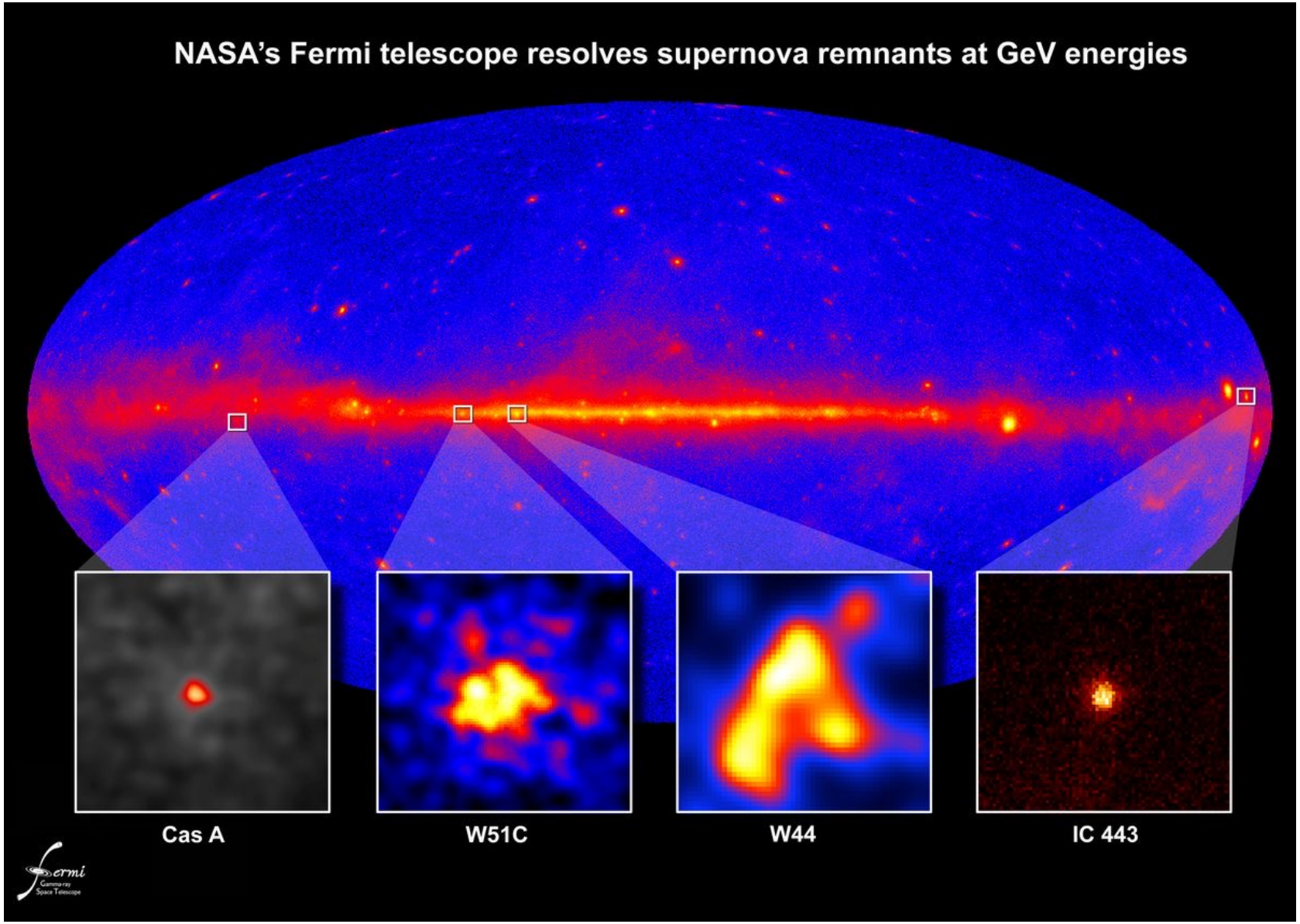
- Large UHE γ -ray bubble with a radius of 6° （~150pc）
  - Larger than the Cygnus Cocoon(2°)
  - SED is connected with Fermi-LAT for core region
- Clear association with gas distribution indicating a hadronic origin of photons;
- 8 photons >1 PeV
- 10 PeV cosmic ray super-PeVatron
- **Question: Which source accelerate particles to such high energy?**







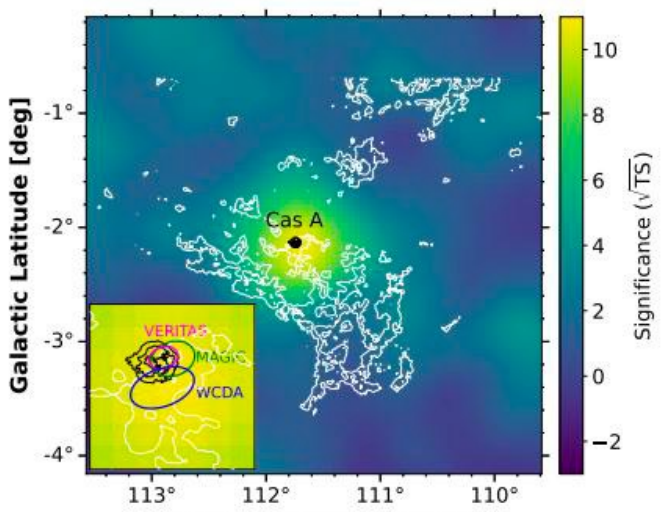
LHAASO coll. Science Bulletin 69:449-457(2024)

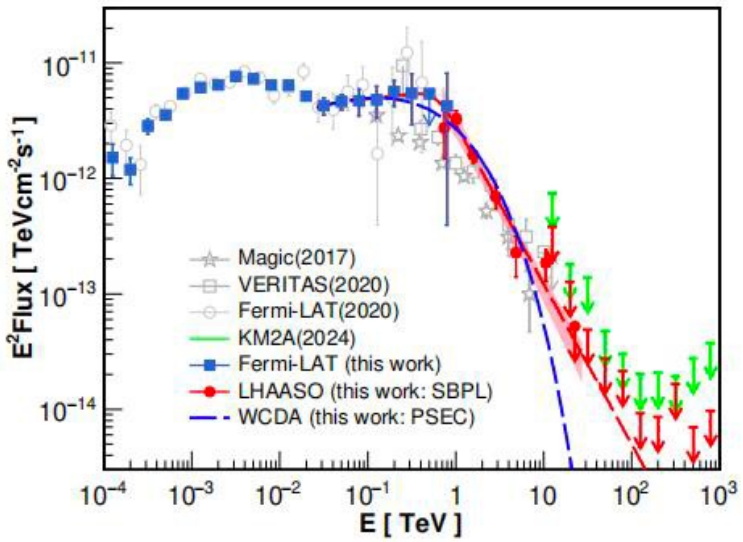


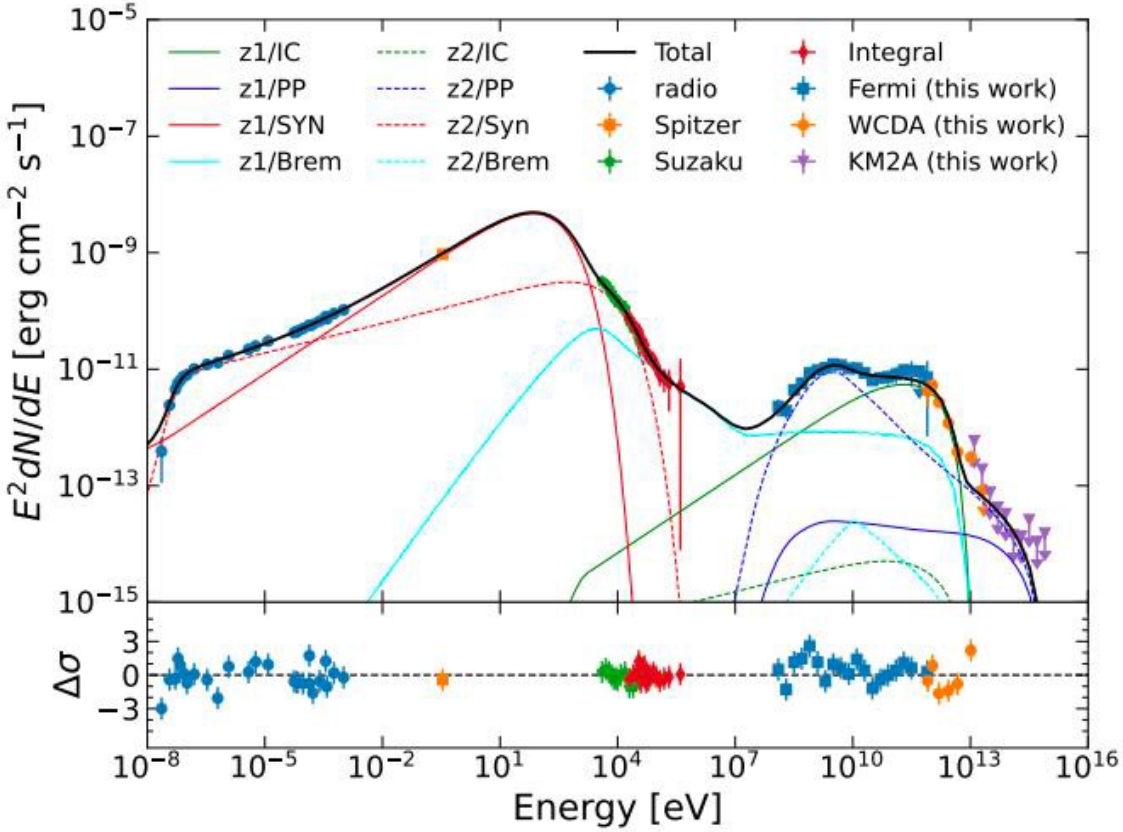
SNR

- Cassiopeia A, which is only 330 years old, appears as a point source
- W51C, W44 and IC 443 are middle-aged remnants between 4,000 and 30,000 years old

Cas A: young SNR





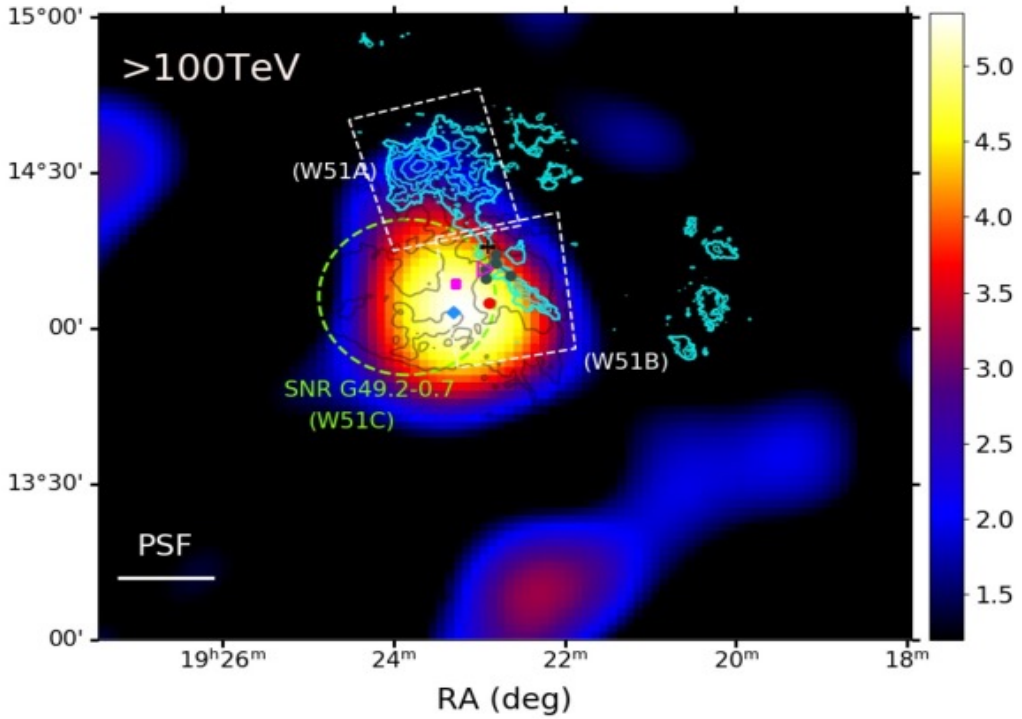


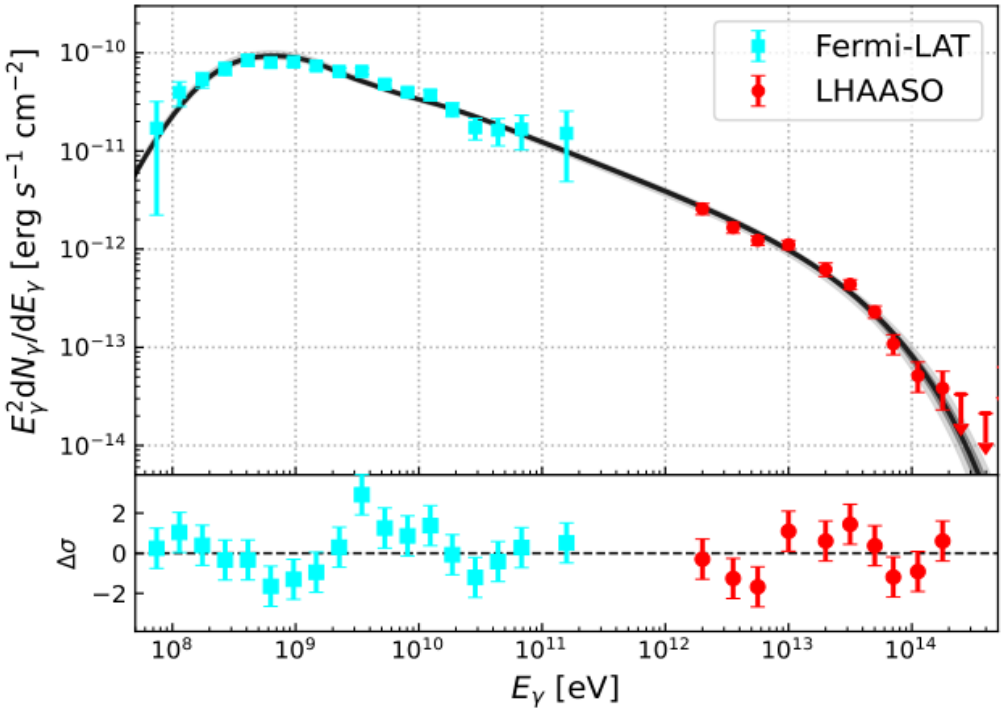
- T~350 yr, d~3.4 kpc
- Soft spectrum above TeV and no strong emission above 10 TeV → challenges young SNR as PeVatron
- Bump spectrum: hybrid or two-zone emission

LHAASO coll. APJL 982 (2025)

SNR W51C: evidence for particle acceleration close to PeV

W51C:~30 kyr, 5.5 kpc



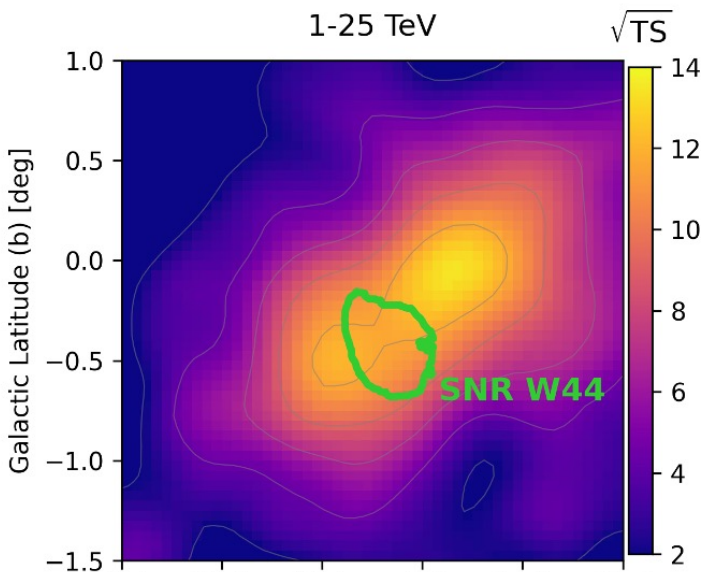


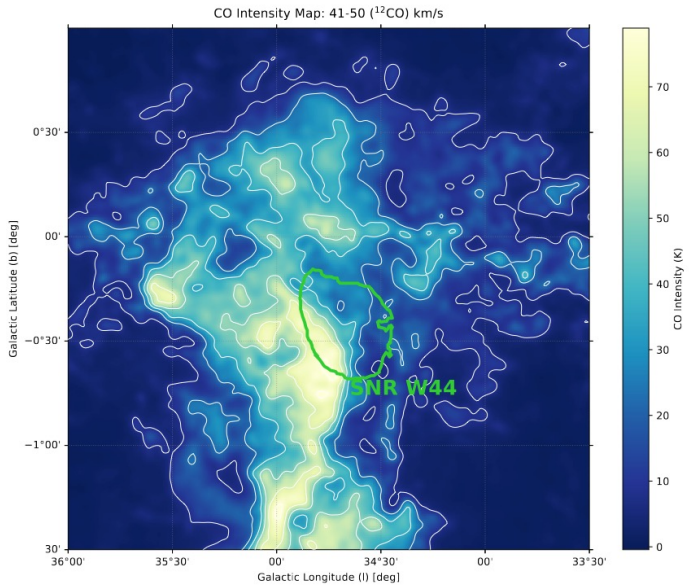
The SED of W51C extends to ~300 TeV. For the first time, UHE gamma-ray emission is discovered in an interacting SNR (with π0-decay bump).

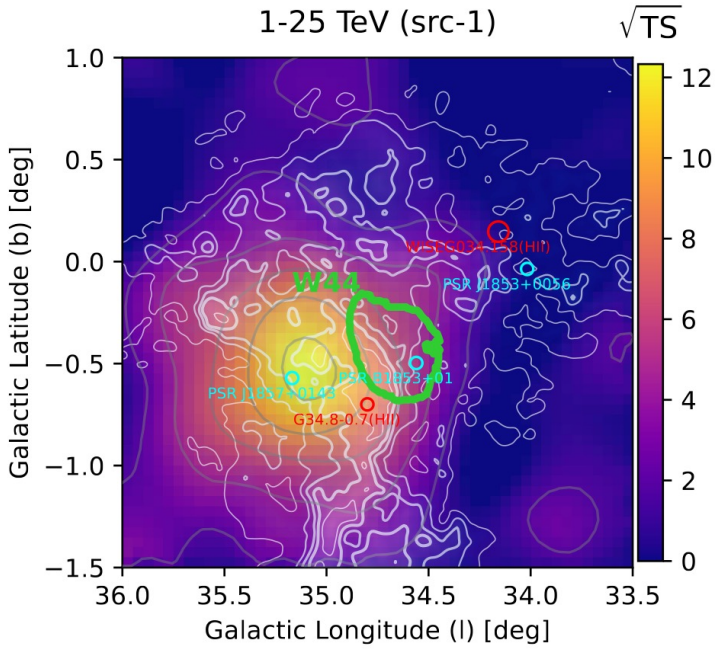
The hadronic emission model is favored and the maximum Proton energy should up to PeV with Ecut around 400 TeV for Power-law+Ecut spectral model.

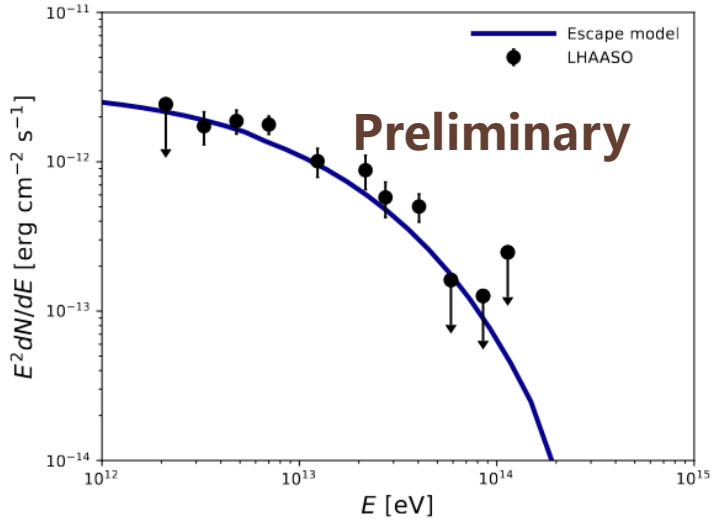
LHAASO coll. Science Bulletin, 69:2833-2841 (2024)

W44: a good candidate to see CR acceleration and escape



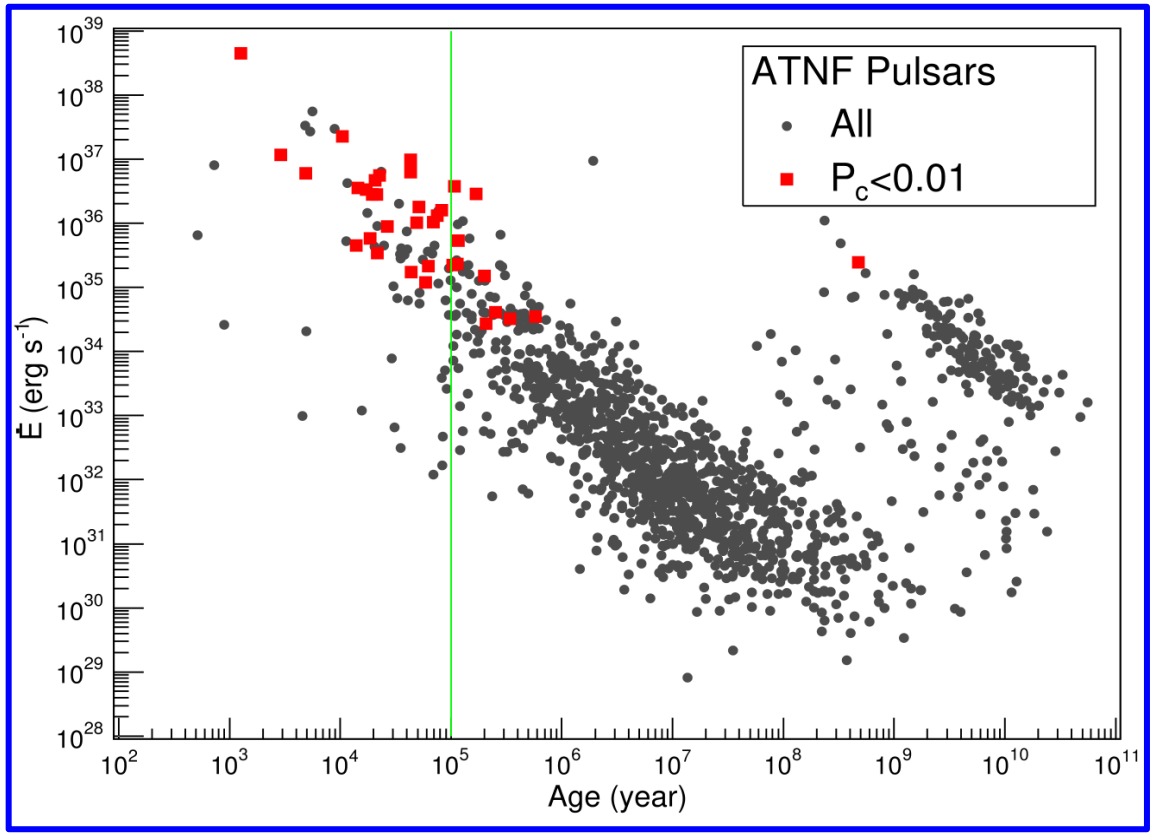






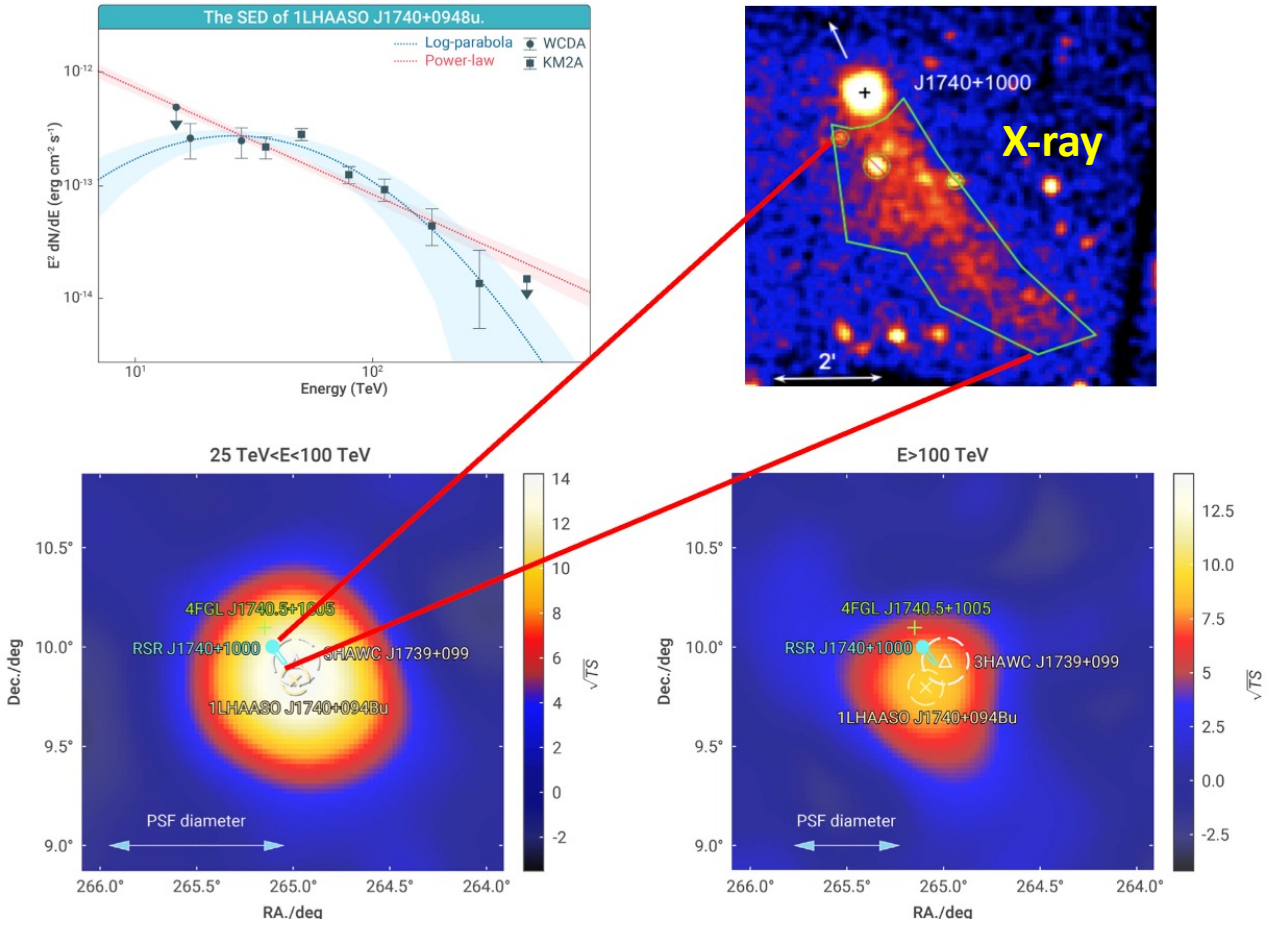
- VHE extended gamma ray emission observed from W44 nearby region with high significance >10
- LHAASO gamma ray emission is associated with giant molecular clouds illuminated by CRs escaped from SNR W44 at an earlier time.

PWN and Pulsar halos



- The PWNe of energetic pulsars are effective VHE gamma-ray emitters.
- Most of the energetic pulsars >10^{36} erg s^{-1} within the FOV of LHAASO are associated with 1LHAASO sources.

UHE emission from bow shock pulsar tail /1LHAASO J1740+0948u

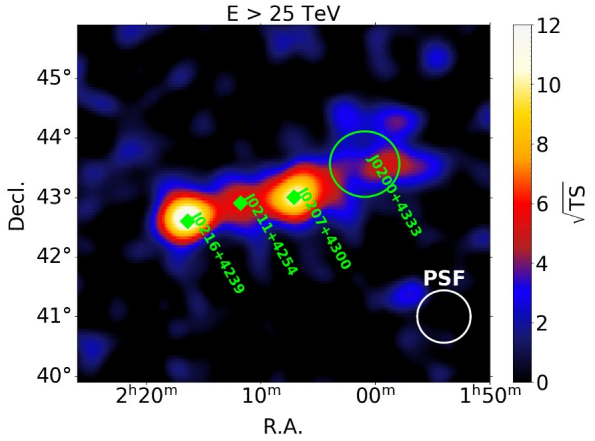


- First detected emission over 300 TeV near the PSR J1740+1000;
- The small morphology disfavors TeV halo scenario.
- The source has 0.2 offset from the pulsar and is located in the direction of its tail.
- Emission may originate from reaccelerated electrons advected away from the bow shock tail.
- Provide a new perspective for studying particle acceleration in pulsar tails?

PSR J1740+1000: 114 kyr, ~1.4 kpc, 2.32 × 10^{35} erg s^{-1}

LHAASO coll. : The Innovation (2025)

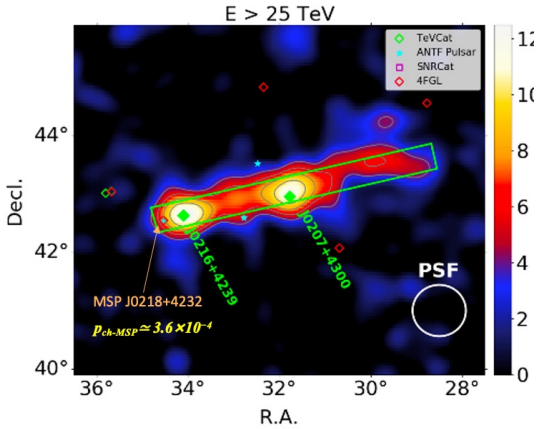
The Peanut: 1384 days observation @ KM2A

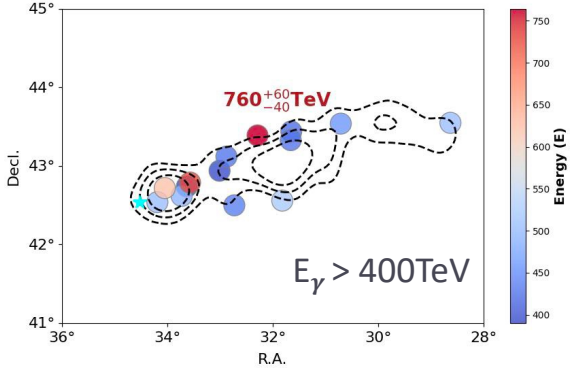


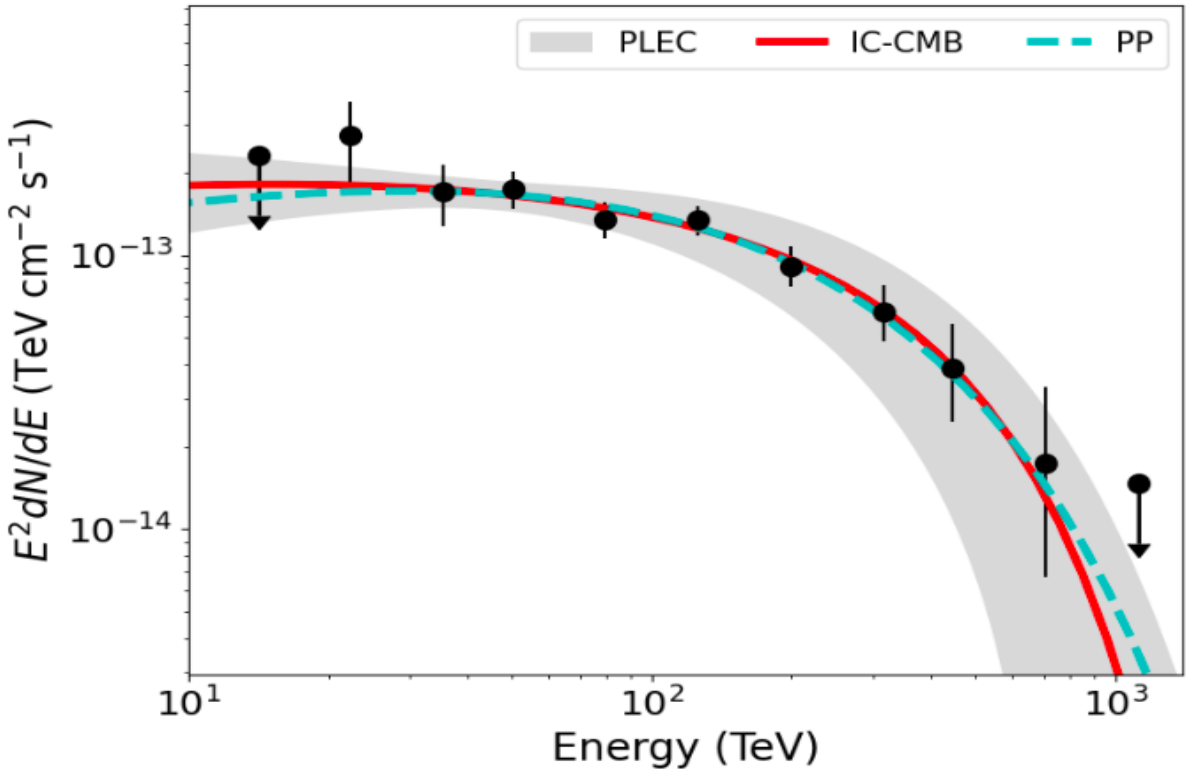
$$\frac{dN}{dE} = J_0(\mathrm{E}/E_0)^{-\Gamma}$$

Γ: 2.68 ± 0.15
2.57 ± 0.17
2.66 ± 0.16
2.60 ± 0.14

$p_{ch} \simeq 8 \times 10^{-7}$





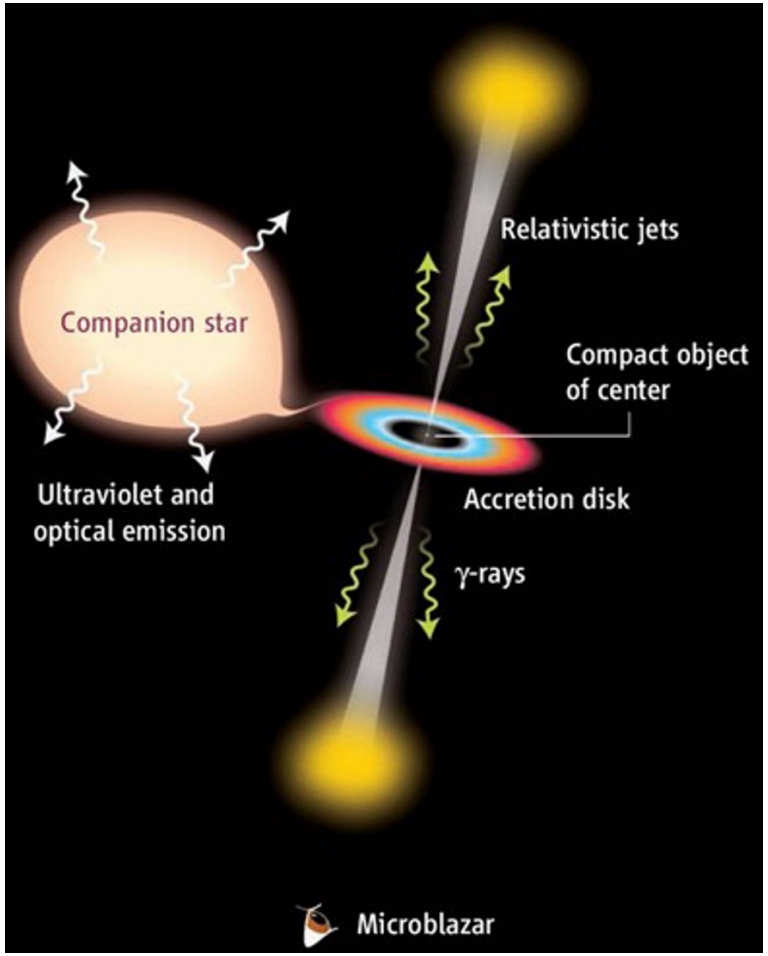


- $\simeq 5^\circ$ in length, $\simeq 0.5^\circ$ in width
- Leptonic scenario with $E_{e,max} \sim$ 2PeV and Hadronic scenario with $E_{p,max} \sim$ 7PeV
- MSP J0218+4232 easily offer the power

Microquasar

Attractive features

- Black hole
- Accretion disk
- Relativistic jet



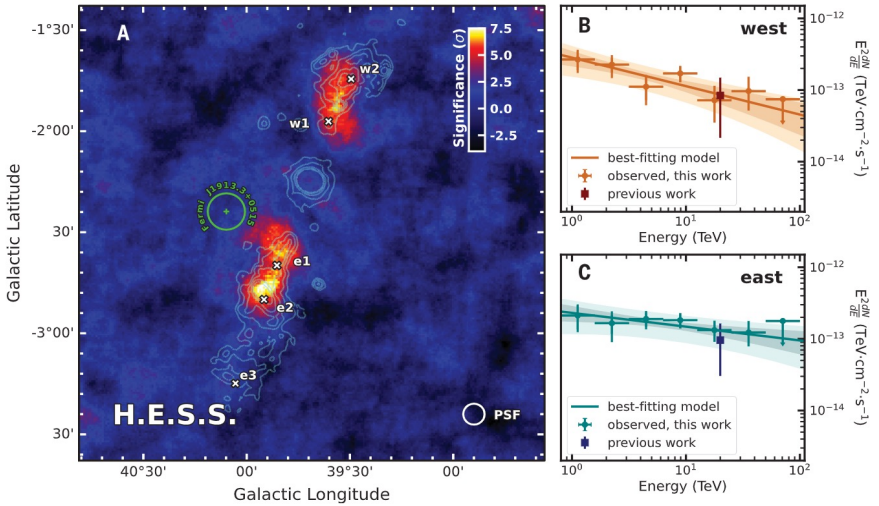
12 Galactic BH-jet systems within LHAASO FOV

5 systems with positive signals

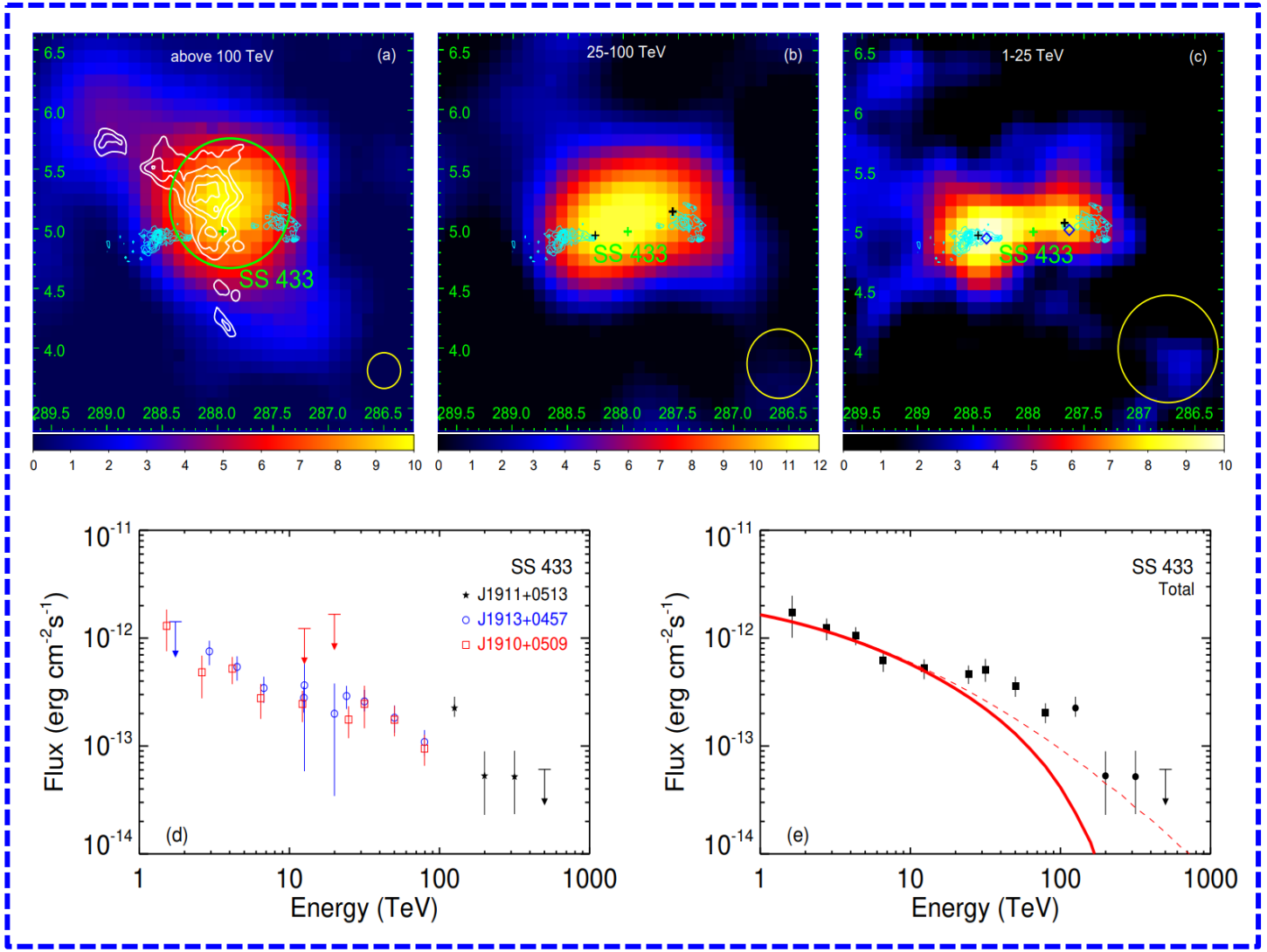
Microquasar	Distance (kpc)	LHAASO Source	Significance (σ)	Photon Index	Energy Range (TeV)	Extension[a]	Flux[b] (Crab Unit)
SS 433 E.		J1913+0457	9.7[c]	2.78 ± 0.19	25 – 100	0.70°	0.10
SS 433 W.	4.6 ± 1.3 [32]	J1910+0509	8.6[c]	2.92 ± 0.21	25 – 100		0.082
SS 433 central		J1911+0513	9.8	4.03 ± 0.29	100 – 400	0.32°	0.32
V4641 Sgr	6.2 ± 0.7 [33]	J1819-2541	8.1	2.67 ± 0.27	40 – 1000	0.36°	3.9
GRS 1915+105	9.4 ± 0.6 [34]	J1914+1049	6.1	3.07 ± 0.15	25 – 630	0.33°	0.17
MAXI J1820+070	2.96 ± 0.33 [35]	J1821+0726	5.9	3.19 ± 0.29	25 – 630	$< 0.28^{\circ}$	0.13
Cygnus X-1	2.2 ± 0.2 [36]	J1957+3517	4.0	4.07 ± 0.35	25 – 100	$< 0.22^{\circ}$	< 0.01
XTE J1859+226	4.2 ± 0.5 [37]	–	1.9	–	–	–	< 0.03
GS 2000+251	2.7 ± 0.7 [38]	–	1.7	–	–	–	< 0.04
CI Cam	$4.1^{+0.3}_{-0.2}$ [39]	–	1.4	–	–	–	< 0.03
GRO J0422+32	2.49 ± 0.3 [40]	–	0.8	–	–	–	< 0.01
V404 Cygni	2.39 ± 0.14 [41]	–	0.5	–	–	–	< 0.02
XTE J1118+480	1.7 ± 0.1 [42]	–	0	–	–	–	< 0.01
V616 Mon	1.06 ± 0.1 [43]	–	0	–	–	–	< 0.01

SS 433

- ~4.6 kpc
- UHE emission is partly overlapped with HI cloud at the same distance, suggesting a hadronic origin.
- Morphology and SED is consistent with H.E.S.S. at <100 TeV



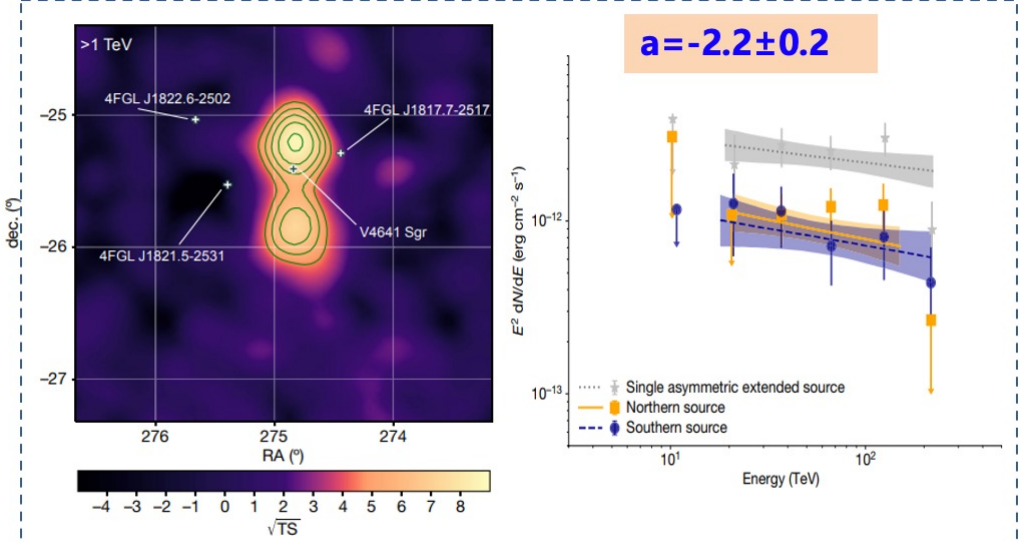
H.E.S.S. coll. 2024



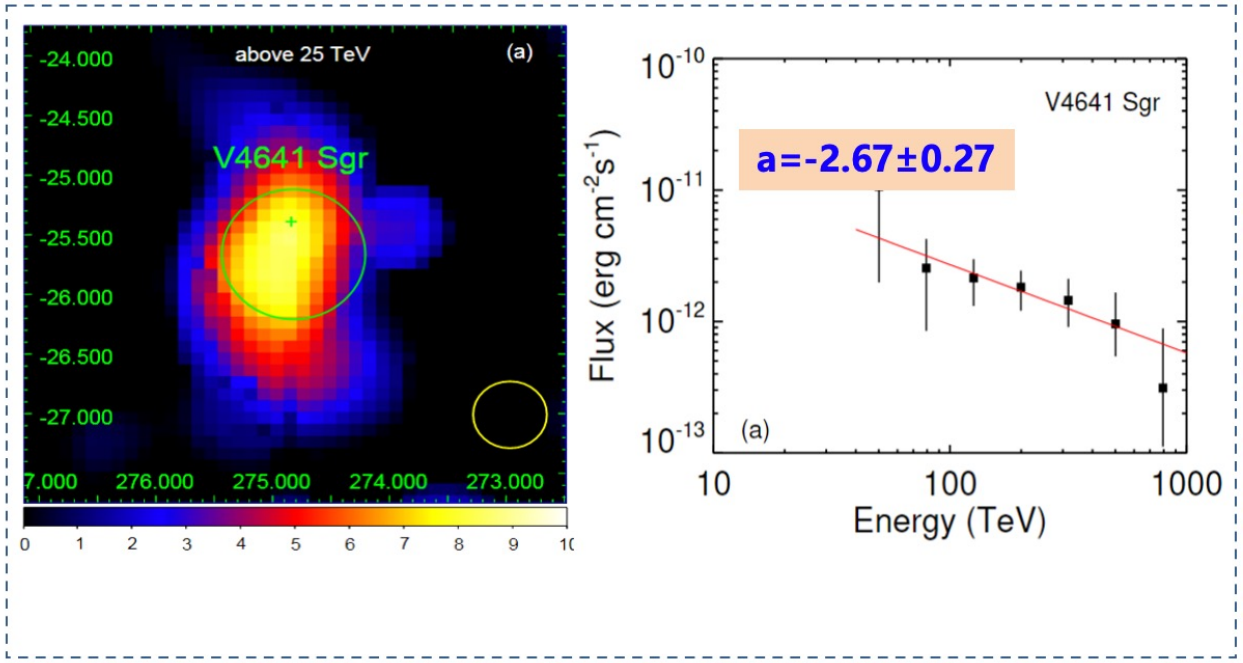
LHAASO coll. arXiv:2410.08988

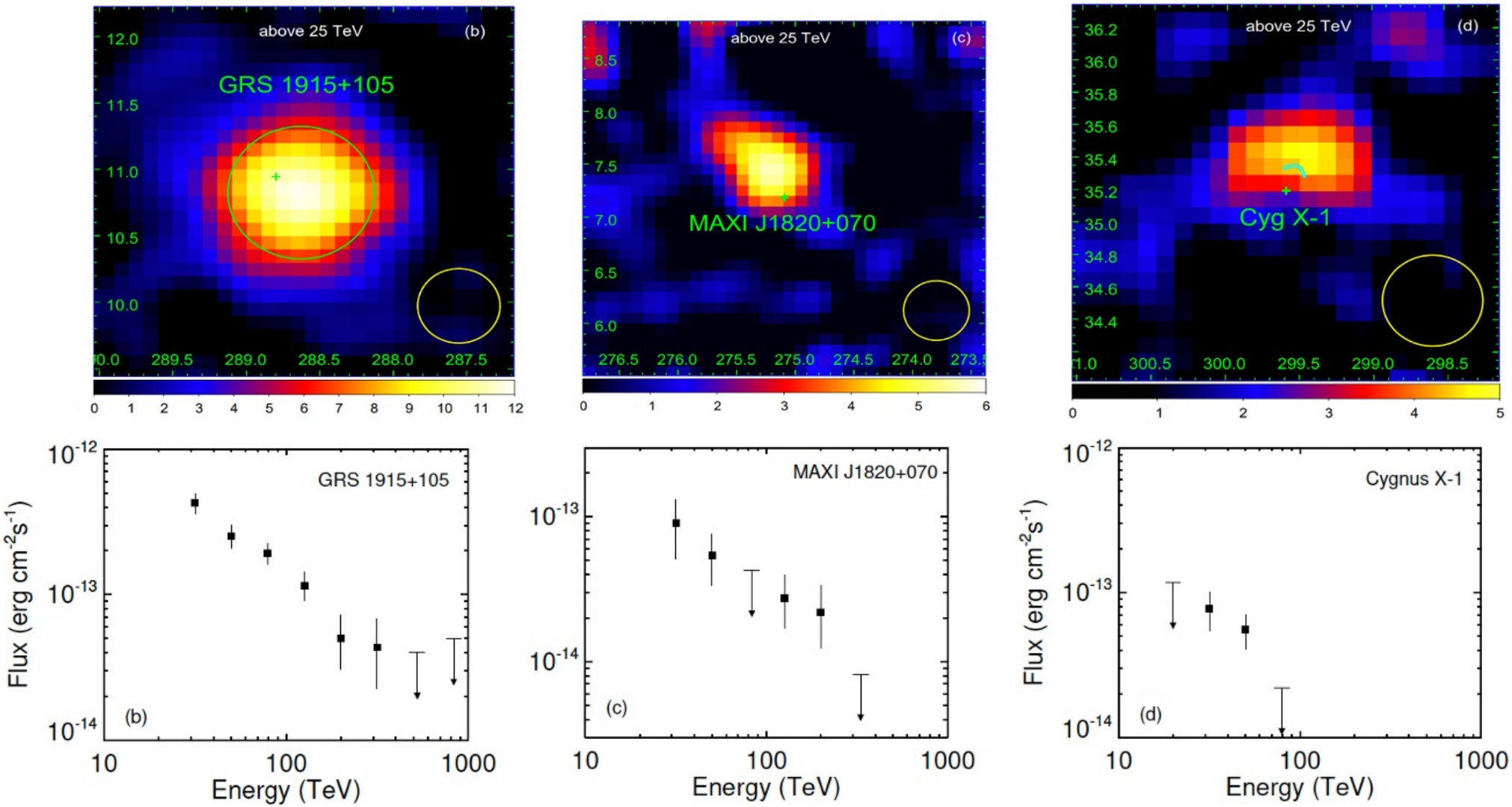
V4651 Sgr

- ~6.2 kpc，large zenith angle (zenith>55°) in LHAASO, >8σ detection
- Hard spectrum up to 1 PeV, a super-PeVatron?
- Jet-like morphology?



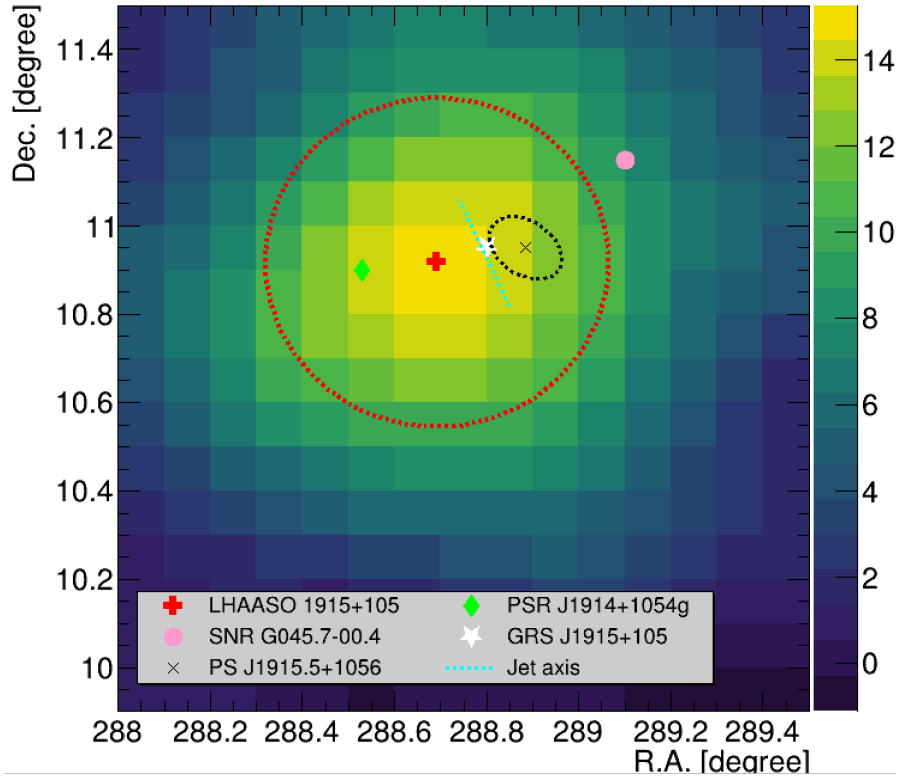
HAWC coll. 2024

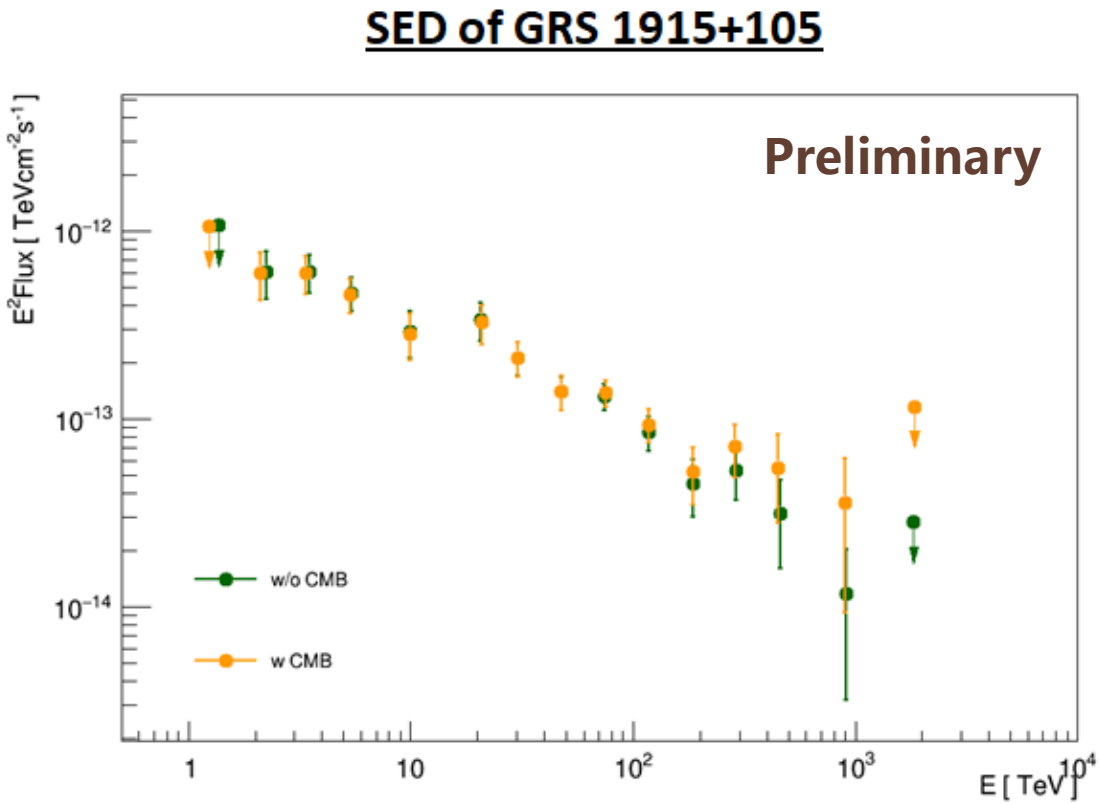




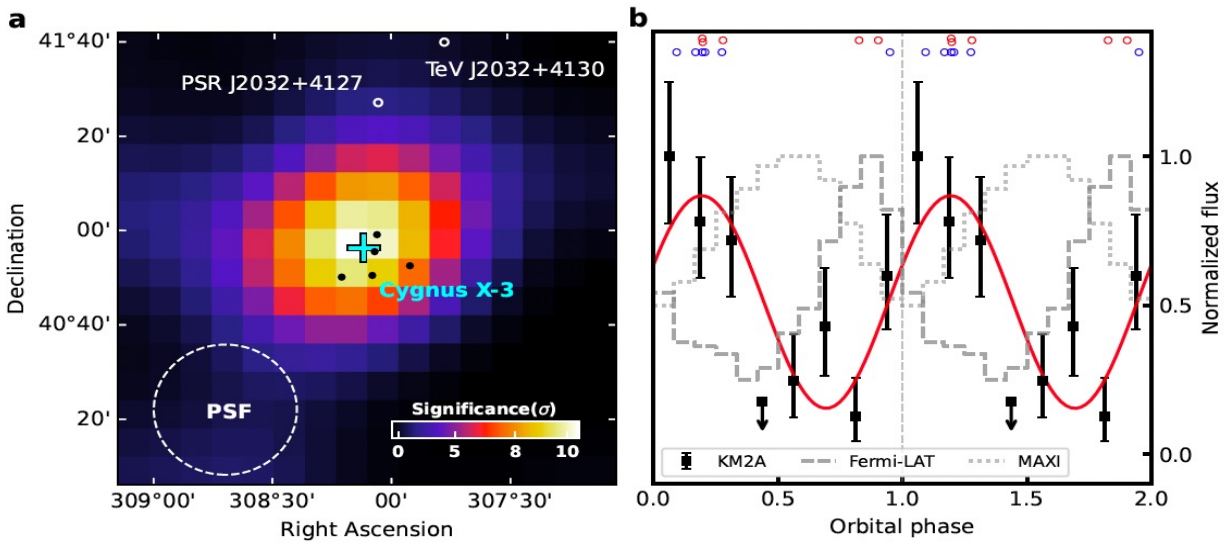
- UHE gamma-ray detection demonstrates that accreting BH-jet system are extremely efficient accelerators.
- Where and how the particle is accelerated? Can it be the main factory for Galactic cosmic rays around knee?

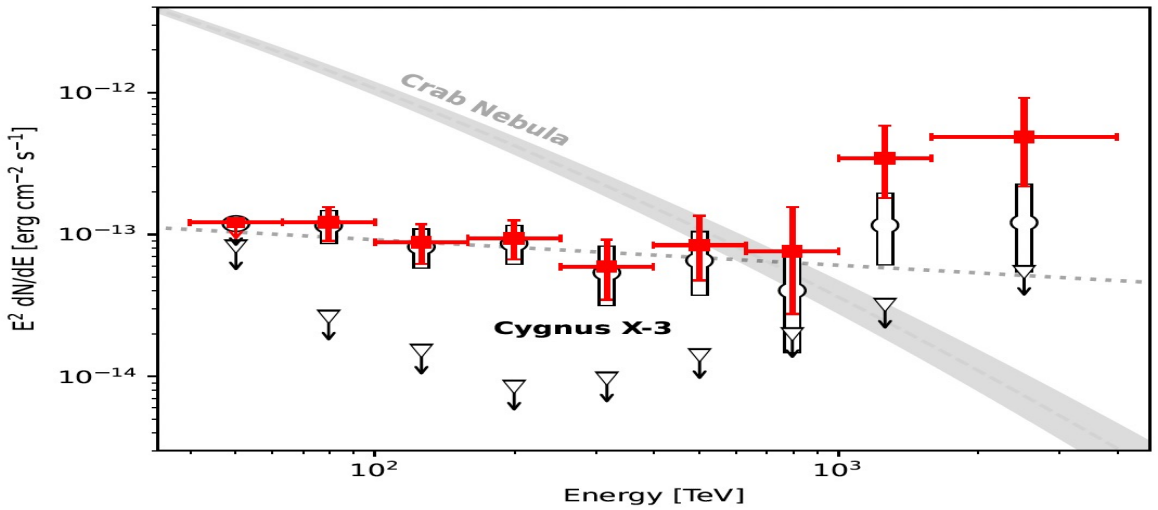
Wide Spectral Energy Distribution @ GRS 1915 + 105





Cygnus X-3: A Varied PeV gamma-ray source

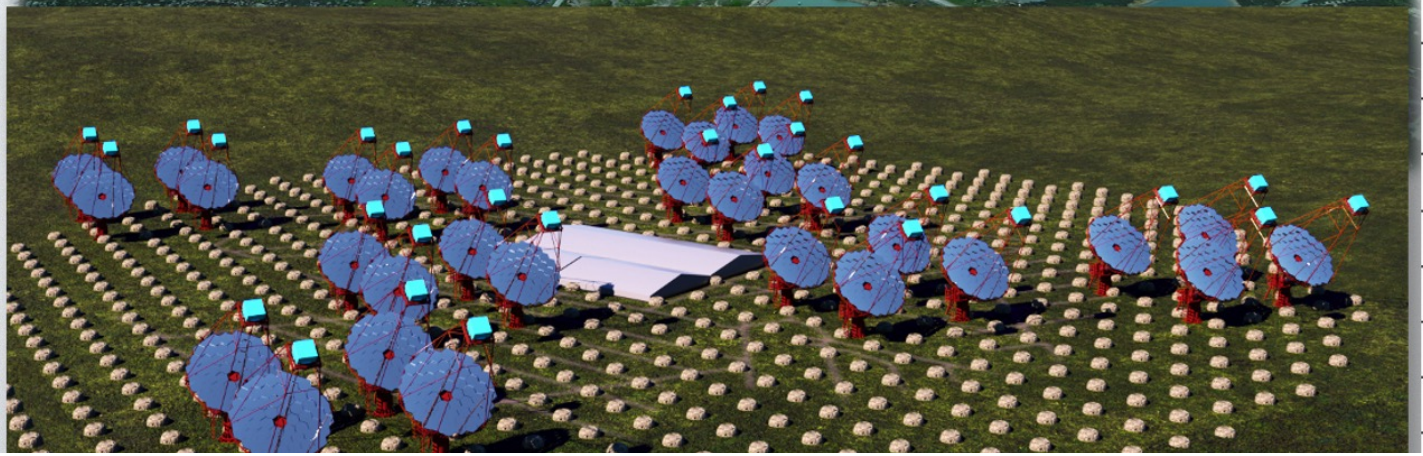




- 10σ detection with 5 PeV events with 10-arminute's during active state;
- Monthly timescale variability;
- A possible 4,8 hour modulation;
- Intrinsic SED, extending from 0.1 to 3.7 PeV, hard spectrum and a distinctive spectral pileup/bump above 1 PeV
- The observed energy spectrum and temporal and modulation can be naturally explained by γ-ray production through photomeson processes in the innermost region of the relativistic jet.

Other sources under active analysis

- **SNR**
  - γ-cygni
  - IC 443
  - Kes 78
  - …
- **PWN/Pulsar halo**
  - Geminga
  - G25.0
  - …
- **Extragalatic**
  - 1ES 1959+650
  - IC 310
  - BL Lacetae
  - …
- **KM2A only**
  - 1LHAASO J1740+0948u
  - J1740+1000
  - 1LHAASO J1959+1129u
  - …
- **Dark sources**
  - 1LHAASO J0343+5254u
  - 1LHAASO J2108+5153u
  - 1LHAASO J2200+5643u
  - …
- **Unidentified**
  - 1LHAASO J1809−1918u
  - 1LHAASO J1908+0615u
  - 1LHAASO J2018+3643u
  - …

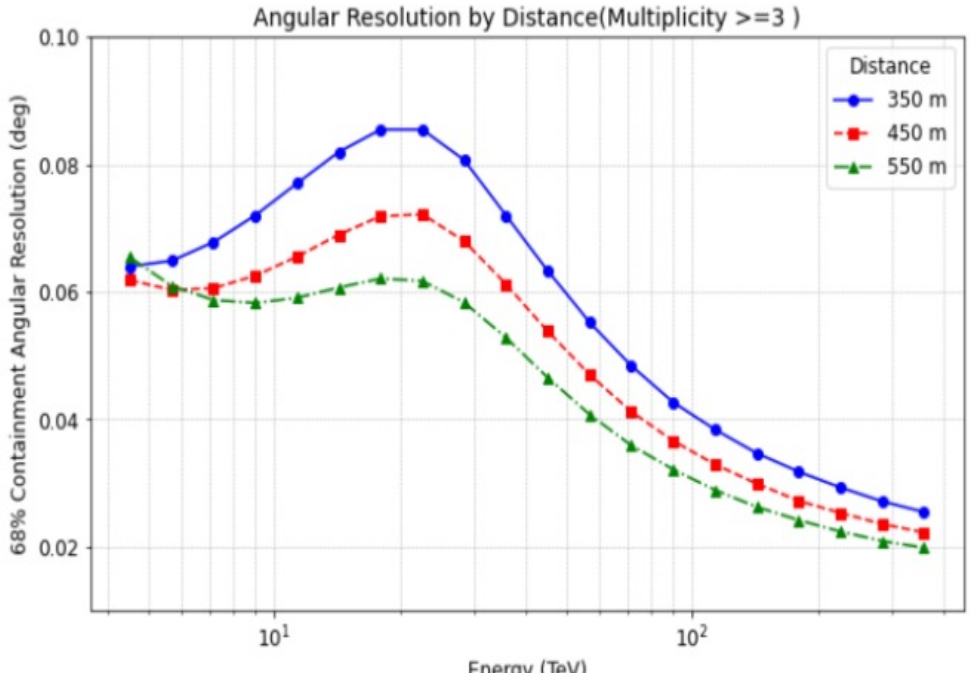


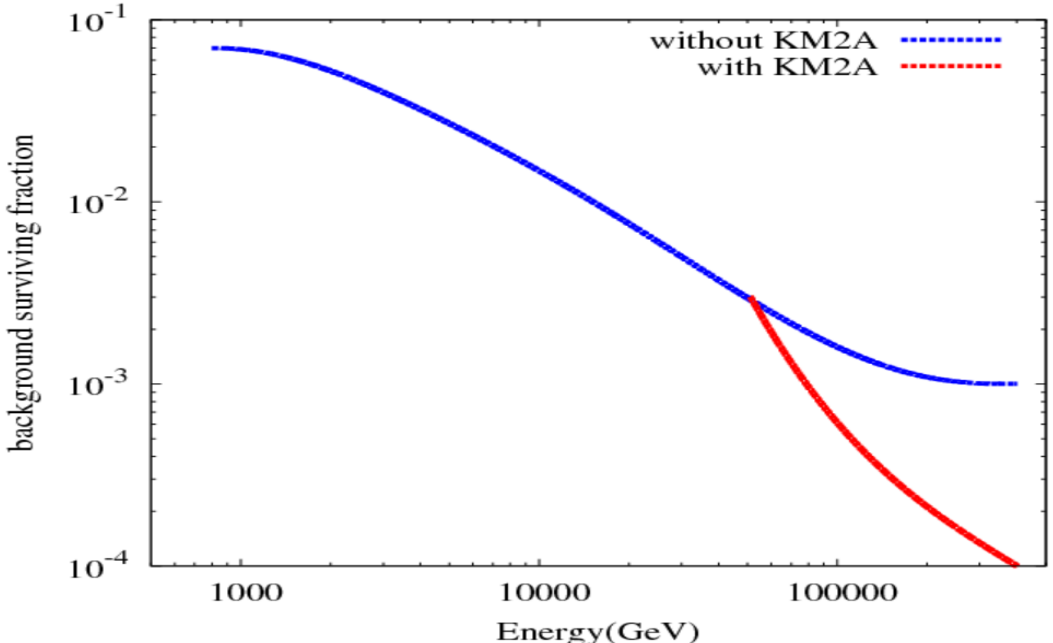
- 6m Davis-Cotten type telescope
- Synergy with LHAASO

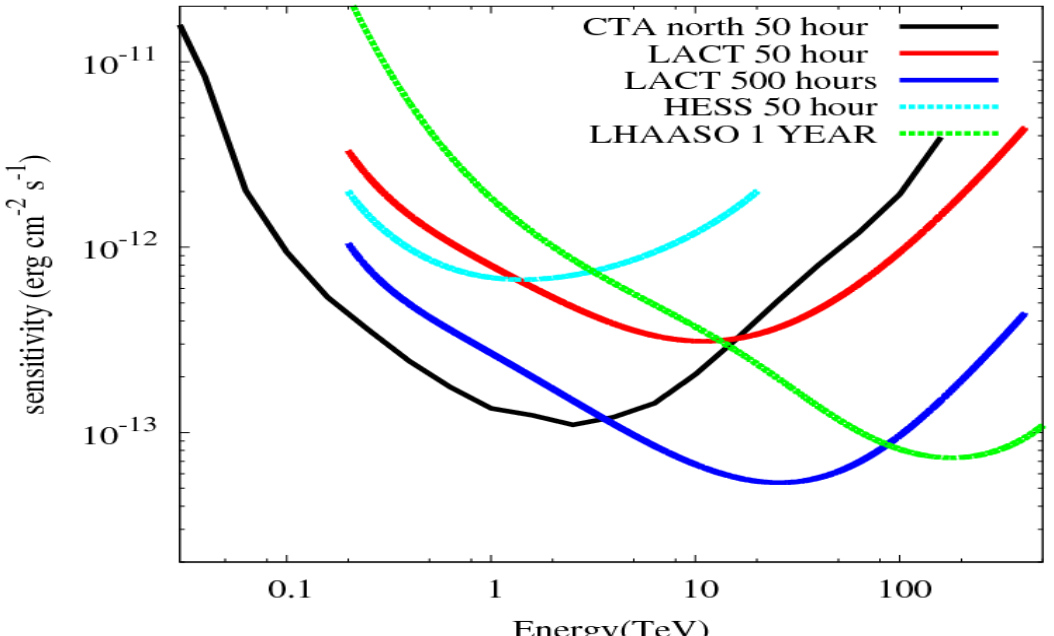
Required energy range	1 TeV - 1PeV
Total number of telescopes of LACT	32
Optical design	Davies-Cotton
Reflector diameter	~ 6 m
Focal length	~ 8 m
Field of view	~ 8°
Number of pixels in each camera	1616
Pixel size	~ 0.19°
Photodetector type	SiPM

LHAASO update plan 1: Large Array Of Cherenkov Telescopes (LACT)

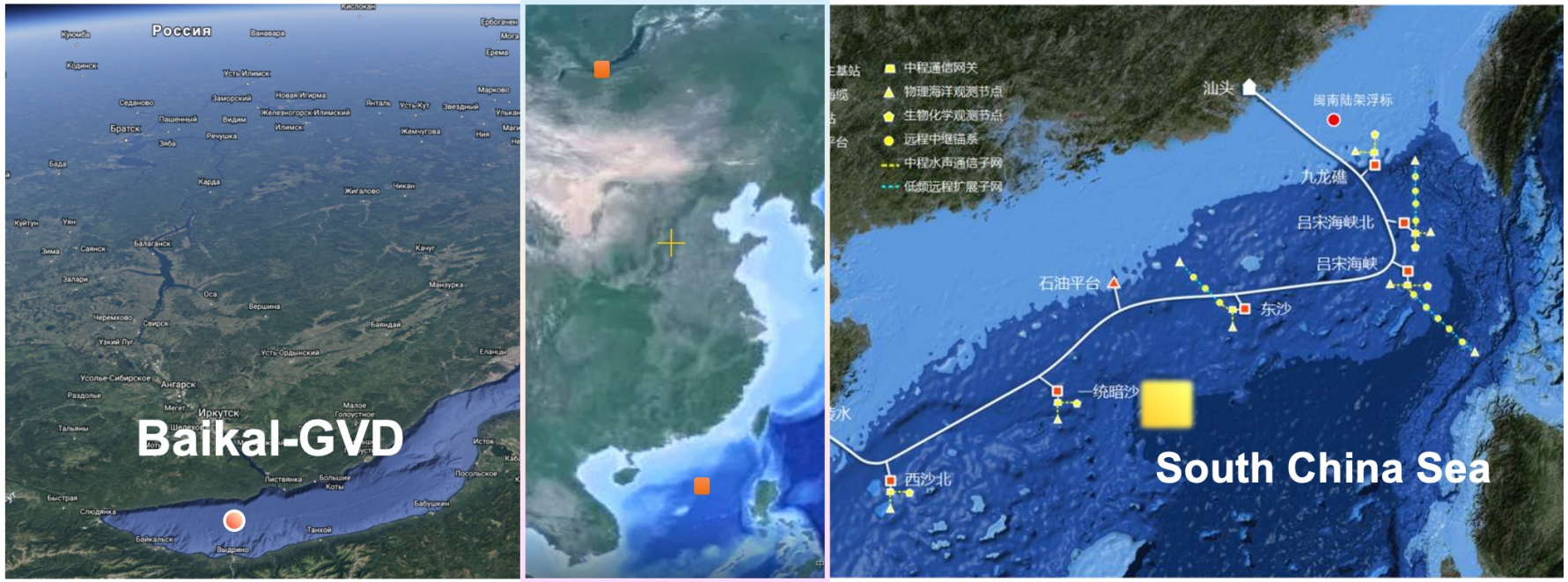
First light soon !







High-energy Underwater Neutrino Telescope (HUNT)



R & D status

- **30 km3 + 2300 string + 700m length of string → TeV – 100 PeV**
- **Angular resolution: 0.1 deg in track events, < 3deg in cascading events**

Summary

- LHAASO is operated very stable with full duty cycle since July 2021 and will continue to scan northern sky for the coming 20 years;
- LHAASO open-up a new UHE era with many new discoveries about Massive star, SNR, PWN and so on.
- There are still much more exciting results soon. Stay tuned for updates.
- Outlook
  - LACT
  - HUNT