LHAASO gamma-ray observations and implications on Cosmic ray science

Ruizhi Yang
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On behalf of LHAASO collaborations

Outline

1. Intro of LHAASO

2. LHAASO results on SNRs/star forming regions/microquasars

3.Summary and prospect

LHAASO collaborations

- **274 Scientists**

- **32 institutions**
- **from 5 countries**

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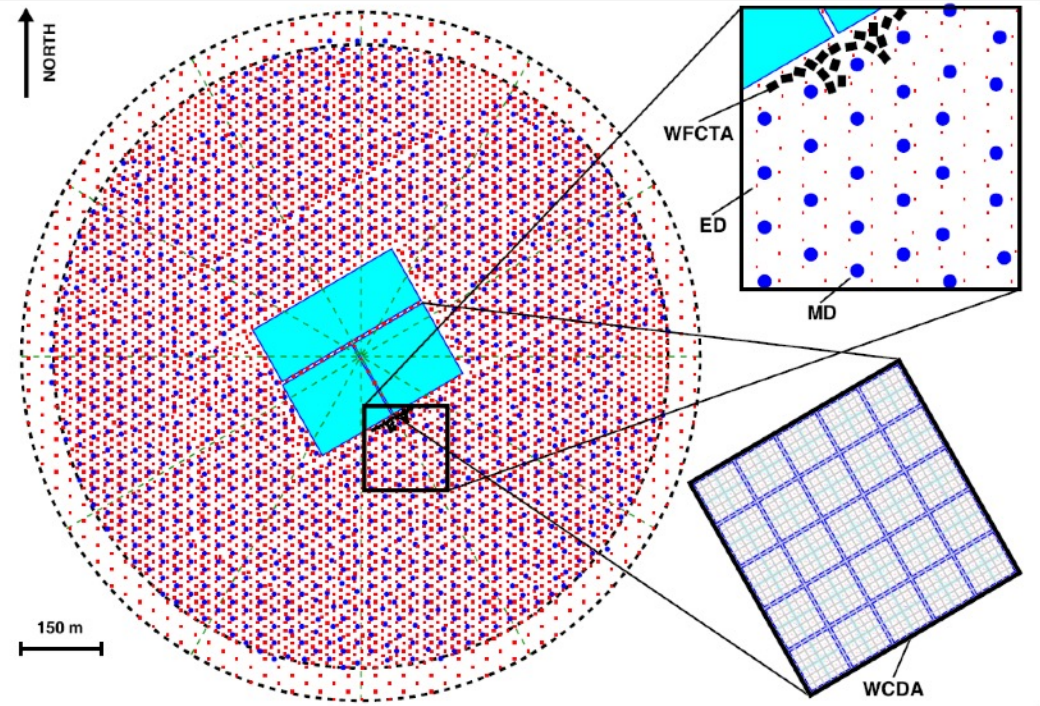
LHAASO site

- Haizi Mountain, Sichuan province, China
- Location：29°21’ 27.6” N, 100°08’19.6” E
- Altitude：4410 m a.s.l.
- 10 km from Yading Airport

LHAASO layout

All detectors are in DAQ since 2021-7-19



1.3 km²

- **5195 EDs**
  - $1\ m^2$ each
  - 15 m spacing
- **1188 MDs**
  - $36\ m^2$ each
  - 30 m spacing

KM2A

- **3120 WCDs**
  - $25\ m^2$ each

WCDA

- **18 WFCTs**

WFCTA

LHAASO FOV

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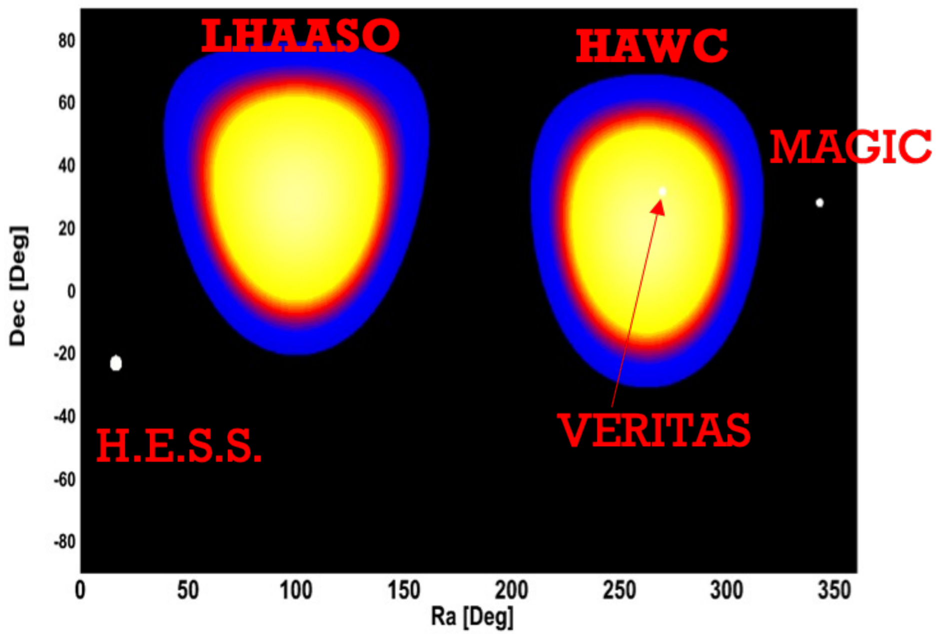
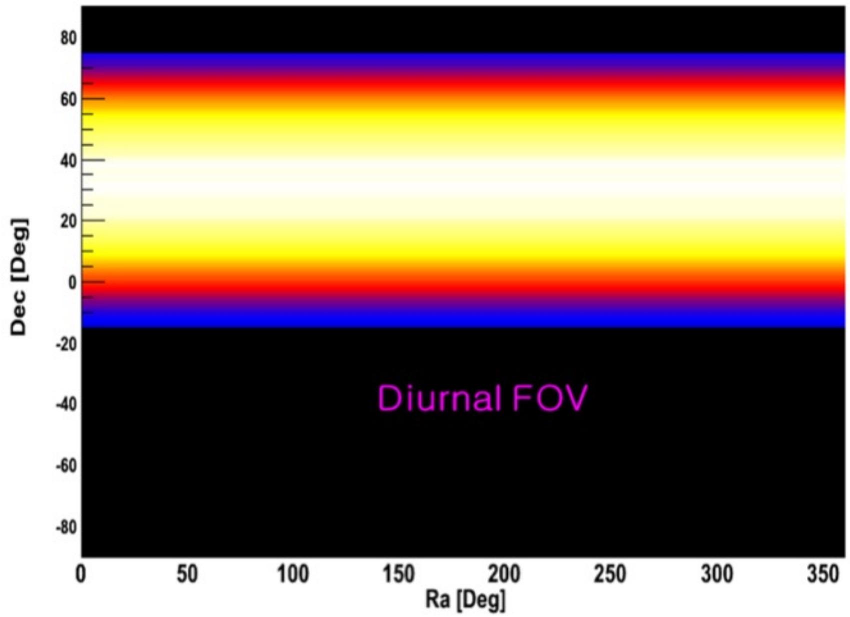
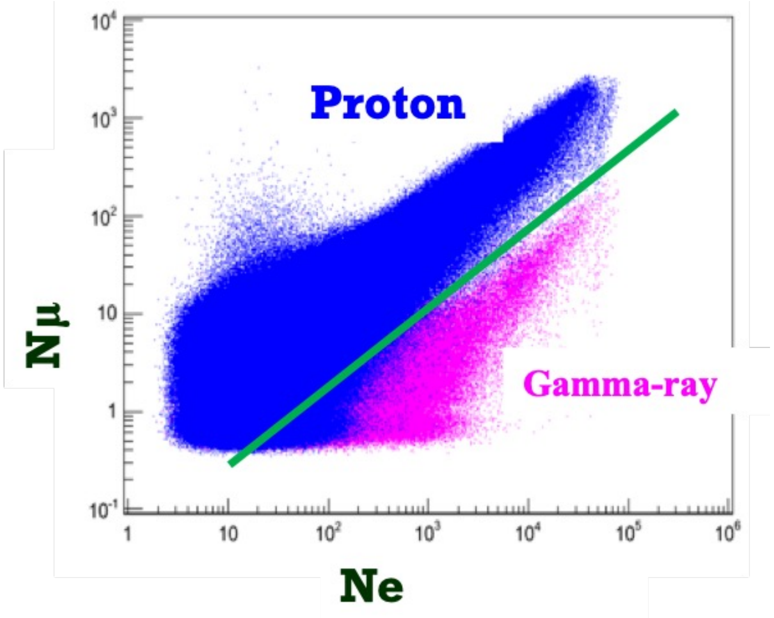
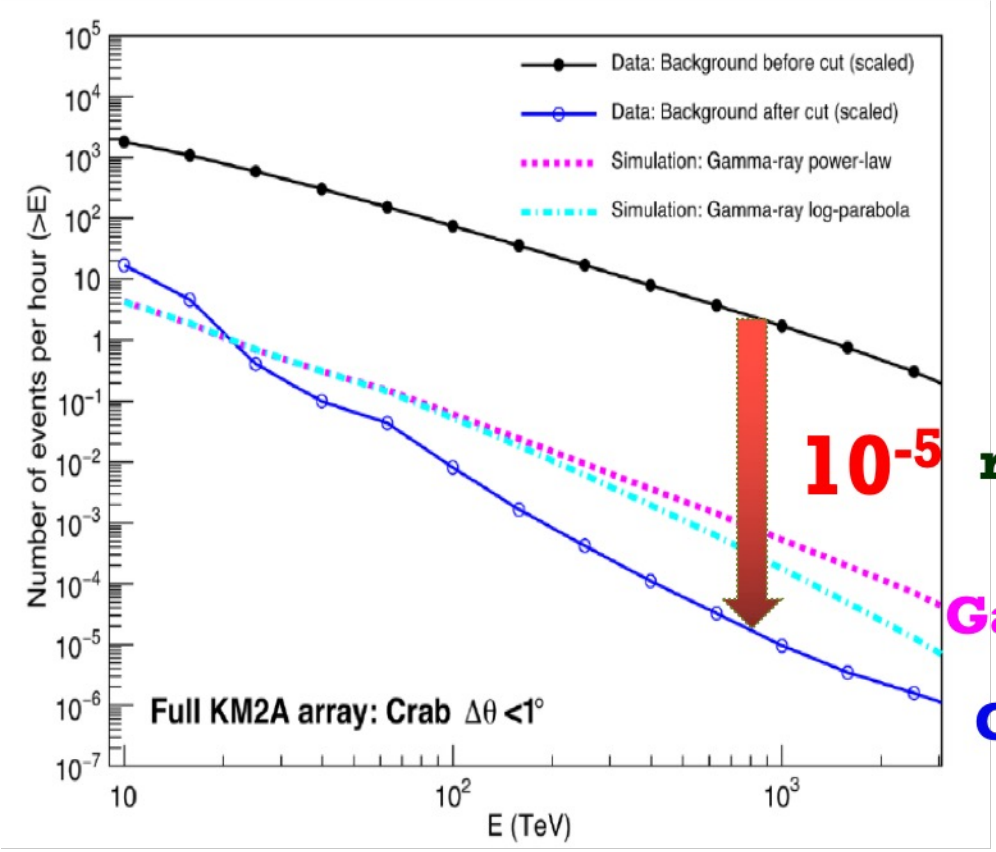
- **High duty cycle: ~100% running time**
- **Large FOV:**
  - **1/7 of the sky at any time**
  - **60% of the sky in a diurnal observation**





γ-ray/cosmic ray discrimination





Cosmic ray rate before cut

Gamma-ray rate

Cosmic ray rate after cut

LHAASO Sensitivities

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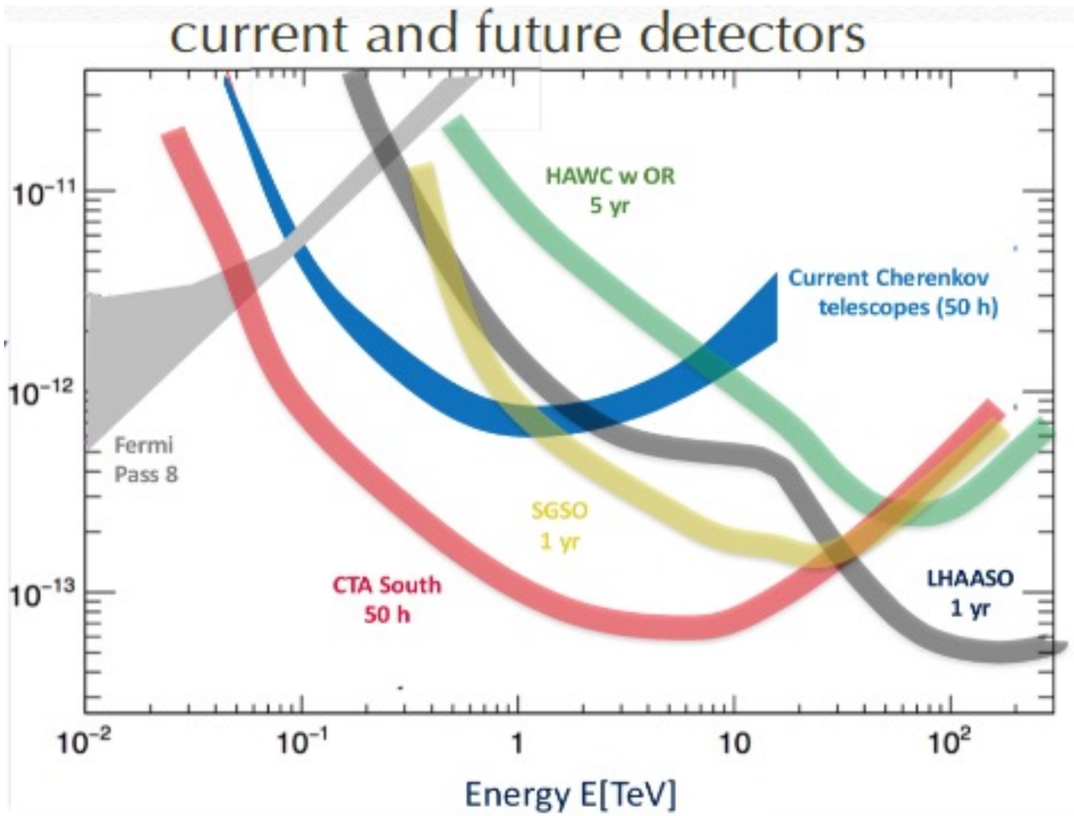
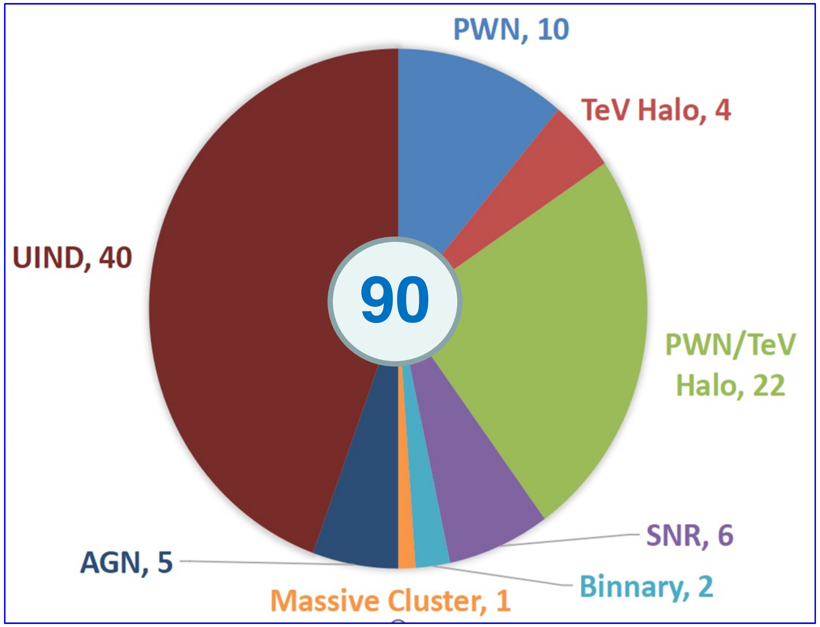


1st LHAASO Catalog (LHAASO Coll. 2024, ApJS) based on data up to 31.07.2022



Operation of LHAASO

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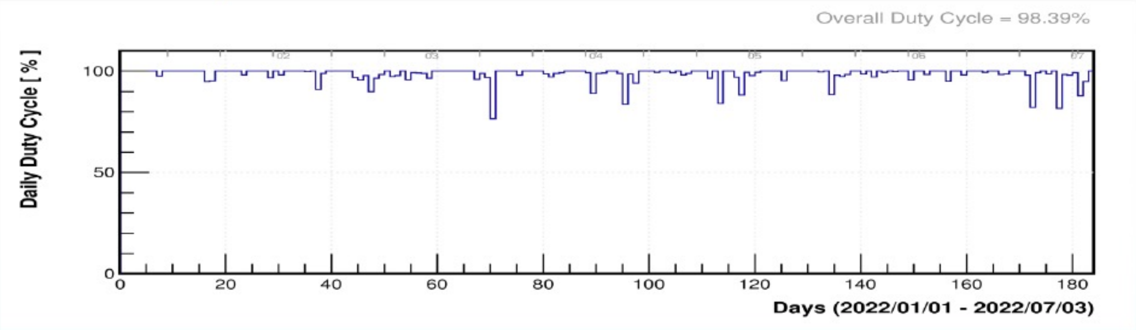
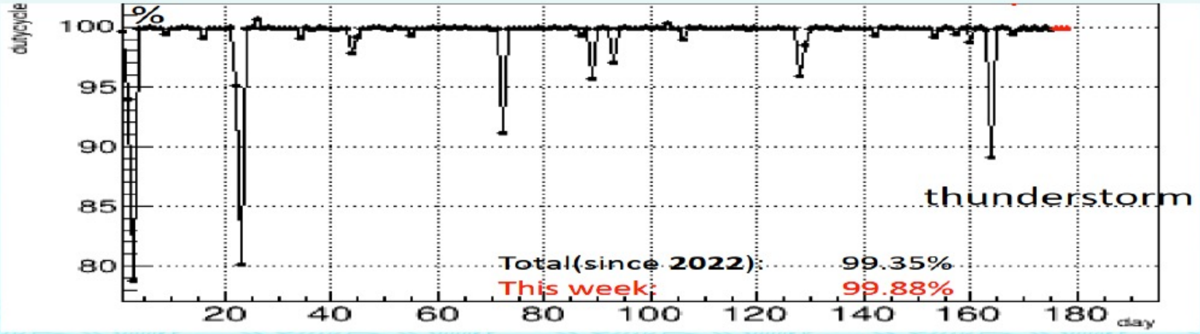
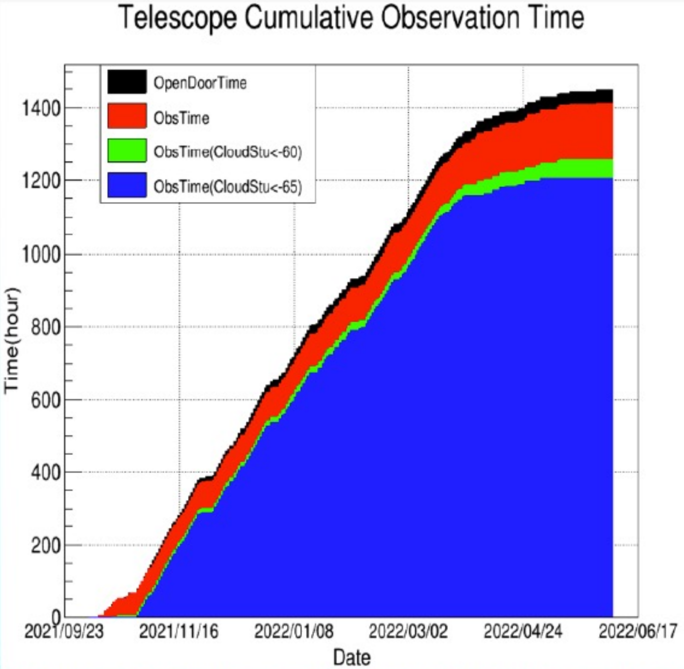
- KM2A is operated with >99.4% duty cycle and event rate 2×10^8 /day
- WCDA is operated with 98.4% and event rate 3×10^9 /day
- Data acquisition time of WFCTA >1400 hrs and number of matched events ~70 million







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LHAASO gamma-ray results

Galactic plane survey

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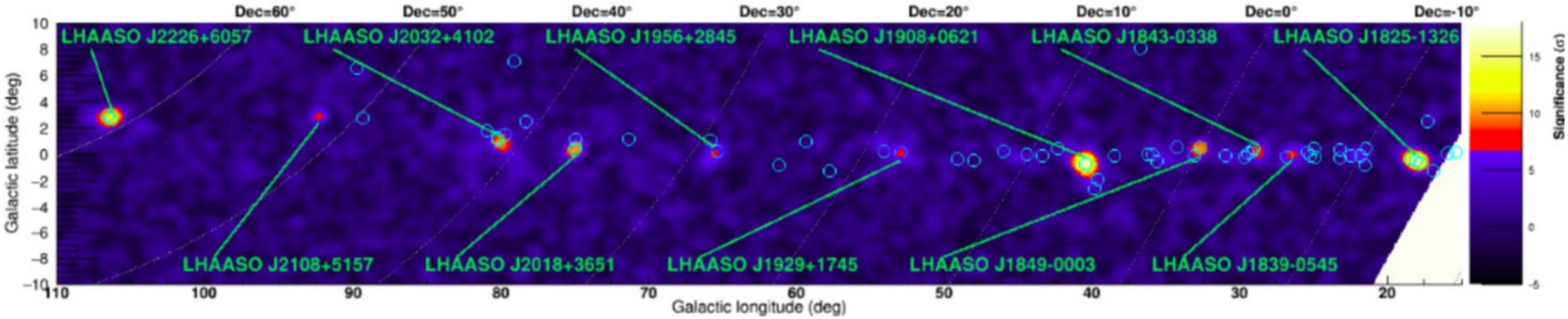
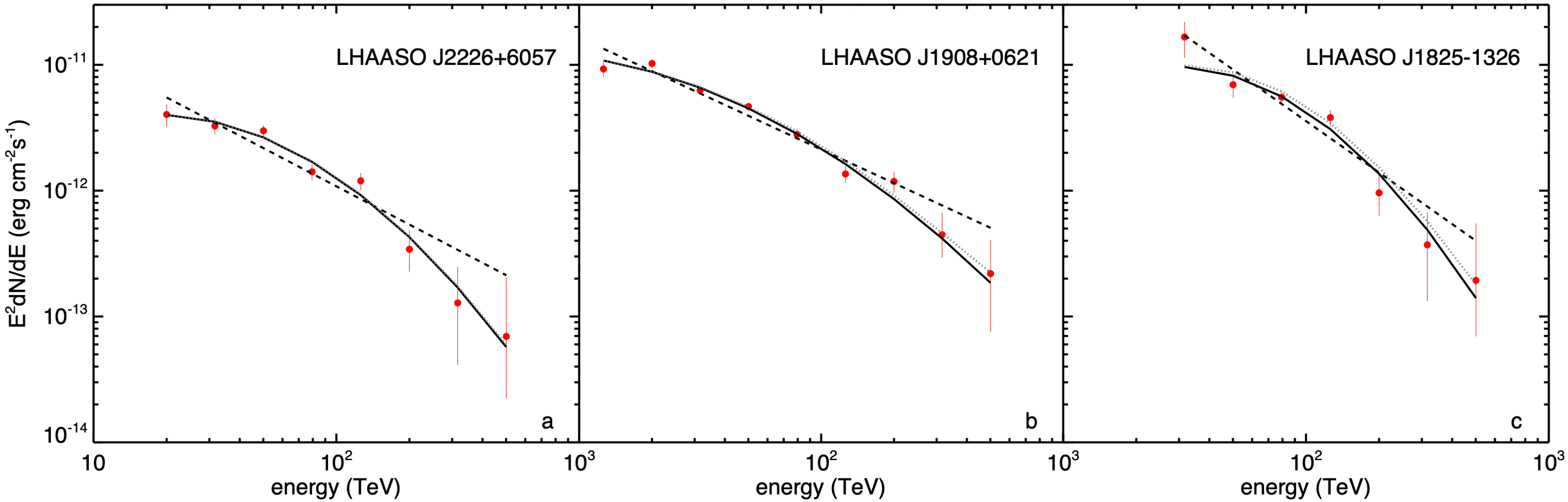
12 UHE sources detected （Cao et.al Nature 594, 33）





11 Months data of Half KM2A-array

Definitely PeVatrons (hadronic or leptonic)

The Galaxy full of powerful accelerators

Three brightest sources

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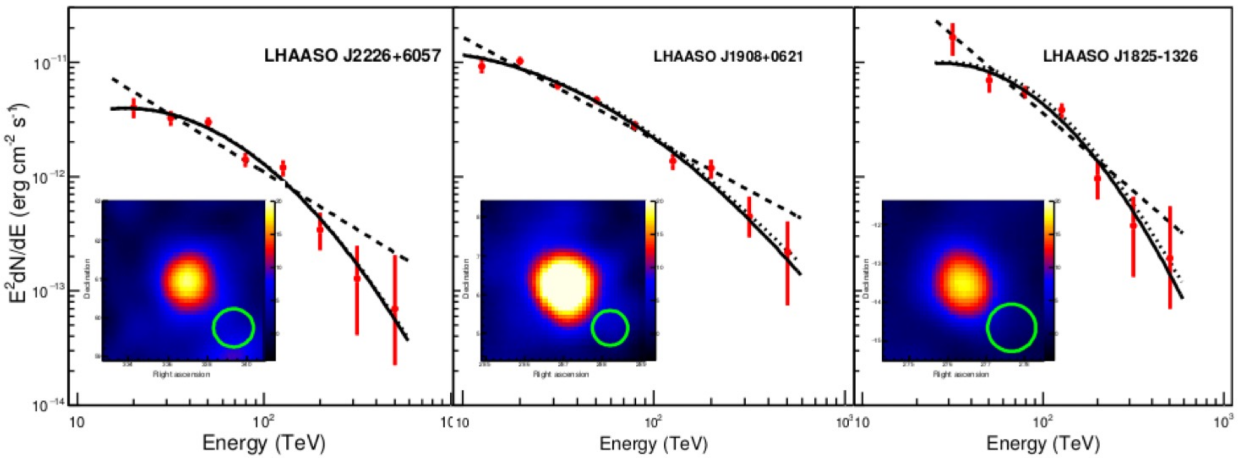
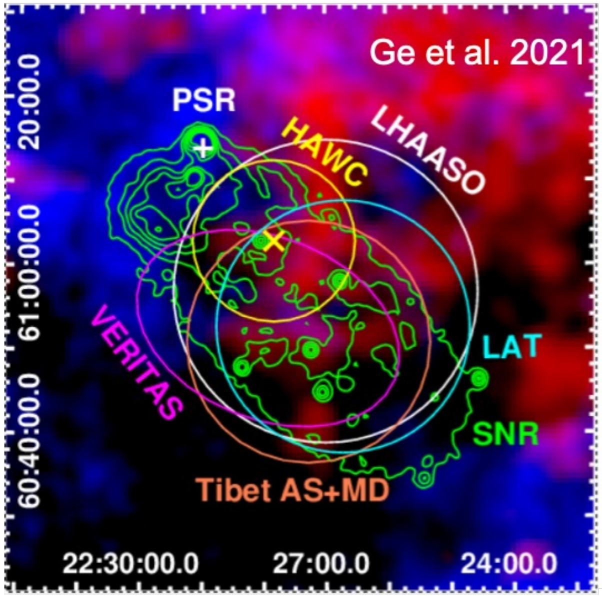
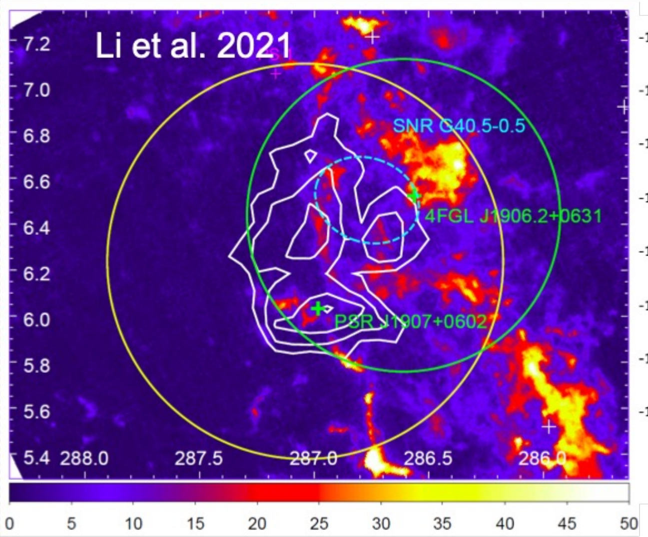


Complex regions

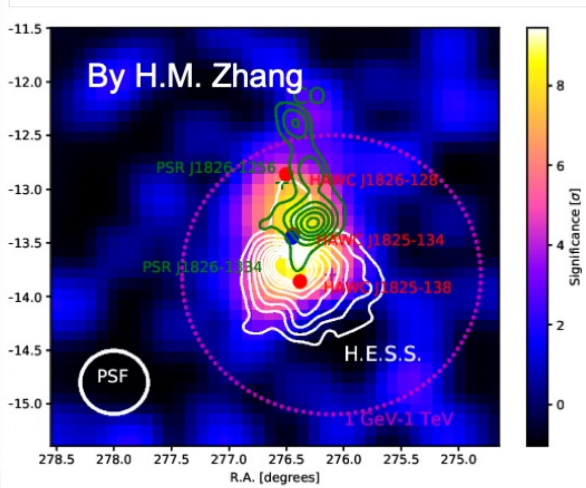
J2226+6057



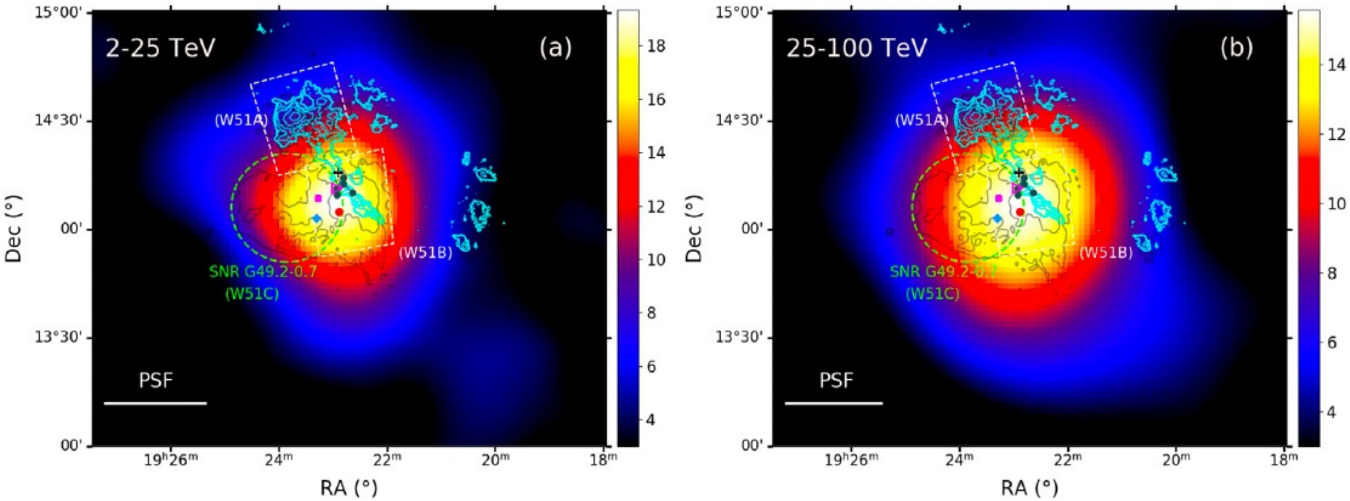
J1908+0621

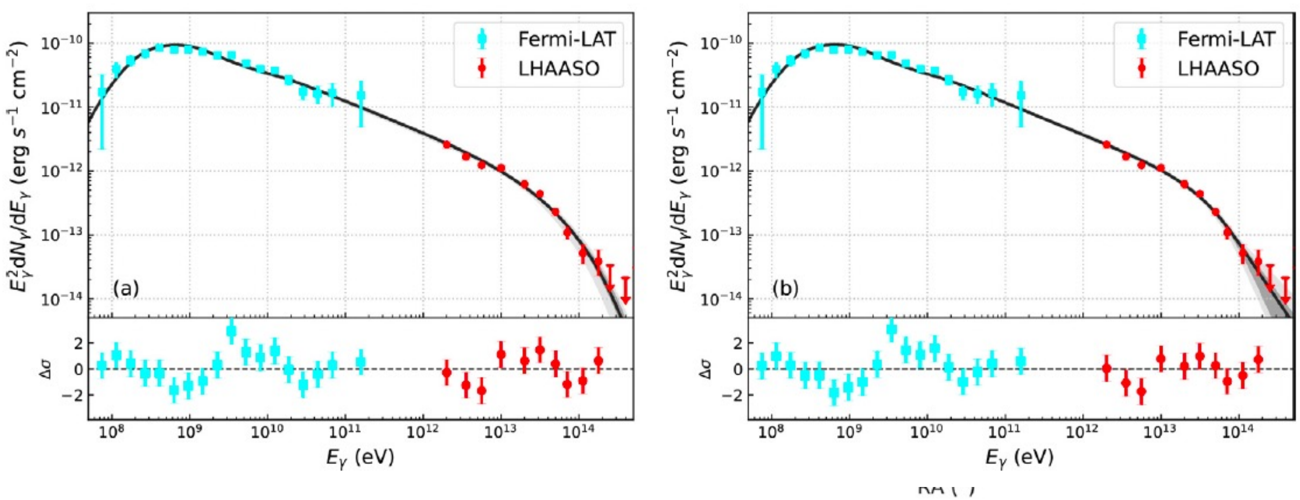


J1825-1326



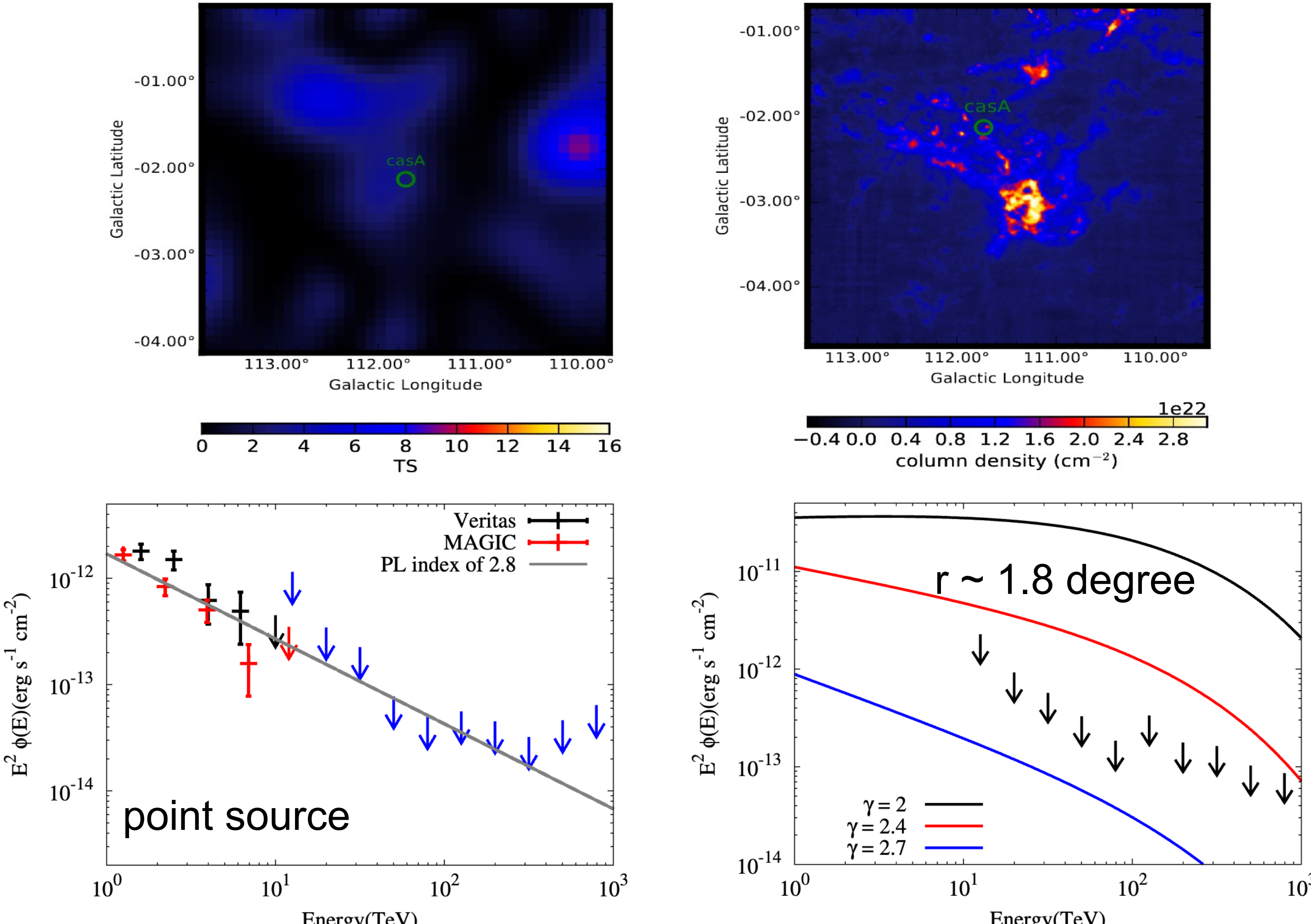
LHAASO observations on Mid-age SNR W51C





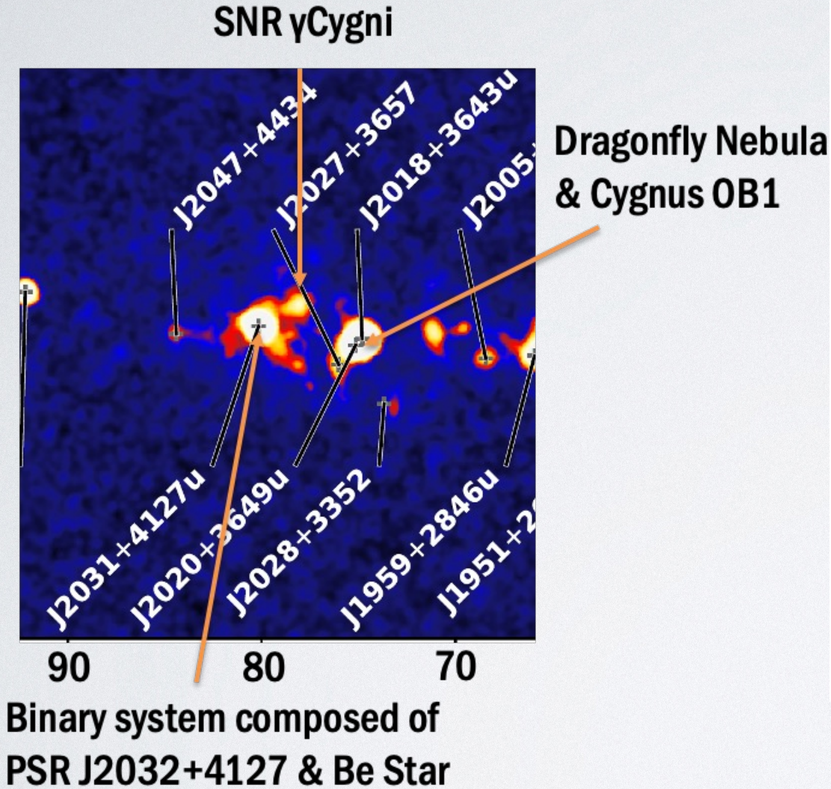
- Wp ~ 1e50 erg
- Index ~2.5
- Break at ~ 300 TeV for CRp
- Escaped CRs accelerated in earlier stage

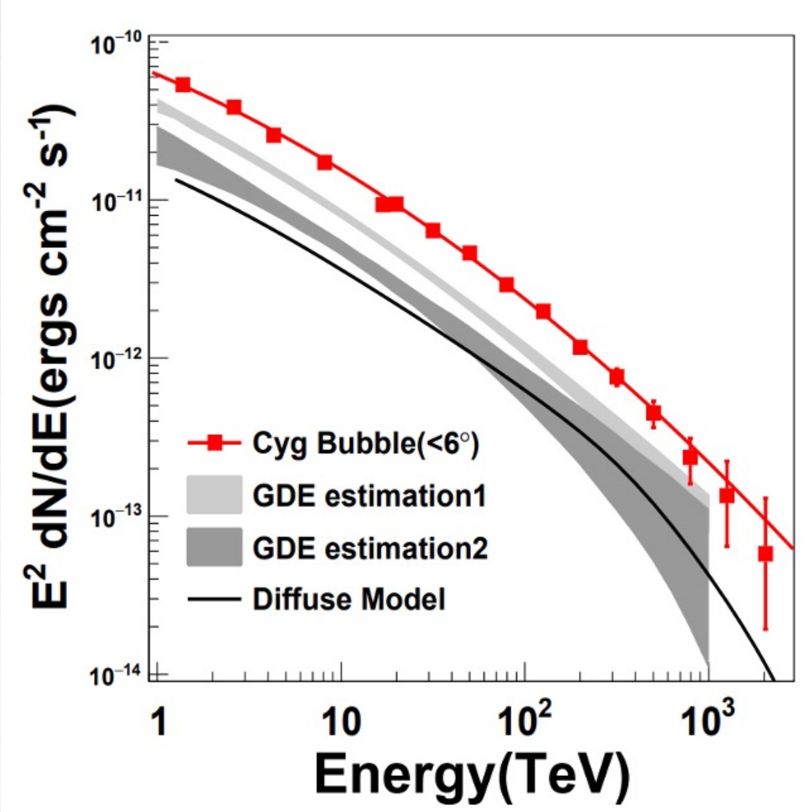
Upper limit on young SNR Cas A



- Stringent upper limit was set for the total VHE CRs injected by Cas A since explosion
- hints for other candidates of PeVatrons

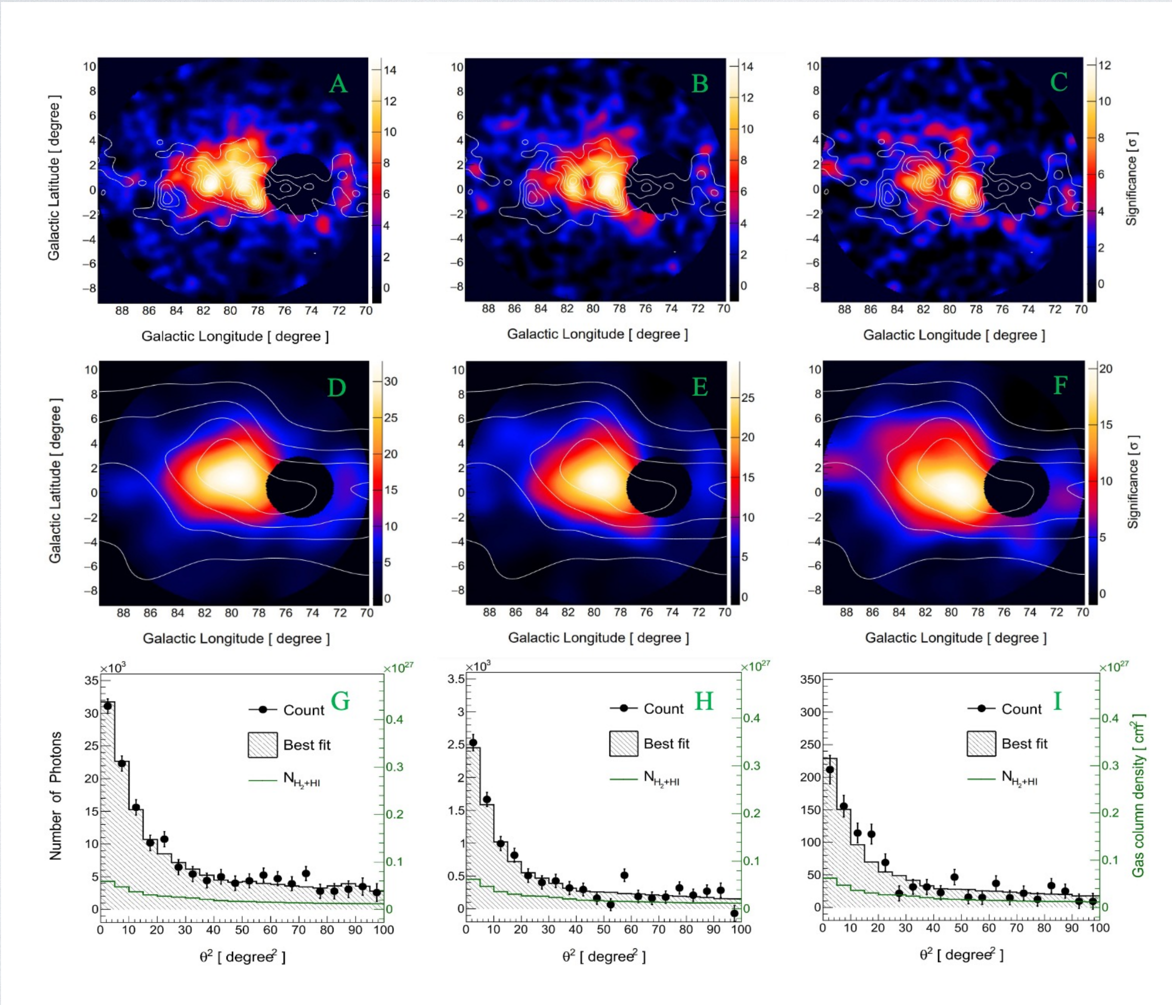
LHAASO VIEW ON CYGNUS





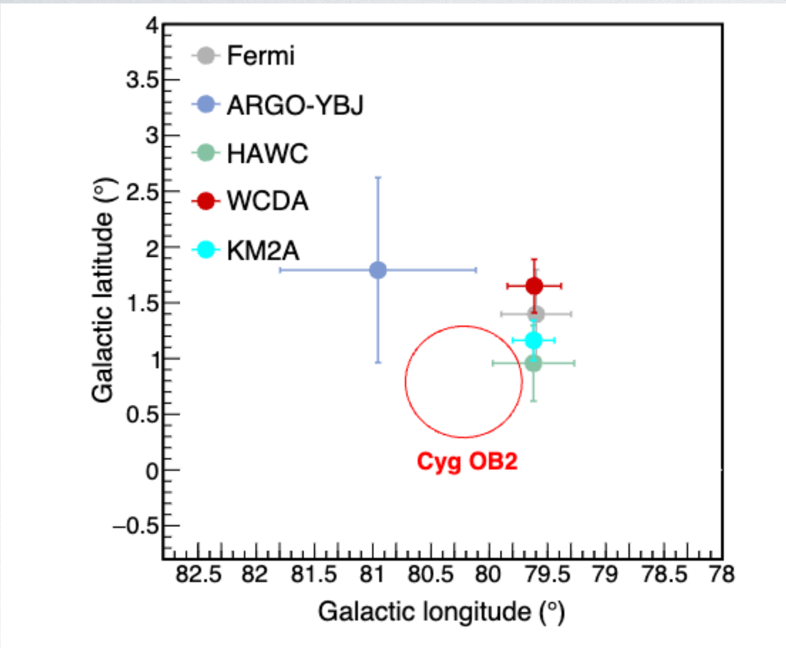
Galactic diffuse gamma-ray background (GDE) must be taken into account

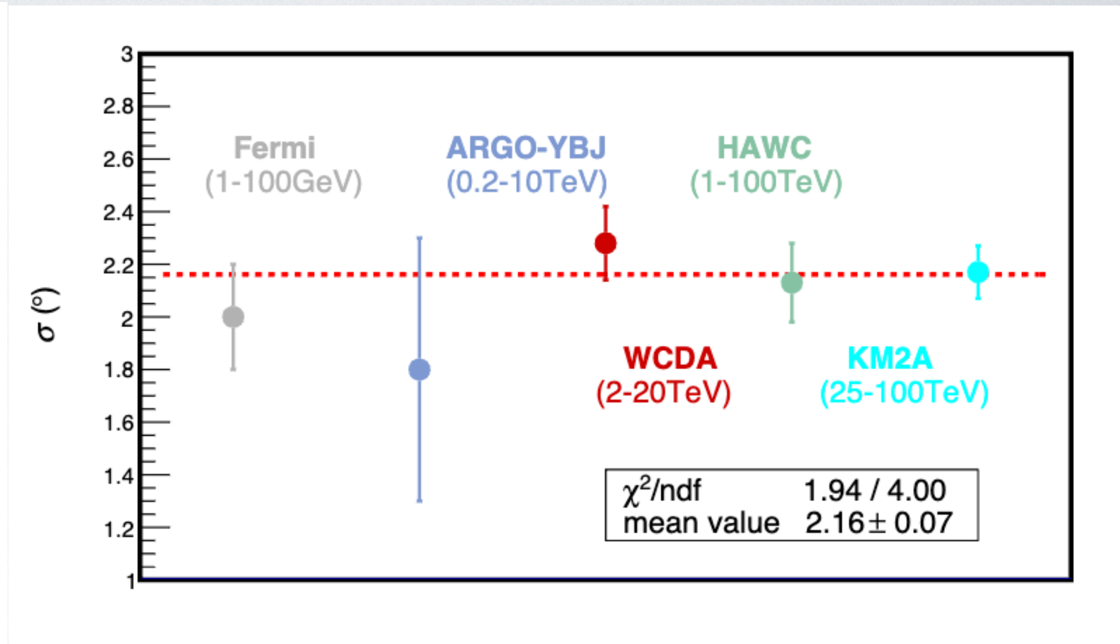
LHAASO VIEW ON CYGNUS



Huge bubble beyond ~6 degrees (150 pc)

LHAASO VIEW ON CYGNUS

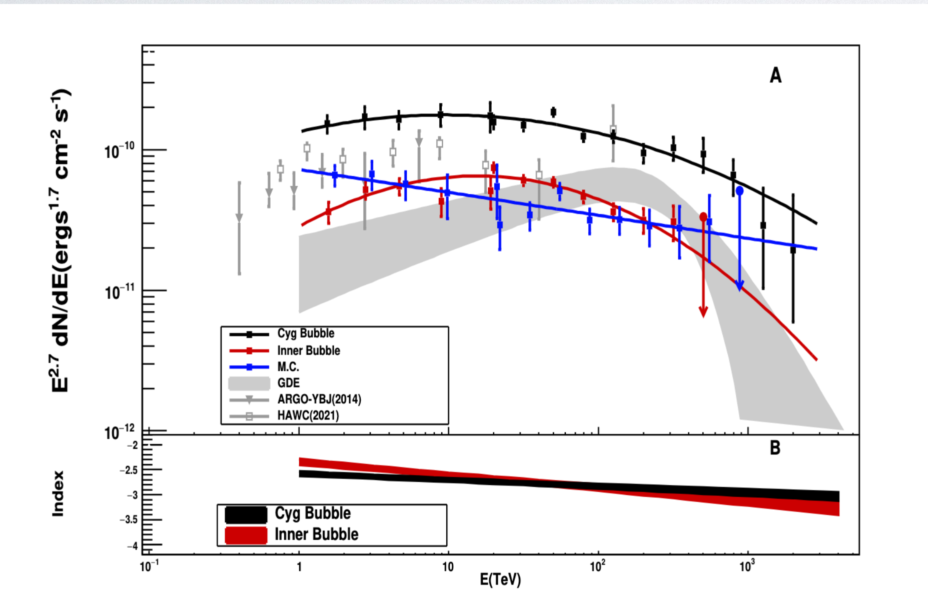




Energy independent morphology
Favor hadronic origin

LHAASO VIEW ON CYGNUS

Source	Components	$\alpha_{2000}(\circ)$	$\delta_{2000}(\circ)$	$r_{39}(\circ)$	TS	$N_0(TeV^{-1}m^{-2}s^{-1})$	Γ
LHAASO J2027+4119	KM2A	307.43 ± 0.16	41.05 ± 0.13	2.17 ± 0.10	145	$(0.62 \pm 0.05) \times 10^{-15}$@$50TeV$	-2.99 ± 0.07
	WCDA	306.90 ± 0.23	41.33 ± 0.16	2.28 ± 0.14	251.44	$(1.27 \pm 0.14) \times 10^{-9}$@$7TeV$	-2.63 ± 0.08
HI	KM2A				108	$(0.69 \pm 0.10) \times 10^{-15}$@$50TeV$	-2.94 ± 0.12
	WCDA				60.77	$(1.43 \pm 0.26) \times 10^{-9}$@$7TeV$	-2.66 ± 0.12
MC	KM2A				88	$(0.46 \pm 0.06) \times 10^{-15}$@$50TeV$	-2.87 ± 0.14
	WCDA				67.47	$(1.08 \pm 0.19) \times 10^{-9}$@$7TeV$	-2.73 ± 0.13
LHAASO J2031+4057	WCDA	307.89 ± 0.09	40.96 ± 0.16	0.33 ± 0.08	115.40	$(0.11 \pm 0.06) \times 10^{-9}$@$7TeV$	-2.75 ± 0.17

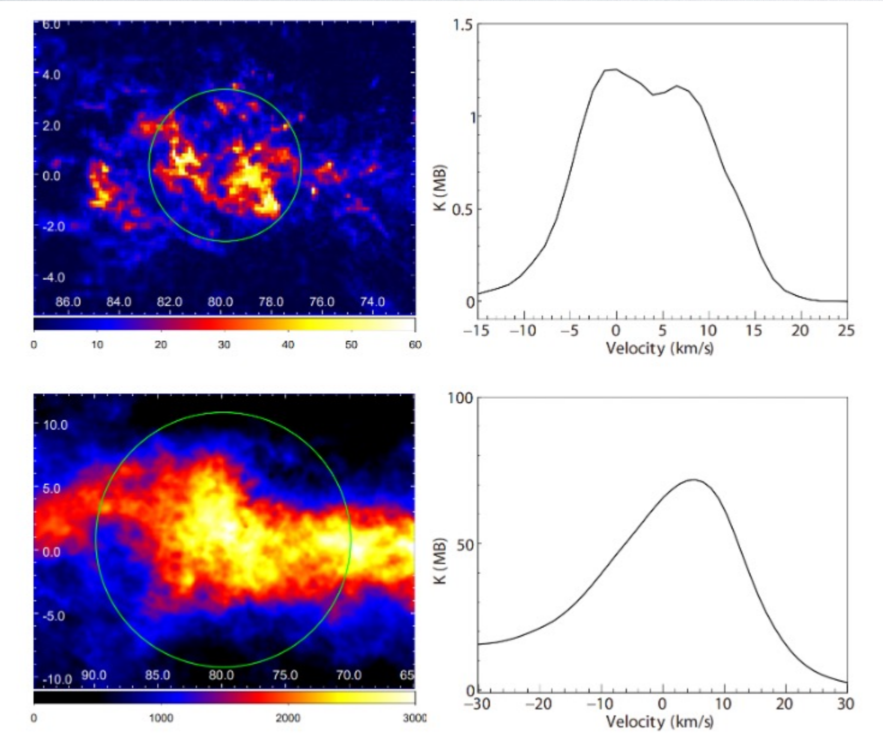


likelihood fitting derived 4 components:

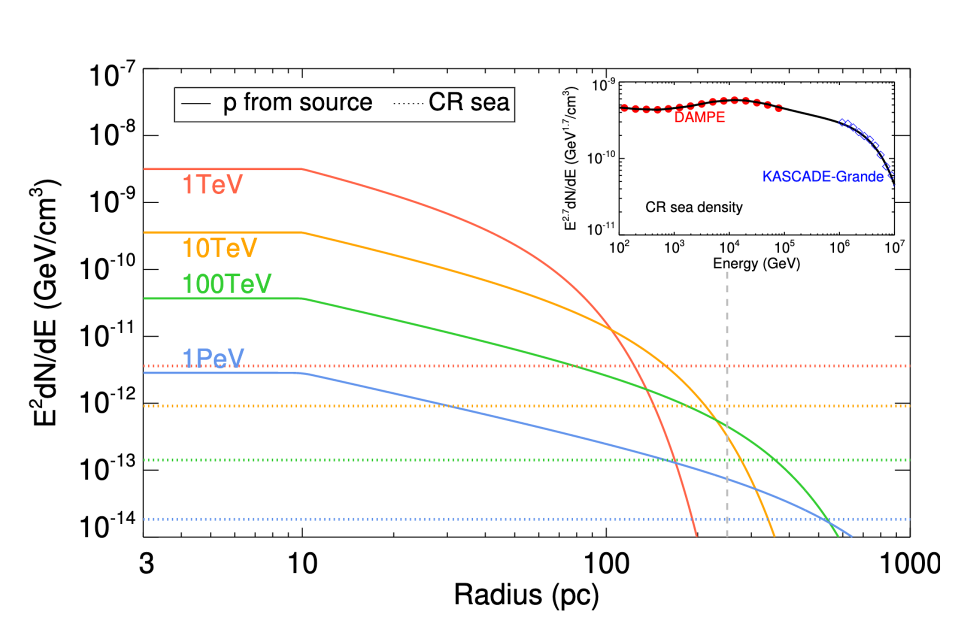
1. inner bubble(Cocoon)
2. Cygnus bubble (~10 degrees, associated with HI gas)
3. Hotspots associated with molecular gas
4. Bright central source

J2032+4127 (PWN/BINARY) are already subtracted from the analysis

Gas distribution and derived CR density

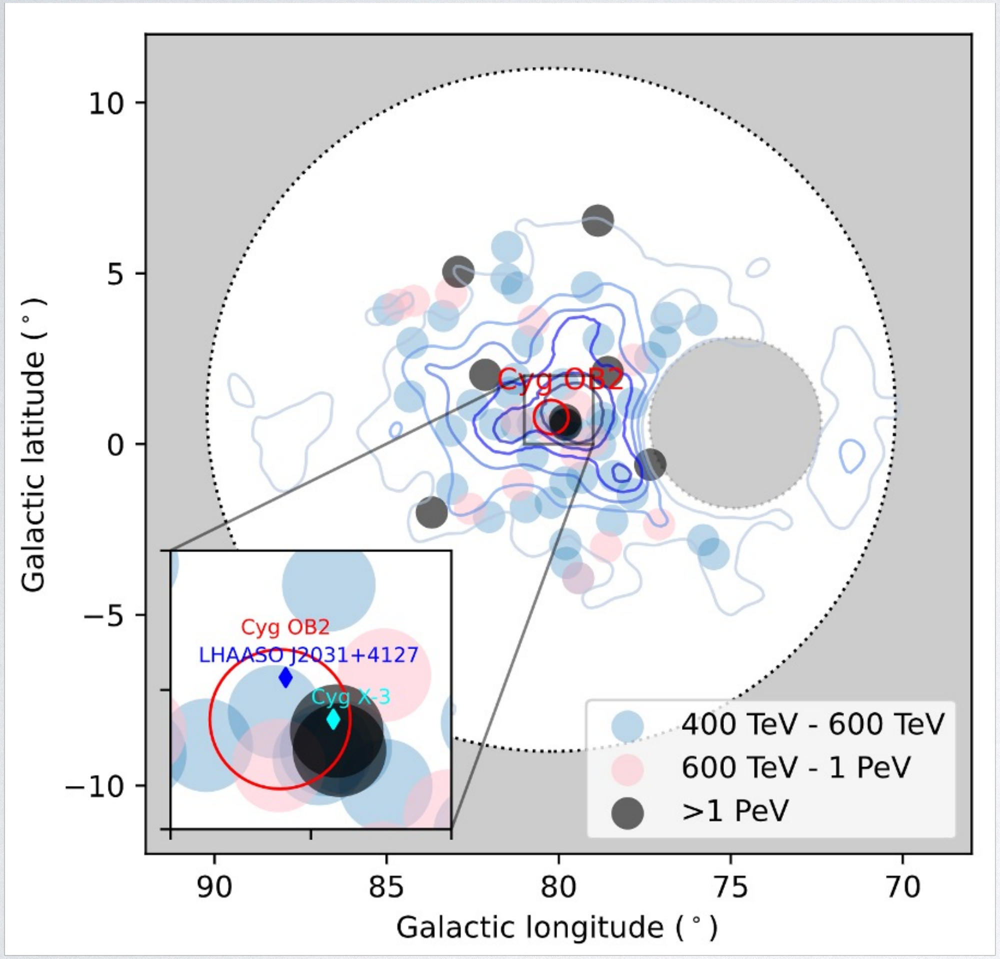


-10 to 20 km/s for CO
-20 to 30 km/s for HI are integrated



CR injected by the source dominate the CR sea up to several hundred pc

HIGHEST ENETGY PHOTONS



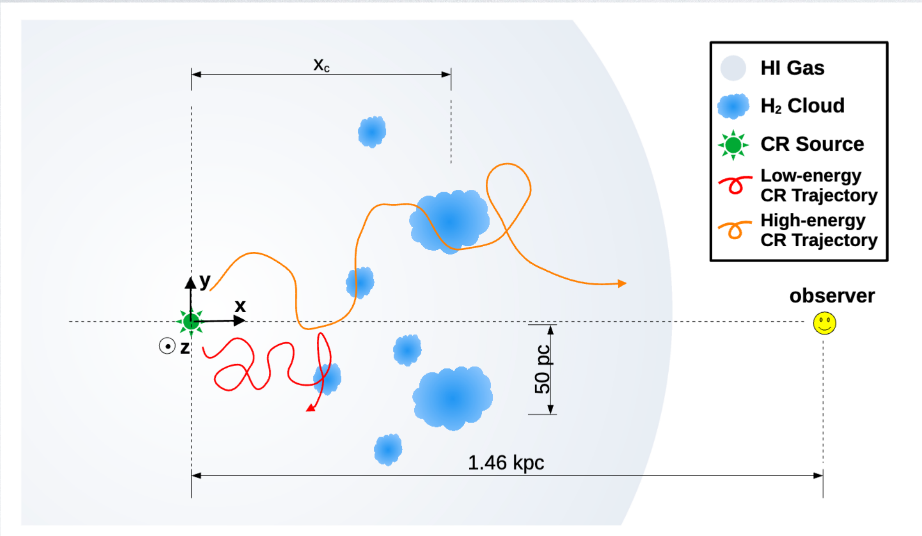
66 photon-like events within a radius of 6 degree with an estimated background of 9.5

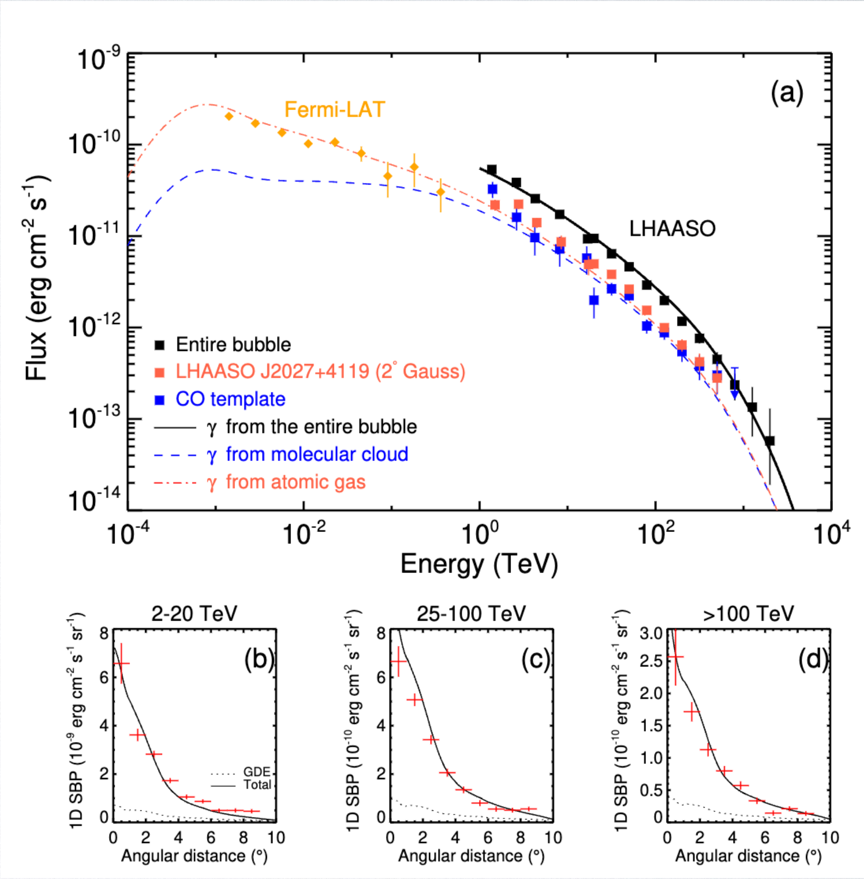
7/66 from central 0.5 deg region v.s. 66*(0.5/6)^2≈0.5
2/8 PeV event from central 0.5 deg region

Overdensity at the centre – injection!

E (PeV)	δE (PeV)	N_e	N_μ	θ(°)	$D_{edge}(m)$	ψ(°)
1.08	0.16	5904	13.0	19.4	143	4.7
1.19	0.18	5480	14.1	34.4	73	0.2
1.20	0.18	6939	12.6	14.2	132	5.8
1.35	0.20	6938	8.4	27.1	43	2.9
1.38	0.20	6469	8.9	17.4	52	2.6
1.42	0.21	6258	6.6	12.7	57	0.1
1.78	0.27	6665	12.8	18.0	41	1.8
2.48	0.37	13815	29.1	33.0	99	5.2

Schematic fitting of observations





comments:

The inner bubble (cocoon/gaussian) component is **just functional representation** of the data

The similar spectrum reveal same origin of "inner bubble " and Entire bubble

- Central **continuous** injection of CRs up to PeV
- **Slow** diffusion near the source (1/100 of fiducial value)
- Harder spectra from Molecular clouds

Galactic mini starburst W43

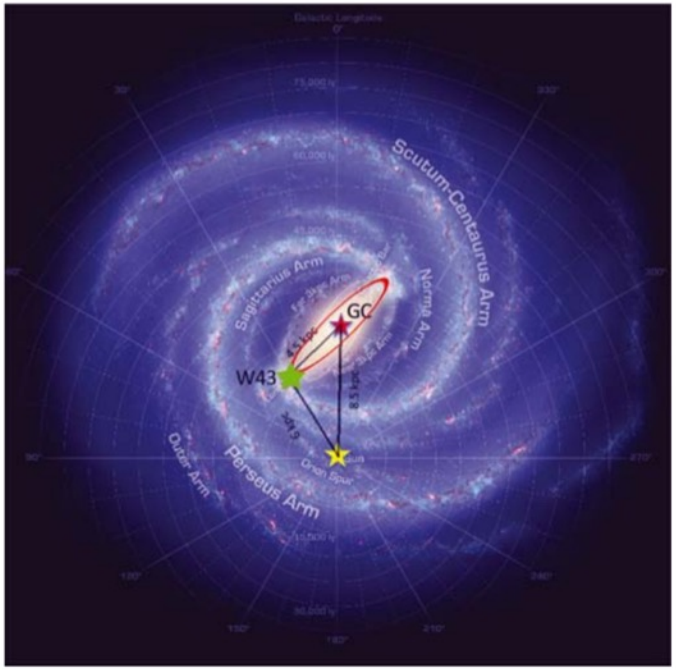
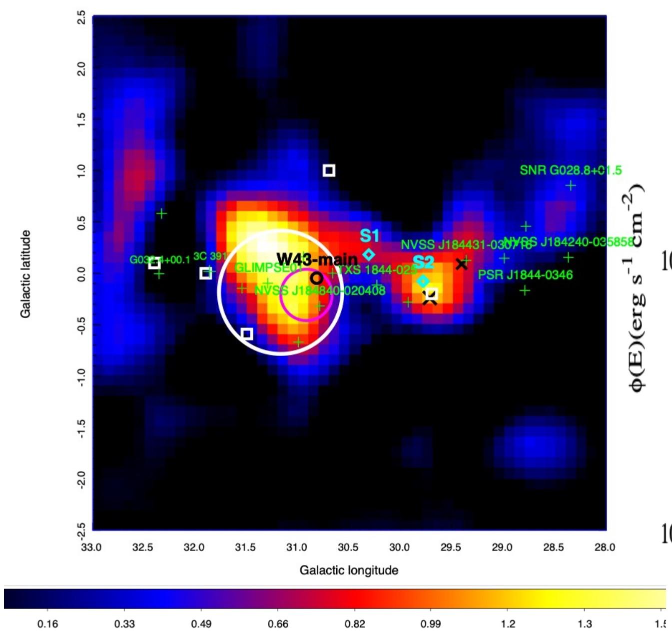
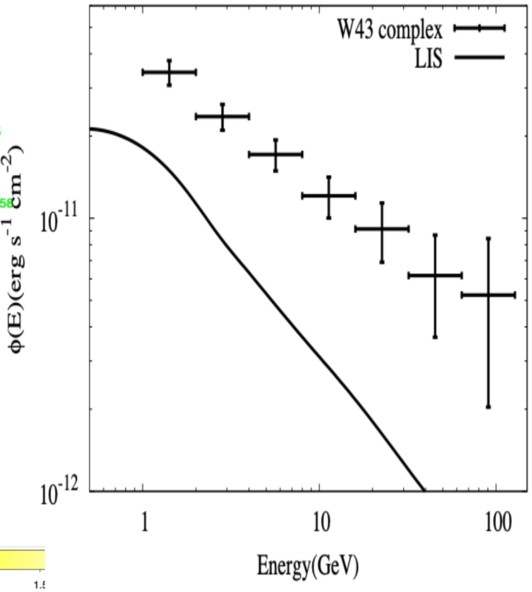


Fig. 9. Artist view of the Galaxy seen face-on with the "long bar" outlined by a red ellipse (Churchwell et al. 2009). W43 is located at the expected transition zone between the bar-dominated region ($R_{GC} < 5$ kpc) and the normal Galactic disk.





- Galactic mini star burst
- Contribute 10% of the Galactic star formation rate
- Huge HII region excited by central WR/OB cluster
- GeV detection

Star forming region: W43

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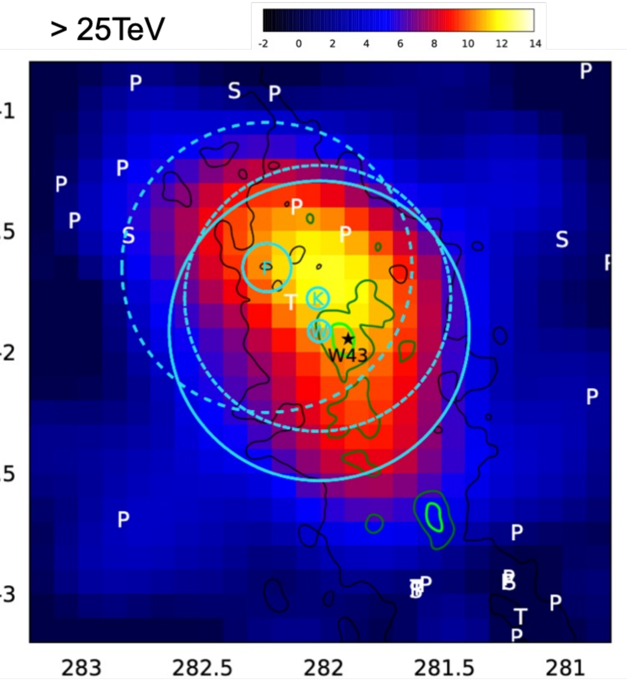
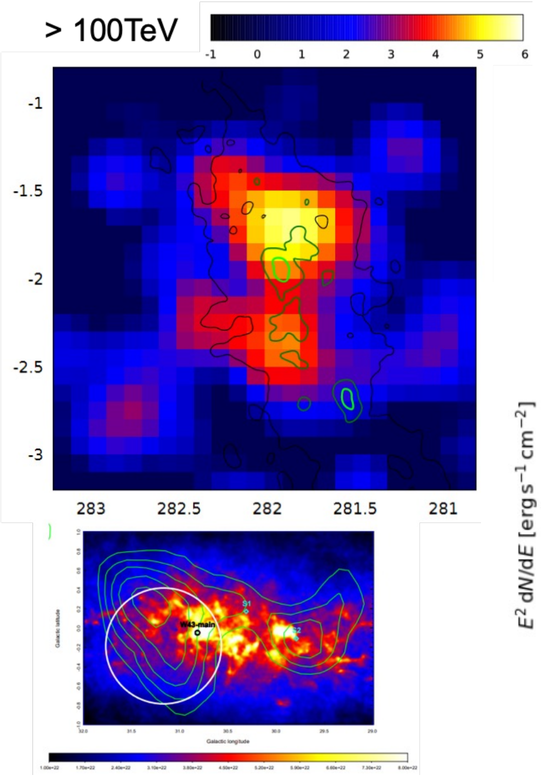
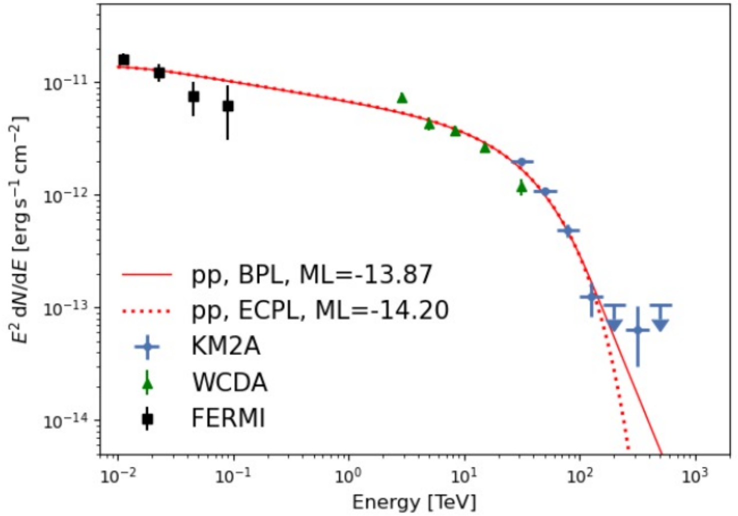
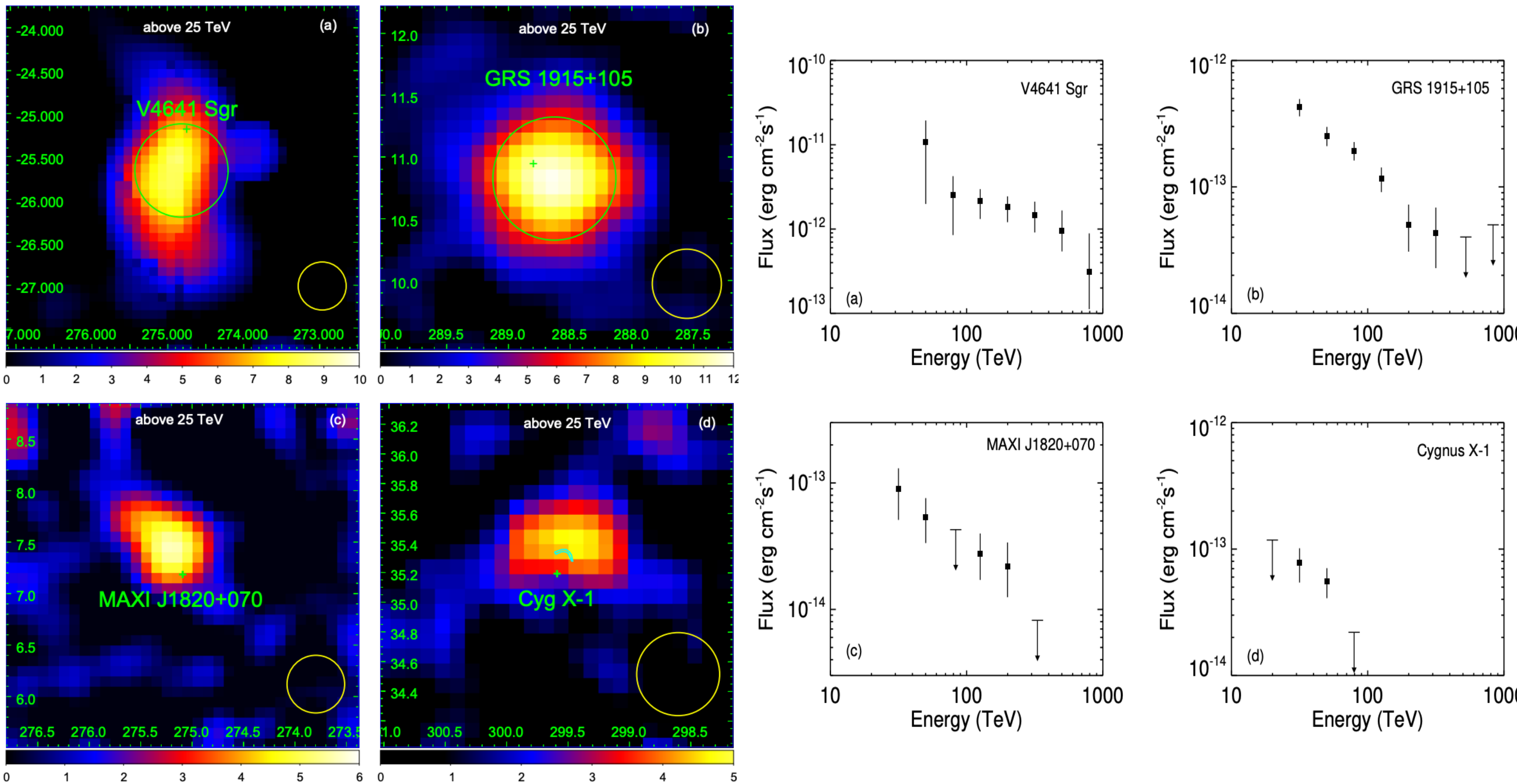






- UHE gamma-ray emission reveal good correlation with dense gas
- Physical size similar to Cygnus cocoon (~ 50 pc)
- Spectrum up to ~ 400 TeV

Microquasars



Significant detection of 6 Microquasars (BH-jet system) in our Galaxy

Microquasar SS433

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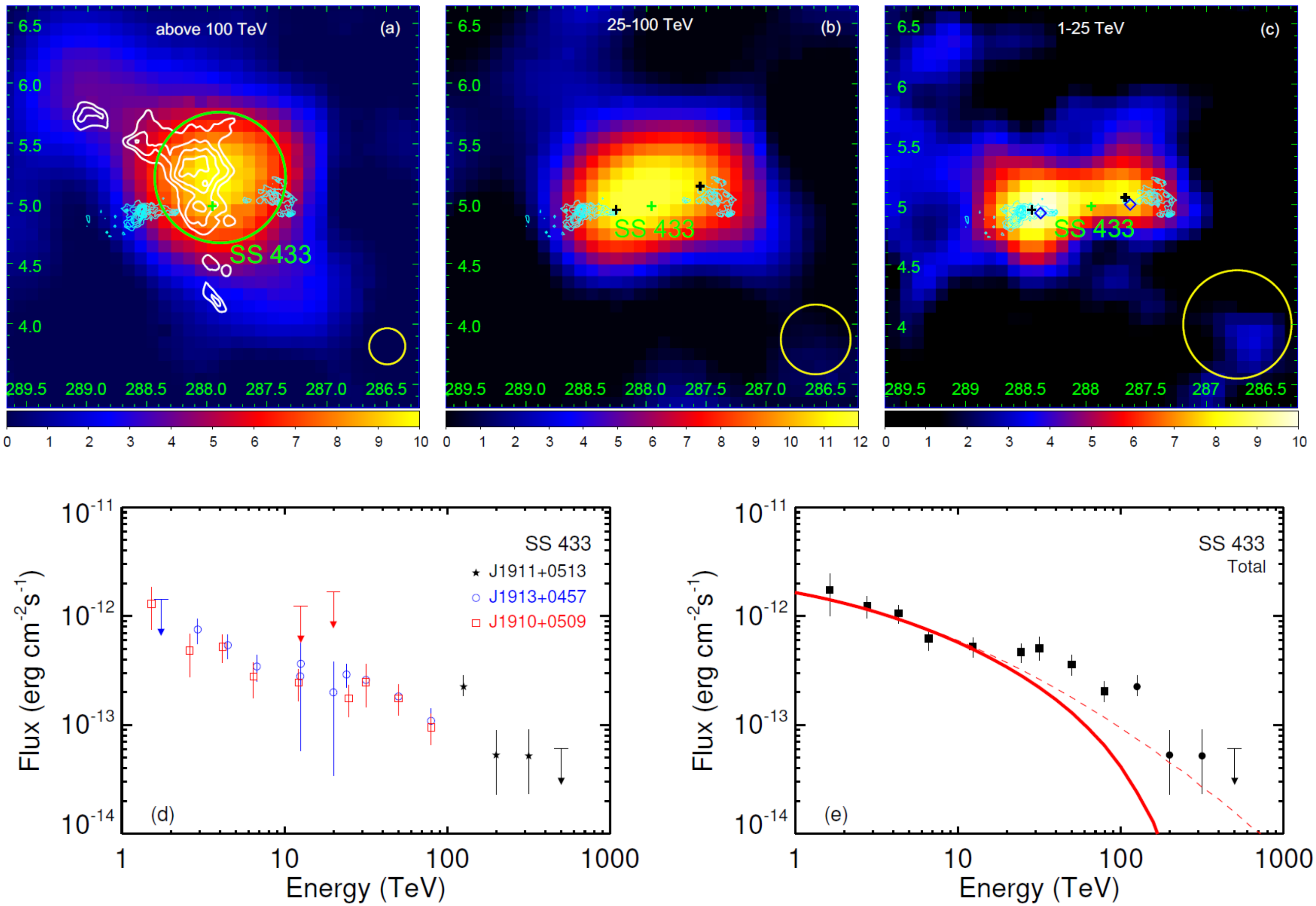

Strong evidence of energy dependence morphology

Microquasar SS433

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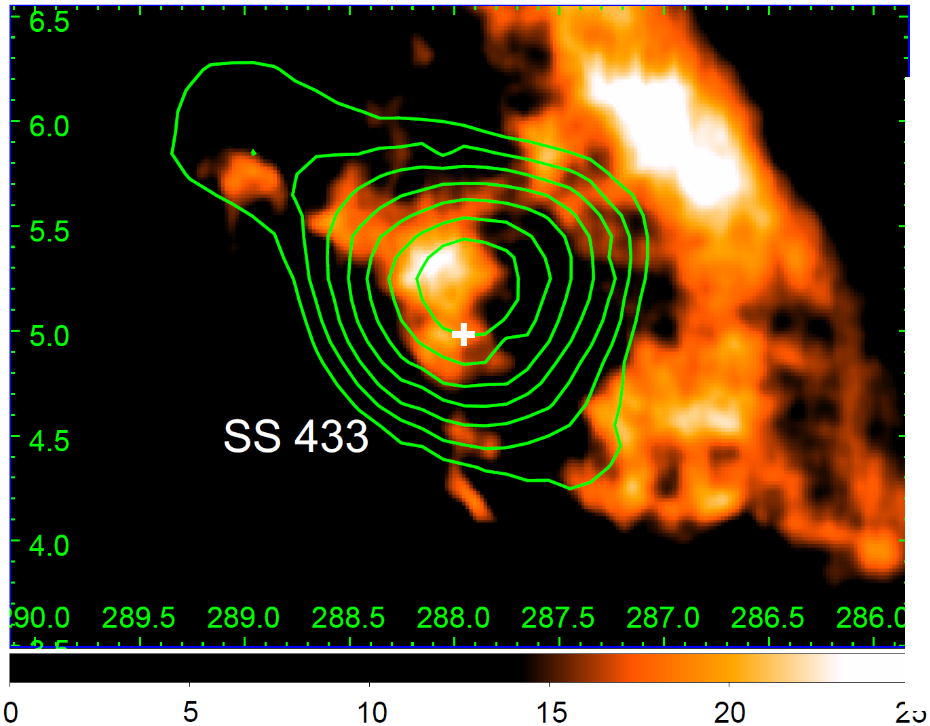

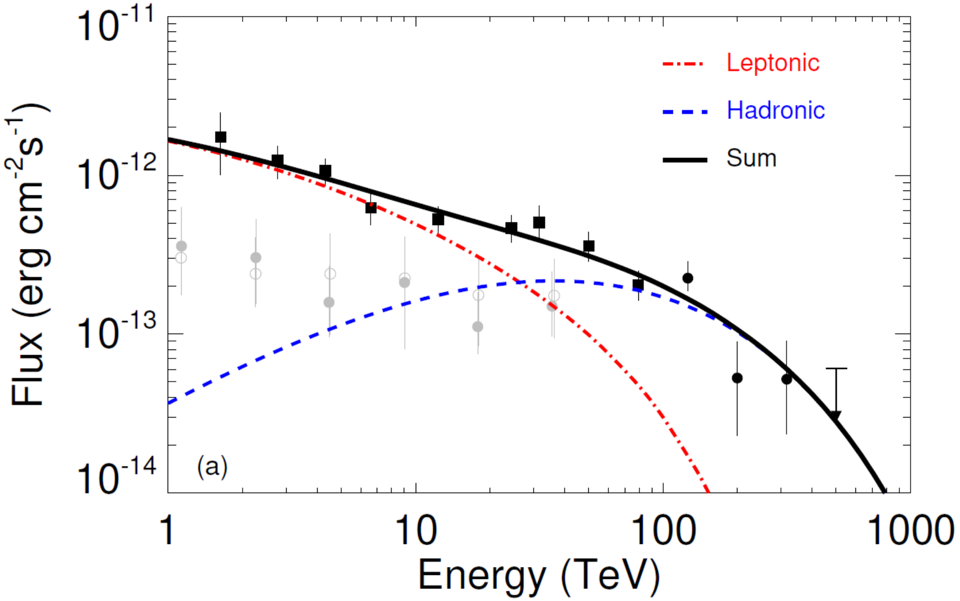

- Correlation with gas structures
- Hint for hadronic component at highest energy (Lp~ 1e38 erg/s)
- Potentially can explain the CRs near the knee

Giant Molecular clouds(GMCs) with LHAASO

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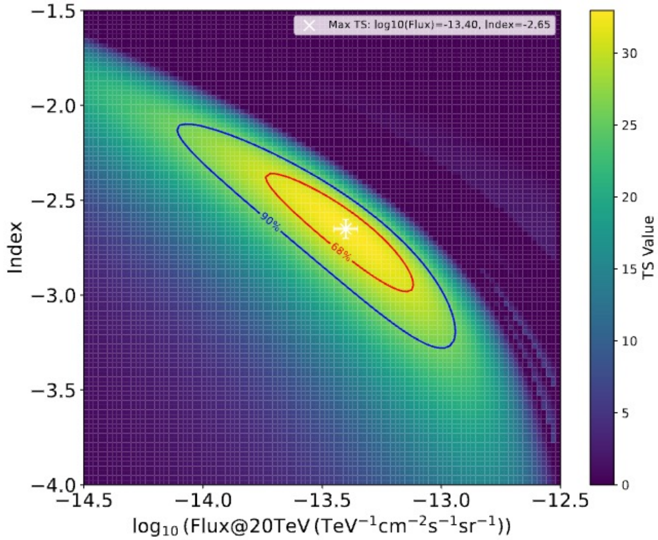
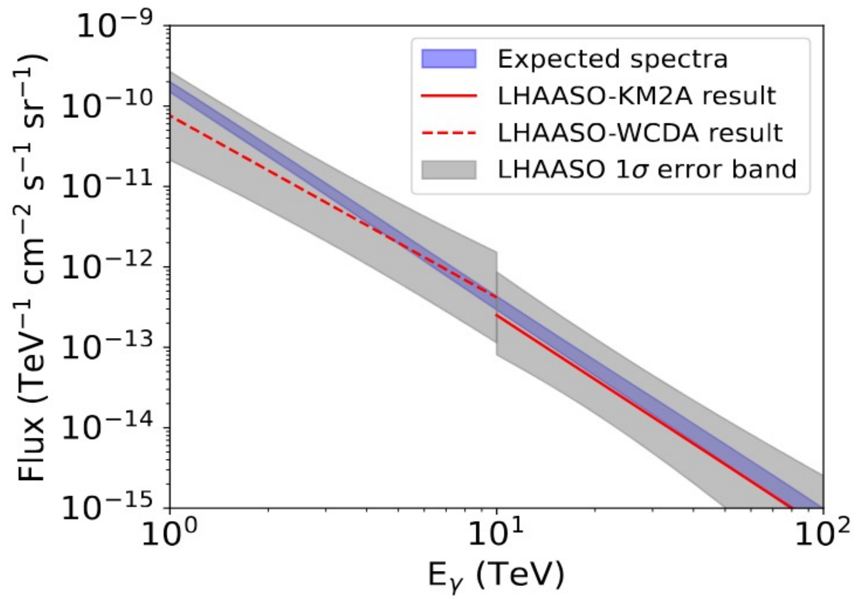
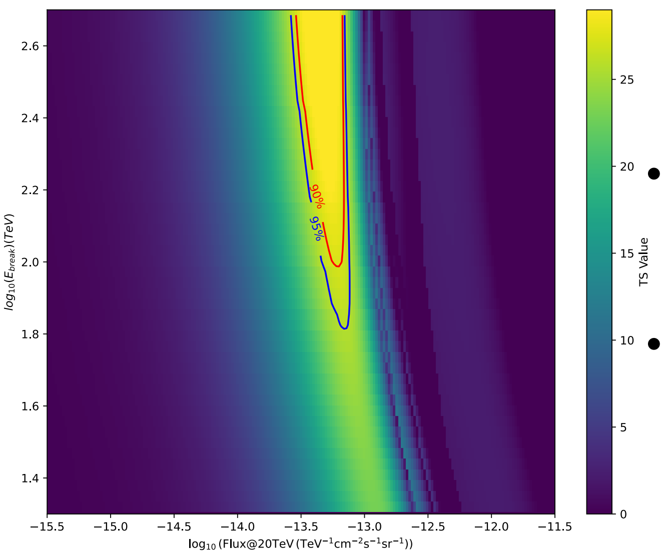
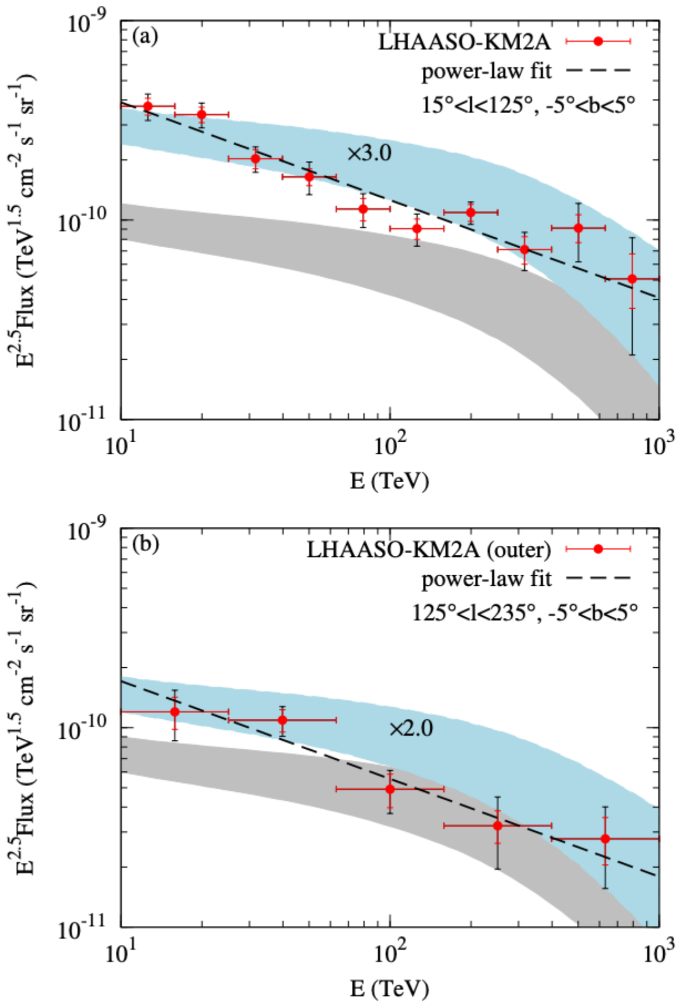


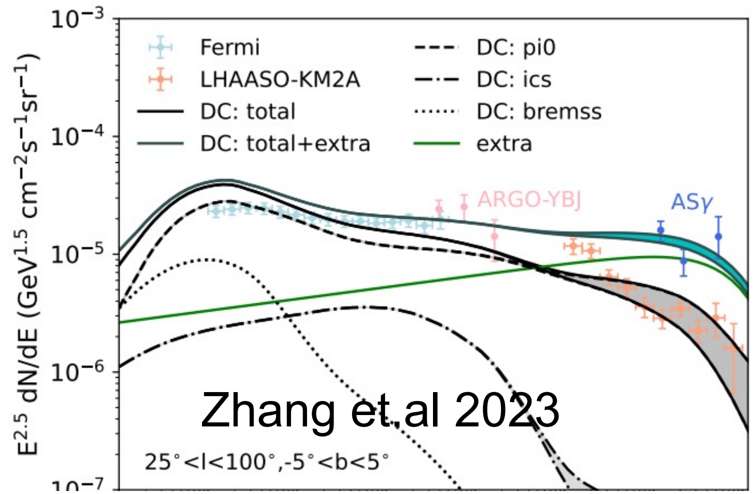


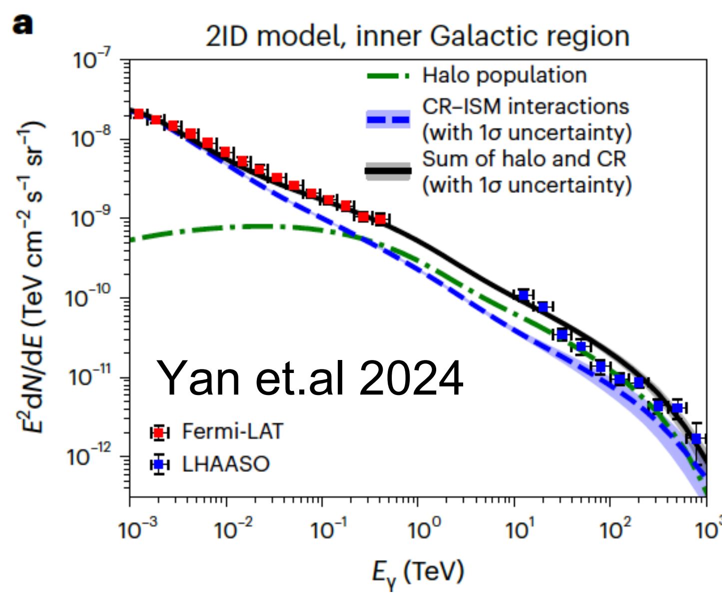


- Detection of UHE gamma-rays, derived CR spectra consistent with the direct measurement
- Favor a proton knee position above 1 PeV (see also Yanhong's poster)

Diffuse gamma-ray emission



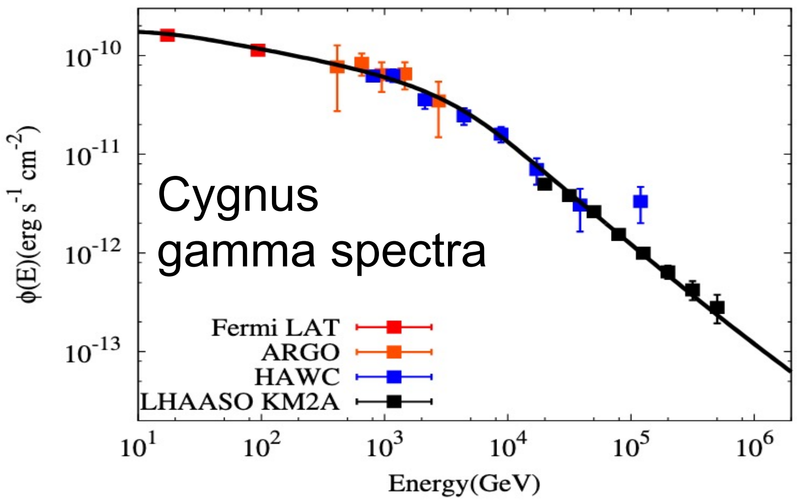


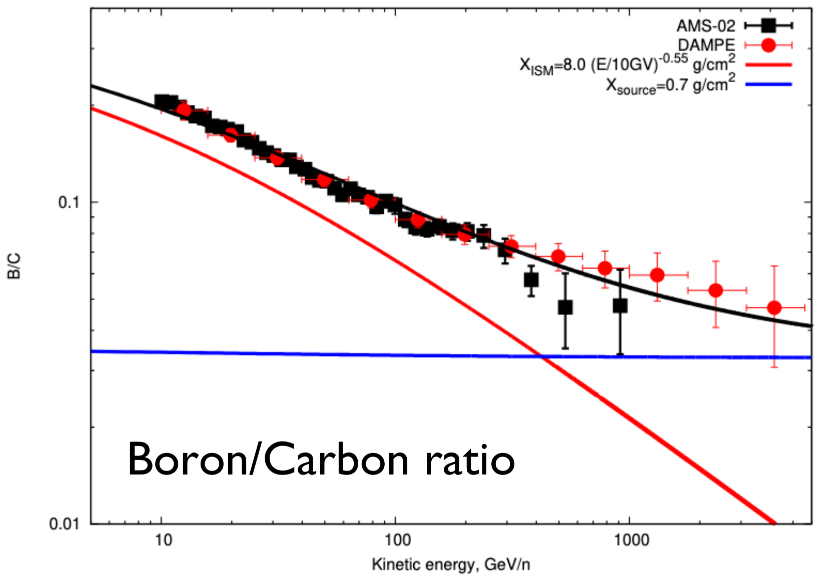


Phys. Rev. Lett. 131, 151001 (2023)
`Excess' revealed in multi-TeV band

A new component in GDE? From Pulsar halos?

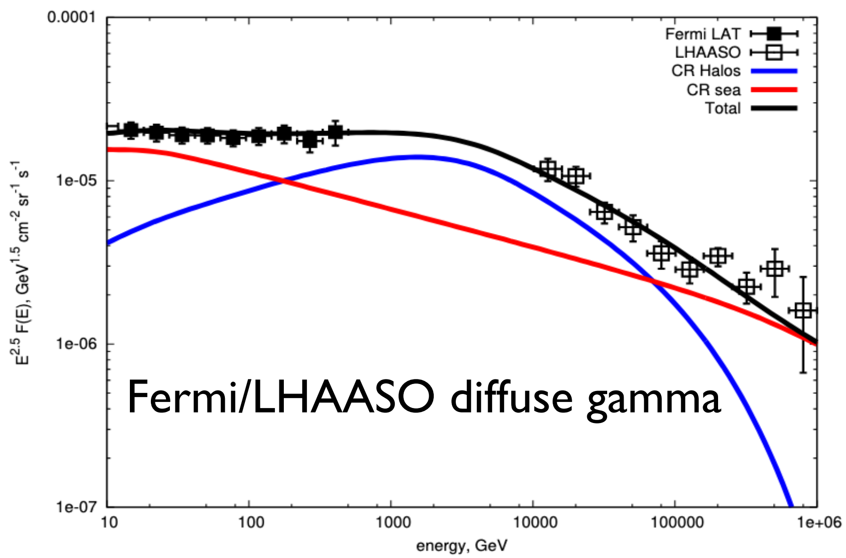
Related sources to the diffuse gamma?





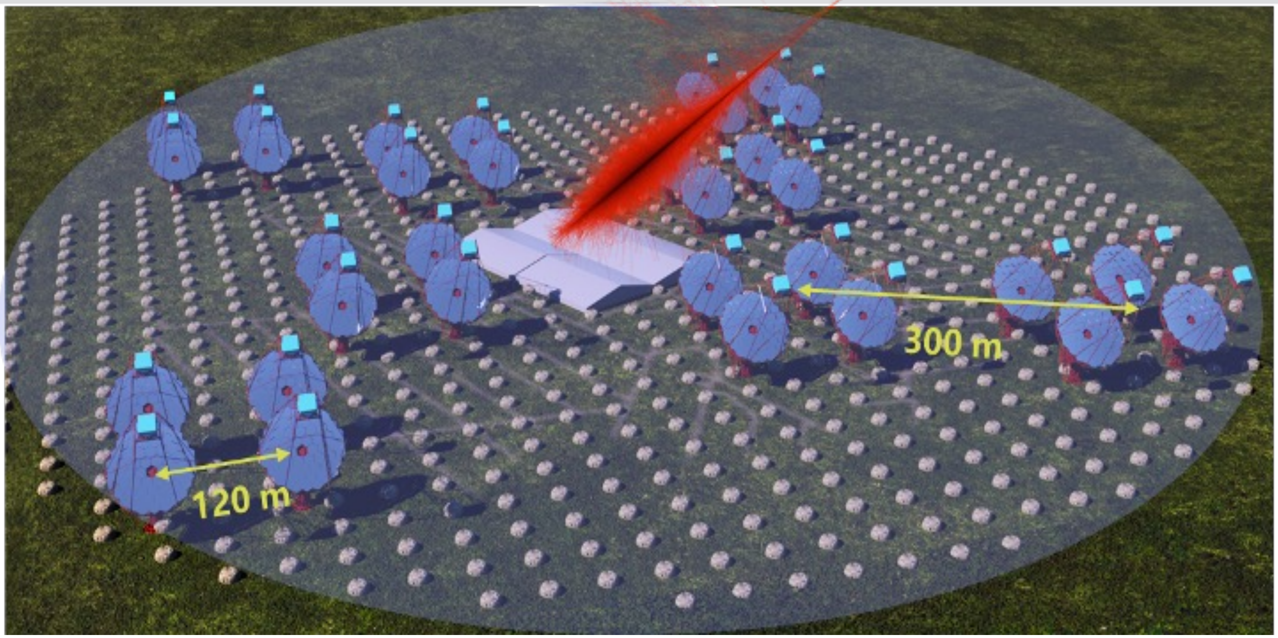
- Effective confinement (slow diffussion) of CR near accelerators
- energy independent below ~10 TeV, from Cygnus spectra
- Accumulation of extra component of "grammage"
- Can account for both B/C and diffuse gamma

arxiv:2410.22199



Prospect

IACTs in LHAASO site (LACT)



- Funded
- 8X4 array at LHAASO site
- 6-m telescopes
- two proto type telescopes
- First light soon!

Synergy with LHAASO-KM2A

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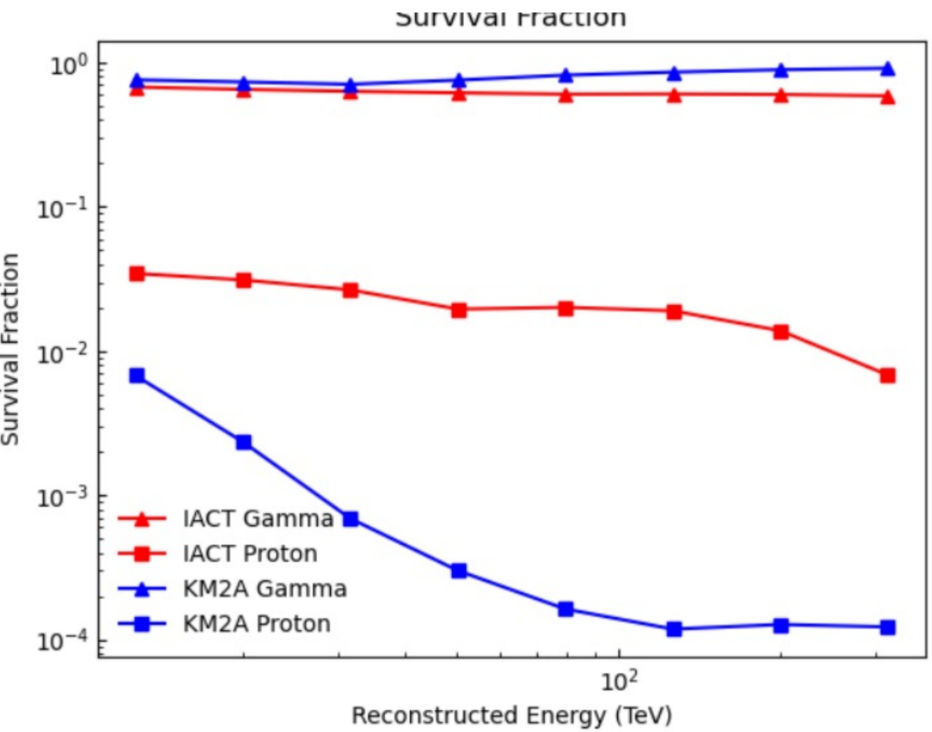
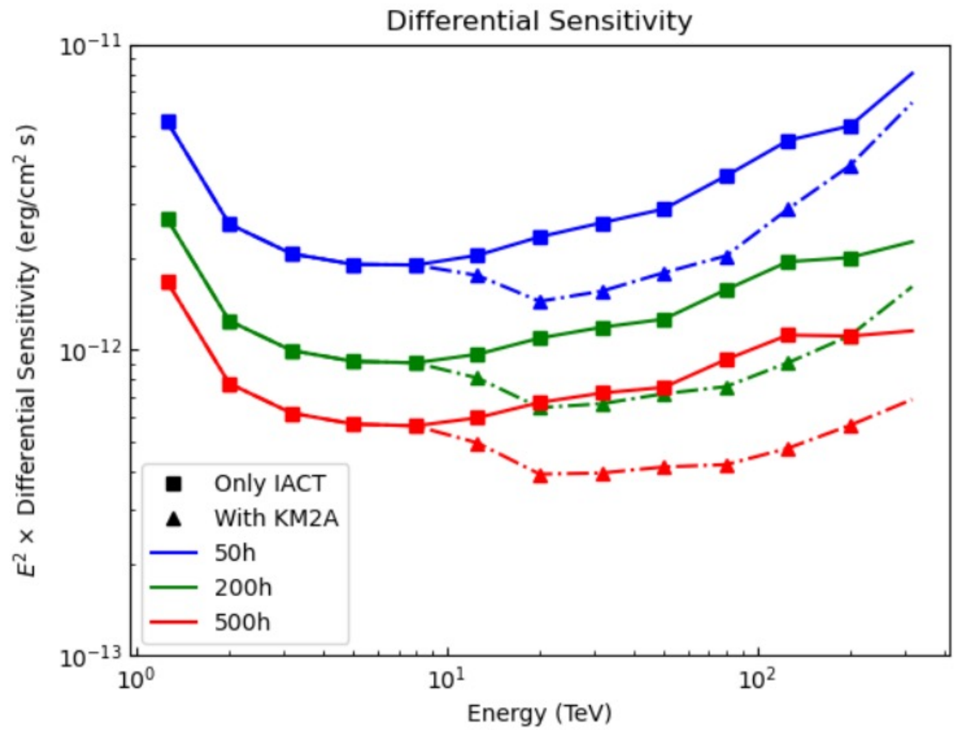
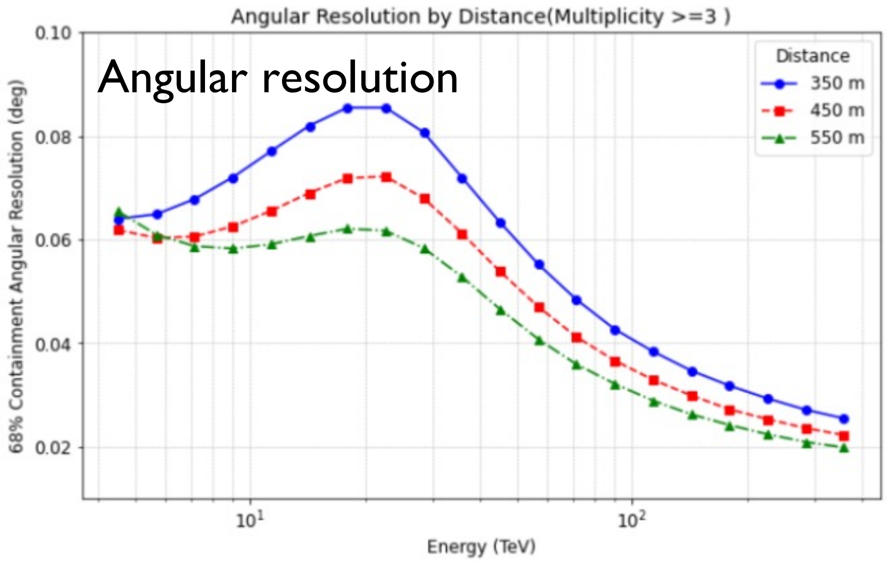


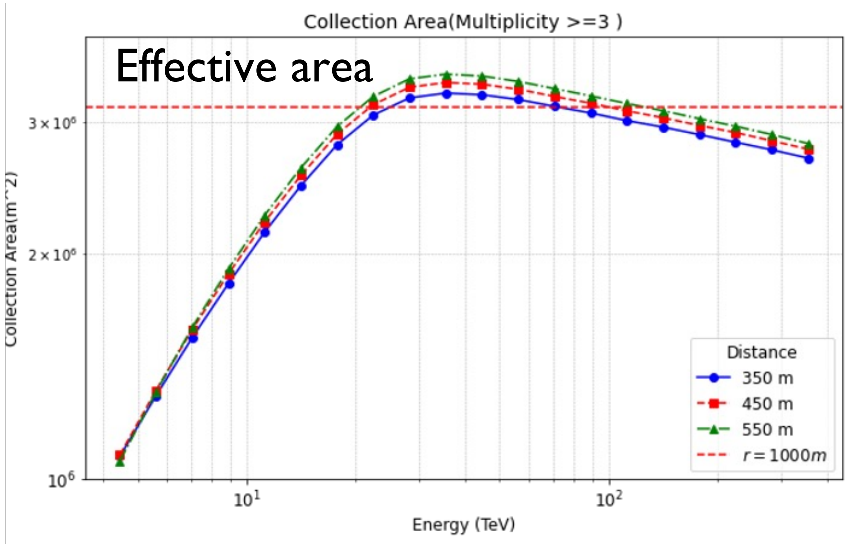
Using KM2A for gamma/p separation

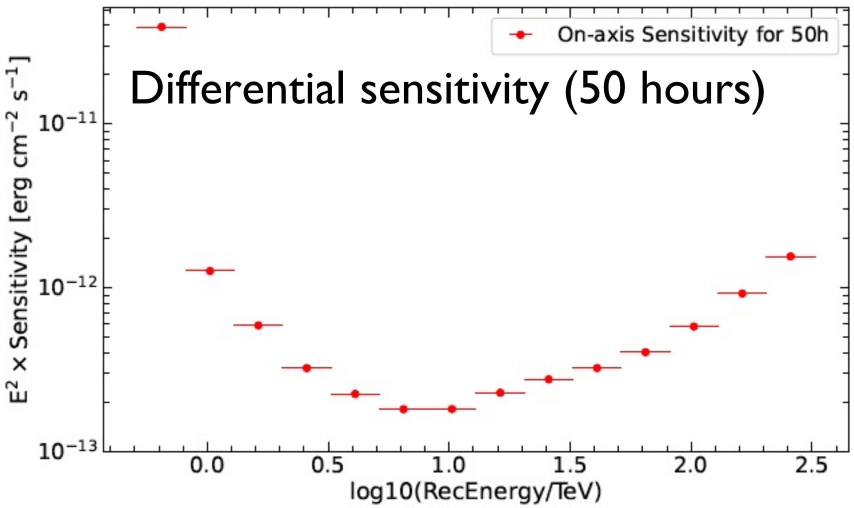


Sensitivity of LACT can be significantly improved above 10 TeV

Expected performance







LACT Schedule

	LACT progresses				
	2024	2025	2026	2027	2028
First telescope	11 months				
¼ array		10 months			
½ array			11 Moths		
32 telescopes				22 months	
Test running					6 months

HUNT (R&D phase)

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High energy Underwater Neutrino Telescopes

- Angular resolurion: ~0.1° (tracks), <3°(cascades).
- Energy resolution: ΔlogE~0.3(tracks), ΔE~10-30% (cascades).
- Discovering Neu sources (>100 TeV) at the level of 5σ within several years.

- Volume：6×6 = 36 km^2, ~30 km^3
- Separations of strings：Dstring ~ 130 m
- Separation of optical modules ：DOM ~36 m
- Length of each string：~860 m
- ~2,300 strings, 24 OMs in each string, 55000 OMs in total

Conclusion

- LHAASO already show great power in gamma-ray astronomy, different possible type of CR sources: SNRs, star forming regions, microquasars…

- A lot of future tasks for LHAASO in CR study: PeVatron identification, Cyg X-3, diffuse gamma-ray, …….

- Further projects: Imaging Air Cherenkov array (LACT) in LHAASO site/HUNT for neutrinos

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LHAASO
高海拔宇宙线观测站

Thanks!