

Highlights from LHAASO and implications on cosmic ray physics and new physics

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2026/10/24-26

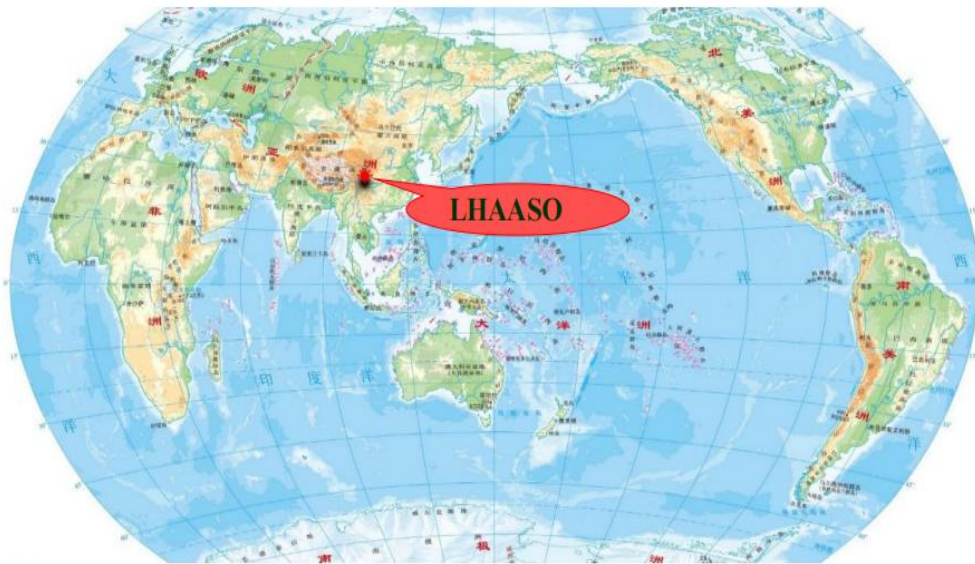
Outline

- Brief overview of LHAASO and its achievements
- Implications on CR physics
- Activities of new physics searches
- Summary

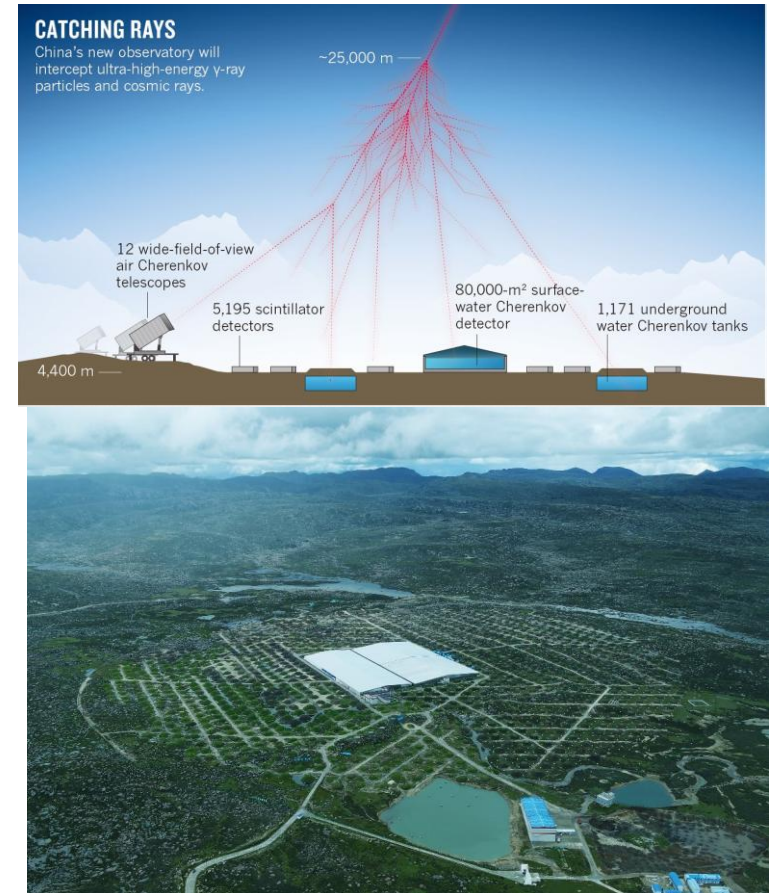
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LHAASO: Large High Altitude Air Shower Observatory



- Haizi mountain, **Sichuan, China, 4410 m** above the sea level
- LHAASO uses hybrid detector arrays: the square kilometer array (KM2A), the water Cherenkov detector array (WCDA), and the wide field-of-view Cherenkov telescope array (WFCTA)
- Full operation since **July 2021**



Layout of LHAASO

Square Kilometer Array (KM2A)

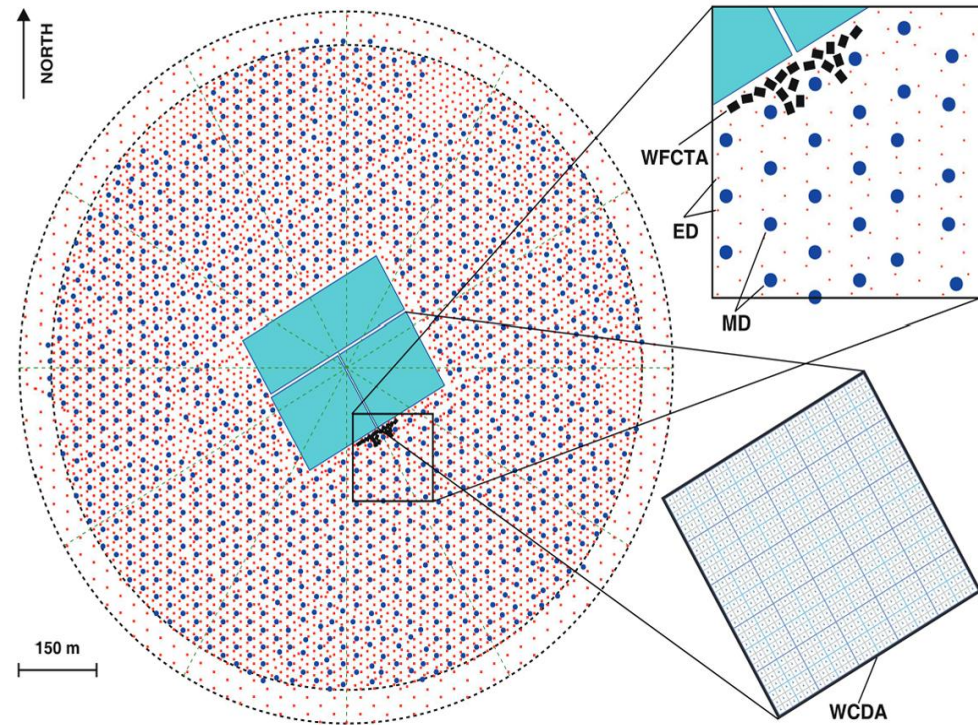
- 1.3 km² area
- 5216 EDs for energy and direction reconstruction
- 1188 MDs to distinguish gamma/hadron
- Energy coverage: 10s TeV - 100 PeV

Water Cherenkov Detector Array (WCDA)

- 78000 m² water tanks
- 3120 WCDs to detect Cherenkov light produced by air shower particles in water
- Energy coverage: 100s GeV-10s TeV

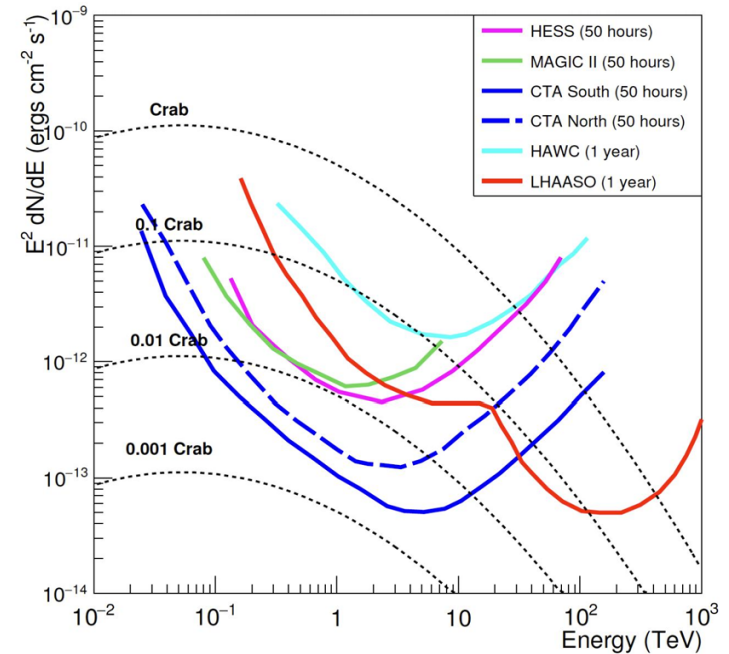
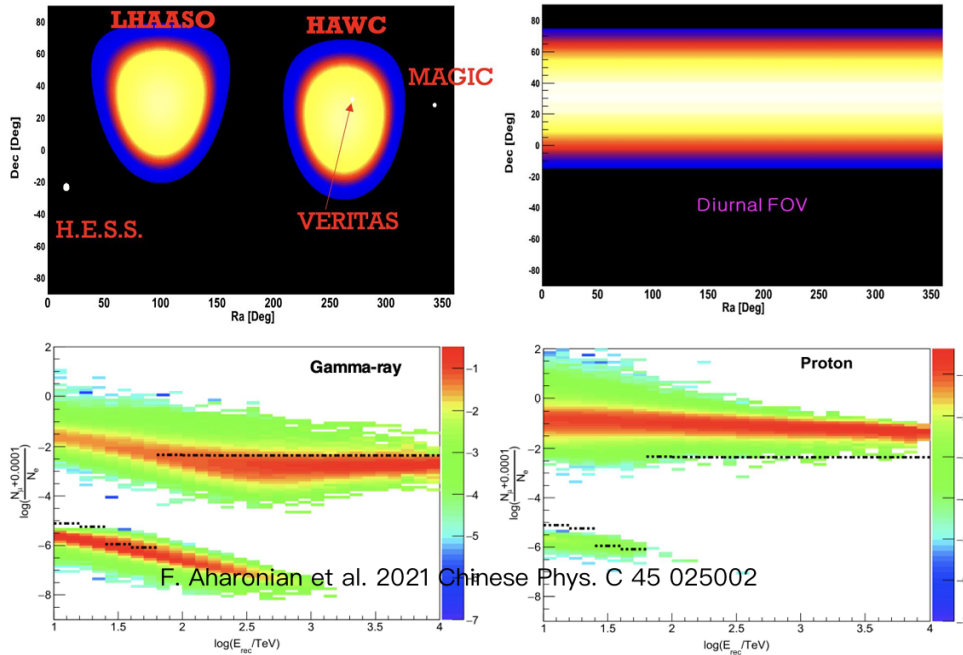
Wide Field-of-view Cherenkov Telescope Array (WFCTA)

- 18 WFCTs to distinguish particles with different mass, each one has an area of 4.7 m² and covers a square sky with area 16°×16°
- Dedicated to CR observations.



Chinese Physics C Vol. 46, No. 3 (2022) 030001

Performance of LHAASO



- Large effective area, wide FOV, powerful γ /hadron discrimination
 - Excellent sensitivity at multi-TeV to PeV energies
 - Exploring the origin of GCRs (knee region, PeVatrons).

- Probe the **origin of CRs**, via precise measurements of spectra and anisotropies
- Study the ultra-high-energy gamma-ray sky with unprecedented sensitivity
- Search for **new physics**

Key problem of CR physics: origin and acceleration

- Cosmic rays are HE charged particle from space

- ▣ P、He、C、O、... Fe

- Highest energy is over 10^{20}eV

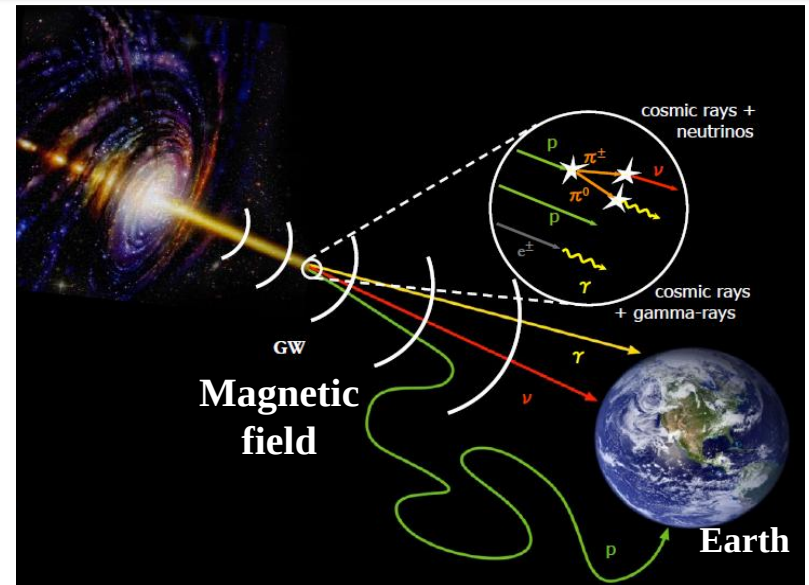
- ▣ 10^7 times the energy of LHC

- Origin of HE CRs is unknown:

- ▣ 《Science》 125 key scientific questions

- Methods: gamma rays、neutrinos

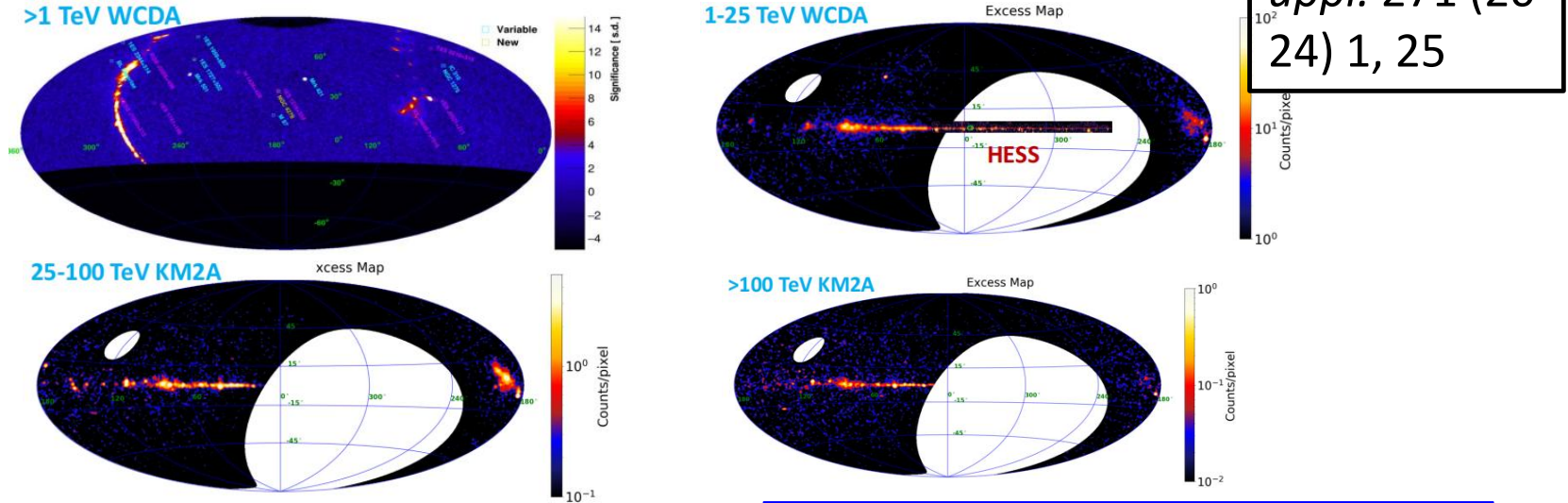
- ▣ Gamma ray astronomy is the active area in recent years



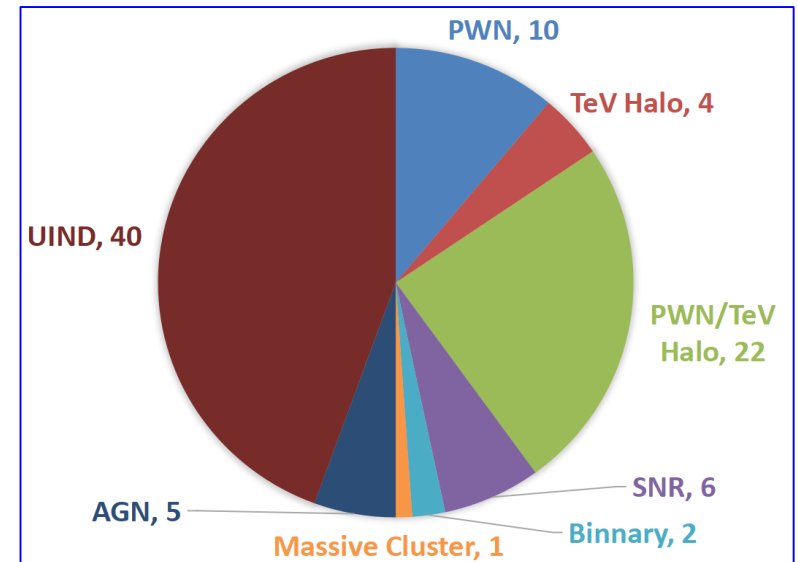
Direct searches of CR sources by γ observation
and implications of precise CR measurements for the origin of CRs

Open a new window above 100TeV for gamma astronomy--

1st LHAASO catalog of VHE-UHE sources



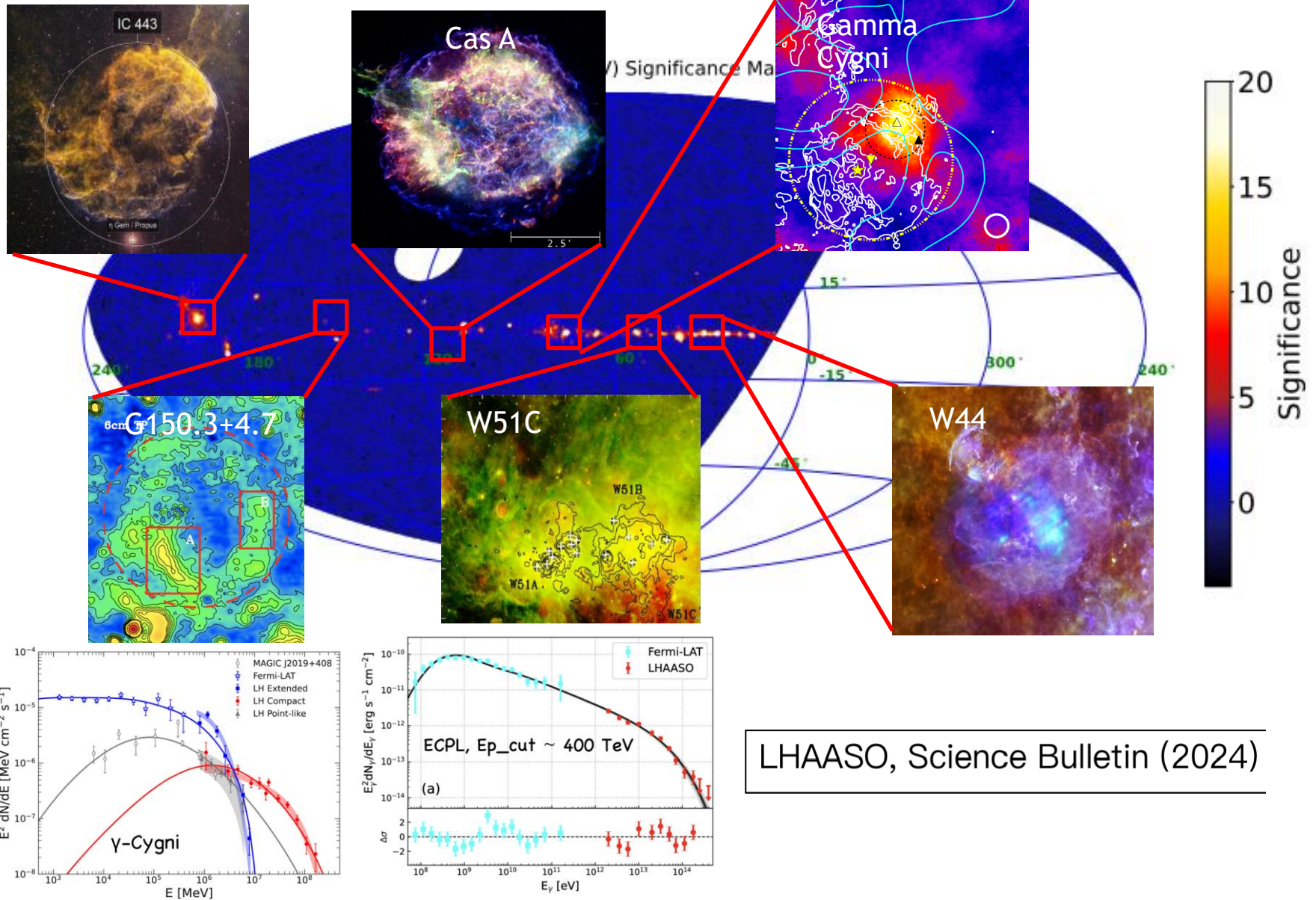
- 90 sources as of Sep. 2022, 32 newly reported, 43 with >100 TeV emission (only 2 before LHAASO)
- 77% by WCDA, 83% by KM2A, 61% by both



Supernova remnants

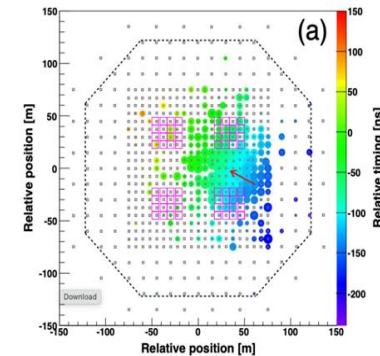
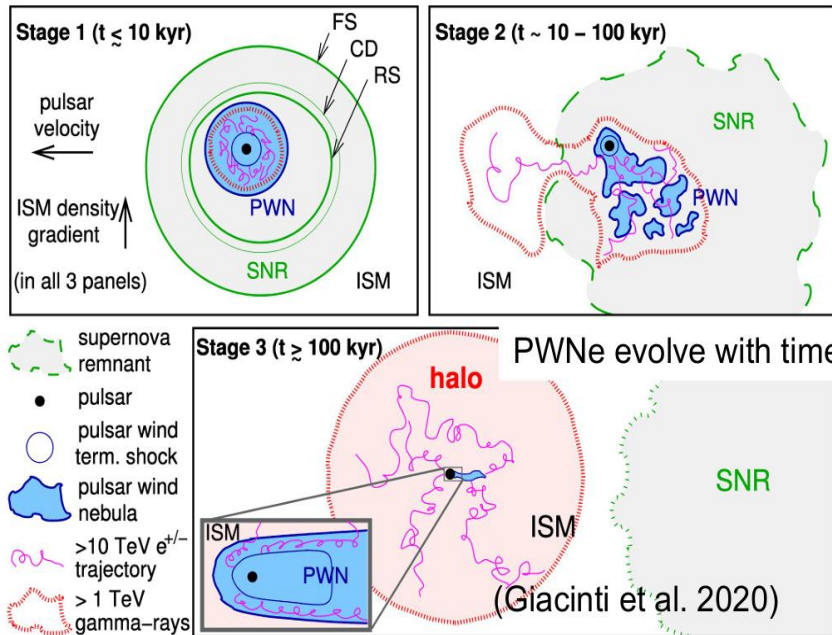
LHAASO, PRL, 136, 161002 (2026)
arXiv: [2510.26112](#)

LHAASO, ApJL, 961, L43 (2024) arXiv: [2310.17082](#)
LHAASO, ApJL, 982, L33 (2025) arXiv: [2502.04848](#)

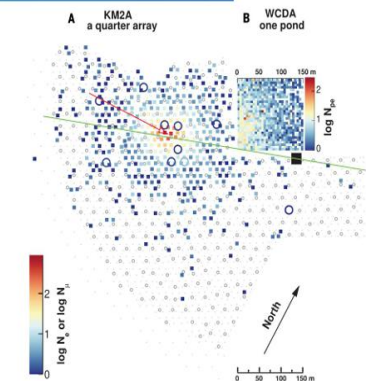


LHAASO, Science Bulletin (2024)

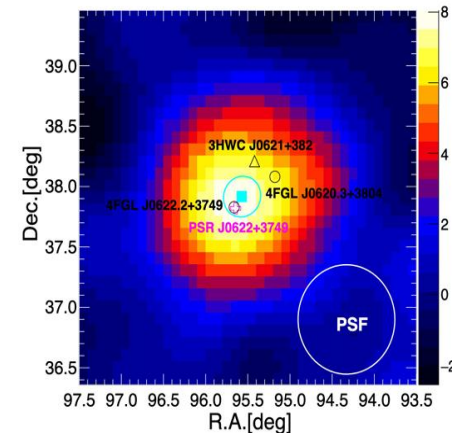
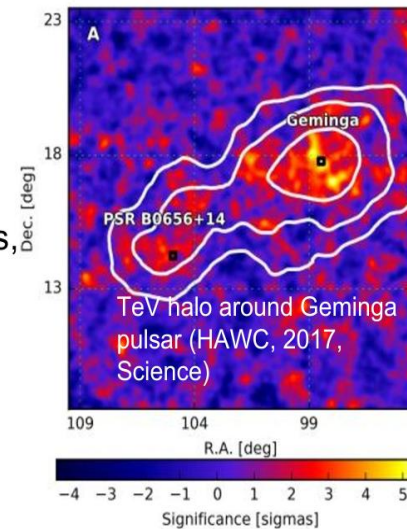
Pulsar Wind Nebulae and pulsar halos



251 TeV photon-like event from Crab nebula (Tibet ASy, 2019, PRL)



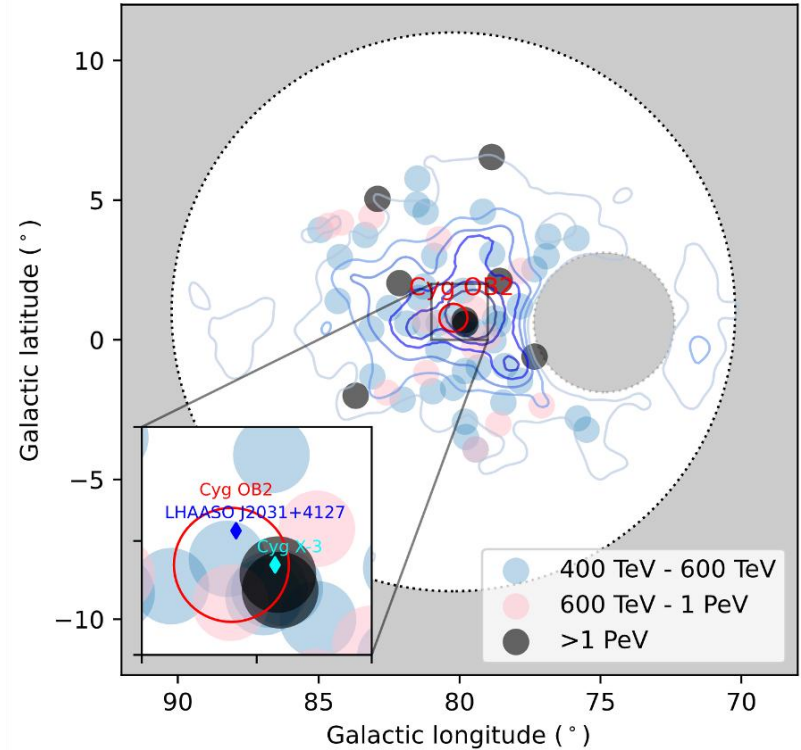
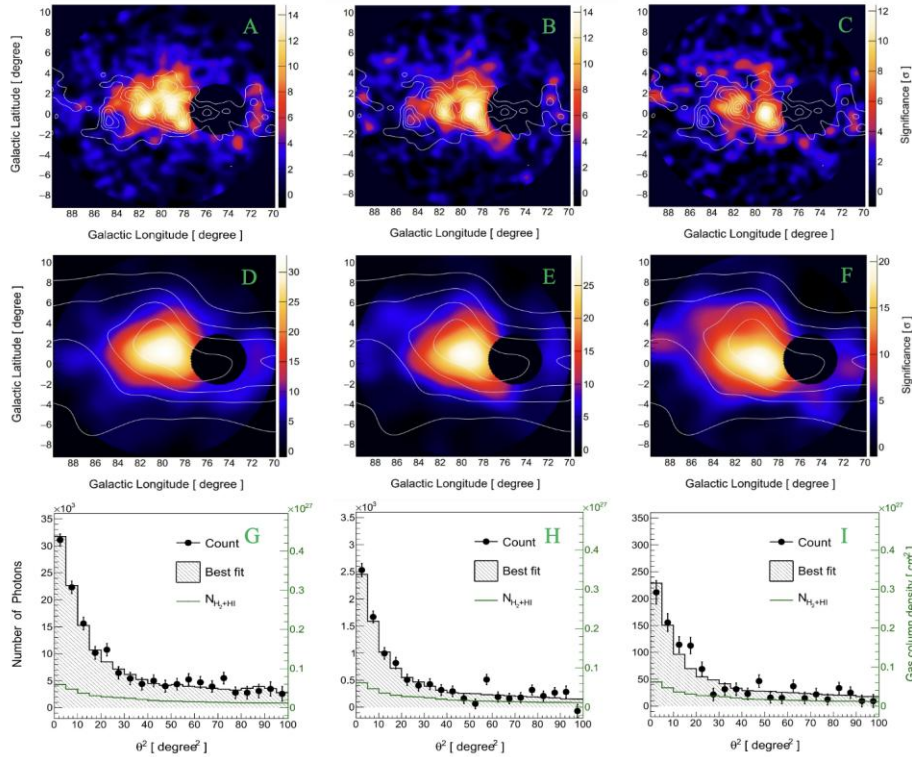
The 0.88-PeV γ -ray event from Crab nebula (LHAASO, 2021, Science)



Halo around PSR J0622+3749 (LHAASO, 2021, PRL) 26

- PWNe: one of the most numerous classes of Galactic TeV sources, samples to study the entire cycle from particle acceleration to particle escape and propagation.
- The **PeV** photons detected from the **Crab Nebula** demonstrated that young PWN could accelerate particles to the **PeV** regime.

Young massive clusters/star-forming regions: Cygnus bubble – a super PeVatron



LHAASO (2024, Sci. Bull.)

8 PeV events, highest energy of 2.5 PeV

6 UHE-emitting Microquasars detected by LHAASO



Microquasar	Distance (kpc)	LHAASO Source	Significance (σ)	Photon Index	Energy Range (TeV)	Extension ^a	Flux ^b (Crab Unit)
SS 433 E.		J1913+0455	9.9 ^c	2.82 ± 0.16	25 – 100	$0.73^\circ \pm 0.07^\circ$	0.10
SS 433 W.	4.9 ± 0.4 [Su2018]	J1910+0509	6.3 ^c	2.94 ± 0.38	25 – 100		0.082
SS 433 central		J1911+0510	8.0	3.96 ± 0.25	100 – 630	$0.32^\circ \pm 0.04^\circ$	0.32
V4641 Sgr	6.2 ± 0.7 [MacDonald14]	J1819-2541	10.5	2.84 ± 0.17	40 – 1000	$0.33^\circ \pm 0.08^\circ$	2.6
GRS 1915+105	9.4 ± 0.6 [Reid23]	J1915+1053	15.1	2.68 ± 0.13	25 – 1000	$0.28^\circ \pm 0.05^\circ$	0.11
MAXI J1820+070	2.96 ± 0.33 [Atri20]	J1821+0723	6.0	3.25 ± 0.26	25 – 400	$< 0.28^\circ$	0.02
Cygnus X-1	2.2 ± 0.2 [Miller-Jones21]	J1958+3522	4.4	3.98 ± 0.40	25 – 100	$< 0.22^\circ$	< 0.01
XTE J1859+226	4.2 ± 0.5 [Shaposhnikov09]	–	2.7	–	–	–	< 0.02
GS 2000+251	2.7 ± 0.7 [Jonker04]	–	2.3	–	–	–	< 0.04
Swift J1727.8-1613	2.7 ± 0.3 [Mata24]	–	0.7	–	–	–	< 0.04
GRO J0422+32	2.49 ± 0.3 [Gelino03]	–	0.7	–	–	–	< 0.01
V404 Cygni	2.39 ± 0.14 [Miller-Jones09]	–	1.5	–	–	–	< 0.03
XTE J1118+480	1.7 ± 0.1 [Gelino06]	–	0.4	–	–	–	< 0.02
V616 Mon	1.06 ± 0.1 [Cantrell10]	–	0.4	–	–	–	< 0.01

PHYSICS

Ultrahigh-energy gamma-ray emission associated with black hole-jet systems

The LHAASO Collaboration^{†,*}

ABSTRACT

Black holes (BH), one of the most intriguing objects in the universe, can manifest themselves through electromagnetic radiation initiated by the accretion flow. Some stellar-mass BHs drive relativistic jets when accreting matter from their companion stars, forming microquasars. Non-thermal emission from the radio to tera-electronvolt (TeV) gamma-ray band has been observed from microquasars, indicating the acceleration of relativistic particles. Here we report detection of four microquasars (SS 433, V4641 Sgr, GRS 1915+105, MAXI J1820+070) of spectrum extending to the ultrahigh-energy (UHE; photon energy $E > 100$ TeV) band and one microquasar (Cygnus X-1) of spectrum approaching 100 TeV, using the Large High Altitude Air Shower Observatory (LHAASO). Notably, the total emission associated with SS 433 cannot be interpreted with a single leptonic component. In the UHE band, its emission is in spatial coincidence with a giant atomic cloud, which is consistent with a hadronic origin. An elongated source is discovered from V4641 Sgr with the spectrum continuing up to 800 TeV. The detection of UHE gamma rays demonstrates that accreting BHs and their environments can operate as extremely efficient accelerators of particles out of 1 peta-electronvolt (PeV), suggesting microquasars to be important contributors to Galactic cosmic rays especially around the ‘knee’ region.

PHYSICS

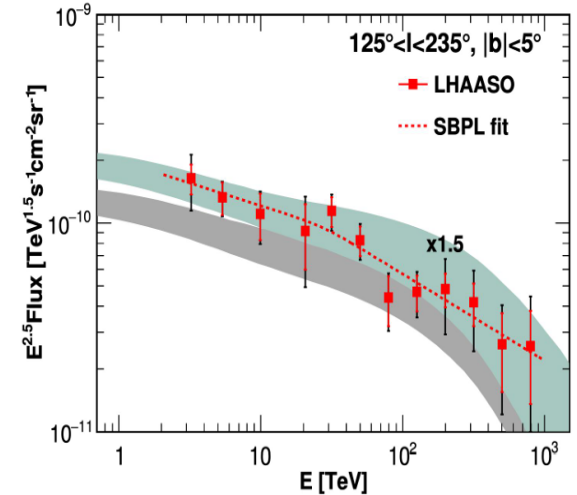
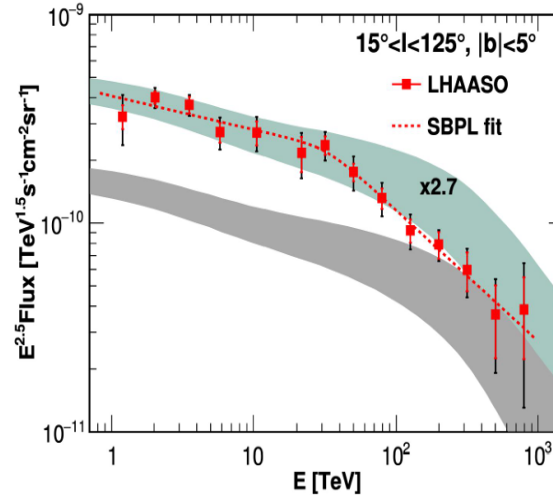
Cygnus X-3: A variable petaelectronvolt γ -ray source

The LHAASO Collaboration^{†,*}

LHAASO, National Science Review (2025, 2026)

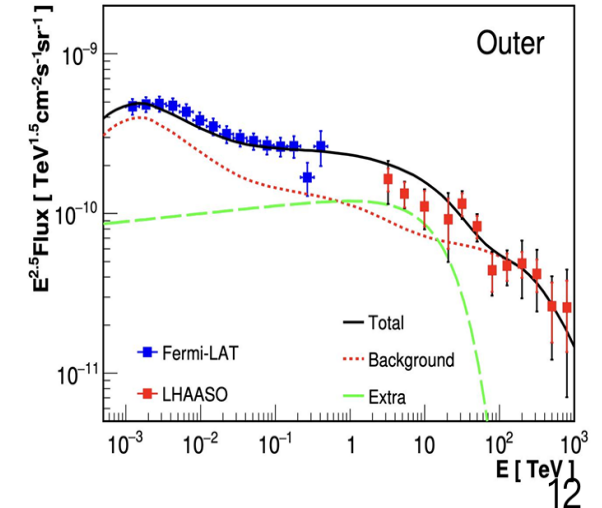
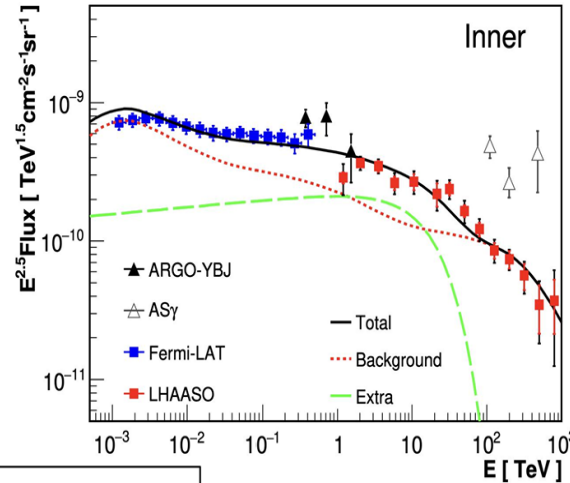
Measurements of Galactic Diffuse Emission

- ❑ Measured fluxes > model prediction
(local CR spectra+gas column density)
- ❑ Inner region: break around 30 TeV
(indices changing from ~ 2.7 to ~ 3.1).
- ❑ An empirical component with spectrum $\propto E^{-2.45} \exp(-E/20 \text{ TeV})$ added to CR propagation model can fit the measured excess.



Possible explanations:

- Unresolved sources ?
(PWN/pulsar halo, YMCs...)
- Confinement and interaction of CRs around acceleration sites?
- Change of the canonical propagation scenario?
- ...



LHAASO, PRL, 134, 081002 (2025) arXiv: [2411.16021](https://arxiv.org/abs/2411.16021)

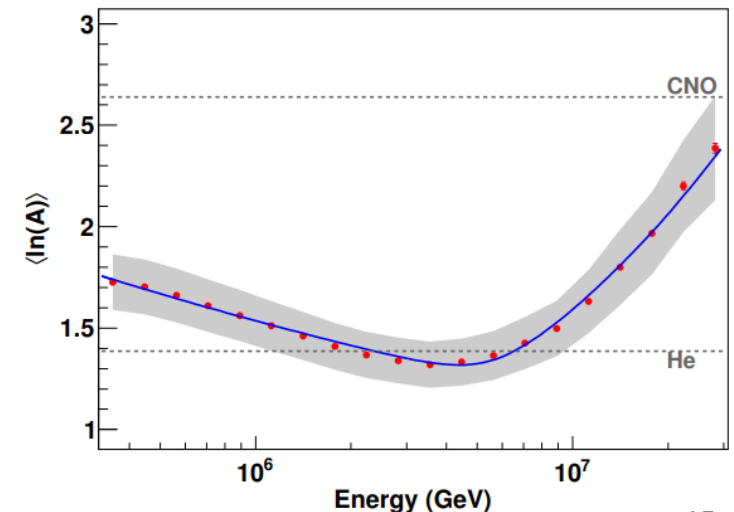
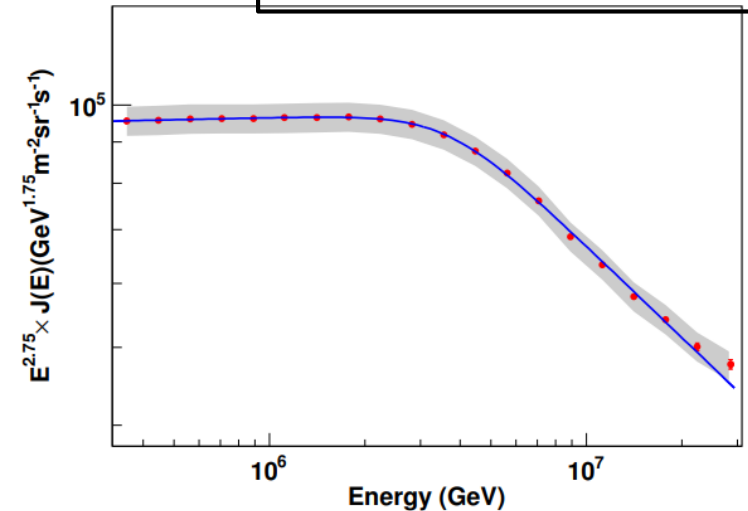
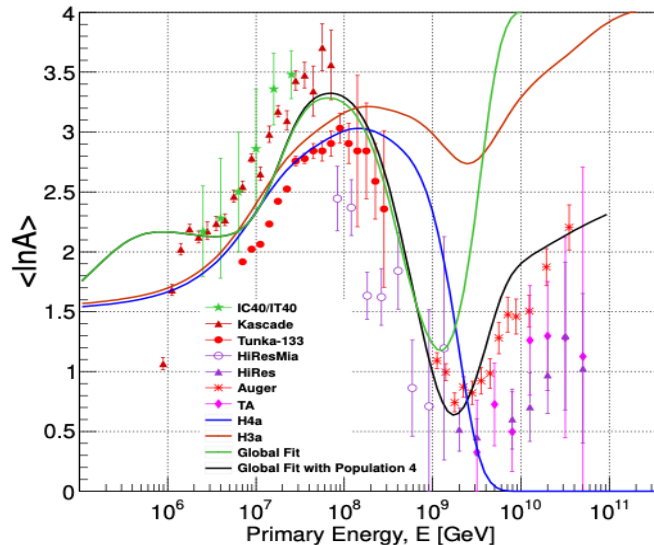
Summary of gamma ray observation

- For SNR, complicated morphologies and spectra are measured with cutoff of hundred TeV. SNR may NOT be the PeVatrons.
- For PWN, $>\text{PeV}$ γ s are detected implying very high acceleration efficiency.
- UHE emission detected from 6 microquasars showing BH+jet systems provide promising sites for extreme multi-PeV acceleration.
- Diffuse gamma ray emission by LHAASO is 2-3 times higher than prediction (CR + gas).

Precise measurement of CR knee spectrum and mass by LHAASO

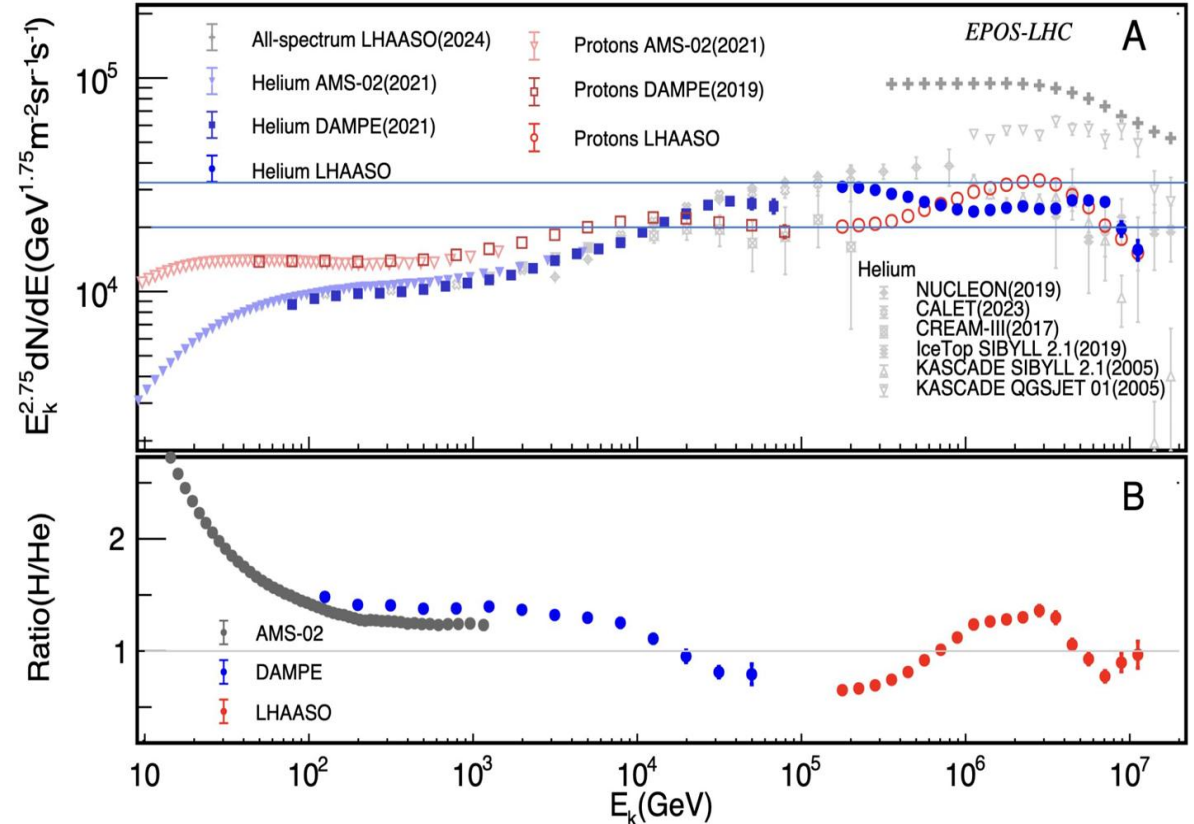
*LHAASO,
Phys.Rev.Lett. 132 (20
24) 13, 131002*

- The new measurement improves precision greatly
- First time detect a decrease of $\langle \ln A \rangle$ before knee, means the heavy component decreases
- We decode the data to uncover the bkg CR model
- **Key:** decrease of $\langle \ln A \rangle$ may be from the cutoff of Fe spectrum of the local source



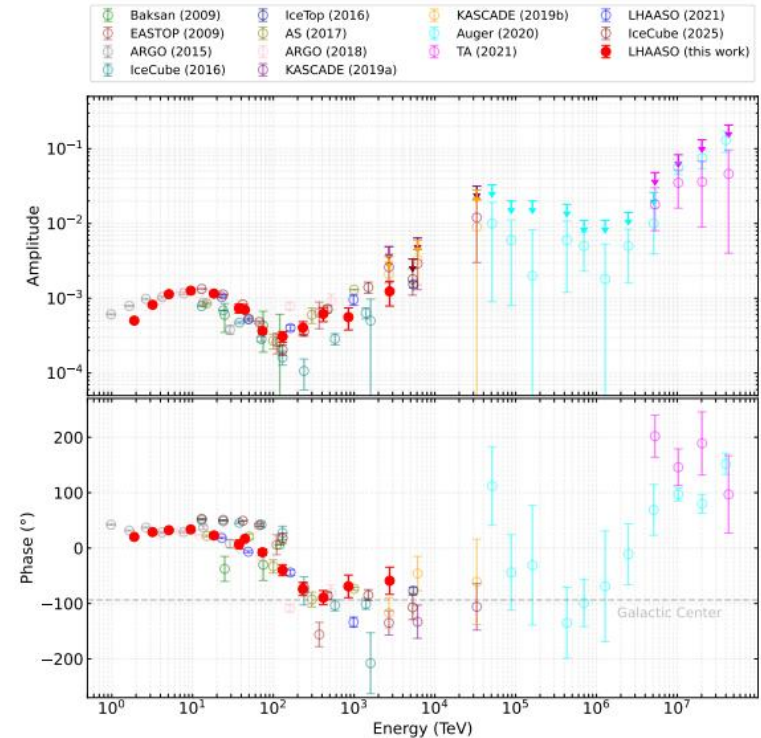
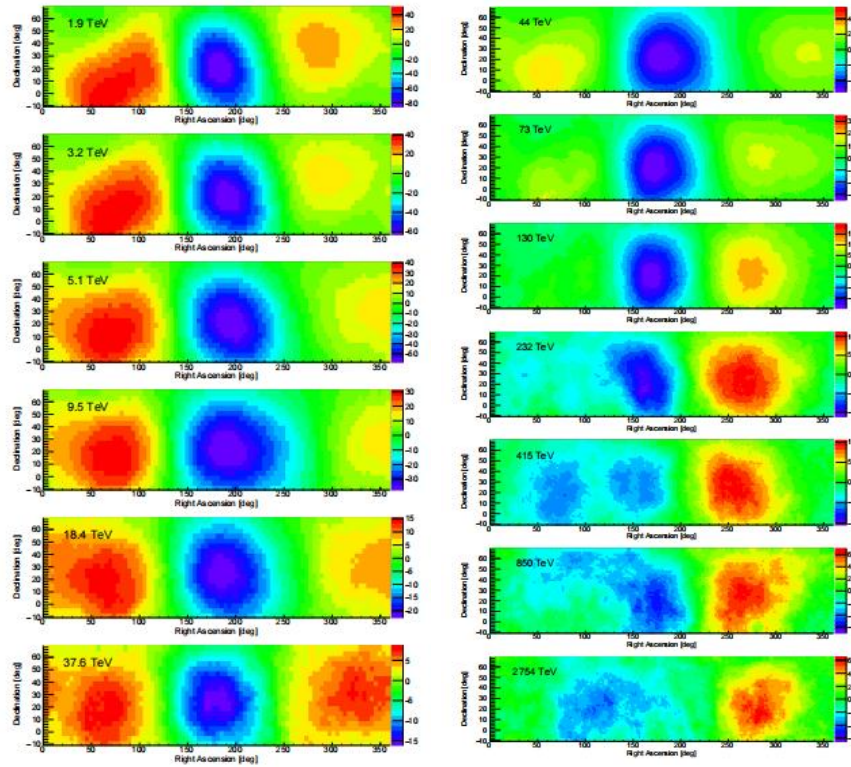
Measurement of CR proton and helium spectra

- ❑ The “knee” is not simply a single cutoff, p and He show different spectral structures and different characteristic energies.
- ❑ p: hardening at ~340 TeV, softening (knee) at ~3.3 PeV
- ❑ He: hardening at ~ 1.1 PeV, softening (knee) at ~7 PeV
- ❑ p/He ratio reverses at least 3 times over the energy range from 10 TeV to 10 PeV (He-rich ~0.1 PeV, P-rich ~3 PeV)



LHAASO, Science Bulletin, 70, 24 (2025) arXiv: [2505.14447](https://arxiv.org/abs/2505.14447)
 LHAASO, PRL, 136, 121001 (2026) arXiv: [2511.05013](https://arxiv.org/abs/2511.05013)

Large-scale anisotropy of all particles



- Energy coverage: 1.9 TeV - 2.7 PeV
- Amplitude peaks at ~10 TeV, reaches a dip at ~100 TeV; phase change smoothly from ~30° to 270° (Galactic center)

LHAASO, PRL, 137, 051004 (2026)

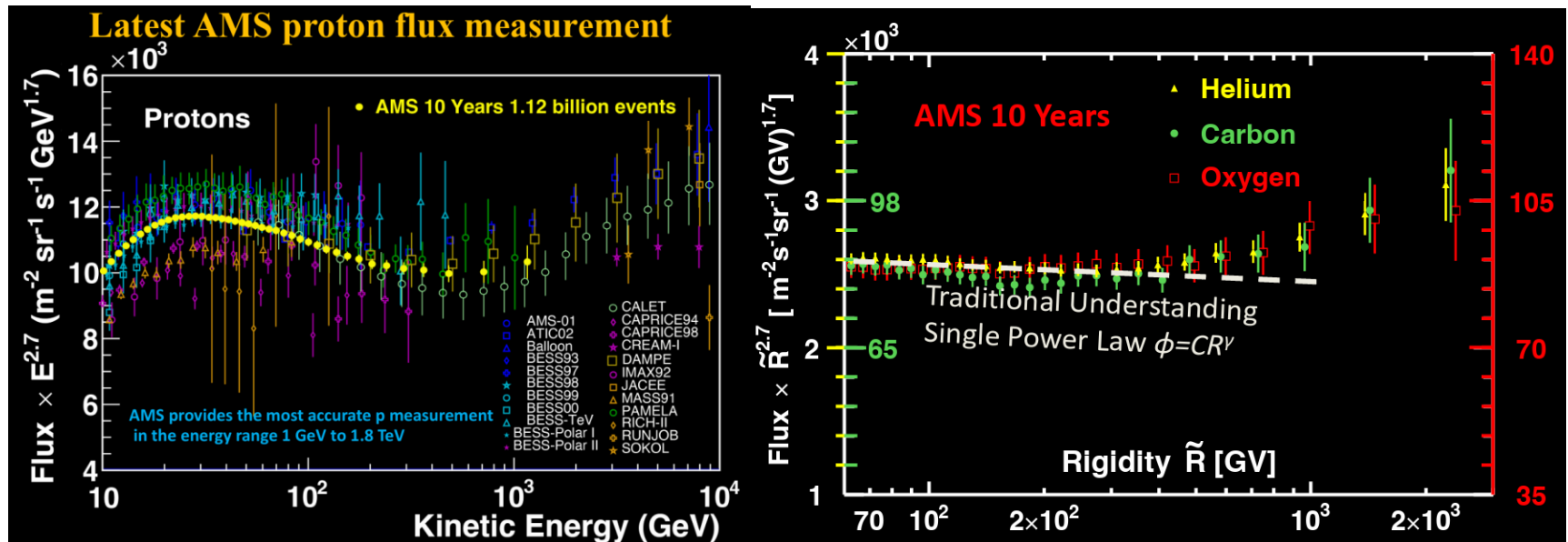
arXiv: [2512.18401](https://arxiv.org/abs/2512.18401)

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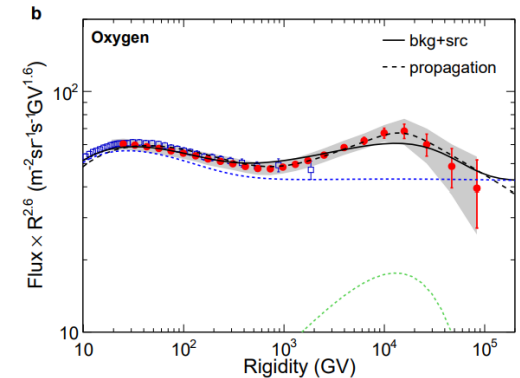
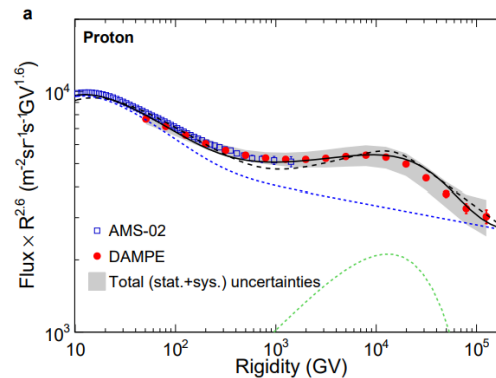
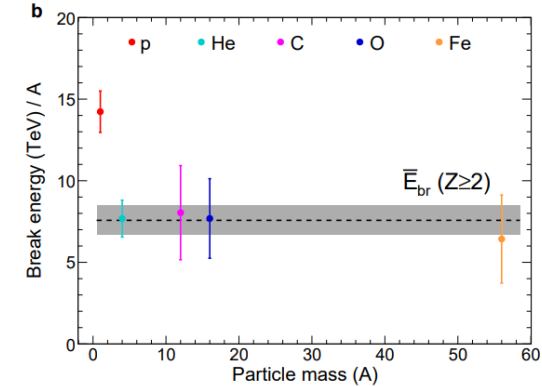
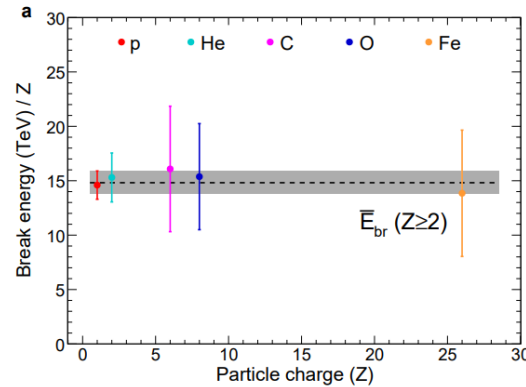
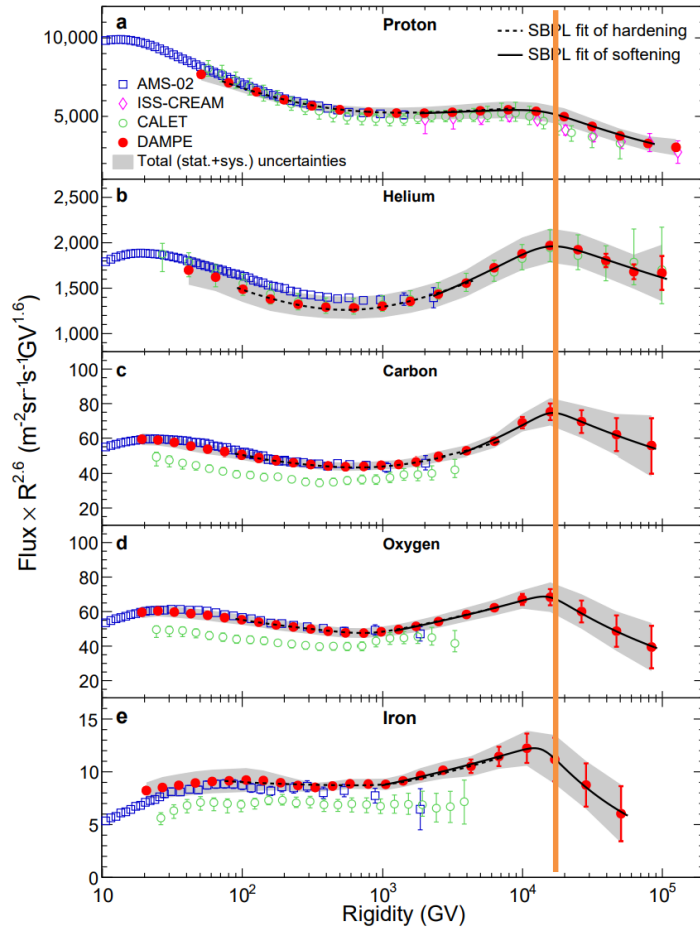
Cosmic ray precise measurements

- AMS02 started a new era of precision cosmic rays – fine features in CRs were detected



Latest result of DAMPE

***Nature* 653 (2026)
8113, 52-55**

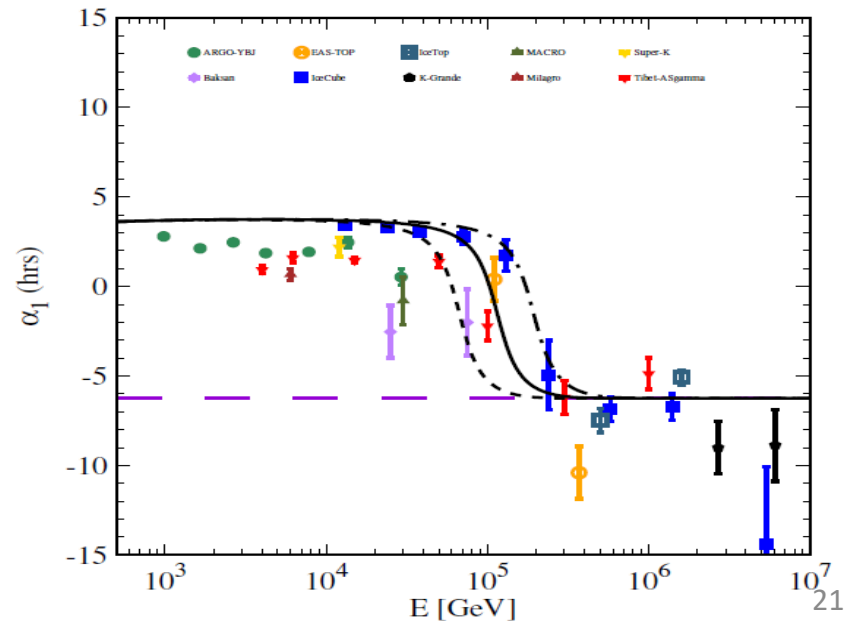
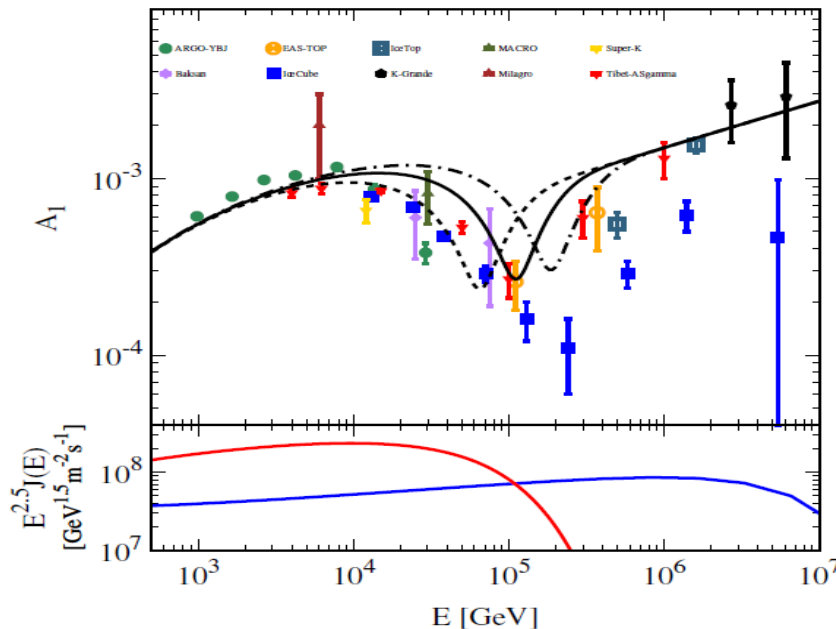
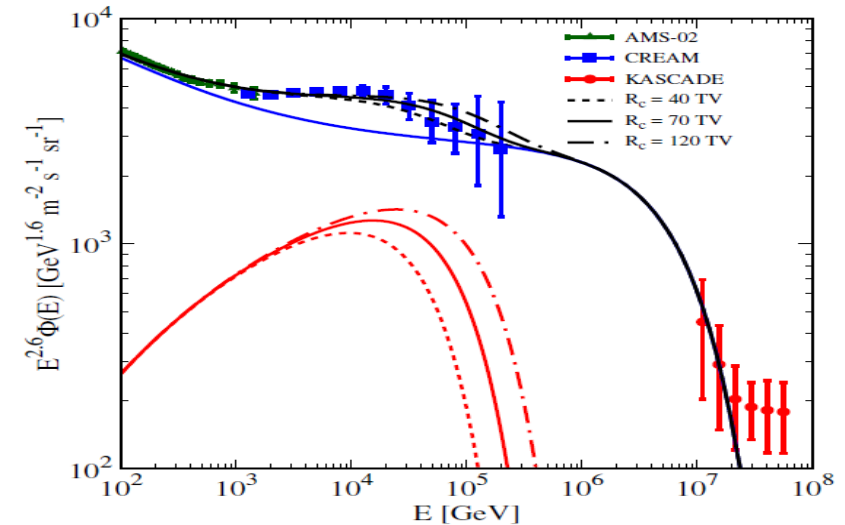


A universal spectral softening at ~13TV of primary species has been observed; the observation favors a local source contributing to the bump

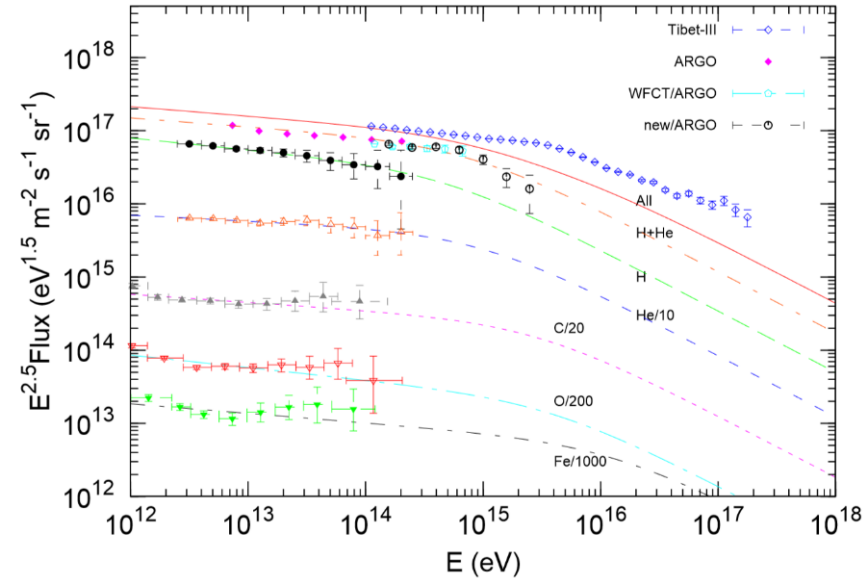
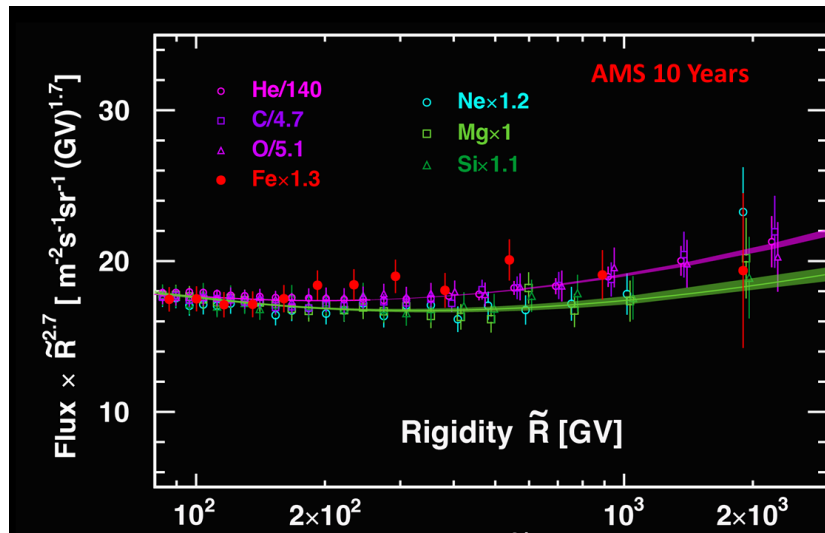
prediction: coevolution of anisotropy and spectra

(Guo et al, 2019, JCAP)

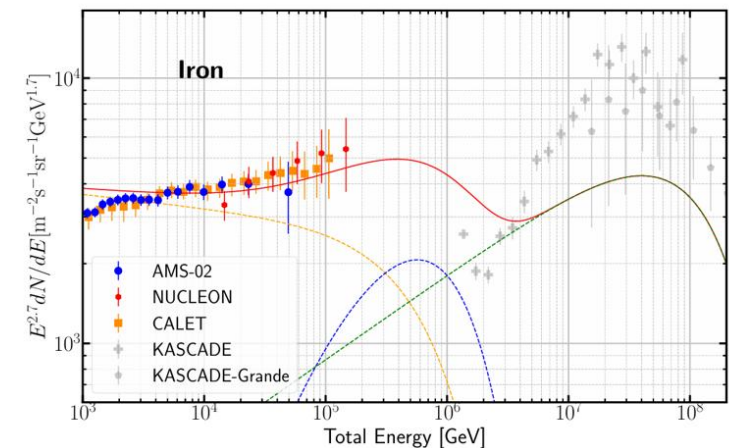
1. Large anisotropy from the nearby source
2. spectra/anisotropy correlated closely;
3. Data strongly support the assumption.



3 components of Galactic CRs

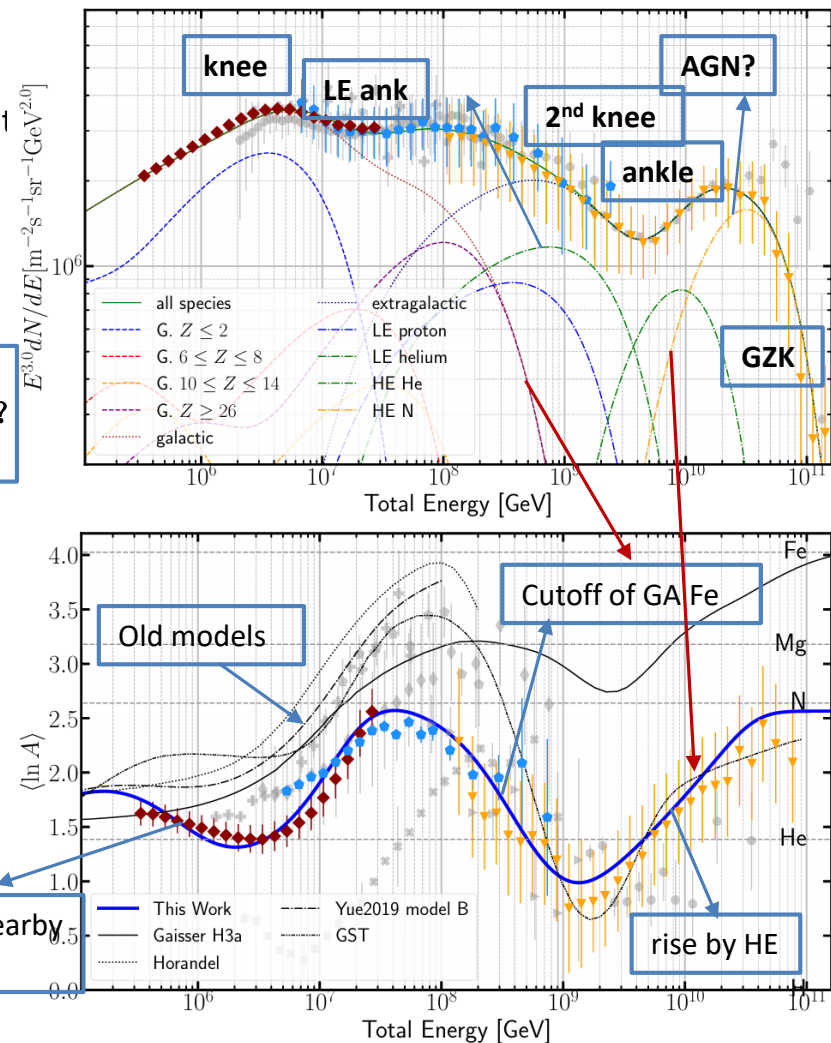
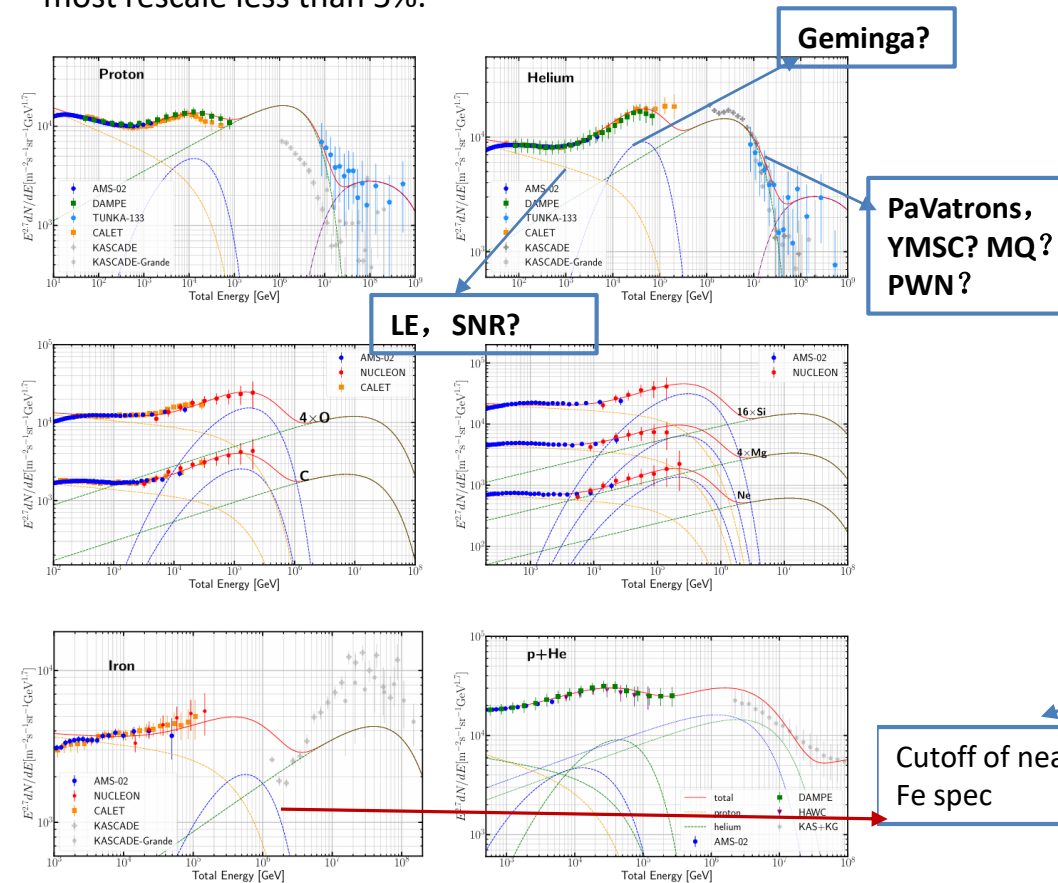


- AMS02 spectra determine bkg; however, they are too soft to account for the knee
- A 'hard' high energy component is needed to account for knee



Lv, XJB et al.,
APJ 979 (2025) 2, 225

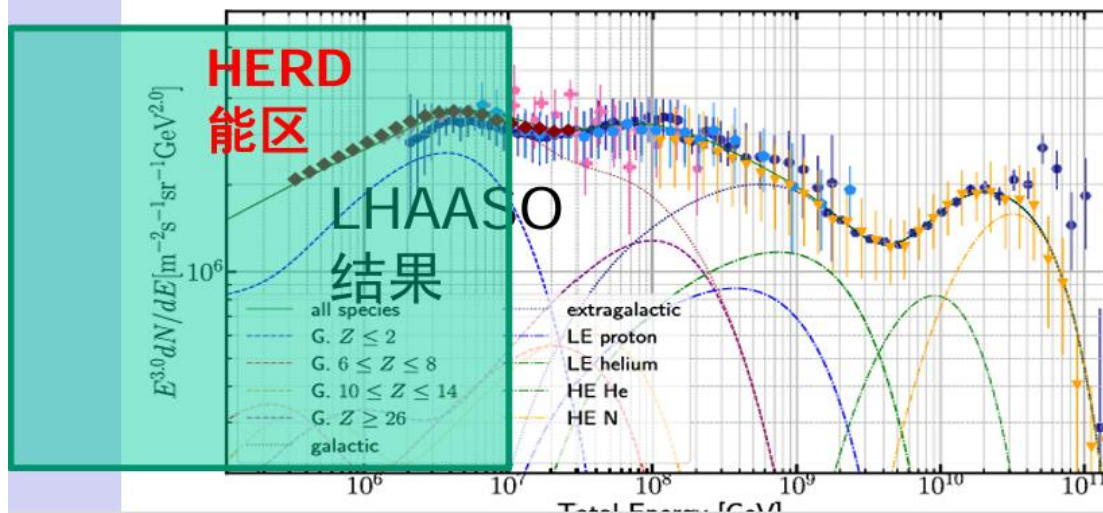
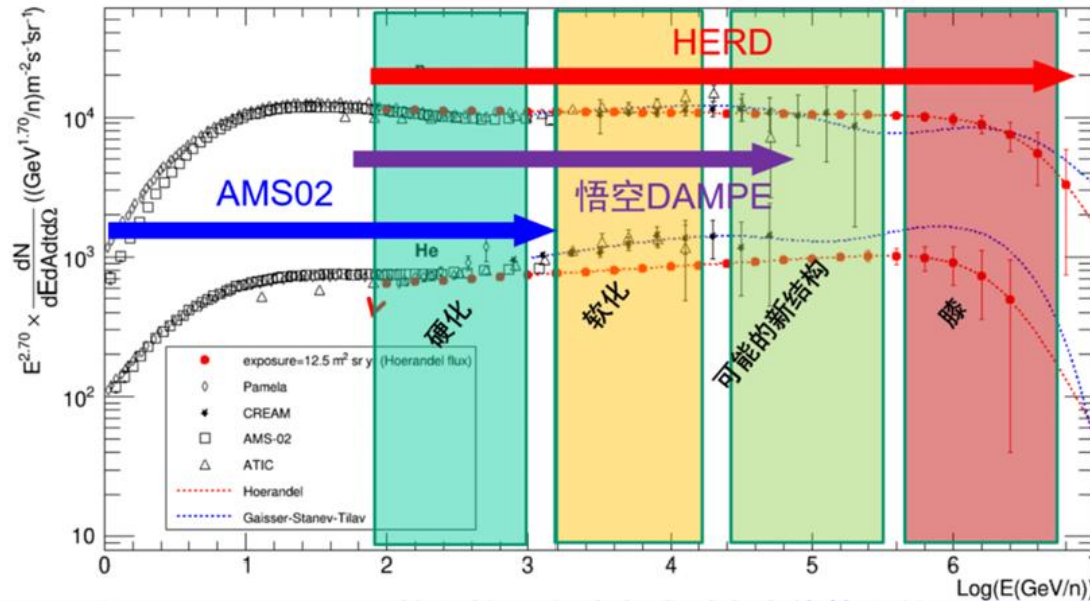
CR Origin: AMS02-DAMPE-HAWC-LHAASO-TUNKA-Auger
 energies are calibrated and rescaled to AMS02. very impressively that
 most rescale less than 5%.



Implications of CR origin

- The observed CRs are contributed by at least 2 kinds of GA sources plus a local source.
- LE CR may come from SNRs according to the energy budget
- 'Hard' HE component may come from YMSC /MQ; 6 microquasars were observed by LHAASO as Pevatrons.
- The above model perspective is consistent with the γ observation of LHAASO.
- **Perspective:** abundance of different CR species implies the nature of the sources.
- HERD will give more precise measurement of spectra of all species and connect the space-based and ground-based spectra

HERD (CSS-based, 2029) capability

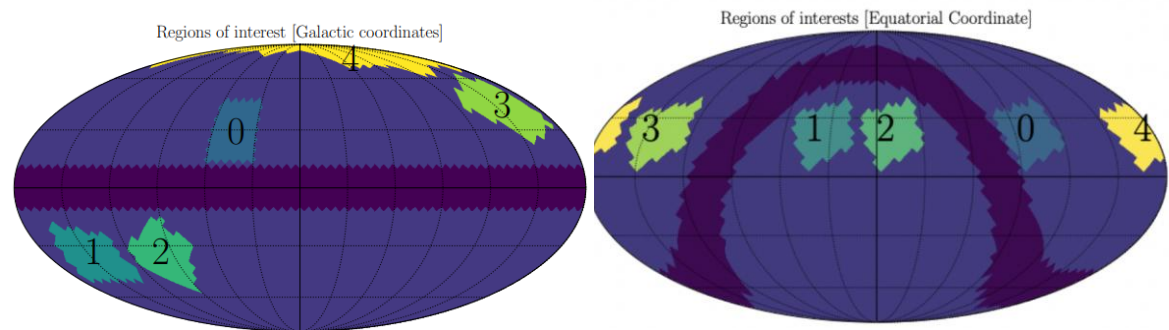


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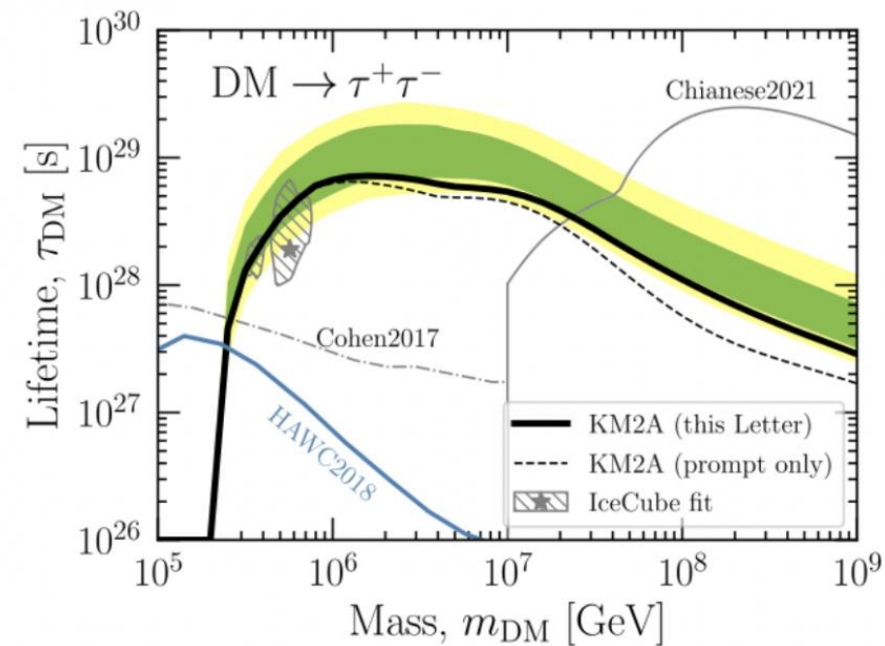
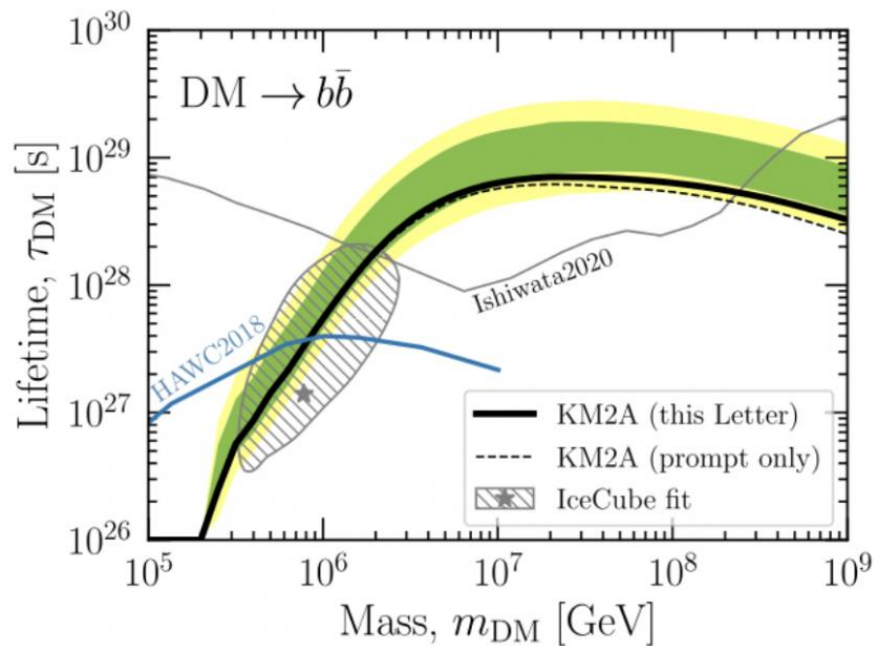
I -Superheavy DM decay from the Galactic halo

- The signal region is chosen ROI_0 , around $15^\circ \leq \tilde{b} \leq 45^\circ$ and $30^\circ \leq \ell \leq 60^\circ$
 - Away from Galactic plane and Fermi bubble
 - As close to the GC as possible
- 4 control regions $\text{ROI}_1 - \text{ROI}_4$ by shifting ROI_0 along the RA direction by 90° , 135° , 240° , 285° respectively
 - Same declination and same detector performance
 - For accurate estimate the bkg and eliminate systematics



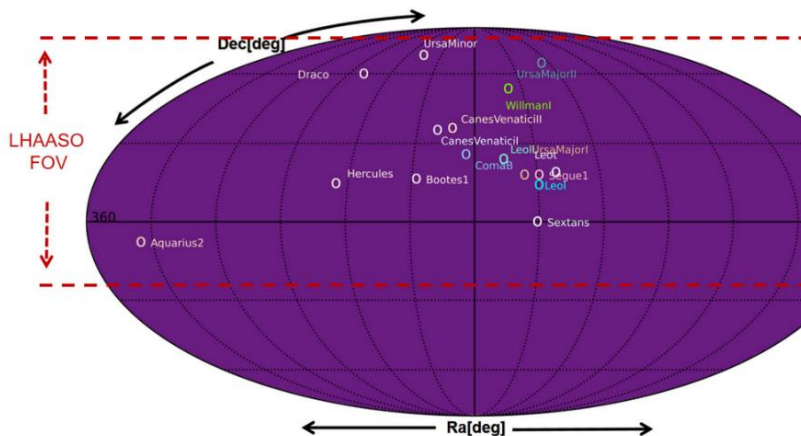
Constraints on Heavy Decaying Dark Matter from 570 Days of LHAASO Observations

Phys.Rev.Lett. 129 (2022) 26, 261103



II -Dark matter annihilation signals from the dwarf galaxies

表 4.1 LHAASO (WCDA 和 KM2A) 视场范围内 16 个矮椭球星系的赤经、赤纬和有效观测时间 (天)



Name	RA[deg]	Dec[deg]	T_{WCDA}	T_{KM2A}
Draco	260.05	57.92	690.37	730.76
UrsaMinor	227.28	67.23	701.59	739.53
UrsaMajorI	158.71	51.92	692.51	742.17
UrsaMajorII	132.87	63.13	688.88	740.83
Bootes1	210.02	14.50	699.85	742.01
CanesVenaticiI	202.02	33.56	699.01	743.28
ComaB	186.74	23.90	696.88	744.34
LeoI	152.12	12.30	692.19	743.02
Segue1	151.77	16.08	691.72	743.06
Sextans	153.26	-1.61	693.36	743.60
CanesVenaticiII	194.29	34.32	698.15	743.81
Hercules	247.76	12.79	699.04	737.33
LeoII	168.37	22.15	693.95	744.18
WillmanI	162.34	51.05	693.45	742.21
Aquarius2	338.48	-9.33	666.84	728.11
LeoT	143.72	17.05	690.84	742.51

Density profile of DM in the dwarf galaxies

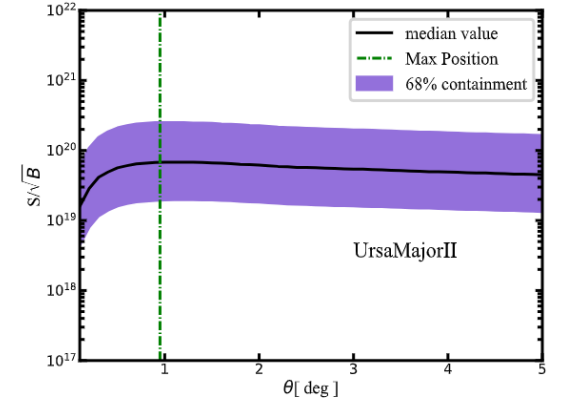
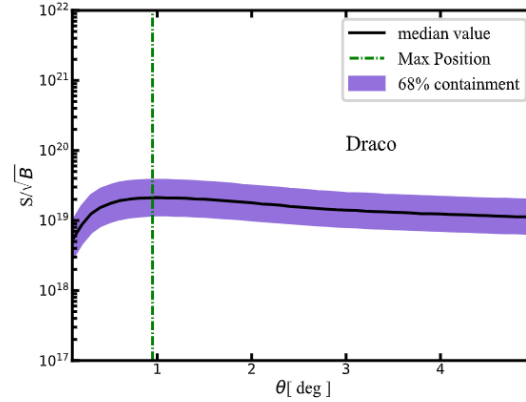


表 4.3 每个矮椭圆星系的 J-因子的相应密度分布参数 ^[146]

Source	d/kpc	r_t/kpc	$\log_{10}(\rho_s/M_\odot \text{kpc}^{-3})$	$\log_{10}(r_s/\text{kpc})$
Draco	67.40	9.07	7.45	0.17
UrsaMinor	73.29	6.92	7.91	-0.18
UrsaMajorI	95.58	8.34	7.83	-0.19
UrsaMajorII	29.90	6.26	7.27	0.38
BootesI	65.69	9.06	6.62	0.58
CanesVenaticiI	211.09	19.82	7.20	0.14
ComaB	42.31	5.14	7.57	0.06
LeoI	266.15	23.25	7.72	-0.09
Segue1	23.88	3.41	6.96	0.39
Sextans	89.63	11.88	6.32	0.65
CanesVenaticiII	166.26	29.91	6.50	0.70
Hercules	138.16	22.21	6.17	0.82
LeoII	242.44	19.15	7.95	-0.23
WillmanI	44.46	8.07	7.81	0.10
Aquarius2	107.50	24.46	6.59	0.78
LeoT	380.69	25.00	6.69	0.74

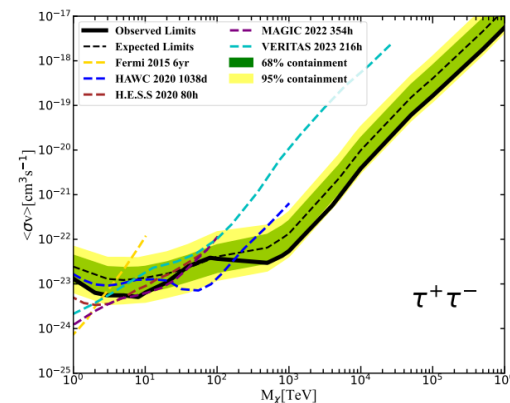
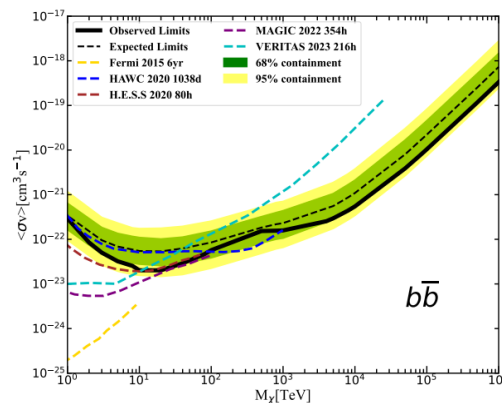
表 4.4 本次工作中考虑的 16 个矮椭圆星系的 ROI 半宽度和 J- (D-) 因子

Name	$\log_{10}(J/\text{GeV}^2 \text{cm}^{-5})$	$\theta_{\text{anni}}[\text{deg}]$	$\log_{10}(D/\text{GeVcm}^{-2})$	$\theta_{\text{decay}}[\text{deg}]$
Draco	$18.96^{+0.16}_{-0.15}$	1.0	$18.49^{+0.33}_{-0.41}$	2.3
UrsaMinor	$18.79^{+0.12}_{-0.11}$	1.0	$18.68^{+0.33}_{-0.15}$	2.1
UrsaMajorI	$18.4^{+0.28}_{-0.27}$	0.9	$18.6^{+0.48}_{-0.46}$	1.6
UrsaMajorII	$19.73^{+0.43}_{-0.42}$	1.1	$19.46^{+0.45}_{-0.59}$	2.2
BootesI	$18.39^{+0.36}_{-0.37}$	0.9	$18.81^{+0.41}_{-0.56}$	2.0
CanesVenaticiI	$17.43^{+0.16}_{-0.15}$	0.8	$18.19^{+0.4}_{-0.39}$	1.3
ComaB	$19.26^{+0.30}_{-0.43}$	0.9	$19.19^{+0.48}_{-0.77}$	2.1
LeoI	$17.58^{+0.10}_{-0.10}$	0.8	$18.47^{+0.34}_{-0.43}$	1.5
Segue1	$19.25^{+0.60}_{-0.69}$	0.8	$18.48^{+0.78}_{-0.70}$	1.2
Sextans	$17.80^{+0.10}_{-0.10}$	1.0	$18.49^{+0.21}_{-0.21}$	1.8
CanesVenaticiII	$17.87^{+0.38}_{-0.37}$	0.8	$18.48^{+0.51}_{-0.75}$	1.5
Hercules	$17.6^{+0.53}_{-0.69}$	0.8	$17.84^{+0.66}_{-0.64}$	1.2
LeoII	$17.72^{+0.18}_{-0.17}$	0.8	$17.85^{+0.62}_{-0.40}$	1.0
WillmanI	$19.8^{+0.50}_{-0.52}$	0.9	$19.03^{+0.72}_{-0.94}$	1.6
Aquarius2	$18.57^{+0.50}_{-0.57}$	1.1	$18.6^{+0.64}_{-0.71}$	1.6
LeoT	$17.66^{+0.55}_{-0.52}$	0.8	$17.9^{+0.66}_{-0.70}$	1.1

Most stringent constraint on heavy DM annihilation by LHAASO

Phys.Rev.Lett. 133
(2024) 6, 061001

- With 756 dates WCDA and 794 dates KM2A data and by combining the 16 dwarfs the most stringent constraint on DM annihilation is derived.



Kinetics with LIV $E^2 = p^2 c^2 * (1 + a_1(pc / M_{pl} c^2) + a_2(pc / M_{pl} c^2)^2 + \dots)$

- A free photon in vacuum is stable in LI; For LIV, if the effective mass of a photon $E_\gamma^2 - p_\gamma^2 = \frac{p_\gamma^{n+2}}{E_{LIV}^n} = m_{\gamma,eff}^2$ is greater than a pair of e^+e^- , the photon decay $\gamma \rightarrow e^+e^-$ very fast and leads to a sharp cutoff at the SED
- Change the threshold of interaction. The threshold of $\gamma\gamma \rightarrow e^+e^-$ $\epsilon_{thr} = \frac{m_e^2 c^4}{E} + \frac{1}{8} \left(\frac{E}{E_{LIV}} \right) E$ is improved; more transparent of EBL
- Energy dependent speed of light at LIV; $\mathbf{v(E)} = \partial \omega / \partial k = \partial E / \partial p$
 $\mathbf{c \left(1 \pm \frac{1+n}{2} (E/E_{LIV,n})^n \right)}$, it leads to time delay for different E from z,
 $\approx$
... others

$$\Delta t = \frac{\Delta z}{H_0} = \frac{1+n}{2H_0} \left(\frac{E_0}{\xi E_{pl}} \right)^n \int_0^z \frac{(1+z')^n dz'}{\sqrt{\Omega_m (1+z')^3 + \Omega_\Lambda}}$$

Photon decay or splitting induced by LIV

- LIV also leads to a photon decay or splitting to 3 photons

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

Splitting: $\gamma \rightarrow 3\gamma$

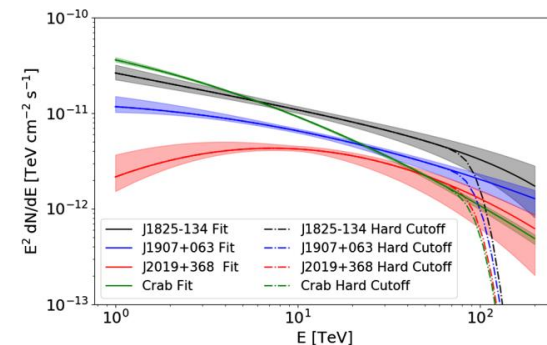
$$E_{\text{LIV}}^{(1)} \gtrsim 9.57 \times 10^{23} \text{ eV} \left(\frac{E_\gamma}{\text{TeV}} \right)^3,$$

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

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

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

- LIV decay or splitting leads to sharp cutoff the high energy end of the spectrum
- We analyze the LHAASO data of gamma ray SED to look for the LIV cutoff



The result

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

Process: $\gamma \rightarrow 3\gamma$

$$E_{LIV}^{(1)} \gtrsim 9.57 \times 10^{23} \text{ eV} \left(\frac{E_\gamma}{\text{TeV}} \right)^3, \quad \Gamma_{\gamma \rightarrow 3\gamma} = 5 \times 10^{-14} \frac{E_\gamma^{19}}{m_e^8 E_{LIV}^{(2)10}},$$

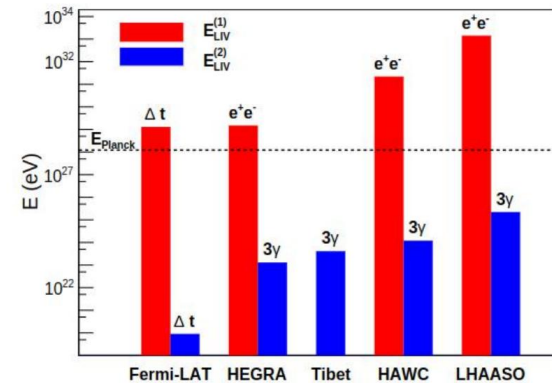
$$E_{LIV}^{(2)} \gtrsim 9.78 \times 10^{17} \text{ eV} \left(\frac{E_\gamma}{\text{TeV}} \right)^2, \quad E_{LIV}^{(2)} > 3.33 \times 10^{19} \text{ eV} \left(\frac{L}{\text{kpc}} \right)^{0.1} \left(\frac{E_\gamma}{\text{TeV}} \right)^{1.9}.$$

Source	L (kpc)	E_{max} (PeV)	$E_{\text{cut}}^{95\%}$ (PeV)	$E_{LIV}^{(1)}$ (eV) $\times 10^{32}$	$E_{LIV}^{(2)}$ (eV) $\times 10^{23}$	$E_{LIV}^{(2)} (3\gamma)$ (eV) $\times 10^{25}$
Crab Nebula	2.0	0.88 ± 0.11	$0.75^{+0.04}_{-0.04}$	$4.04^{+0.69}_{-0.62}$	$5.5^{+0.61}_{-0.58}$	$1.04^{+0.11}_{-0.10}$
J2032+4102	1.4	1.42 ± 0.13	$1.14^{+0.06}_{-0.06}$	$14.2^{+2.42}_{-2.18}$	$12.7^{+1.41}_{-1.34}$	$2.21^{+0.23}_{-0.22}$

$$E_{\text{planck}} = 1.22 \times 10^{19} \text{ GeV}$$

$10^5 E_{\text{planck}}$

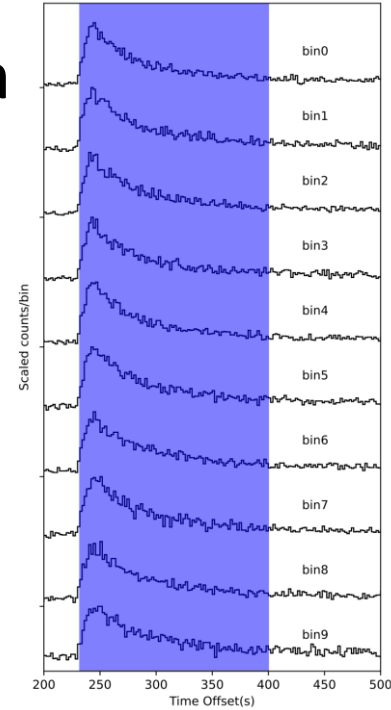
$0.1\% E_{\text{planck}}$



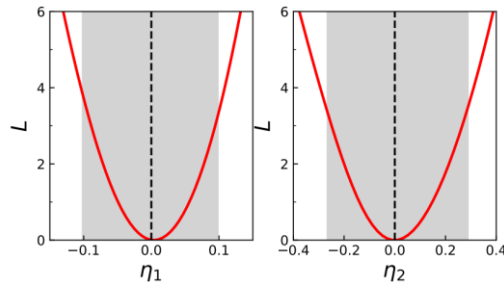
$E_{LIV}^{(1)}$ and $E_{LIV}^{(2)}$ more than 1 order of magnitude

Time lag by LIV of different energy photons from GRB 221009A

- **Cross correlation function (CCF).** Light curves of different energy bands are given by the WCDA data. CCF method is adopted to derive the time lags of the different light curves.
- **Maximal likelihood method.** The probability density function (PDF) of a photon at time t and N_{hit} is given. $\lambda(t)$ is the intrinsic light curve with possible time lag $\Delta t_{LIV}(E)$.



Light curves of different energy bins by WCDA



$$P(t, N_{hit} | \eta_n, I) \propto \int_0^\infty \lambda[t - \Delta t_{LIV}(E, \eta_n)] \gamma(E) \times F(E) A_{N_{hit}}(E) dE; N_{hit} = 0, 1, \dots, 9$$

The stringent LIV constraint by time of flight

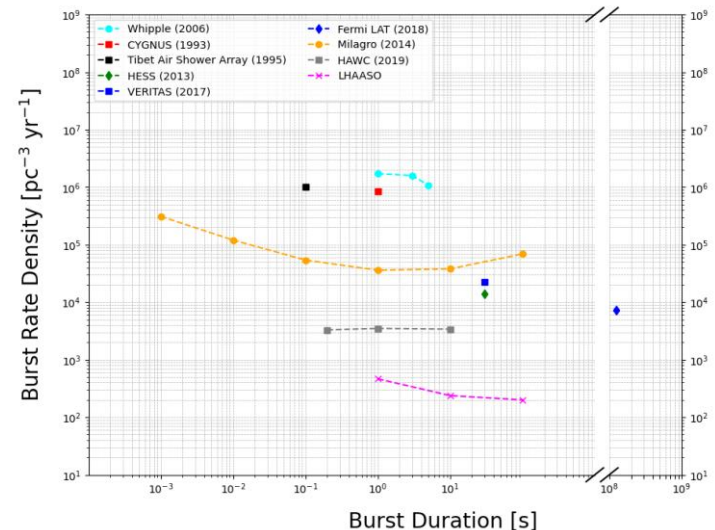
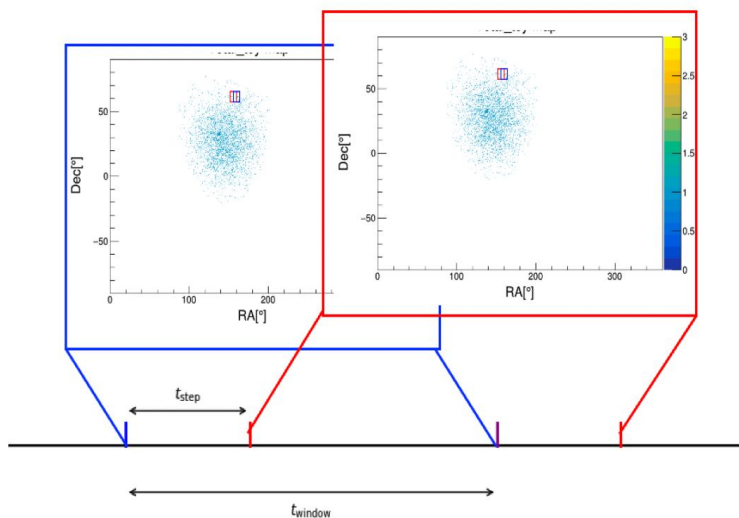
*LHAASO Coll, PRL
133 (2024) 7, 071501*

- For the 2nd LIV the LHAASO constraint is the best one with 6-8 times improvement to Fermi-LAT result.

Method	Cross correlation function			Maximum likelihood		
	η^{LL}	η^{BF}	η^{UL}	η^{LL}	η^{BF}	η^{UL}
η_1	-0.25	0.05	0.18	-0.10	0.00	0.10
η_2	-0.60	0.25	0.64	-0.27	0.00	0.29
	superluminal		subluminal	superluminal		subluminal
$E_{\text{QG},1} [10^{20} \text{ GeV}]$	0.5		0.7	1.2		1.2
$E_{\text{QG},2} [10^{11} \text{ GeV}]$	5.0		4.8	7.5		7.2

Constraints on PBH burst rate

- We perform a search for individual local PBH burst events using the LHAASO-WCDA data
- With time windows of 1s, 10s, and 100s, no significant gamma-ray burst events are observed, except for GRB 221009A.
- The upper limit of the local PBH burst rate density is set to be as low as $200 \text{ pc}^{-3} \text{ yr}^{-1}$ at 99% confidence level, representing the strongest limit achieved to date

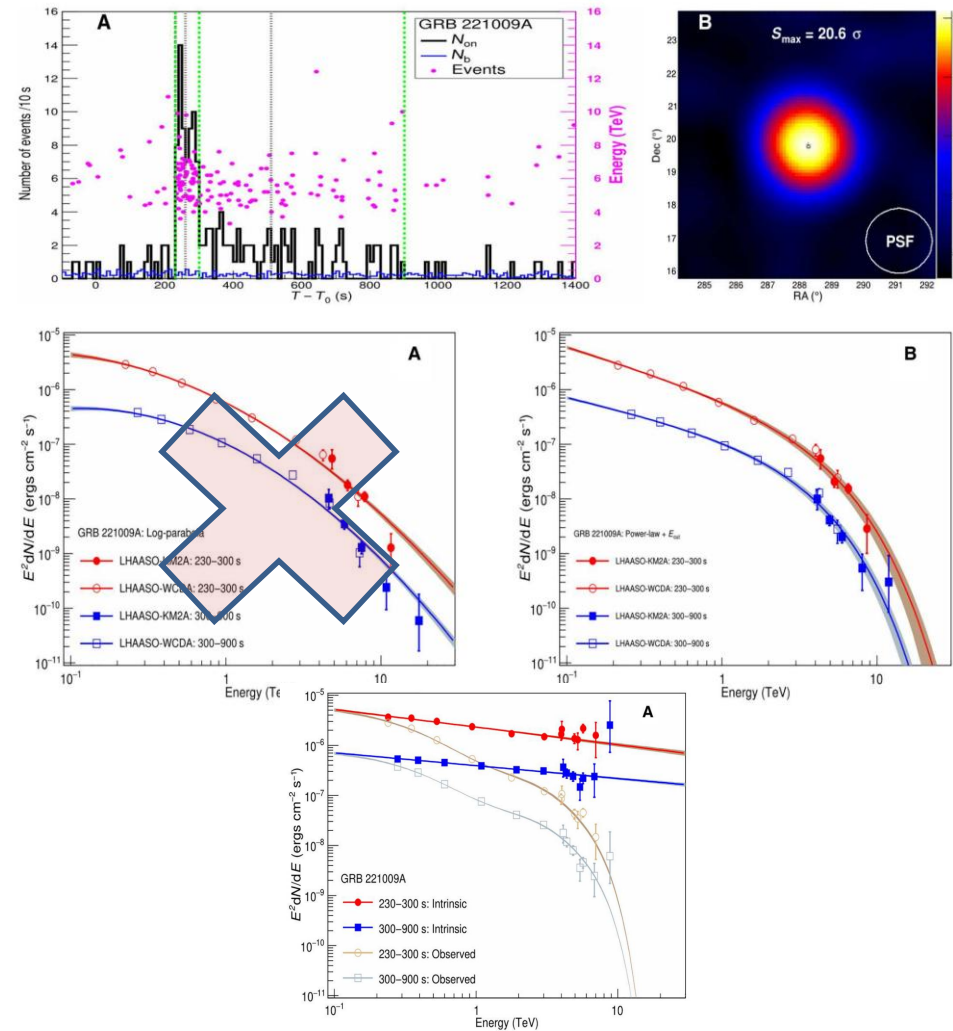


LHAASO observation of GRB 221009A (BOAT)

LHAASO coll. *Science*, 380:1390 (2023)

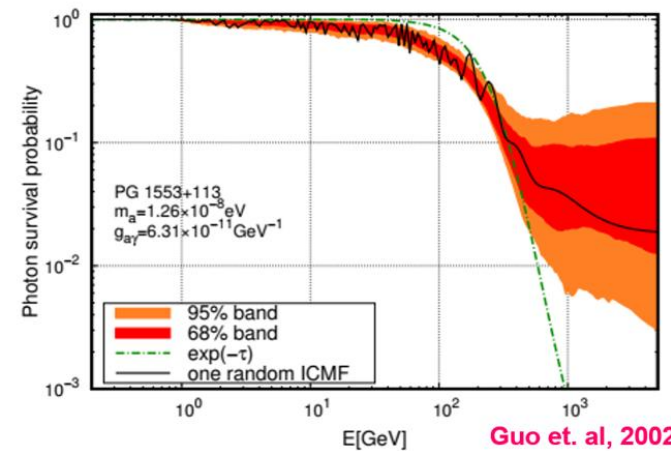
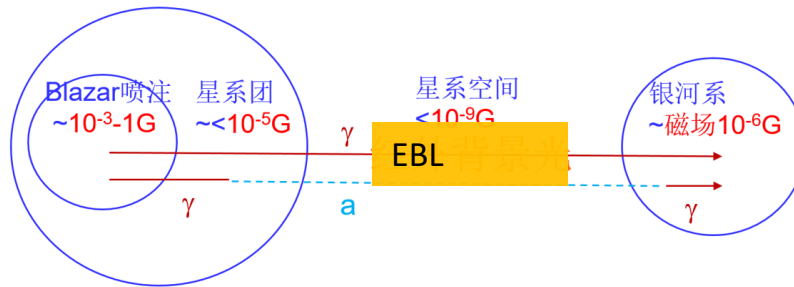
LHAASO coll. 2023 (*Science adv.* 9, 2778)

- Direct observation of the extragalactic background light (EBL) absorption of gamma flux
- The highest energy photon is about $\sim 13\text{TeV}$, depending on the spectrum
- The 13 TeV event is out of expectation for a source at $z=0.151$. Flux is about 1 order of magnitude higher than expectation.



gamma-axion oscillation

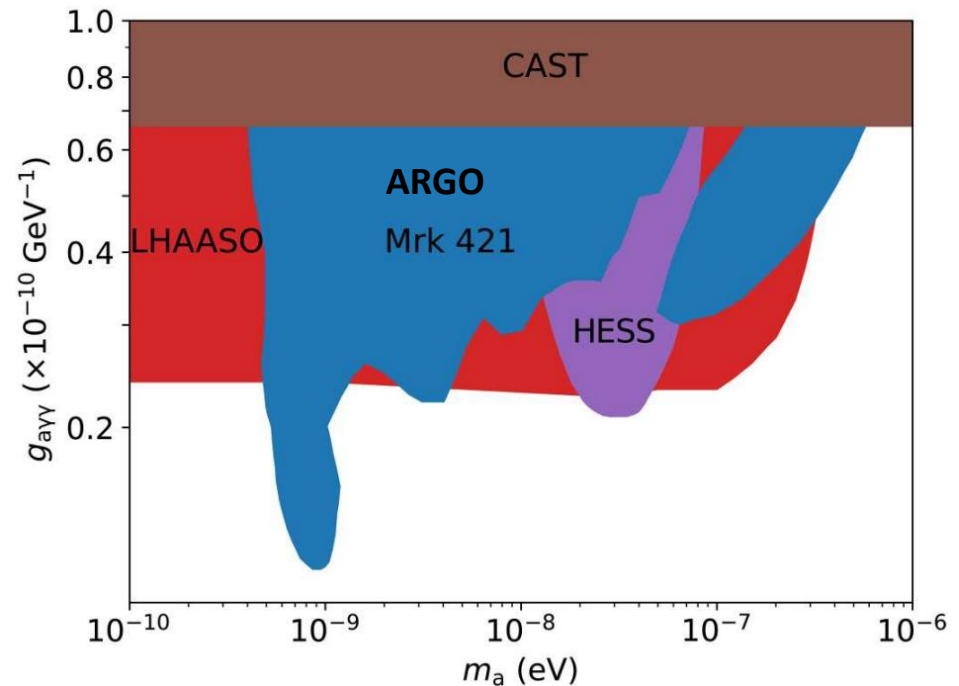
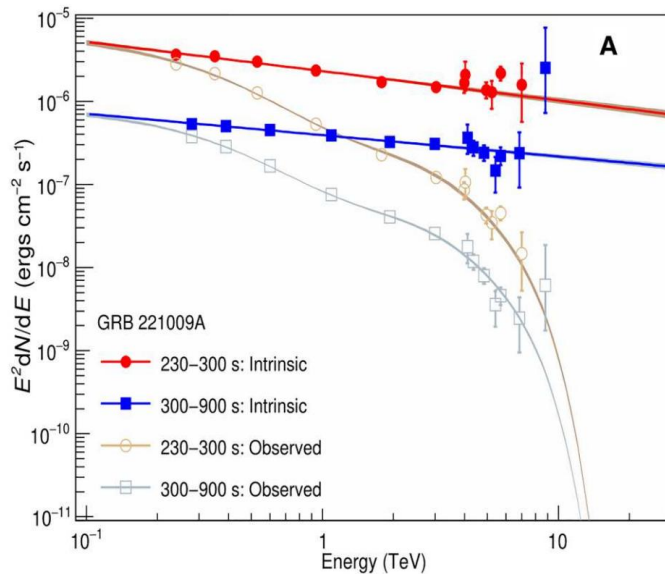
- Oscillation between axion-gamma evade the absorption by EBL



- The gamma ray spectrum is modified

A stringent constraint is set on axion coupling

- Axion significance $< 2\sigma$, we give constraints on axion coupling



Summary

- LHAASO is successful in UHE gamma ray astronomy, CR measurement and new physics searches.
- Combining results from AMS02, DAMPE and LHAASO implies a multiple-source origin of CRs.
- Stringent constraints on DM decay/annihilation, LIV, axion coupling, PBH burst rate have been derived.