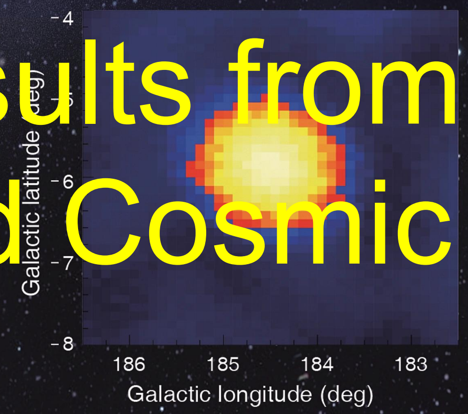
Status and Latest Results from LHAASO on γ-ray and Cosmic Ray Physics



Siming Liu

Southwest Jiaotong University

On behalf of the

LHAASO Collaboration

LHAASO
高海拔宇宙线观测站

Large High Altitude Air Shower Observatory

Electromagnetic Detectors (EDs)
Muon Detectors (MDs)
Water Cherenkov Detector Array (WCDA)
Wide Field of view Cherenkov Telescope Arrays (WFCTA)

Scientific Goals

γ-ray astronomy

Survey for sources (above 500 GeV)

PeVatrons (above 100 TeV)

All kind of sources: SNR, PWN, MYC, binary, pulsar

AGN, GRB etc.

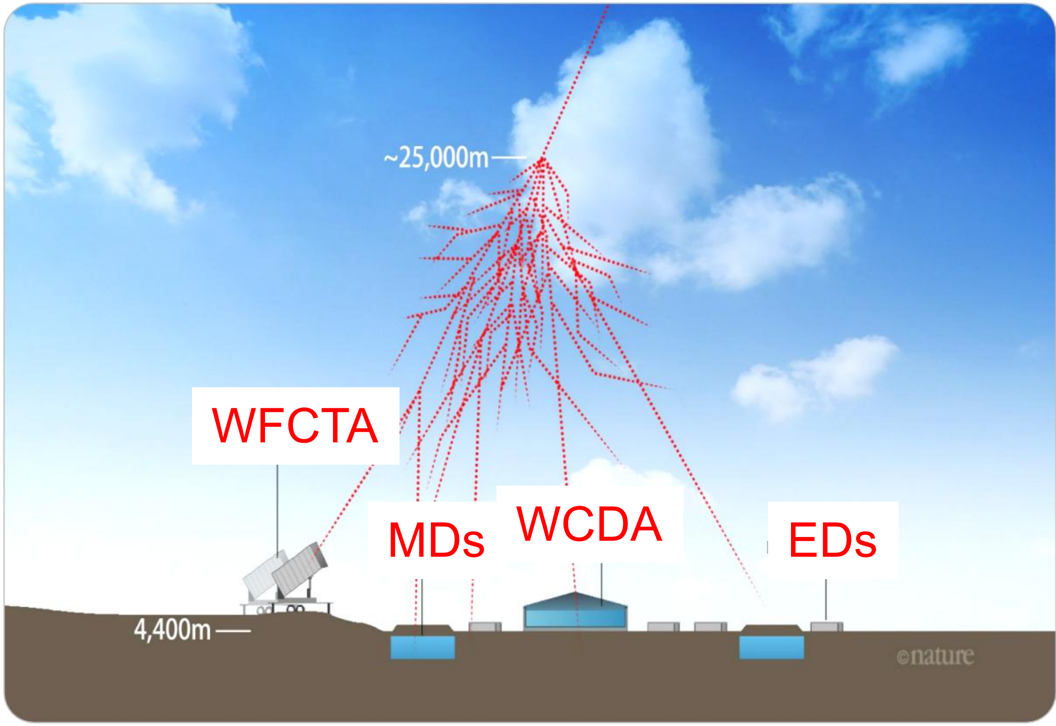
Cosmic Ray Physics

The knees

Compositions : individual species H, He and Fe

Anisotropy: (1 TeV to 10 PeV)

New Physics Front: DM, LIV, etc.



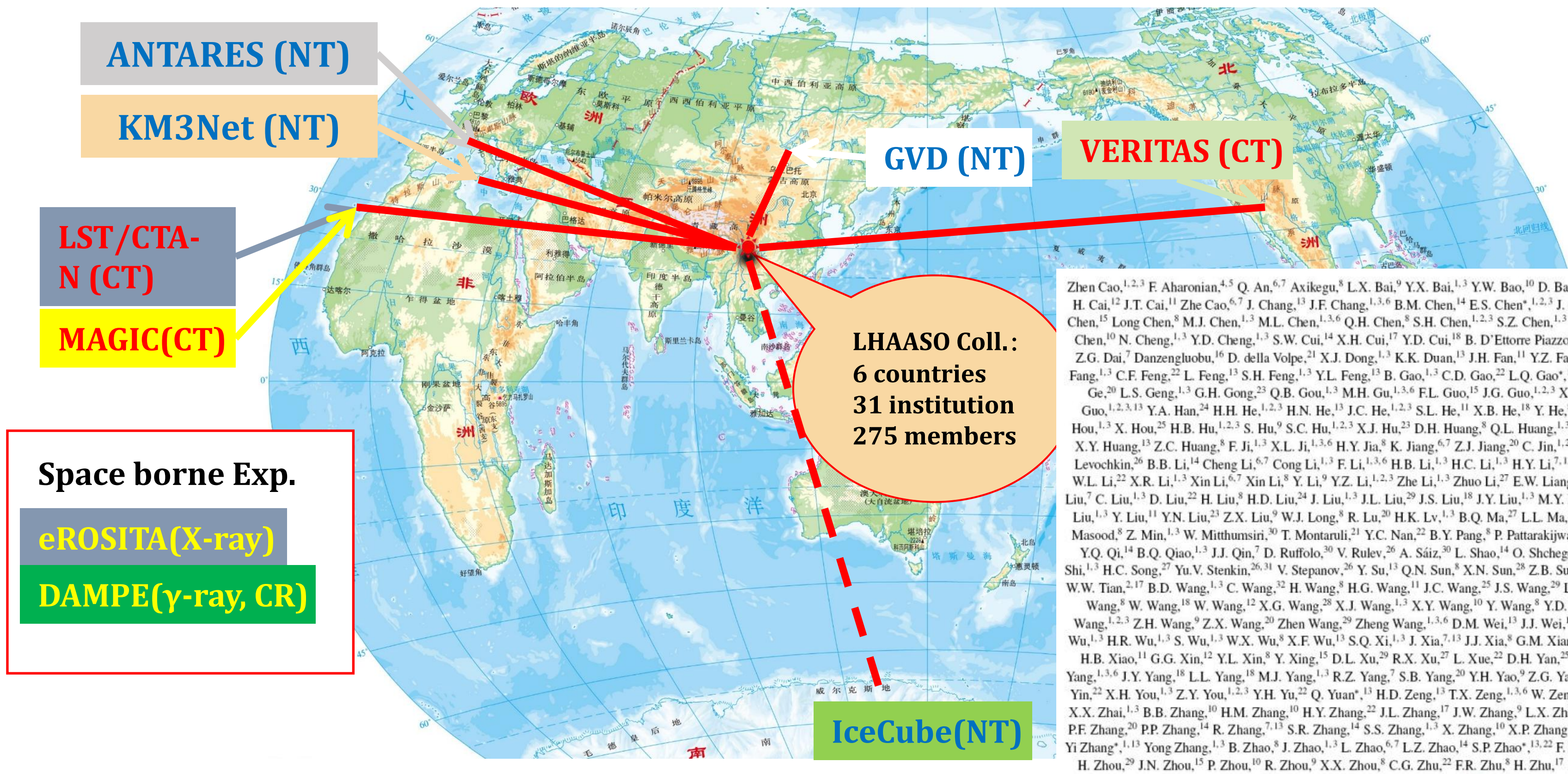
Location And Construction

- Location： 29°21’ 27.6” N , 100°08’19.6” E
- Altitude: 4410 m
- Funded at the end of 2015
- Construction started in 2017
- First Science Results Released in May 2021
- Completed in July 2021

Daocheng, Sichuan, China
On the east edge of Tibet plateau

Large High Altitude Air Shower Observatory

Multi-Messenger Collaboration Network



Zhen Cao,[1,2,3] F. Aharonian,[4,5] Q. An,[6,7] Axikegu,[8] L.X. Bai,[9] Y.X. Bai,[1,3] Y.W. Bao,[10] D. Bastieri,[11] X.J. Bi*,[1,2,3] Y.J. Bi,[1,3] H. Cai,[12] J.T. Cai,[11] Zhe Cao,[6,7] J. Chang,[13] J.F. Chang,[1,3,6] B.M. Chen,[14] E.S. Chen*,[1,2,3] J. Chen,[9] Liang Chen,[1,2,3] Liang Chen,[15] Long Chen,[8] M.J. Chen,[1,3] M.L. Chen,[1,3,6] Q.H. Chen,[8] S.H. Chen,[1,2,3] S.Z. Chen,[1,3] T.L. Chen,[16] X.L. Chen,[1,2,3] Y. Chen,[10] N. Cheng,[1,3] Y.D. Cheng,[1,3] S.W. Cui,[14] X.H. Cui,[17] Y.D. Cui,[18] B. D'Ettorre Piazzoli,[19] B.Z. Dai,[20] H.L. Dai,[1,3,6] Z.G. Dai,[7] Danzengluobu,[16] D. della Volpe,[21] X.J. Dong,[1,3] K.K. Duan,[13] J.H. Fan,[11] Y.Z. Fan,[13] Z.X. Fan,[1,3] J. Fang,[20] K. Fang,[1,3] C.F. Feng,[22] L. Feng,[13] S.H. Feng,[1,3] Y.L. Feng,[13] B. Gao,[1,3] C.D. Gao,[22] L.Q. Gao*,[1,2,3] Q. Gao,[16] W. Gao,[22] M.M. Ge,[20] L.S. Geng,[1,3] G.H. Gong,[23] Q.B. Gou,[1,3] M.H. Gu,[1,3,6] F.L. Guo,[15] J.G. Guo,[1,2,3] X.L. Guo,[8] Y.Q. Guo,[1,3] Y.Y. Guo,[1,2,3,13] Y.A. Han,[24] H.H. He,[1,2,3] H.N. He,[13] J.C. He,[1,2,3] S.L. He,[11] X.B. He,[18] Y. He,[8] M. Heller,[21] Y.K. Hor,[18] C. Hou,[1,3] X. Hou,[25] H.B. Hu,[1,2,3] S. Hu,[9] S.C. Hu,[1,2,3] X.J. Hu,[23] D.H. Huang,[8] Q.L. Huang,[1,3] W.H. Huang,[22] X.T. Huang,[22] X.Y. Huang,[13] Z.C. Huang,[8] F. Ji,[1,3] X.L. Ji,[1,3,6] H.Y. Jia,[8] K. Jiang,[6,7] Z.J. Jiang,[20] C. Jin,[1,2,3] T. Ke,[1,3] D. Kuleshov,[26] K. Levochkin,[26] B.B. Li,[14] Cheng Li,[6,7] Cong Li,[1,3] F. Li,[1,3,6] H.B. Li,[1,3] H.C. Li,[1,3] H.Y. Li,[7,13] Jian Li,[7] Jie Li,[1,3,6] K. Li,[1,3] W.L. Li,[22] X.R. Li,[1,3] Xin Li,[6,7] Xin Li,[8] Y. Li,[9] Y.Z. Li,[1,2,3] Zhe Li,[1,3] Zhuo Li,[27] E.W. Liang,[28] Y.F. Liang,[28] S.J. Lin,[18] B. Liu,[7] C. Liu,[1,3] D. Liu,[22] H. Liu,[8] H.D. Liu,[24] J. Liu,[1,3] J.L. Liu,[29] J.S. Liu,[18] J.Y. Liu,[1,3] M.Y. Liu,[16] R.Y. Liu,[10] S.M. Liu,[8] W. Liu,[1,3] Y. Liu,[11] Y.N. Liu,[23] Z.X. Liu,[9] W.J. Long,[8] R. Lu,[20] H.K. Lv,[1,3] B.Q. Ma,[27] L.L. Ma,[1,3] X.H. Ma,[1,3] J.R. Mao,[25] A. Masood,[8] Z. Min,[1,3] W. Mitthumsiri,[30] T. Montaruli,[21] Y.C. Nan,[22] B.Y. Pang,[8] P. Pattarakijwanich,[30] Z.Y. Pei,[11] M.Y. Qi,[1,3] Y.Q. Qi,[14] B.Q. Qiao,[1,3] J.J. Qin,[7] D. Ruffolo,[30] V. Rulev,[26] A. Sáiz,[30] L. Shao,[14] O. Shchegolev,[26,31] X.D. Sheng,[1,3] J.R. Shi,[1,3] H.C. Song,[27] Yu.V. Stenkin,[26,31] V. Stepanov,[26] Y. Su,[13] Q.N. Sun,[8] X.N. Sun,[28] Z.B. Sun,[32] P.H.T. Tam,[18] Z.B. Tang,[6,7] W.W. Tian,[2,17] B.D. Wang,[1,3] C. Wang,[32] H. Wang,[8] H.G. Wang,[11] J.C. Wang,[25] J.S. Wang,[29] L.P. Wang,[22] L.Y. Wang,[1,3] R.N. Wang,[8] W. Wang,[18] W. Wang,[12] X.G. Wang,[28] X.J. Wang,[1,3] X.Y. Wang,[10] Y. Wang,[8] Y.D. Wang,[1,3] Y.J. Wang,[1,3] Y.P. Wang,[1,2,3] Z.H. Wang,[9] Z.X. Wang,[20] Zhen Wang,[29] Zheng Wang,[1,3,6] D.M. Wei,[13] J.J. Wei,[13] Y.J. Wei,[1,2,3] T. Wen,[20] C.Y. Wu,[1,3] H.R. Wu,[1,3] S. Wu,[1,3] W.X. Wu,[8] X.F. Wu,[13] S.Q. Xi,[1,3] J. Xia,[7,13] J.J. Xia,[8] G.M. Xiang,[2,15] D.X. Xiao,[16] G. Xiao,[1,3] H.B. Xiao,[11] G.G. Xin,[12] Y.L. Xin,[8] Y. Xing,[15] D.L. Xu,[29] R.X. Xu,[27] L. Xue,[22] D.H. Yan,[25] J.Z. Yan,[13] C.W. Yang,[9] F.F. Yang,[1,3,6] J.Y. Yang,[18] L.L. Yang,[18] M.J. Yang,[1,3] R.Z. Yang,[7] S.B. Yang,[20] Y.H. Yao,[9] Z.G. Yao,[1,3] Y.M. Ye,[23] L.Q. Yin,[1,3] N. Yin,[22] X.H. You,[1,3] Z.Y. You,[1,2,3] Y.H. Yu,[22] Q. Yuan*,[13] H.D. Zeng,[13] T.X. Zeng,[1,3,6] W. Zeng,[20] Z.K. Zeng,[1,2,3] M. Zha,[1,3] X.X. Zhai,[1,3] B.B. Zhang,[10] H.M. Zhang,[10] H.Y. Zhang,[22] J.L. Zhang,[17] J.W. Zhang,[9] L.X. Zhang,[11] Li Zhang,[20] Lu Zhang,[14] P.F. Zhang,[20] P.P. Zhang,[14] R. Zhang,[7,13] S.R. Zhang,[14] S.S. Zhang,[1,3] X. Zhang,[10] X.P. Zhang,[1,3] Y.F. Zhang,[8] Y.L. Zhang,[1,3] Yi Zhang*,[1,13] Yong Zhang,[1,3] B. Zhao,[8] J. Zhao,[1,3] L. Zhao,[6,7] L.Z. Zhao,[14] S.P. Zhao*,[13,22] F. Zheng,[32] Y. Zheng,[8] B. Zhou,[1,3] H. Zhou,[29] J.N. Zhou,[15] P. Zhou,[10] R. Zhou,[9] X.X. Zhou,[8] C.G. Zhu,[22] F.R. Zhu,[8] H. Zhu,[17] K.J. Zhu,[1,2,3,6] and X. Zuo[1,3]

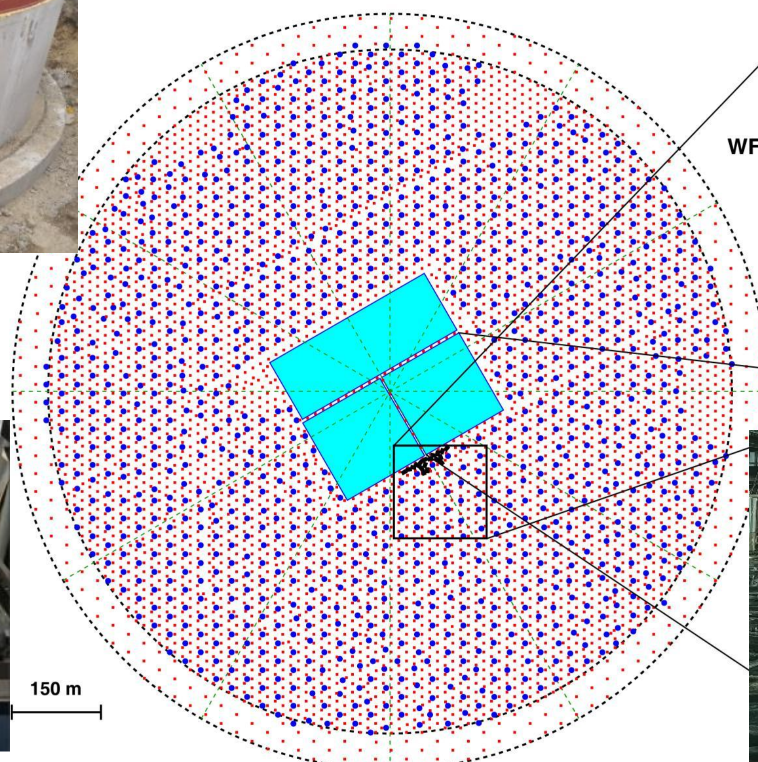

THE 1ST LHAASO SYMPOSIUM
May 29-June 1 2023
Tianfu New Area,Chengdu,China
Host: The Institute of High Energy Physics of the Chinese Academy of Sciences
TIANFU Cosmic Ray Research Center,Chengdu,Sichuan,China
Co-organizer: Southwest Jiaotong University
• Gamma Ray Burst
• Gamma Ray Astronomy
• Cosmic Ray Physics
• Neutrinos
• Gravitational Waves
• Multi-messenger Astronomy
Scientific Organizing Committee
Felix Aharonian, Elena Amato, Barry Barish, John Beacom
Roger Blandford, Zhen Cao, Jin Chang, Francis Halzen
Jim Hinton, Takaaki Kajita, Martin Lemoine, Rene Ong
Marco Tavani, Masahiro Teshima, Samuel Ting, Bing Zhang
Local Organizing Committee
Yunxiang Bai, Zhen Cao, Songzhan Chen, Jinyan Du, Jian Li, Shuye Liao
Ruoyu Liu, Jing Luo, Ruizhi Yang, Qiang Yuan, Shoushan Zhang, Hao Zhou

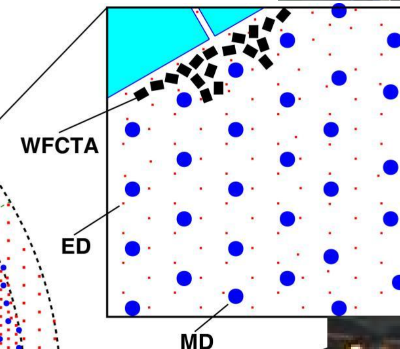

THE 1st LHAASO SYMPOSI
中国科学院高能物理研究
Institute of High Energy Physics Chinese Academy of Sc
LHAASO
天府宇宙线研究中心

LHAASO Detectors

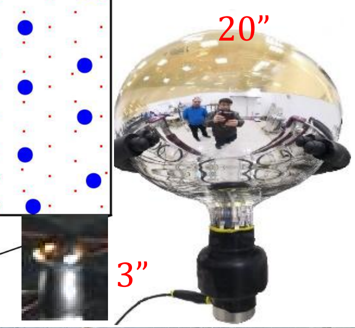
MD

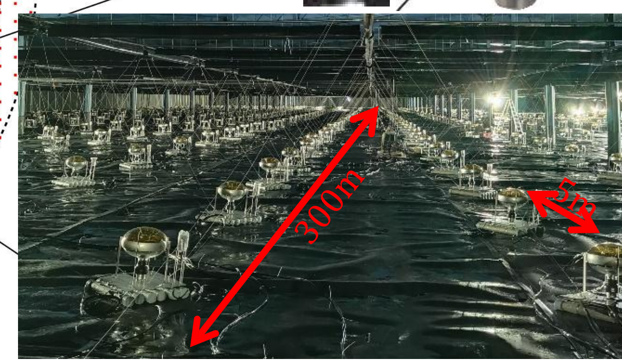
ED





WFCTA



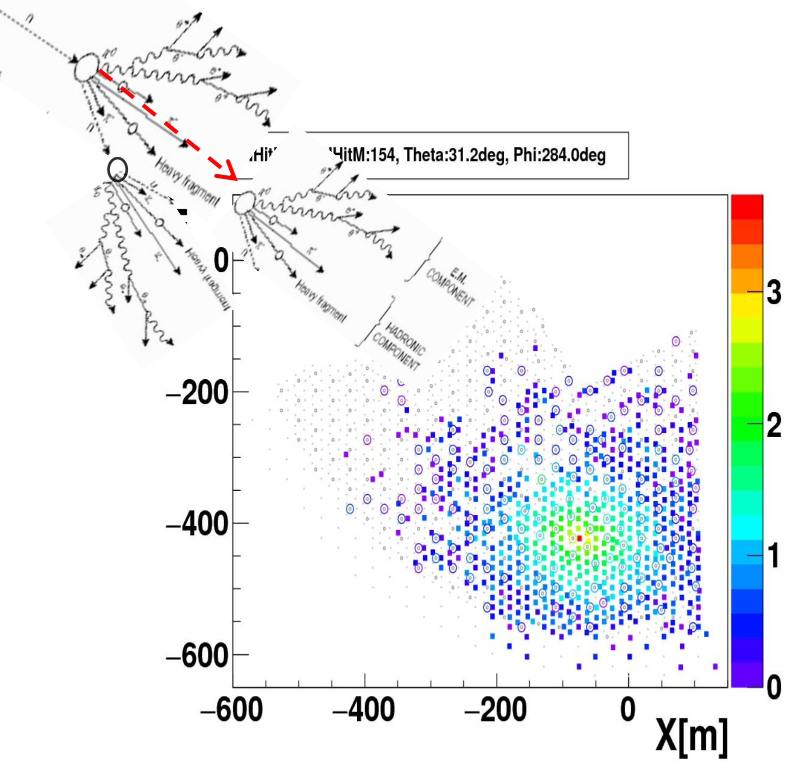


WCDA

Eds+MDs=LHAASO-KM2A
Kilometer Square Array

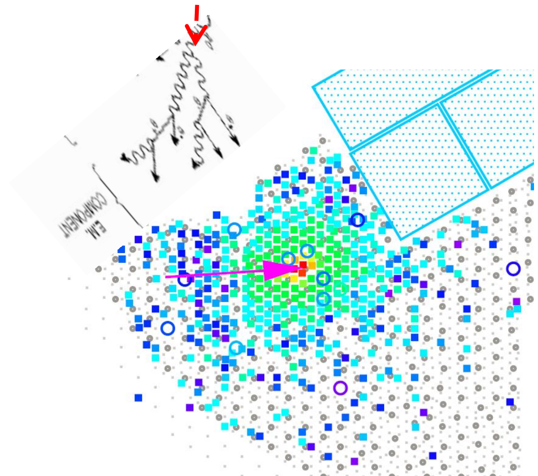
Selection of γ–rays out of CR background

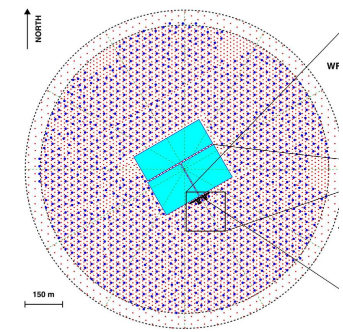
~1 PeV CR event: many muons



~ 1 PeV γ–ray event :
very few muons

~1 PeV from the Crab





- Area:
  1.3 km²
- Detectors:
  5216 EDs
  1188 MDs
- Energy Range:
  0.01-10 PeV

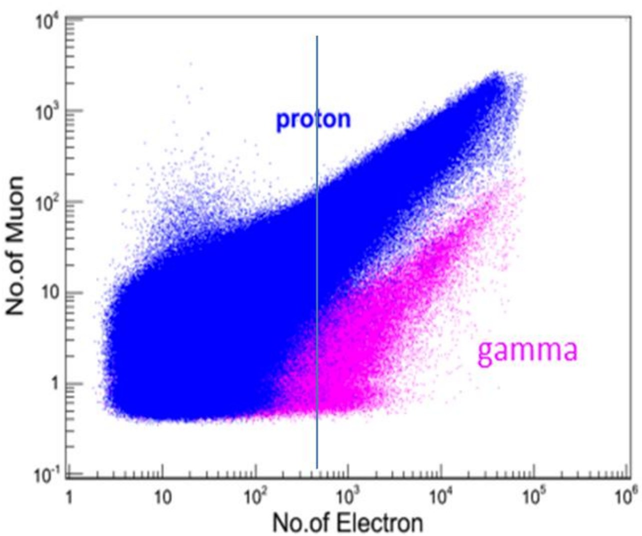
Active Area for Muons vs. Array Area:
4% ~ 50,000m²
ED 10% ~ 100,000m²

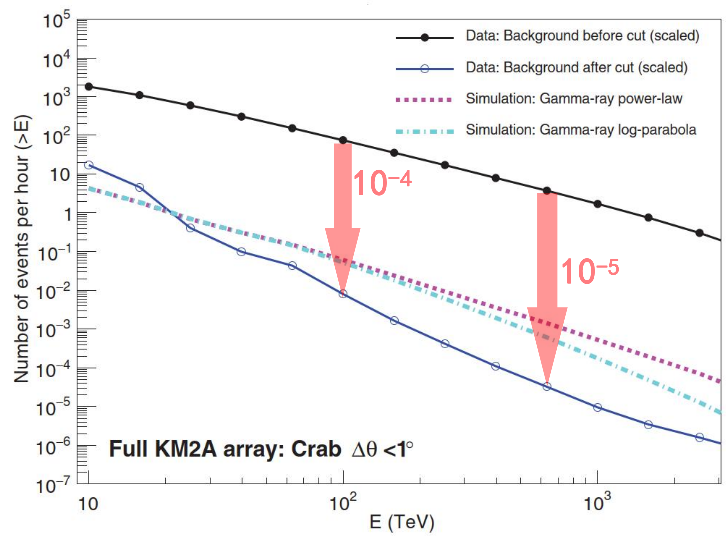
LHAASO 高海拔宇宙线观测站

CR background Rejection in KM2A

- Counting number of measured muons in a shower
- Cutting on ratio N_μ/N_e<**1/230**
- BG-free ($N_\gamma > 10 N_{CR}$) Photon Counting

  for showers with E>100 TeV from the Crab

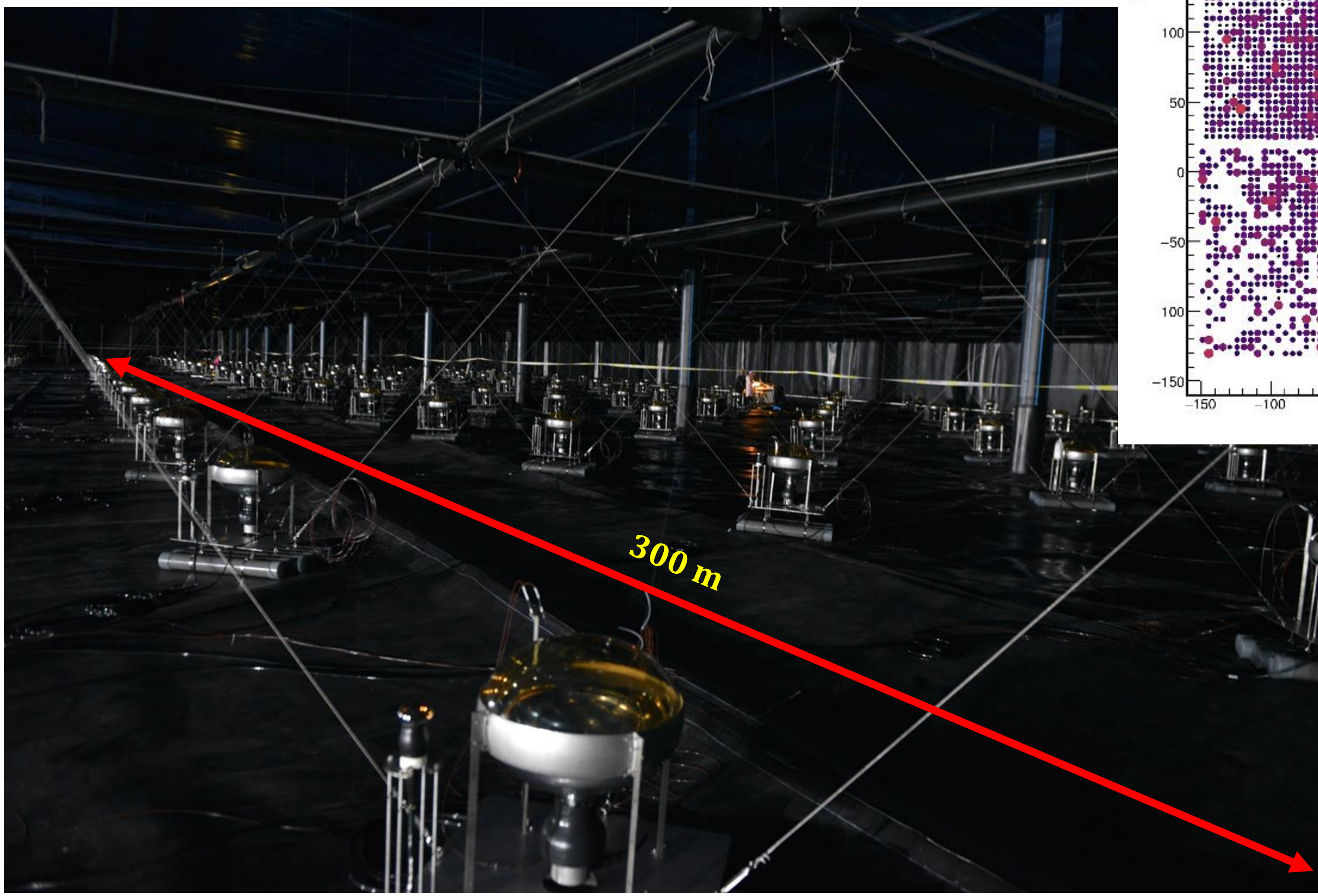


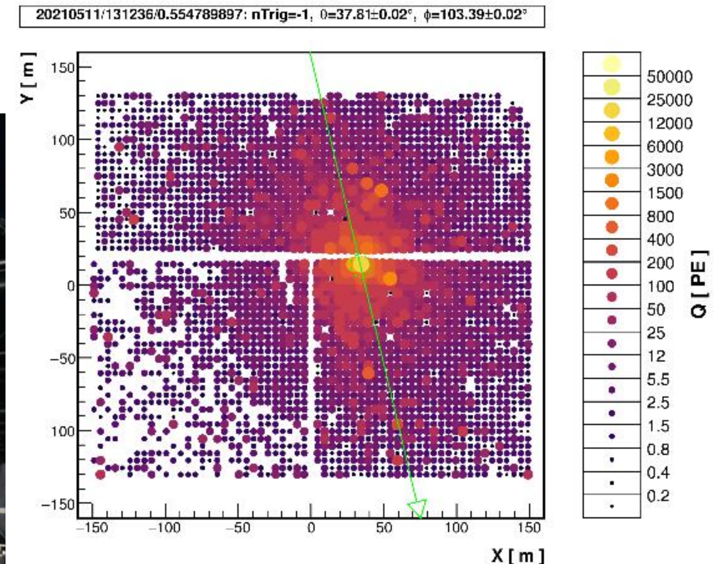


LHAASO Coll., ***Science***, 373, 425 (2021)

LHAASO-WCDA

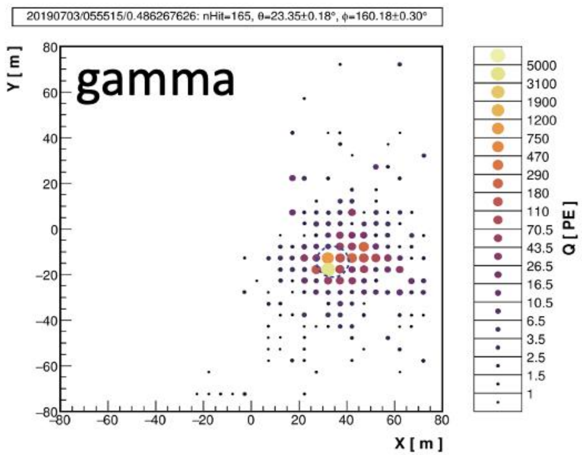
Water Cherenkov Detector Array

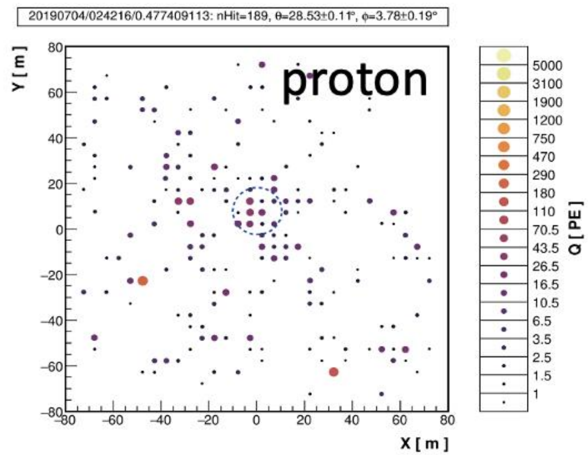


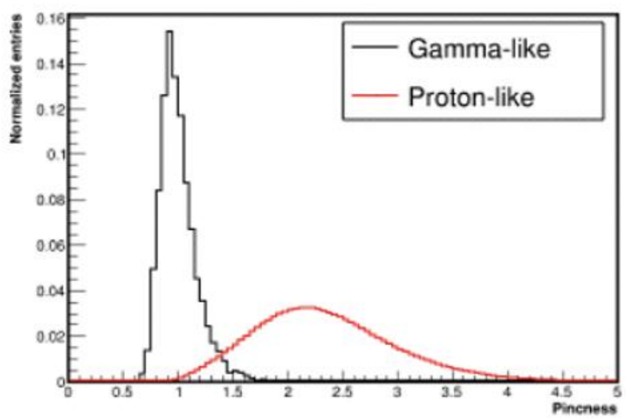


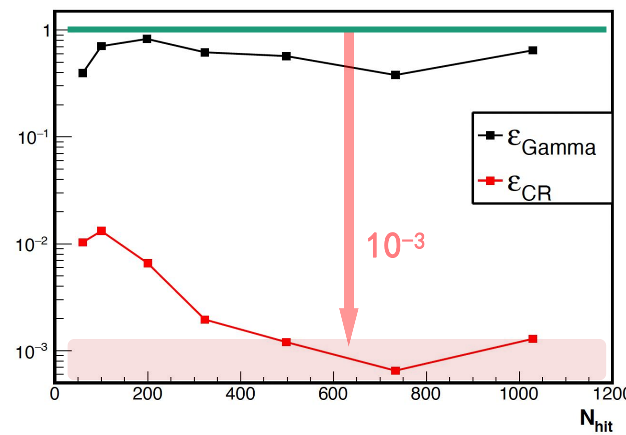
- **Area:**
  78,000 m²
- **Detector units:**
  3120
- **Energy Range:**
  0.1-10 TeV

CR Background rejection in WCDA





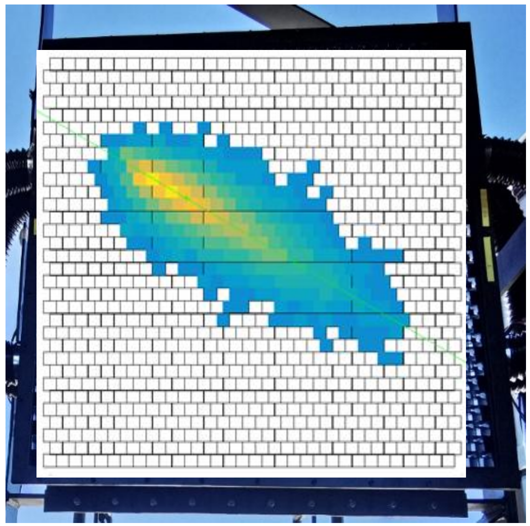


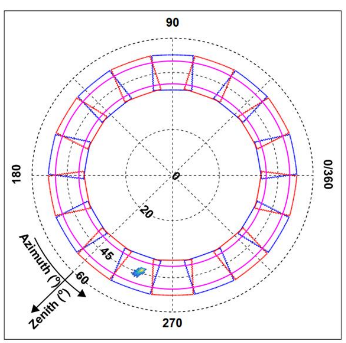


LHAASO-WFCTA
Wide Field of view Cherenkov Telescope Arrays

Separate of individual CR species & measure the knees

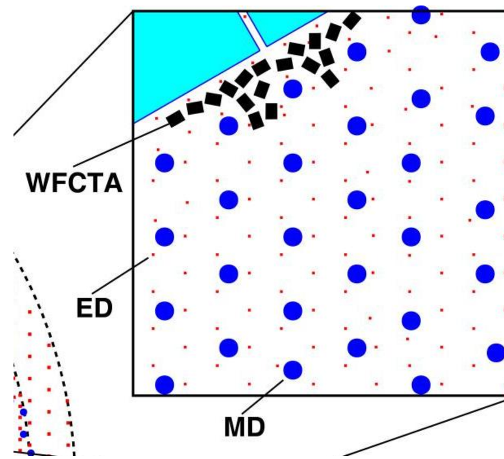
~0.1 PeV
CR event

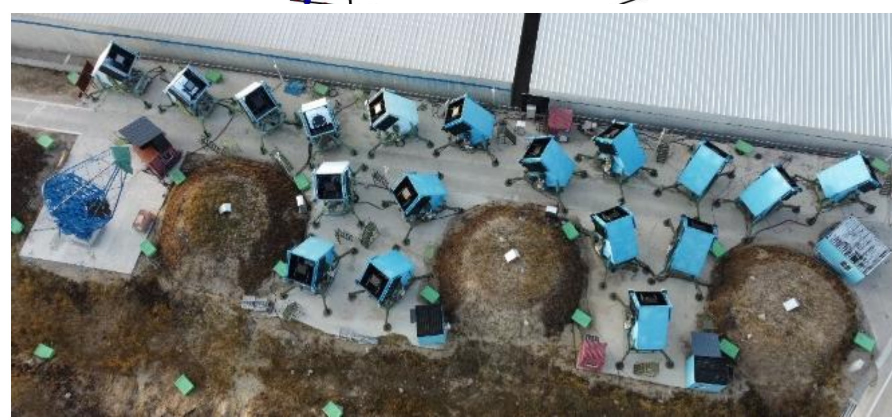




WFCTA: 18 IACTs

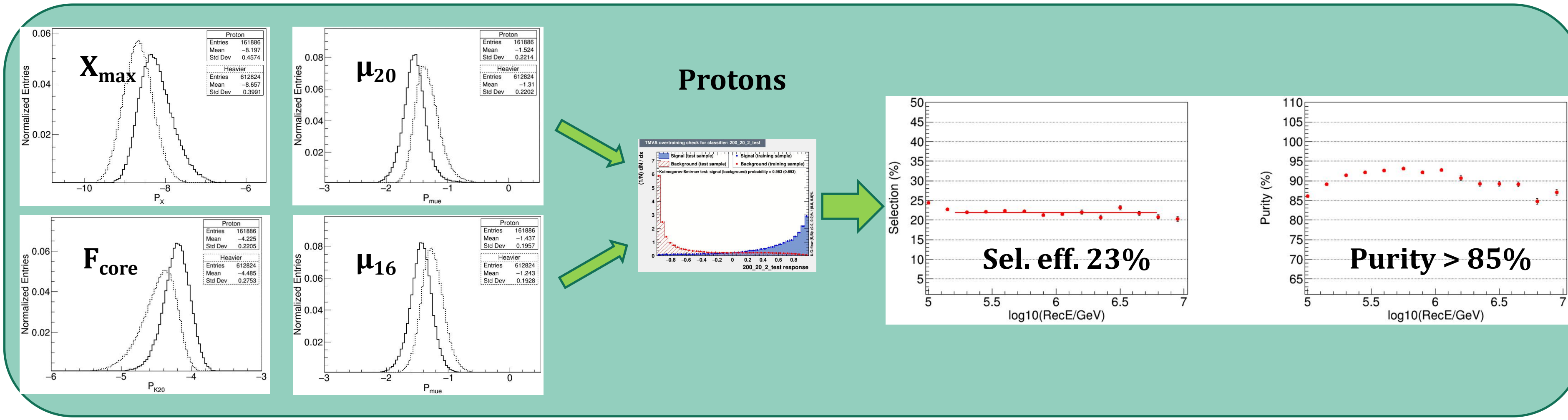
Mirror: 5 m²
SiPM camera
FOV: 16×16°
Pixel size: 0.5°
Energy: 0.1-100 PeV

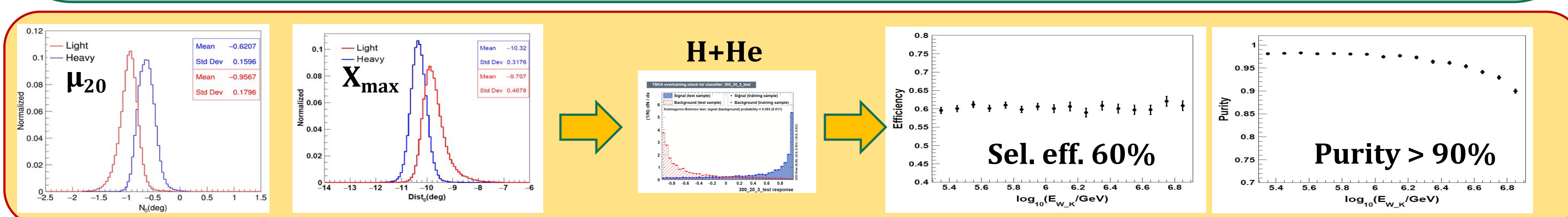




CR Composition Separation

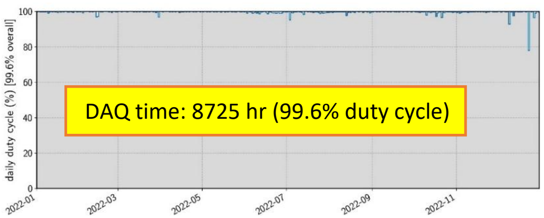
- Multi-parameter analyses for pure H,H+He,Fe samples

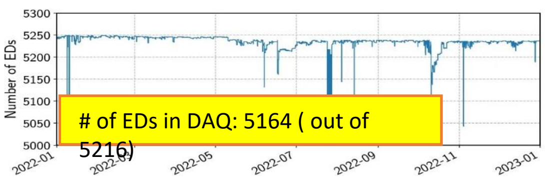


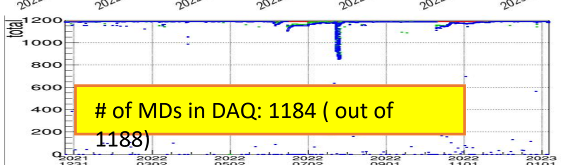


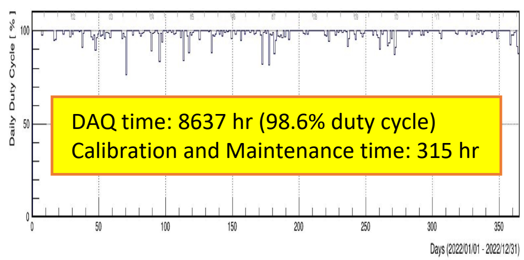
Supper Stable & Fruitful Operation

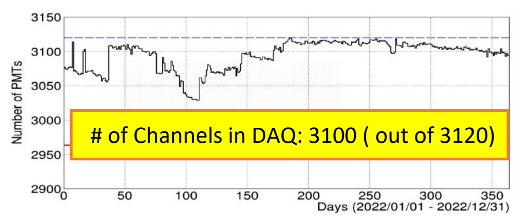


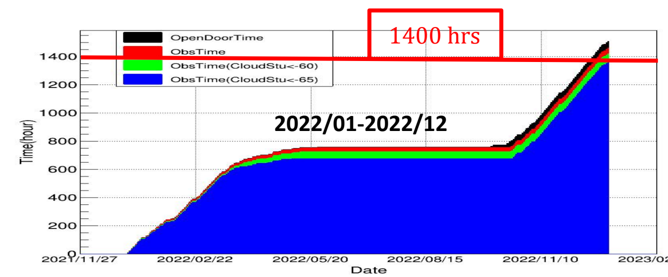










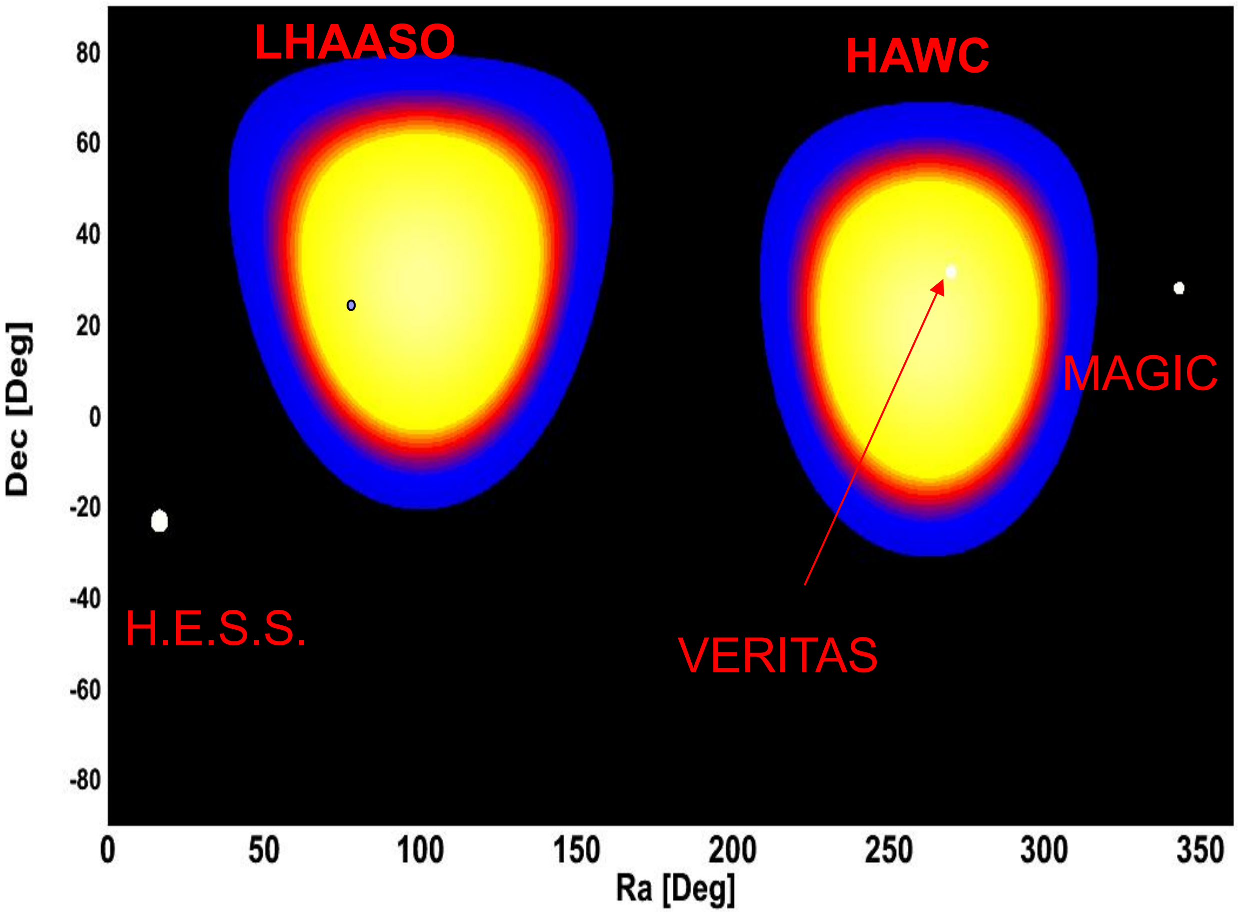


Reconstruction and Analysis

- Data procession
  - # of events: 1 trillion LE、70 billion HE、70 million hybrid
  - Amount: 11 PB
- Simulation
  - # of events: 1 billion LE、0.7 billion HE、150 million hybrid
  - Amount: 4 PB
- # of jobs: 10M for data, 50M for simulation

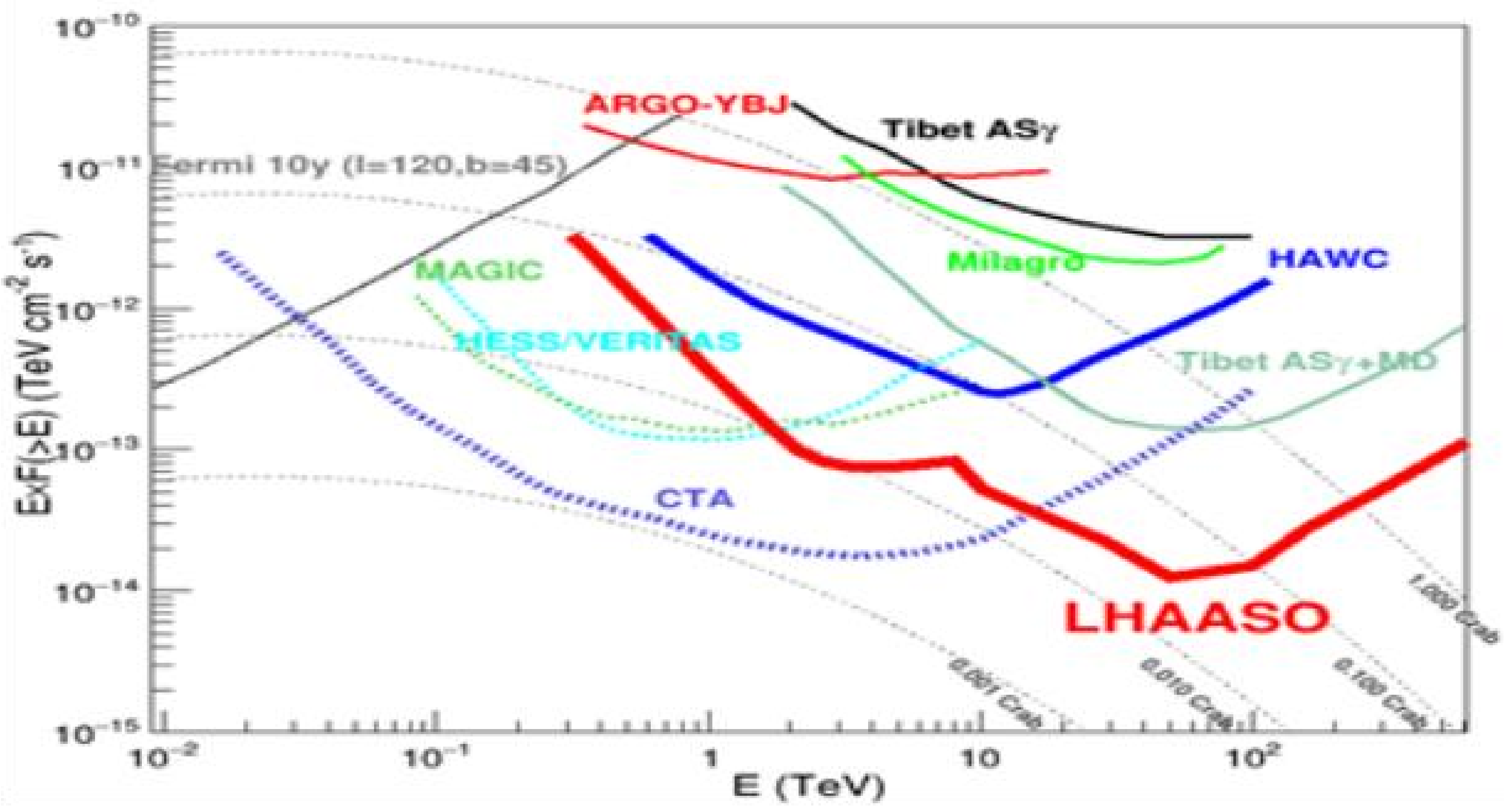
Field of view for GRB/TOO

1/7 of the sky at any time

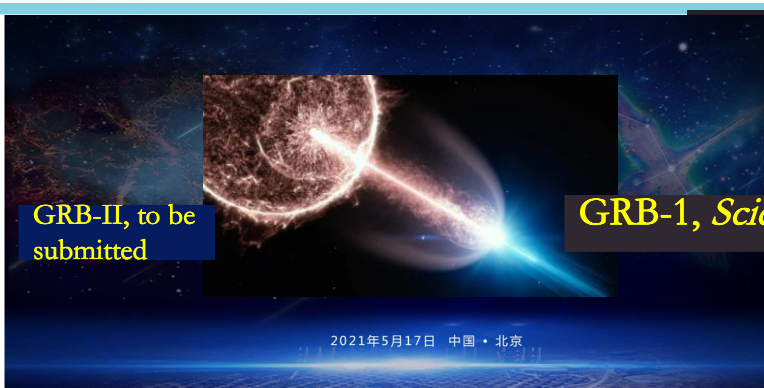


LHAASO sensitivity

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

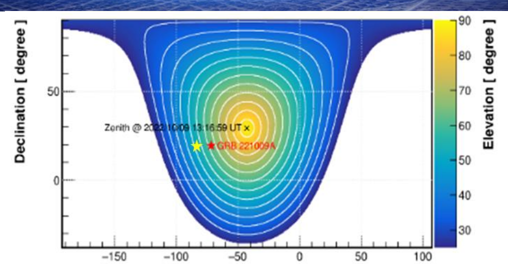


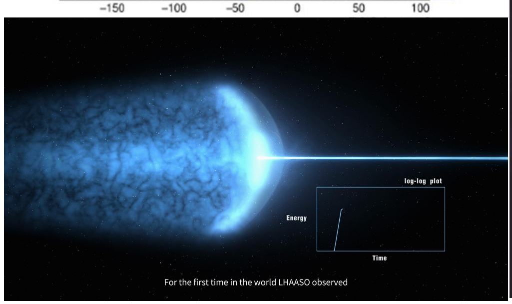
Discovery Highlights

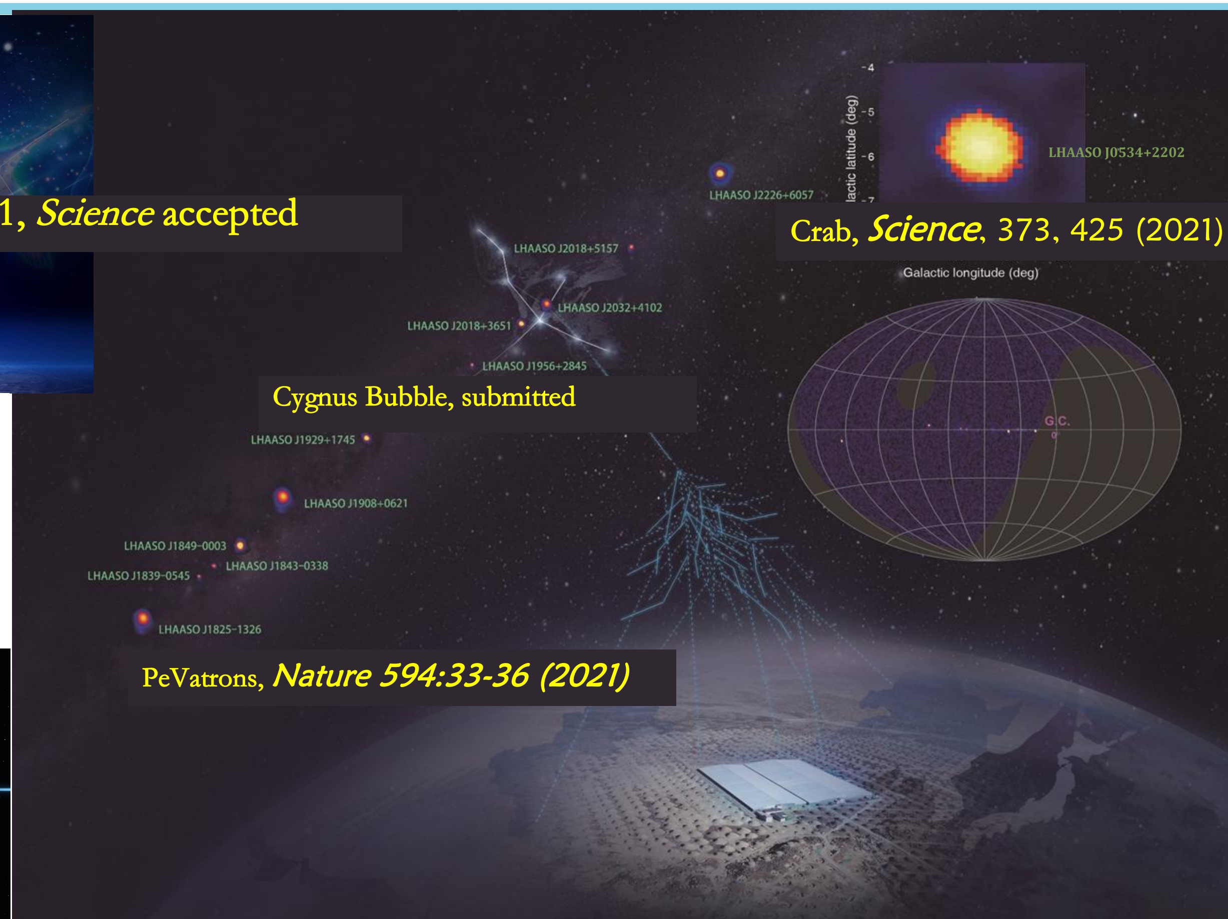


GRB-II, to be submitted

GRB-1, *Science* accepted



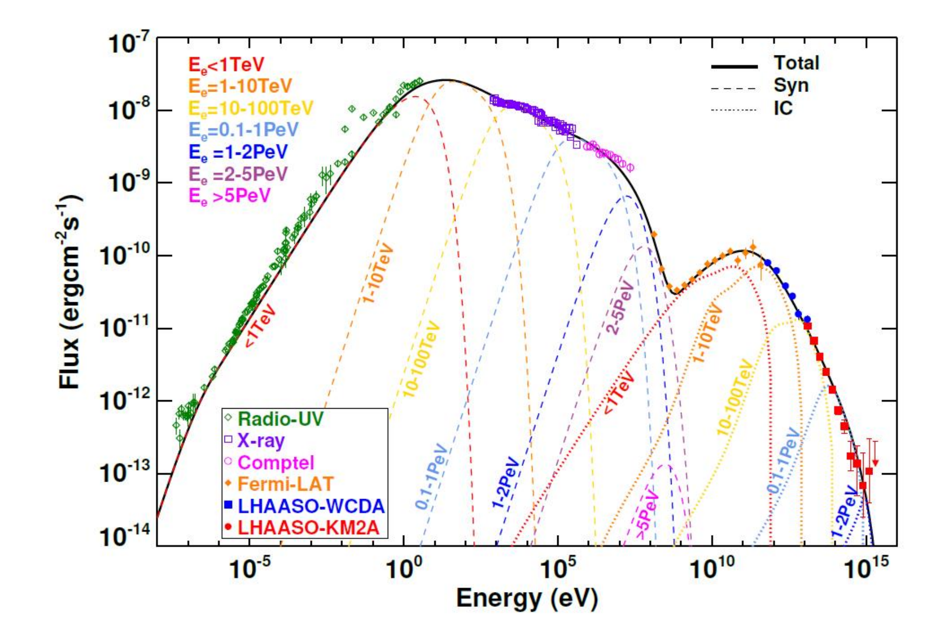


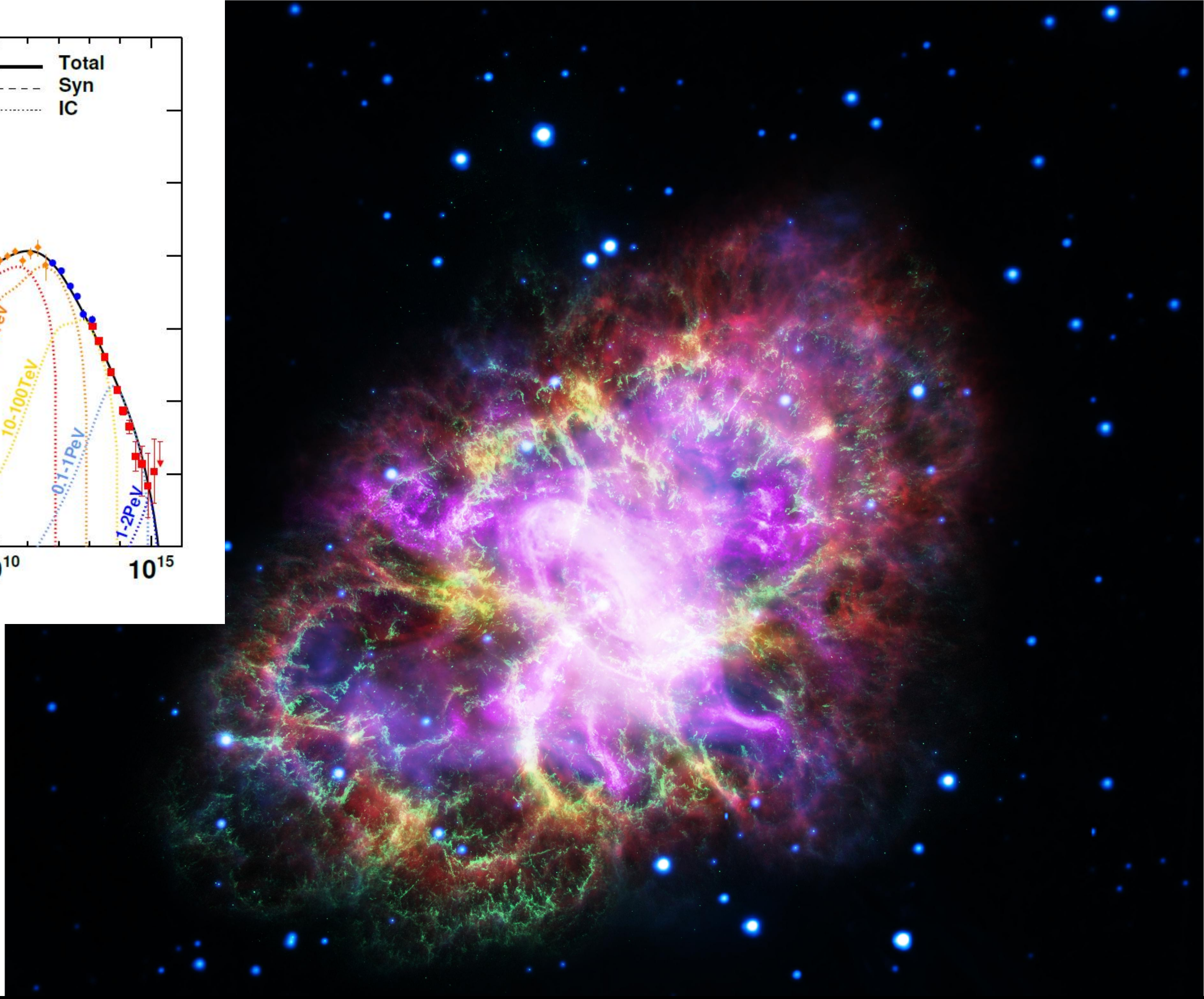


Crab, *Science*, 373, 425 (2021)

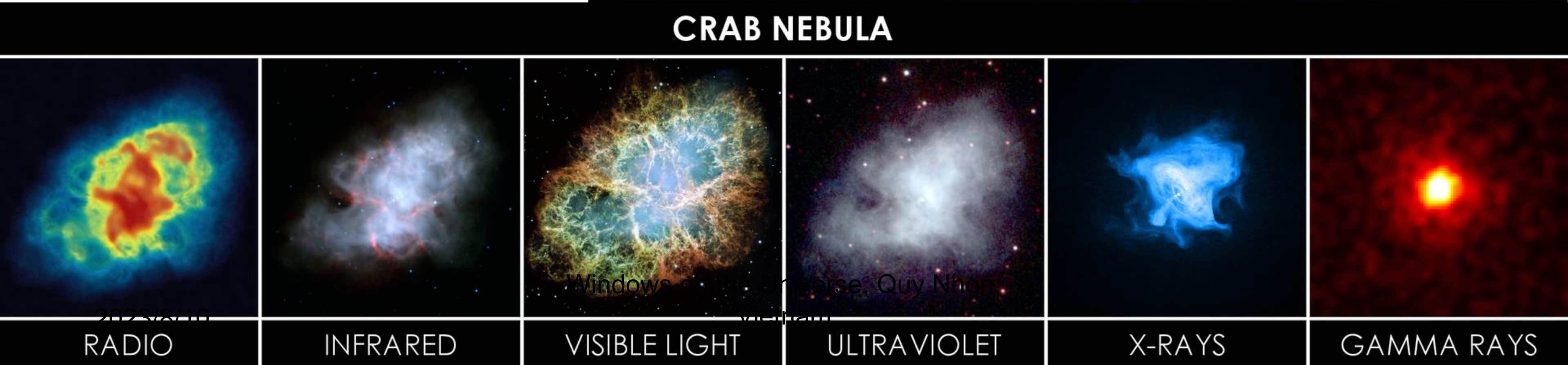
Cygnus Bubble, submitted

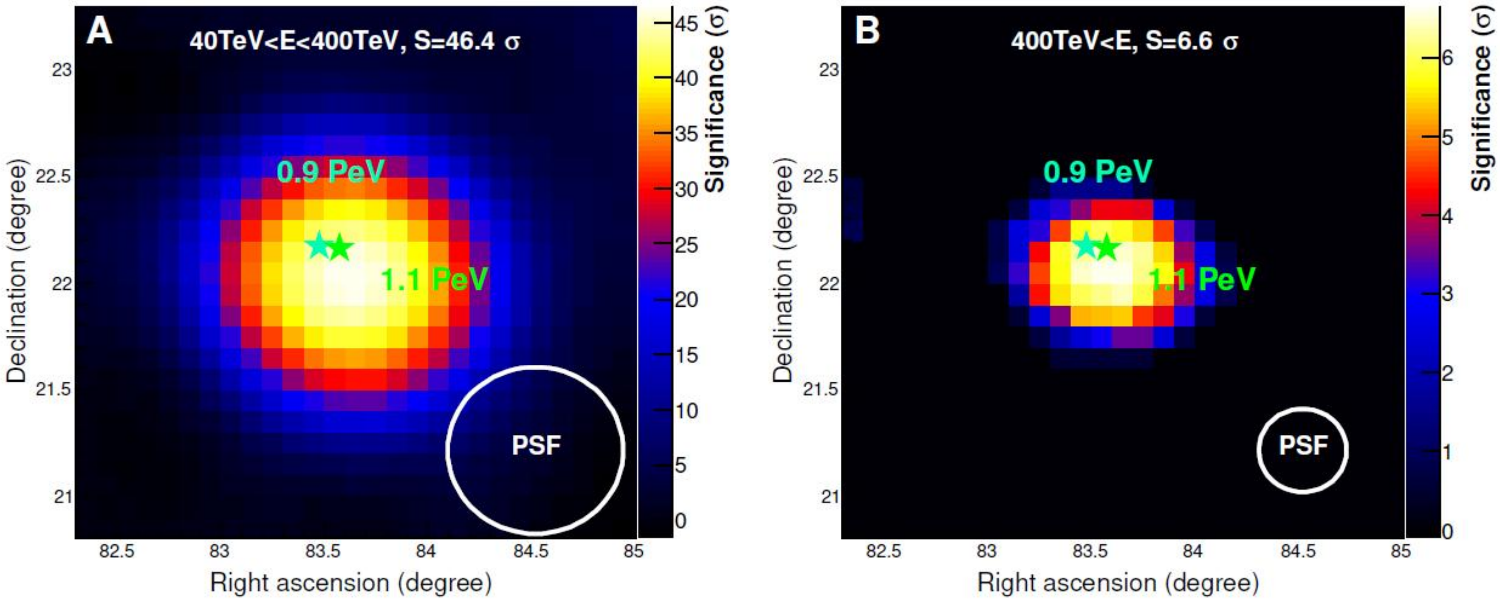
PeVatrons, *Nature 594:33-36 (2021)*


Flux (ergcm^{-2}s^{-1})
Energy (eV)
E_e<1TeV
E_e=1-10TeV
E_e=10-100TeV
E_e=0.1-1PeV
E_e =1-2PeV
E_e =2-5PeV
E_e >5PeV
Total
Syn
IC
Radio-UV
X-ray
Comptel
Fermi-LAT
LHAASO-WCDA
LHAASO-KM2A
<1TeV
1-10TeV
10-100TeV
0.1-1PeV
1-2PeV
2-5PeV
>5PeV
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-5}
10^{0}
10^{5}
10^{10}
10^{15}

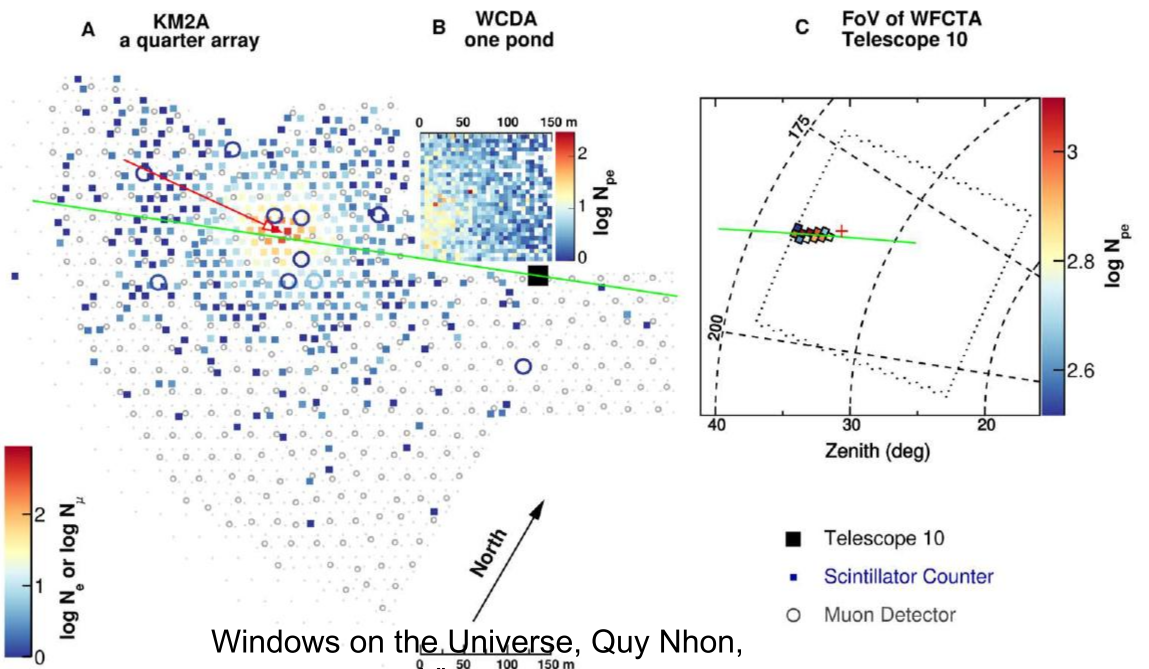


Crab Nebula


CRAB NEBULA
RADIO
INFRARED
VISIBLE LIGHT
ULTRAVIOLET
X-RAYS
GAMMA RAYS


A
40TeV<E<400TeV, S=46.4 σ
0.9 PeV
1.1 PeV
PSF
Declination (degree)
Right ascension (degree)
Significance (σ)
B
400TeV<E, S=6.6 σ
0.9 PeV
1.1 PeV
PSF
Declination (degree)
Right ascension (degree)
Significance (σ)

0.88PeV


A
KM2A
a quarter array
B
WCDA
one pond
C
FoV of WFCTA
Telescope 10
log N_pe
log N_e or log N_μ
North
Zenith (deg)
Telescope 10
Scintillator Counter
Muon Detector

Science

RESEARCH ARTICLES

Cite as: The LHAASO Collaboration, *Science* 10.1126/science.abg5137 (2021).

PeV gamma-ray emission from the Crab Nebula

The LHAASO Collaboration*†

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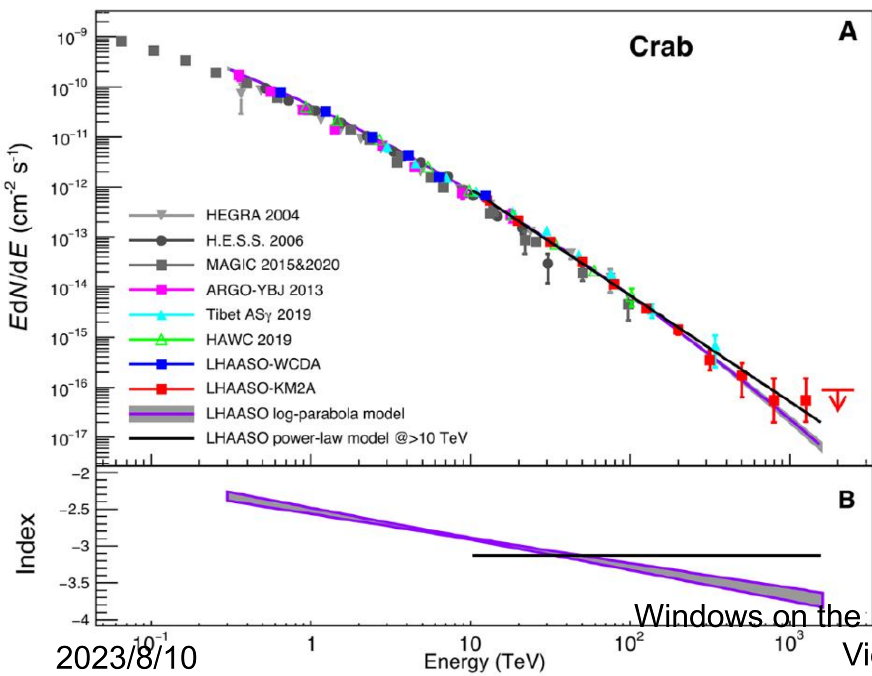
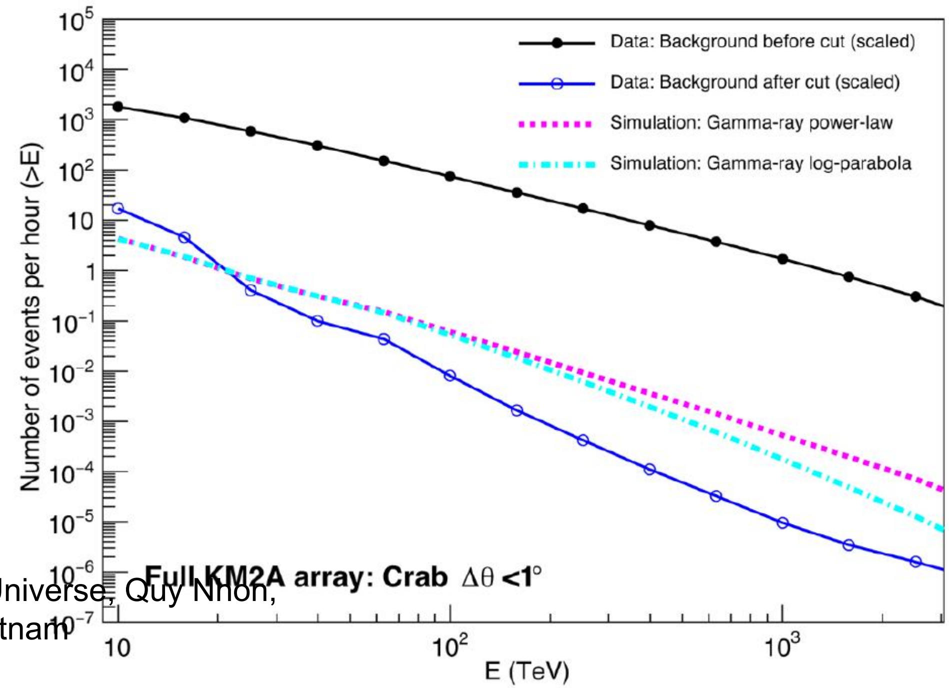
†The LHAASO Collaboration authors and affiliations are listed in the supplementary materials.





Gamma-ray detectors

Space-based
EGRET, AGILE,
Fermi, DAMPE

HE: >0.1 GeV
Large FOV
80% duty cycle
0.1° ~ 5°
resolution
1 m^2 area

IACTs:
H.E.S.S., MAGIC, VERITAS,
CTA

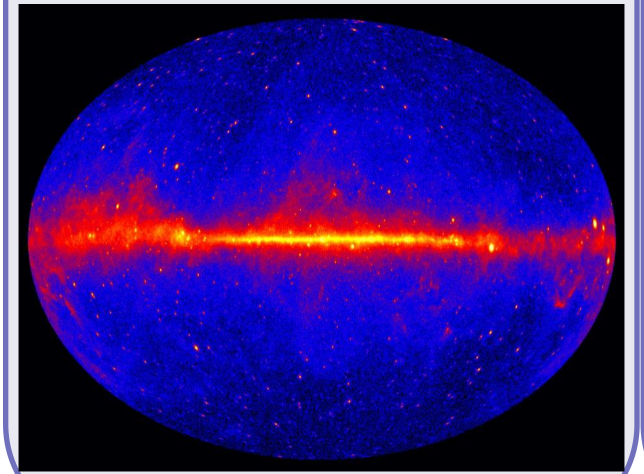
VHE:>0.1 TeV
3°~5° FOV
15% duty cycle
0.06°~ 0.17°
resolution
10^5 m^2 area

EAS arrays:
Milagro, ARGO-YBJ
Tibet ASγ, HAWC,
LHAASO

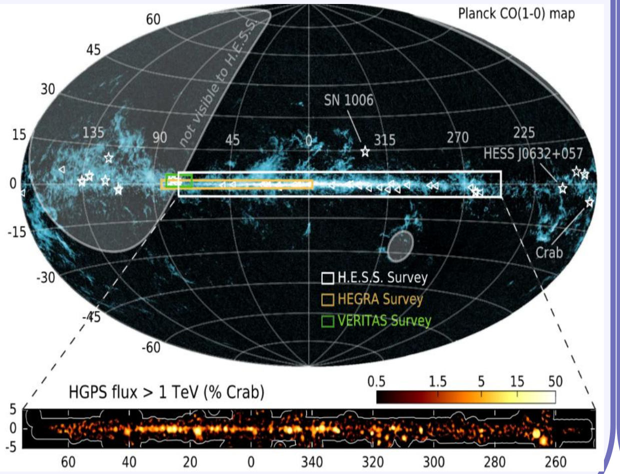
VHE: >0.1 TeV
UHE: >0.1 PeV
Large FOV
100% duty cycle
0.1° ~ 1° resolution
10^{3-6} m^2 area

Impressive Gamma-ray Source Catalogs

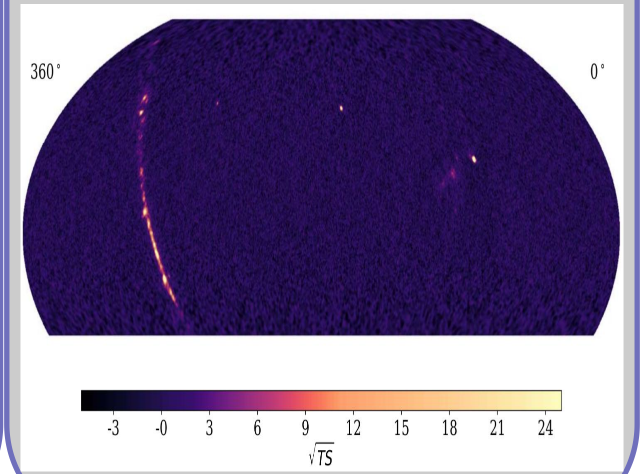
Fermi-LAT
12ys data
6658 sources
50 MeV to 1 TeV



H.E.S.S.
10ys data
78 sources
0.2-100 TeV

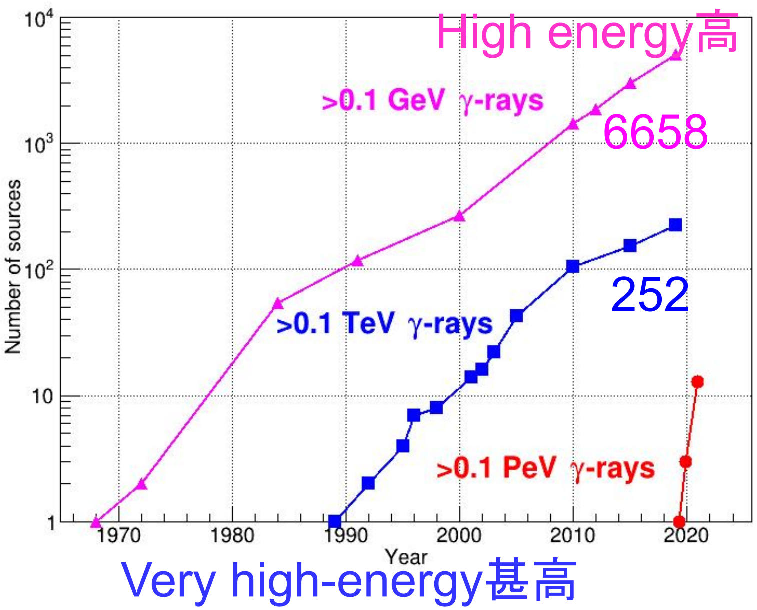


HAWC
5ys data
65 sources
1~100 TeV

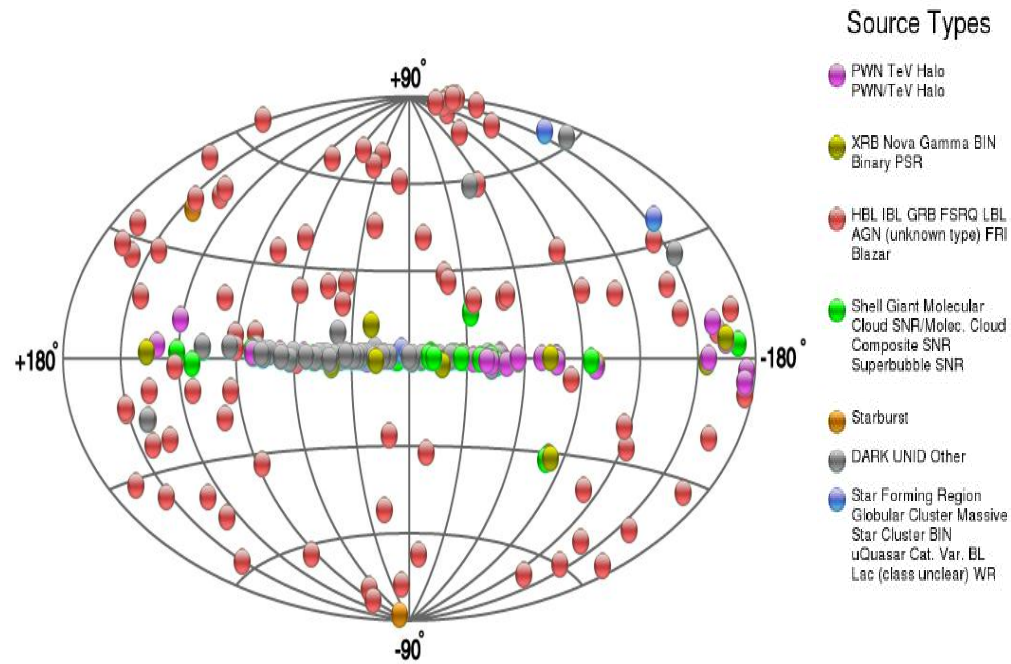


Current status of Very High Energy gamma-ray sources

Great progresses are achieved in ground-based VHE gamma-ray astronomy!



Ultra-high energy超高

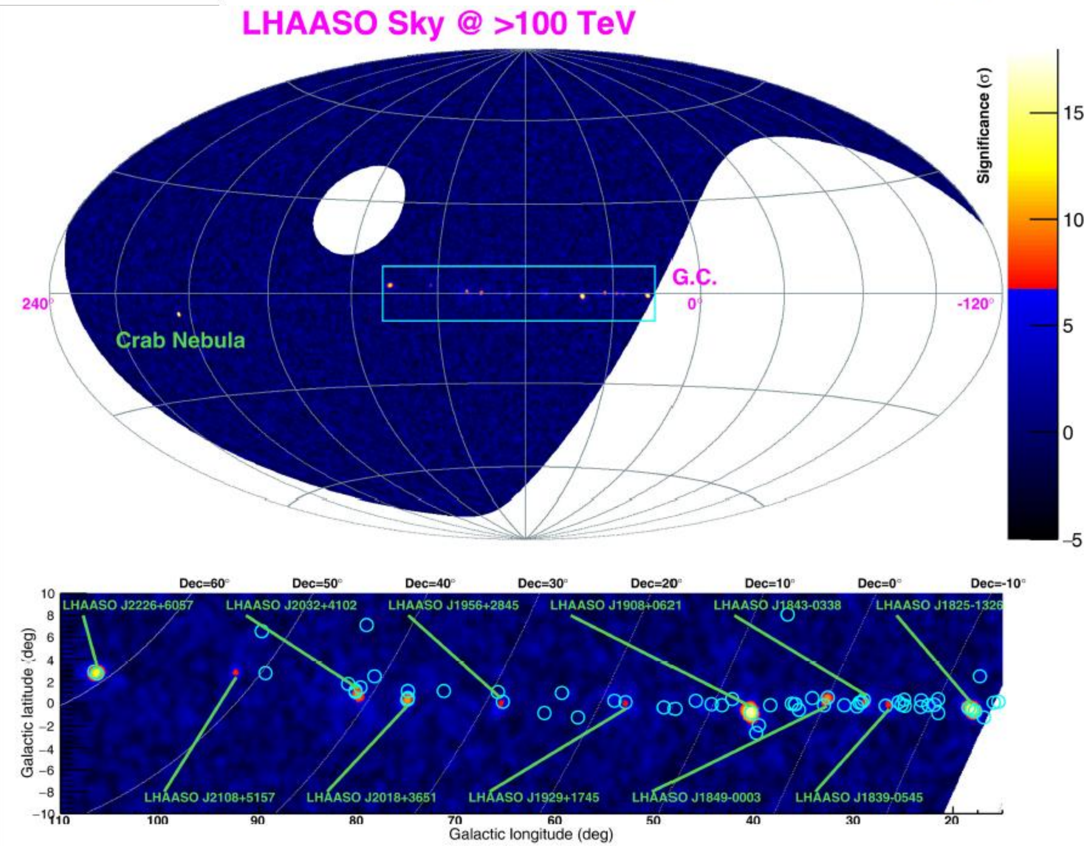


Article

Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

https://doi.org/10.1038/s41586-021-03498-z

A list of authors and affiliations appears at the end of the paper.



Extended Data Fig. 4 | LHAASO sky map at energies above 100 TeV. The circles indicate the positions of known very-high-energy γ-ray sources.

Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

https://doi.org/10.1038/s41586-021-03498-z

A list of authors and affiliations appears at the end of the paper.

Table 1 | UHE γ-ray sources

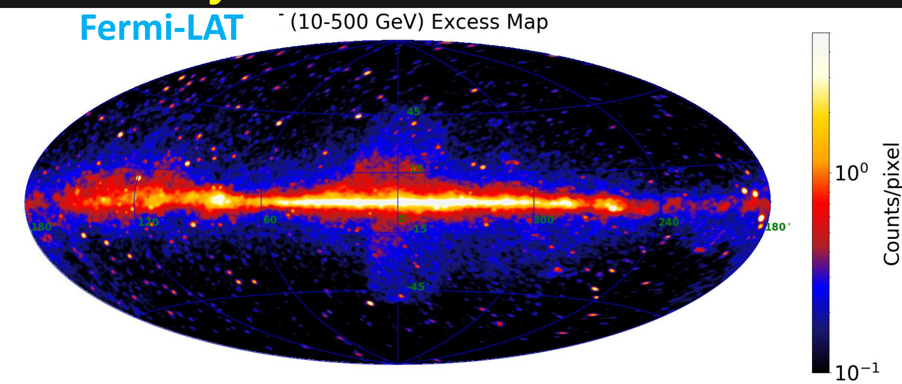
Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	−13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	−5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	−3.65	8.5	$0.26 -0.10^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	−0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71 -0.07^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)

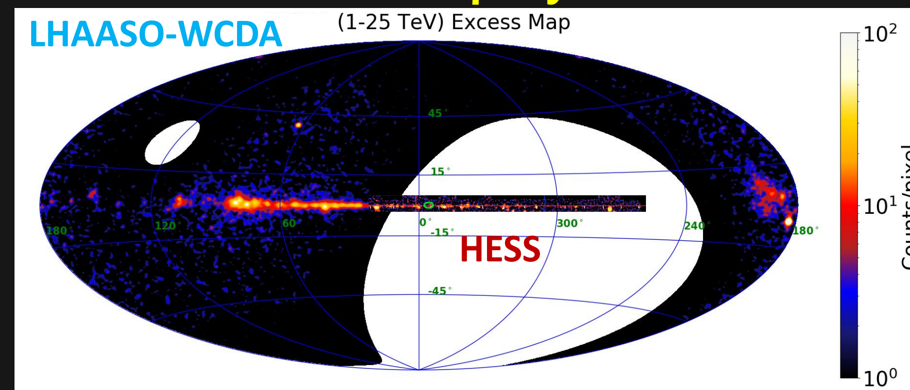
Celestial coordinates (RA, dec.); statistical significance of detection above 100 TeV (calculated using a point-like template for the Crab Nebula and LHAASO J2108+5157 and 0.3° extension templates for the other sources); the corresponding differential photon fluxes at 100 TeV; and detected highest photon energies. Errors are estimated as the boundary values of the area that contains ±34.14% of events with respect to the most probable value of the event distribution. In most cases, the distribution is a Gaussian and the error is 1σ.

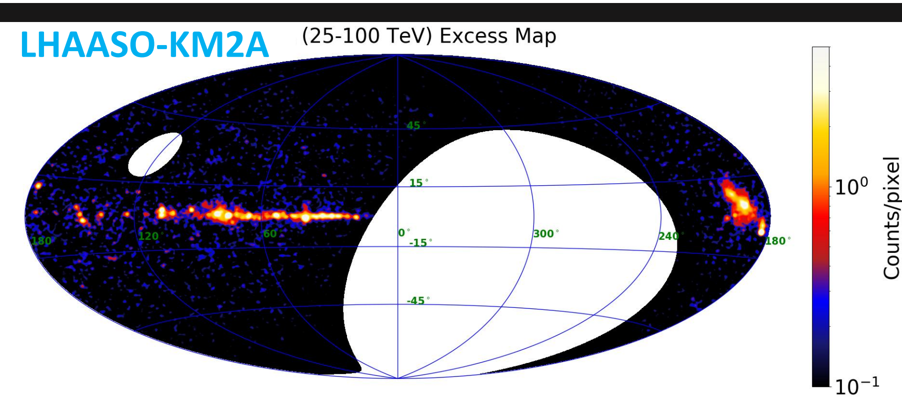
Ultra-High-Energy γ-ray Astronomy

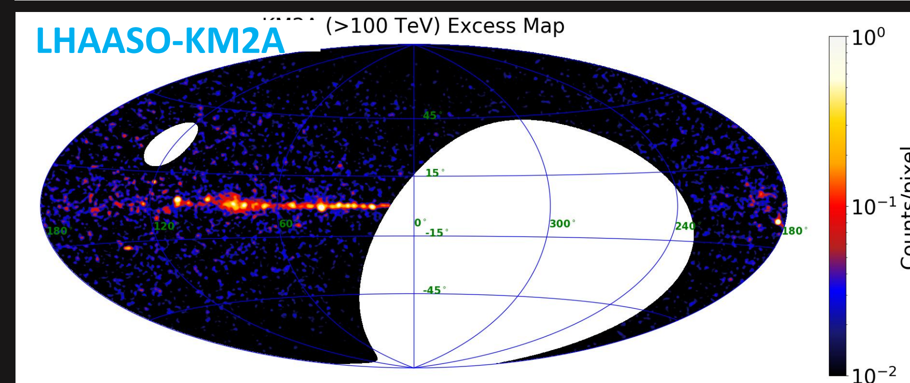
arXiv:2305.17030v1

- **Survey discovered 30+ new sources, 40+ PeVatrons and diffuse γ-ray emission**

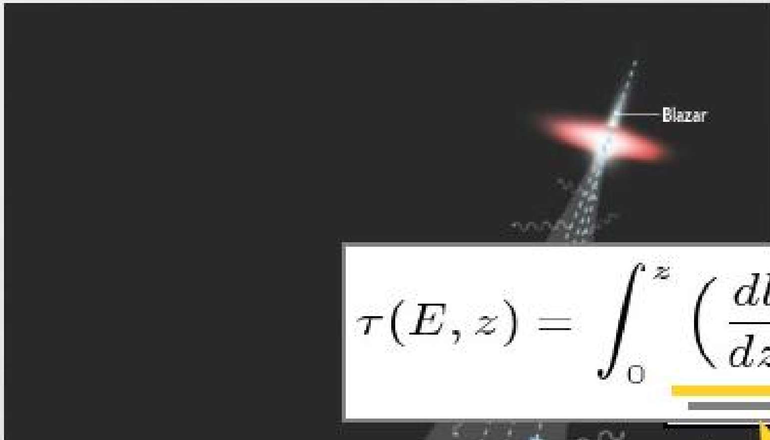








Gamma-Ray Attenuation



$$\left.\frac{dN}{dE}\right|_{obs} = \left.\frac{dN}{dE}\right|_{int} \exp\left[-\tau(E,z)\right]$$

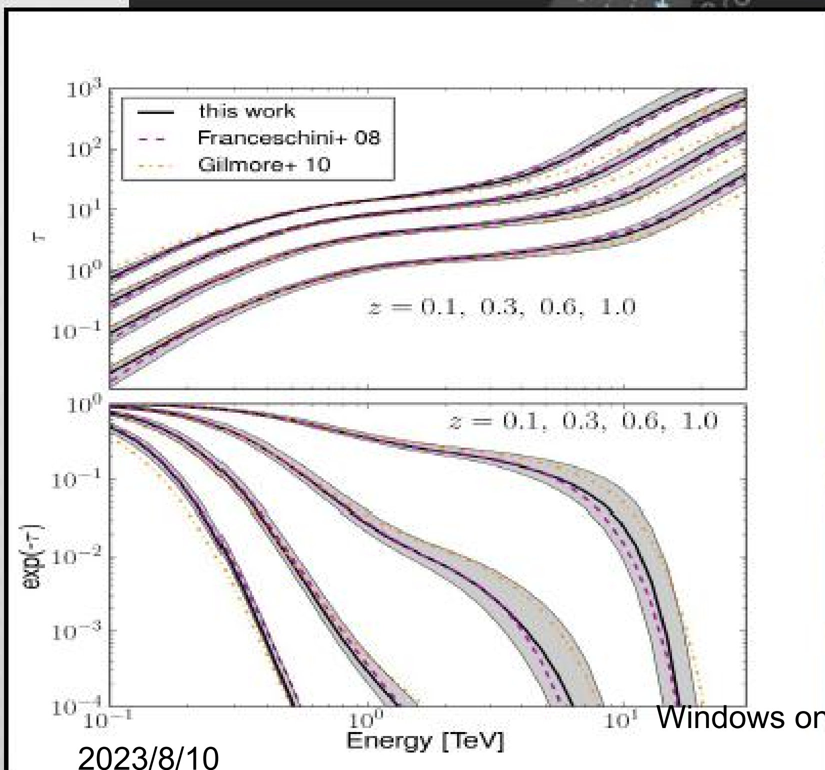
$$\tau(E,z) = \int_0^z \left(\frac{dl'}{dz'}\right) dz' \int_0^2 d\mu \frac{\mu}{2} \int_{\varepsilon_{min}}^{\infty} d\varepsilon' \, \sigma_{\gamma\gamma}(\beta') n(\varepsilon', z')$$

Distance (cosmology)

Interaction angle

Cross section

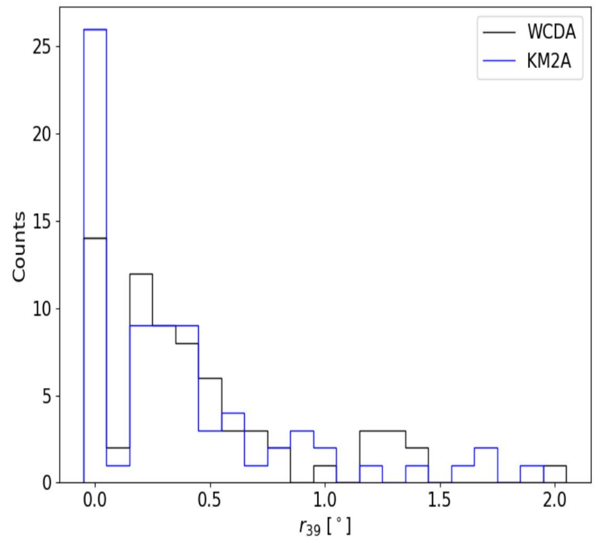
EBL photon density evolution (cosmology)



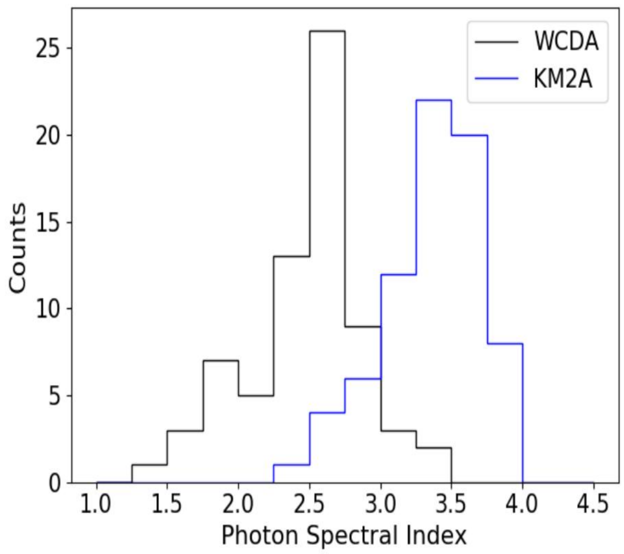
Properties of WCDA and KM2A sources

- WCDA detected 69 sources at >5σ (TS>37) and extension <2º
- KM2A detected 75 sources at >5σ (TS>37) and extension <2º

Source extension



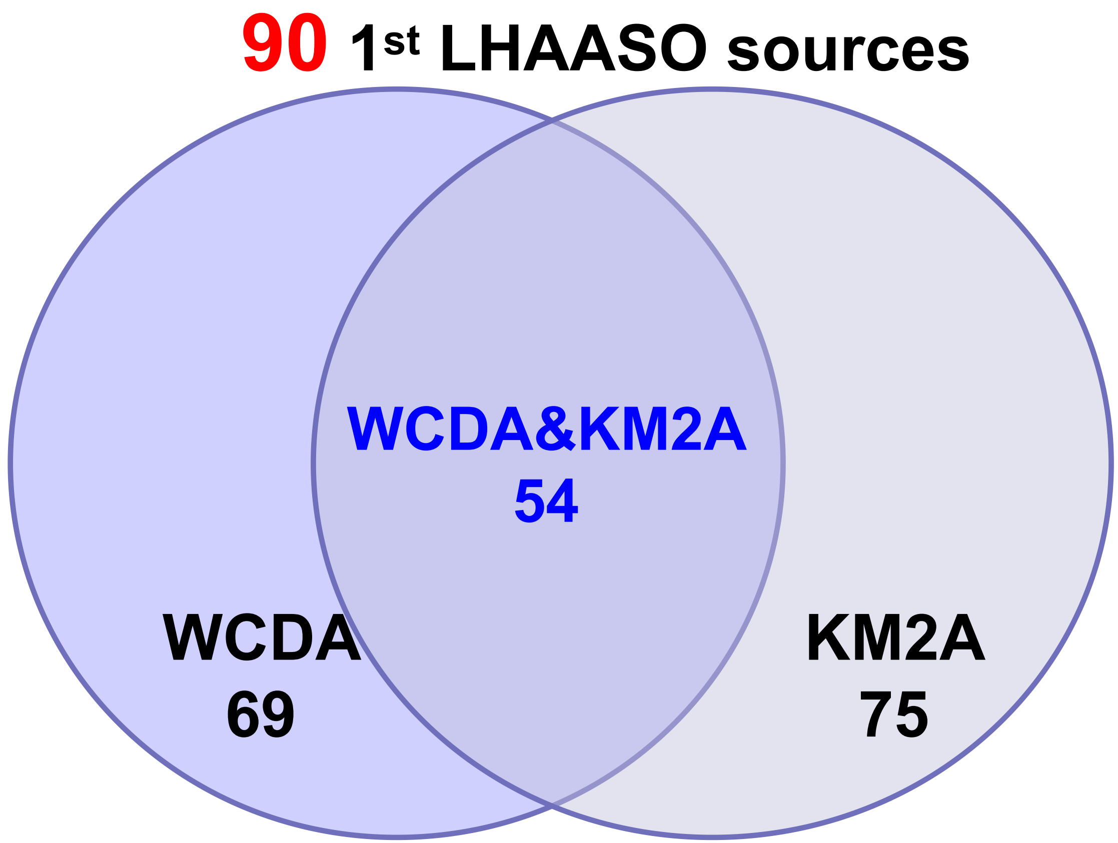
Spectral index



Construction of the 1st LHAASO sources

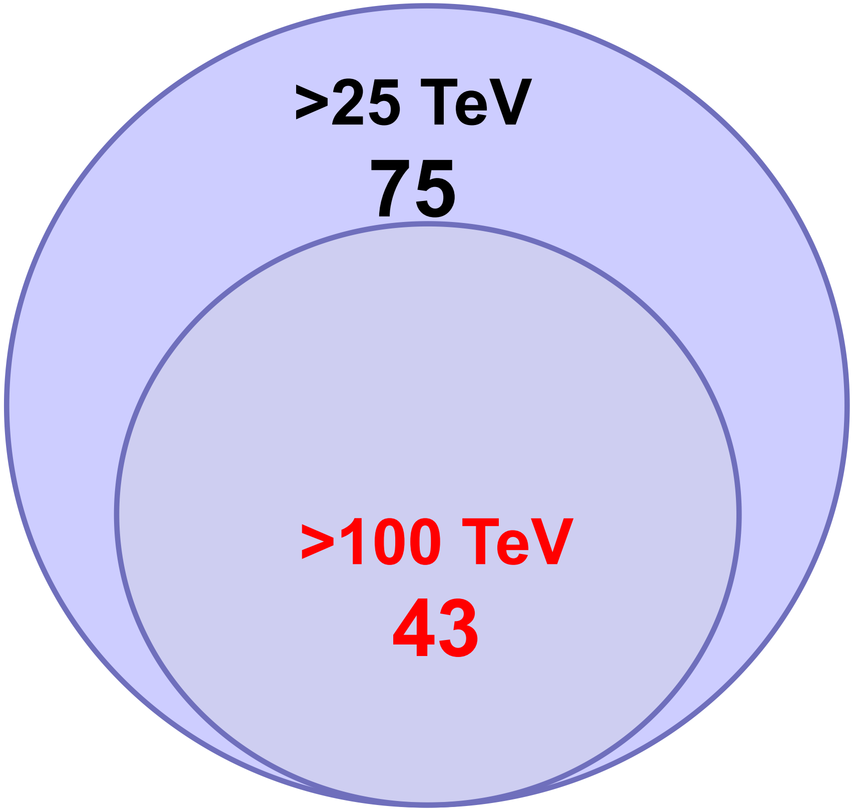
WCDA&KM2A

- Separation Angle
- Position error
- Source extension



UHE gamma-ray sources

- The position and extension achieved by KM2A at >25 TeV are used.
- Sources with significance >4σ at >100 TeV are labeled as UHE sources

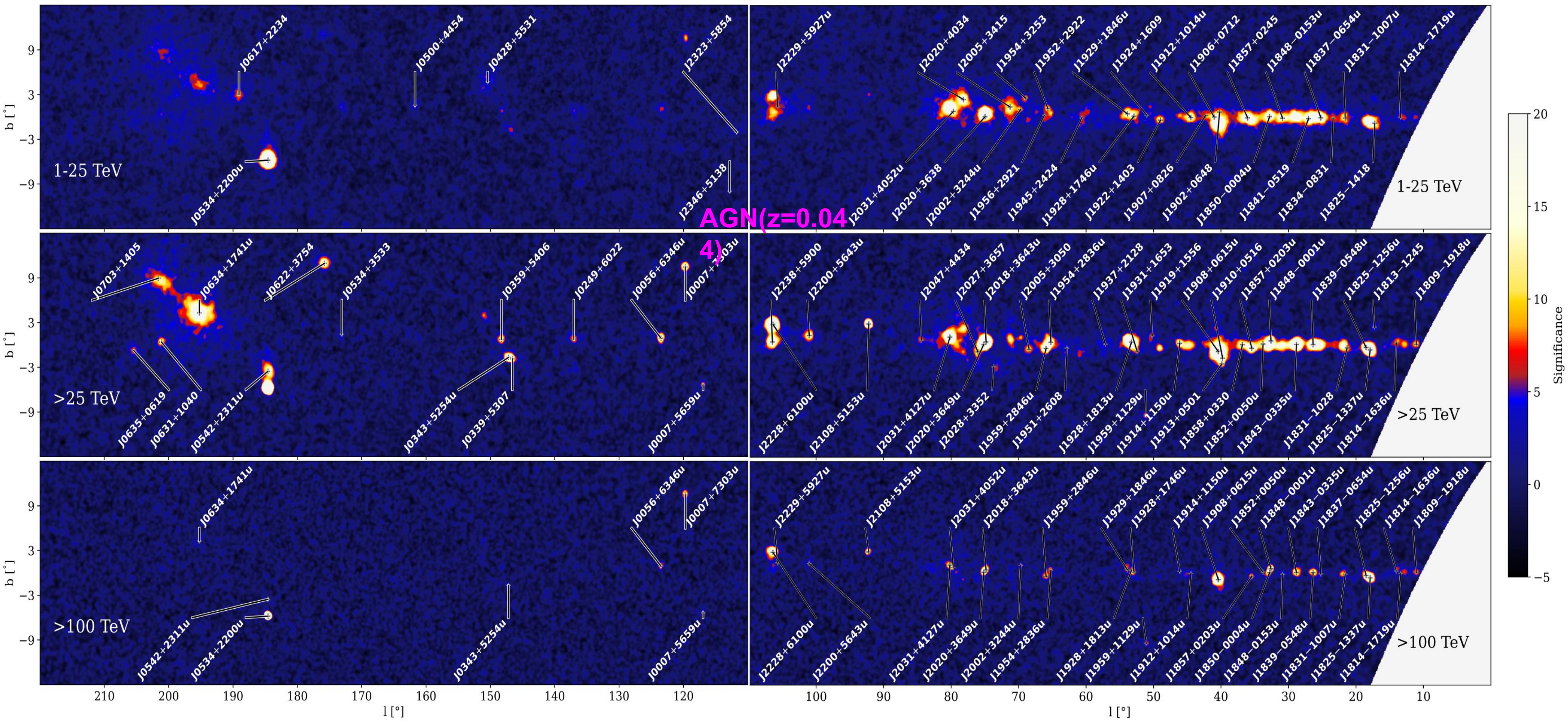


1st LHAASO source catalog

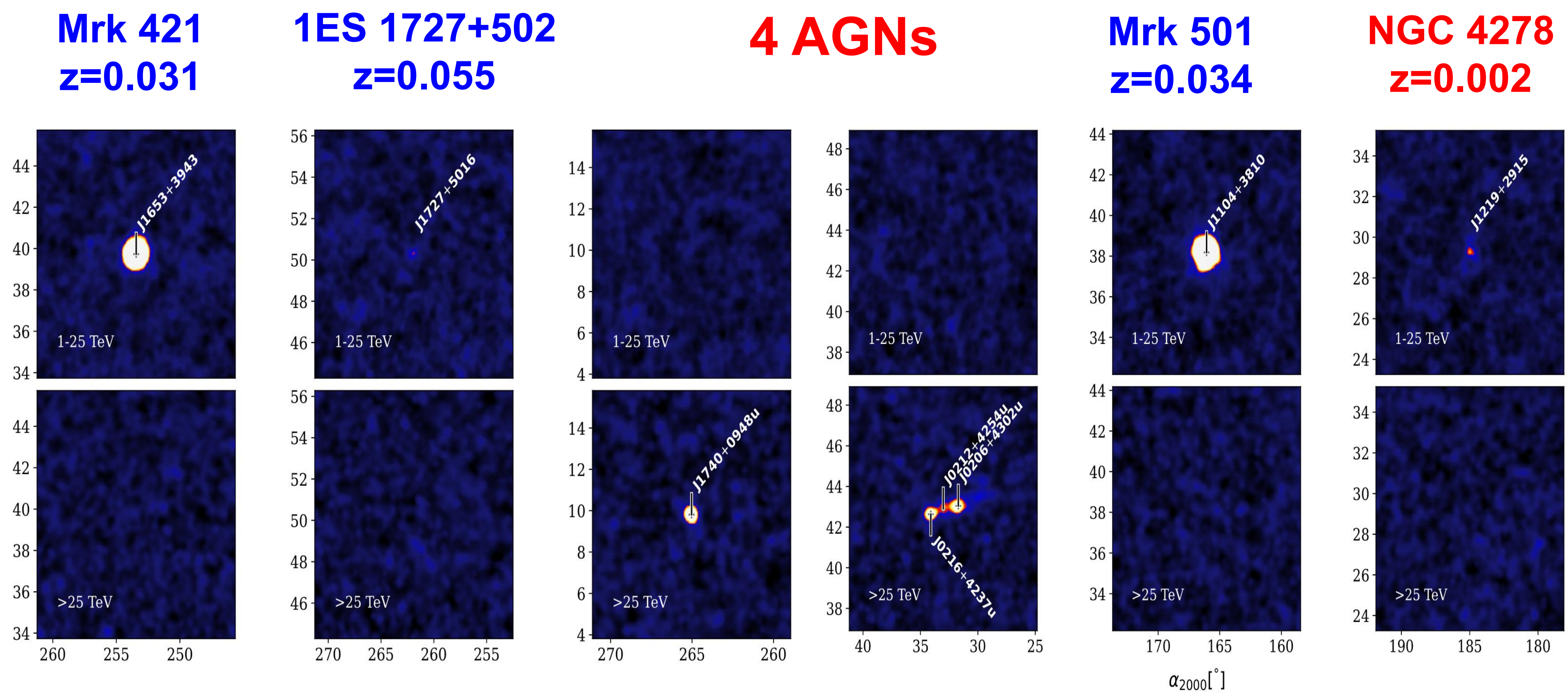
arXiv:2305.17030v1

Source name	Components	α_{2000}	δ_{2000}	$\sigma_{p,95,stat}$	r_{39}	TS	N_0	Γ	TS_{100}	Asso.(Sep.[°])
1LHAASO J0007+5659u	KM2A	1.86	57.00	0.12	<0.18	86.5	0.33±0.05	3.10±0.20	43.6	
	WCDA						<0.27			
1LHAASO J0007+7303u	KM2A	1.91	73.07	0.07	0.17±0.03	361.0	3.41±0.27	3.40±0.12	171.6	CTA 1 (0.12)
	WCDA	1.48	73.15	0.10	<0.22	141.6	5.01±1.11	2.74±0.11		
1LHAASO J0056+6346u	KM2A	14.10	63.77	0.08	0.24±0.03	380.2	1.47±0.10	3.33±0.10	94.1	
	WCDA	13.78	63.96	0.15	0.33±0.07	106.1	1.45±0.41	2.35±0.13		
1LHAASO J0206+4302u	KM2A	31.70	43.05	0.13	<0.27	96.0	0.24±0.03	2.62±0.16	82.8	
	WCDA						<0.09			
1LHAASO J0212+4254u	KM2A	33.01	42.91	0.20	<0.31	38.4	0.12±0.03	2.45±0.23	30.2	
	WCDA						<0.07			
1LHAASO J0216+4237u	KM2A	34.10	42.63	0.10	<0.13	102.0	0.18±0.03	2.58±0.17	65.6	
	WCDA						<0.20			
1LHAASO J0249+6022	KM2A	42.39	60.37	0.16	0.38±0.08	148.8	0.93±0.09	3.82±0.18		
	WCDA	41.52	60.49	0.40	0.71±0.10	53.3	1.96±0.51	2.52±0.16		
1LHAASO J0339+5307	KM2A	54.79	53.13	0.11	<0.22	144.0	0.58±0.06	3.64±0.16		LHAASO J0341+5258 (0.37)
	WCDA						<0.21			
1LHAASO J0343+5254u*	KM2A	55.79	52.91	0.08	0.20±0.02	388.1	1.07±0.07	3.53±0.10	20.2	LHAASO J0341+5258 (0.28)
	WCDA	55.34	53.05	0.18	0.33±0.05	94.1	0.29±0.13	1.70±0.19		

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

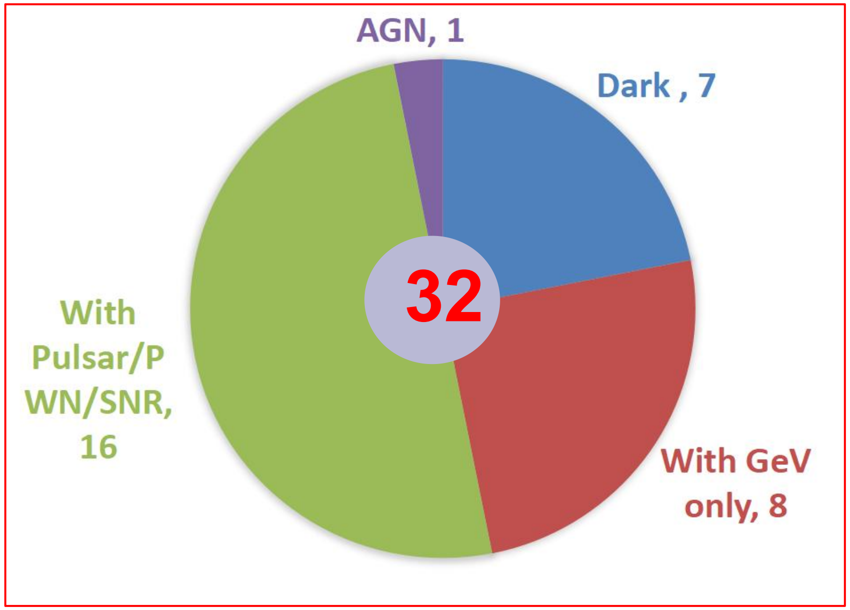


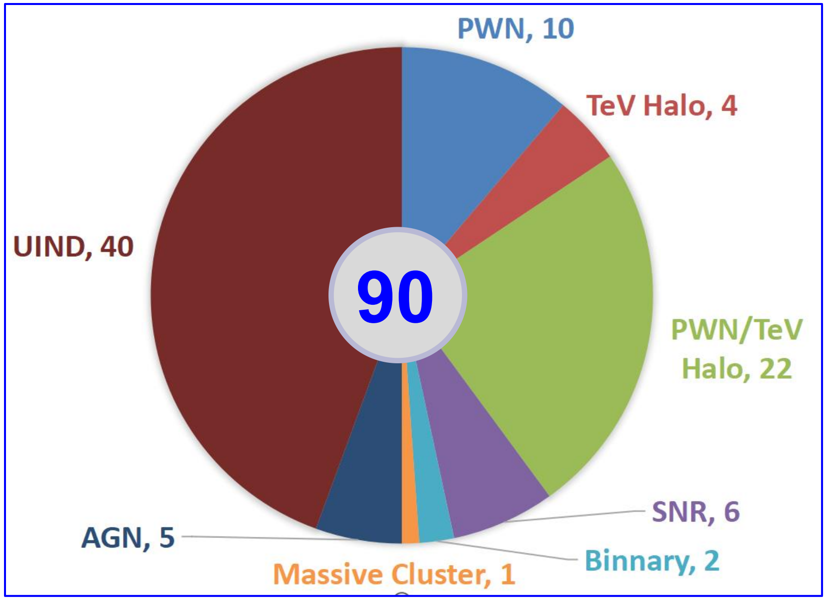
8 sources with the Galactic latitude |b|>12º



Association with known TeV Sources

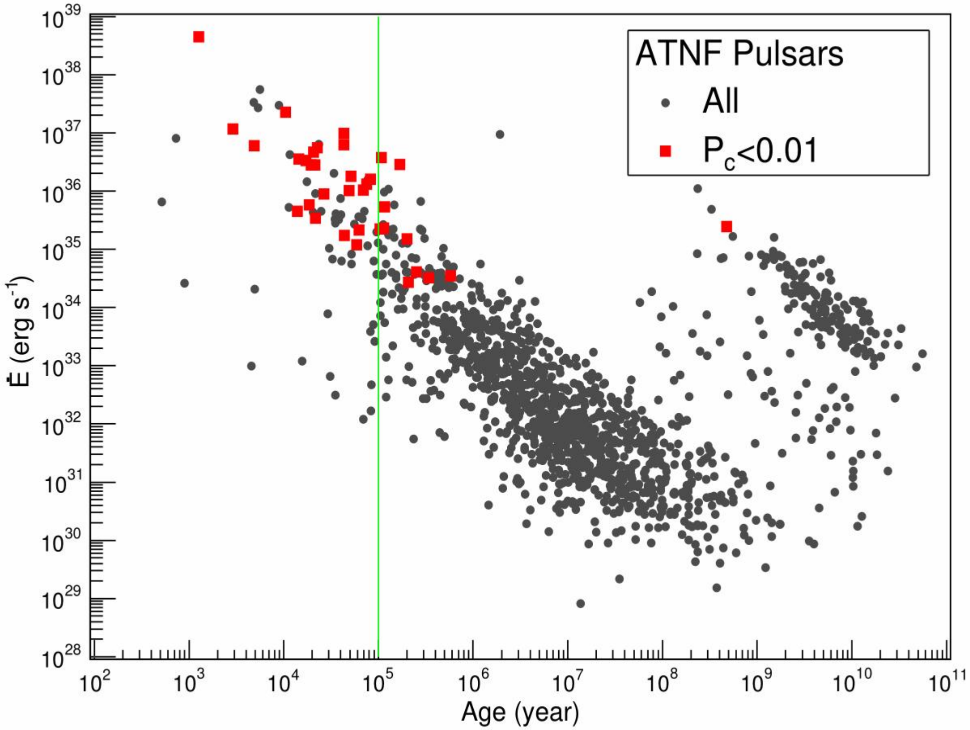
- **58** sources with TeVCat+3HAWC association
- **32** new sources（25+7）





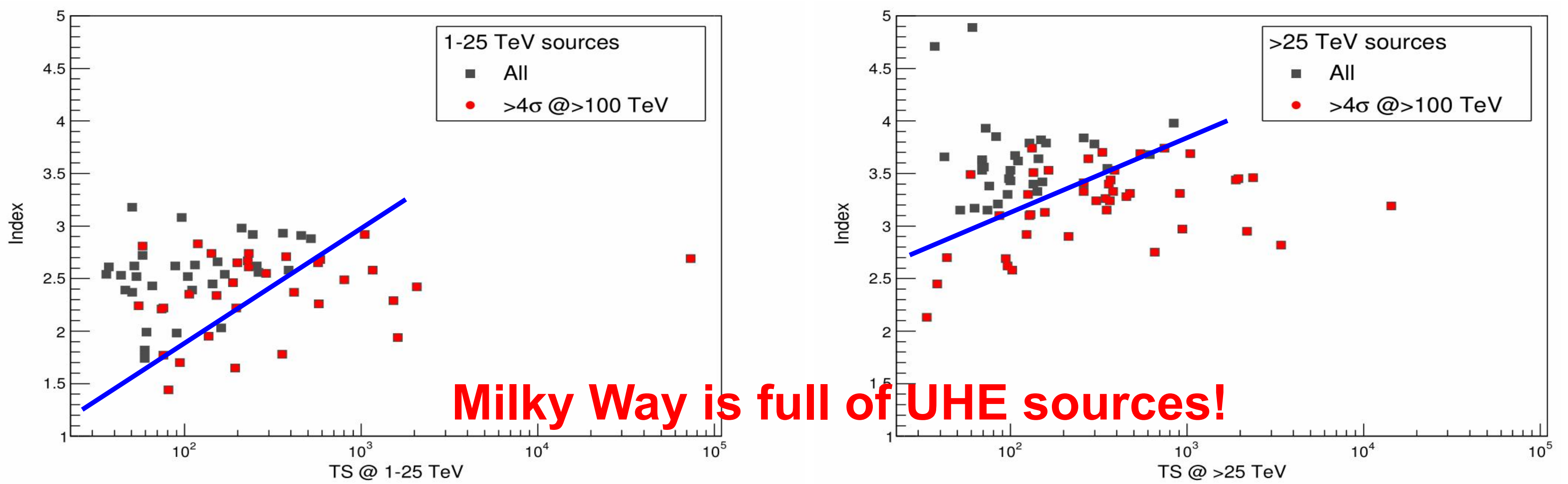
Association with ATNF pulsars

- 65 1LHAASO sources with pulsar nearby <0.5º.
- 35 associations with chance coincide probability <1%. (13 labeled as PWN or Halo in TeVCat)
- 22 new possible PWN/TeV Halo



PeVatrons

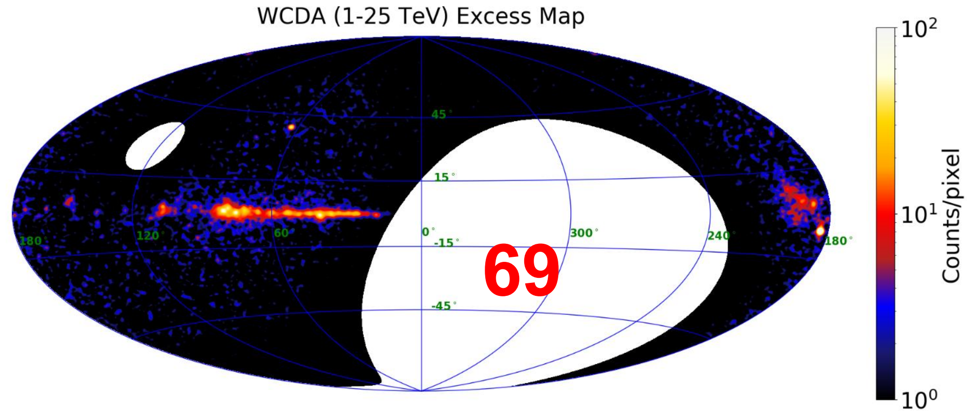
- **51% (35/69) 1-25TeV sources are UHE sources.**
- **57% (43/75) >25TeV sources are UHE sources.**
- **19% (8/43) UHE sources are not detected at 1-25TeV (new class?).**

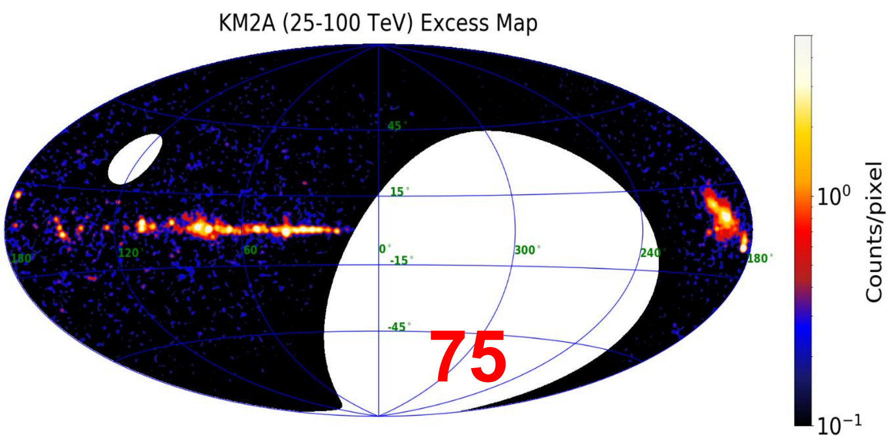


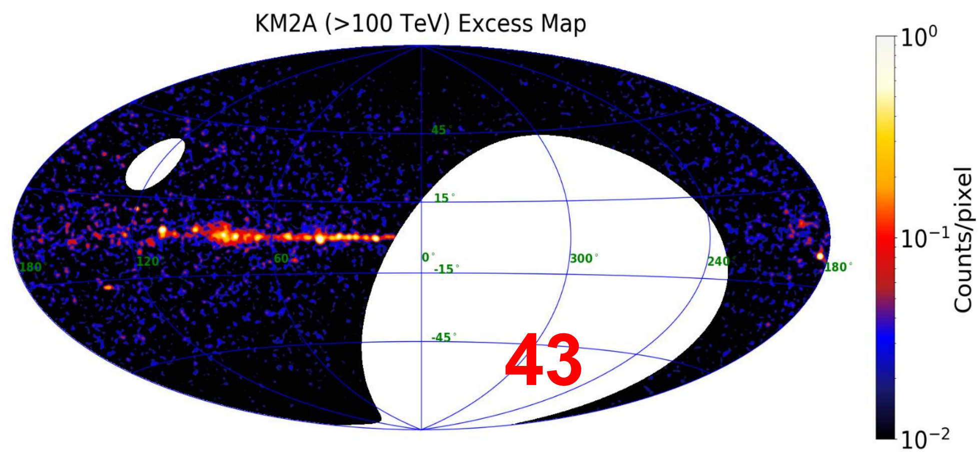
Milky Way is full of UHE sources!

LHAASO catalog

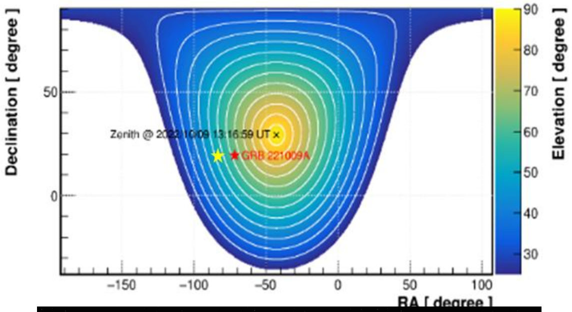
- **90 in 1st LHAASO sources.**
- **32 new discoveries**
- **43 UHE**

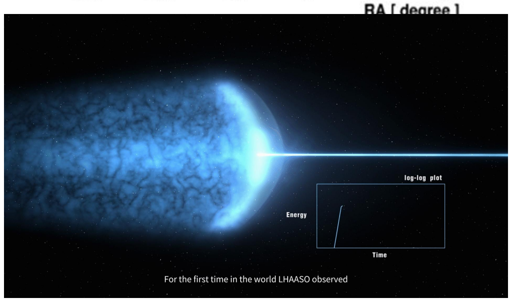


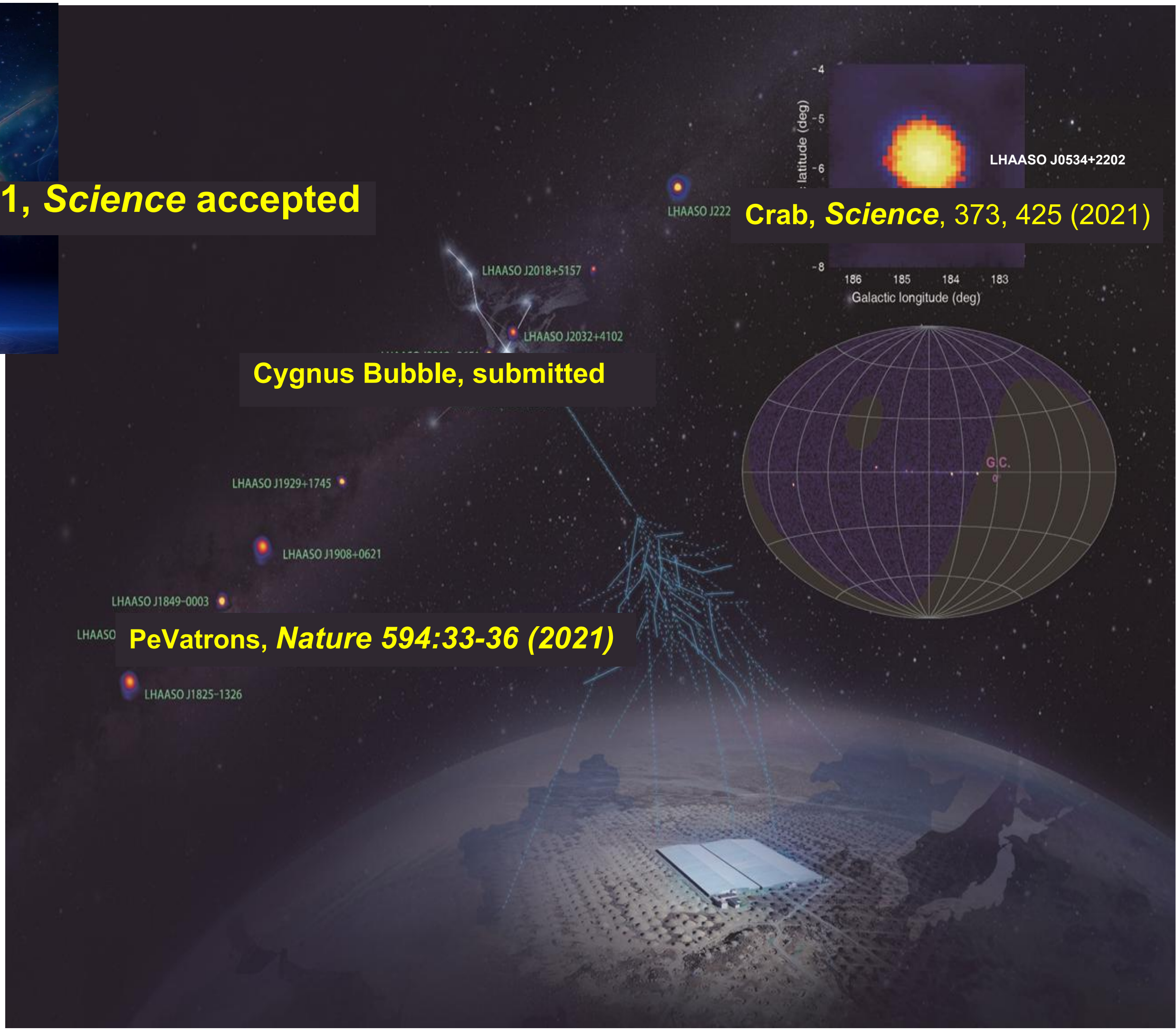




Discovery Highlights



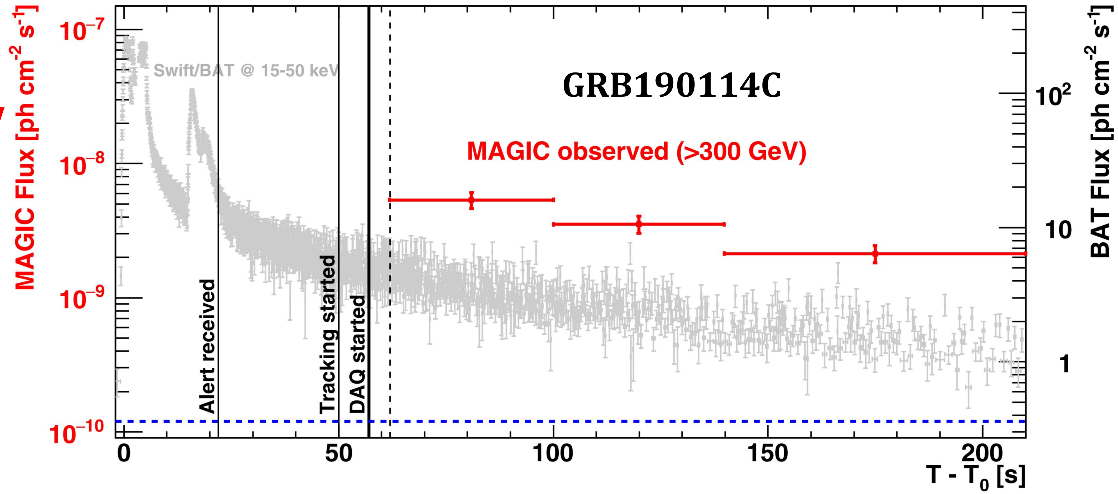


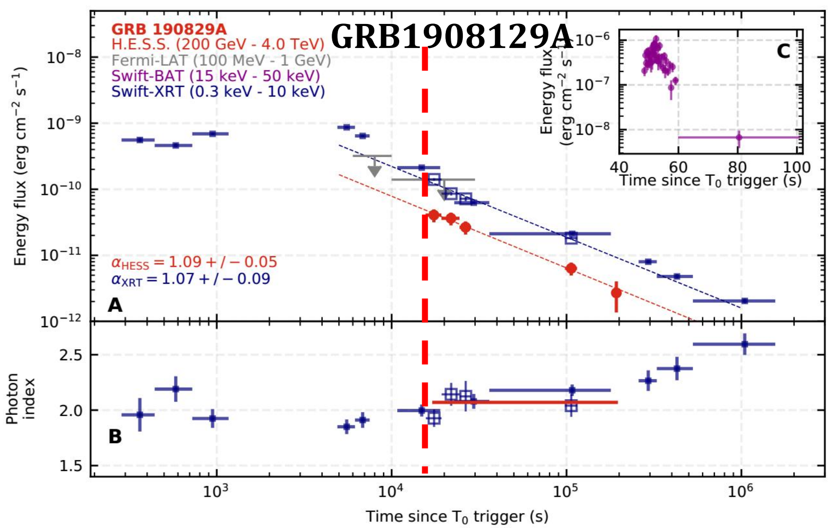


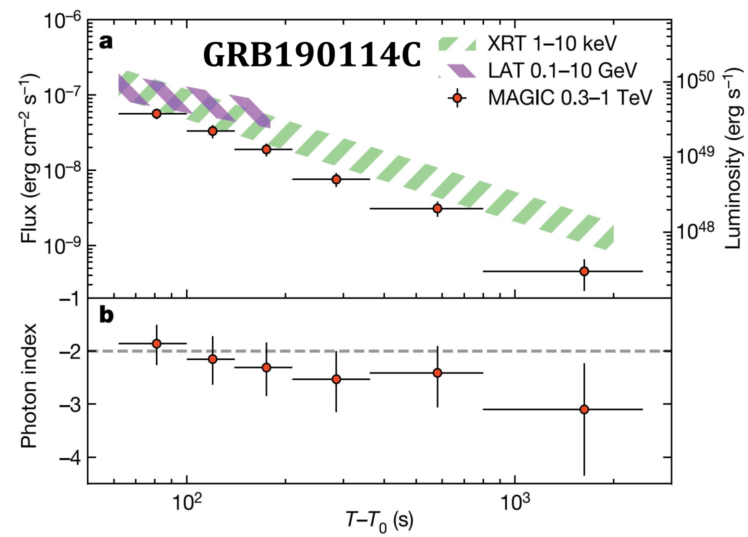
LHAASO
高海拔宇宙线观测站

TeV afterglow

- Smooth **decaying** of TeV emission
- Low redshift



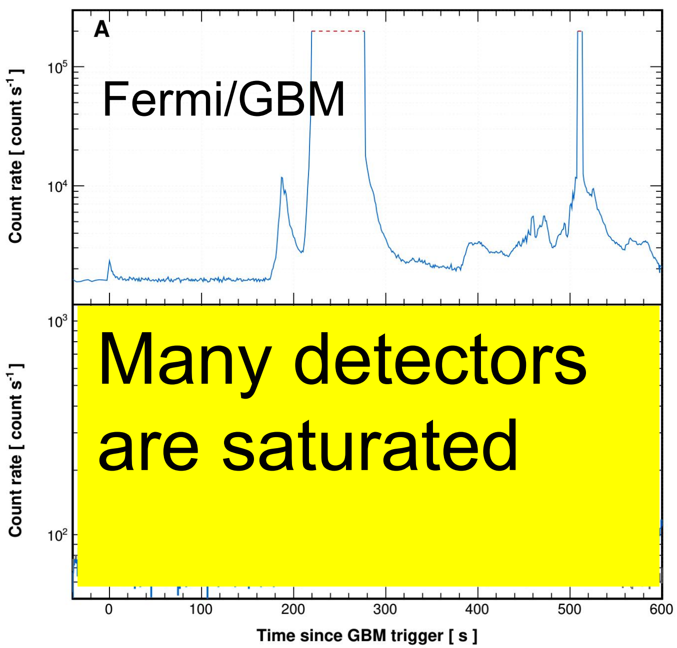


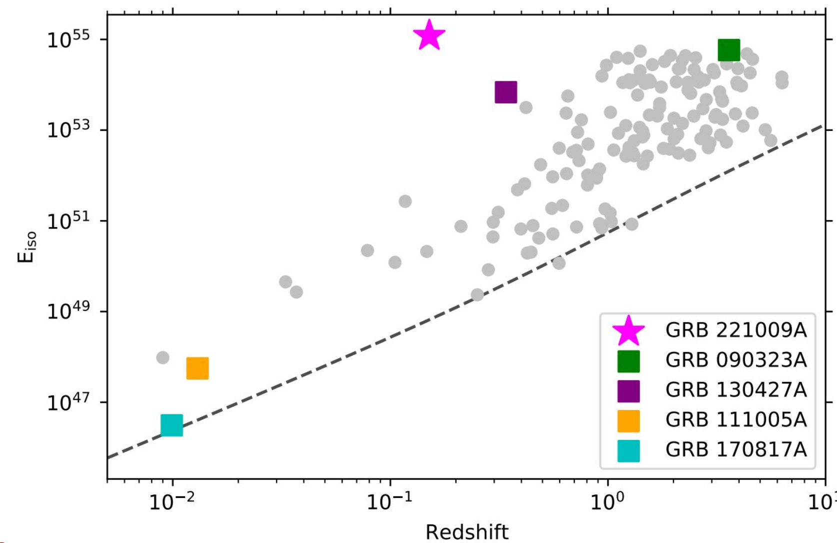


GRB 221009A: *brightest-of-all-time (BOAT) GRB*

- Triggered on a weak precursor
- Fluence: >5e-2 erg/cm^2, low redshift (z=0.151)
- deriving an enormous energy

GRB)





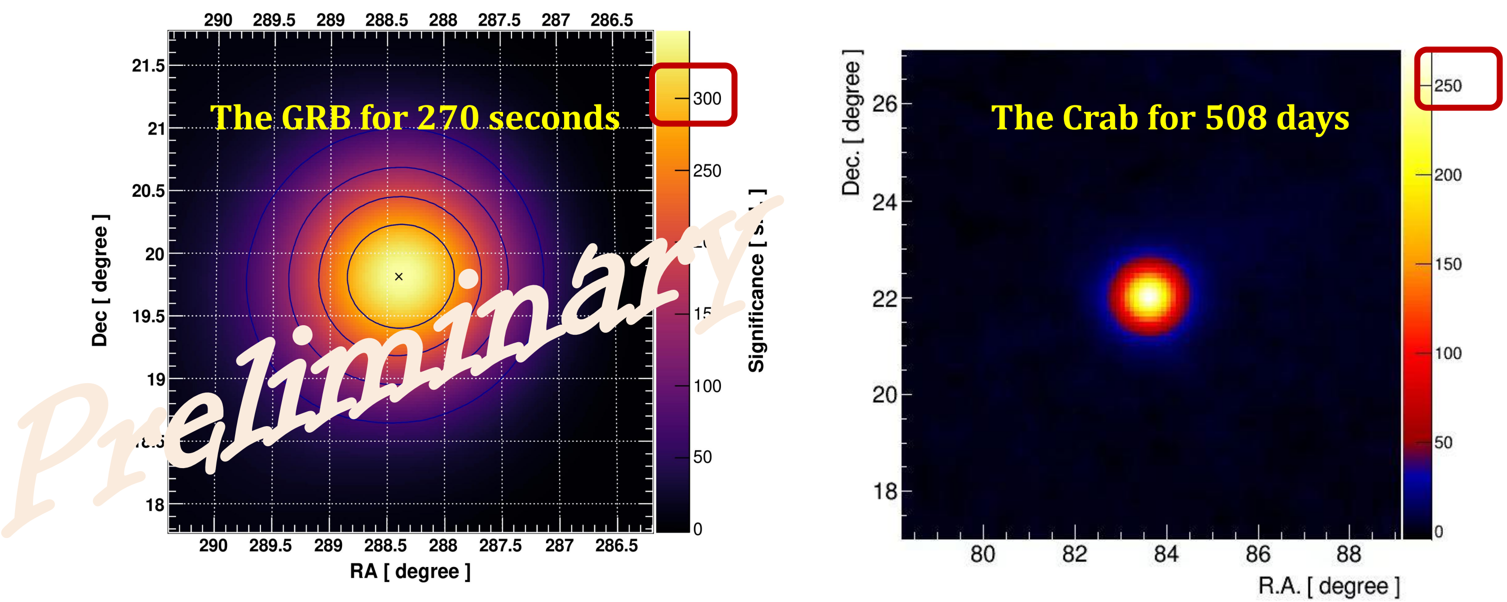
R<10^{-3} yr

R_GRB≤ 6.1 × 10^{-4} Gpc^{-3} yr^{-1}

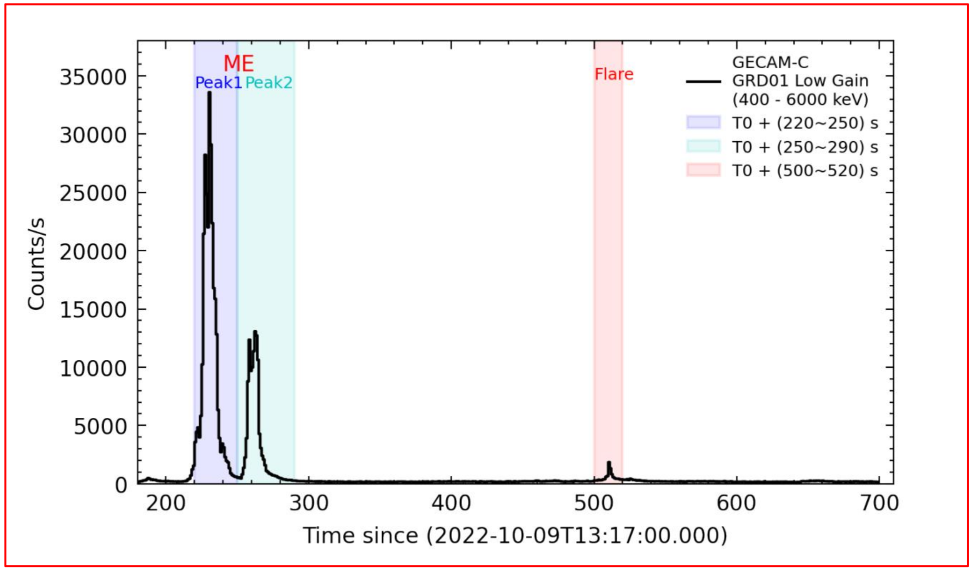
z=0.151 volume ~ 1 Gpc^3

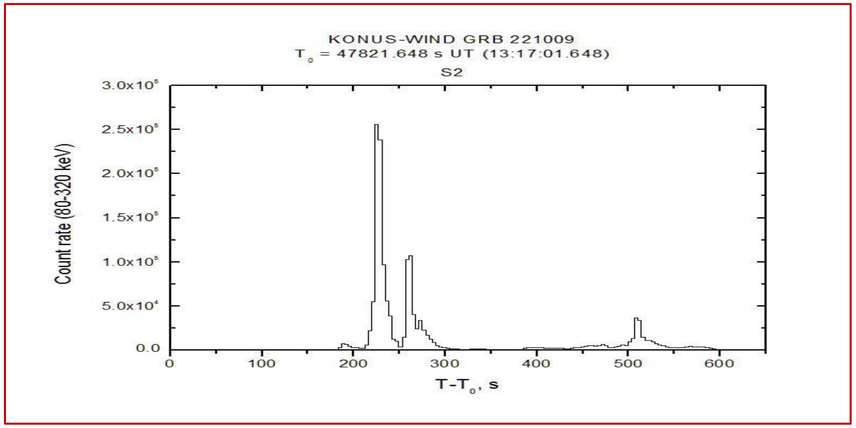
Even much less chance for it in the middle of FoV of LHAASO

The burst of 64k photons in **270 seconds**
versus the exposure of the Crab for 508 days



GECAM/Konus-Wind Observations of GRB 221009A





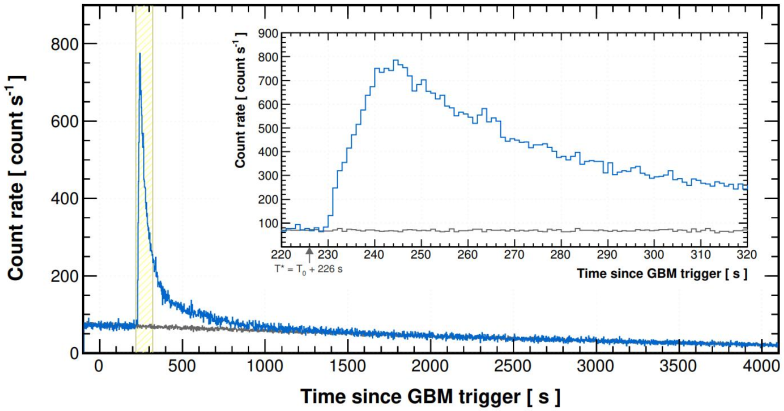
E_iso~ 1.5 × 10^55 erg

Main peak 1 lasts ~10 s

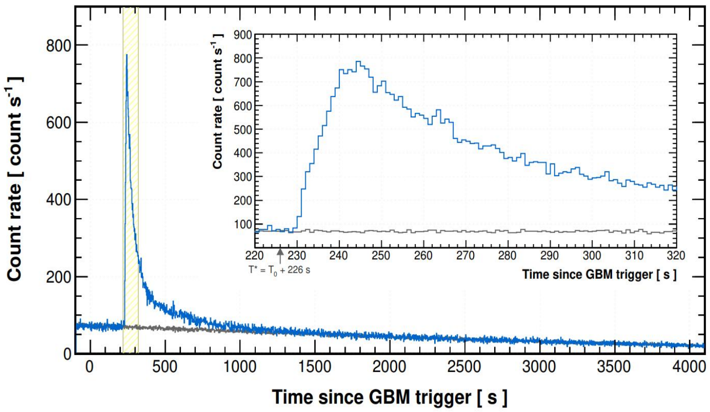
LHAASO GRB221009A

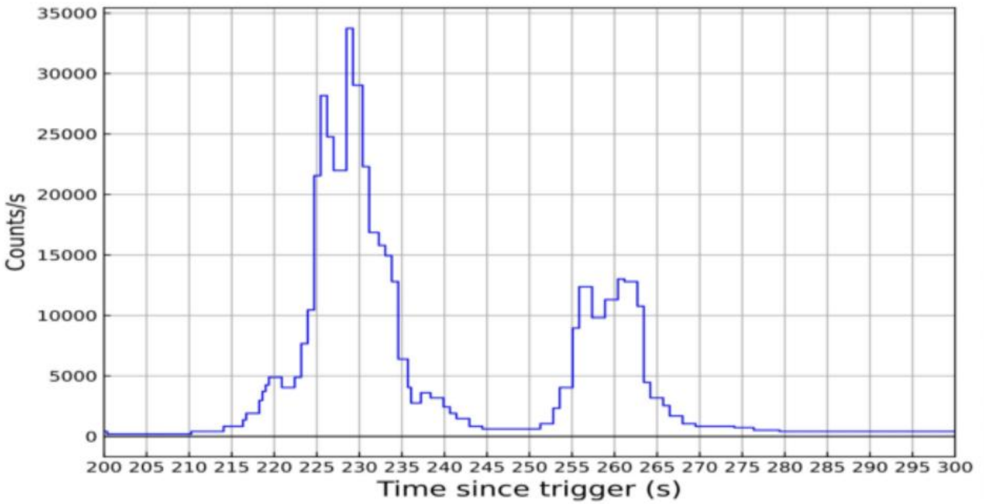
- LHAASO detection of GRB 221009A: first GRB seen by a extensive air shower detector
- High statistics: >60,000 photons above 0.2TeV (LHAASO-WCDA)
- TeV count rate light curve: Smooth temporal profile –**external shock origin**

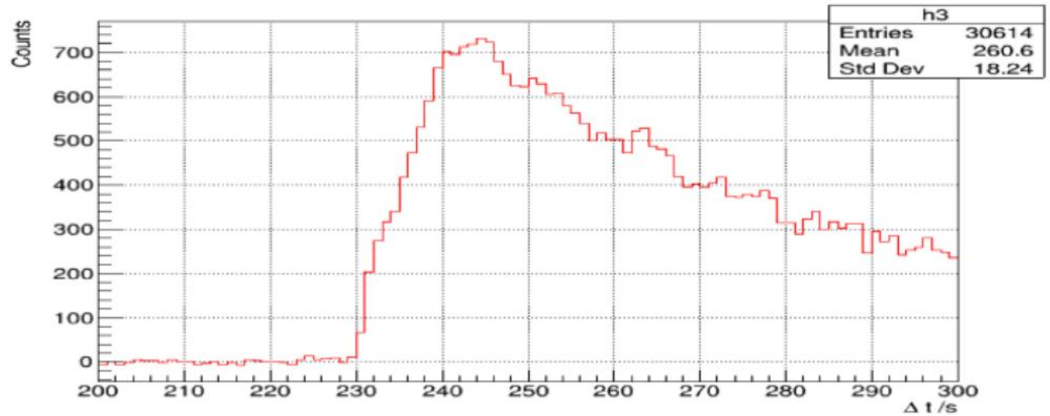
First time detection of the TeV afterglow onset !



MeV vs TeV light curves: external shock origin







Science

RESEARCH ARTIC

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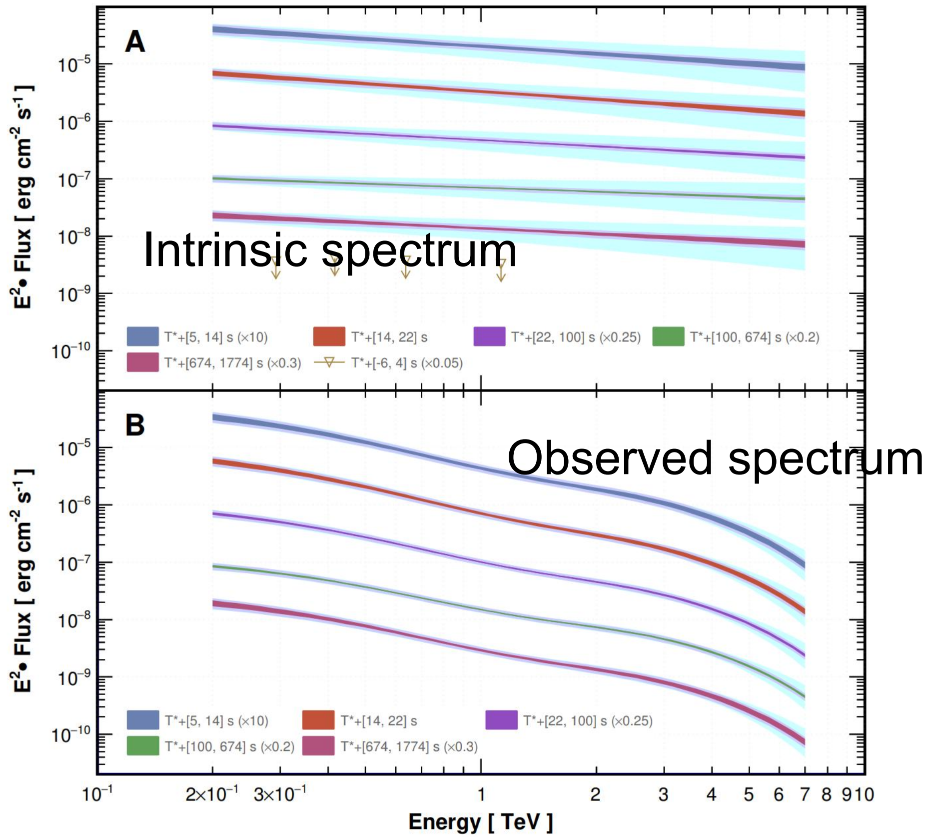
A tera-electron volt afterglow from a narrow jet in an extremely bright gamma-ray burst

LHAASO Collaboration†*

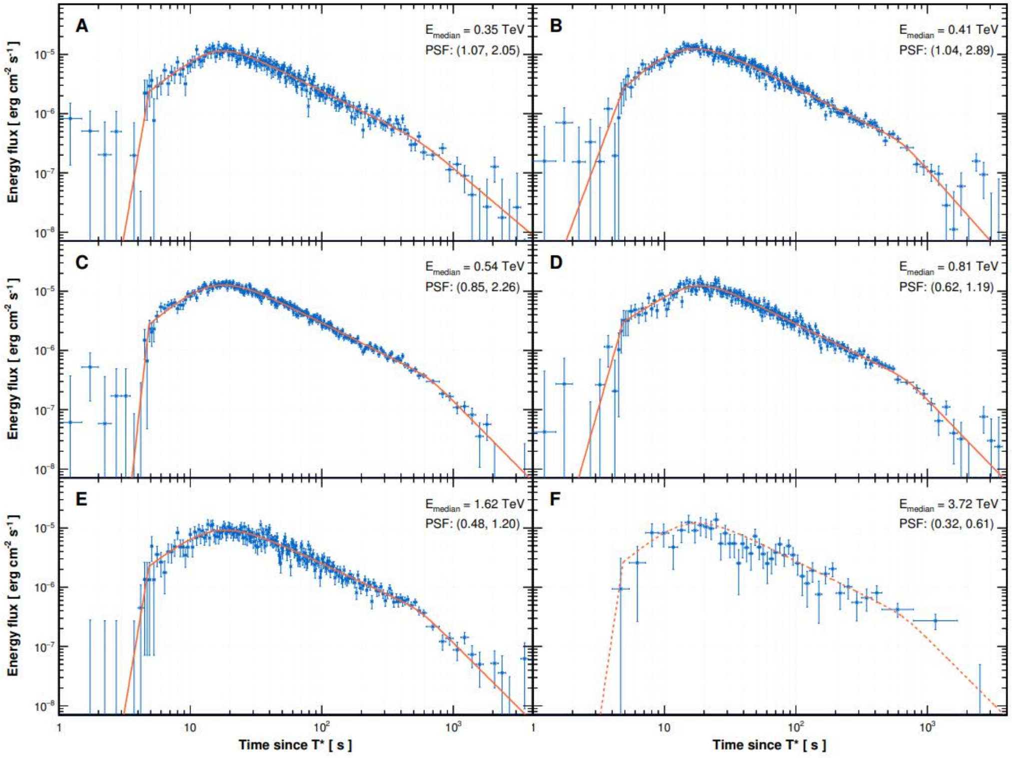
SED from WCDA



- EBL model: A. Saldana-Lopez et al. (2021)

Time interval (seconds after T_0)	A (10^{-8} TeV^{-1} cm^{-2} s^{-1})	γ	$E_{\rm cut}$ TeV	χ^2/dof
Observed spectrum				
231–240	42.9 ± 2.7	2.983 ± 0.061	3.14 (fixed)	4.6/6
240–248	70.1 ± 3.8	3.006 ± 0.052	3.14 (fixed)	8.0/6
248–326	39.9 ± 1.0	2.911 ± 0.028	3.14 (fixed)	14.8/6
326–900	7.35 ± 0.16	2.788 ± 0.026	3.14 (fixed)	8.9/6
900–2000	0.959 ± 0.043	2.880 ± 0.067	3.14 (fixed)	2.9/5
Intrinsic spectrum, *standard* EBL				
231–240	127.3 ± 7.9	2.429 ± 0.062	\	3.1/6
240–248	208 ± 11	2.455 ± 0.054	\	6.5/6
248–326	117.8 ± 3.0	2.359 ± 0.028	\	8.7/6
326–900	21.77 ± 0.47	2.231 ± 0.026	\	3.4/6
900–2000	2.84 ± 0.13	2.324 ± 0.065	\	2.2/5

Fast decay phase



$$\alpha_3 = -2.21^{+0.30}_{-0.83}$$

$$T_{b,2} = T^* + 670^{+230}_{-110}\,\mathrm{s}$$

Revealing a jet break at the earliest time.

Summary

- Construction of LHAASO finished in September 2021. LHAASO operates with almost 100% duty cicle. It's one year sensitivity is better compared to 50 hours for present Cherenkov telescopes above few TeV. Above 20 TeV it is better compared to future CTA.
- LHAASO presented first catalog of 90 sources from about 2 first years of observation. 32 are new sources. Number of UHE gamma-ray sources above 100 TeV increased from 4 to 43 by LHAASO observations
  - 35 sources are PWN. Crab, Geminga, milisecond pulsar
  - 7 SNR, gamma-Cygni can not be explained by leptons
  - Star clusters Cygnus, w43
- GRB 221009A: detailed properties of GRB afterglow from 60000 photons in LHAASO WCDA

Welcome to Join the LHAASO collaboration!