# Status and recent results from the LHAASO experiment


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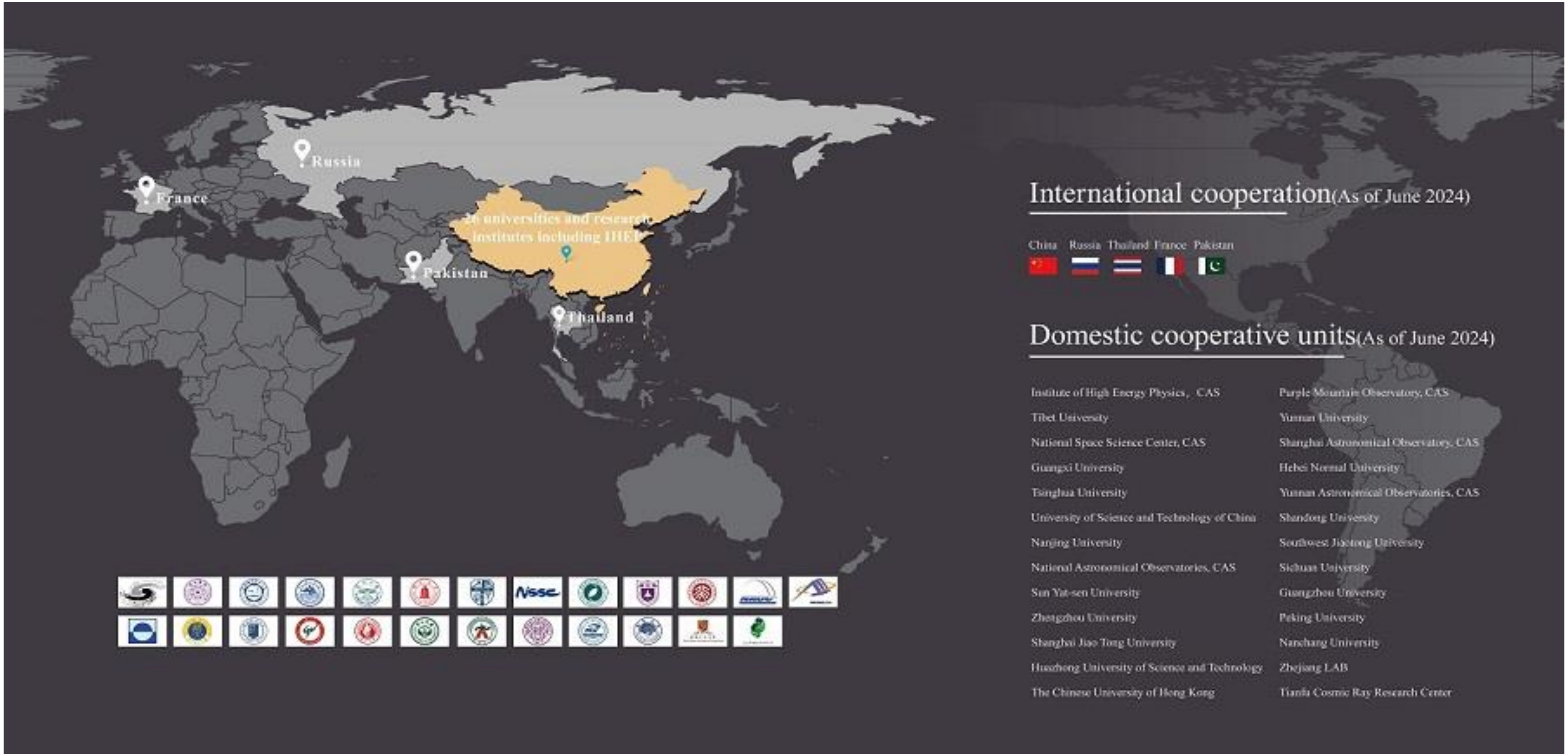
**on behalf of the LHAASO collaboration**

**IHEP,CAS**


**2024.9.25@RICAP-2024**

# LHAASO collaboration

- **298 researchers from 30 institutes of 5 countries.**



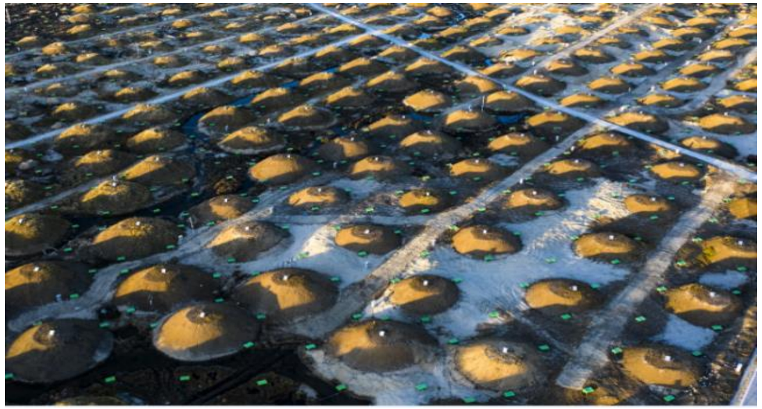
# Large High Altitude Air Shower Observatory

**The partial arrays since 2019**
**The full arrays since July 2021**

## WCDA
VHE γ-ray detector
0.1 TeV-20 TeV

## KM2A
UHE γ-ray detector
10 TeV-10 PeV

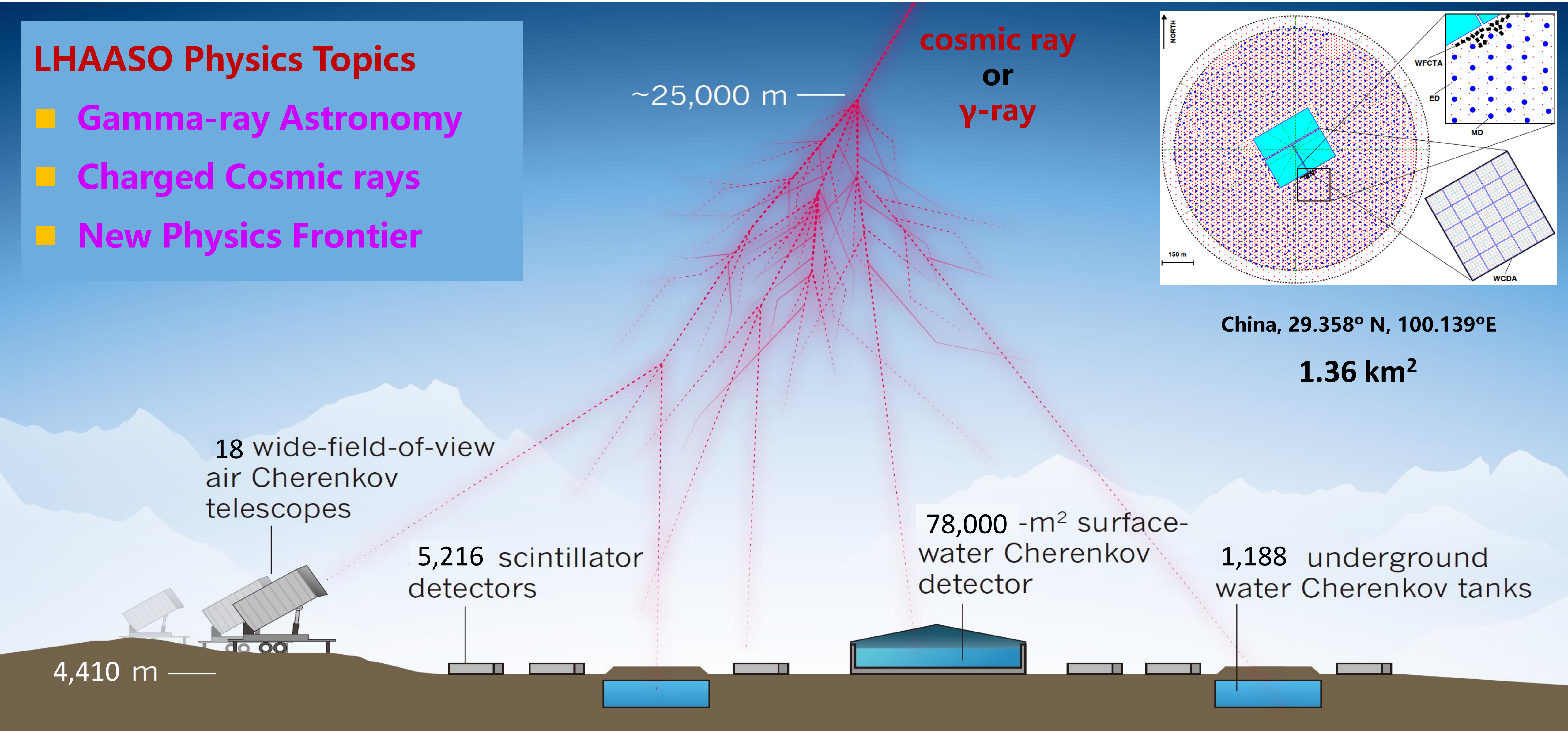
## WFCTA+KM2A+WCDA
Cosmic ray detector
10 TeV-100 PeV



# LHAASO detectors

## LHAASO Physics Topics

- Gamma-ray Astronomy
- Charged Cosmic rays
- New Physics Frontier

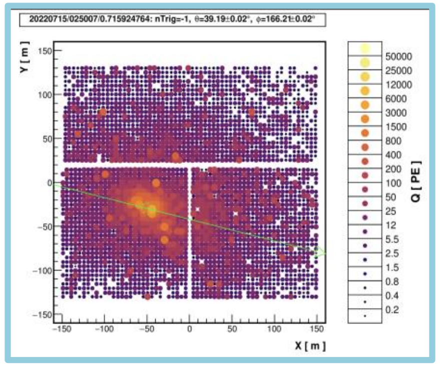



China, 29.358° N, 100.139°E

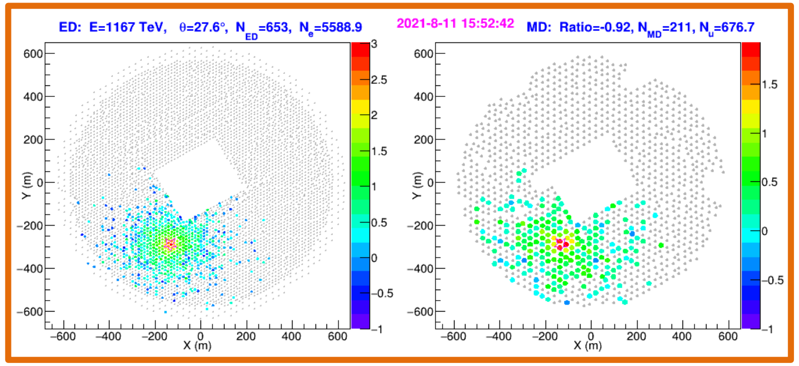
1.36 km$^2$

# Status of LHAASO

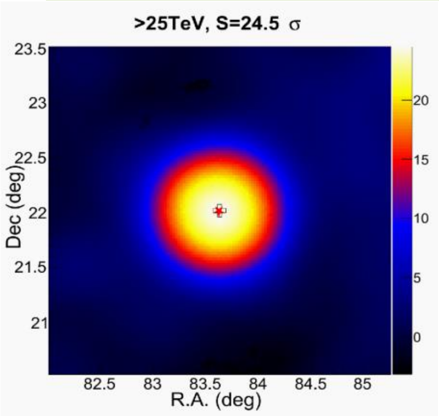
## 10 TeV event




## 1.2 PeV event

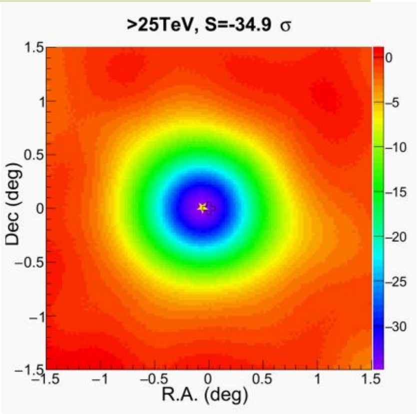



## Crab Nebula

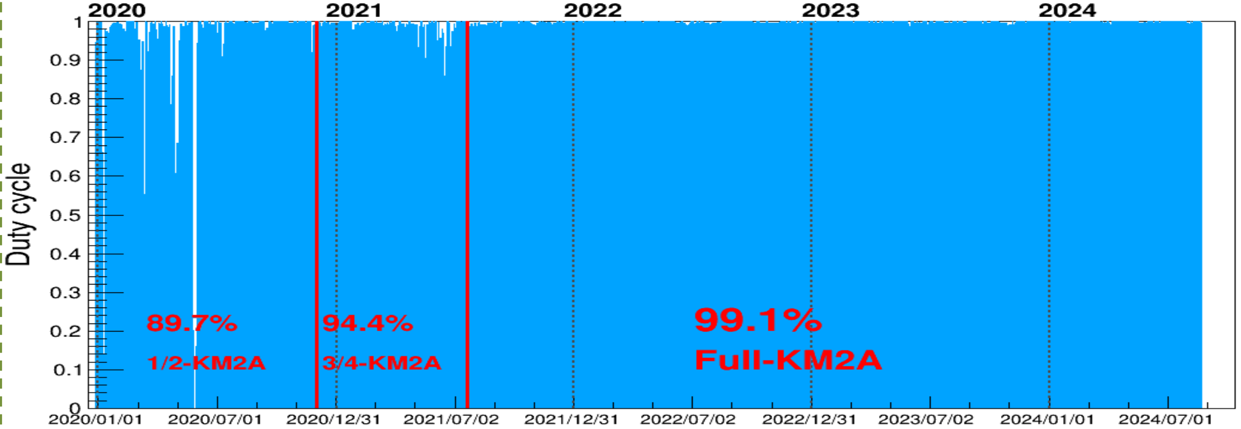



per Month

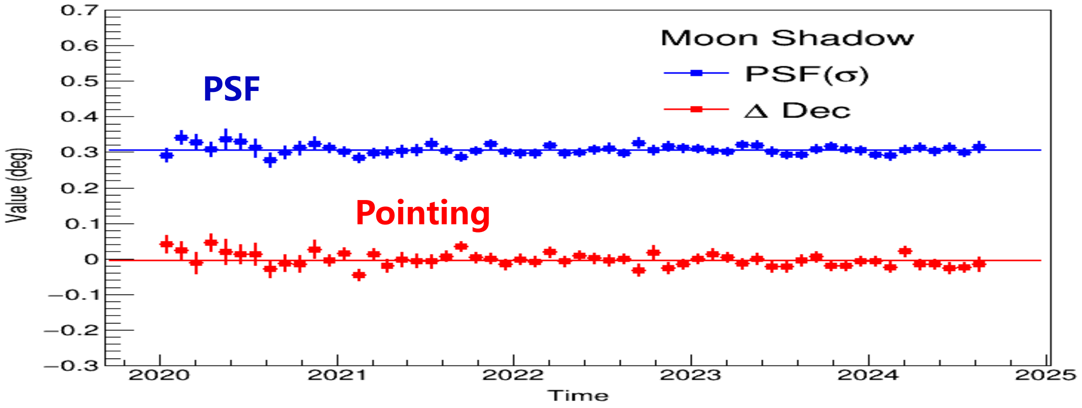
## Moon shadow




## Duty cycle >99%, 4.5 years data




## Stable pointing and angular resolution



# LHAASO recent highlight results on Gamma-ray astronomy

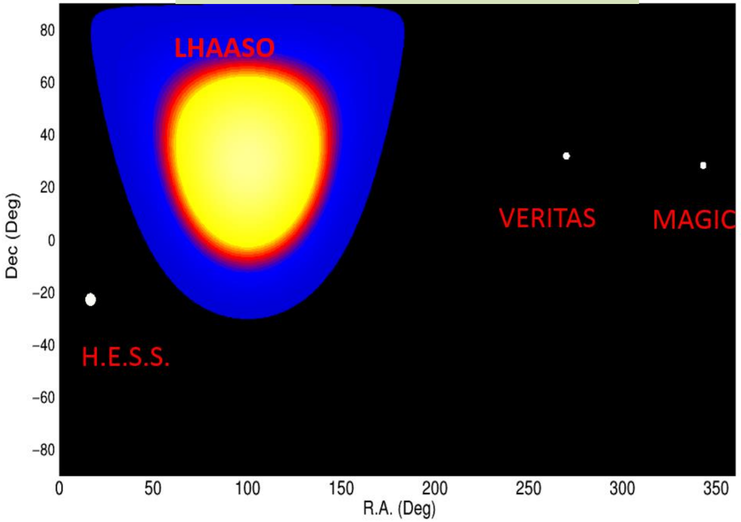
# LHAASO for γ-ray astronomy

## Good for

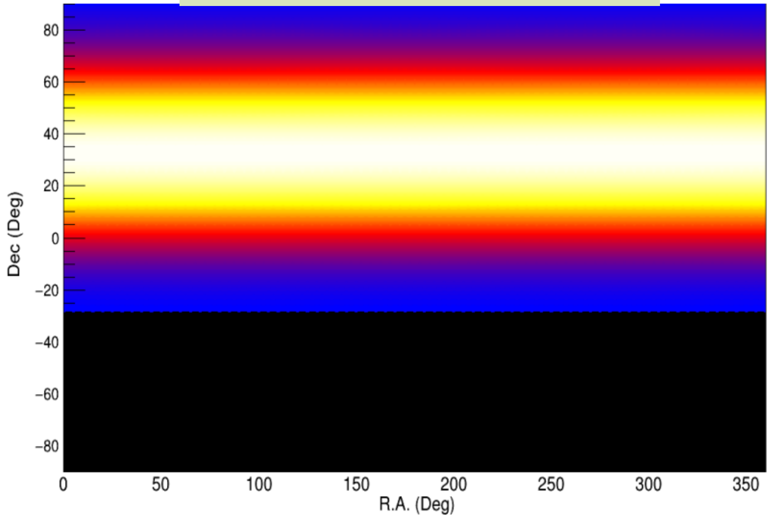
**Sky survey, Extended sources, Transient sources**

**Large FOV**

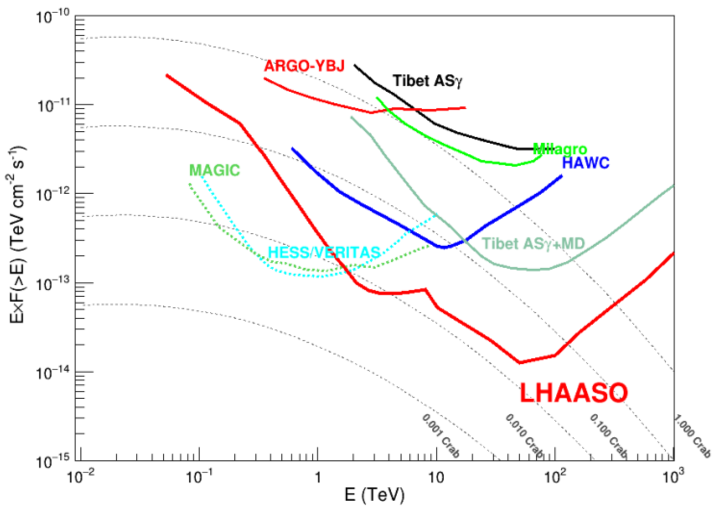
**Every moment**
**(θ<50º,18% sky)**




**One day**
**(66% sky)**

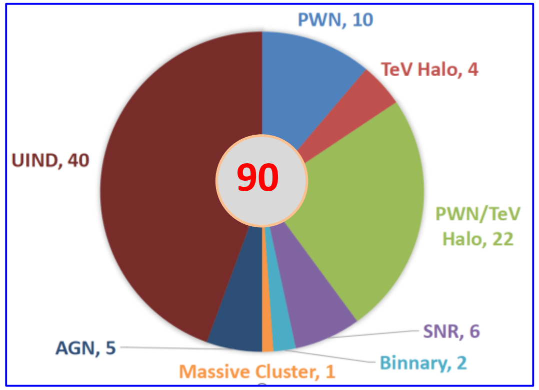


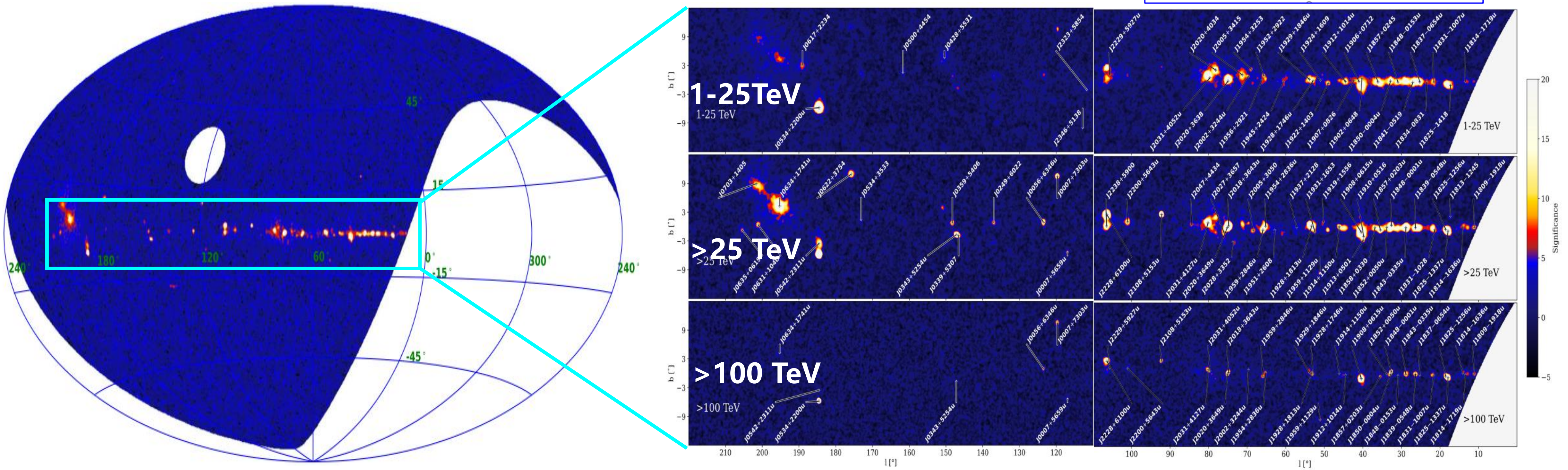

**High sensitivity**
**Wide energy range**



# The 1st LHAASO catalog

- **90** VHE sources with **32** new discoveries.
  - 32 : 7 dark sources, 8 only with Fermi-LAT sources
- **43 UHE (>100 TeV)** sources



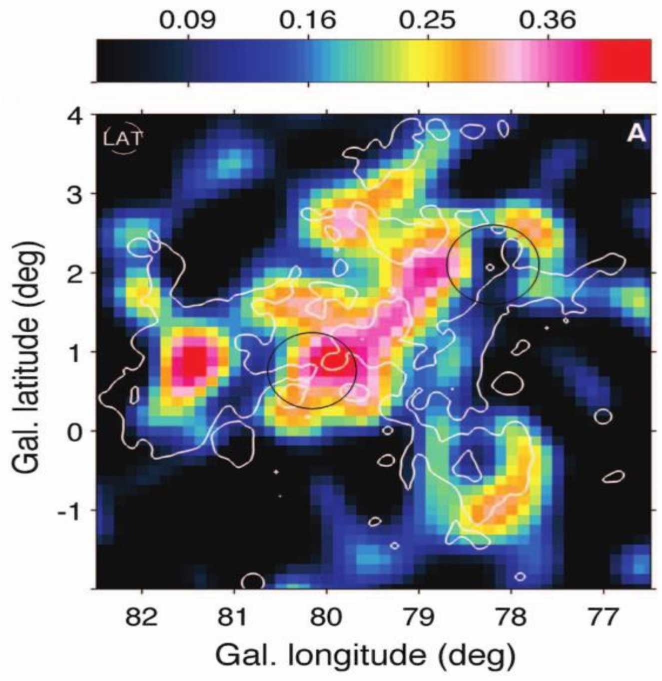




LHAASO coll. ApJS, 271:25 (2024)

# Highlight 1: Cygnus Cocoon

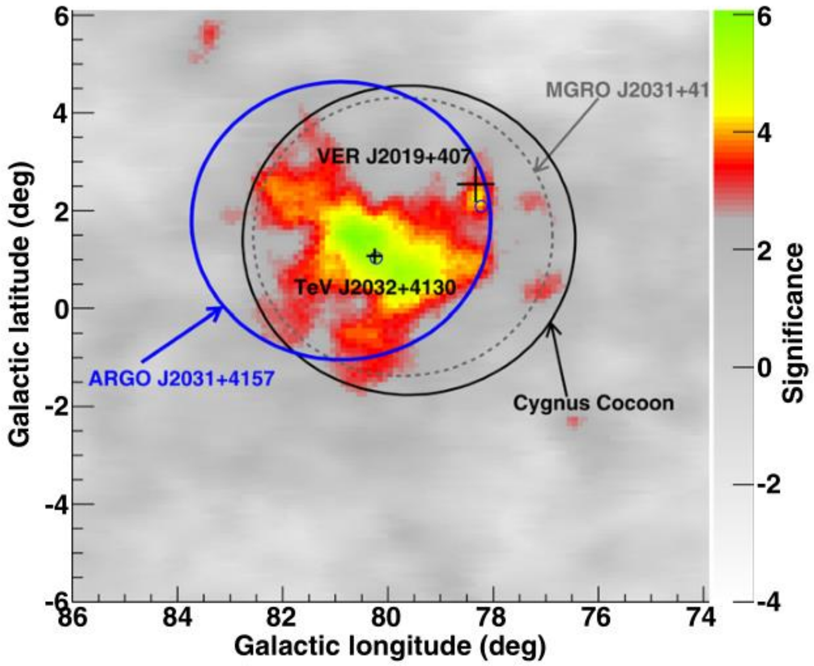
**A freshly accelerated cosmic rays source revealed in GeV-TeV with extension radius ~2°.**

**Fermi-LAT: 10~100 GeV**



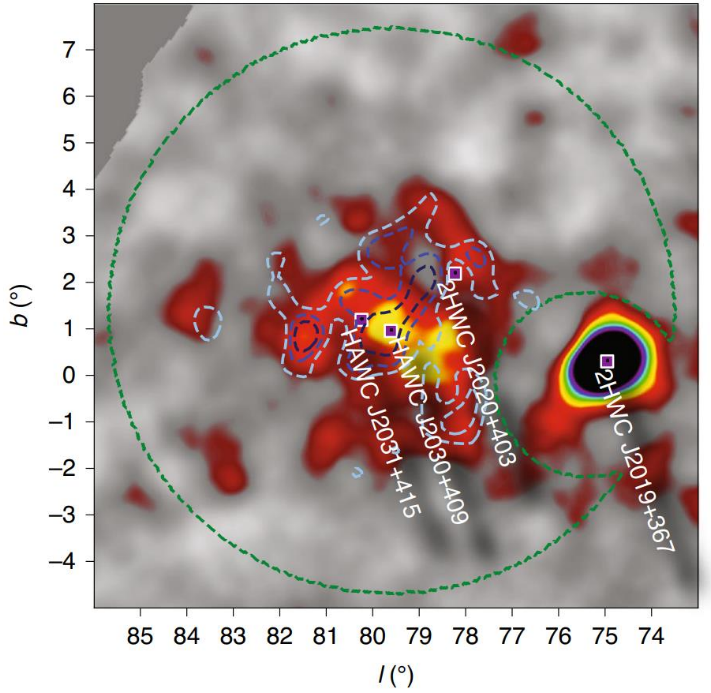

Fermi-LAT coll. 2011

**ARGO-YBJ: 0.2-10 TeV**




ARGO-YBJ coll. 2014

**HAWC: 1-100 TeV**



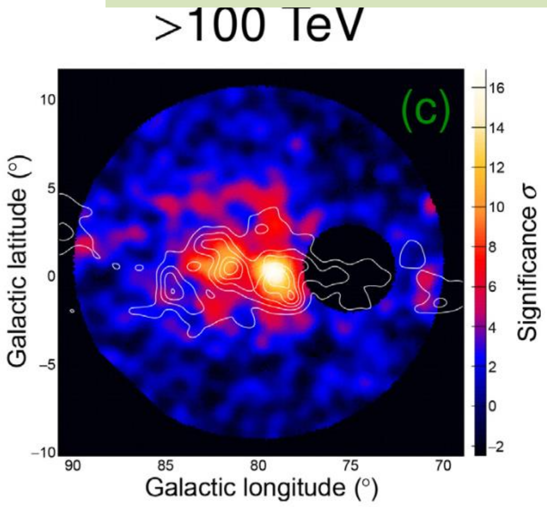

HAWC coll. 2021

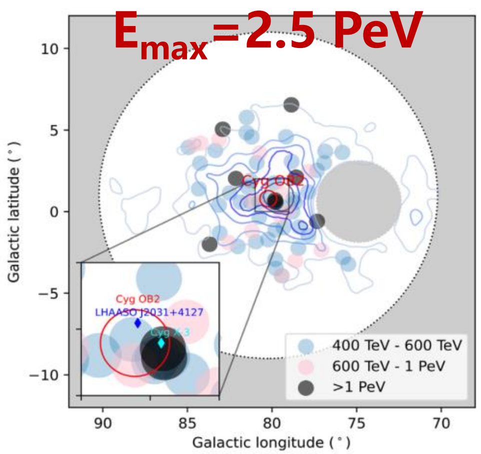
# LHAASO identify a super PeVatron

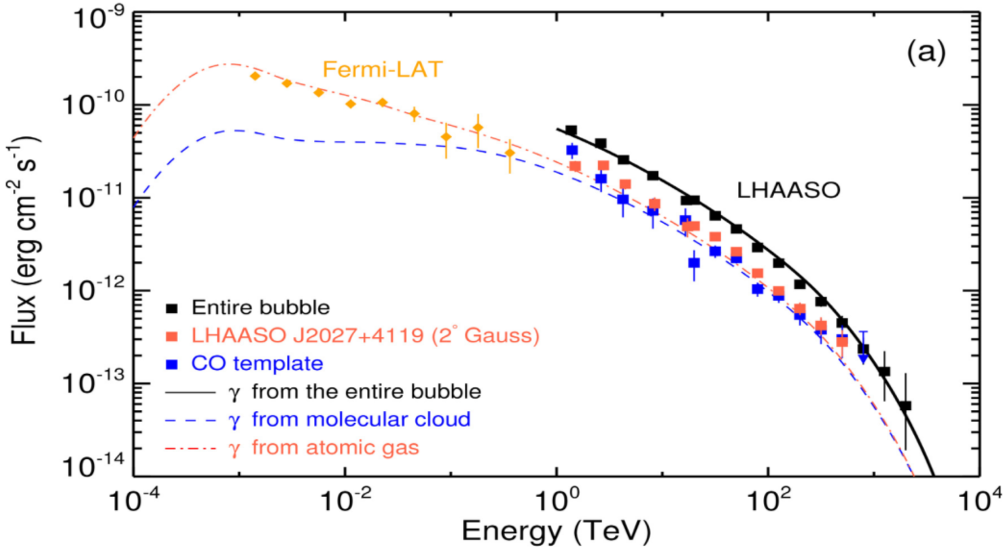
- Large UHE γ-ray bubble with a radius of 6° (~150pc)
  - Larger than the Cygnus Cocoon(2°)
  - SED is connected with Fermi-LAT for core region
- Associated with Molecular Clouds
- 8 photons >1 PeV
- 10 PeV cosmic ray super PeVatron

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

**LHAASO: 1-2500 TeV**



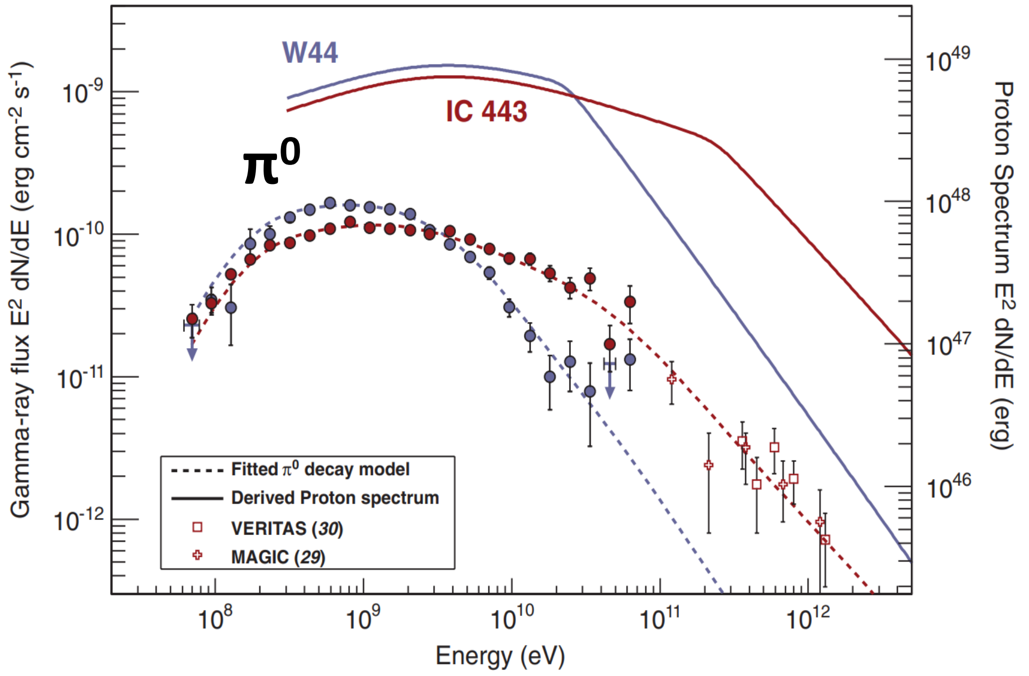
# Highlight 2: SNR as cosmic ray sources

**SNRs are very important CR accelerators!**

**What is the maximum energy that SNR can accelerate?**

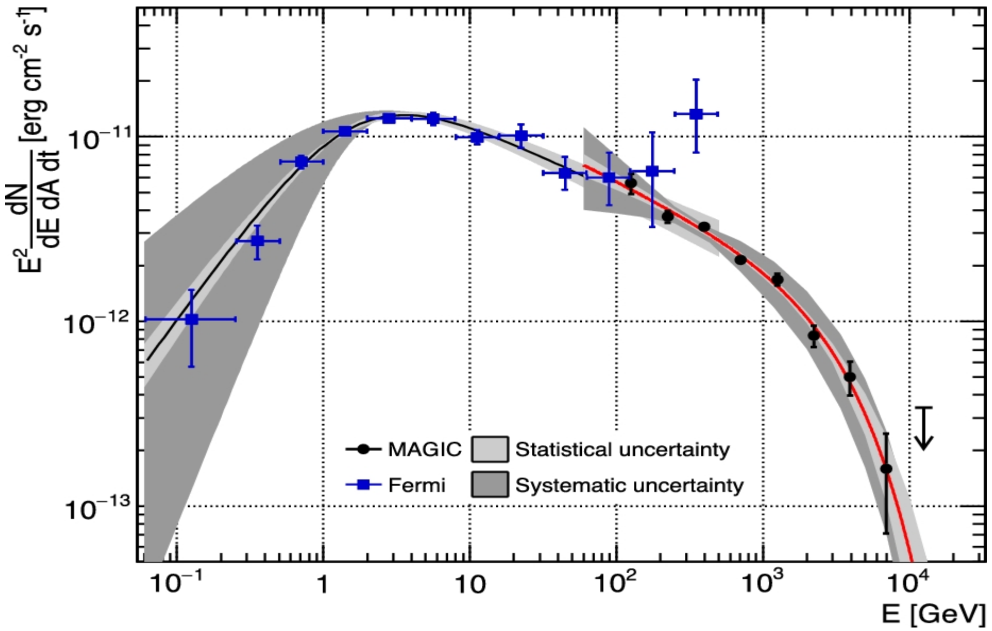
**Only up to 10 TeV?**

**~10k yr**




**Fermi-LAT coll. 2013**

**Cas A(330 yr)**

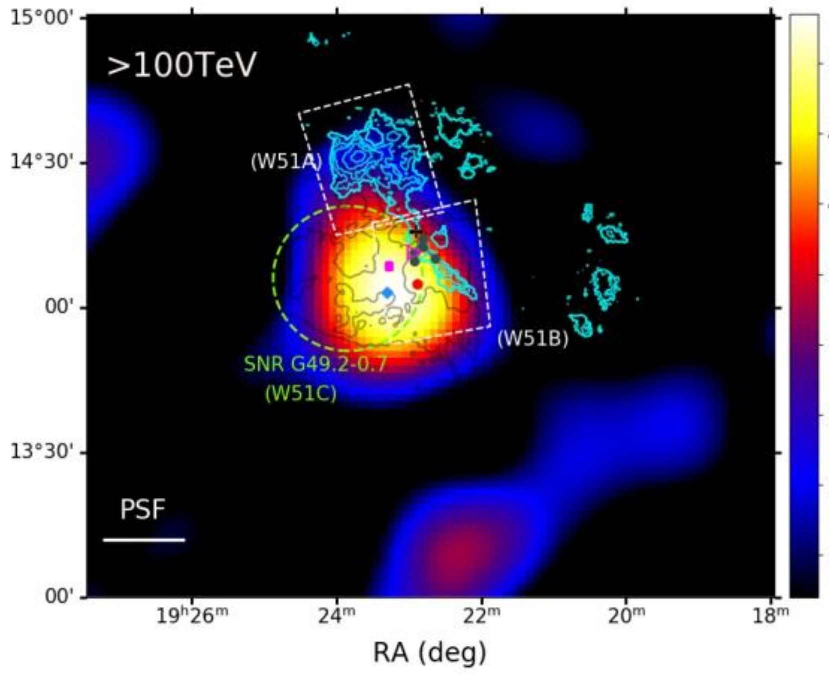


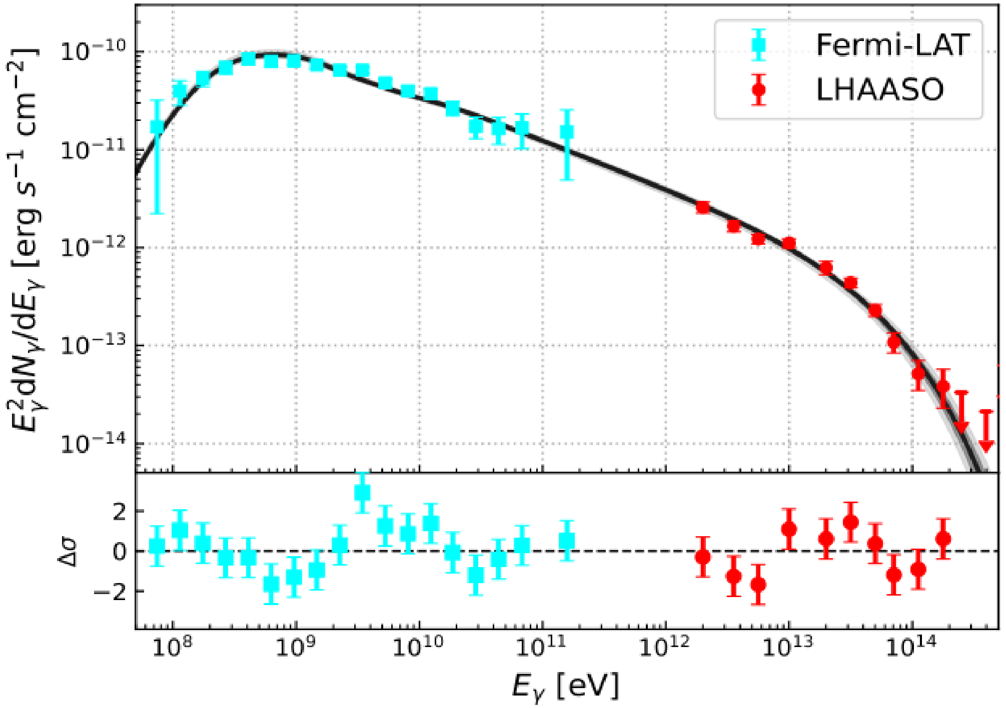

**MAGIC coll. 2017**

# LHAASO reveal SNR approaching PeV

- **SNR W51C:** **An interaction region between the cosmic rays and the dense molecular clouds.**
- **Underline cutoff energy of proton up to** $E_{p,\mathrm{cut}} = 385^{+65}_{-55}\ \mathrm{TeV}$

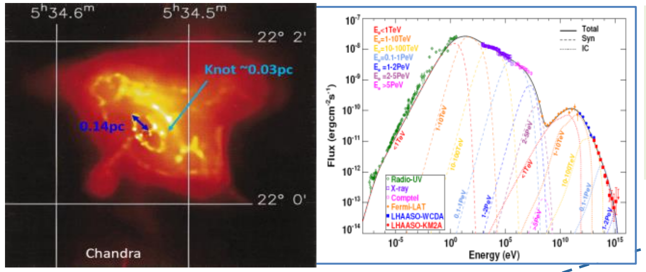
**W51C:~30k yr**




LHAASO coll. Science Bulletin, (2024, https://doi.org/10.1016/j.scib.2024.07.017)

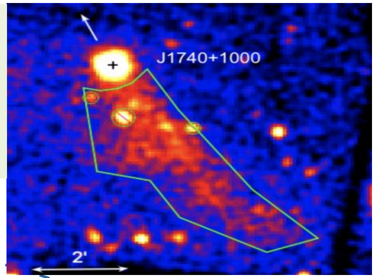
# Highlight 3: New phenomena from PWNs

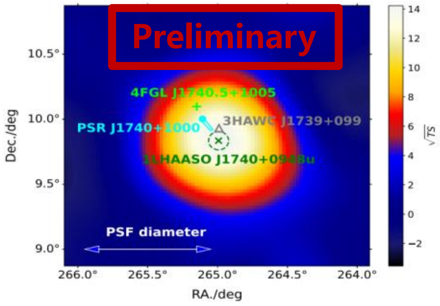


Science,373:425 (2021)

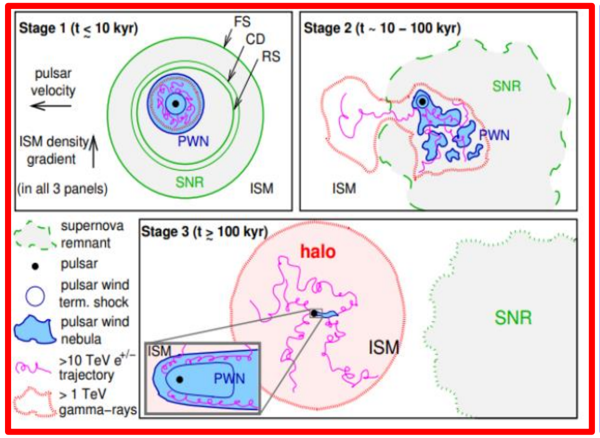
**1k yr, 1.1 PeV photon from Crab Nebula**

**114k yr,UHE from bow show pulsar tail?**

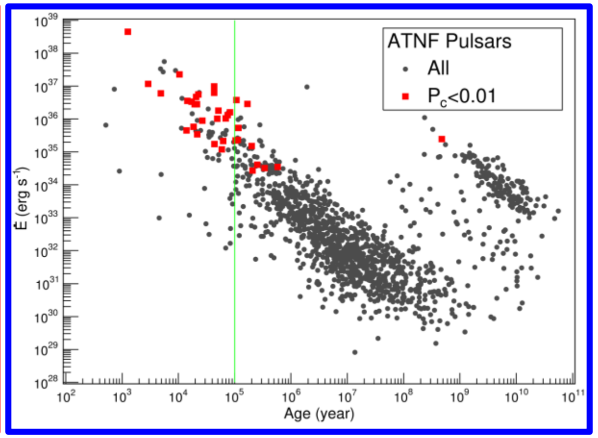



**LHAASO sources**

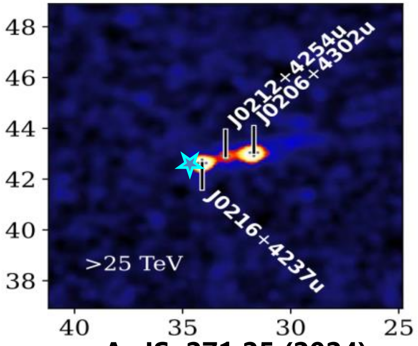


Giacinti et al.(2020)



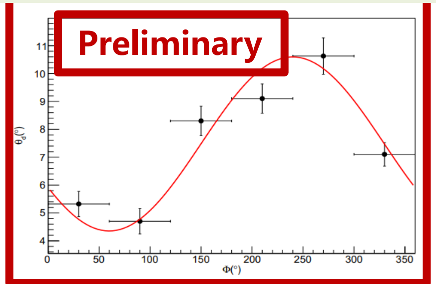
ApJS, 271:25 (2024)

**476M yr, UHE MS pulsar wind nebula?**

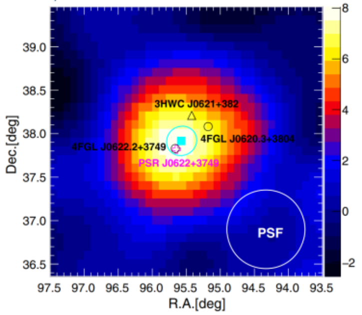


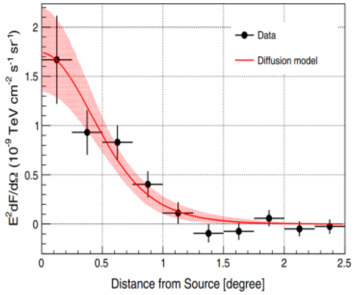
ApJS, 271:25 (2024)

**342k yr, Geminga: Asymmetric diffusion**


**208k yr, New UHE halo**

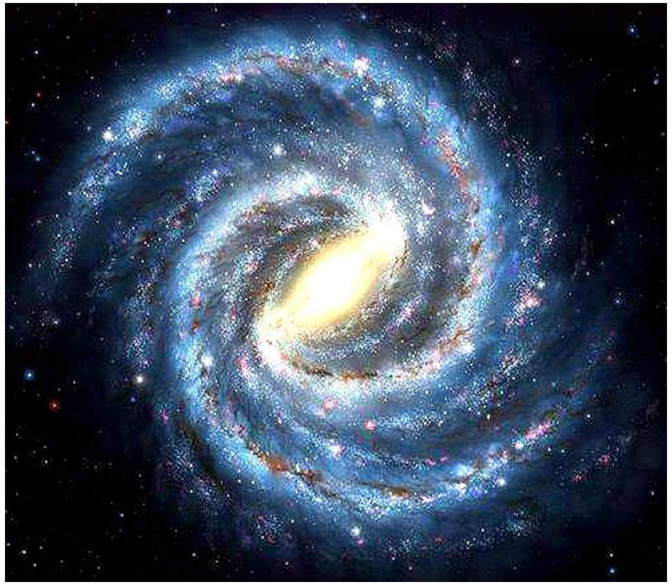


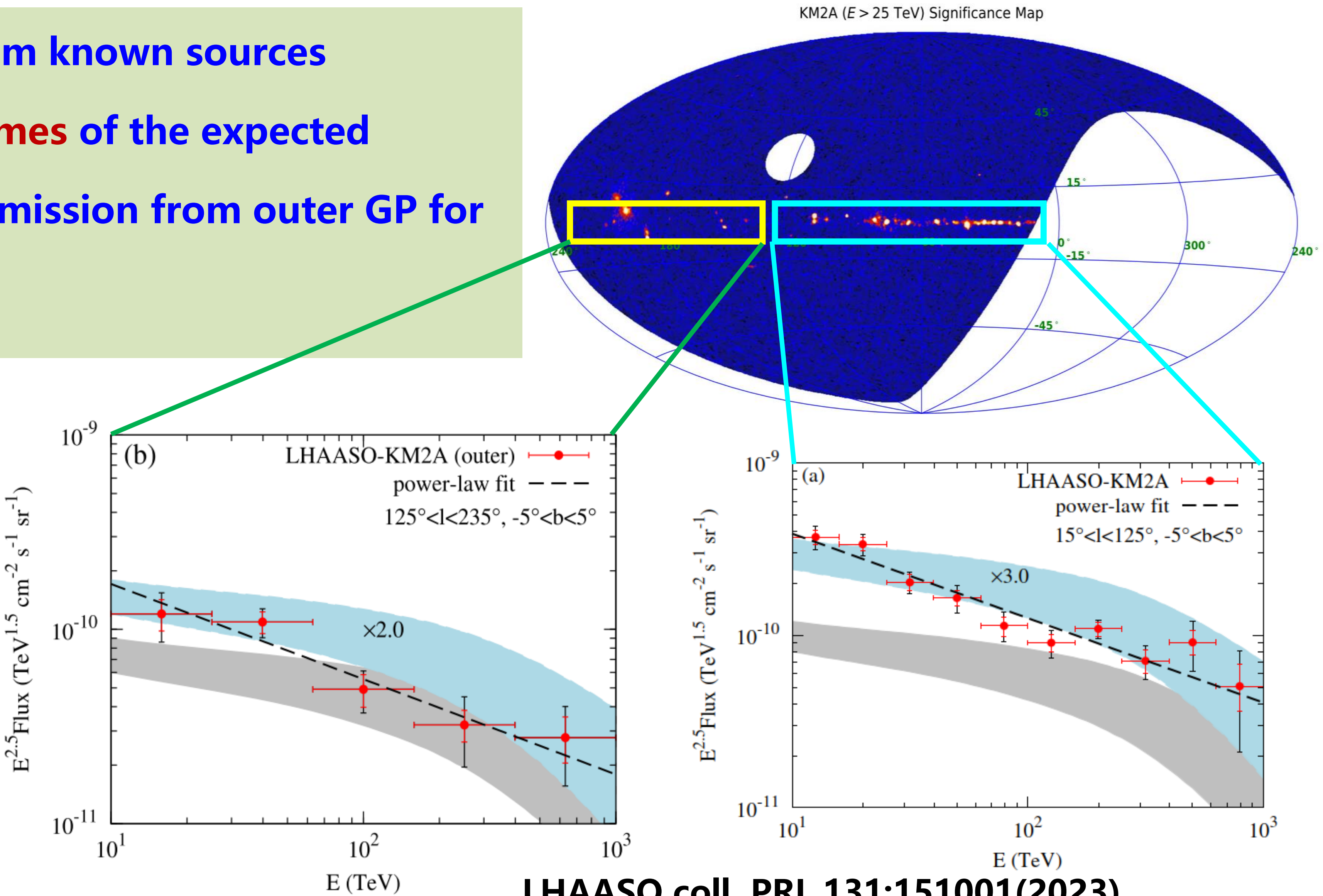



PRL 126, 241103 (2021)

# Highlight 4: GP diffuse γ-ray

- **Little contamination from known sources**
- **The inner GP flux is 3 times of the expected**
- **Detect the 10TeV-PeV emission from outer GP for the first time**

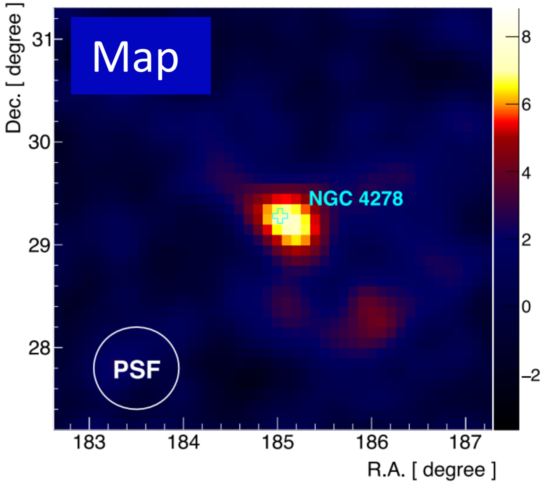


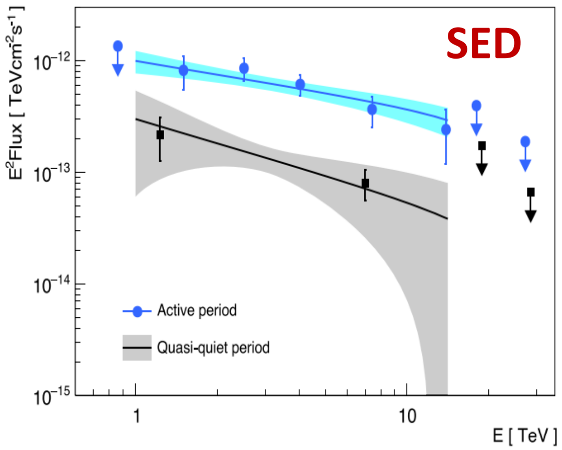


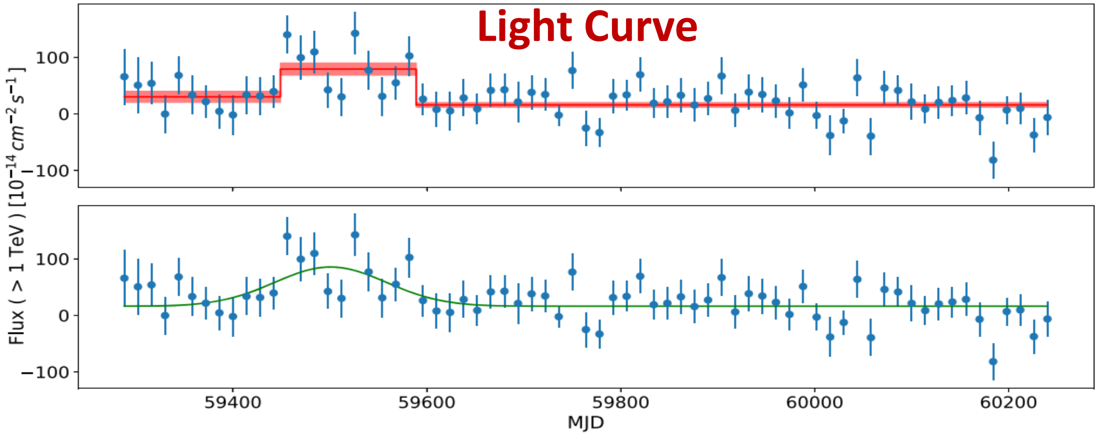

LHAASO coll. PRL 131:151001(2023)

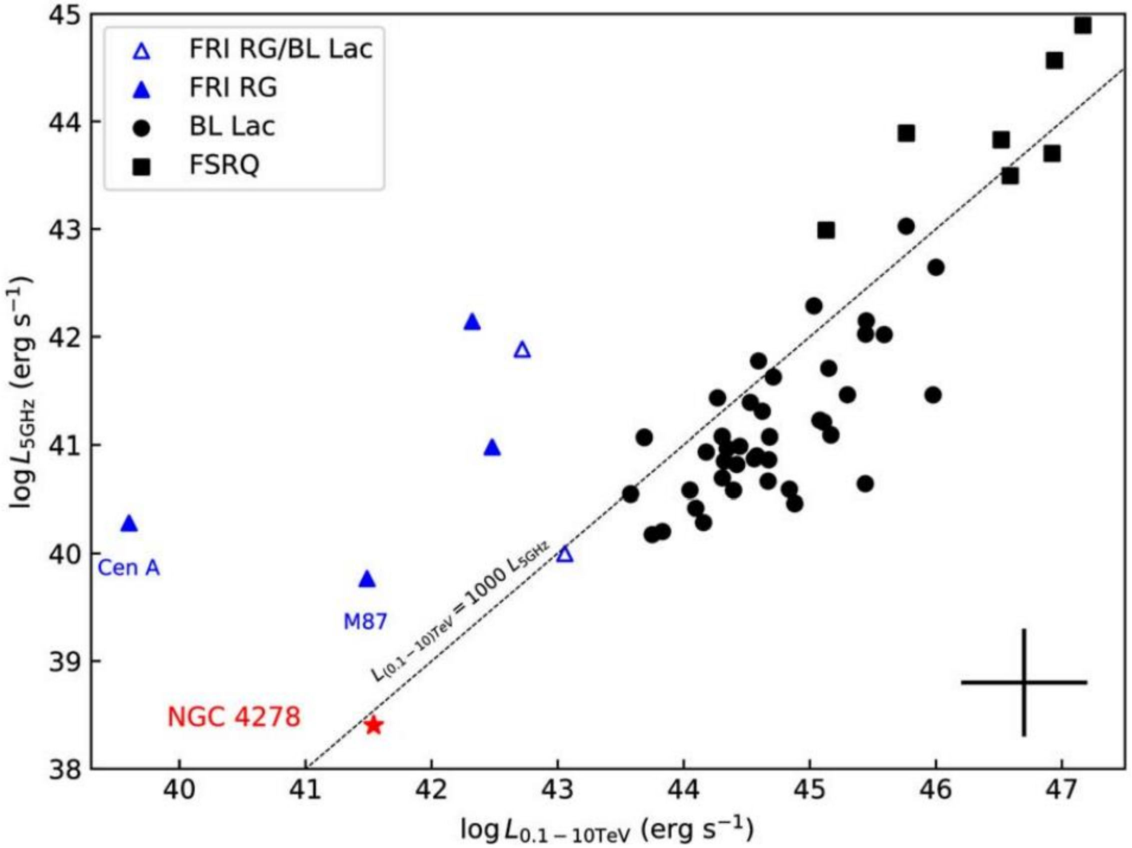
# Highlight 5: AGN NGC 4278

**First evidence for the Low-luminosity AGN with VHE γ-ray!**



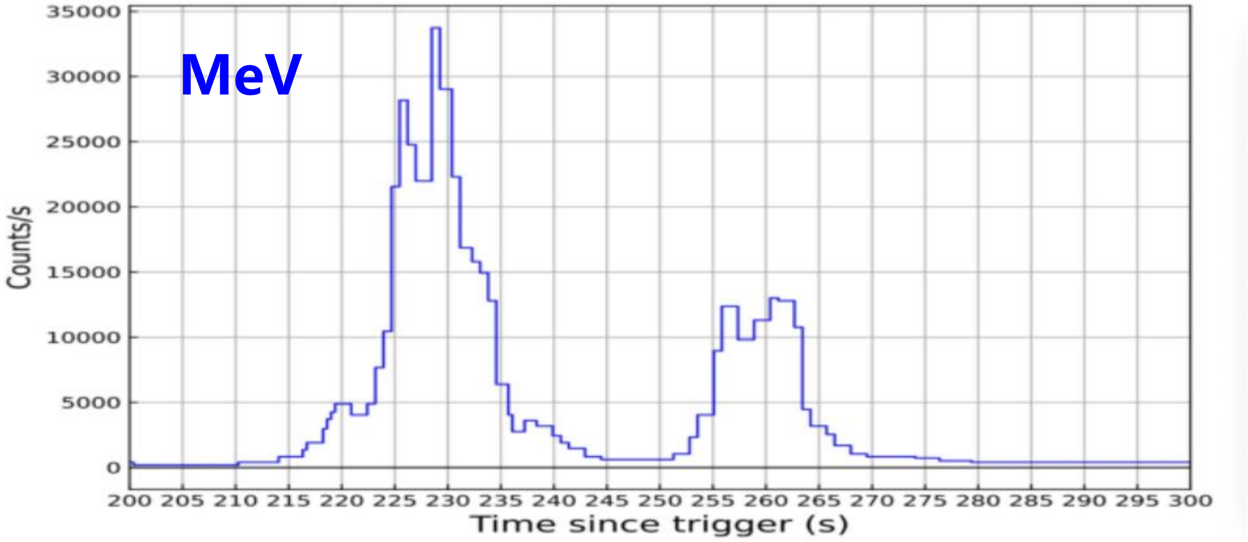



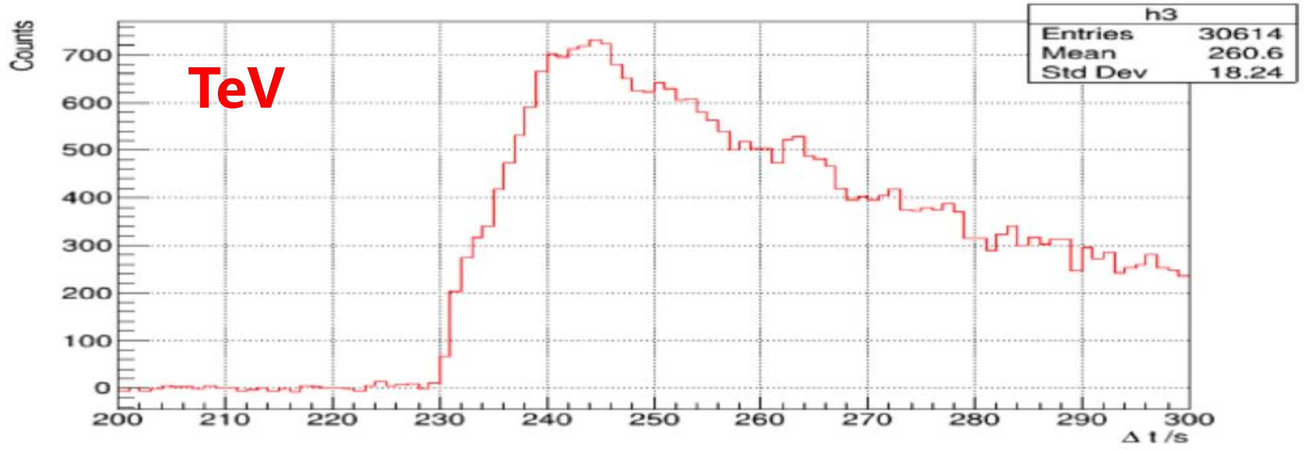

**LHAASO coll. ApJL, 971:L45 (2024)**

# Highlight 6: The BOAT GRB 221009A

- >60,000 photons
- TeV emission is afterglow!
- First time detect onset of the TeV afterglow!
- The most strict limit on the prompt TeV emission: $R = F_{TeV}/F_{MeV} < 2 \times 10^{-5}$

A large $\gamma\gamma$ absorption optical depth ?
OR
A magnetized jet?



# Precise Light Curve analysis

**The LHAASO TeV light curve provides us with a unique opportunity to study the early afterglow physics!**

**Slow rise:** Favor ISM environment?

$$\alpha_1 = 1.82^{+0.21}_{-0.18}$$

**Peak time :** The bulk Lorentz factor of ~**500.**

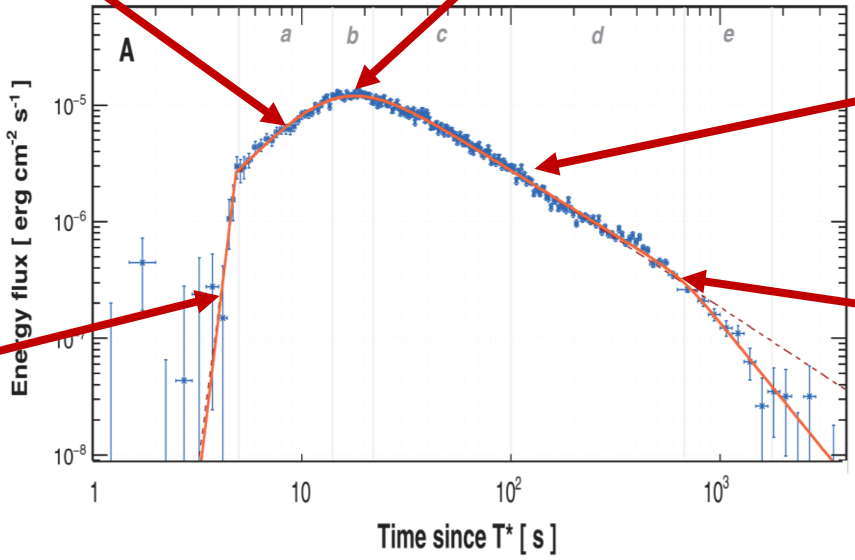
$$\Gamma_0 = \left(\frac{3E_k}{32\pi n m_p c^5 t_{\rm peak}^3}\right)^{1/8} = 440 E_{k,55}^{1/8} n_0^{-1/8} \left(\frac{t_{\rm peak}}{18\,{\rm s}}\right)^{-3/8}$$

**Slow decay:** Electron SED index -2.1

$$\alpha_2 = -1.115^{+0.012}_{-0.012}$$

**Unusual Fast rise: energy injection ?**

$$\alpha_0 = 14.9^{+5.7}_{-4.0}$$




- **Fast decay:** A **jet break** at the earliest time! Jet half opening angle of **0.8°**. $\alpha_3 = -2.21^{+0.30}_{-0.83}$

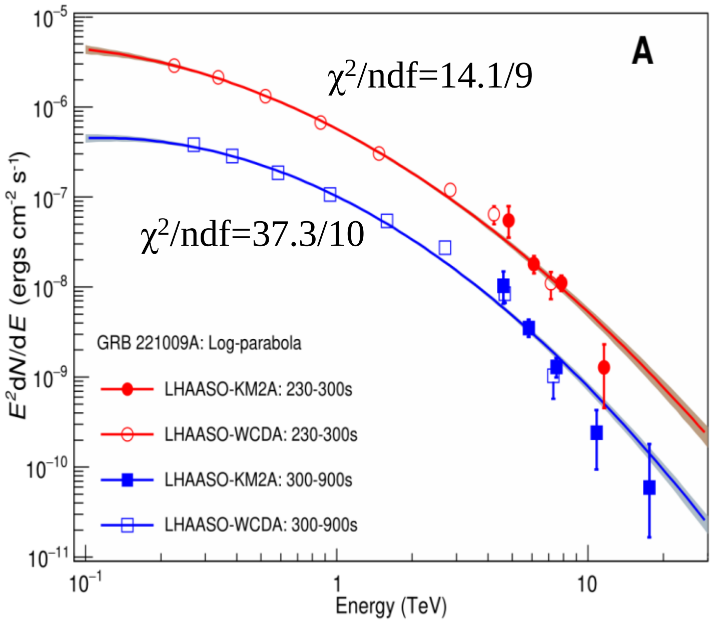
$$\theta_0 \sim 0.6^\circ E_{k,55}^{-1/8} n_0^{1/8} \left(\frac{t_{\rm b,2}}{670\,{\rm s}}\right)^{3/8}$$

LHAASO coll. Science,380:1390 (2023)

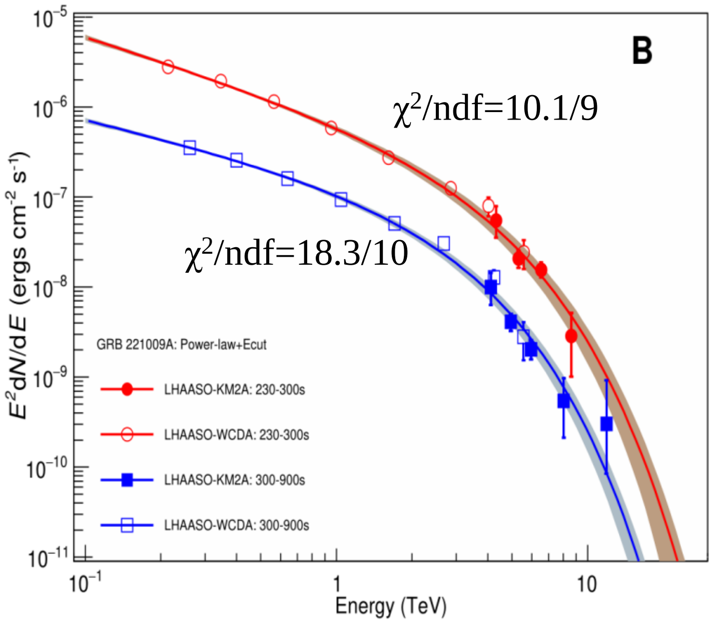
# WCDA+KM2A SED

## Observed SED

**SED function: Log-parabola**

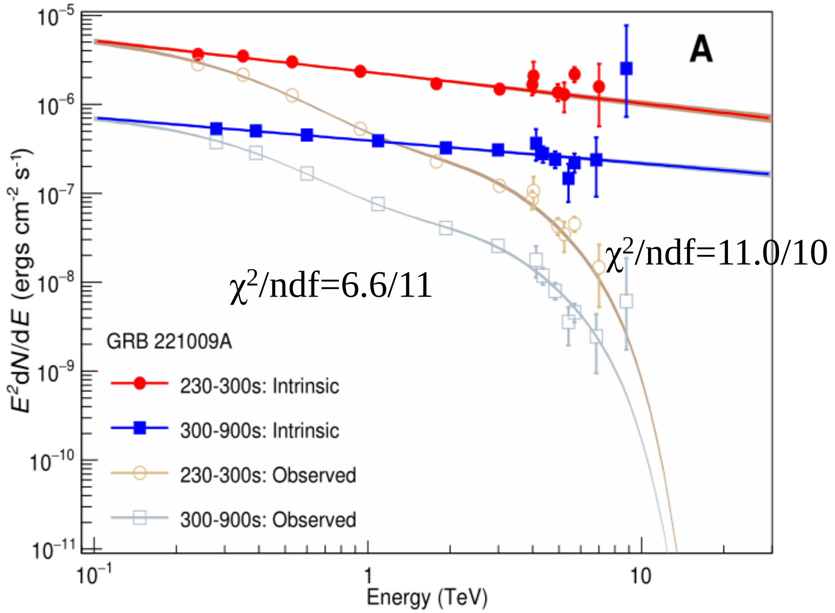



**SED function: Power-law+Ecut (favored)**




## EBL corrected SED

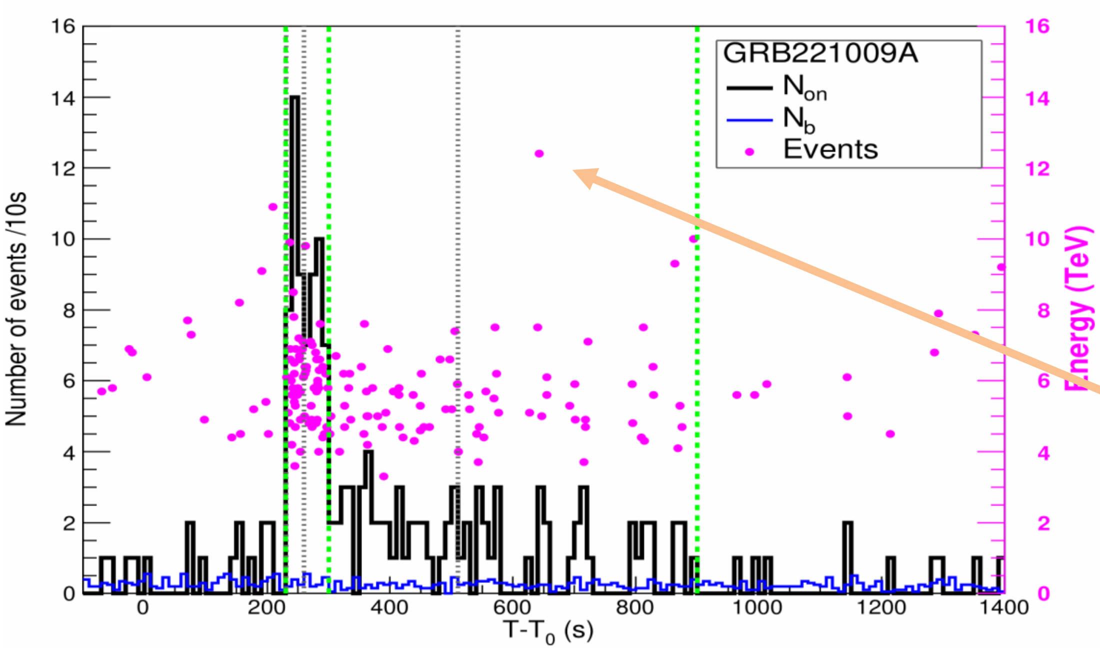
**EBL model: Saldana-Lopez et al.2021**




LHAASO coll. Science Advances,9: eadj2778 (2023)

# The highest energy photons

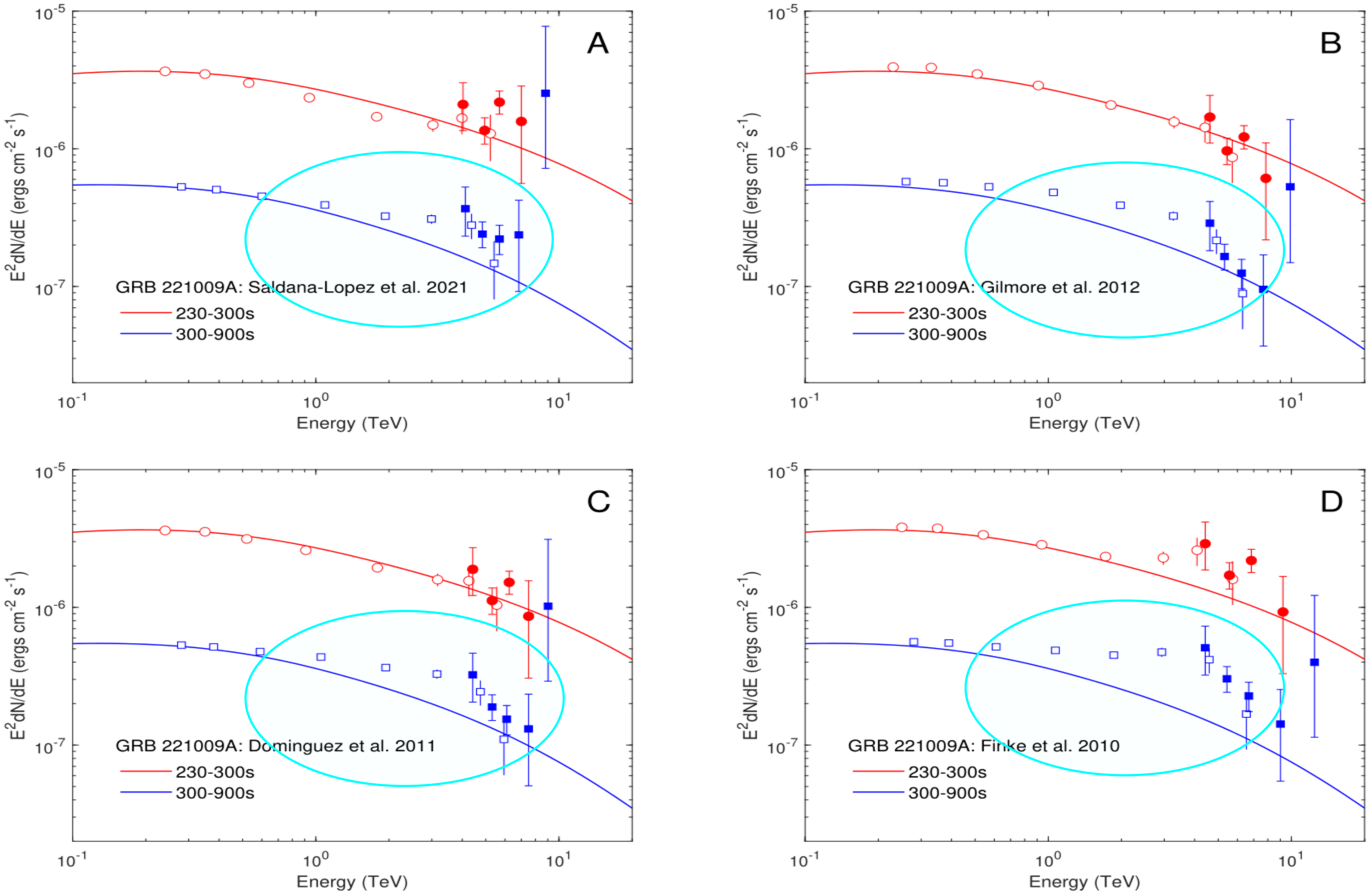
- **The maximum energy photons from GRB:**
  - **17.8TeV for LP SED model**
  - **12.2TeV for PLEC model**
  - **12.5TeV for LP+EBL model**




| $T_{event}$(s) | $E_{LP}$ (TeV) | $E_{PLEC}$ (TeV) | $E_{EBL}$ (TeV) | $N_e$ | $N_\mu$ | $\theta$ (°) | $\Delta\psi$ (°) | $D_{edge}$ (m) | P (%) |
|---|---|---|---|---|---|---|---|---|---|
| 236.6 | $12.7^{+6.2}_{-3.8}$ | $9.7^{+3.3}_{-2.1}$ | $9.8^{+3.1}_{-2.3}$ | 60.6 | 0 | 28.5 | 0.46 | 77 | 7.0 |
| 242.5 | $10.5^{+5.0}_{-3.2}$ | $8.3^{+3.0}_{-2.1}$ | $8.4^{+3.2}_{-2.2}$ | 57.4 | 0 | 28.8 | 0.45 | 111 | 10 |
| 262.4 | $12.6^{+5.5}_{-3.8}$ | $9.5^{+3.4}_{-2.3}$ | $9.6^{+3.3}_{-2.4}$ | 57.3 | 0 | 28.6 | 0.53 | 180 | 5.7 |
| 358.1 | $10.0^{+4.8}_{-3.2}$ | $7.4^{+3.1}_{-1.8}$ | $7.9^{+3.3}_{-2.2}$ | 46.0 | 0 | 28.7 | 0.54 | 119 | 6.0 |
| 571.1 | $9.4^{+5.1}_{-3.0}$ | $7.4^{+2.6}_{-2.5}$ | $7.7^{+3.0}_{-2.5}$ | 45.7 | 0 | 29.5 | 0.52 | 99 | 7.8 |
| 643.0 | $17.8^{+7.4}_{-5.1}$ | $12.2^{+3.5}_{-2.4}$ | $12.5^{+3.2}_{-2.4}$ | 81.8 | 0.3 | 29.7 | 0.62 | 181 | 4.5 |
| 812.4 | $11.1^{+5.9}_{-4.3}$ | $7.4^{+3.6}_{-2.8}$ | $7.6^{+3.9}_{-3.0}$ | 68.0 | 0 | 30.3 | 0.66 | 112 | 11 |
| 863.8 | $12.9^{+6.1}_{-3.9}$ | $9.2^{+3.0}_{-2.8}$ | $9.7^{+3.2}_{-3.1}$ | 100.2 | 0.8 | 30.1 | 1.07 | 81 | 17 |
| 894.1 | $13.6^{+6.1}_{-4.2}$ | $9.7^{+3.4}_{-2.5}$ | $10.4^{+3.3}_{-3.0}$ | 60.5 | 0 | 31.8 | 0.83 | 214 | 16 |

# Challenge to GRB afterglow model

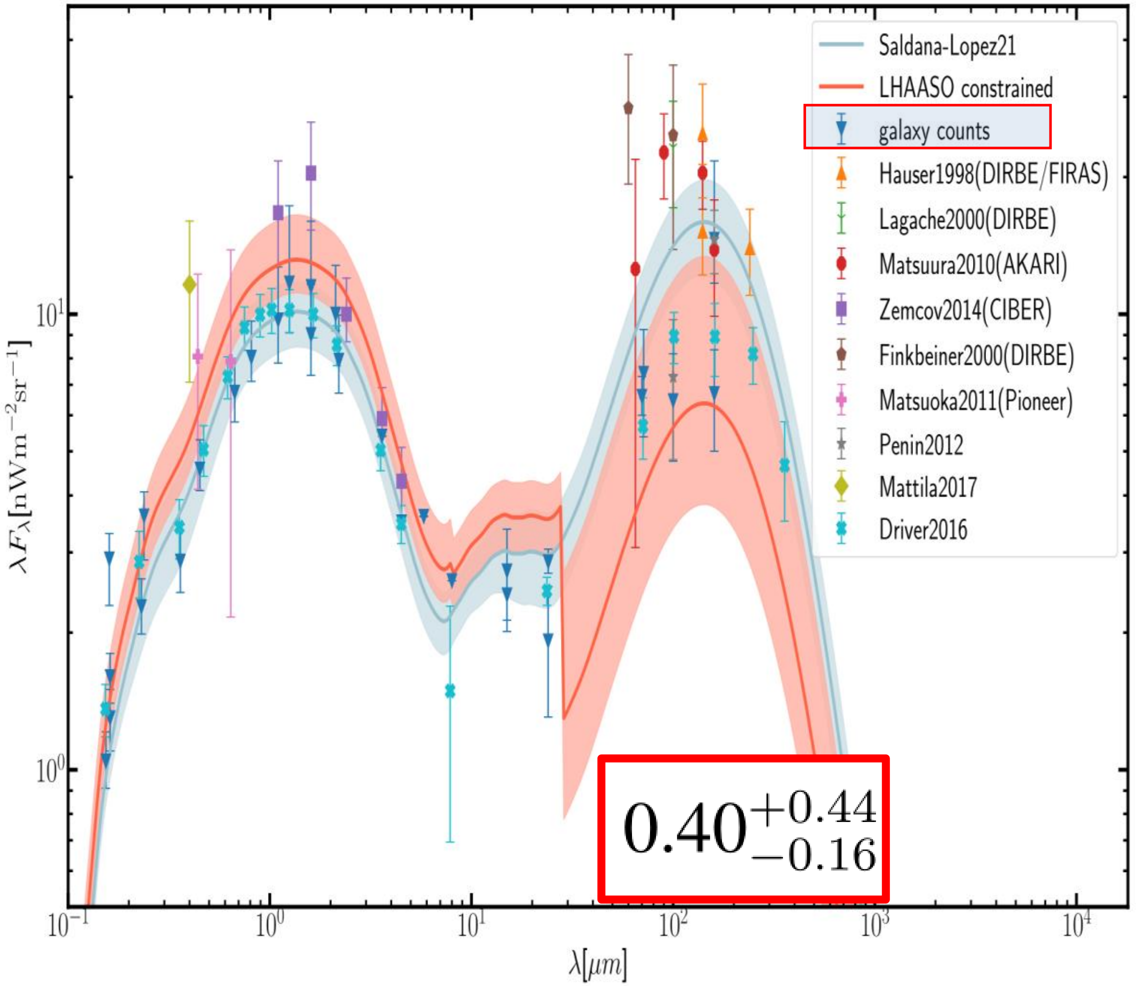
- More complicated processes during the early afterglow phase?
- An additional hard spectral component emerges at the highest energy end?

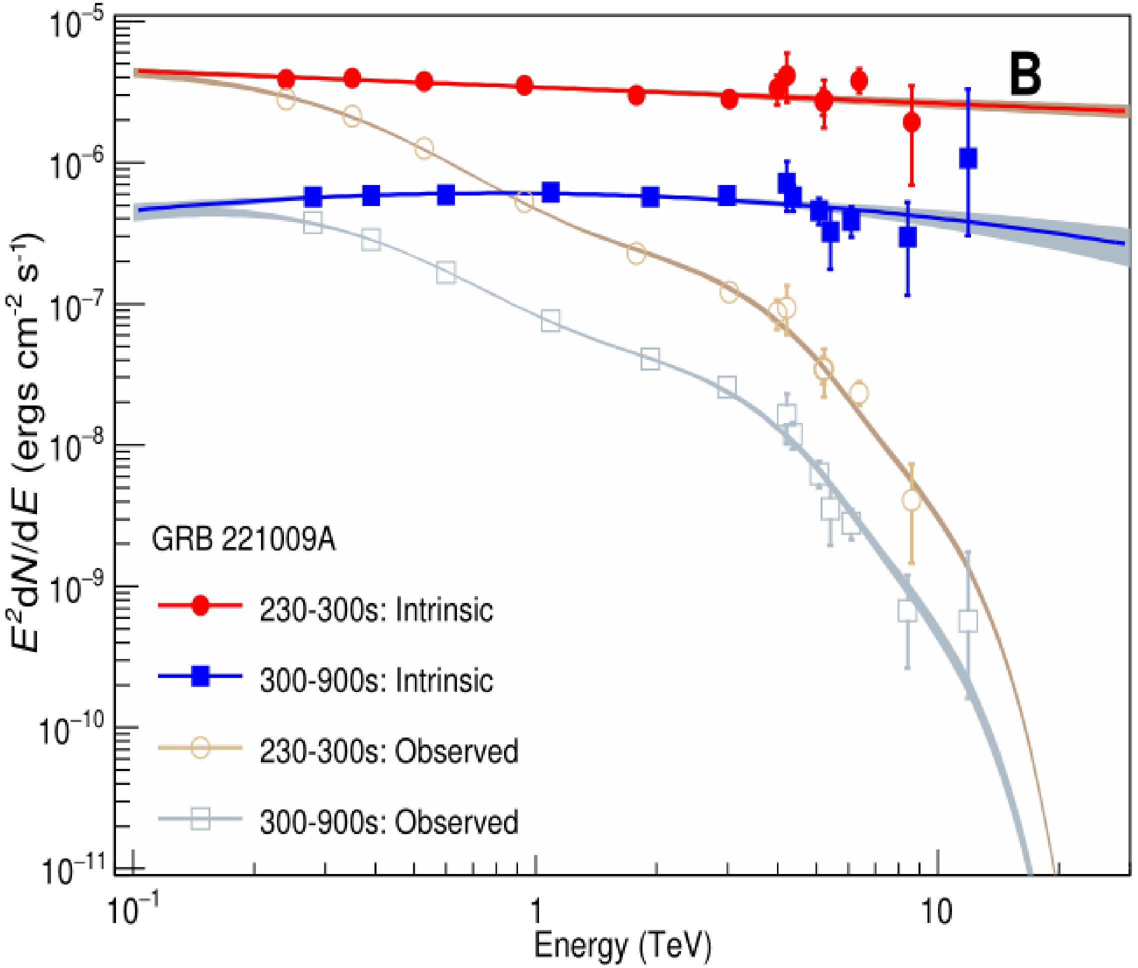



LHAASO coll. Science Advances,9: eadj2778 (2023)

# Constraints on EBL distribution

$\lambda < 8\mu m, 8\mu m < \lambda < 28\mu m, \lambda > 28\mu m$



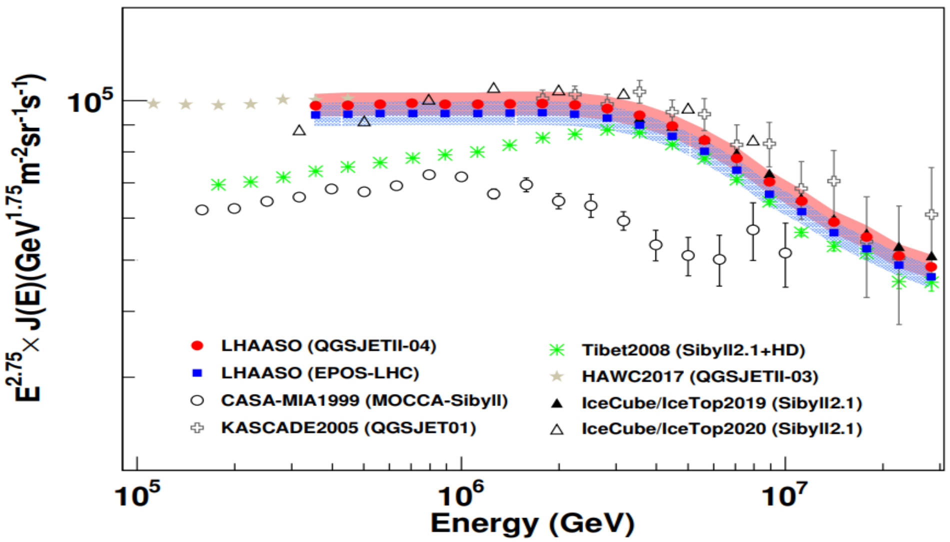

LHAASO coll. Science Advances,9: eadj2778 (2023)

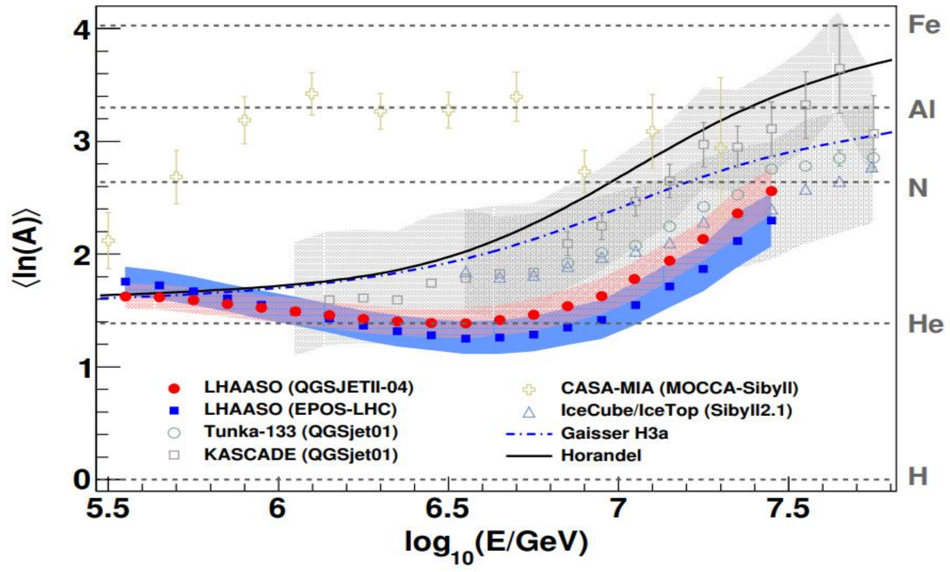
# LHAASO recent highlight results on Charged Cosmic rays

# Highlight 1: All particle cosmic ray SED

- Cover 0.3-30 PeV
- Precise SED with small sys. error
- Precise average mass with small sys. error
- New structure indicate light component dominating at knee

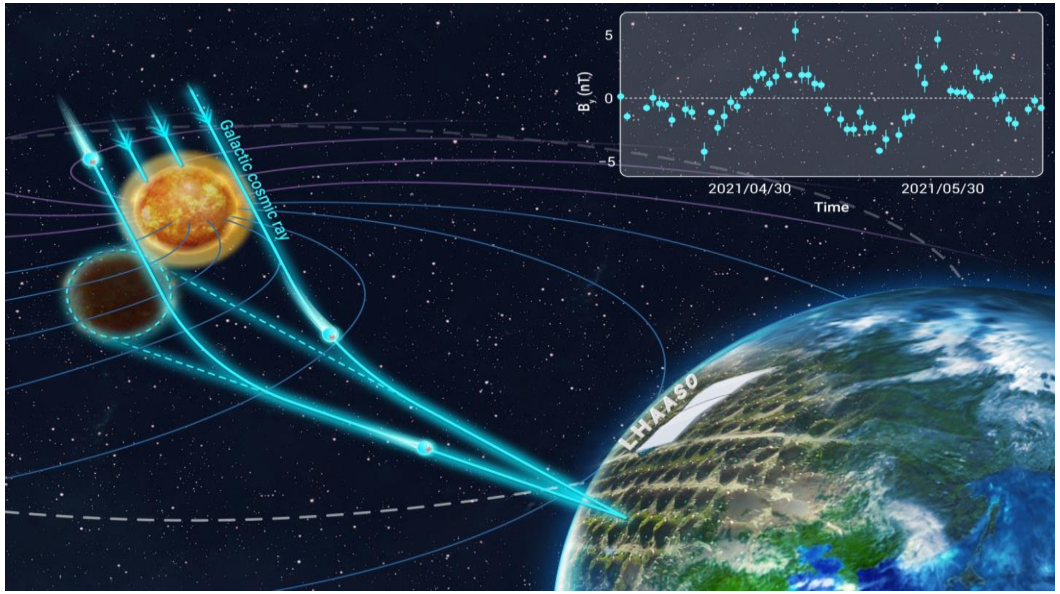
LHAASO coll. PRL, 132, 131002 (2024)

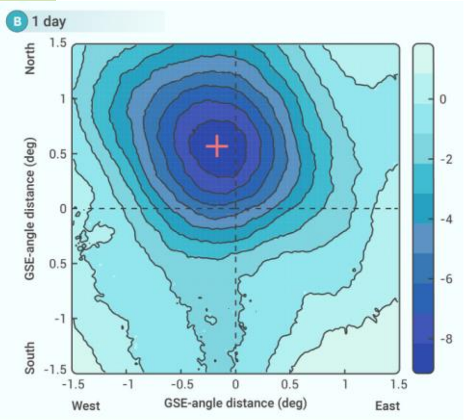


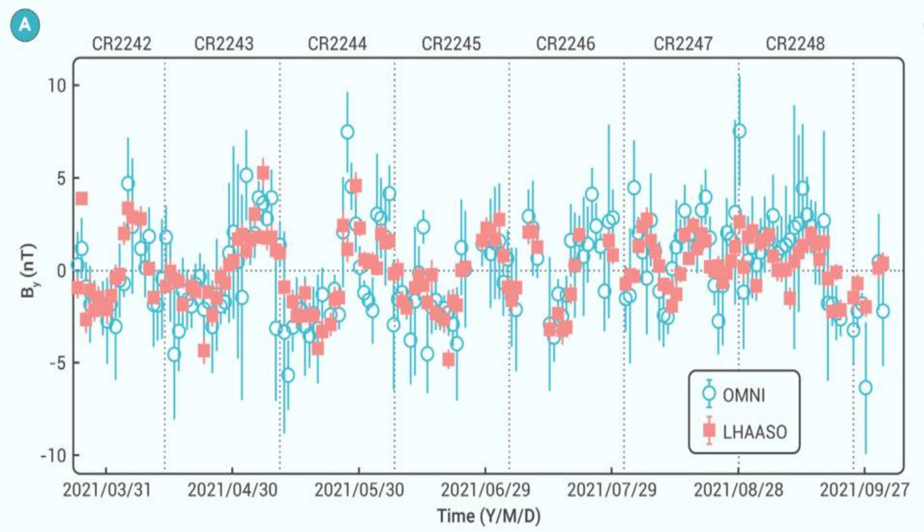



# Highlight 2: Monitor the daily IMF using CR

- Daily Sun shadow achieved for the first time
- The Sun's shadow provide 3.3-day earlier predictions for the IMF.
- The timing advance significantly deviated from the predictions of current IMF models.
- A novel method for monitoring the Sun-Earth IMF.



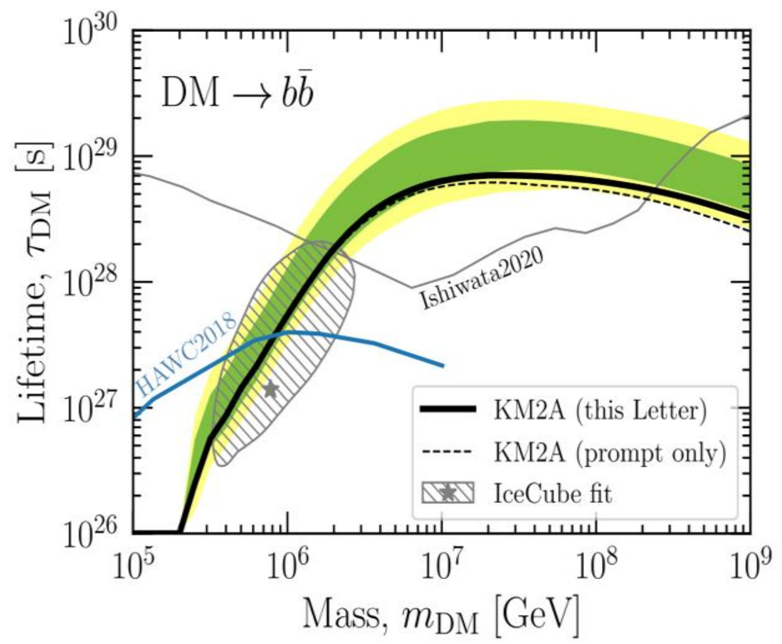

LHAASO coll. The innovation, in press (2024)

# LHAASO recent highlight results on New Physics Frontier

# LHAASO constraints on dark matter

**The strongest constraints on heavy dark matter decay lifetime**

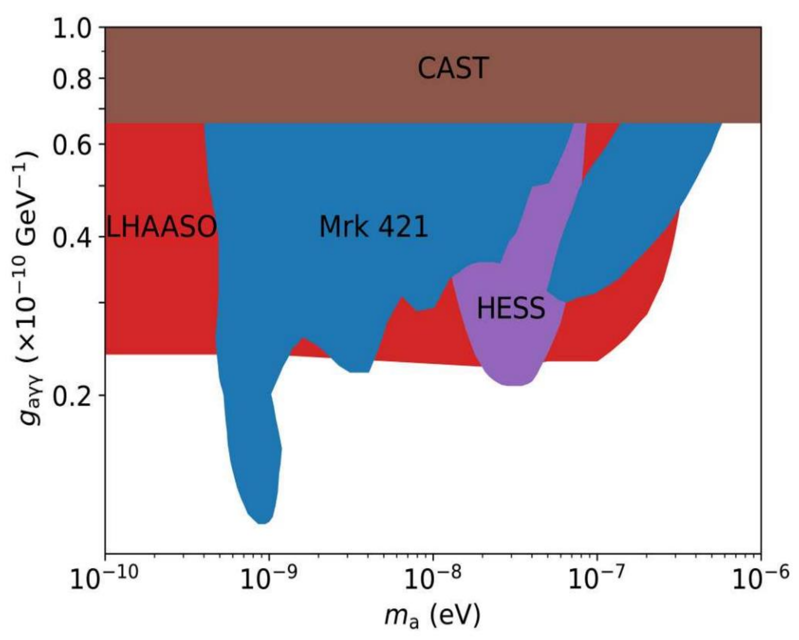
**Galactic Halo UHE γ-ray**




**PRL 129:261103(2022)**

**Strong constraints on the axion–γ-ray coupling constant**

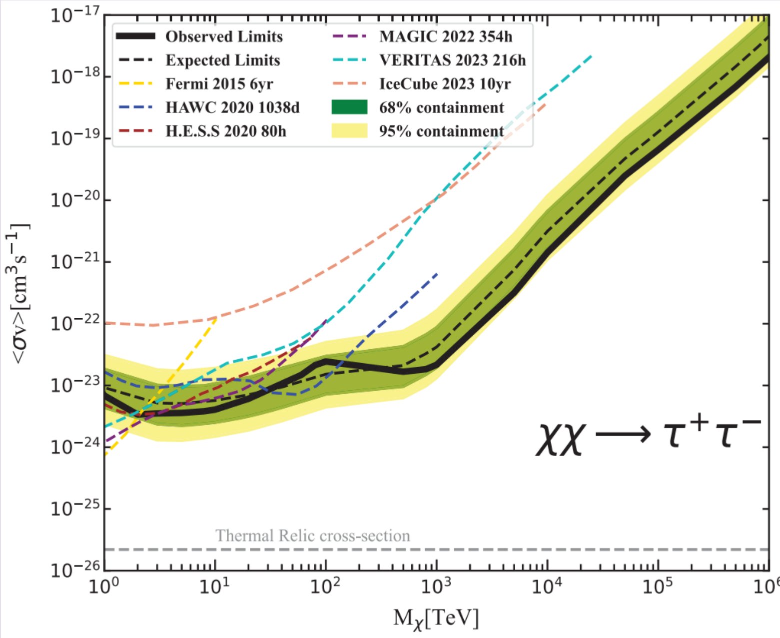
**GRB VHE γ-ray**




**Science Advances 9:eadj2778 (2023)**

**The strongest constraints on dark matter annihilation cross section**

**Dwarf galaxies UHE γ-ray**

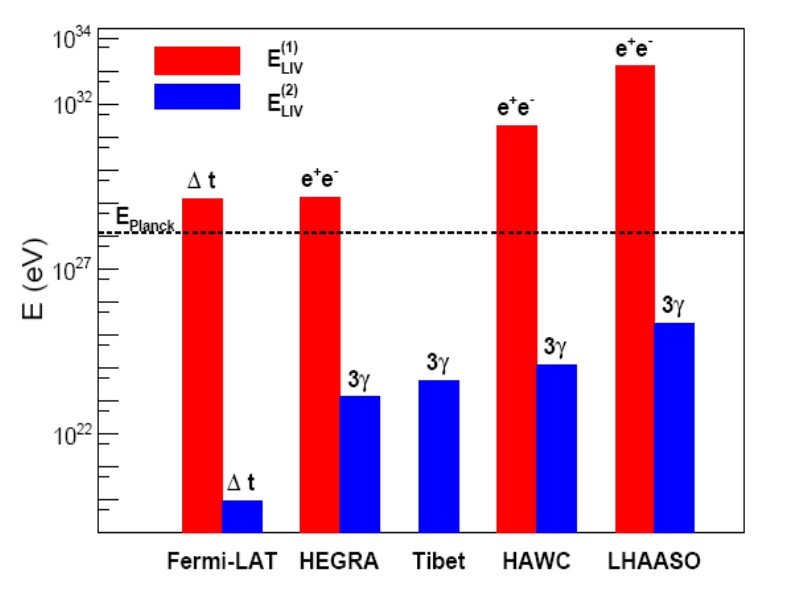



**PRL 133:061001 (2024)**

# LHAASO Constraints on LIV

- **Using decay of PeV γ-ray**

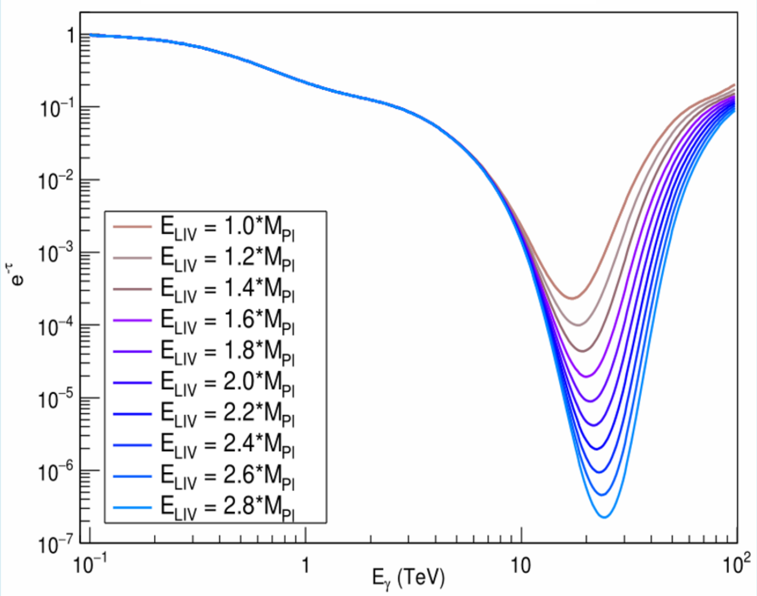
$$E_\gamma^2 - p_\gamma^2 = \pm|\alpha_n| p_\gamma^{n+2}$$




PRL 128:051102(2022)

- **Using the EBL absorption on 10 TeV γ-ray (EBL)**

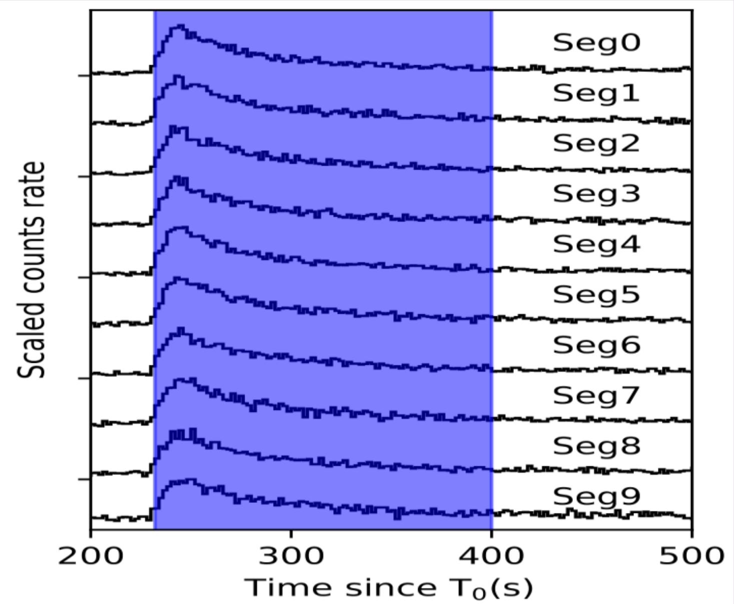
$$\epsilon_{\rm thr} = \frac{m_e^2}{E} + \frac{E^2}{8E^{(1)}_{\rm LIV}}$$




Science Advances 9:eadj2778 (2023)

- **Using the time lag of different energy γ-ray**

$$\Delta t_{\rm LIV} = s\frac{n+1}{2}\frac{E_h^n - E_l^n}{E^n_{{\rm QG},n}}\int_0^z \frac{(1+z')^n}{H(z')}dz'$$




PRL 133, 071501(2024)

# Summary

- LHAASO is operated very stable with full duty cycle since July 2021.
- LHAASO open-up a new UHE era with many new discoveries about Massive star, SNR, PWN, AGN, GRB and so on.
- LHAASO also throw light on the cosmic ray related physics and new physics frontier.
- There are still much more new interesting phenomena ahead!

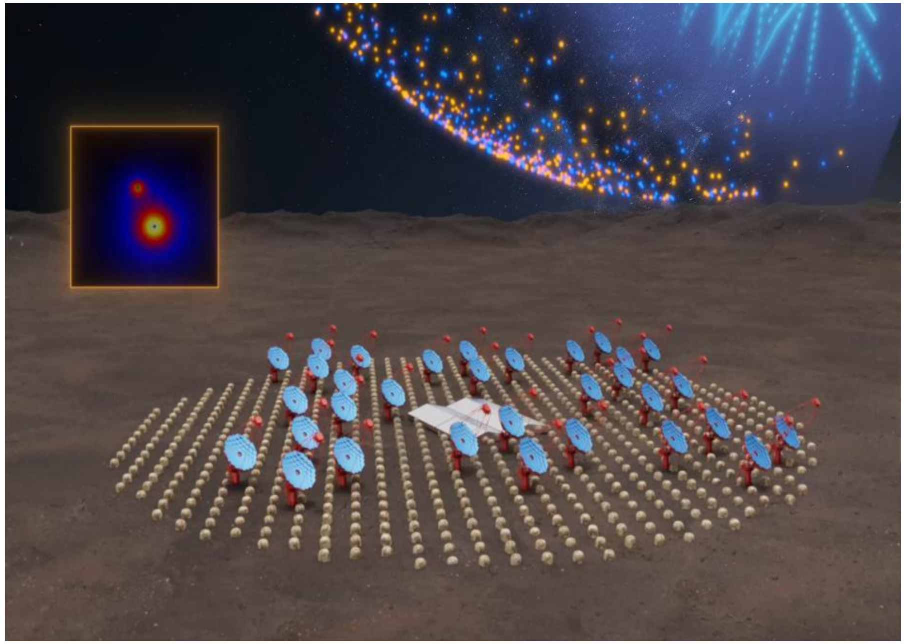
**LHAASO: 0.3TeV-10000TeV**

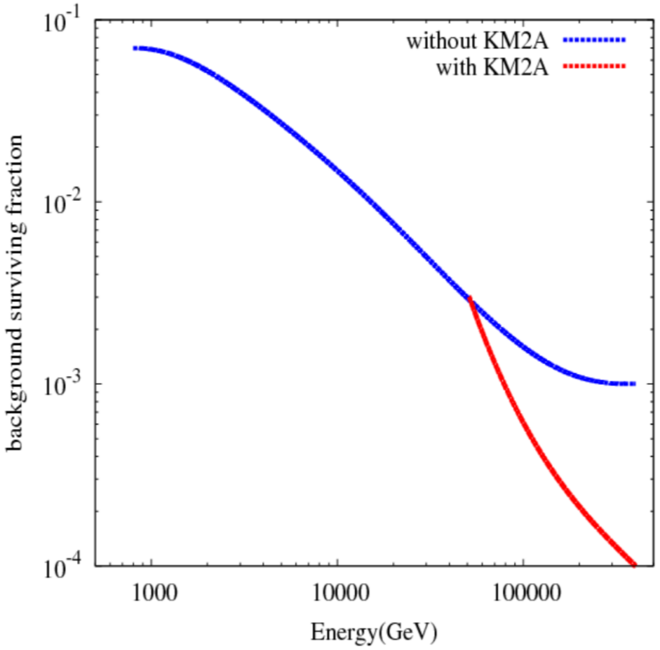
**(2019-2021-now)**

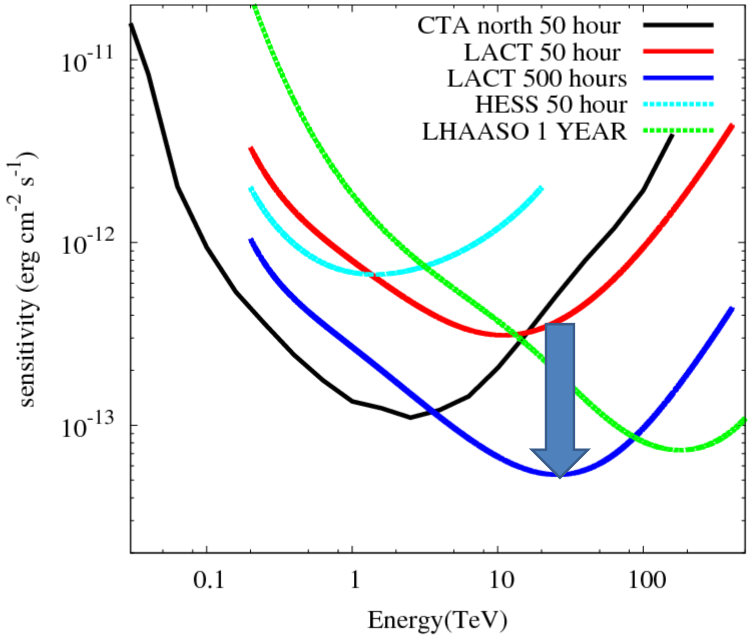
# Outlook: LHAASO upgrade plan LACT

- **LACT improve the angular resolution <0.05°**
- **LACT + KM2A muon detectors**
  → **Better gamma-ray selection**
- **Construction: 2024.10 – 2028.9**

A prototype in LHAASO



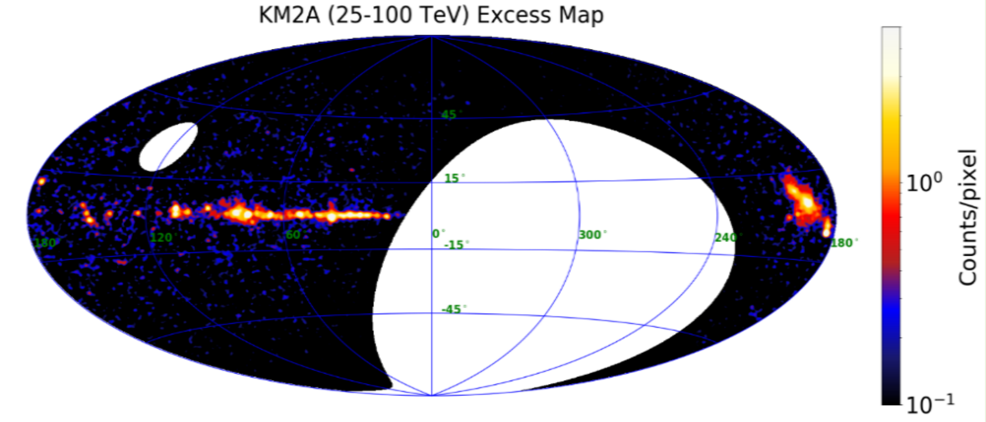


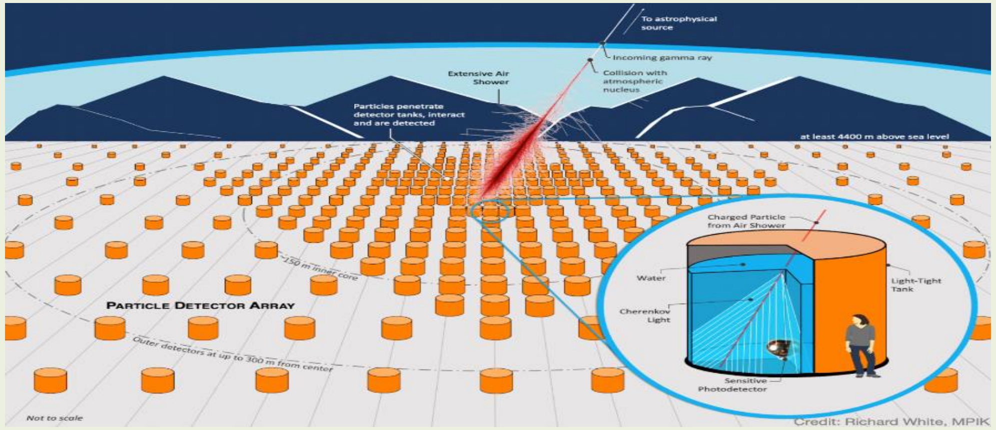



# Outlook: Future plans

## SWGO

(Southern Wide-field Gamma-ray Observatory)



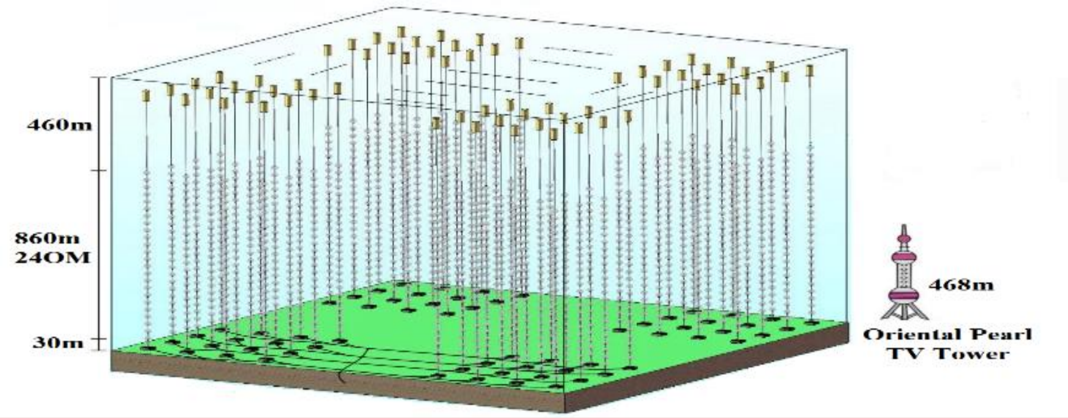




## HUNT

(High-energy Underwater Neutrino Telescope)

2023.02@South China Sea

2024.02@Baikal



More LHAASO results can be found from:
http://english.ihep.cas.cn/lhaaso/

**Thank you!**