中国科学技术大学
University of Science and Technology of China

LHAASO
高海拔宇宙线观测站

LHAASO detection of Ultra-high-energy Gamma-Ray Emissions from the Giant Molecular Clouds

Yu Yanhong， Cao Wenyu， Li Jian， Yang Ruizhi
University of Science and Technology of China
On behalf of LHAASO collaboration

Outline

1. Introduction of Giant Molecular Clouds (GMC)

2. LHAASO observations and results

3. Summary and prospect

Giant Molecular Clouds

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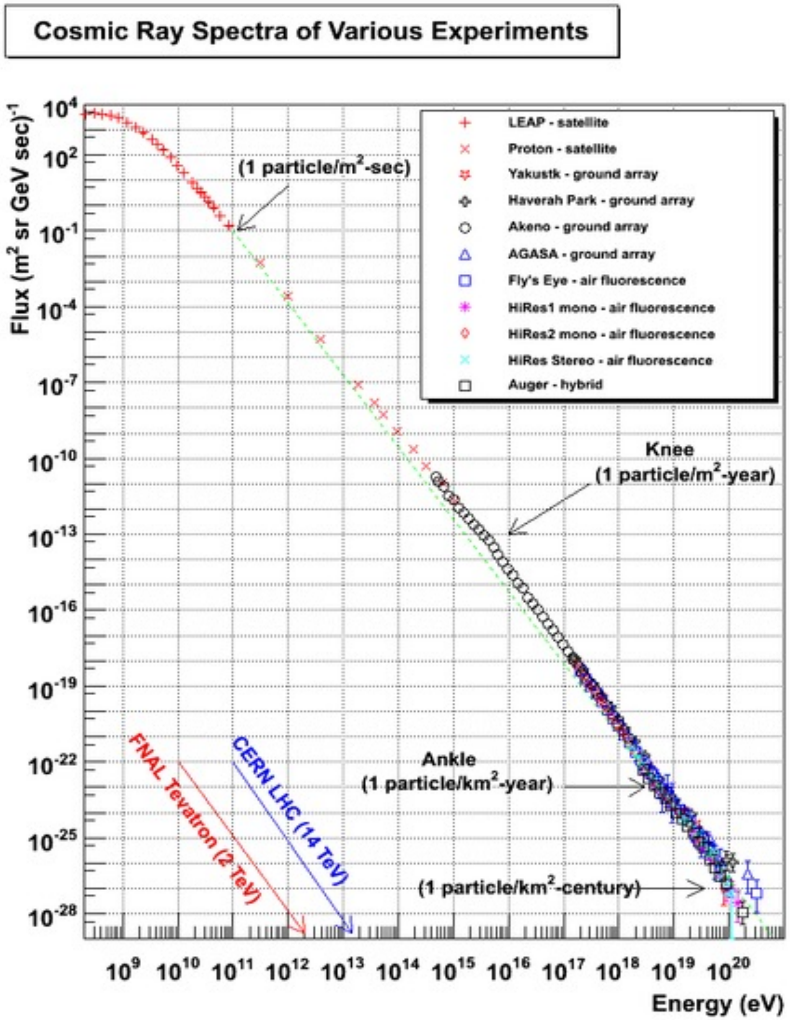
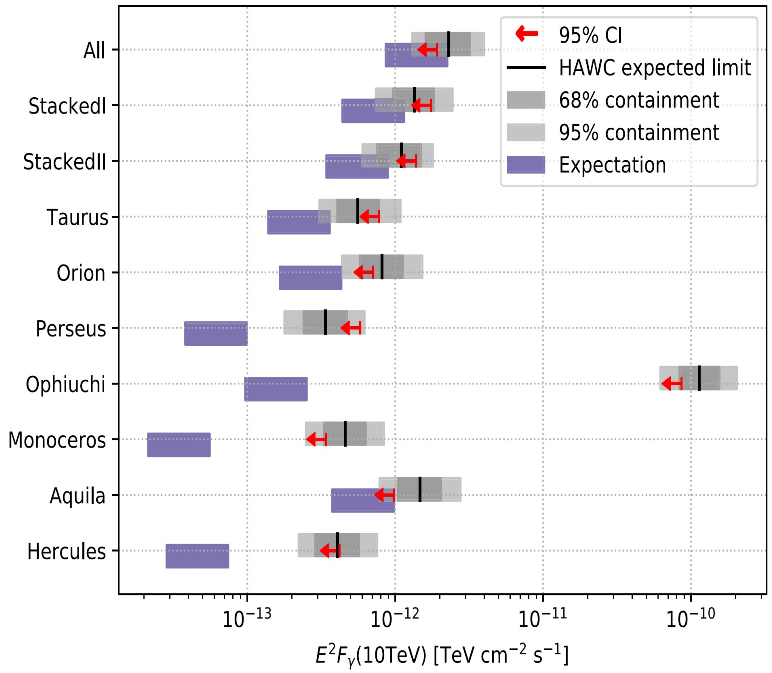


- The current paradigm of CRs suggests that the majority of the CR flux up to the so-called knee around 10^{15} eV, originates from galactic sources, presumably to supernova remnants .
- Giant Molecular Clouds (GMCs) are massive reservoirs of gas and dust, with masses typically around $10^5 M_\odot$
- GMCs are critical regions for studying CR interactions and their effects on the ISM. They serve as natural laboratories to observe the impact of CRs on the surrounding matter and to probe variations in CR density throughout the galaxy.

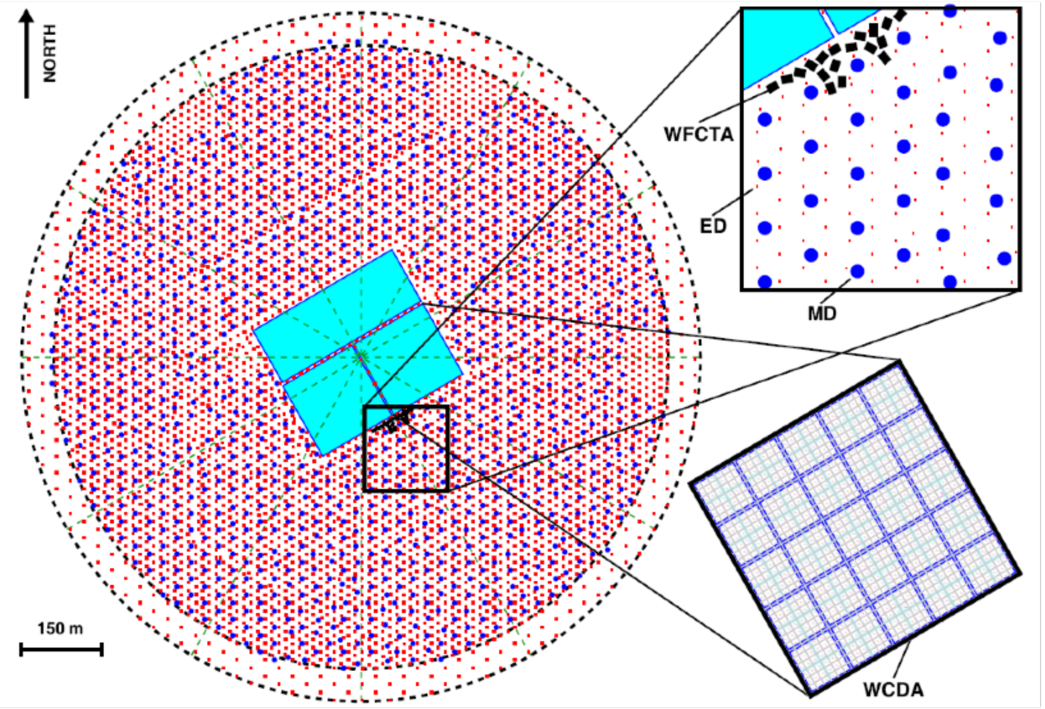
Giant Molecular Clouds



HAWC result on the GMC: 95% C.I. upper limits on the gamma-ray flux

- In GeV energies, some analyses like Yang et al.2014 focused on high-latitude clouds, where the gamma-ray spectra derived from massive clouds align with local CR measurements.
- In higher energy, HAWC has recently reported the observations towards several nearby GMCs, the derived upper limit is consistent with the predicted gamma-ray emissivities assuming a same CR density as local measurements.

All detectors are in DAQ since 2021-7-19



1.3 km^2

- **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 Data analysis

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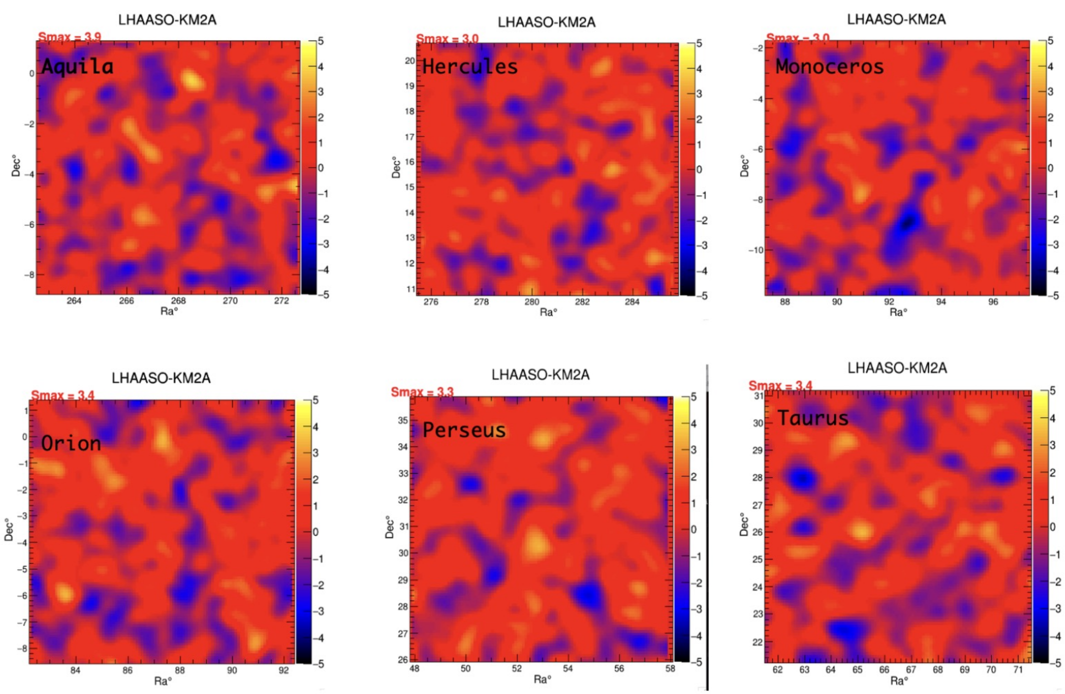
- We produced significant sky maps of six GMC regions listed in Table 1 using KM2A data from 2019.12 to 2024.07, and found no significant excess at each cloud.

- We chose high-density regions in which the column density is larger than 8 × 10^21 cm^−2 as our source templates



The significance map of the GMC regions at energy above 25 TeV

- The TS value for each GMC produced by 3D Likelihood analysis is too low (< 25) to give a significant detection.

GMC	Distance (pc)	R.A. (deg)	Decl. (deg)
Aquila Rift	255 ± 55	267.6	-3.72
Hercules	200±30	280.6	15.7
Monoceros	830±83	92.3	-6.8
Orion	490±50	87.3	-3.6
Perseus	315±32	52.9	30.9
Taurus	140±30	66.5	26.2

Table 1: Properties of the GMCs

Stacking analysis

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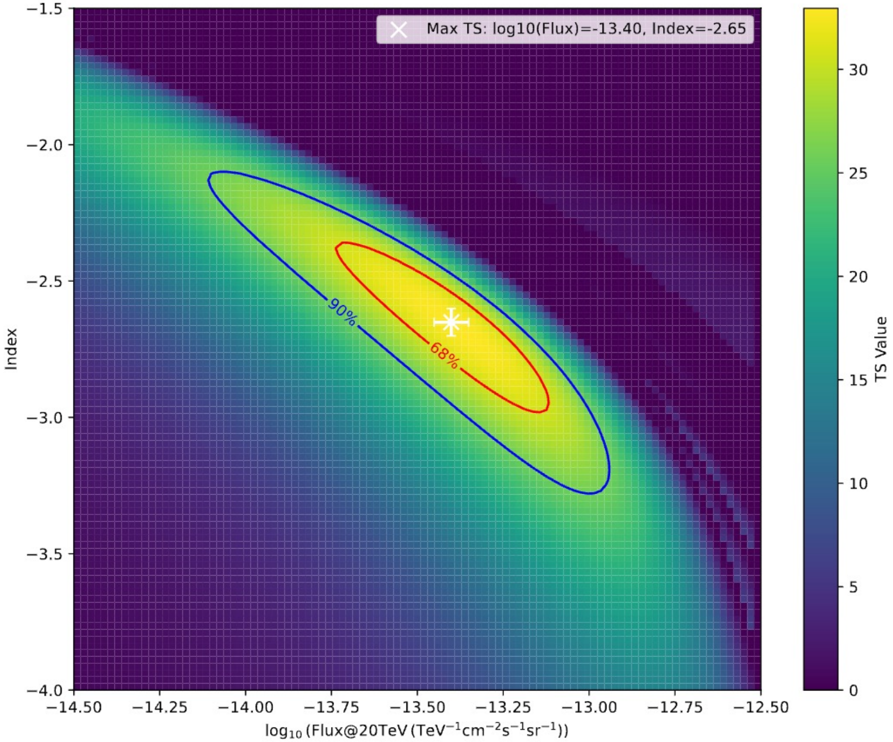
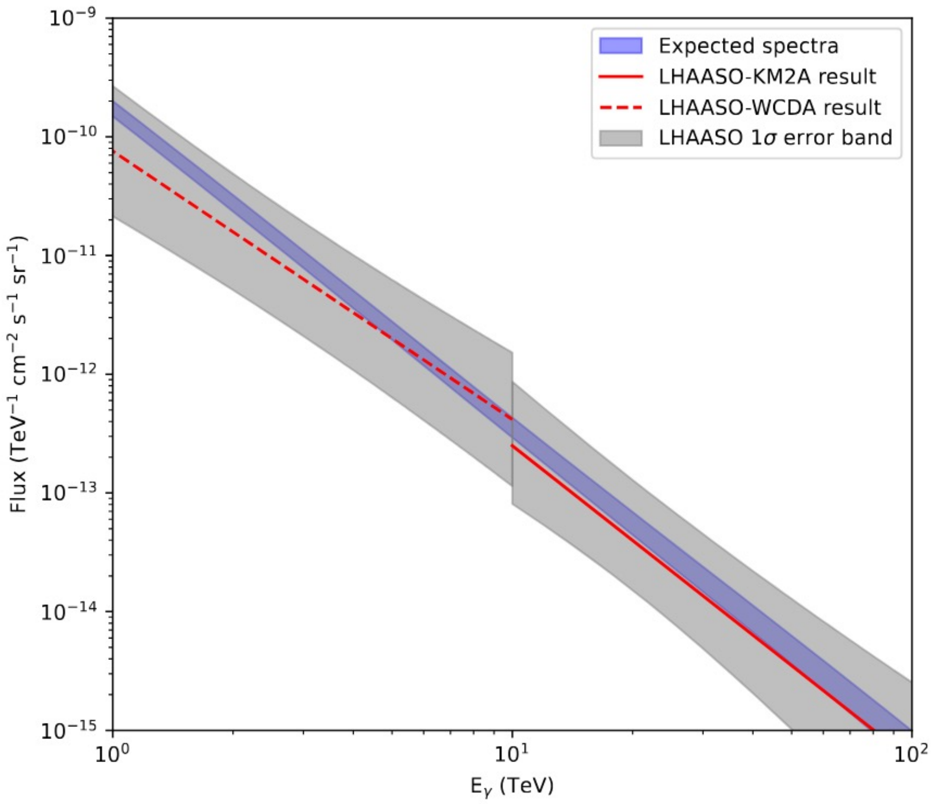
- A stacking technique was adopted to search for the weak gamma-ray from the GMCs. The stacking technique is often used to explore gamma-ray average properties for astrophysical populations.
- The spectrum of GMCs is assumed to follow a power-law distribution.



- Stacked TS profile for GMC sample containing 6 sources.
- The stacked gamma-ray flux is weighted according to the average gas column density of each cloud.
- Max TS: 33

$$F_s = (3.98^{+2.33}_{-1.47})\times 10^{-14}\times \left(\frac{E}{20TeV}\right)^{-2.65^{+0.40}_{-0.37}}$$

Stacking analysis



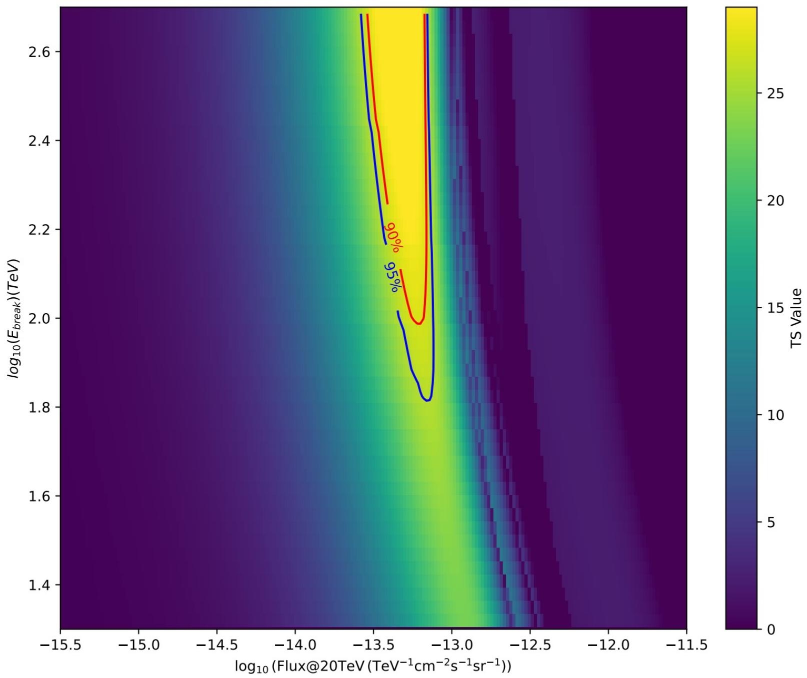
- The SED of the GMC as measured by LHAASO-KM2A and WCDA
- The blue shaded band represents the expected γ-ray flux produced via CR interacting with ISM assuming the CR proton and Helium spectrum summarized in KM2A diffuse paper.
- We found that the measured gamma-ray flux assuming a single power law is consistent with the expectation for the gamma-ray spectrum of the clouds based on CR measurements.

Constraining to the CR spectrum

- CR 'knee' implies that the corresponding gamma-ray spectrum should also have a spectral break at about 100 TeV, which lies in the energy range of KM2A
- We performed the likelihood analysis by adding a spectral break to test such predictions , the result shows that the likelihood fitting was not improved

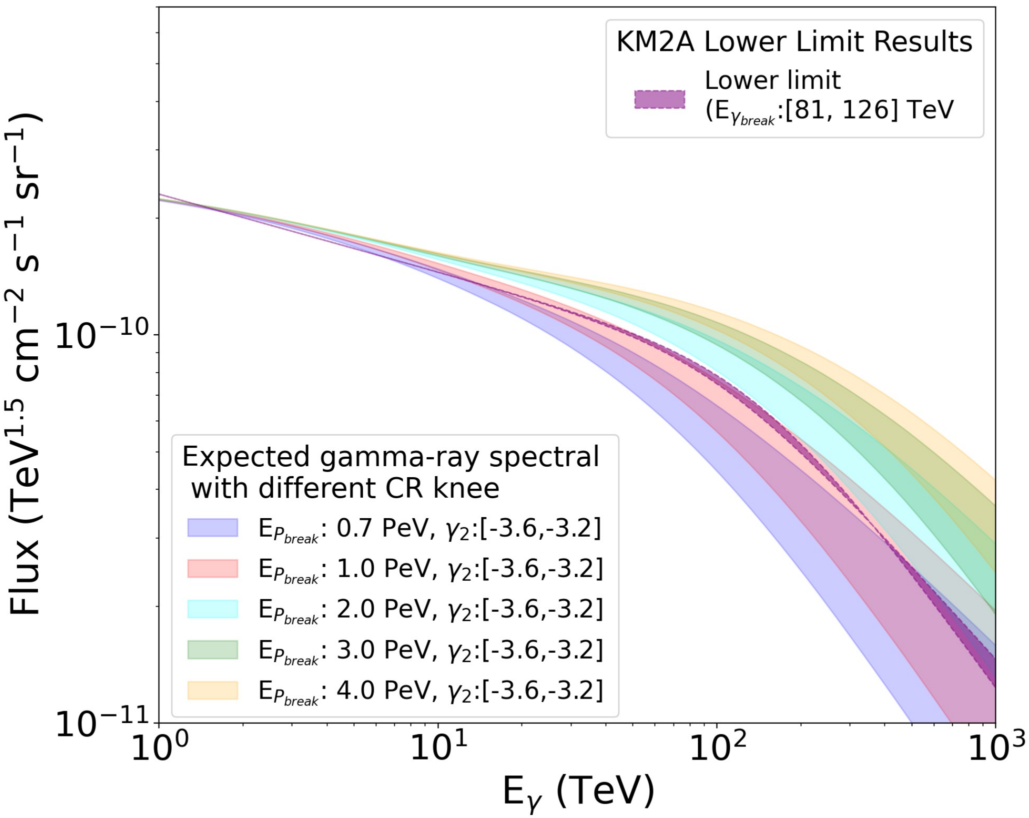
$$J(E) = \Phi_0 \times (\frac{E}{E_0})^{\gamma_1}(1 + (\frac{E}{E_{break}})^s)^{(\gamma_2-\gamma_1)/s}$$

broken power-law (BPL)



Stacked TS profile for GMCs. The spectrum of GMCs is considered to follow a break power-law.

Constraining to the CR spectrum

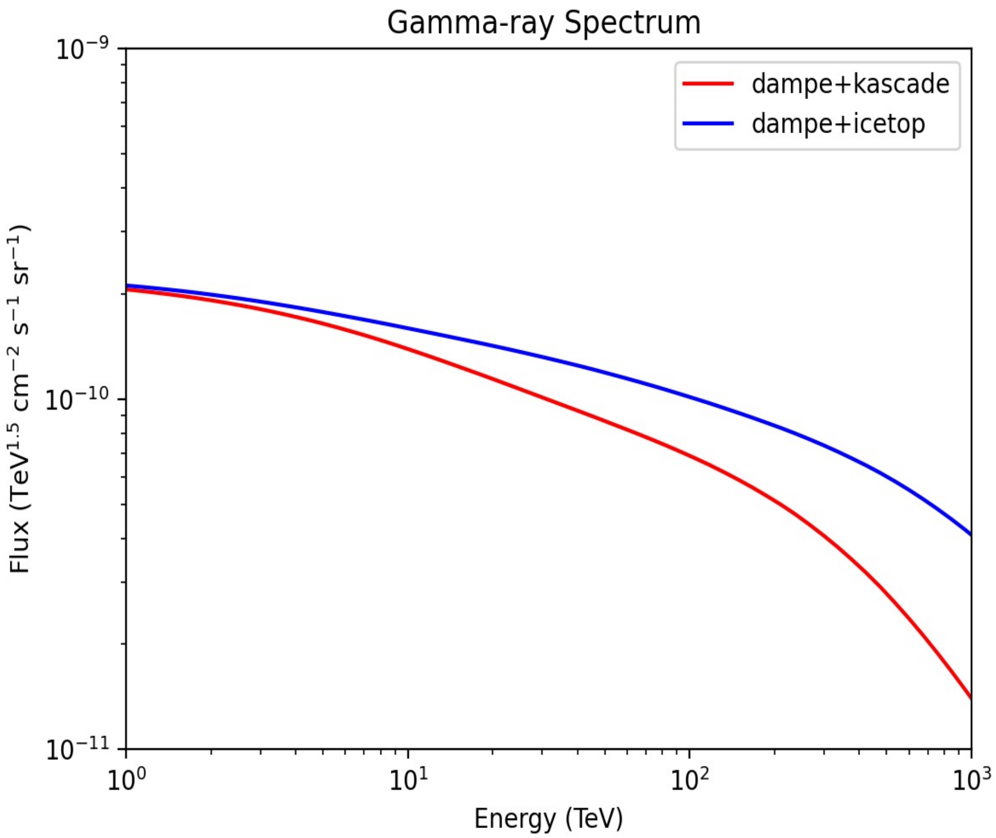


- The shadow bands show the model prediction from hadronic interactions between CR nuclei and the ISM with different 'knee' of CRs.
- We used the CR proton and helium spectra measured by DAMPE up to 100 TeV, then extrapolated to higher energy and added an spectral break by hand to represent the position of the “knee”
- The dashed lines are the 90% lower-limit flux derived from the stacked data with different γ_2 expressed in BPL model
- The Km2a results show that at 90% confidence level the ‘knee’ of the proton is larger than 1 PeV.

Summary and prospect

- We report the first detection of gamma-ray emissions in the very-high-energy (VHE) domain from the nearby GMCs using the LHAASO array.
- We found that the measured gamma-ray flux domain from the GMCs assuming a single power law are in good consistency with the expected γ-ray flux produced via CR interacting with ISM.
- We also performed the likelihood analysis adding a spectral break to give a constraining to the CR ‘knee’, and the Km2a results show that at 90% confidence level the ‘knee’ of the proton is larger than 1 PeV.

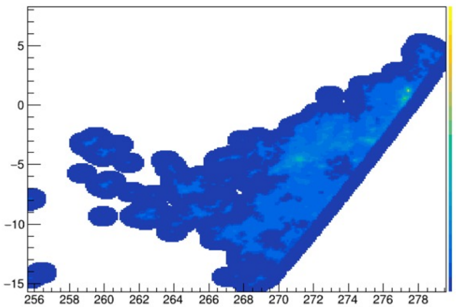
Constraining to the CR spectrum



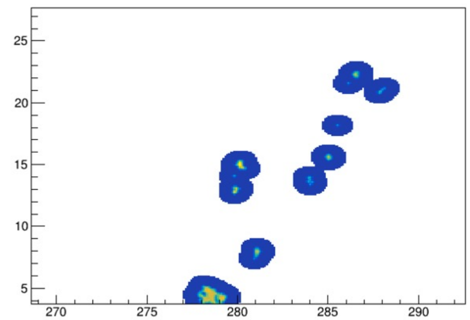
- The expected γ-ray spectra produced via CR interacting with ISM assuming a spectrum of CR which coincides with the DAMPE+ Kascade and DAMPE+ Icetop
- We found that the TS value, assuming the gamma-ray model based on the DAMPE+Icetop results, improves by about 3 compared to the DAMPE+KASCADE results.

GMC template

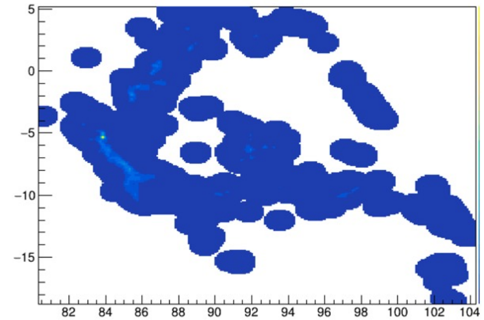
- We choose high-density regions in which the column density is larger than 8 × 10^21 cm−2 as our source templates.



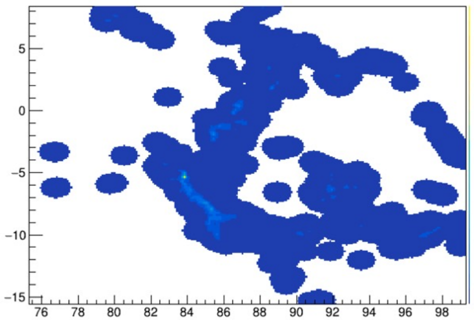
Aquila



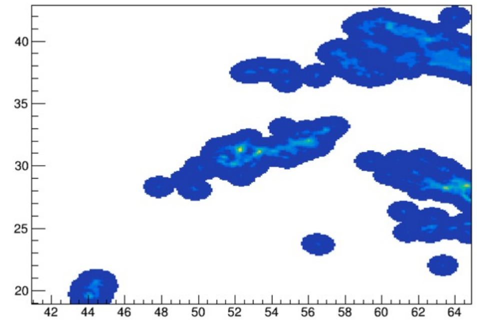
Hercules



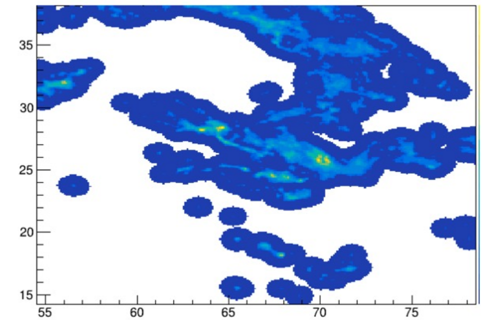
Monoceros-



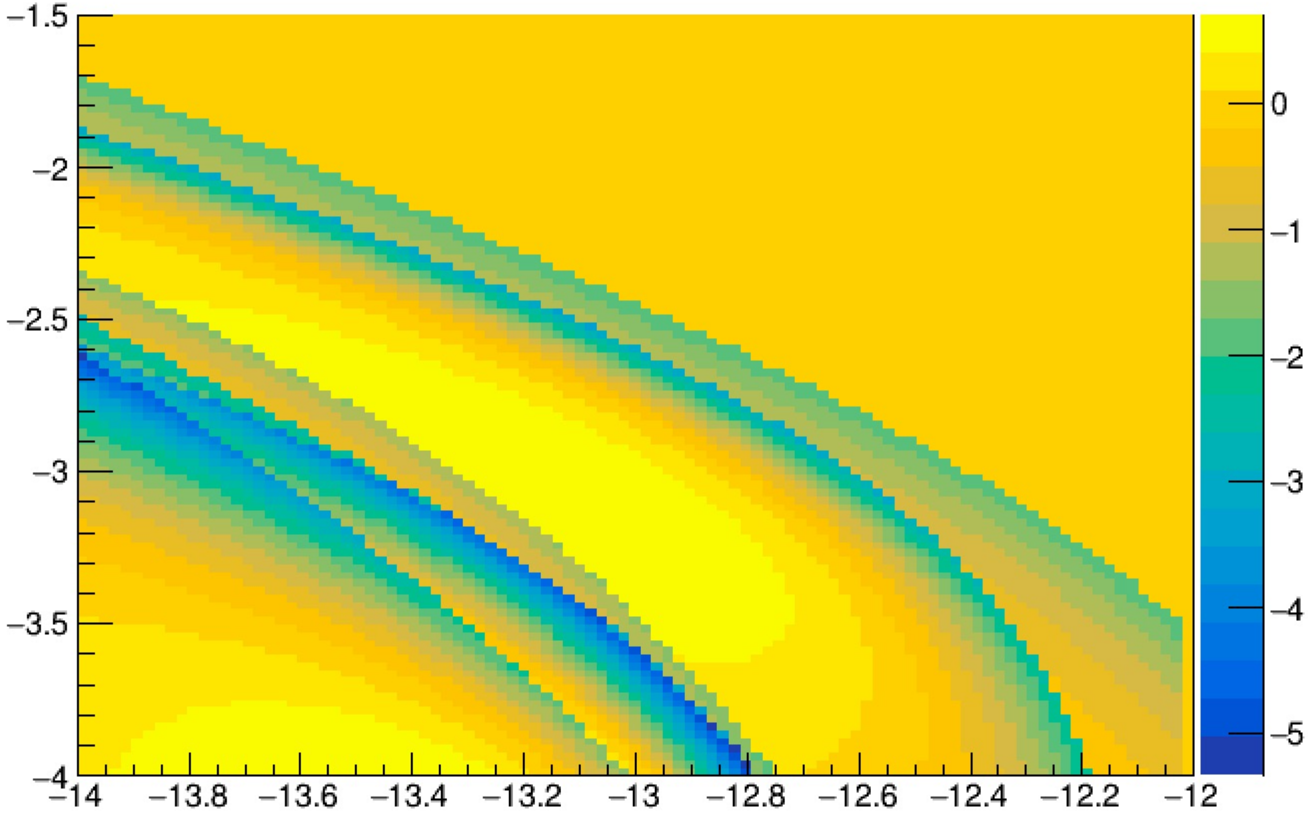
Orion



Perseus



Taurus


−1.5
−2
−2.5
−3
−3.5
−4
−14
−13.8
−13.6
−13.4
−13.2
−13
−12.8
−12.6
−12.4
−12.2
−12
0
−1
−2
−3
−4
−5