Searching for Gamma-Ray Signal from Giant Molecular Clouds with HAWC

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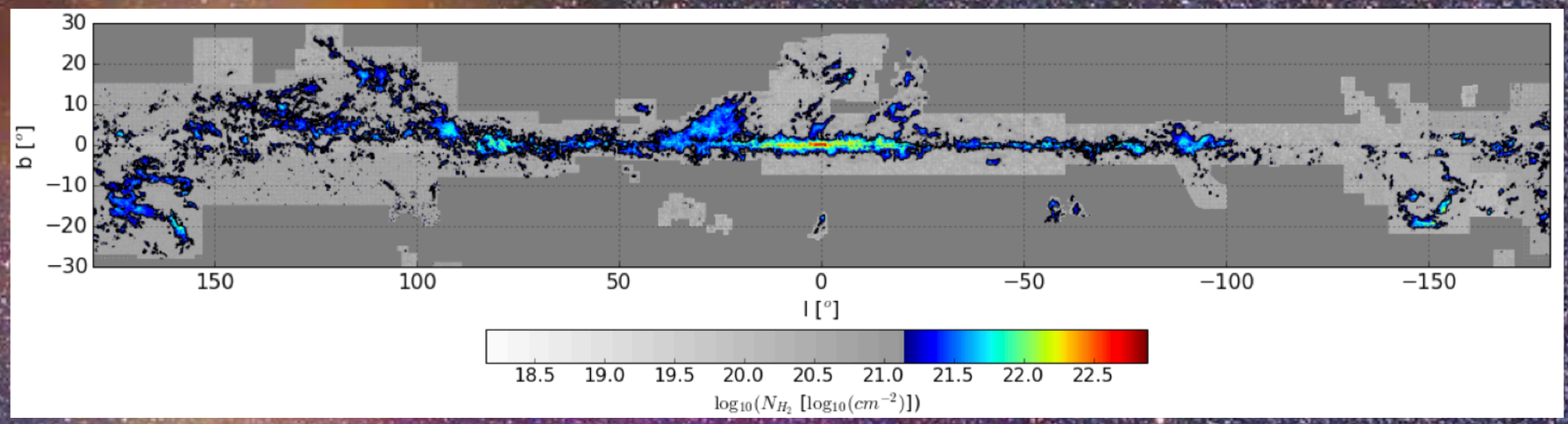
Giant Molecular Clouds

- Giant Molecular Clouds (GMCs) are dense concentrations of interstellar gas where stars can be formed.
    - Composed mainly of **dust and gas.**
        - Gas mostly hydrogen and helium.
    - **Masses around 10^4 - 10^6 $M_\odot$.**
    - **Sizes of 50 - 200 pc.**



CfA-Chile survey mapping the CO distribution in the galaxy (Dame et al. 2001).

Photo by Luis Argerich https://flic.kr/p/eHZVB8

Gamma-Ray Emission

- Ideal places for the **interaction of cosmic rays with the ambient gas** that produces **gamma rays** through hadronic processes.

- Tracing the propagation and distribution of cosmic rays in the Galaxy

  - Can **probe the flux of cosmic rays** in distant galactic regions and compare it with the local measurement (Casanova, et al. 2010)

  - Can measure the amount of gas if the cosmic ray flux is assumed (Ackermann, et al. 2012)

- Gamma-ray flux produced by the **interaction** of GMCs with cosmic rays is proportional to (Aharonina, 1990):

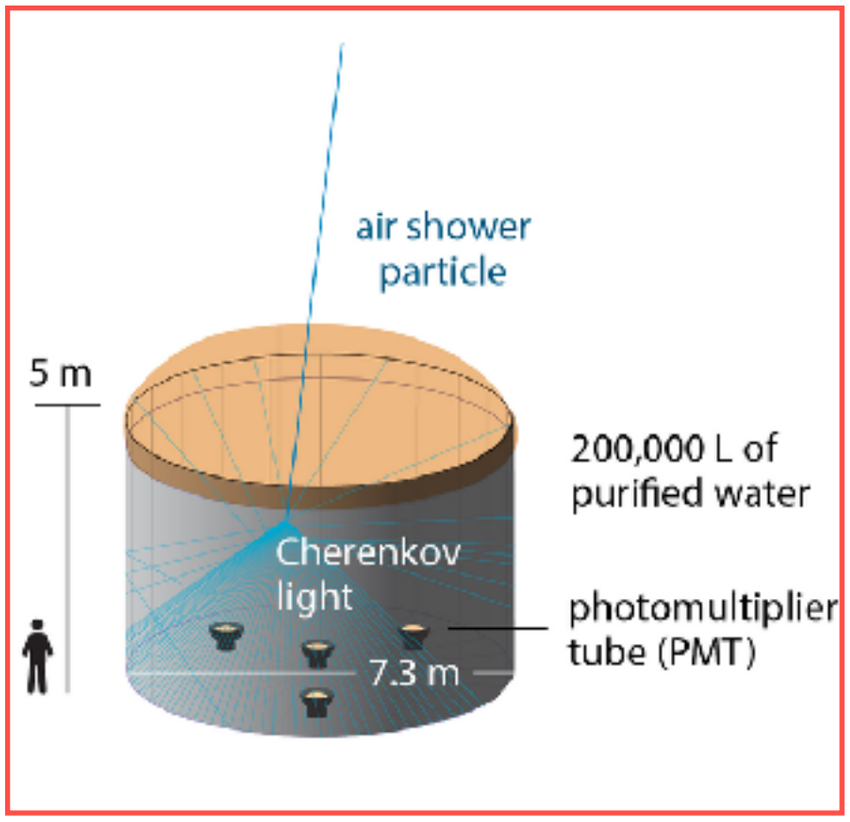
$$F_\gamma \propto \Phi_{CR} \frac{M_5}{d_{kpc}^2}$$

  - Where $\boldsymbol{\Phi}_{CR}$ is the cosmic-ray flux, $M_5 = M_\odot / 10^5$ is the mass of the GMC, and d_{kpc}=d/1kpc is the distance to the cloud.

  - We will focus on **passive GMCs**, i.e. GMCs with no particle accelerator inside them.

The HAWC Observatory

- Altitude: 4100m
- Daily Coverage: 2/3 of sky
- Instantaneous FoV: 2sr
- >95% Duty Cycle
- Sensitivity: 100 GeV to 100 TeV



Sensitivity of HAWC to Extended Sources

- Assuming that the cosmic-ray flux is the same as the locally measured cosmic-ray flux, the gamma-ray flux from GMCs can be estimated as (Aharonian, 1990)

$$F_\gamma = \begin{cases} 1.45 \times 10^{-13} E_{\rm TeV}^{-1.75} (M_5/d_{\rm kpc}^2)\,{\rm cm}^{-2}\,{\rm s}^{-1} & 100\,{\rm MeV} < E_\gamma < 1\,{\rm TeV} \\ 2.85 \times 10^{-13} E_{\rm TeV}^{-1.6} (M_5/d_{\rm kpc}^2)\,{\rm cm}^{-2}\,{\rm s}^{-1} & E_\gamma > 1\,{\rm TeV} \end{cases},$$

- We look at three GMCs: Aquila Rift, Taurus and Hercules.

GMC	Mass	Distance	Decl. Center	Extension
Aquila Rift	$1.5 \times 10^5\ M_\odot$ [1]	225±55 pc [2]	-7.6°	<0.068 sr
Taurus	$0.2 \times 10^5\ M_\odot$ [3]	135±20 pc [4]	25.8°	<0.203 sr
Hercules	$0.5 \times 10^5\ M_\odot$ *	200±30pc [4]	14.7°	<0.013 sr

[1]Dame et al. ApJ 1987

[2]Straizys, V., et al., A&A 2003

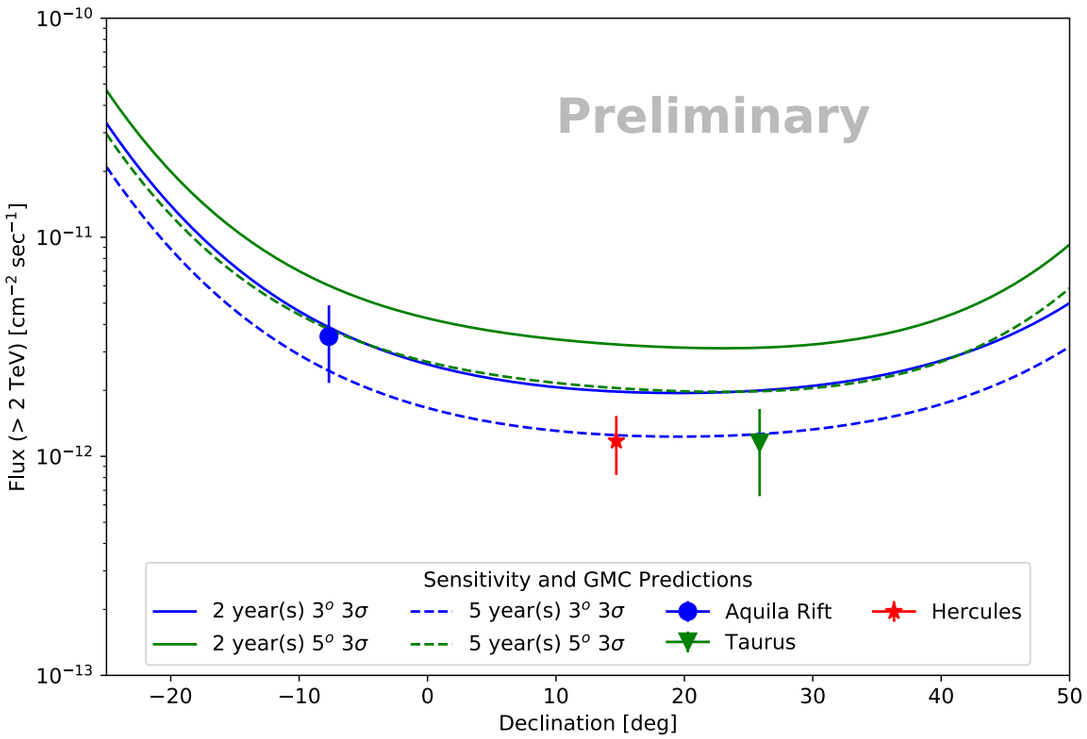
[3]Kenyon, S. J., et al., AJ 1994

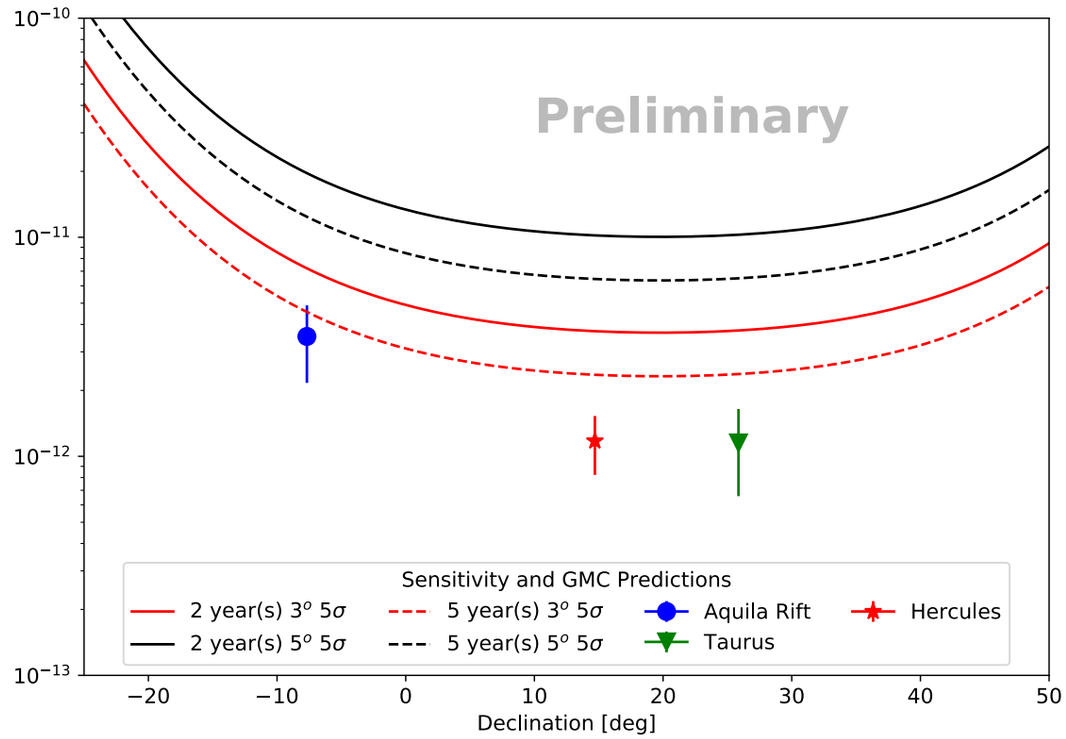
[4]Schlaffly, E., et al. ApJ 2014

*Mass is assumed

Sensitivity of HAWC to Extended Sources

- Compare expected fluxes from previous equation to the HAWC sensitivity for 3σ and 5σ detection after 2 and 5 years of data for a circular source with 3° and 5° in radius.

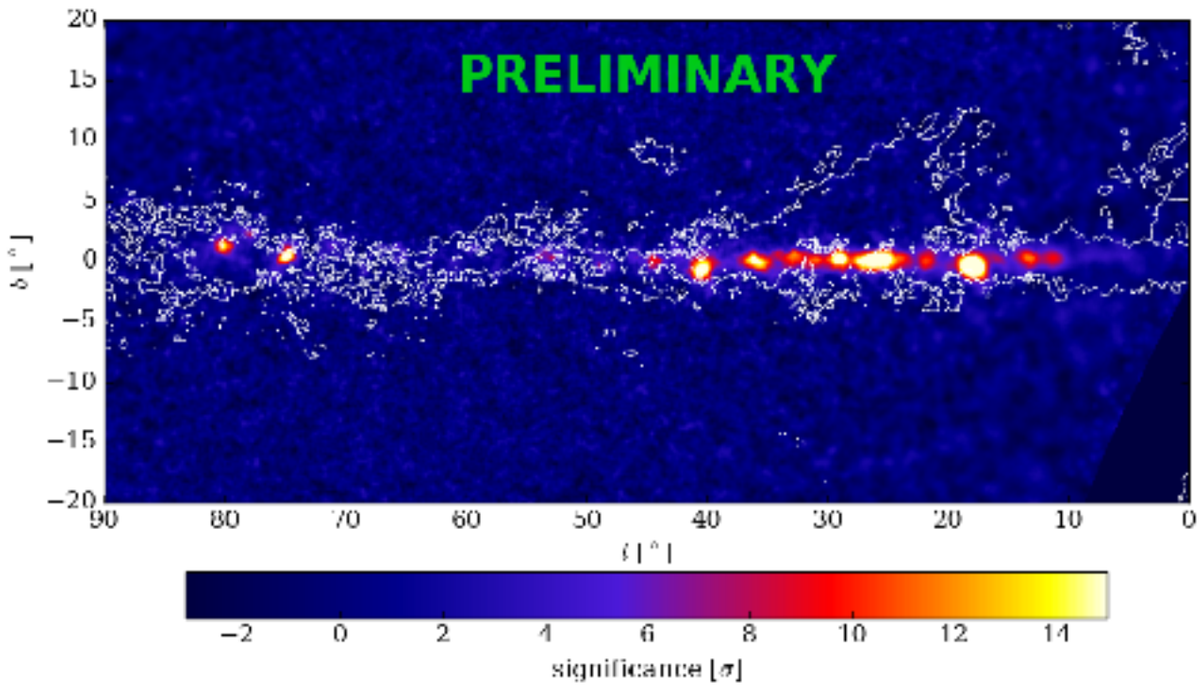




HAWC sensitivity to extended sources and predicted integral fluxes of the GMCs in their respective declination. The error bars are calculated from the respective mass and distance errors.

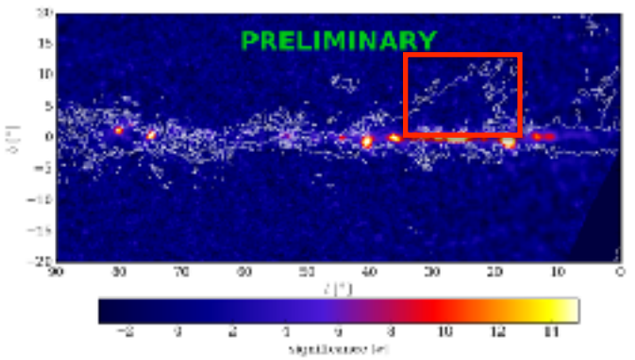
Search of Gamma-Ray Emission in HAWC Data

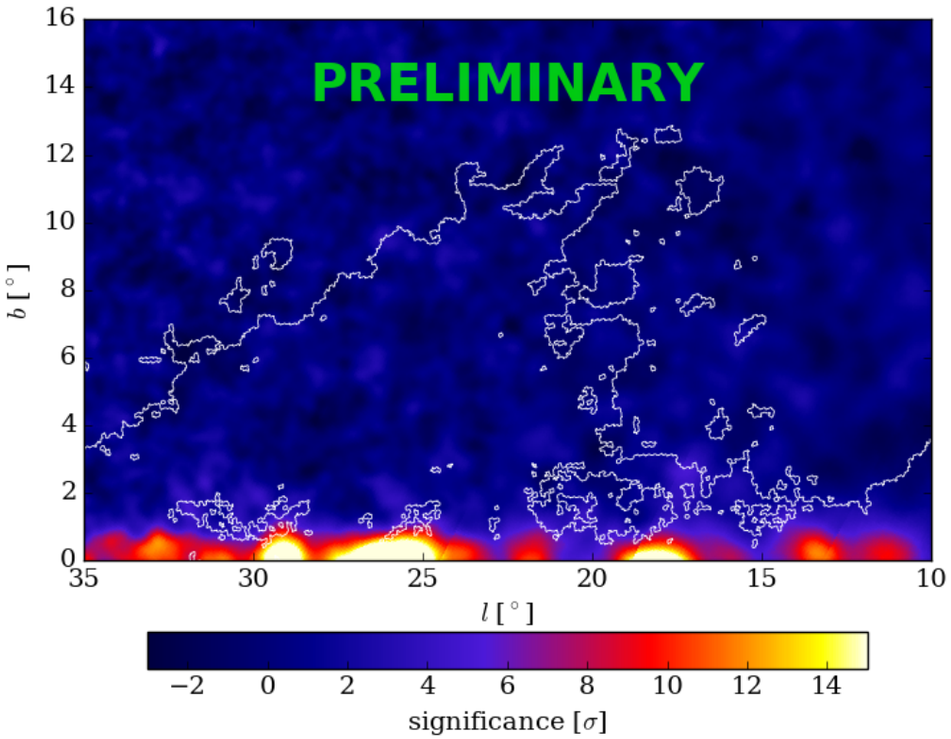
- Using 760 days of HAWC data
    - Search for a gamma-ray excess in the regions of Aquila Rift, Taurus, and Hercules.
    - Background calculated using the direct integration with an integration time of 2 hours.

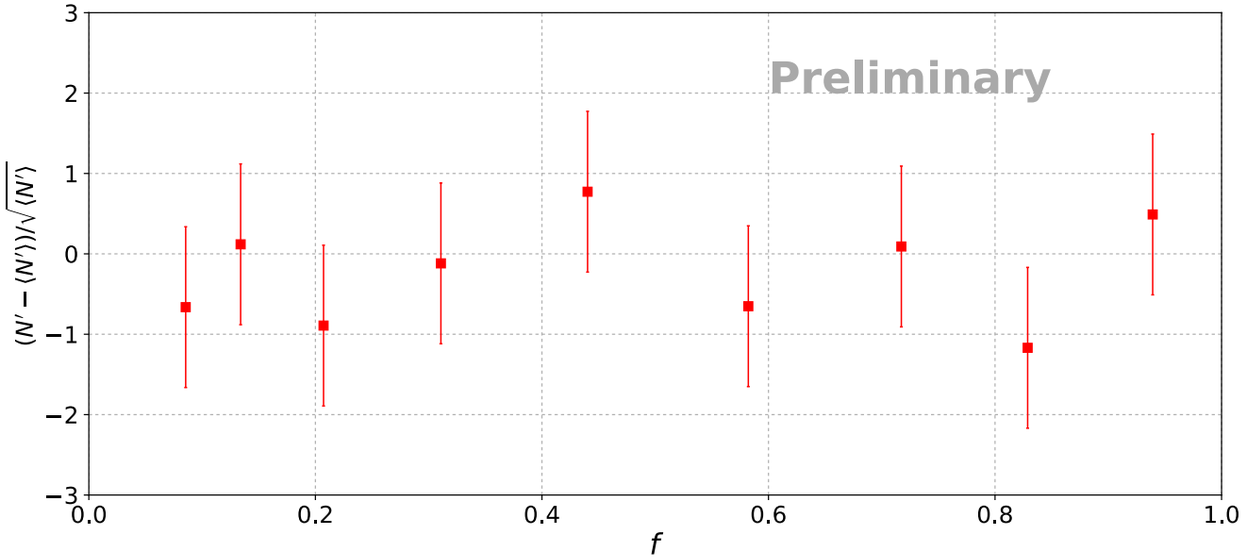


- Contour line corresponds to $\log_{10}(N_{H_2}[cm^{-2}]) = 21.15$

Aquila Rift

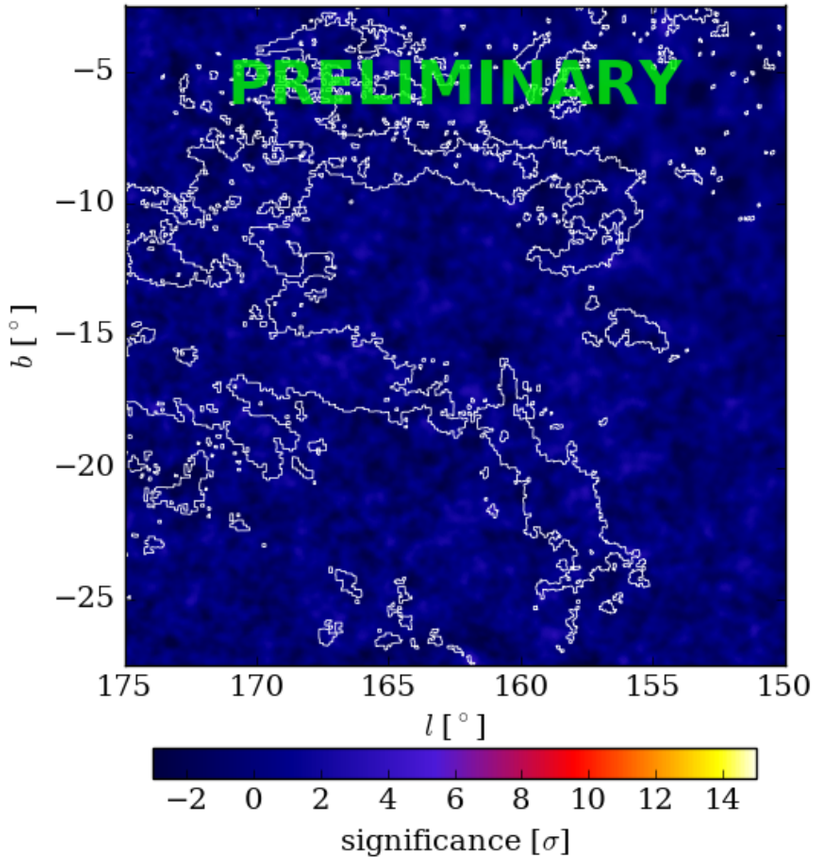


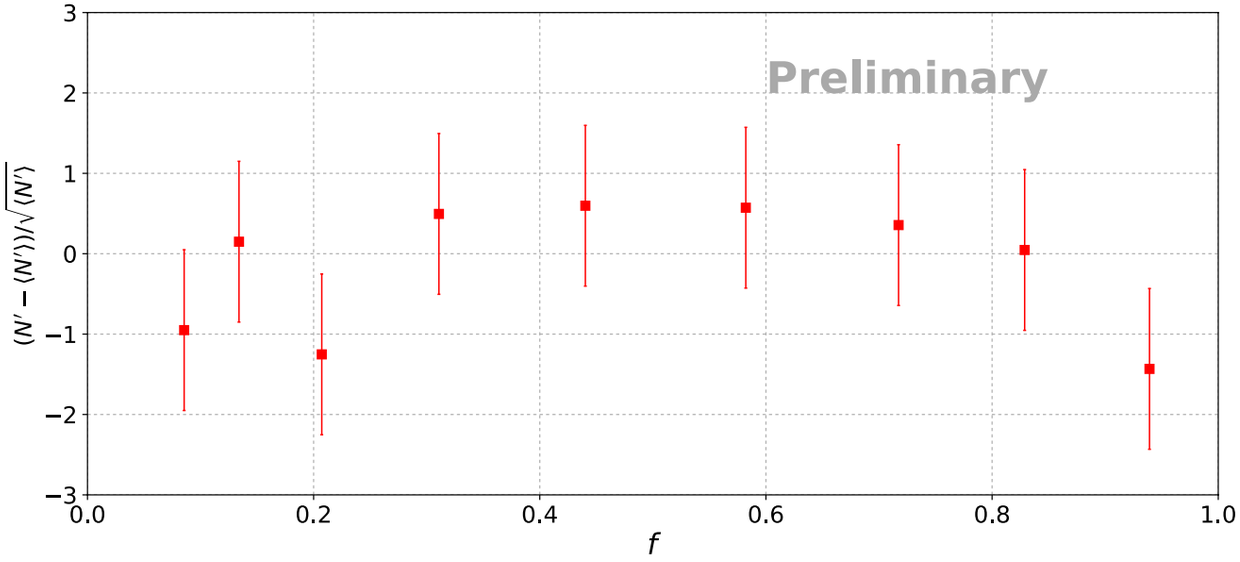




- Where: N' is the data; <N'> is the estimated background and f is the fractional number of PMTs that participated in the reconstruction of a shower event.

Taurus





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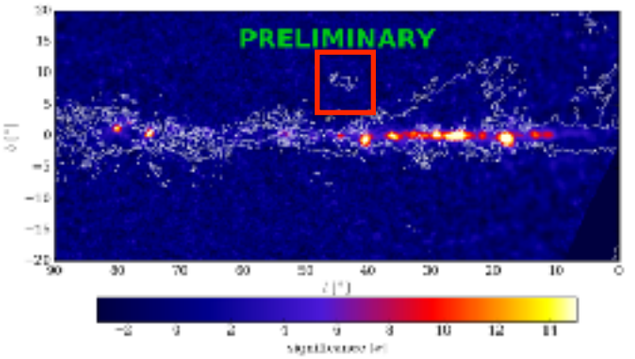
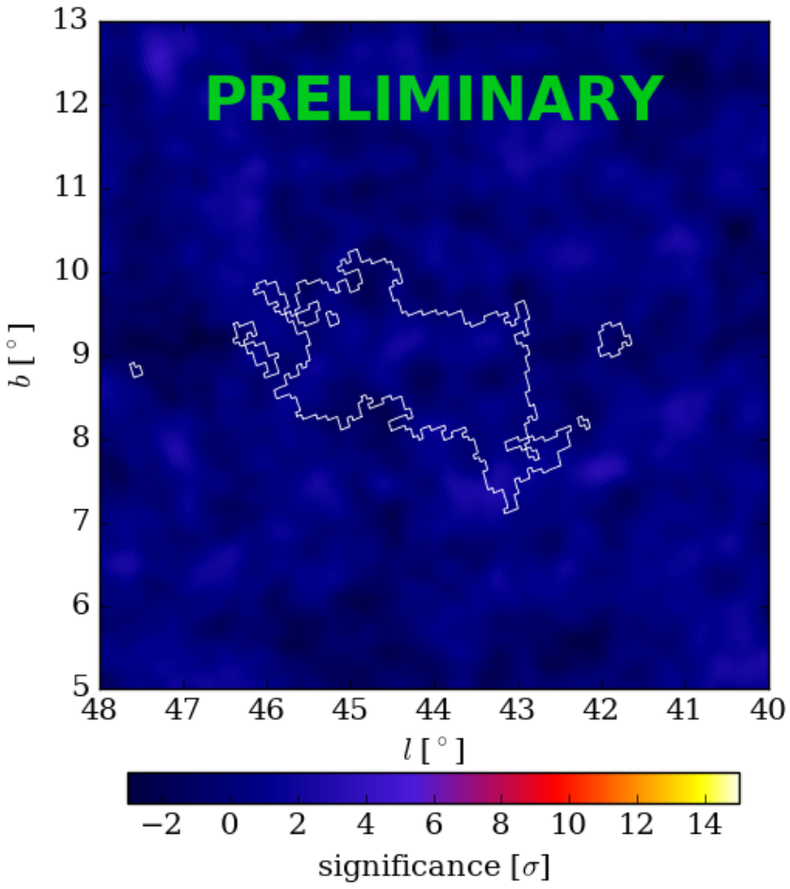
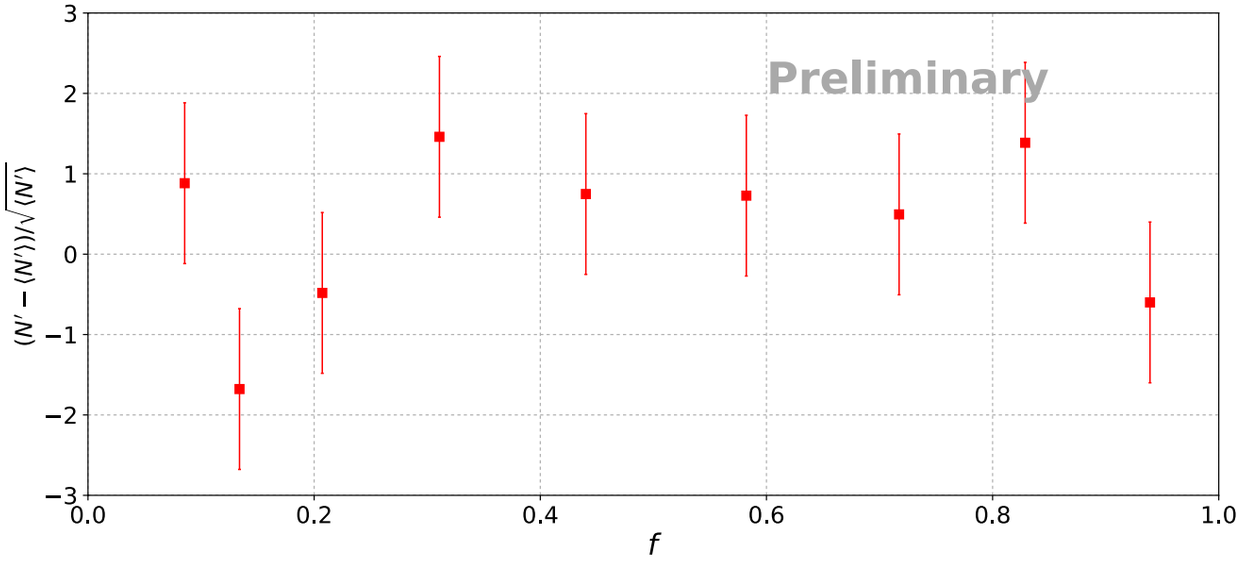
Hercules



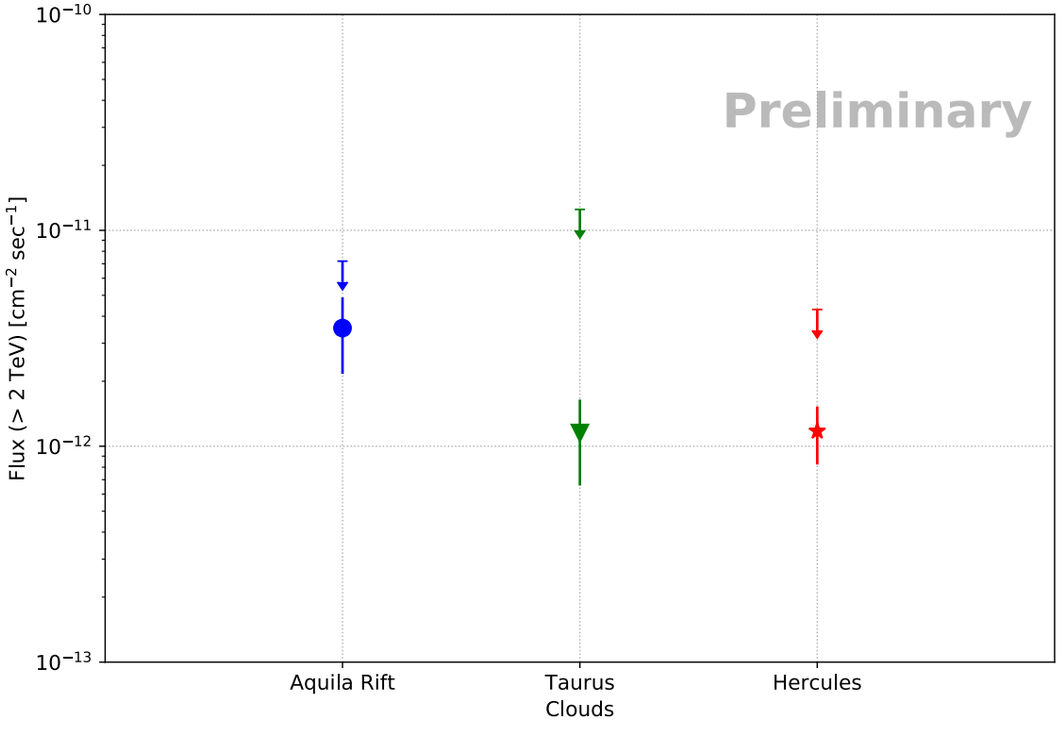


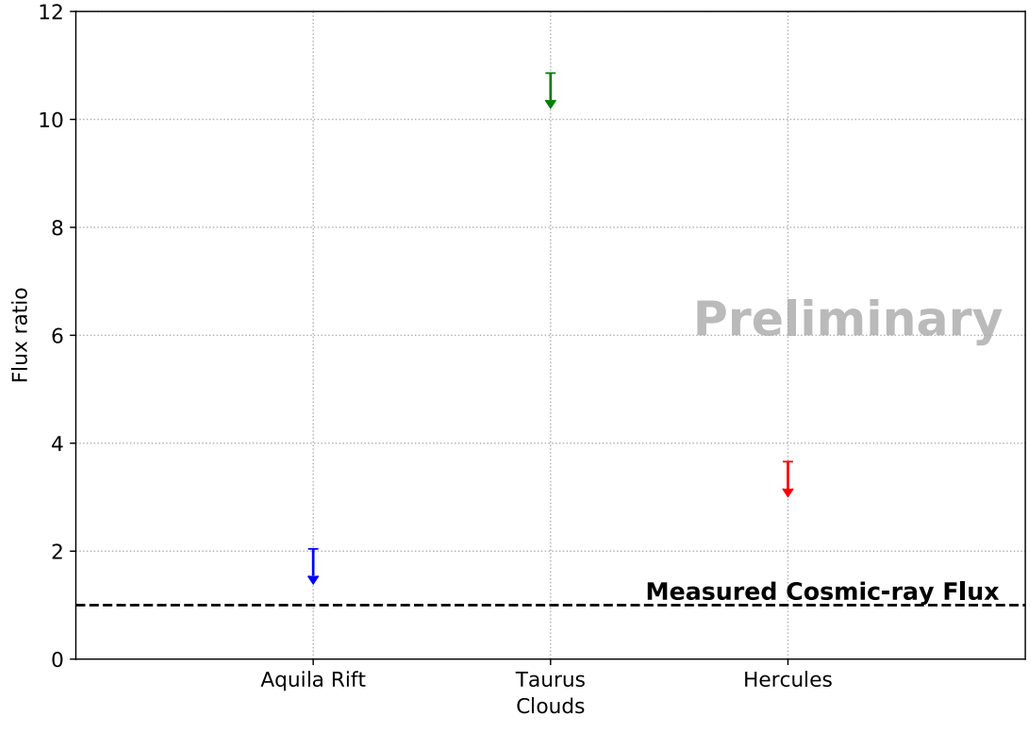


- Where: N’ is the data; <N’> is the estimated background and f is the fractional number of PMTs that participated in the reconstruction of a shower event.

Upper Limits

- No significant excess was observed so 95% C. L. Upper limits are calculated.
- Also, the ratio of the upper limits to expected fluxes is calculated. The ratio is an upper limit on the cosmic-ray flux in the GMC region.





Conclusion

- Search of **gamma-ray emission** from **passive GMCs** produced by the **interaction of cosmic rays with the ambient gas**.

- HAWC data from Aquila Rift, Hercules and Taurus show **no significant excess** of gamma-rays.

- **Upper limits at 95% C.L.** are calculated. There is **no evidence** for a deviation from the assumption that the cosmic-ray flux in the GMC regions is the same as the locally measured cosmic-ray flux.