Giant Molecular Clouds: The Epicentre of Gamma-Rays and Neutrino Emission in the Milky Way

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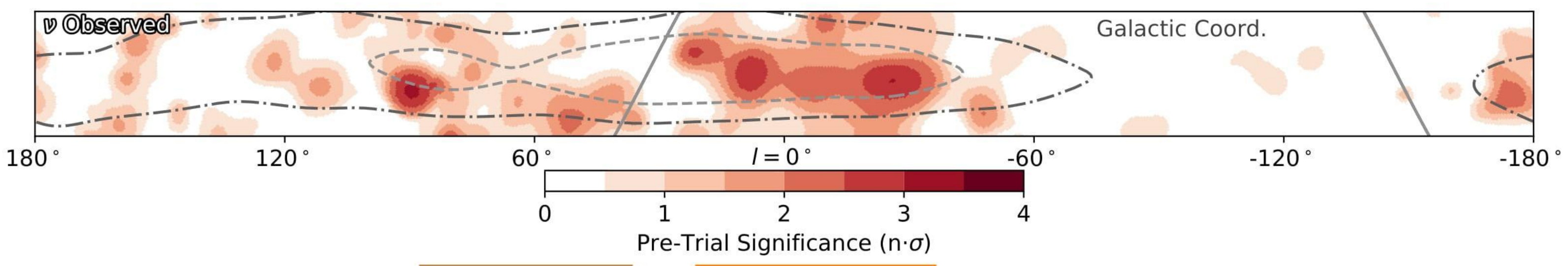
Motivation

In the recent paper by the IceCube[1], 4.5σ neutrino signal from the Galactic plane was discovered. This recent analysis paper is a significant progress to reveal the neutrino sources, as in the previous IceCube paper[2] they had reported only a 2σ hint of neutrino signal from our Galaxy. The origin of these neutrinos are unknown. However, they are most likely to be produced from the interaction GCR with the interstellar gas along with some source contributions.



$$\varphi_{\nu,tot}(E_\nu) = \varphi_{\nu,diff}(E_\nu) + \varphi_{\nu,S}(E_\nu)$$

The IceCube detected neutrino flux from the inner Galactic plane is very important to study the nature of Galactic cosmic-rays (GCRs) and gain valuable insights into these extreme processes. In our recent work[3], we reported that Aquila Rift is very promising point source for the neutrino signal, this has motivated us to study the role of all known Giant Molecular Clouds (GMCs) in our Galaxy for the production of neutrino signal.

Objective

Our main objective is to study the sources of diffuse gamma-ray and neutrino emission from the Galactic plane. One of the potential regions could be the dense gas regions i.e., GMCs in the Milky Way (MW) Galaxy.

A population of GMCs in the MW is considered for this and the effects of GCR spectrum on the neutrino flux is also studied. For the CR spectrum we consider two main cases:

- Case-I: Constant CR intensity in our Galaxy based on the observations at the Solar system.
- Case-II: Radially dependent CR intensity based on the supernova distributions in our Galaxy.

Investigation of the multimessenger connection between gamma-ray and neutrino emissions from GMCs is conducted and compared with detector sensitivity to determine their minimum detection limits.

Method

The gamma ray and neutrino flux, emitting from the interaction of GCR with a GMC having mass M and situated at a distance d can be calculated by

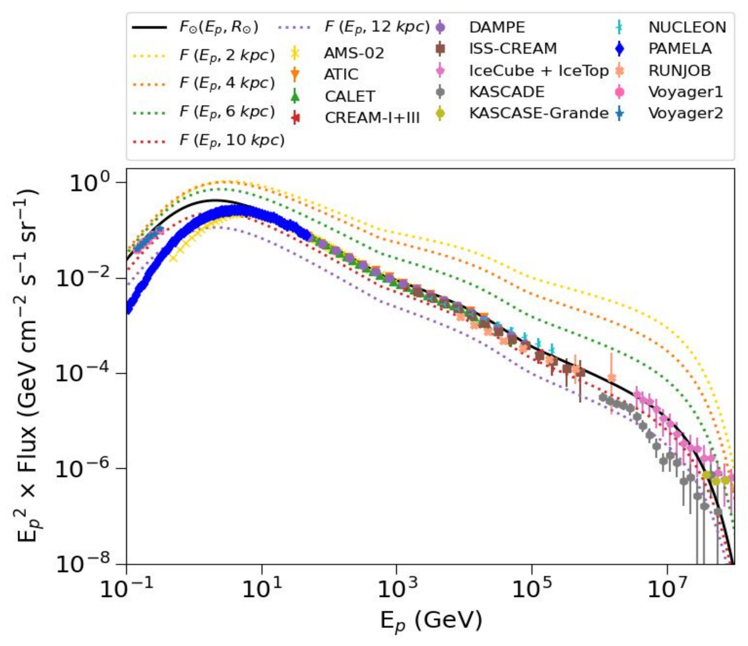
$$\varphi_{\gamma,\nu}(E_{\gamma,\nu}) = \frac{M}{d^2}\frac{\xi_N}{m_p}\int \frac{d\sigma(E_{\gamma,\nu},E_p)}{dE_{\gamma,\nu}}\varphi(E_p,R_{gal})\,dE_p$$
$$\simeq 1.25\times 10^{19}\,\mathcal{A}\,\xi_N \int \frac{d\sigma(E_{\gamma,\nu},E_p)}{dE_{\gamma,\nu}}\varphi(E_p,R_{gal})\,dE_p$$
$$[where\ \mathcal{A} = M_5/d_{kpc^2},\ M_5 = M/10^5 M_\odot]$$

"Case-I" we consider the observed GCR flux near the solar neighbour, shown by the black solid line.

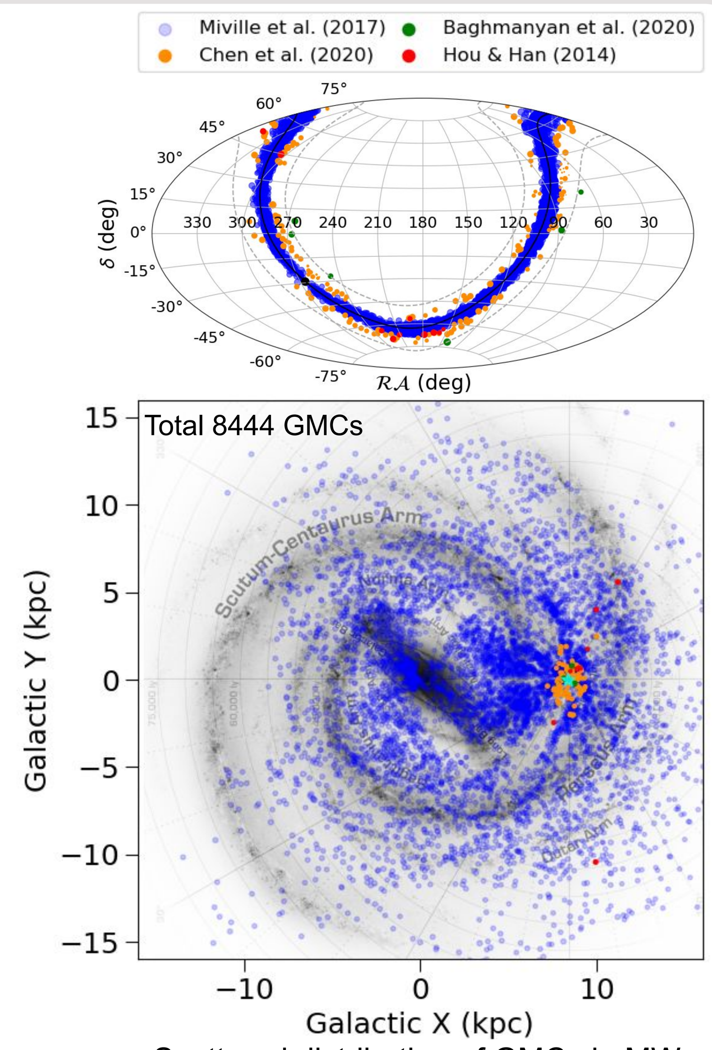
"Case-II" is more realistic and considers a position-dependent GCR flux variation model influenced by the two types of source (SNR) parameterization (Case-IIa[4] & Case-IIb[5]).

$$\varphi(E_p, R_{gal}) = \varphi_\odot(E_p, R_\odot)\times S(R_{gal})\times H(E_p, R_{gal});$$

$$H(E_p, R_{gal}) = \left(\frac{E_p}{20\ \mathrm{GeV}}\right)^{0.3\left(1-\frac{R_{gal}}{R_\odot}\right)}$$



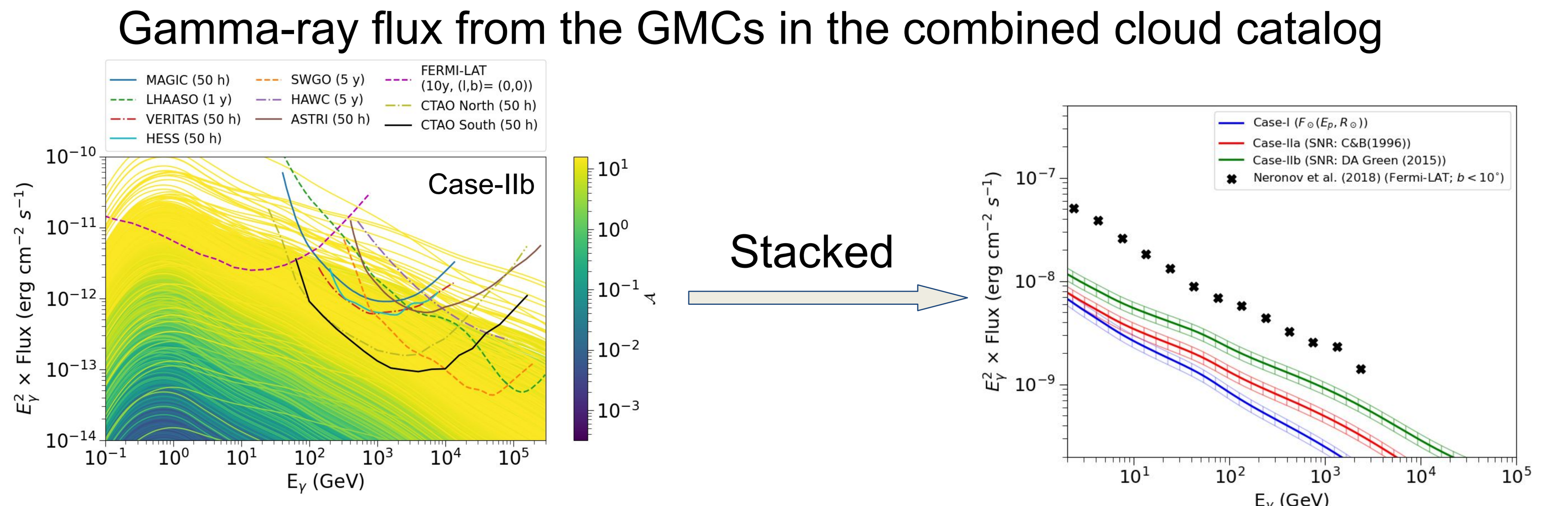
Diffused GCR protons spectrum.



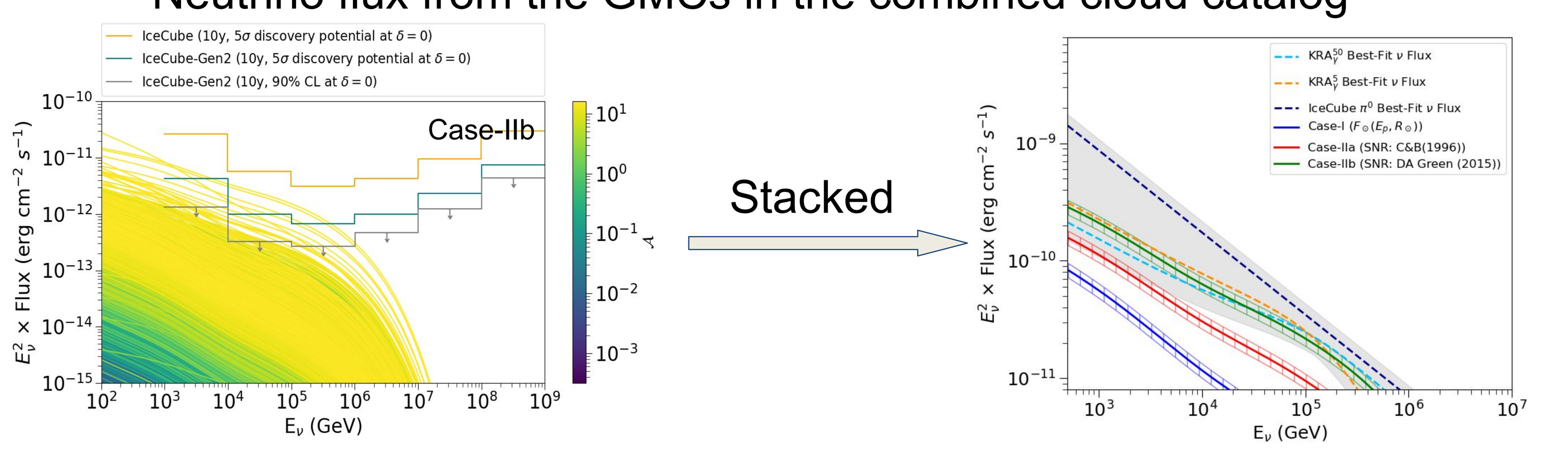
Scattered distribution of GMCs in MW.

Results

Gamma-ray flux from the GMCs in the combined cloud catalog

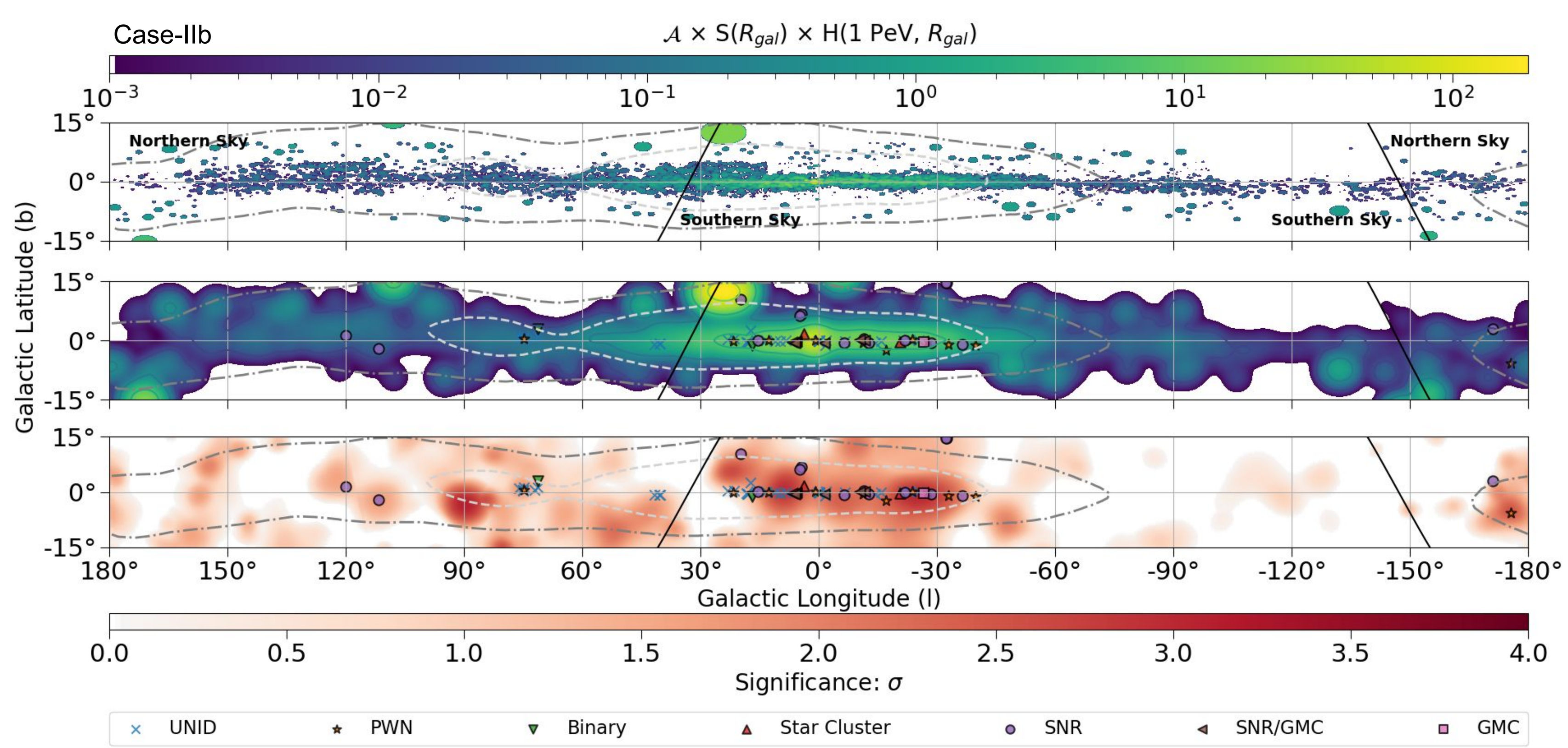


Neutrino flux from the GMCs in the combined cloud catalog



Results

Spatial Correlation of GMCs and TeVCat[10] sources against IceCube Significance Correlation Map



Key Takeaways

A large fraction of the gamma-ray and neutrino signals observed from the Galactic plane are associated with the GMCs. However, non-negligible contributions could also come from the diffuse atomic gas and astrophysical sources.

The spatially dependent GCR flux variation is also important to explain the observed harder and enhanced flux of gamma-ray and neutrinos at higher energies.

References

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