Galactic molecular clouds as sources of secondary positrons

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Based on Agnibha De Sarkar, Sayan Biswas, Nayantara Gupta, JHEAp **29** (2021) 1-18

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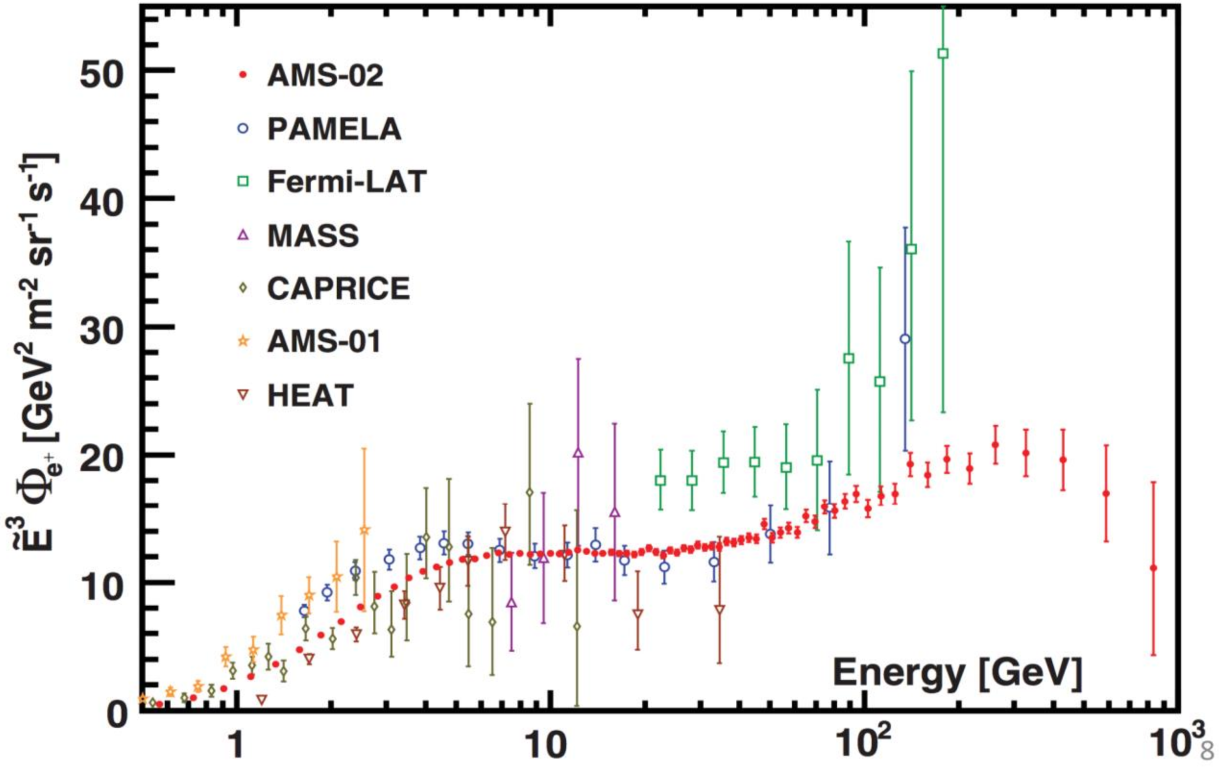
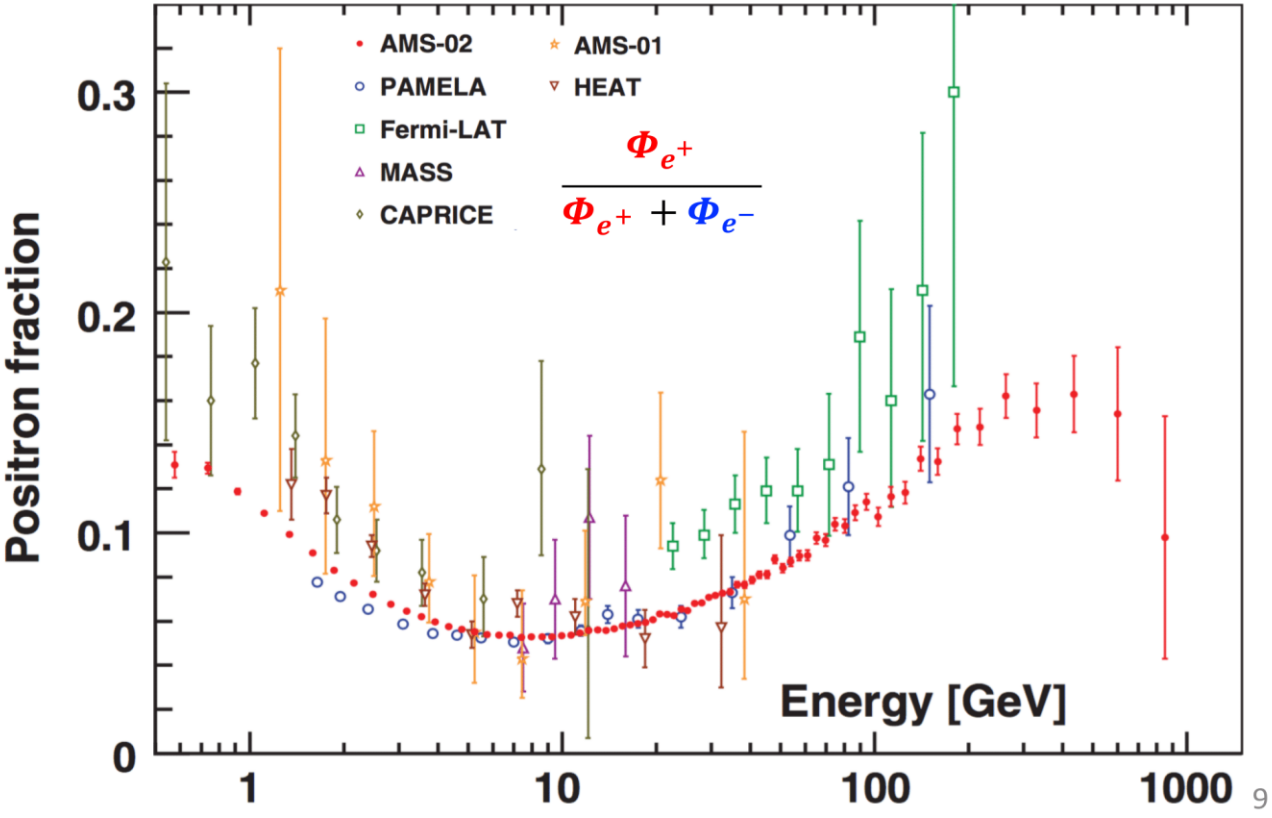
Introduction to positron excess :





Zhili Weng, AMS-02 collaboration, ICRC 2019

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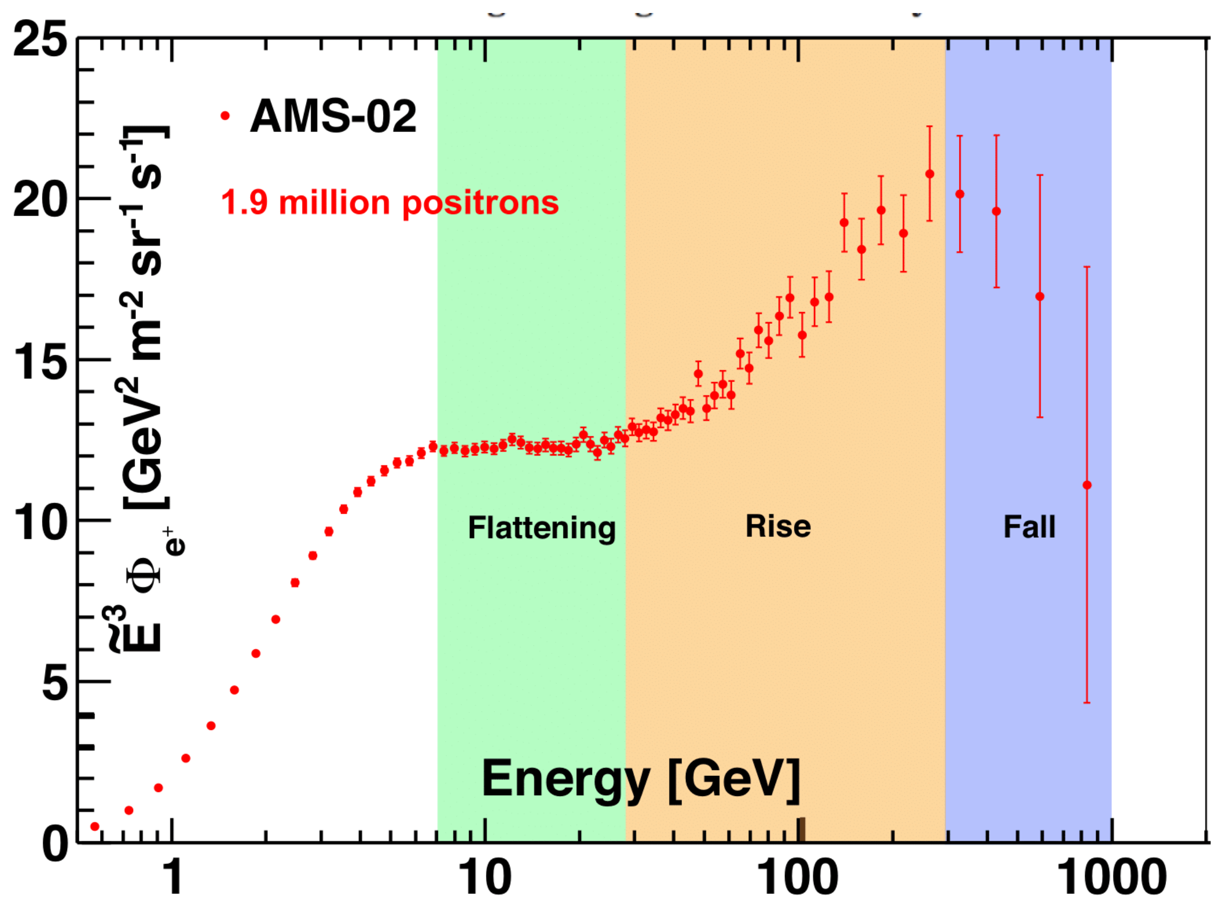

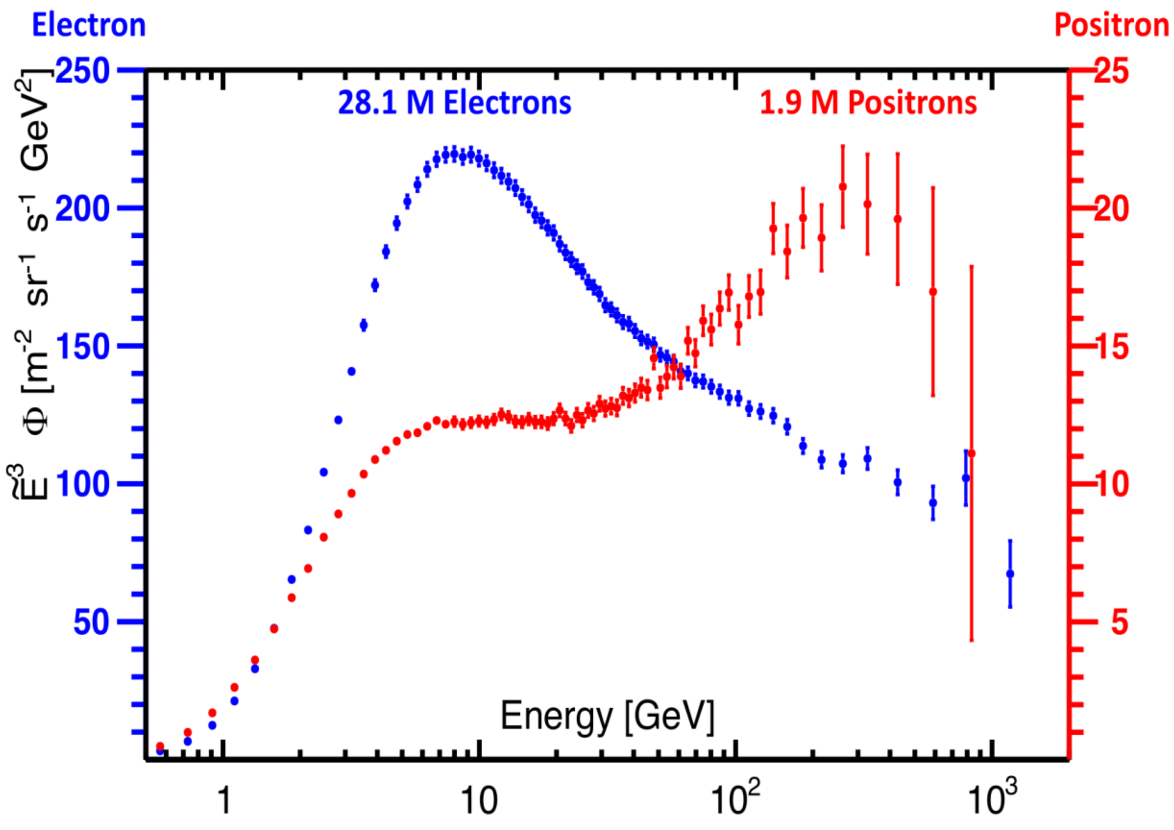

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Zhili Weng, AMS-02 collaboration, ICRC 2019

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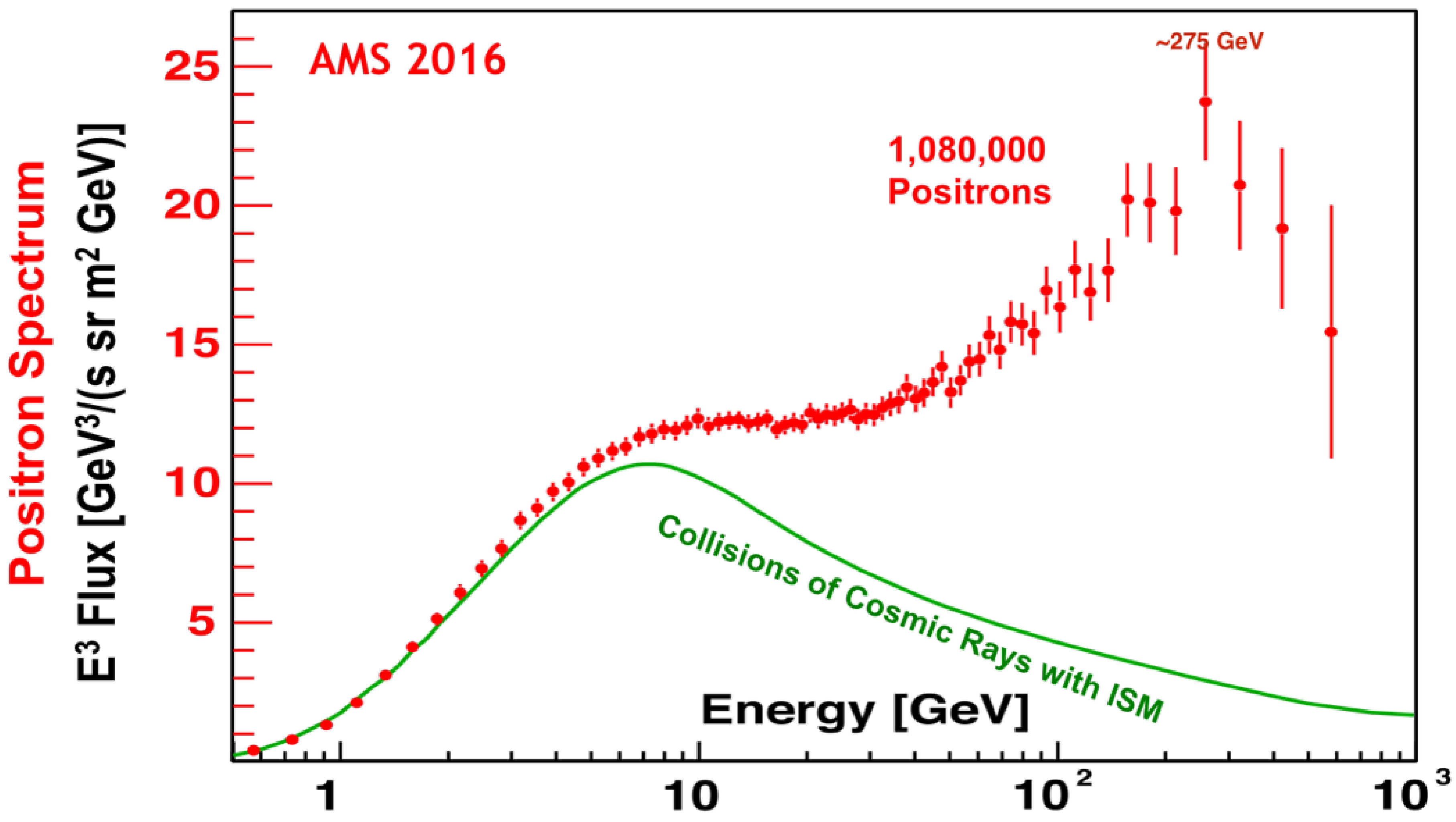

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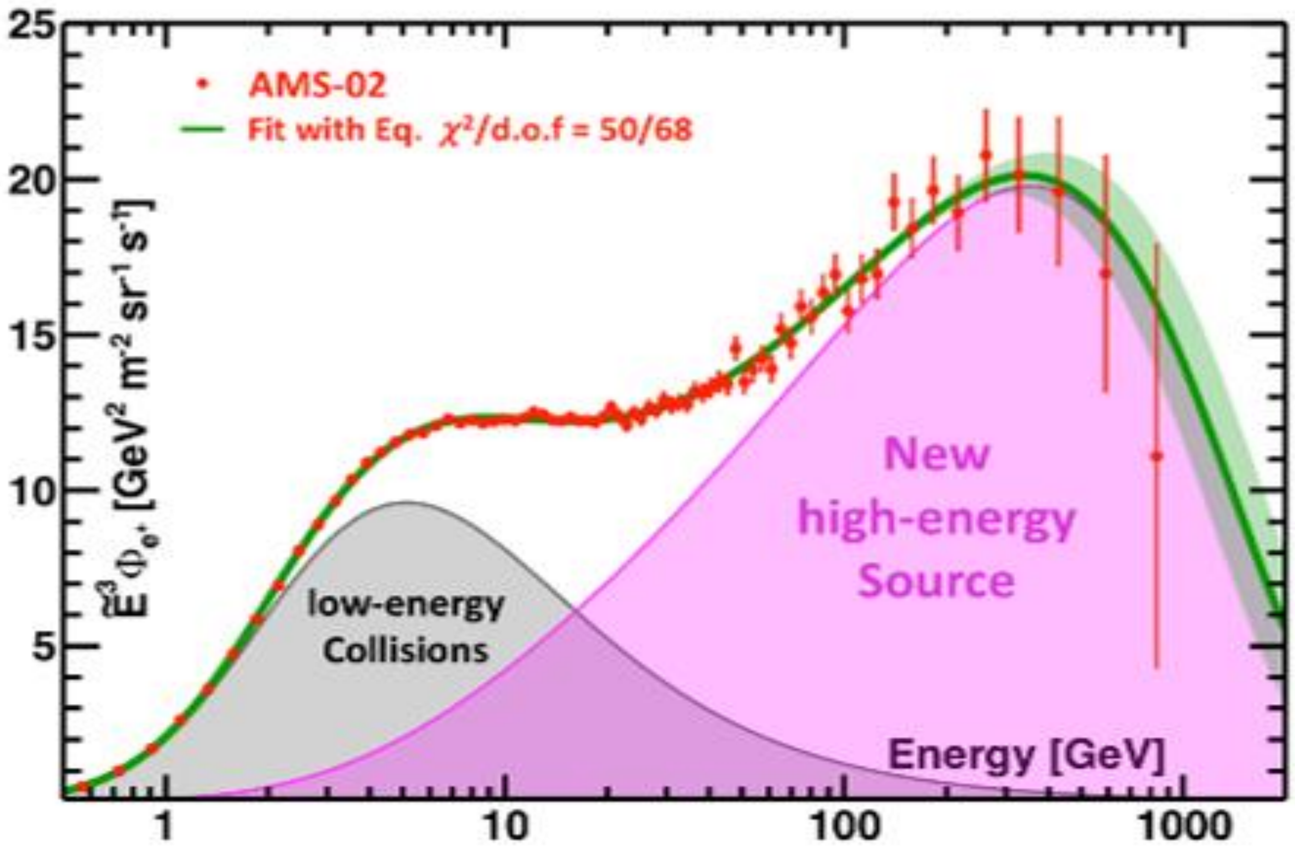

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Possibilities :

- 1) Nearby Pulsars : Geminga, Monogem, B1055-52.

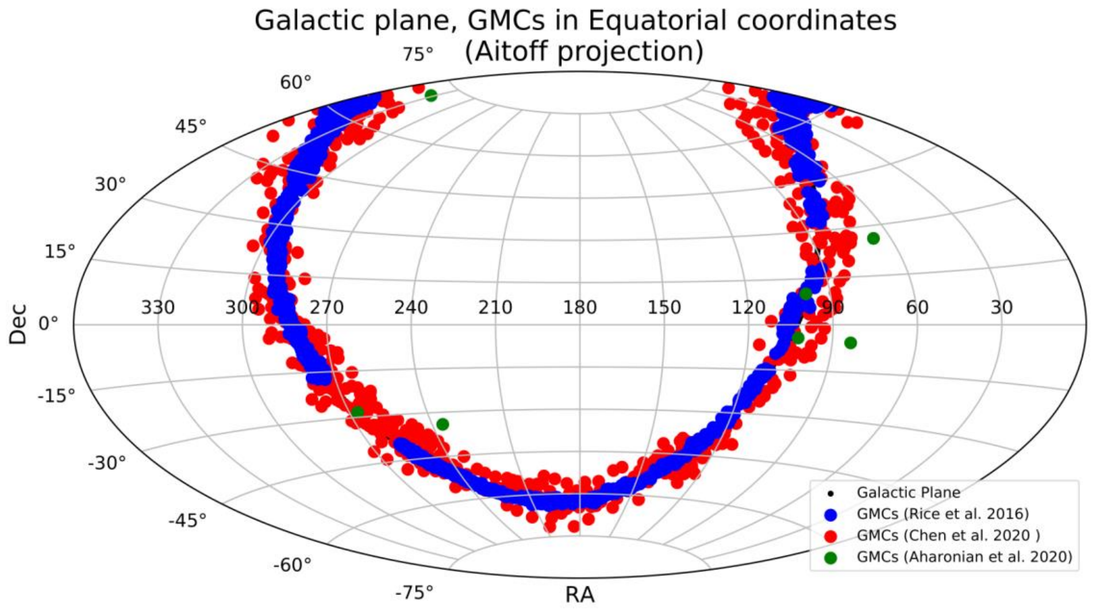
- 2) Dark matter annihilations.

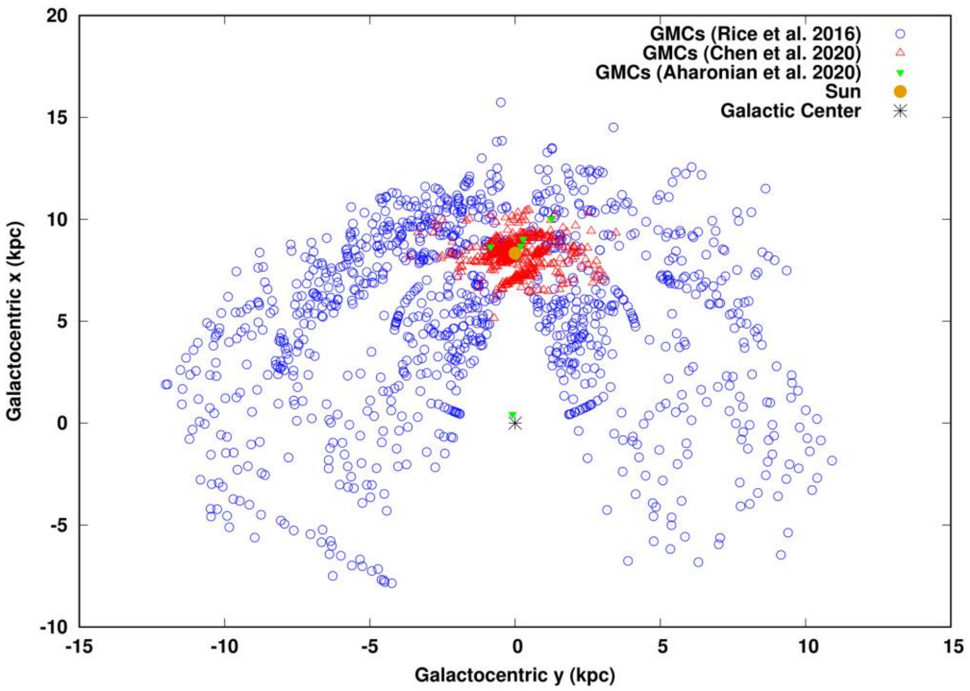
- **3) Alternate scenario : Interactions inside nearby GMCs.**

  3. a) Hadronic interaction inside GMCs

  b) Reacceleration inside GMCs.

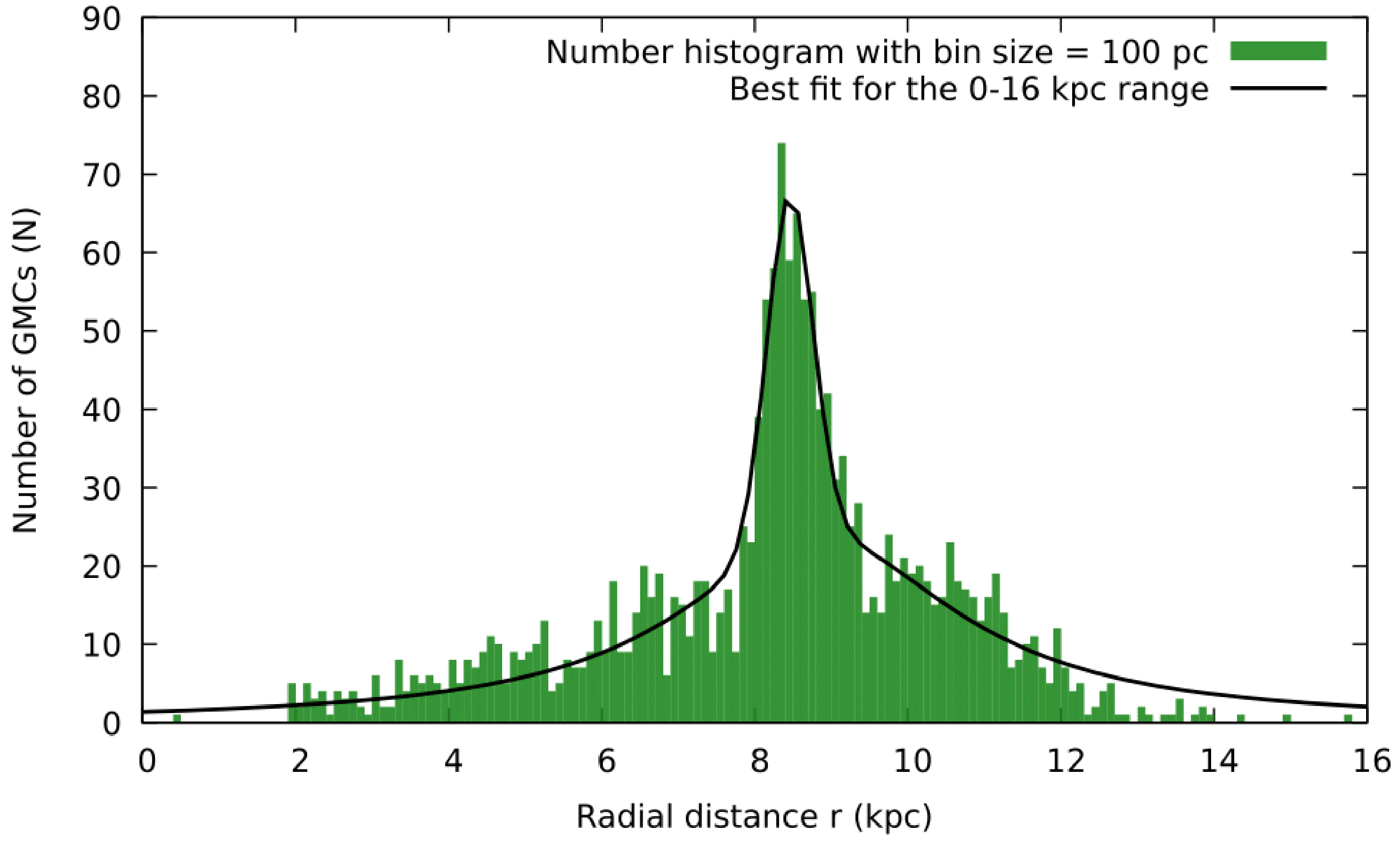
GMC distribution in Milky Way :





1) 1064 GMCs detected from all-Galaxy CO survey, Rice et al ApJ **822** (2016) 52.
2) 567 GMCs detected by optical/NIR dust extinction measurements, Chen et al MNRAS **493** (2020) 351.
3) 7 GMCs analysed using Fermi-LAT data, Aharonian et al PRD **101** (2020) 083018, arXiv : 1811.12118.

Number distribution of GMCs (1) :



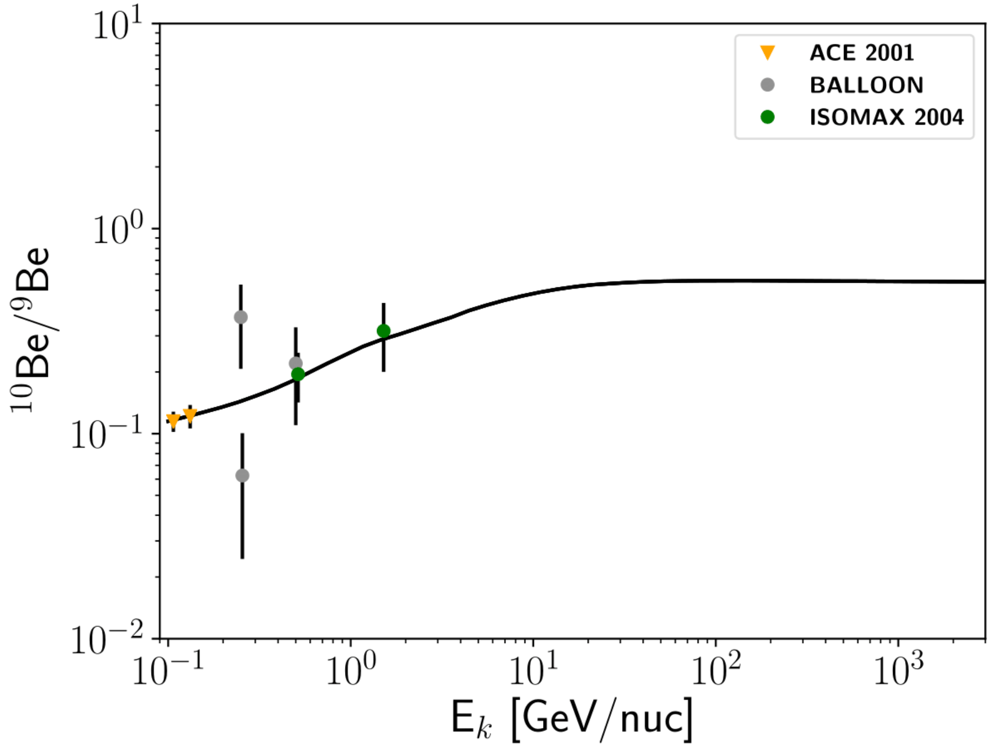
1) HISTOGRAM 1 :
   a) 1064 GMCs (Rice et al 2016)
   b) 567 GMCs (Chen et al 2020)
   c) 7 GMCs (Aharonian et al 2020)

2) Radial number distribution N(r) fitted by Pseudo-Voigt profile i.e.
V(r) = η*G(r) + (1 – η)*L(r), where η ∈ [0, 1]

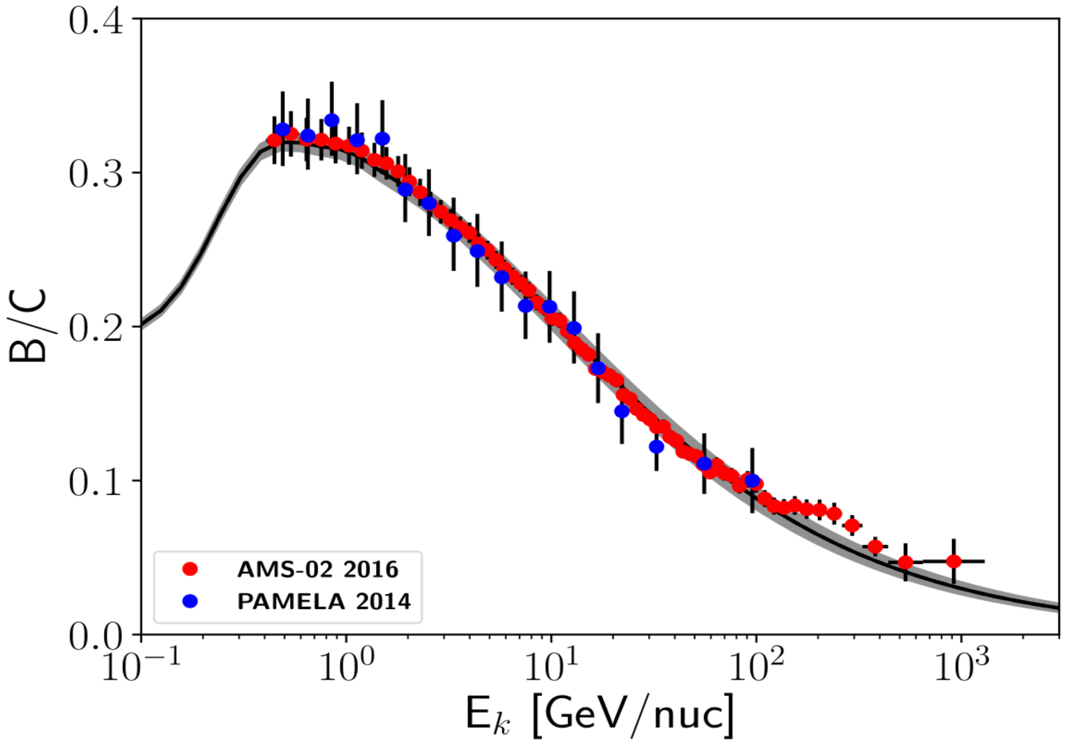
3) $n_{H_2}(r) = < n_{H_2} > \times \left(\frac{N(r)}{N_{Total}}\right)$

4) Used to calculate proton, antiproton spectra & $10_{\mathrm{Be}}/9_{\mathrm{Be}}$, B/C ratios.

DRAGON $10_{\mathrm{Be}}/9_{\mathrm{Be}}$ and B/C ratios fits :



$10_{\mathrm{Be}}/9_{\mathrm{Be}} \propto \sqrt{D(E)}/z_t$



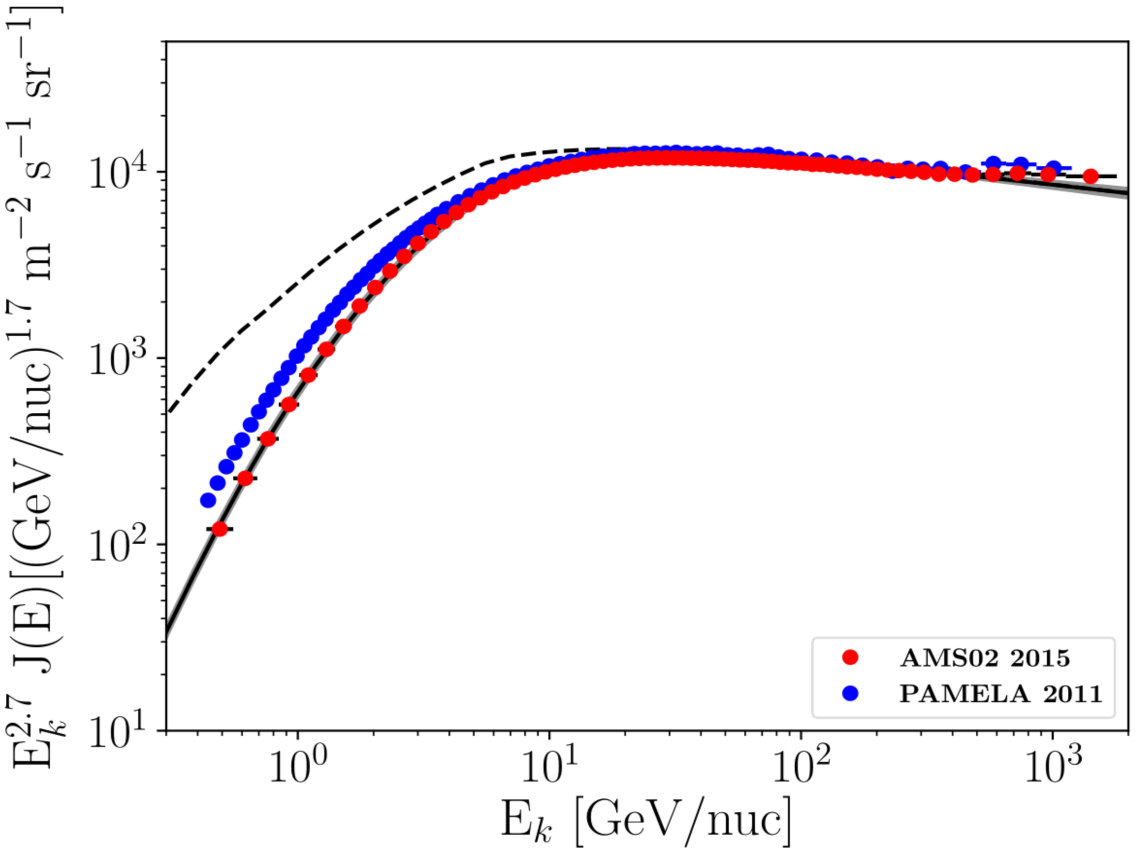
B/C $\propto z_t$/D(E)

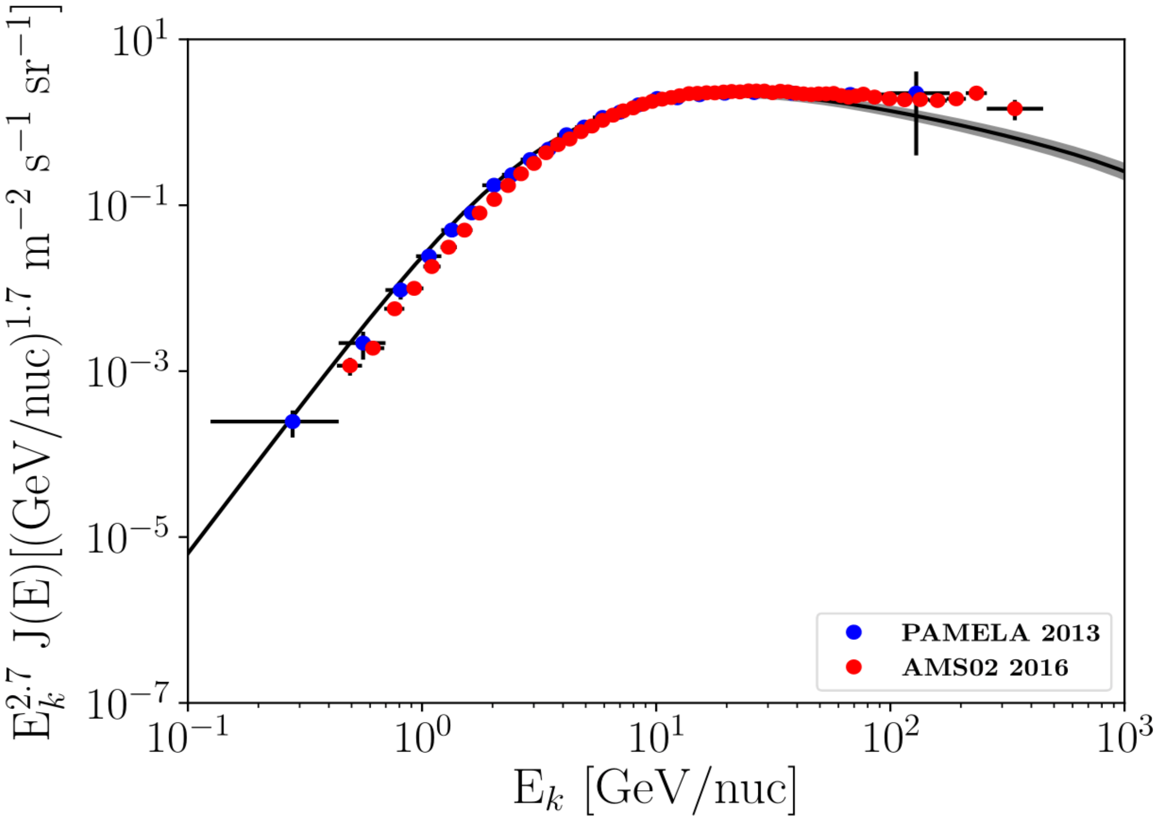
1) Maximum halo height $z_t = 8\ kpc$.

2) Normalisation of diffusion coefficient = D_0 = 2.4 × $10^{29}\ cm^2$/s.

3) δ = 0.53 (close to Kraichnan model).

DRAGON Proton & Antiproton spectra fits :



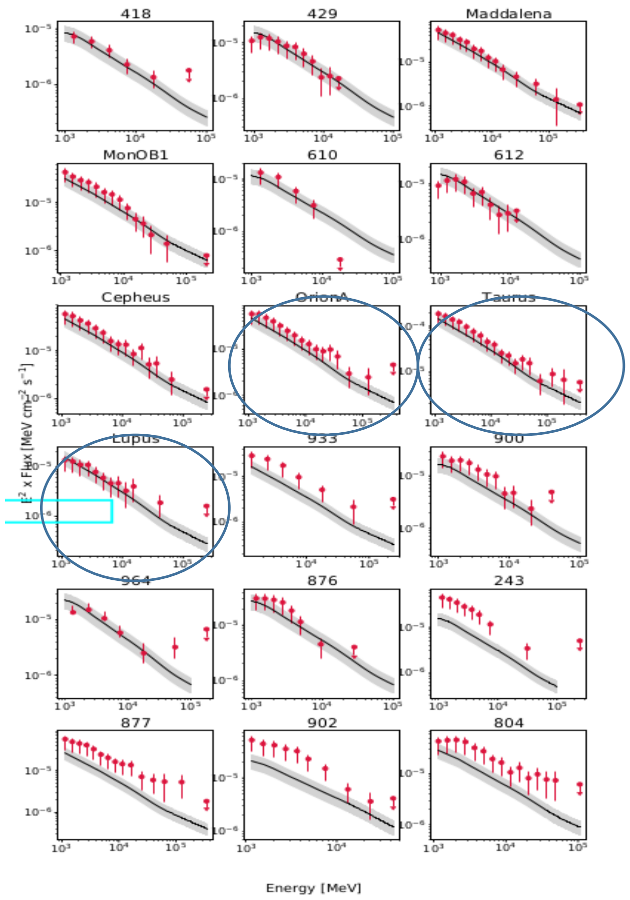


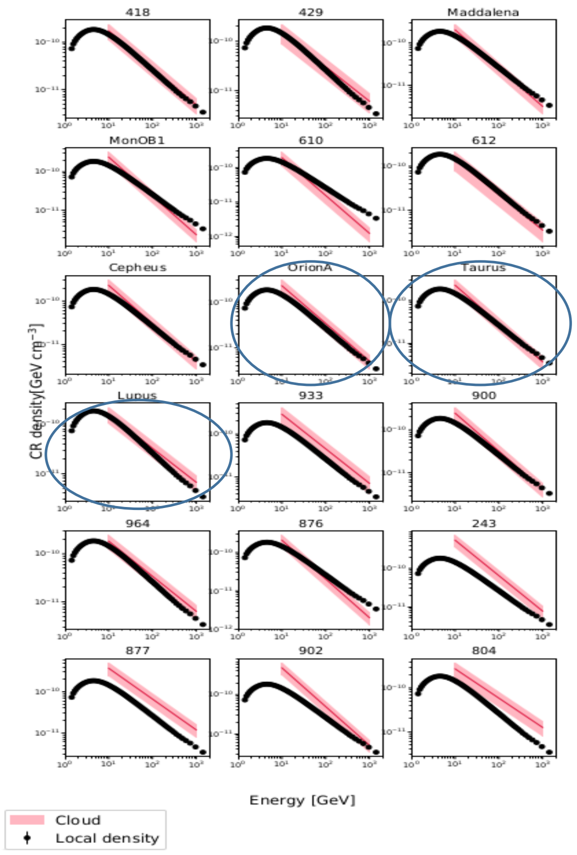
1) Broken power law spectrum for proton (heavy nuclei) injection.

2) The spectral indices : α_1 = 1.95 ; α_2 = 2.33.

3) Spectral break at 7 GV.

Hadronic interaction inside nearby GMCs :





Aharonian et al PRD **101** (2020) 083018, arXiv : 1811.12118

1) Leptons need special treatment : lose energy very fast.

2) Taurus, Lupus & Orion A : three nearest GMCs (< 0.5 kpc), analysed by Fermi-LAT data.

3) Hadronic inelastic pp interaction inside GMCs :

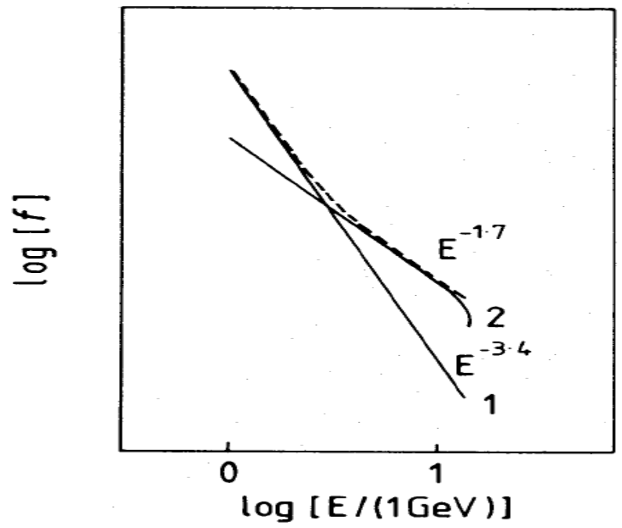
$$p + p \rightarrow \pi_0 \rightarrow \gamma\,\gamma$$
$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$$
$$\mu^{\pm} \rightarrow e^{\pm} + \bar{\nu}_e$$

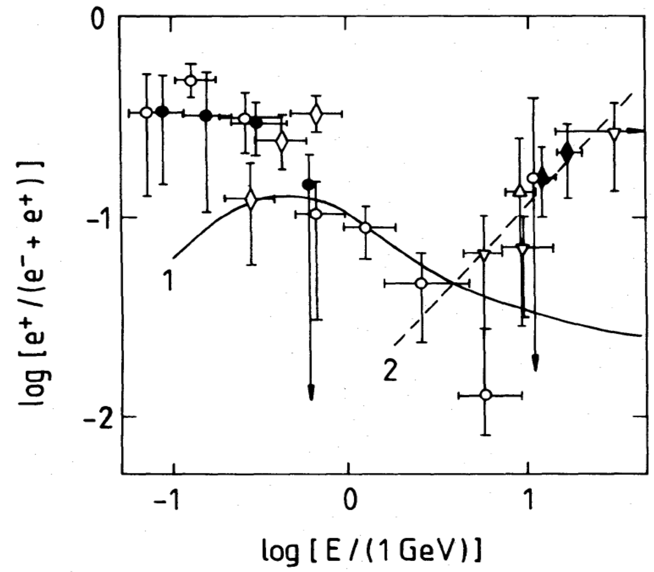
From knowledge of gamma ray emission, parent proton spectrum can be found (given known proton density & interaction cross-section).

4) Injected lepton fluxes were calculated using formalism given in Kelner et al PRD **74** (2006) 034018.

5) Propagated lepton fluxes from three GMCs at Earth were calculated using formalism from Atoyan et al PRD **52** (1995) 3265.

Reacceleration inside nearby GMCs :





1) Theoretically, it is possible that particles inside the GMCs get reaccelerated due to fluctuating EM field (Dogiel et al MNRAS **228** (1987) 843).

2) Gravitational energy ≈ Turbulence energy
   Extra gravitational energy → turbulent energy in the medium → particle energy

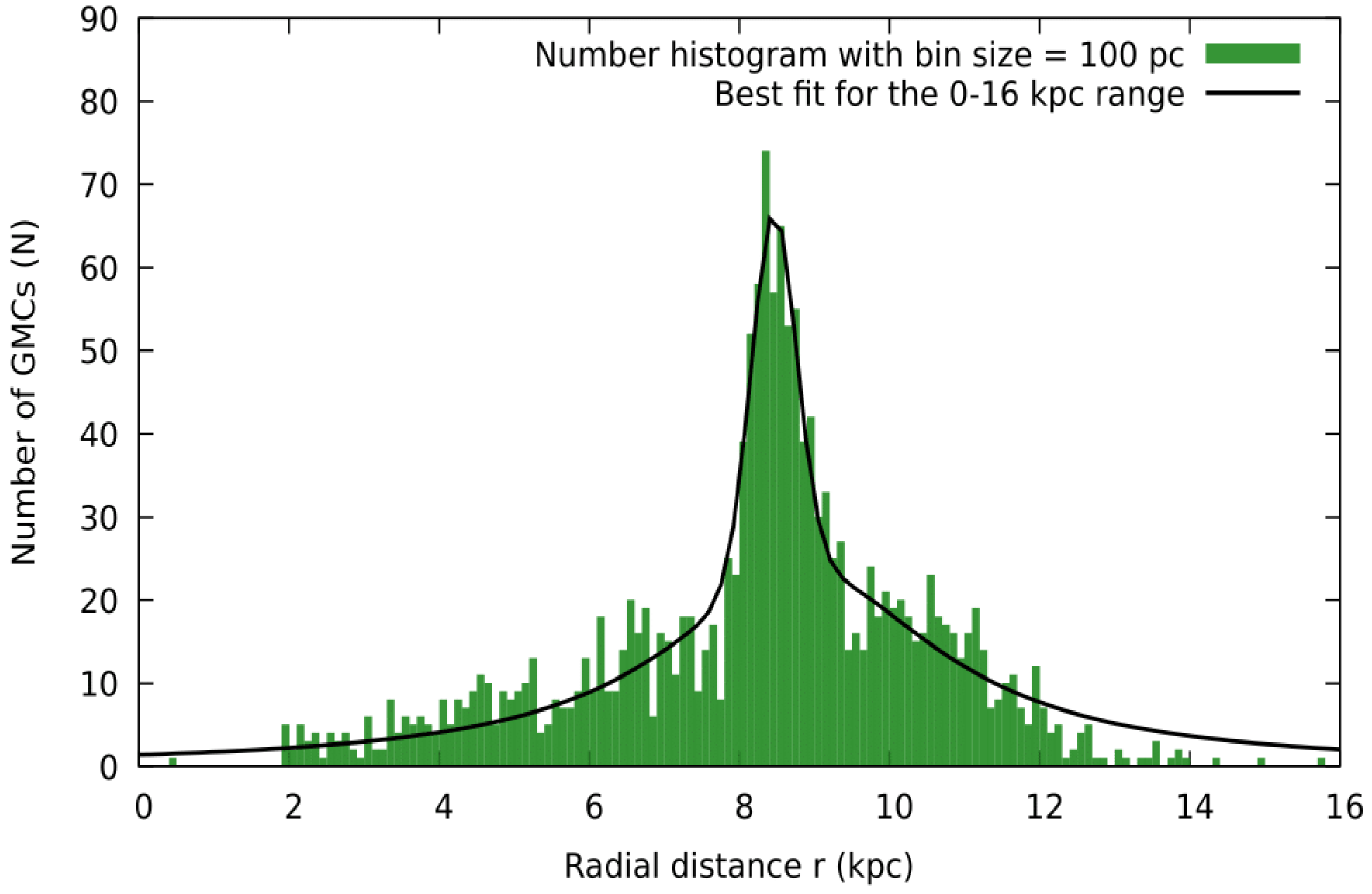
3) Hard injection spectra of injected positrons : $E_{e^+}^{-1.7}$ for E_{e^+} > 1 GeV.

4) Not yet detected, hence three conditions,
   a) Fermi-LAT detection incapability, M_5 / d_{kpc}^2 < 0.2.
   b) Radius greater than 10 pc.
   c) Nearby GMCs, less than 1 kpc from Earth.

5) 7 GMCs were selected from Chen et al 2020. Reacceleration within these GMCs were assumed, with hard lepton injection spectra.

6) Propagated lepton flux observed at Earth was calculated (Atoyan et al PRD **52** (1995) 3265).

Number distribution of GMCs (2) :



1) HISTOGRAM 2 :

a) 1064 GMCs (Rice et al 2016)

b) 560 GMCs (Chen et al 2020)

c) 4 GMCs (Aharonian et al 2020)

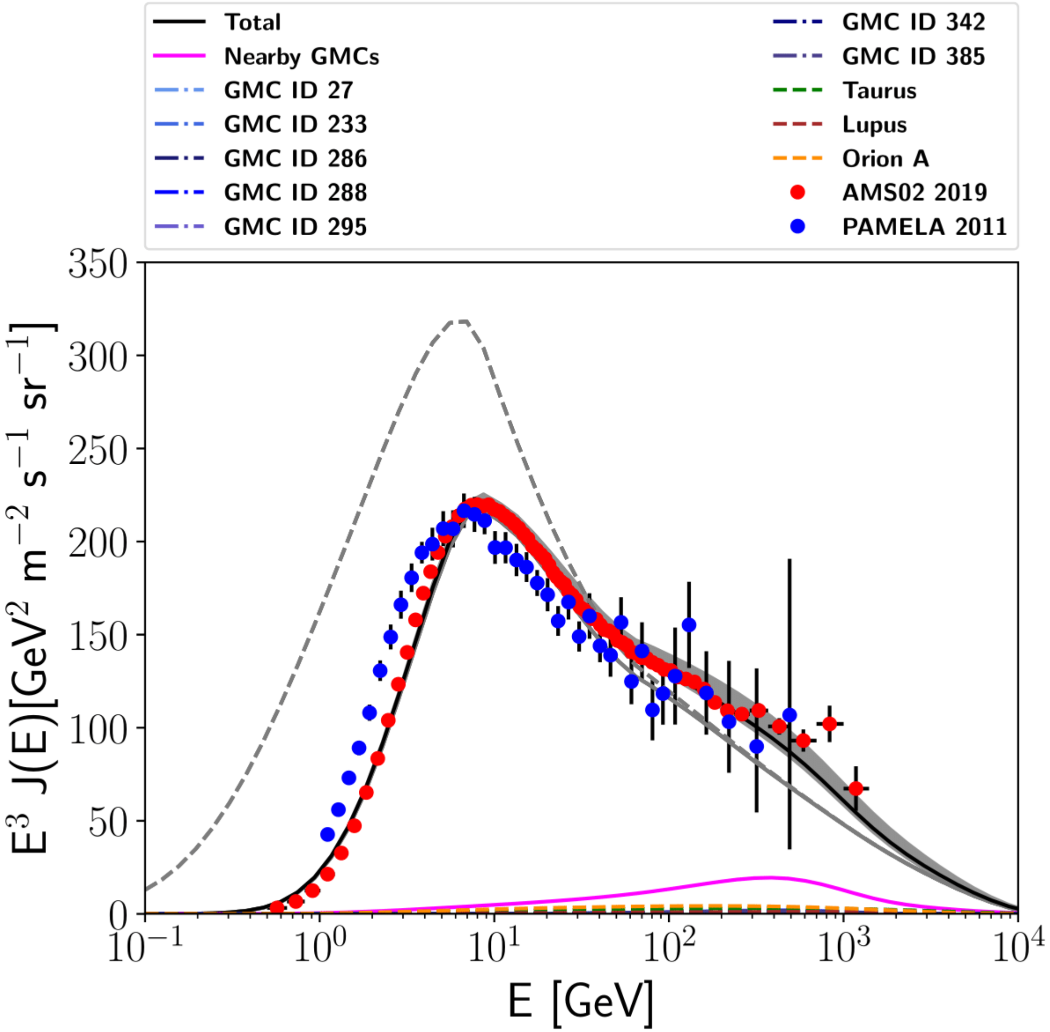
i.e. all GMCs except Taurus, Lupus, Orion A & 7 selected GMCs.

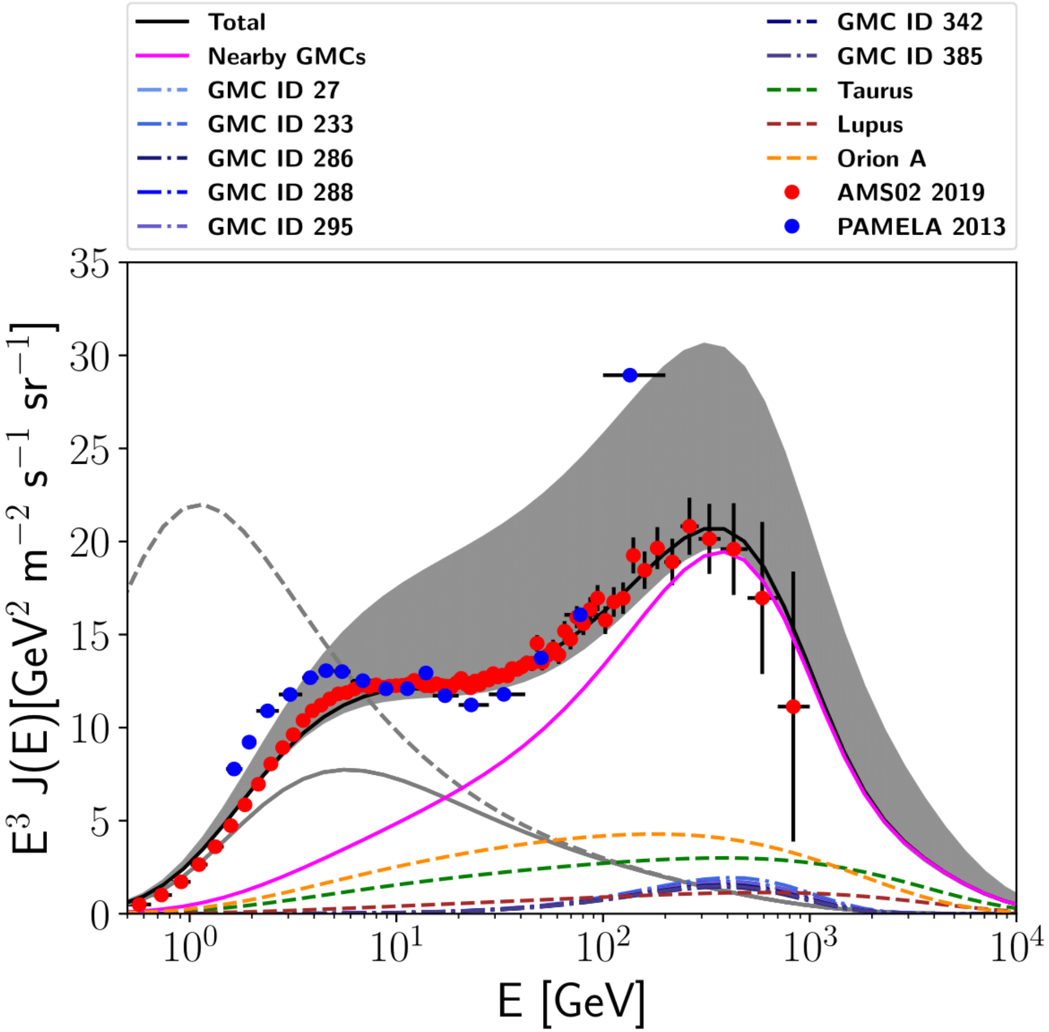
2) Radial number distribution N(r) fitted by Pseudo-Voigt profile i.e.
V(r) = η*G(r) + (1 – η)*L(r), where η ∈ [0, 1]

3) $n_{H_2}(r) = < n_{H_2} > \times \left(\frac{N(r)}{N_{Total}}\right)$

4) Used to calculate electron and positron fluxes.

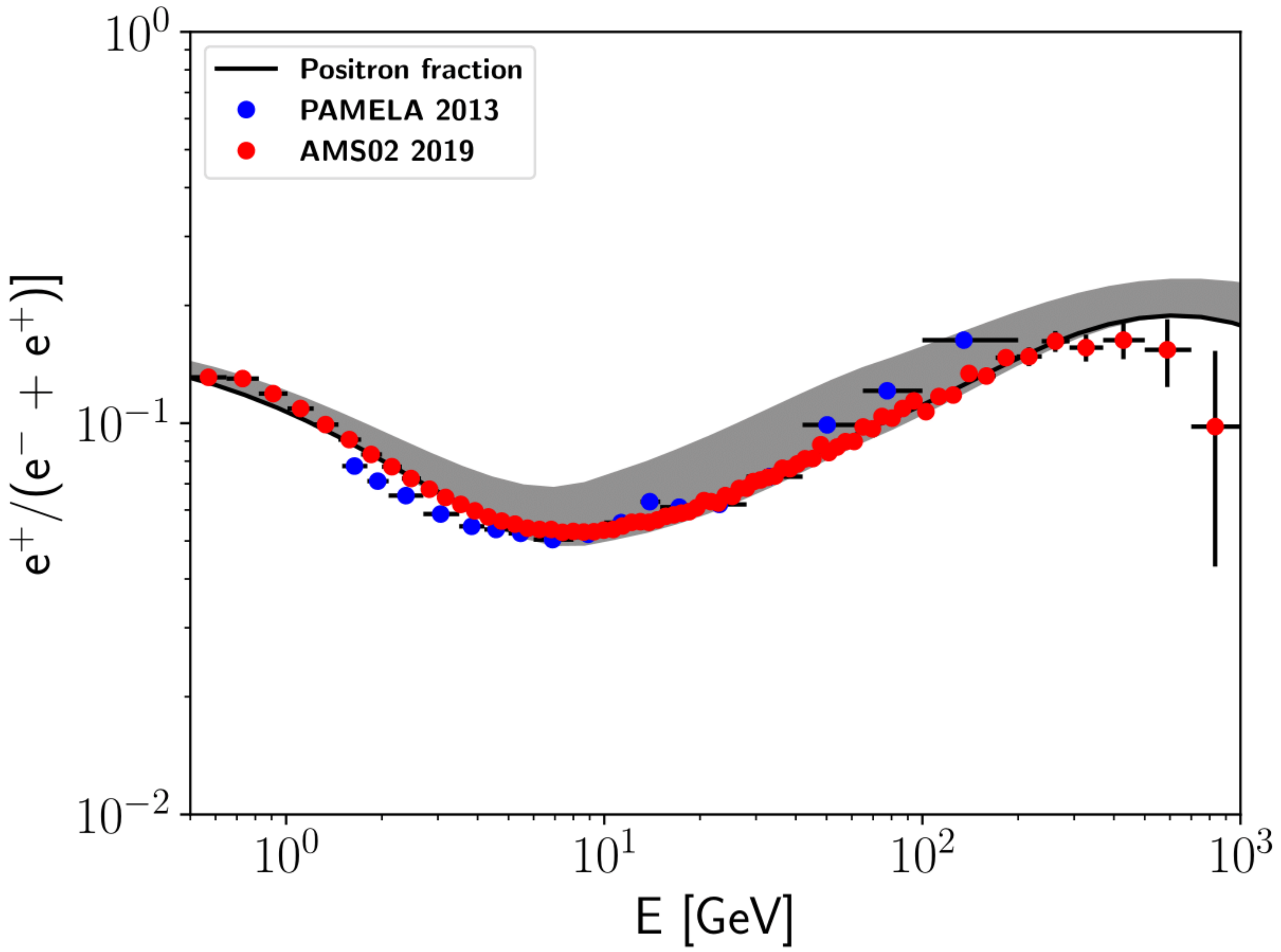
Electron and positron spectra fits :





Broken power law primary electron injection spectrum : spectral indices : α_1^e = 2.0 ; α_2^e = 2.7 ; α_3^e = 2.4, with spectral breaks at 8 GV and 65 GV.

Positron fraction :



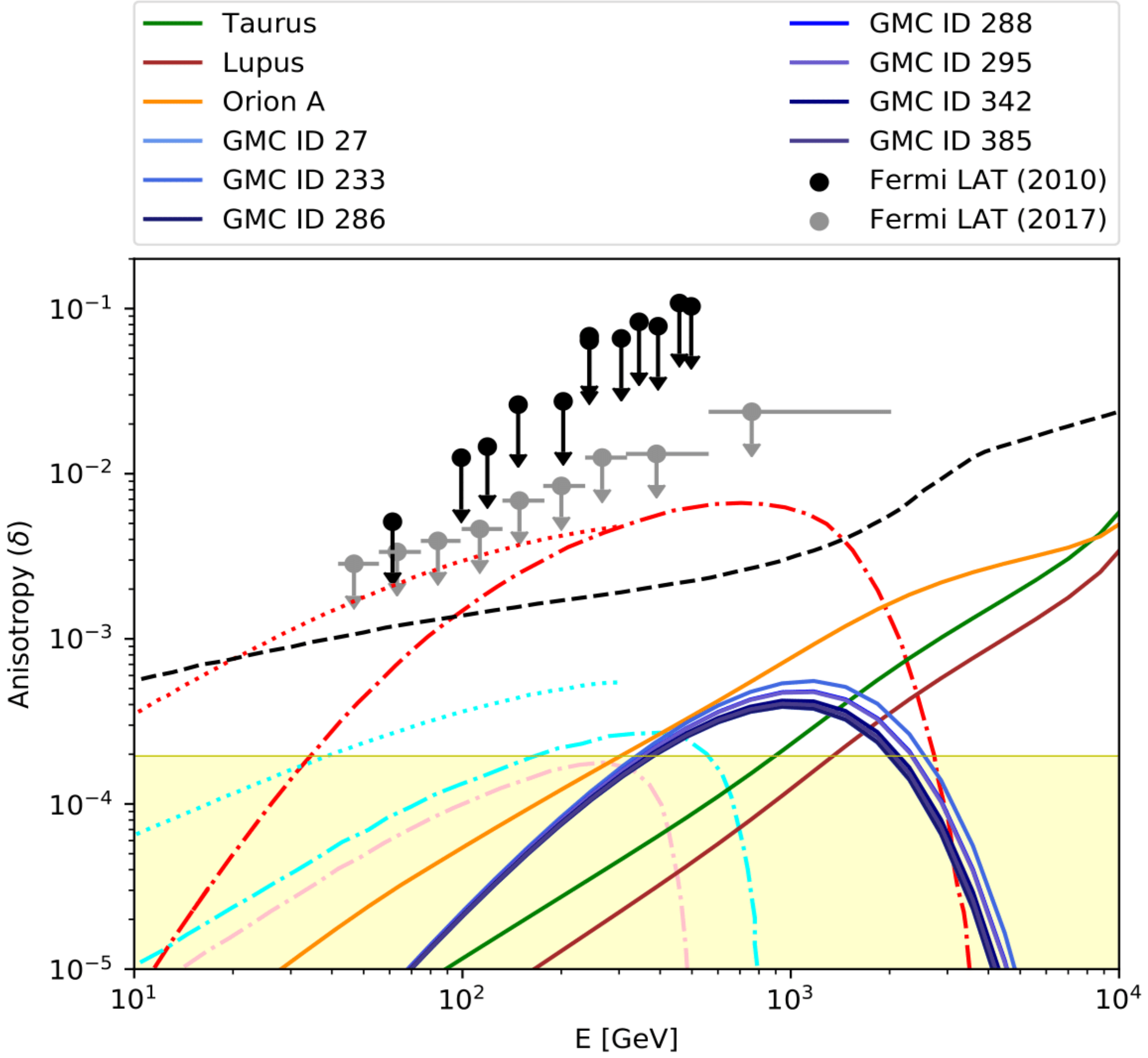
1) Observed lepton fluxes from Taurus, Lupus and Orion A were calculated from parent proton flux.

2) Observed lepton fluxes from 7 selected GMCs were calculated assuming reacceleration due to magnetized turbulence. Injected spectra is hard ($E_e^{-1.7}$).

3) Diffusion parameters, D_0 and δ are kept the same.

4) Total electron luminosity from 7 selected GMCs is a free parameter. The required electron luminosity to fit the data is comparable to Taurus, Lupus or Orion A.

Anisotropy of the nearby GMCs :



1) Anisotropy of GMCs $= {}^{3\,d}/_{2\,c\,t_{\gamma e}} \left(\frac{N^{GMC}_{e^- + e^+}}{N^{Total}_{e^- + e^+}} \right)$.

2) Taurus, Lupus, Orion A or 7 selected GMCs do not violate the Fermi-LAT upper limit of observed anisotropy (Abdollahi PRL **118** (2017) 091103)

3) Yellow region signifies dipole anisotropy detection threshold of Fermi gamma ray telescope. Sources with anisotropy value greater than the threshold, will be detected at 2σ confidence level (Hooper et al JCAP 2009).

4) Monogem, Geminga as well as Taurus, Lupus, Orion A & 7 selected GMCs cross threshold, albeit B1055-52 does not.

5) One can distinguish between GMC and pulsar contribution by the observed anisotropy.

Summary :

- Positron excess is a long-standing anomaly that directly challenges the standard paradigm.
- We have explored an alternate way : Can nearby GMCs contribute to the observed positron excess??? Or even explain it???
- Self – consistent model : explains different CR observables.
- Contribution from nearby GMCs : 1) Hadronic p-p interaction
  2) Reacceleration
- GMCs can contribute to the observed positron excess, or even explain it.
- Signature of cosmic ray excess was detected in Fermi-LAT data analysis of local GMCs (Baghmanyan et al ApJL 901 (2020) L4).