# Untangling the Complexity in the Galactic Centre: a way to understand the origin of the gamma-ray emission from the inner Galaxy

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# OUTLINE

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# Context

The nature of the Very High Energy (VHE)

gamma-ray diffuse emission

in the Galactic Center (GC) region is still unknown

Two main scenarios:

- Local PeVatron
- Inhomogeneous

Galactic CR-sea

→ SMBH (SGR A*)

→ Stellar Wind Cluster

→ Motivated by Fermi-LAT, Milagro, HAWC results

Extrapolation at the GC position of the diffuse emission tuned on local observations

# The Galactic Center Region

- The most interesting regions for high energy astrophysics
- The perfect laboratory for studying phenomena & physical processes may be occur in other galactic nuclei
- CMZ is one of the densest region of the MW
- Thick target for CR hadron collisions
- $M_{\rm gas} \sim 10^5\ M_\odot$
- $\rho_{\rm gas} \sim 10^2\ {\rm cm}^{-2}$
- Extends up to $\sim 250$ pc away from the GC along the GP
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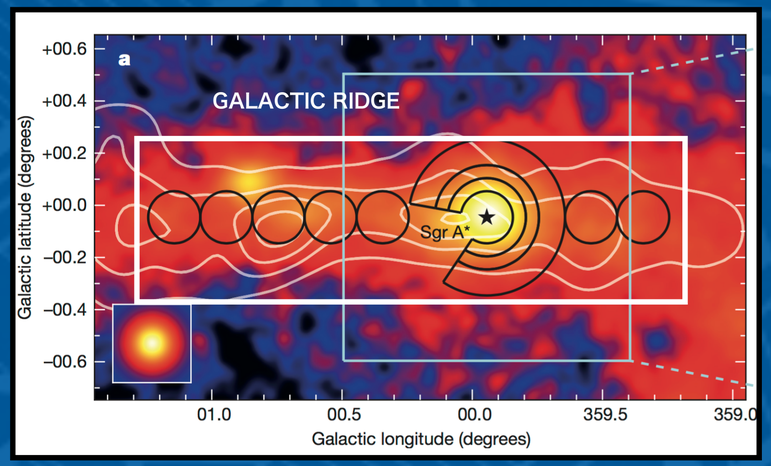
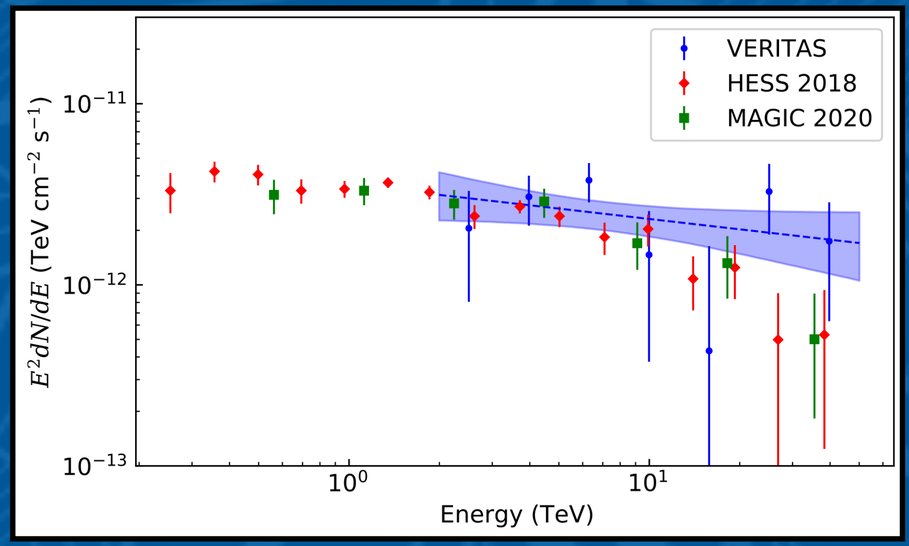
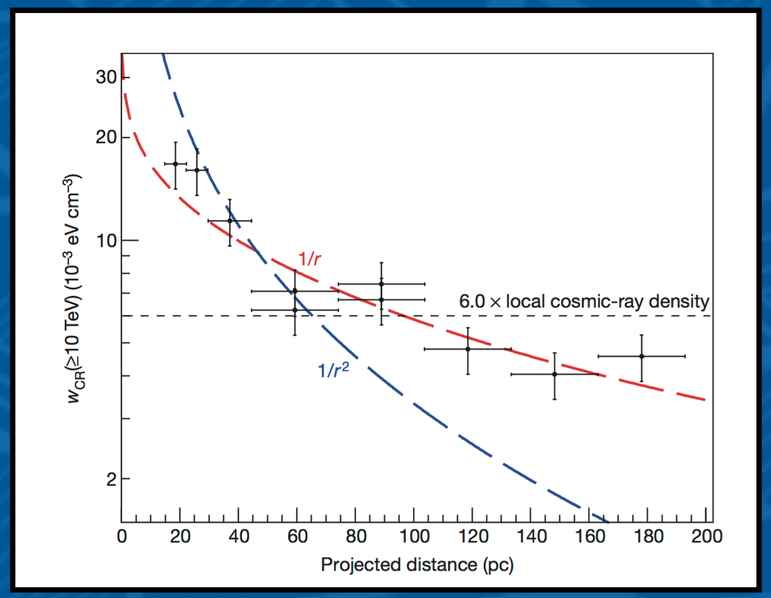
# IACT observations: PeVatron Scenario




- diffuse emission from CMZ correlated with gas distribution
- The observed spectrum is harder ($\Gamma \sim 2.3$, $\Gamma_{\rm Earth} \sim 2.7$)
- Fresh accelerated (hard) CR hadron (PeVatron)




HESS Coll. (2016)




VERITAS Coll. (2021)

Inferred CR density profile consistent with that expected from CR diffusing out stationary source & continuous CRs injection in the CMZ

$$w_{CR}(E,r) = \frac{\dot{Q}_{source}(E)}{4\pi D(E)}\frac{1}{r} \propto E^{-(\Gamma_{source}+\delta)}$$

$$D(E) \propto E^{\delta}$$

# Towards Inhomogeneous CR Diffusion Scenario

Large-scale background detected by Fermi-LAT explained in terms of galactic CR populations (CR-sea) diffusing within the Galaxy

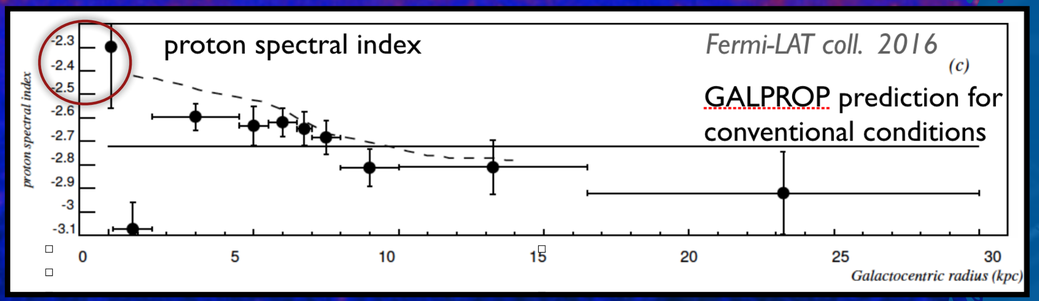
**Gamma Model**

- CRs undergo to inhomogeneous diffusion
- Motivated by several independent analyses of Fermi-LAT data
- Additional hardening at 300 GeV/n (PAMELA, AMS-02, CREAM – Gaggero et al., 2015)

Linear dependence of diffusion coefficient with galactocentric distance & rigidity (Gaggero et al., 2015)

Spectral index of γ-ray diffuse emission increase from $\Gamma \sim 2.8$ to $\Gamma \sim 2.3$ for R decreasingfrom 10 kpc to 0 kpc

Reproduce 15 TeV Milagro anomaly




Acero et al. (2016)

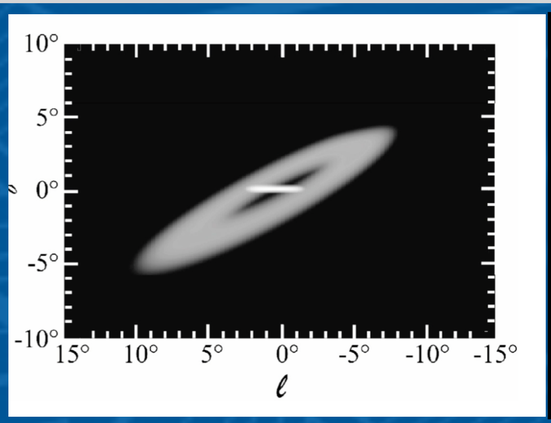
Due to large uncertanities of proton spectral index in the inner galaxy, this hypothesis represents an extrapolation for $R \sim 0$ of the trend between $8 < R < 3$ kpc

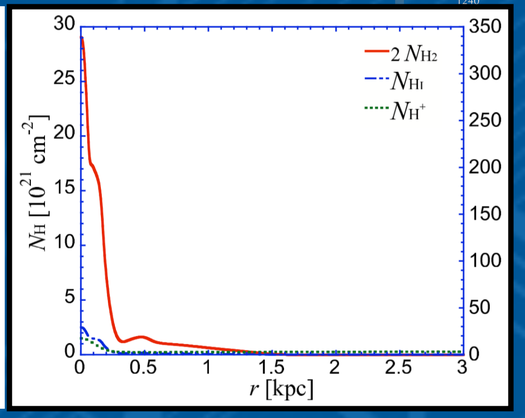
$$D(E) = D_0 \left( \frac{E}{E_0} \right)^{\delta(r)}$$

$$\delta(r) = Ar + B$$

# Models Comparison

- Inner ring ⇒ analytical 3D model gas distribution (smooth w/o cluds)
- 4 models comparison:
  - I. Gamma model: radial depedence diffusion coefficient, hardening at 300 GeV
  - II. Gamma model w/o hardening at 300 GeV
  - III. Base model: constant diffusion coefficient, hardening at 300 GeV
  - IV. Conventional model: constant diffusion coefficient w/o hardening at 300 GeV

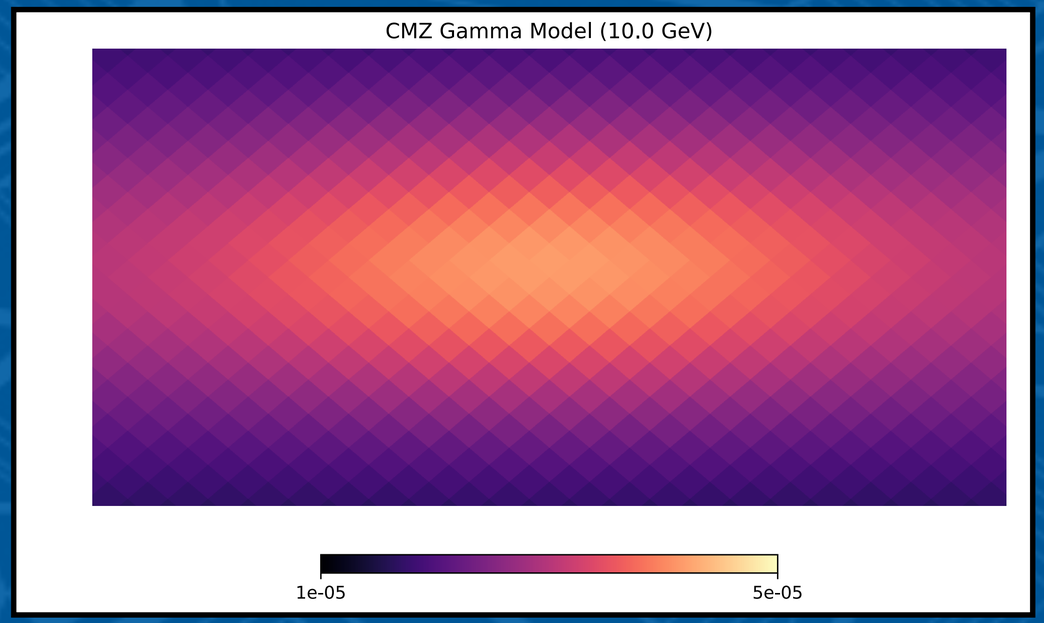


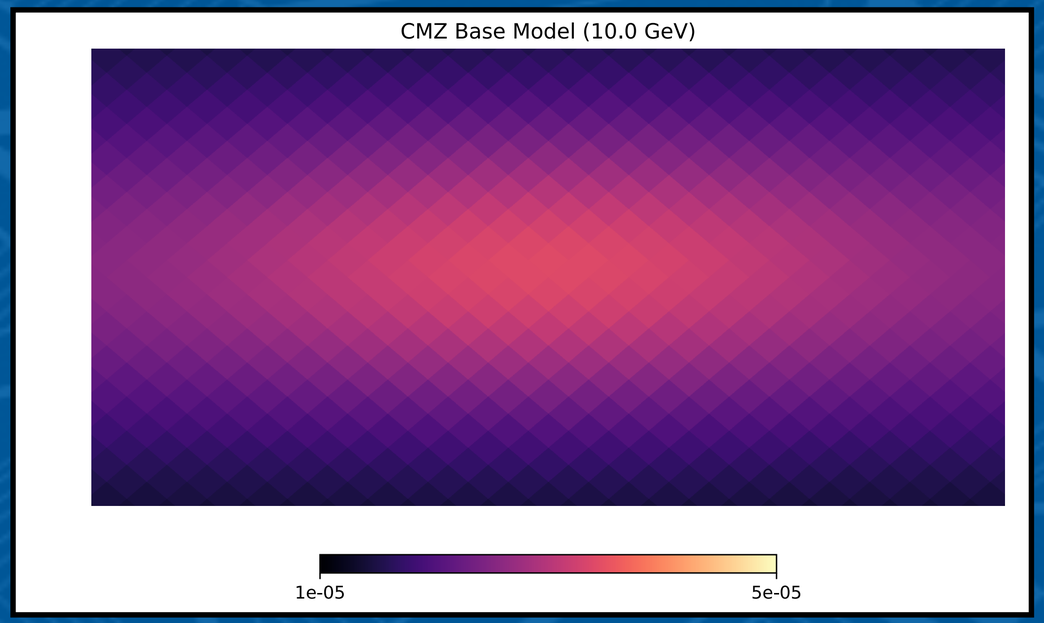



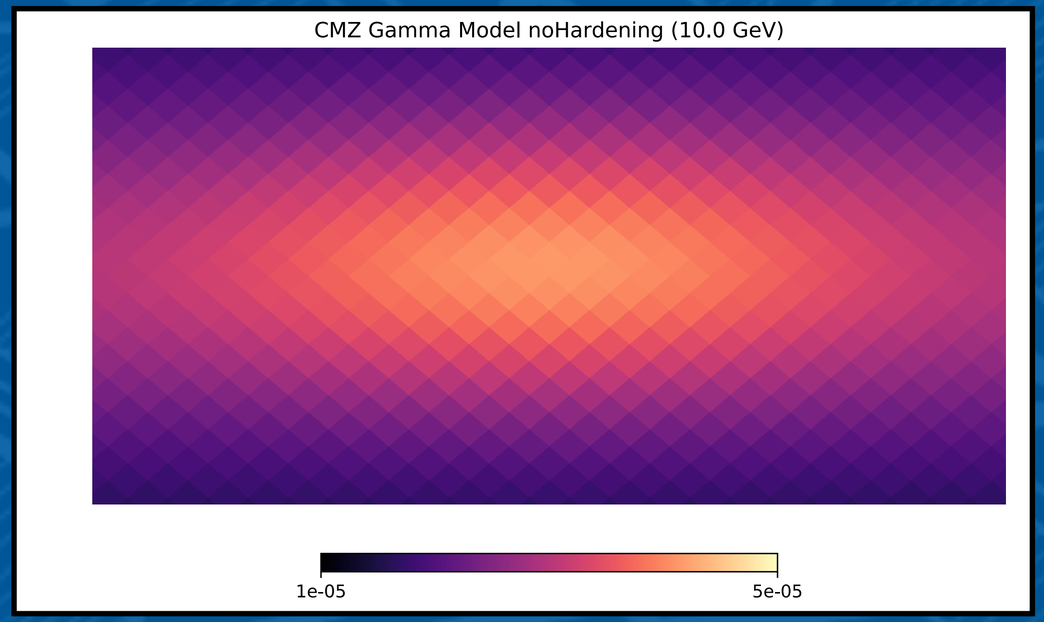

Ferriere et al. (2007)

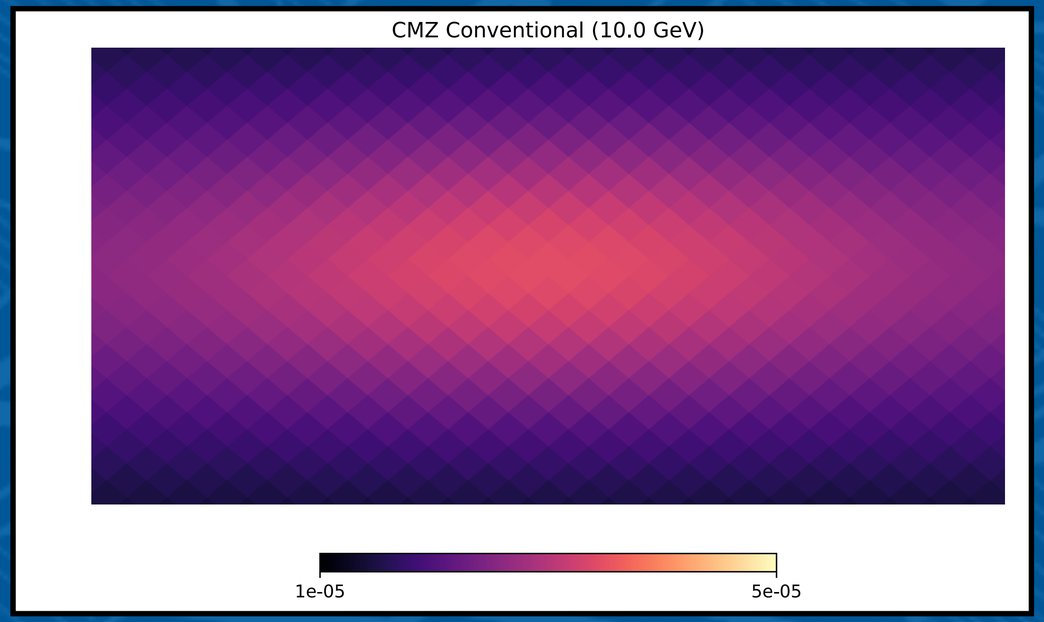
DRAGON code to compute CR distribution
GAMMASKY to perform integration along the line-of-sight

# Results: Models Comparison



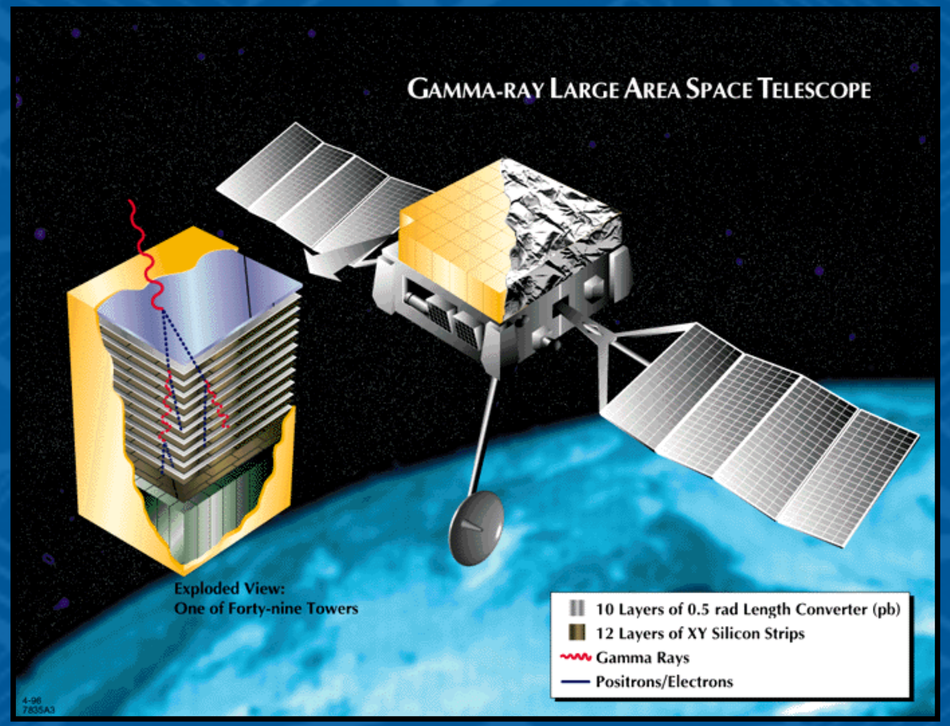



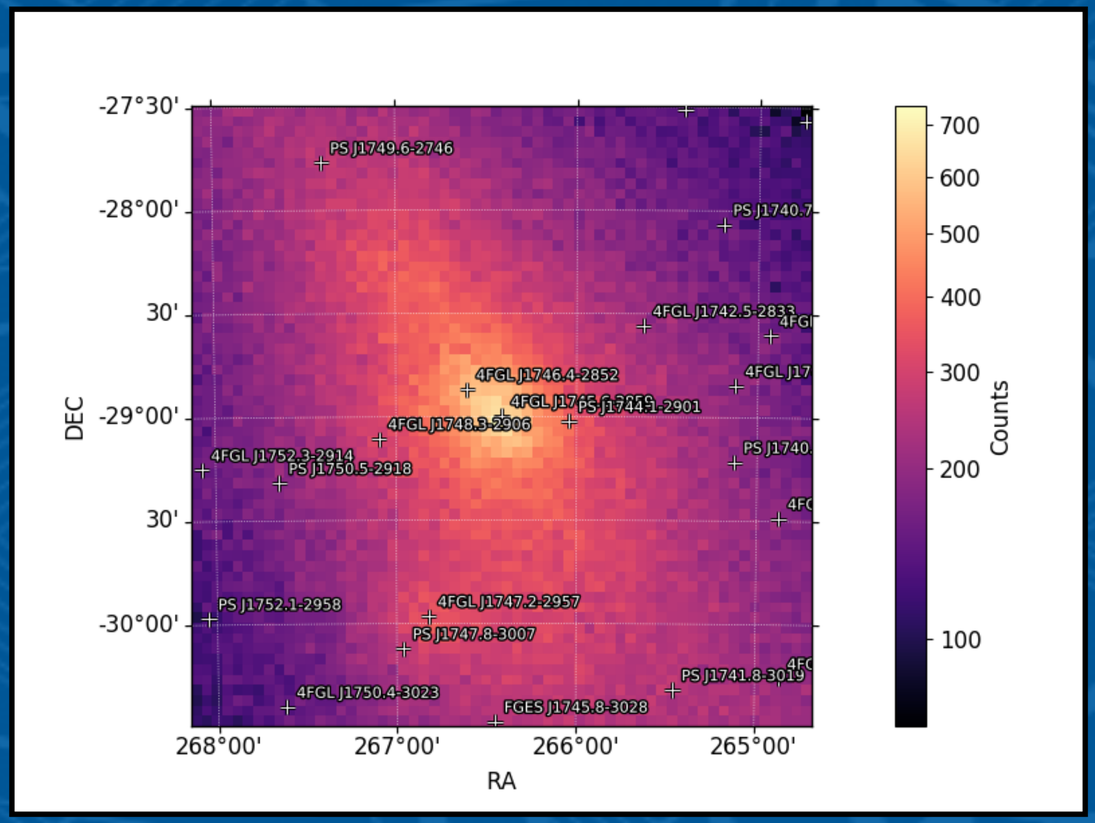



# Results: Fermi-LAT Analysis

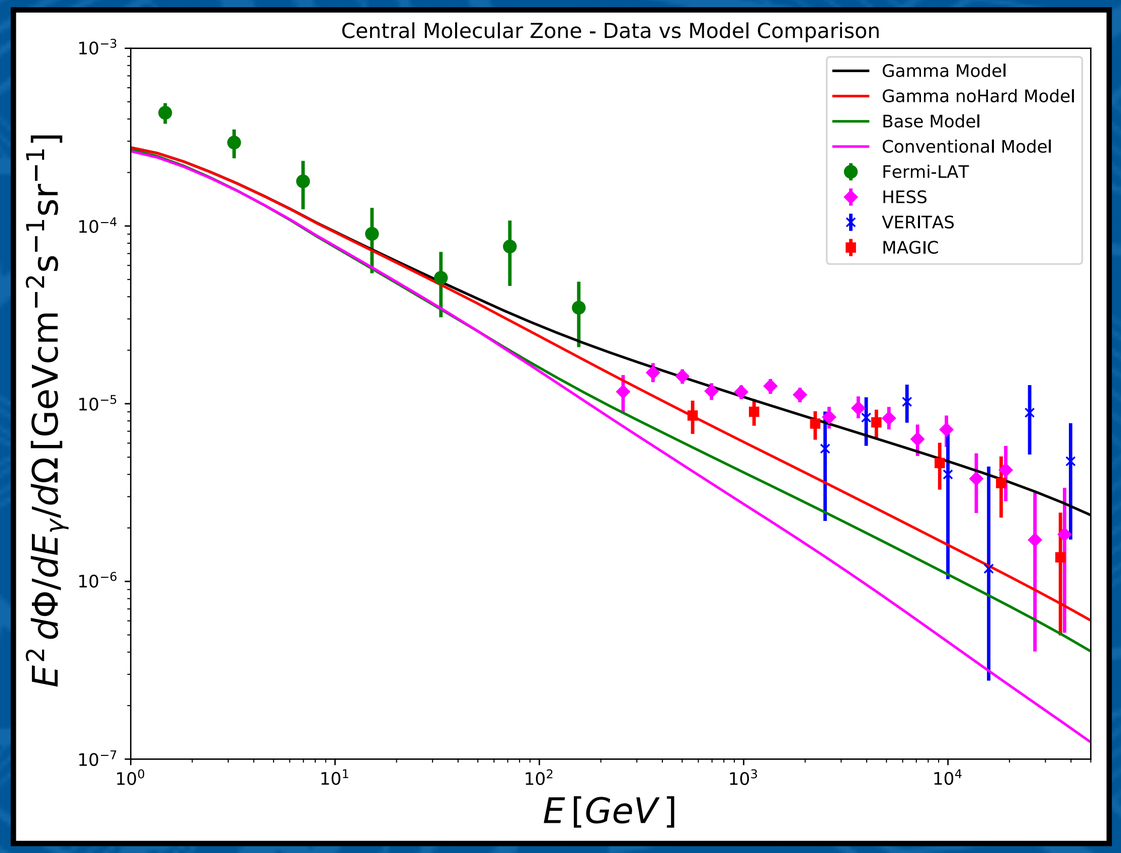
- Fermi-LAT analysis ~ 10 yr
- 4FGL catalog
- P8R3_CLEAN_V2
- iso_CLEAN_V2

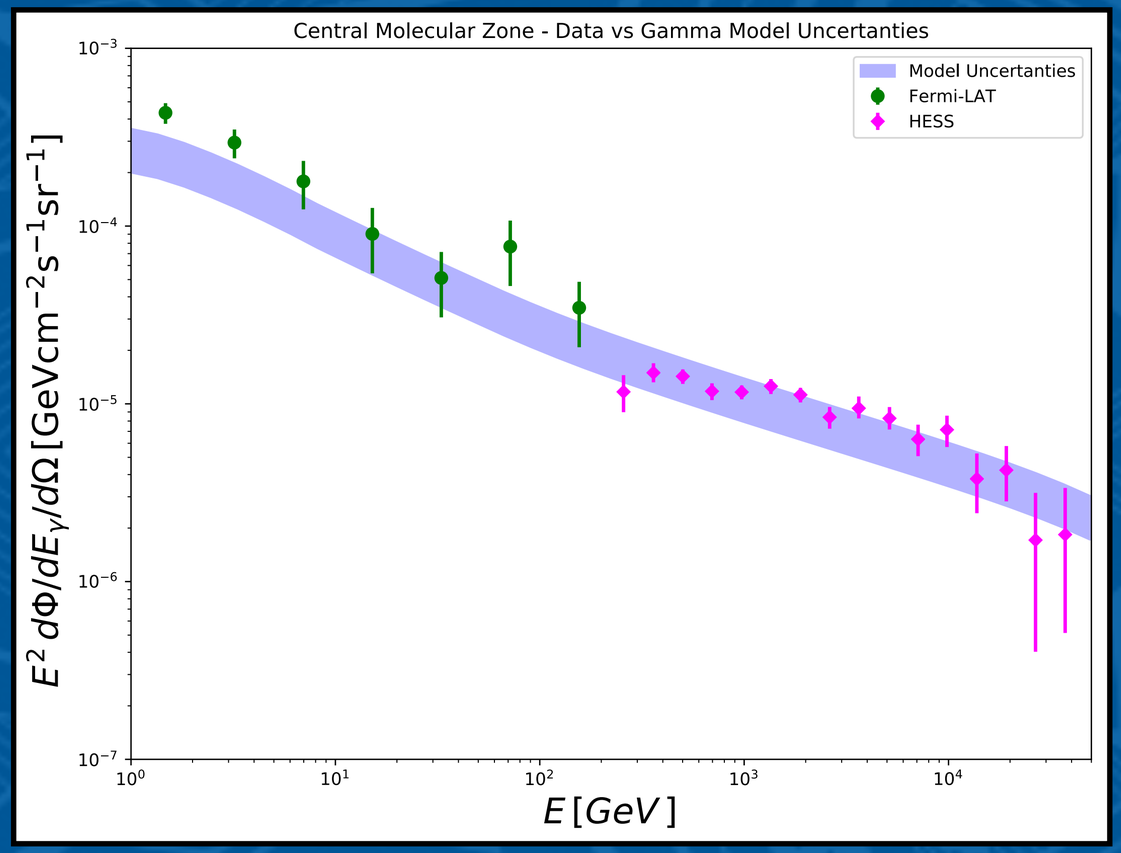



HEASARC

# Results: Spectrum



# Conclusions

- The γ-ray emission from CMZ measured by IACTs & Fermi-LAT (few GeV ÷ 50 TeV) may be originated by Galactic CR-sea undergoes inhomogeneous diffusion ⇒ producing harder spectrum in GC because of dense molecular clouds filling the region
- Uncertainties on gas density distribution & dynamical description of inner Galaxy does not allow definitive conclusions
- At higher energies contribution of diffuse emission is highly depedent to CR transport parameter variations
- Molecular clouds reside farther from the GC (within the 1 kpc) may be the ideal targets to discriminate between the PeVatron & hard diffusion scenario (Ventura, 2018, Ventura et al., 2019)
- Cherenkov Telescope Array (CTA) with increased sensitiviy & anguluar resolution may lead to definitive conclusions

**FUTURE STEPS**

- Realistic 3D gas distribution maps
- Recently released DRAGON2 & HERMES codes
- Updated Gamma Model
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