The role of the Galactic Centre region at TeV energies: a study of diffuse emission phenomenological models

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TeVPA 2023 – September 13, 2023

OUTLINE

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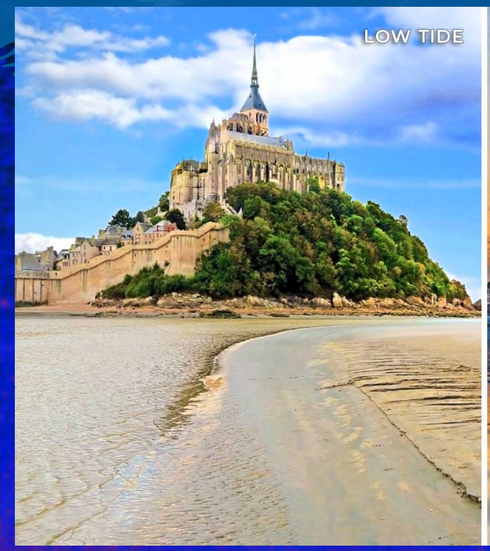
- Towards Inhomogeneous CR Diffusion Scenario
- The Galactic Center Region
- IACTs observations: PeVatron Scenario
- Models Comparsion
- Results
- Conclusions & Applications

Context

EGRET

Fermi-LAT

Observation of γ-ray diffuse emission ⇒ large-scale background emission expecially along the GP



It is crucial to not under/over estimate the galactic diffuse large-scale background emission

building icreasingly realistic large-scale background models

Context

The nature of the Very High Energy (VHE)

gamma-ray diffuse emission

in the Galactic Center (GC) region is still unknown & debated

Two main scenarios:

- **Local PeVatron**
- **Inhomogeneous Galactic CR-sea**

→ **SMBH (SGR A*)**
Unknown population of SNRs,
PWNe & Stellar Wind Cluster

→ **Motivated by Fermi-LAT, Milagro, HAWC, Tibet ASγ, LHAASO results**

↓

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

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

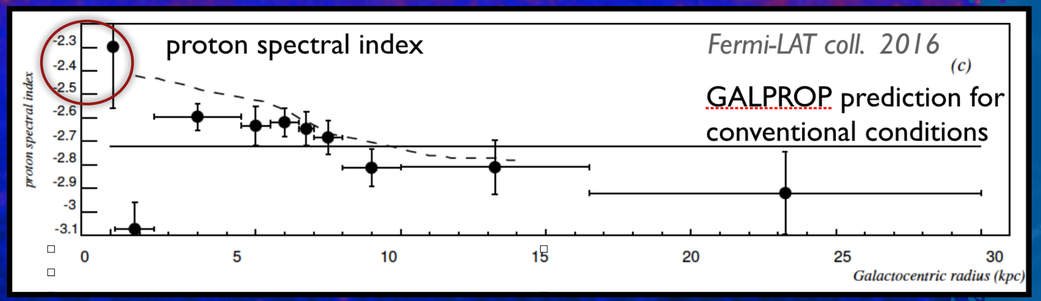
Gamma Model

- 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 decreasing** from 10 kpc to 0 kpc

Reproduce 15 TeV **Milagro anomaly**



Acero et al. (2016)

Due to large uncertainties 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

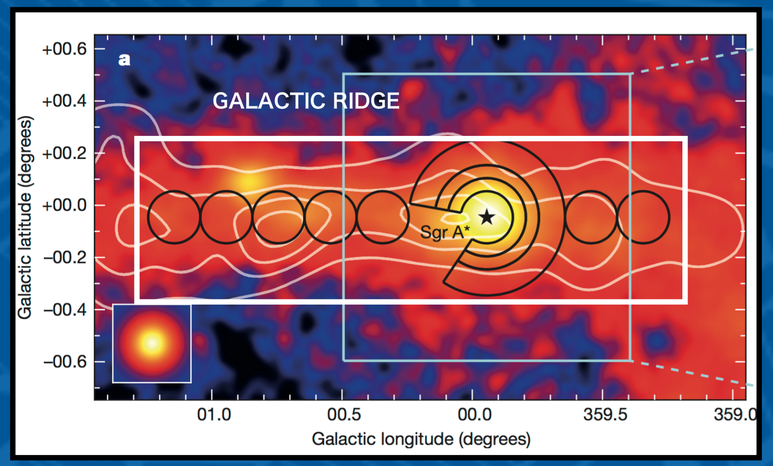
$$D(E) = D_0 \left(\frac{E}{E_0} \right)^{\delta(r)}$$

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

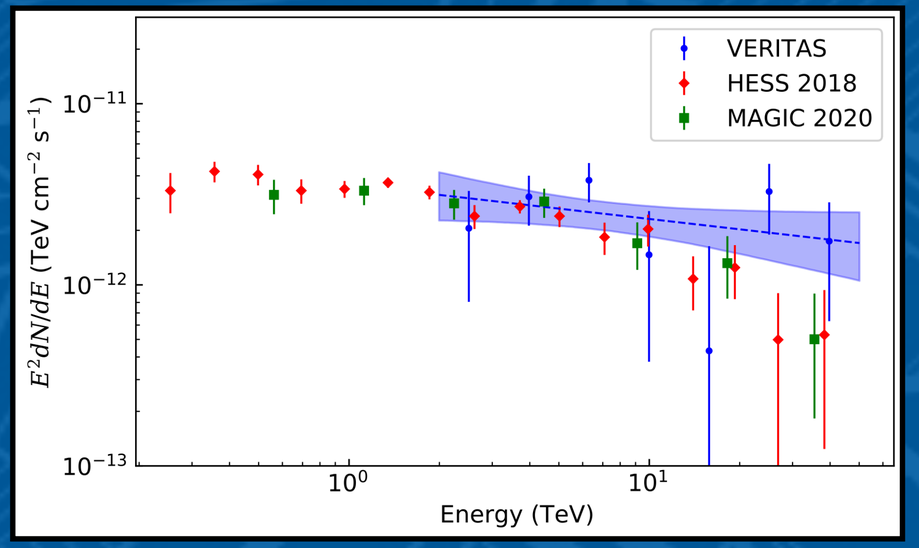
The Galactic Center Region

- One of the most interesting regions for the astroparticle physics & 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
- $M_{\rm gas} \sim 3 \cdot 10^7\ M_\odot$ inner 150 pc
- $N_{\rm H_2} \sim 10^3\ {\rm cm}^{-3}$
- Extends up to ~ 250 pc away from the GC along the GP

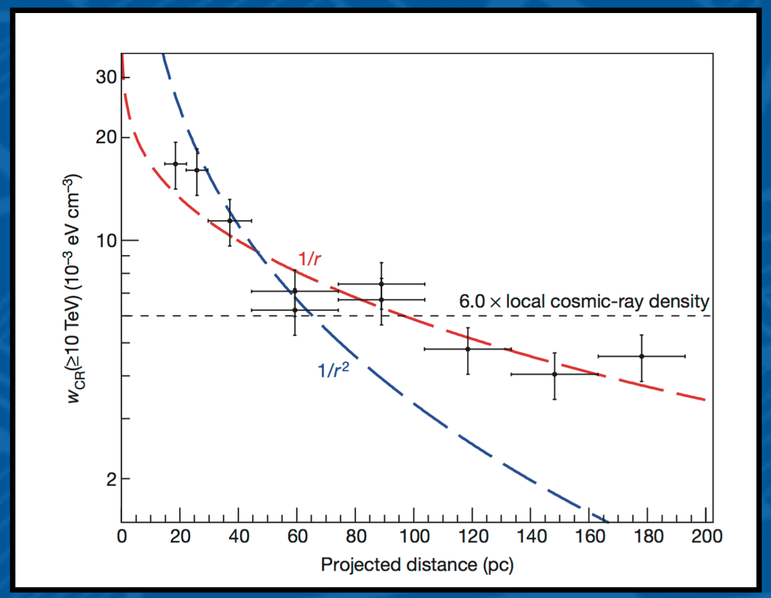
IACT observations: PeVatron Scenario



- 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)



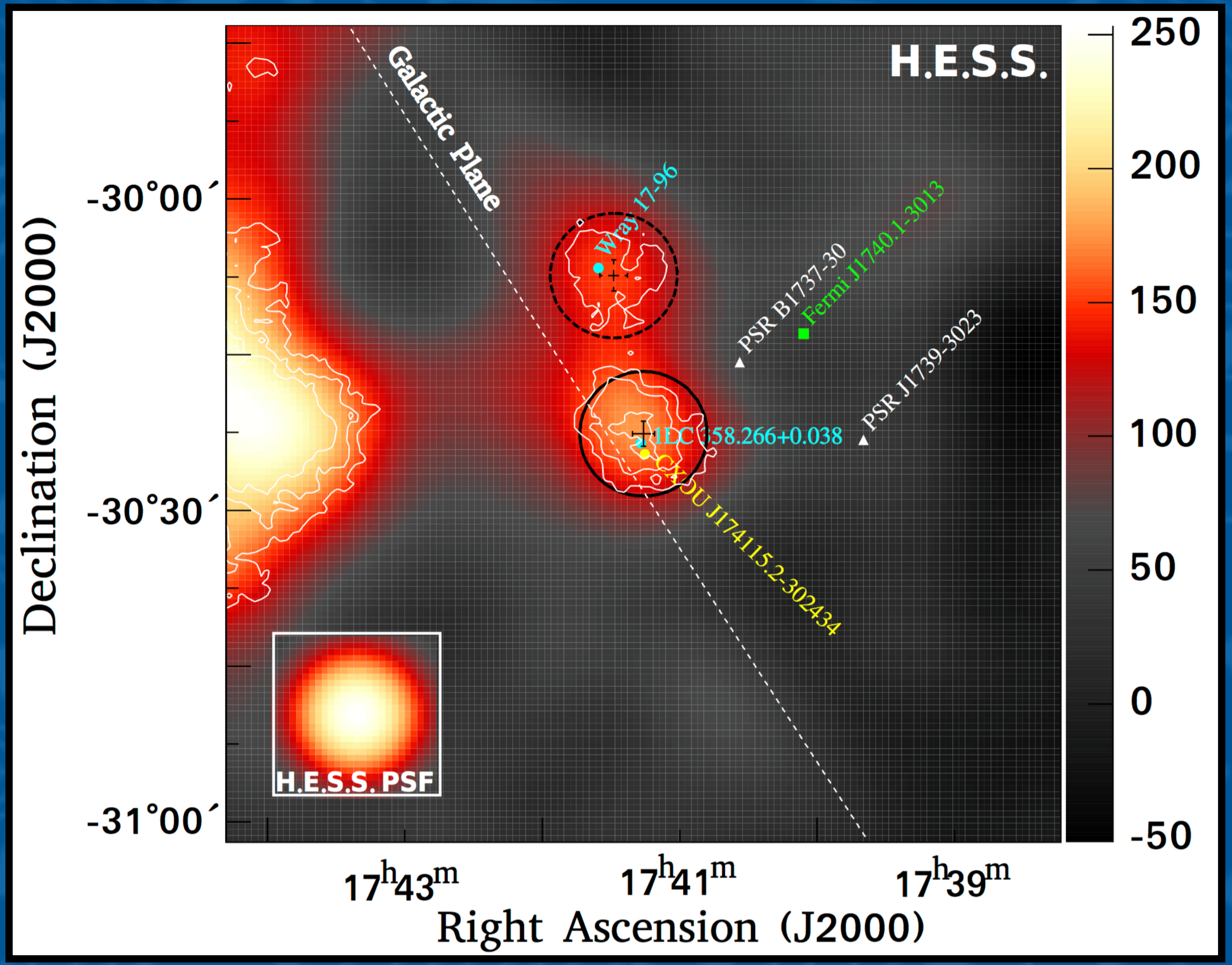
VERITAS Coll. (2021)

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

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

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

HESS J1741−302



H.E.S.S. Collab. (2018)

$$M = 6.8 \cdot 10^4\ M_\odot$$

$$l = -1.7° \ ; \ d \sim 260 \text{ pc}$$

$$\Gamma \sim 2.3$$

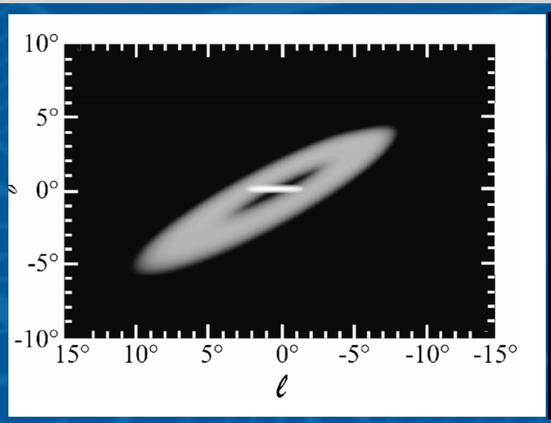
The energy spectrum extends up to 10 TeV with no evidence of a cutoff

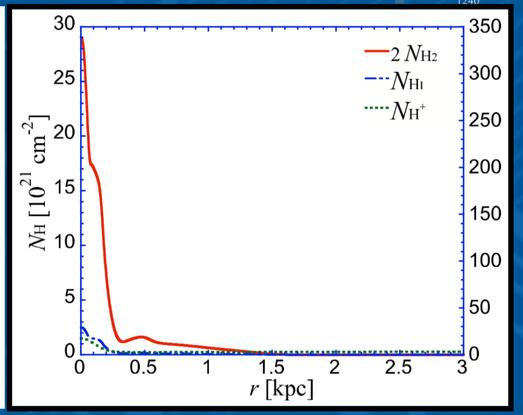
The source is a natural target to probe how/if the CR population properties change with R

Hadronic scenario favored
Active or passive source?

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/0 hardening at 300 GeV

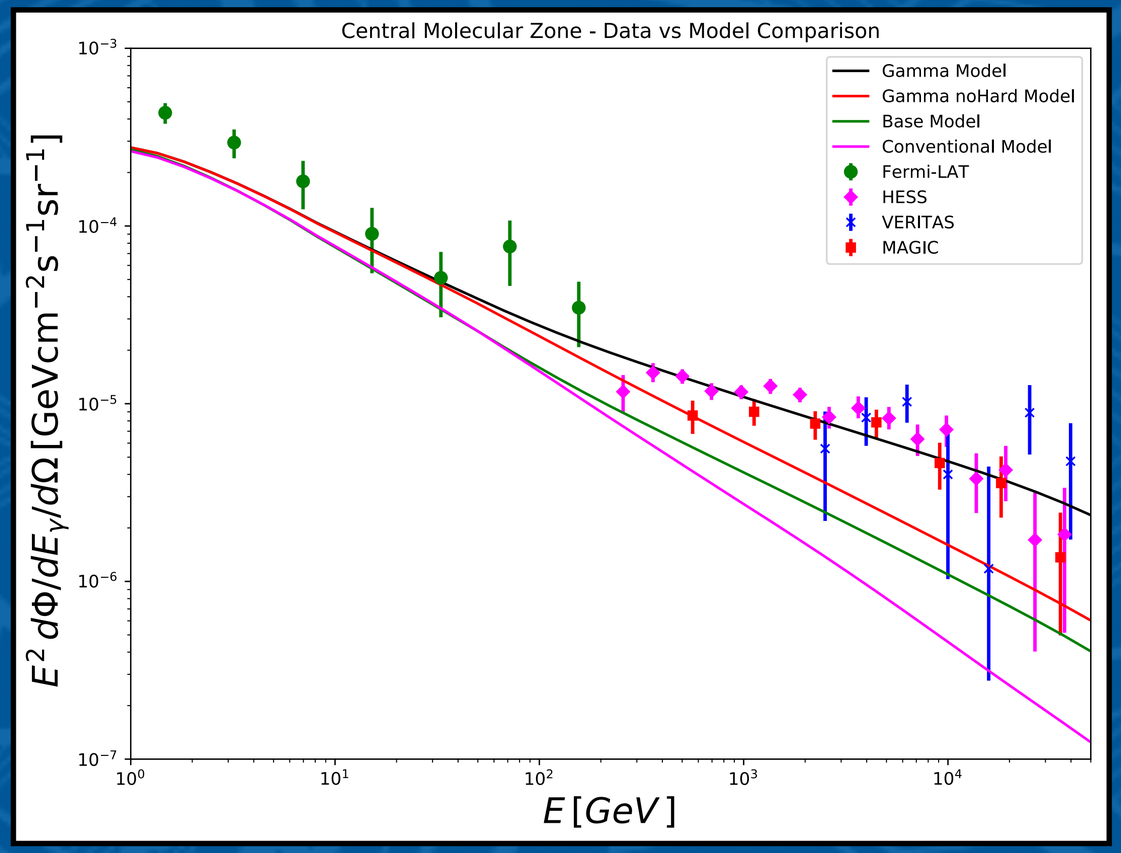


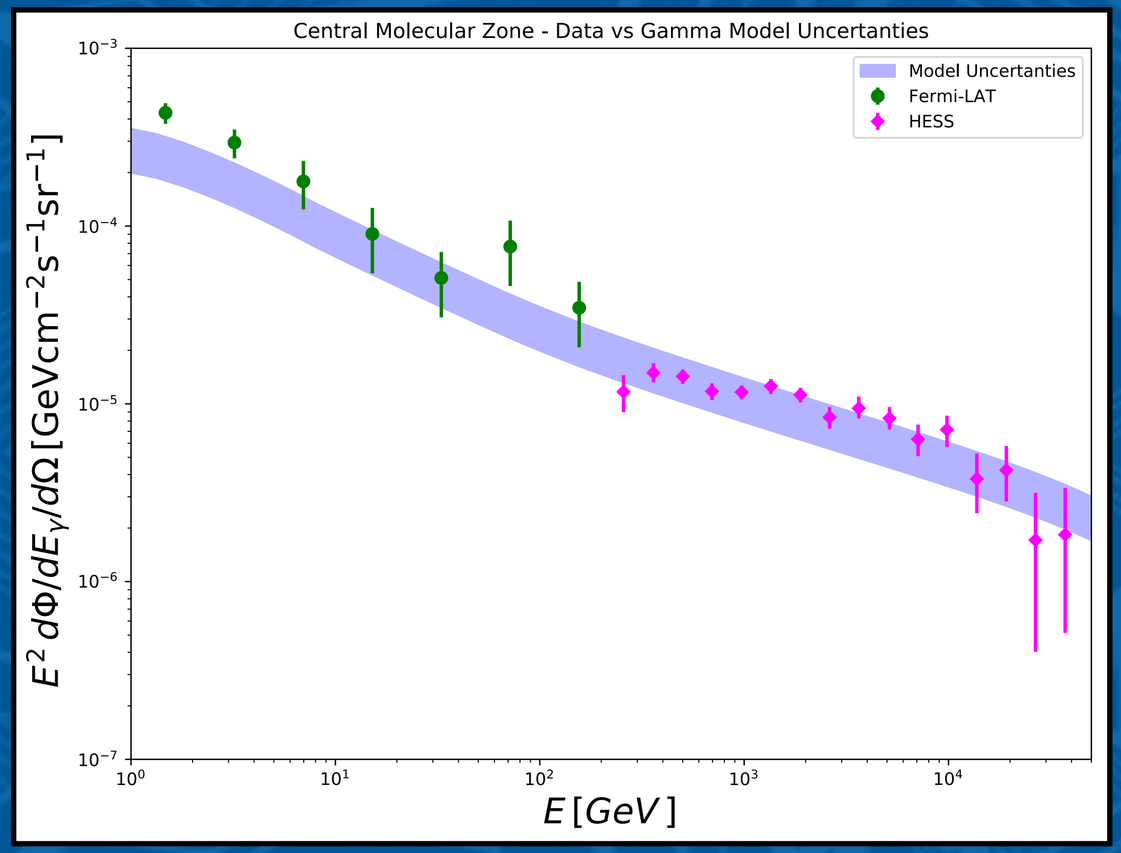


Ferriere et al. (2007)

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

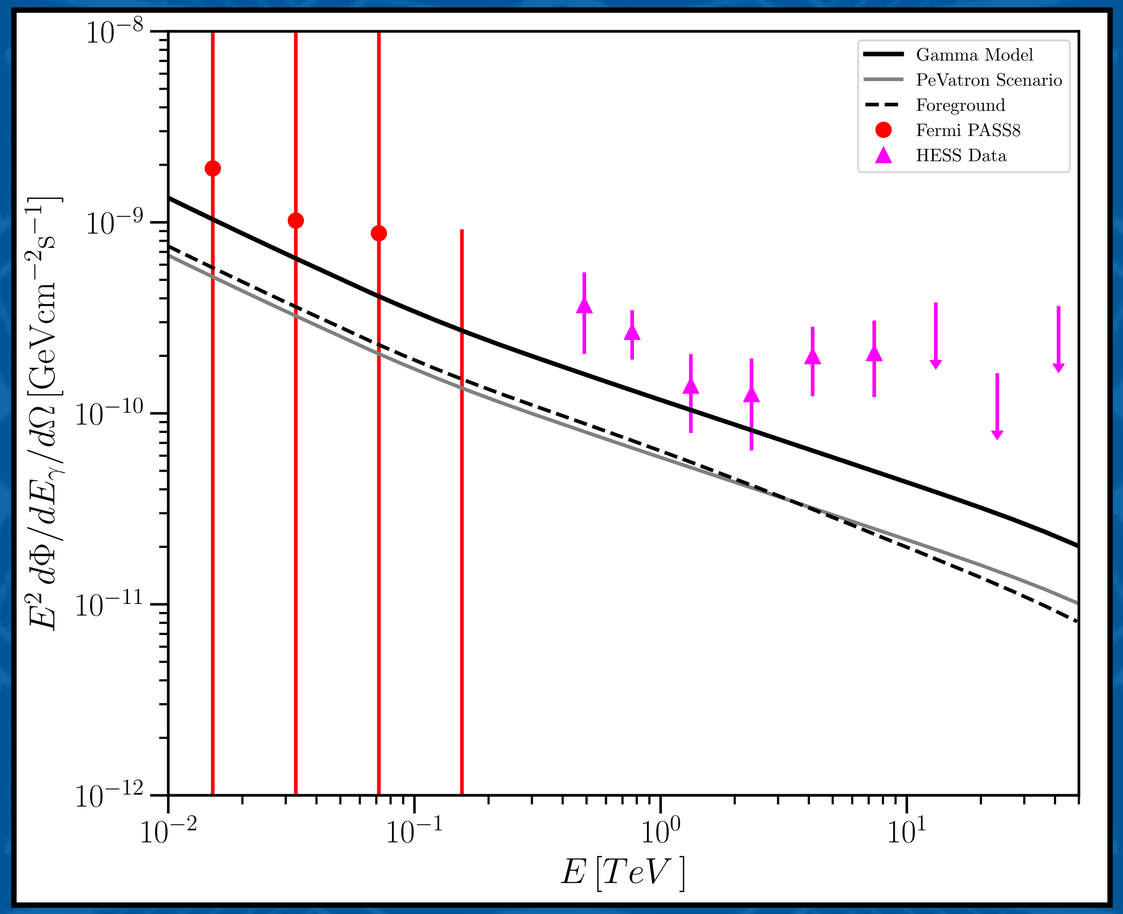
Results: Galactic Ridge





$$\Gamma = 2.36 \pm 0.08$$

Results: HESS J1741−302



$$\Gamma = 2.24 \pm 0.02$$

Conclusions

- The γ-ray emission from CMZ measured by IACTs & Fermi-LAT (few GeV ÷ 50 TeV) may be compatible with 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 (3D gas modelling is required)
- Source confusion
- 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 (Bania Clump, HESS J1848-018 — Ventura, 2018, Ventura et al., 2019, Ventura 2022)
- Cherenkov Telescope Array (CTA) with increased sensitivity & angular resolution may lead to definitive conclusions

APPLICATIONS

- CTA GC working group
- Recently updated gamma model (DRAGON2 & HERMES codes; De La Torre Luque et al, 2023)
- Synthetic population of unknown SNRs, PWNe and YSC

⇒ waiting for next conferences for the results !!!

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Phenomenological models comparison to untangle the origin of the gamma-ray emission from the Galactic Centre region

TeVPA 2023

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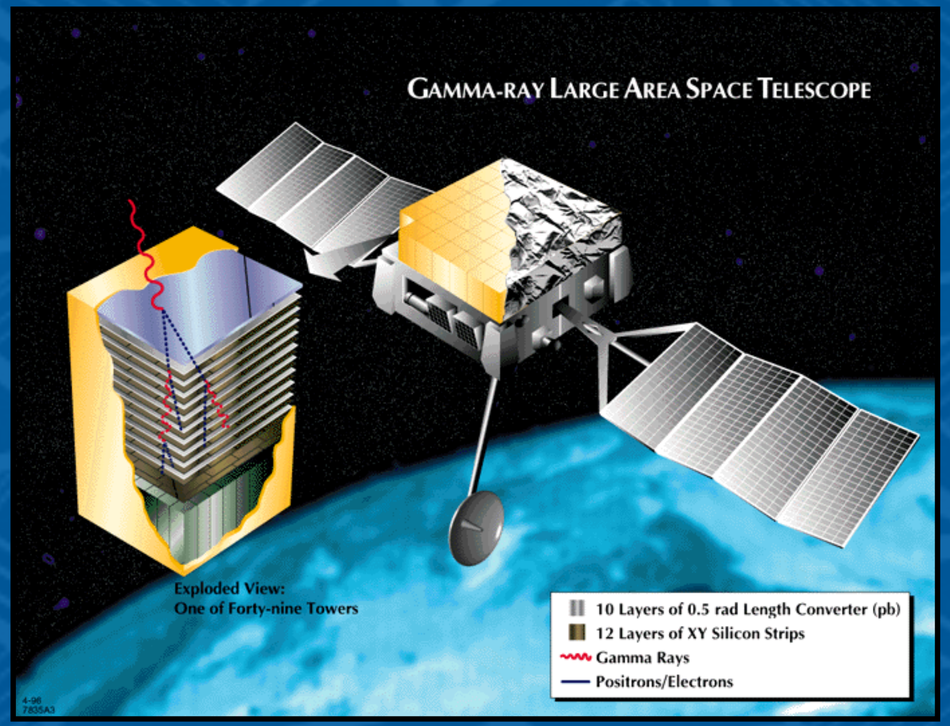
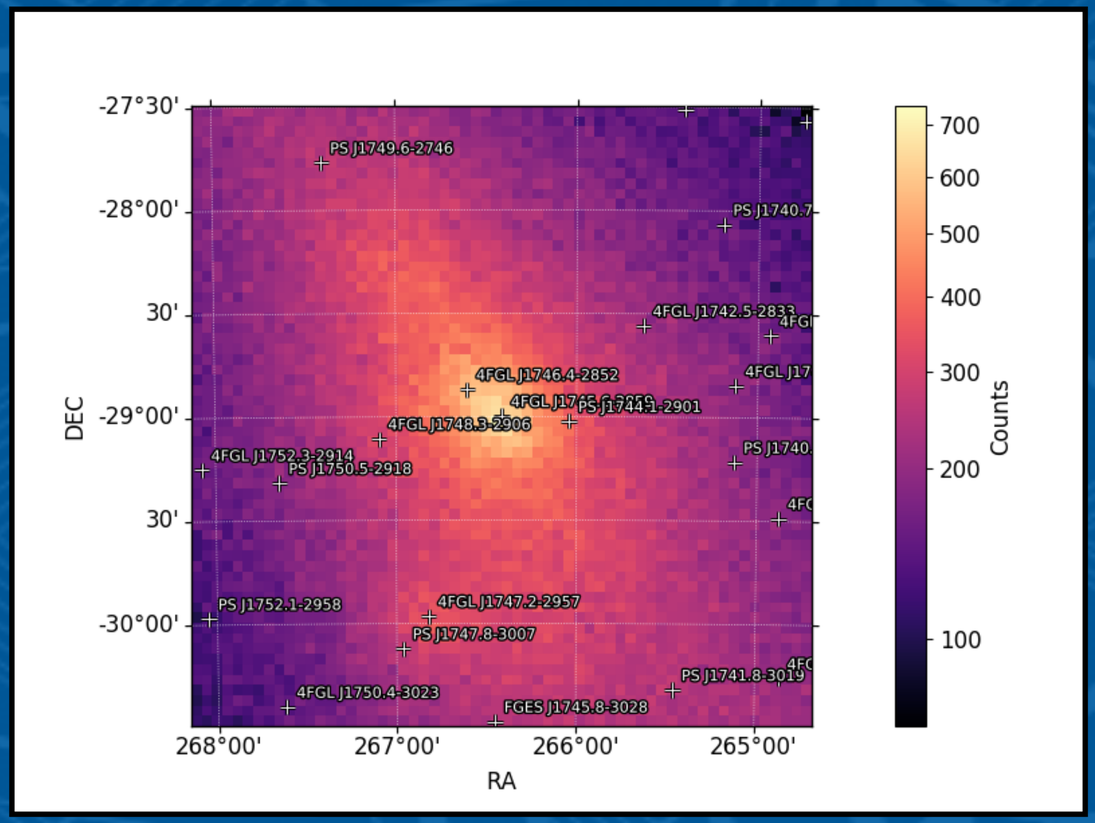
BACKUP

Fermi-LAT Analysis

- Fermi-LAT analysis ~ 10 yr
- 4FGL-DR2 catalog
- P8R3_CLEAN_V2
- iso_CLEAN_V2





HEASARC

Results: Models Comparison