A New GeV-TeV Particle Component and the Barrier of Cosmic-ray Sea in the CMZ Region

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The sea of galactic cosmic rays

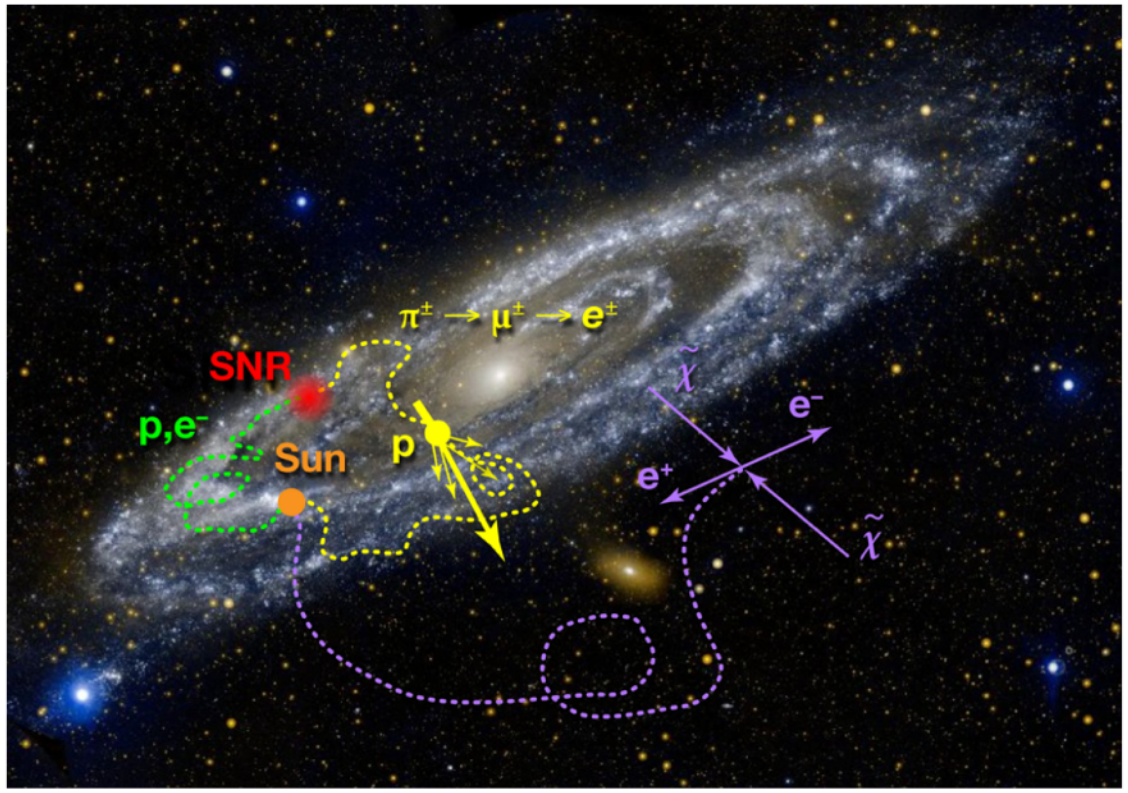
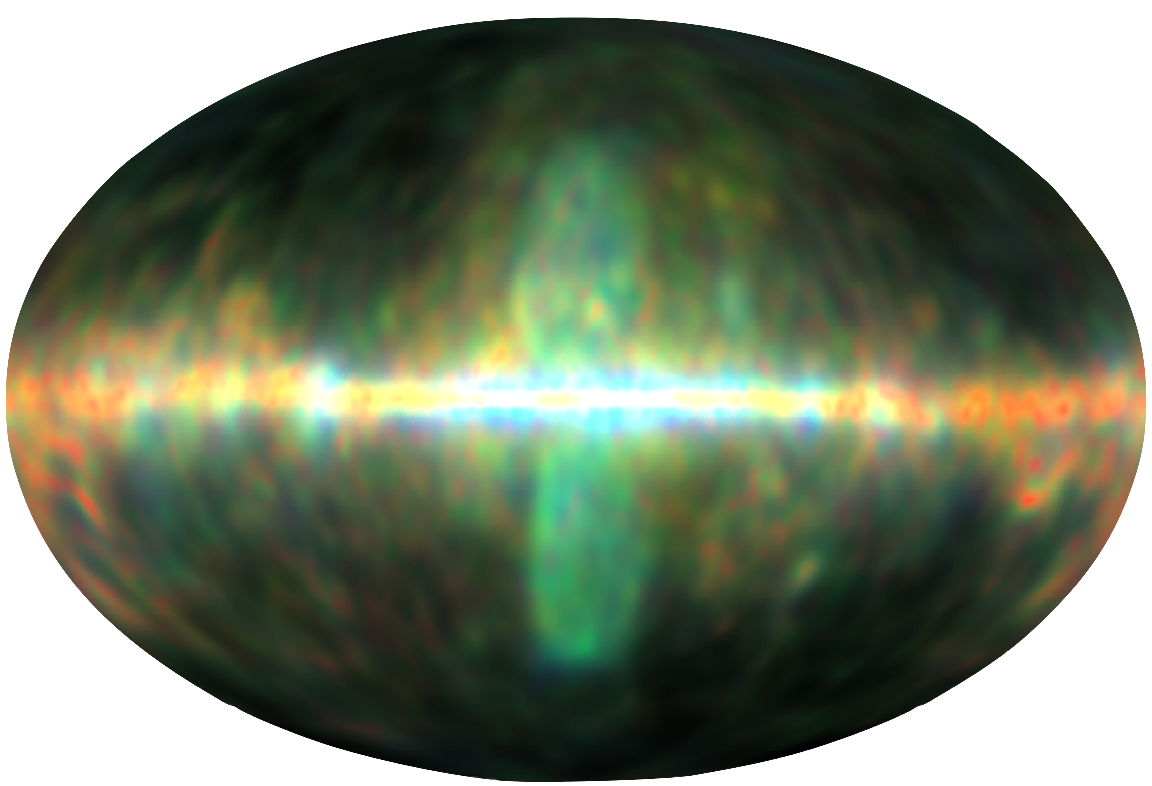
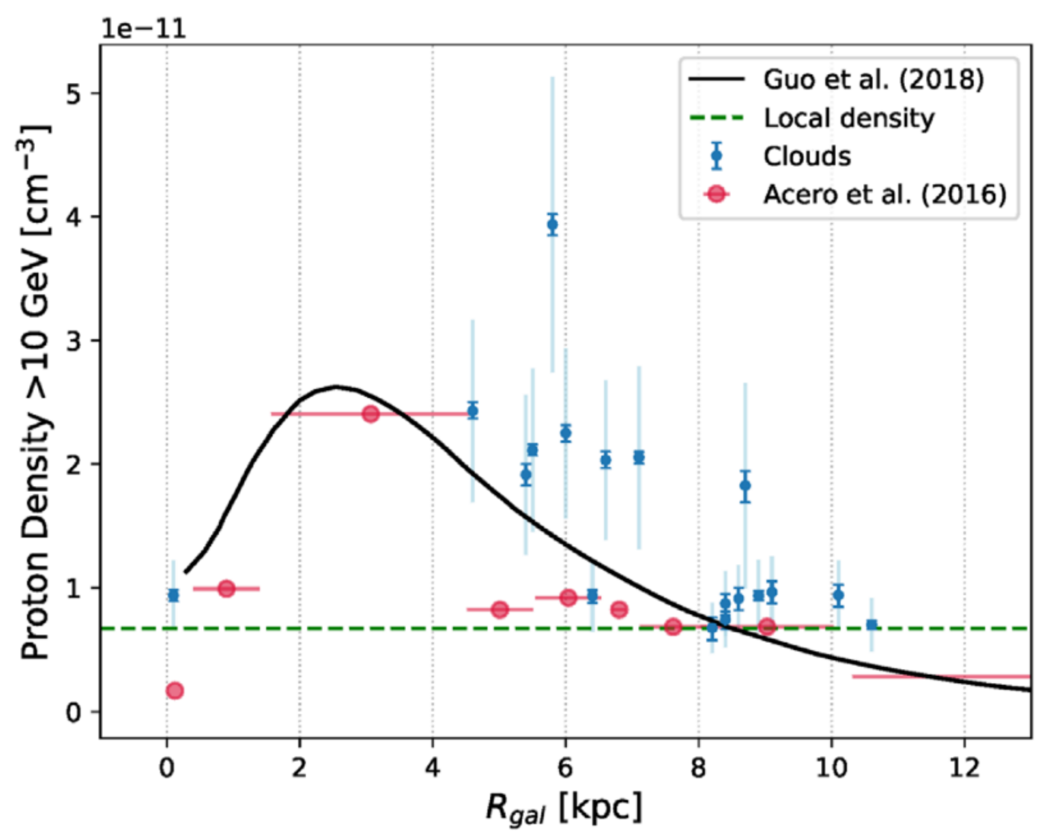


Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker

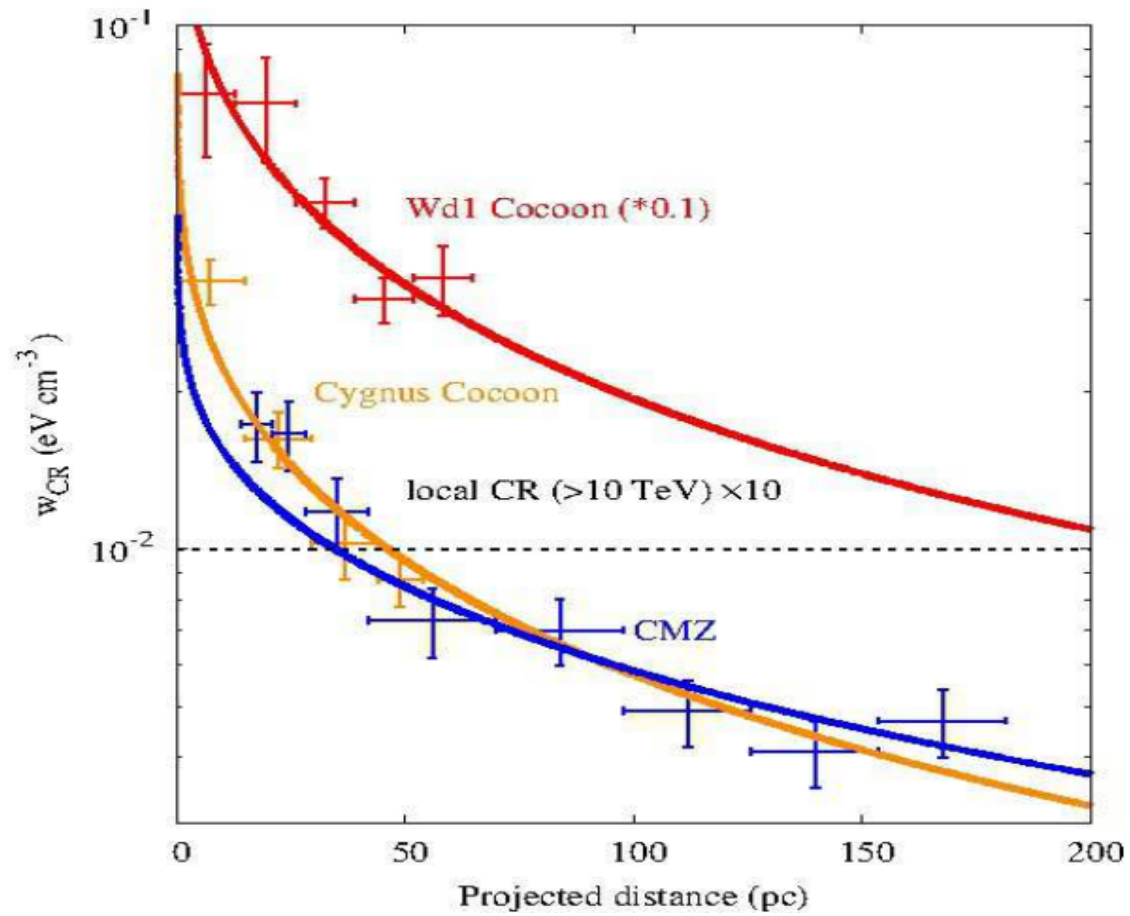
Selig et al. 2015



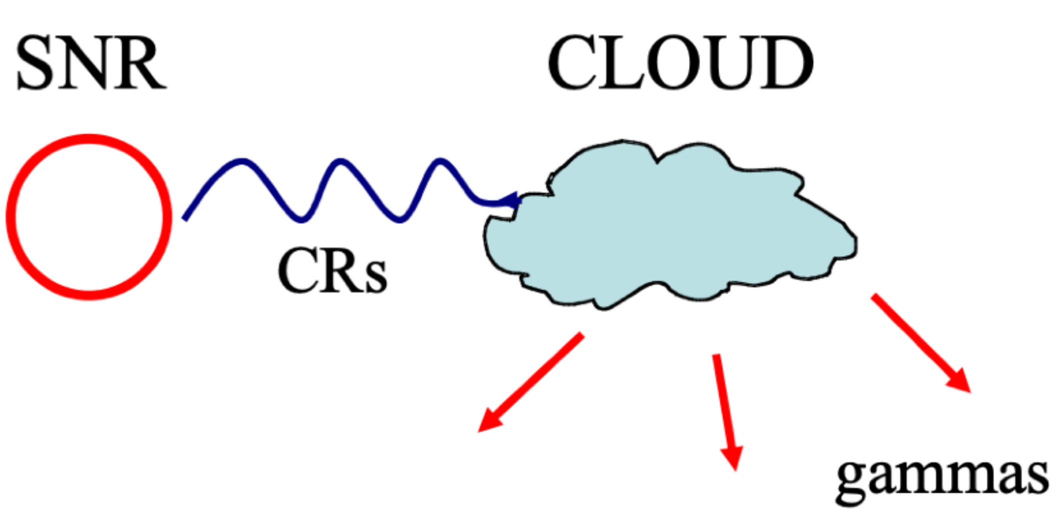
Aharonian et al. 2020

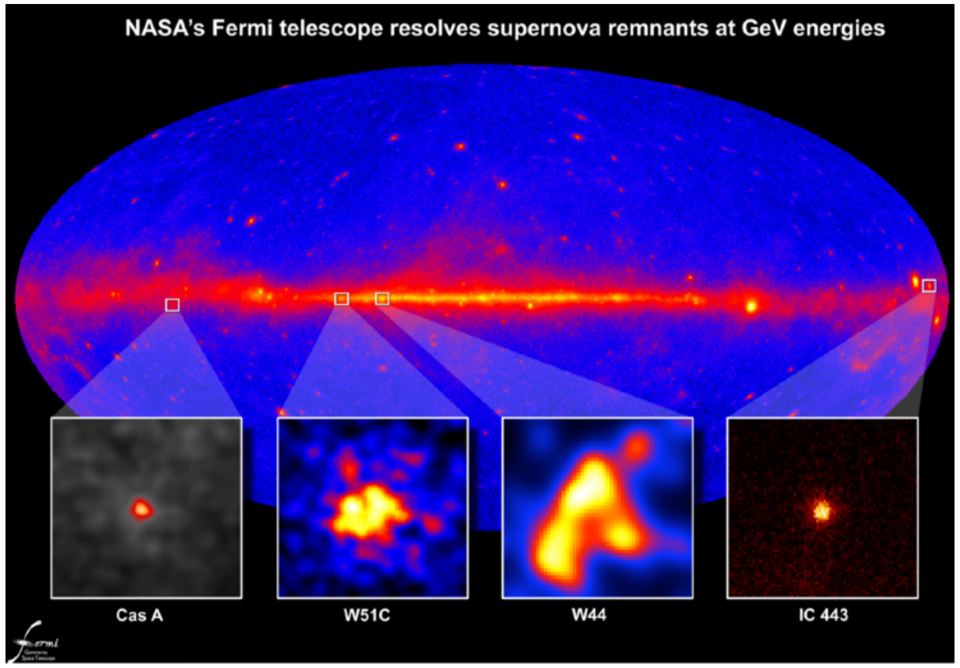


Enhanced cosmic/gamma rays around accelerators



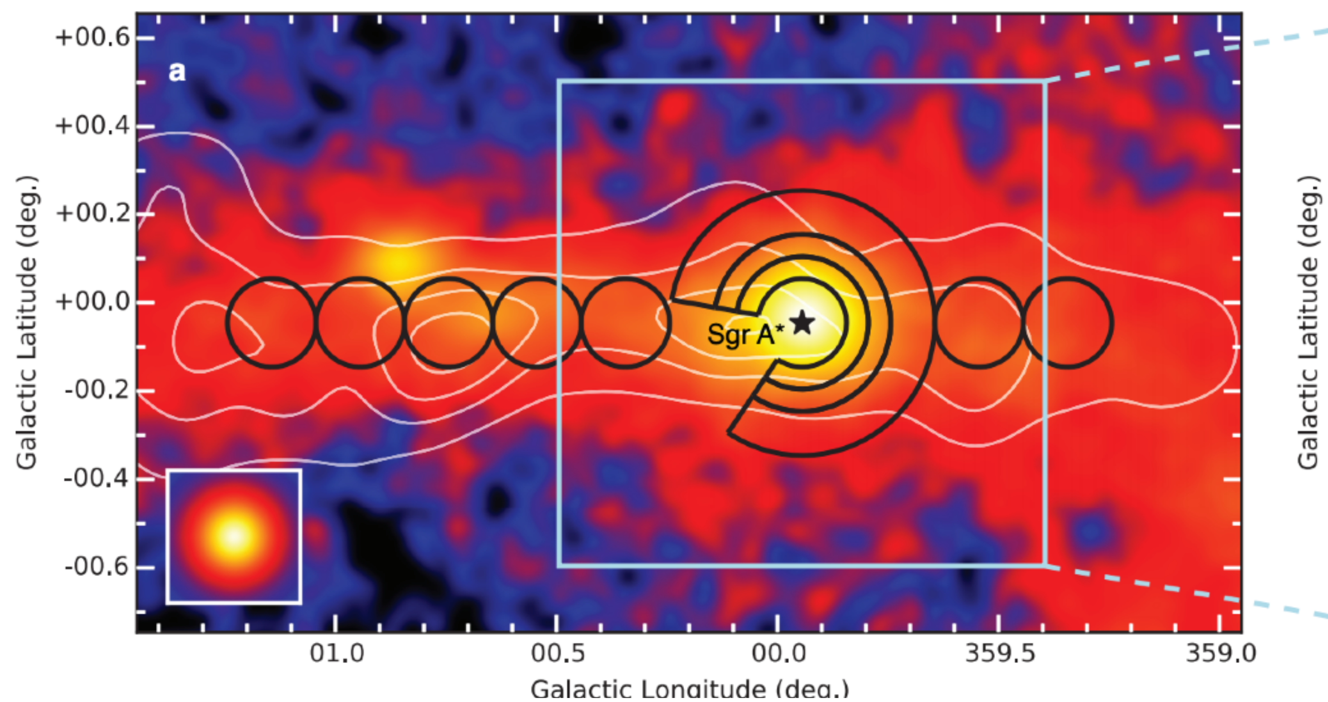
Aharonian et al. 2019

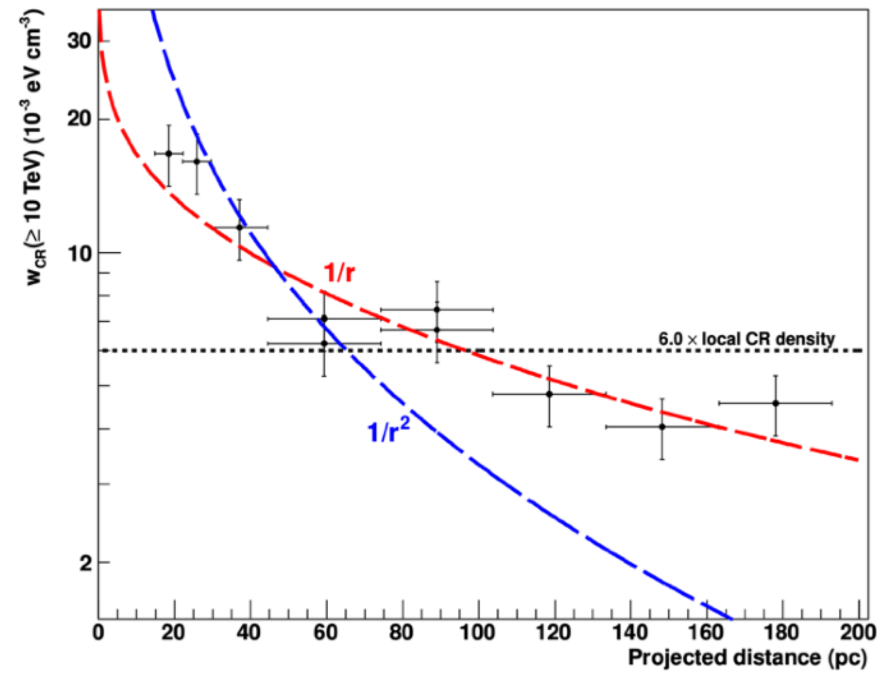


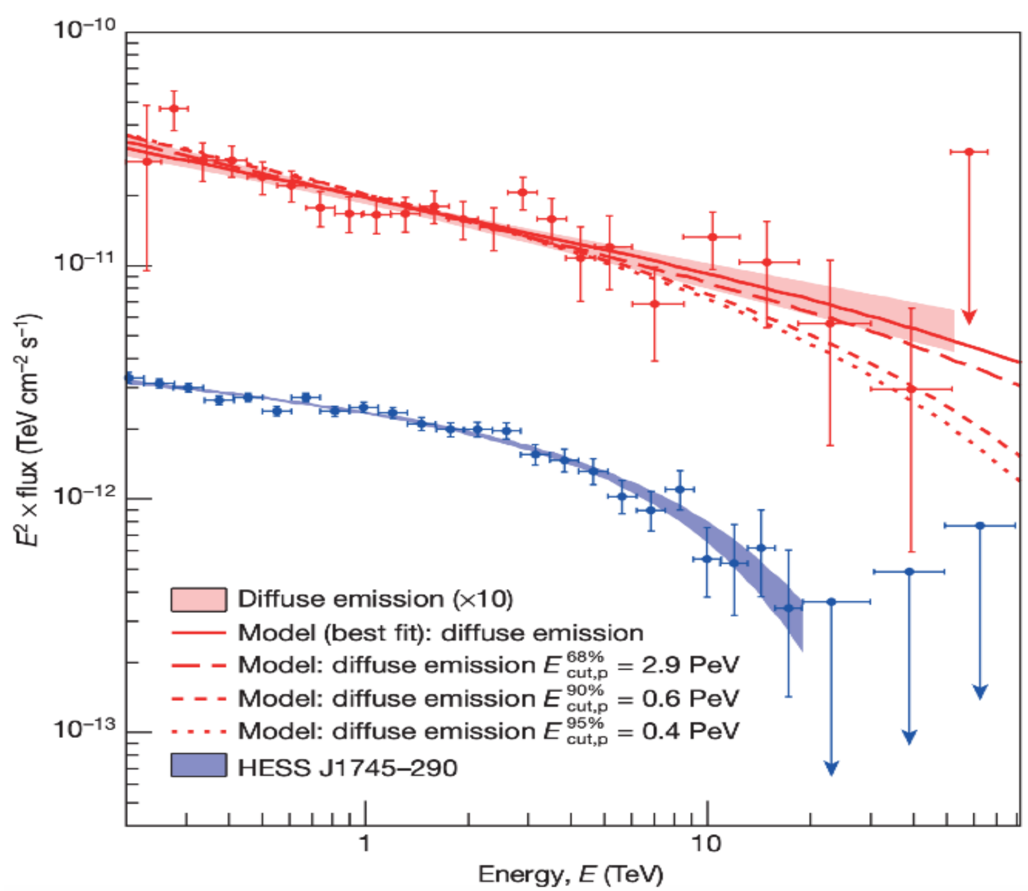


Galactic center, a possible PeVatron

HESS Collaboration et al. 2016





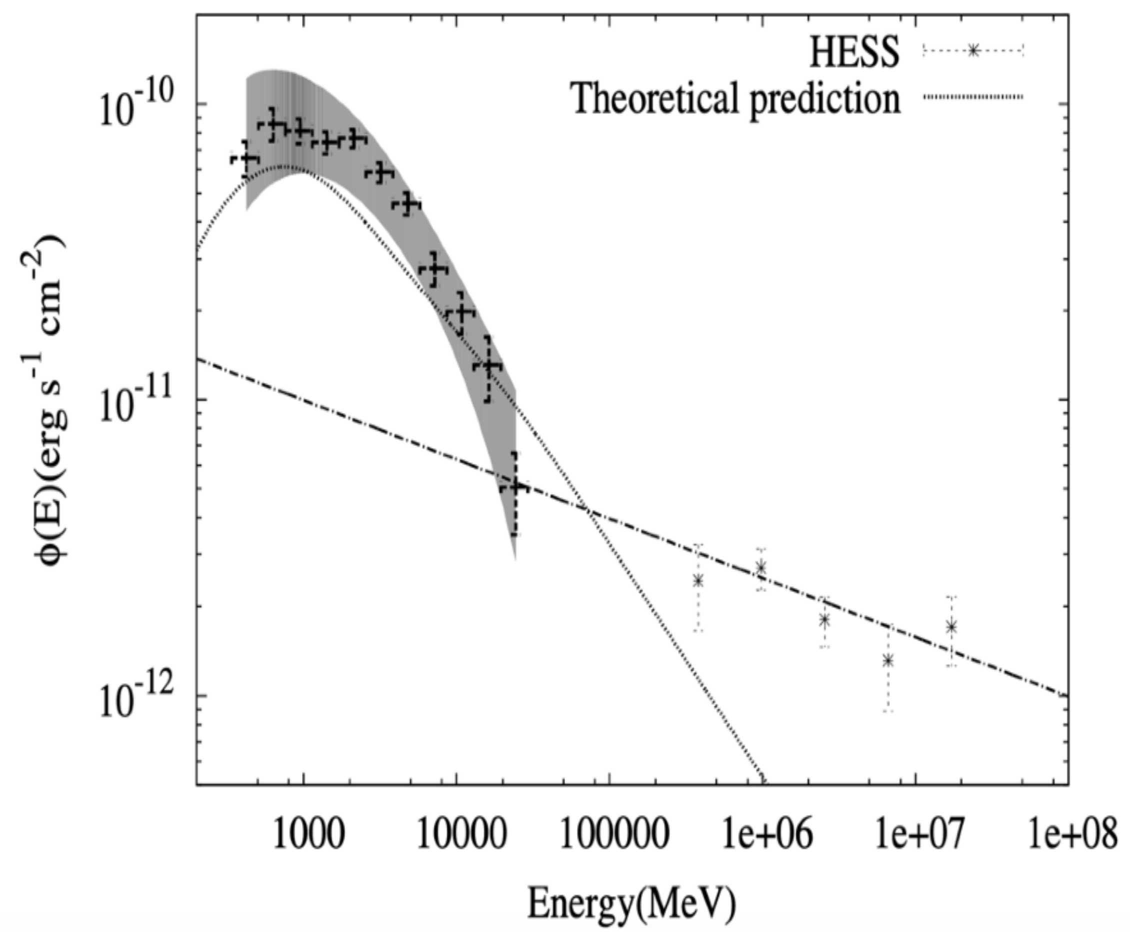


The best fit of a $1/r^{\alpha}$ profile to the data is found for α=1.10±0.12 (1σ). The 1/r radial profile is clearly preferred for the HESS data.

A spectrum following a power law extending with a photon index of ~2.3 to energies up to tens of TeV, without a cut-off or a break.

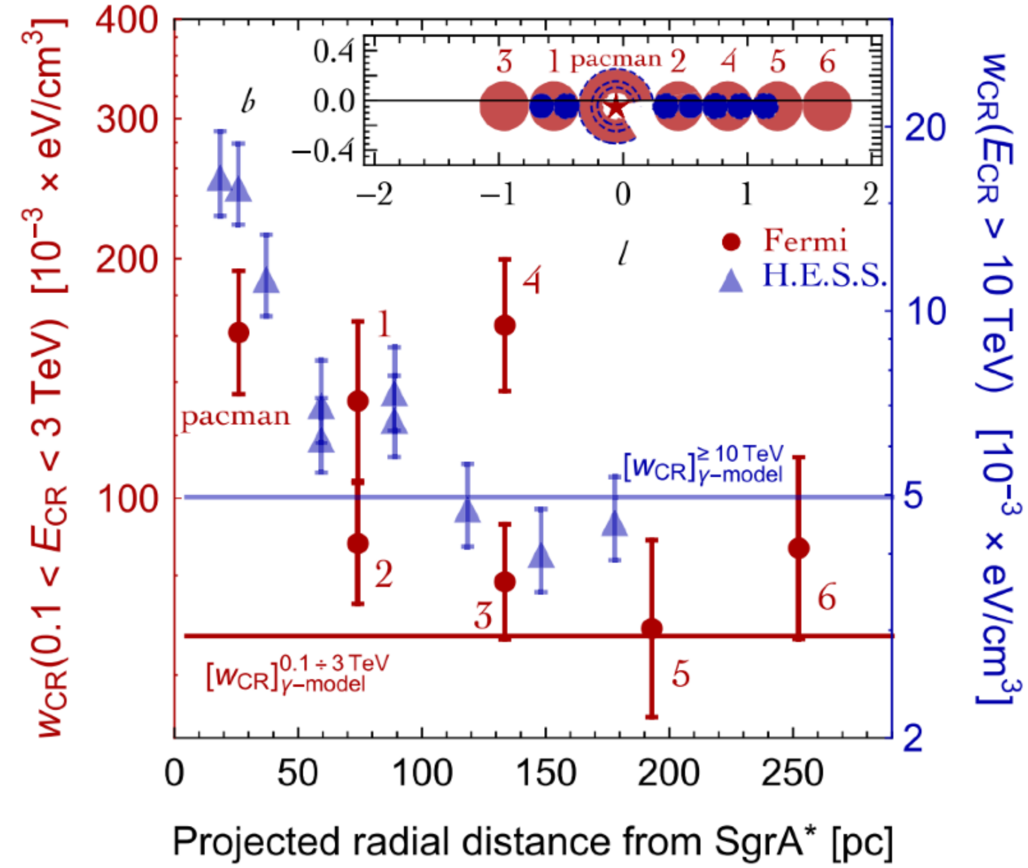
Galactic center at GeV

Yang et al. 2015



The γ-ray spectrum in the region can be well-fitted using a local cosmic-ray spectrum. Contribution from the new component should be sub-dominate.

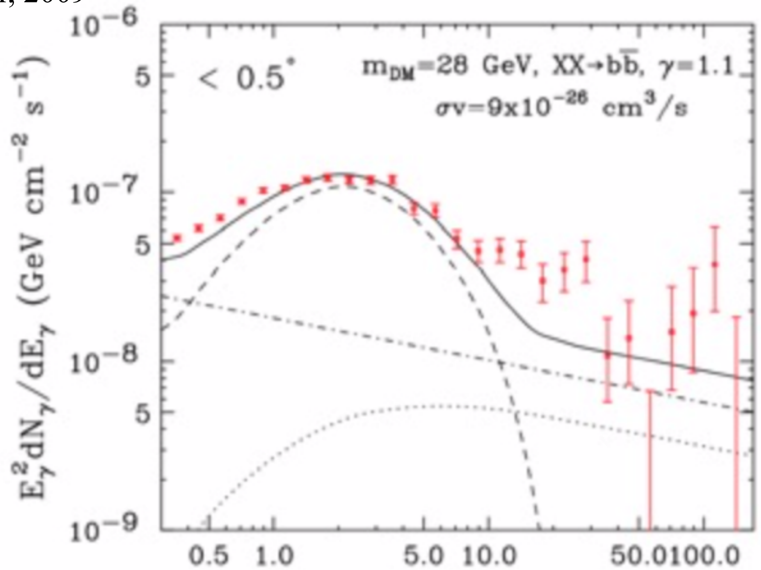
Gaggero et al. 2017

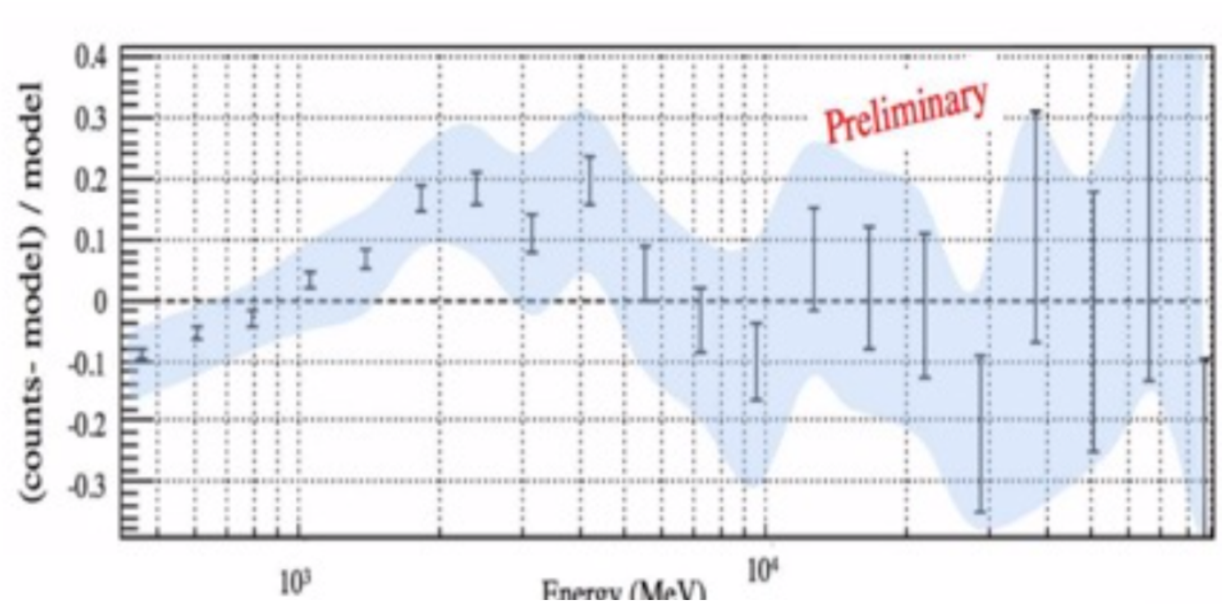


An energy independent shape of the CR density profile. It is clear that both data sets are consistent with being constant for r ≳ 100 pc

Another exotic component at the GC

Goodenough & Hopper, 2009



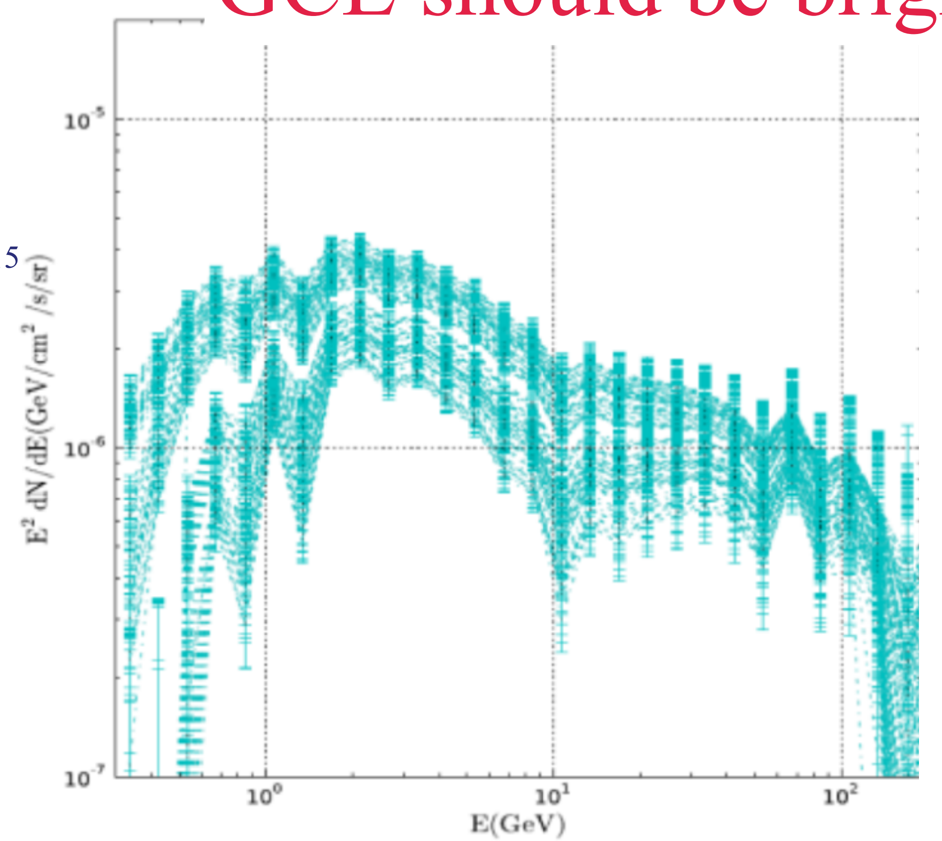


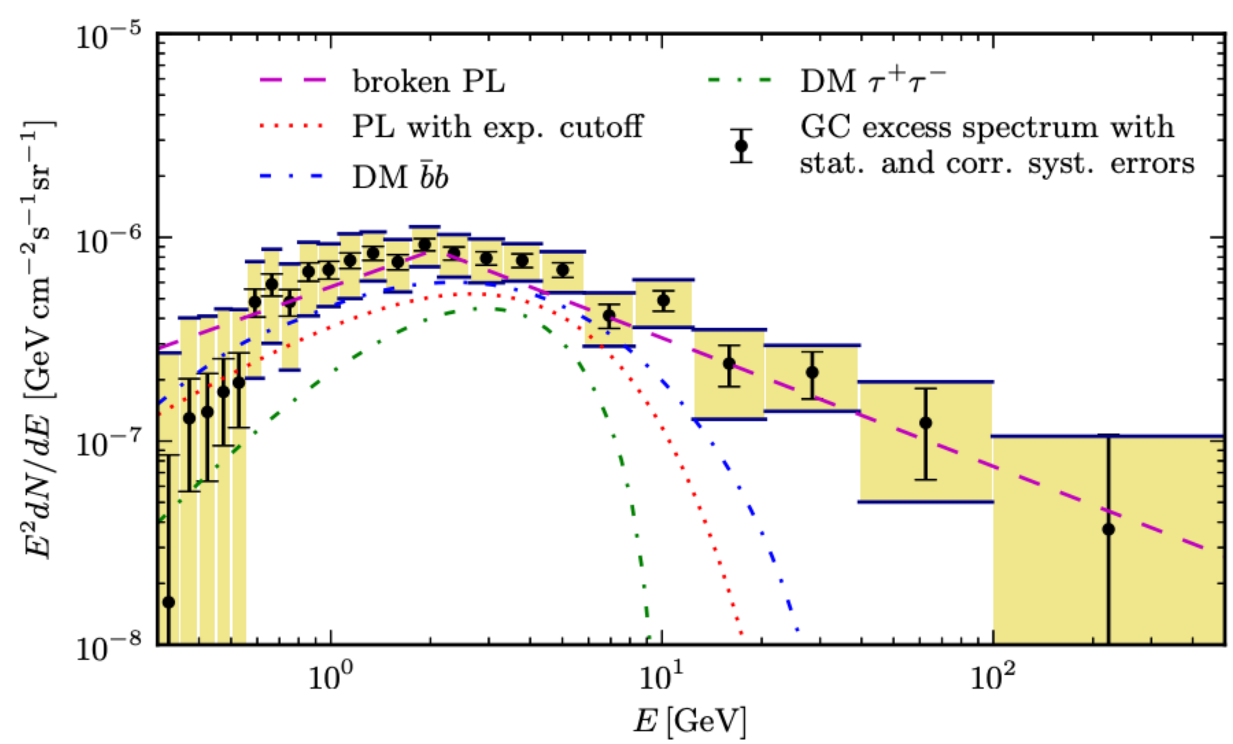
Vitale & Morselli, 2009

GCE should be bright at GC, even above 10 GeV

Calore et al. 2015

Zhou et al. 2015





Re-investigating the GC region

Point sources (4FGL and 3FHL)

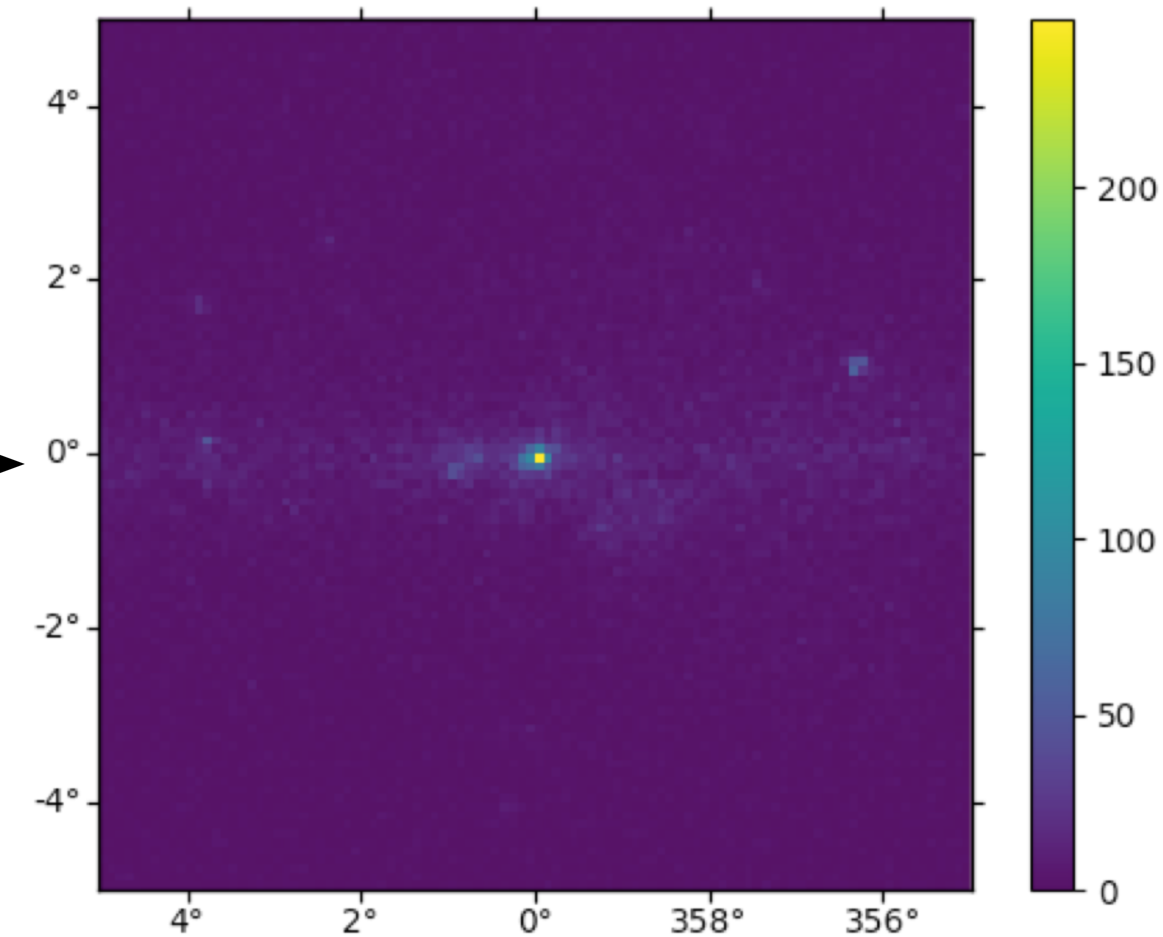
GCE (gNFW, power-law)

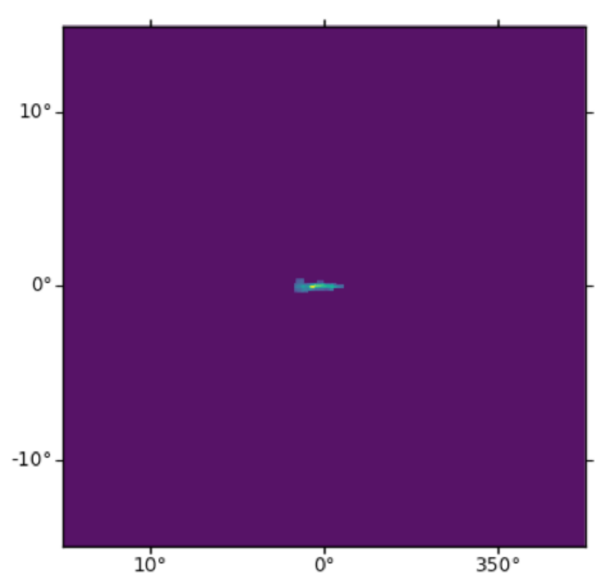
gamma-ray from Pion decay

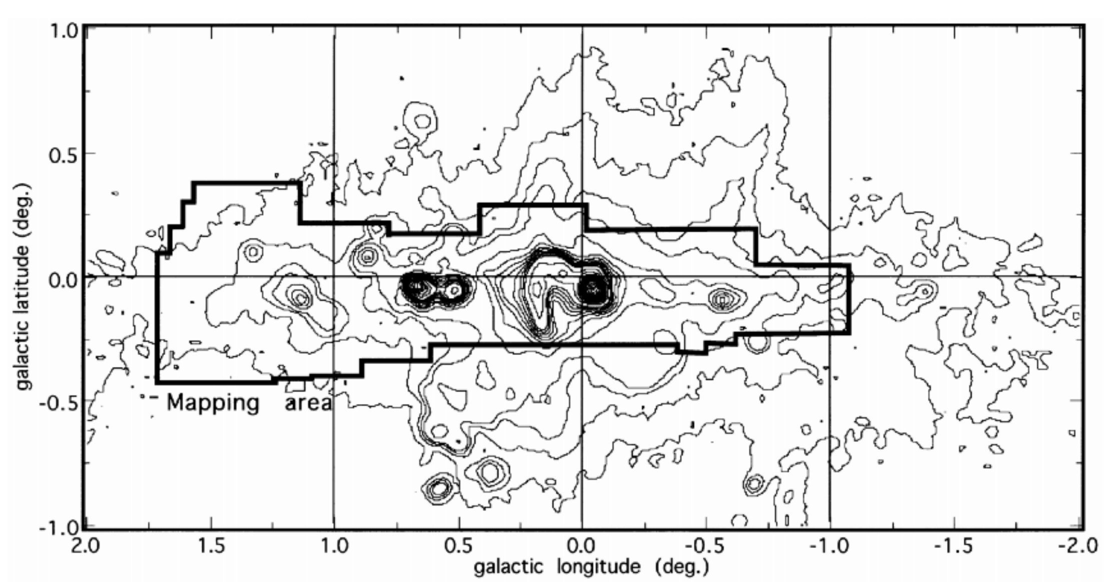
gamma-ray from ICS (GALPROP)

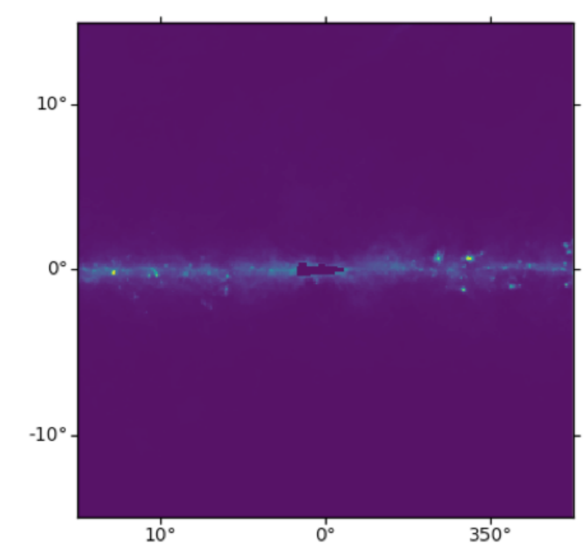
Isotropic emission (power-law)

Data > 8 GeV

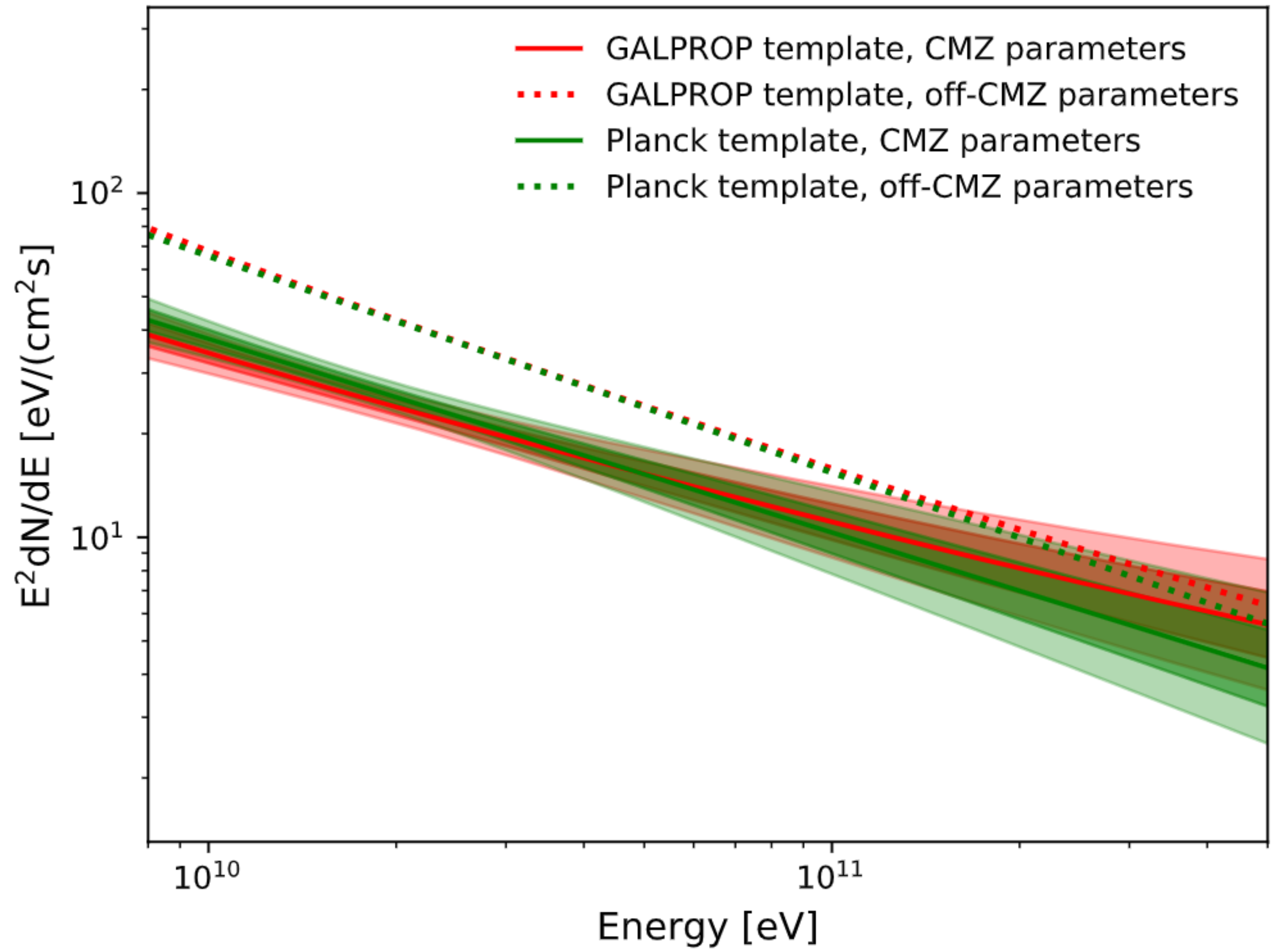








Two types of gamma-ray emission

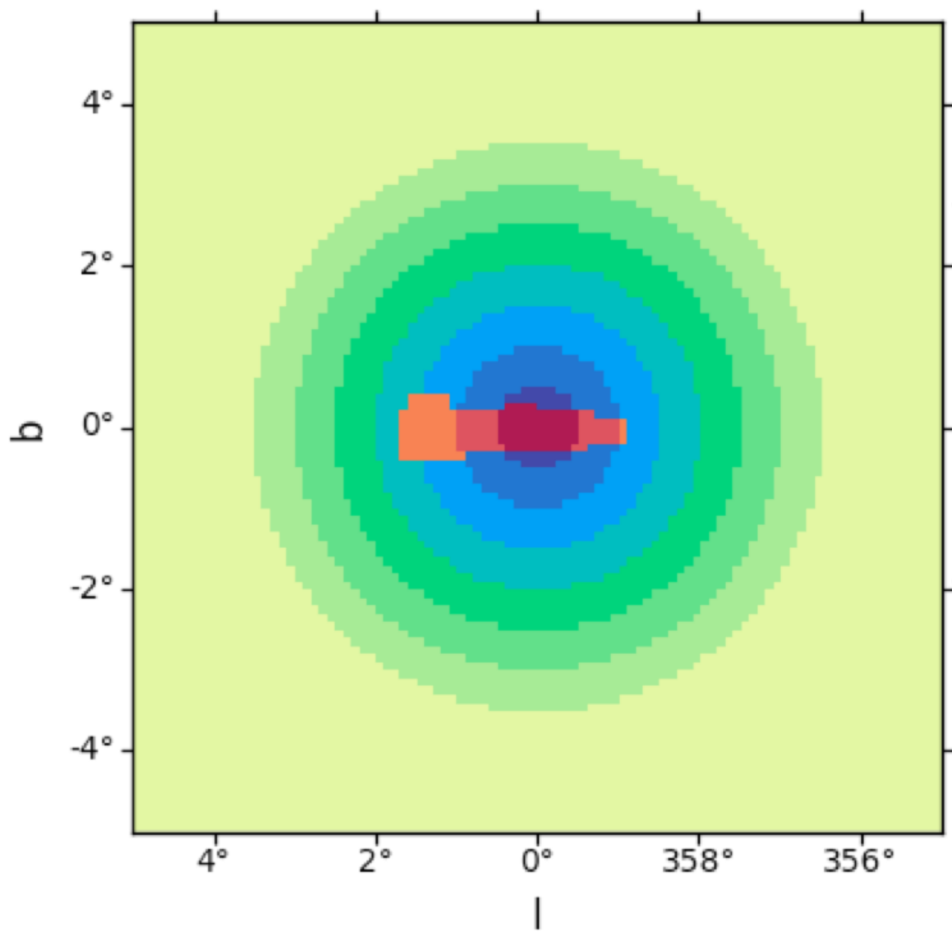


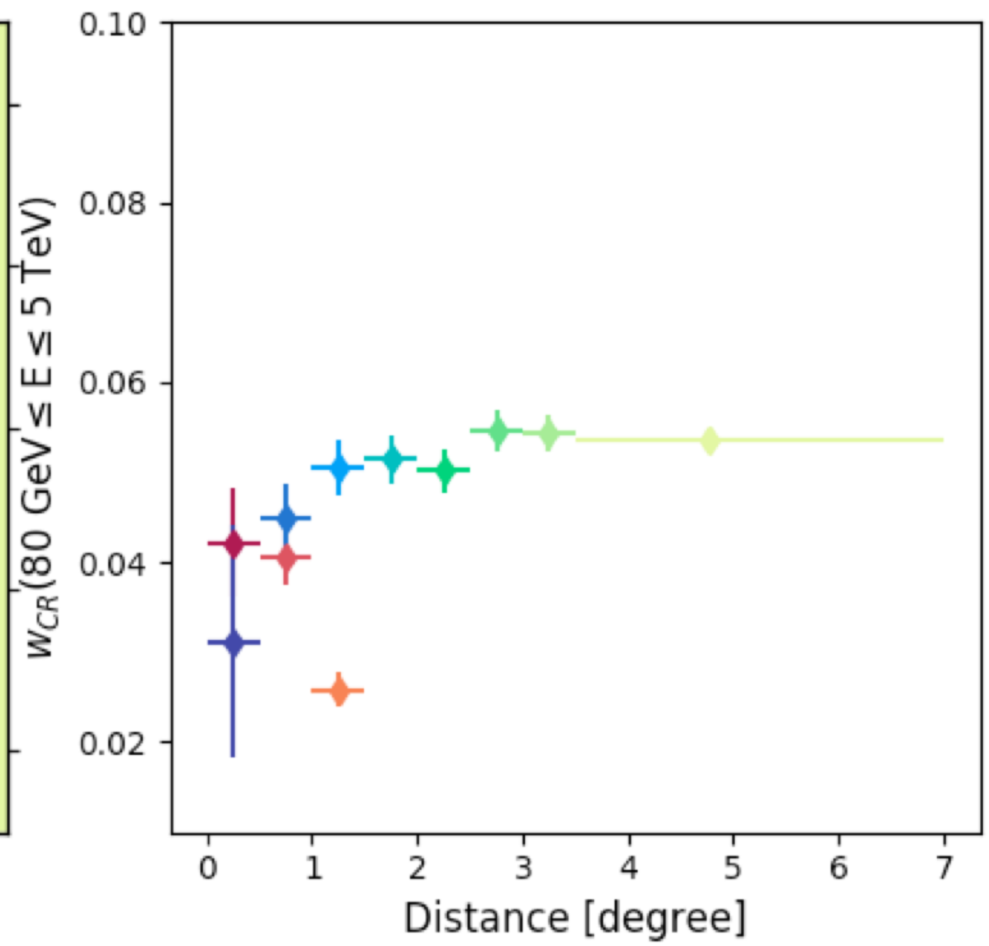
For all these templates to model γ-ray from neutral pion decay, parameters derived from the CMZ region would predict a harder spectrum and a lower flux of γ-ray.

The X_{co} factor in the center region is smaller than that used in the GALPROP for the CO-to-H_2 conversion, making less targets for the cosmic-ray interaction. ✗

The cosmic-ray density in the center region is lower than the density of the cosmic-ray sea in the off-center region. ✓

Two types of cosmic-ray component

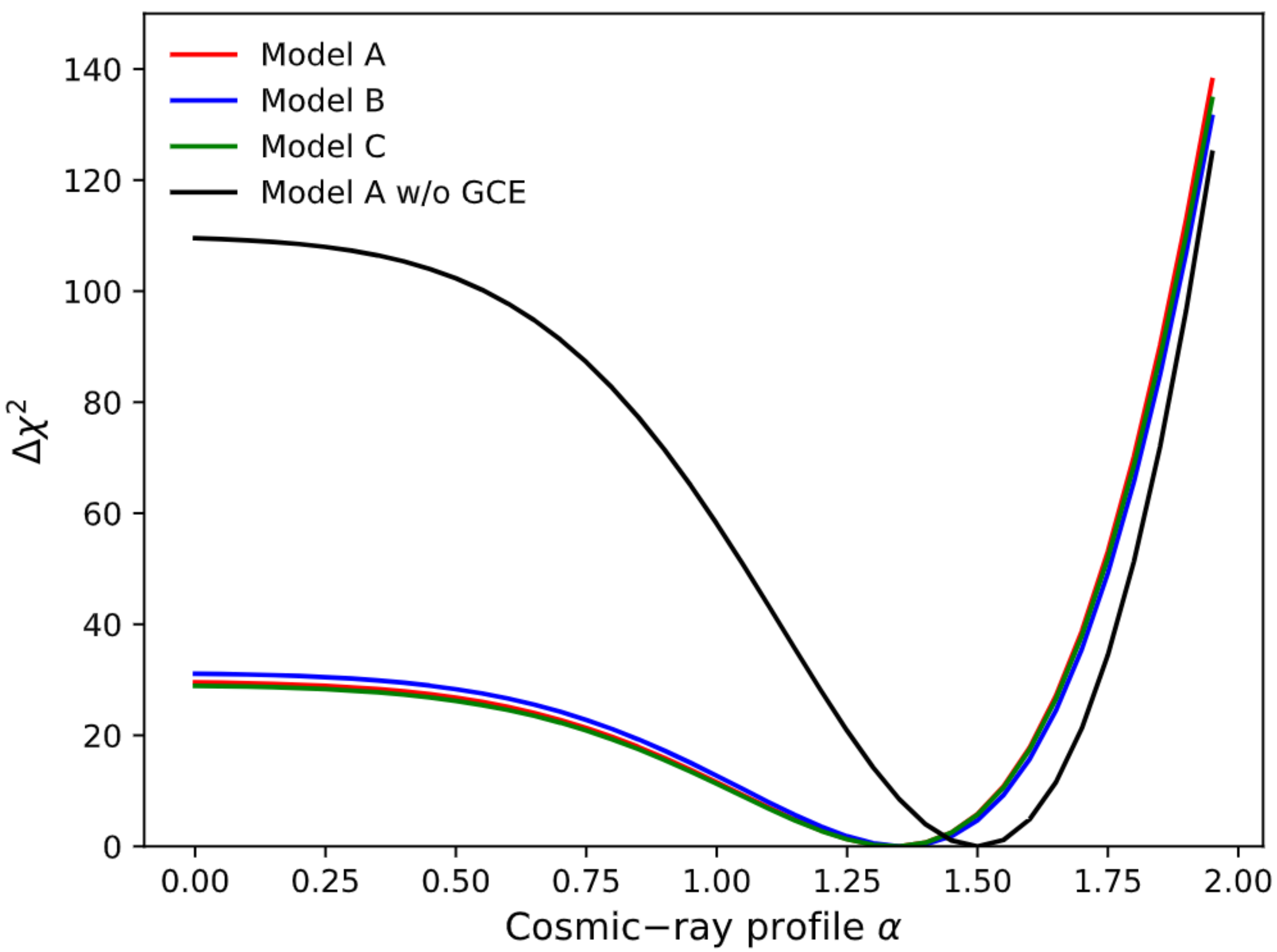




Cosmic-ray energy density in the CMZ region would decline with distance to the GC. (A new component)

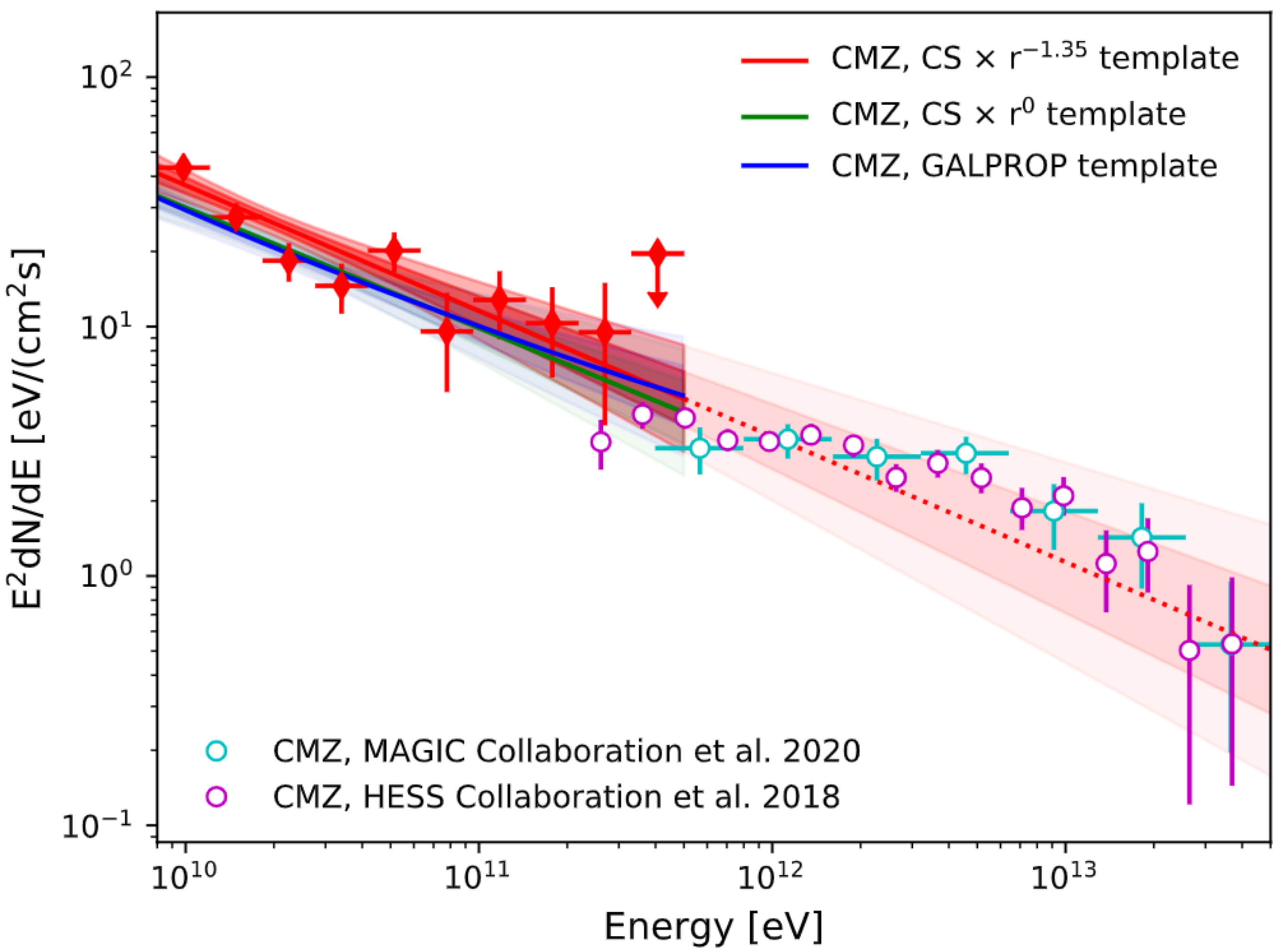
Cosmic-ray energy density in the off-CMZ region would almost be a constant. (Cosmic-ray sea)

The GeV-TeV counterpart of the VHE CR component



We find the Fermi-LAT data would indicate the index of the cosmic-ray profile as $1.35^{+0.06}_{-0.09}$, which is consistent with that derived at very-high energy, α = 1.2 ± 0.3 in MAGIC Collaboration et al. (2020) and α = 1.1 ± 0.12 in HESS Collaboration et al. (2016).

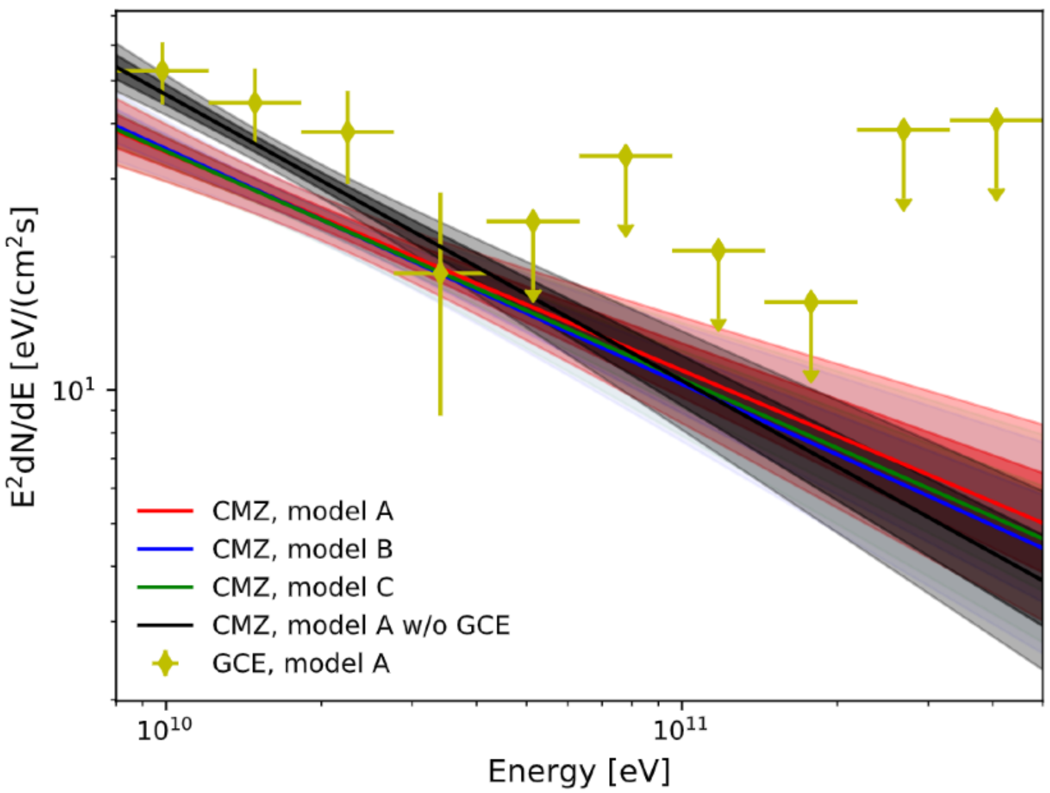
The GeV-TeV counterpart of the VHE CR component



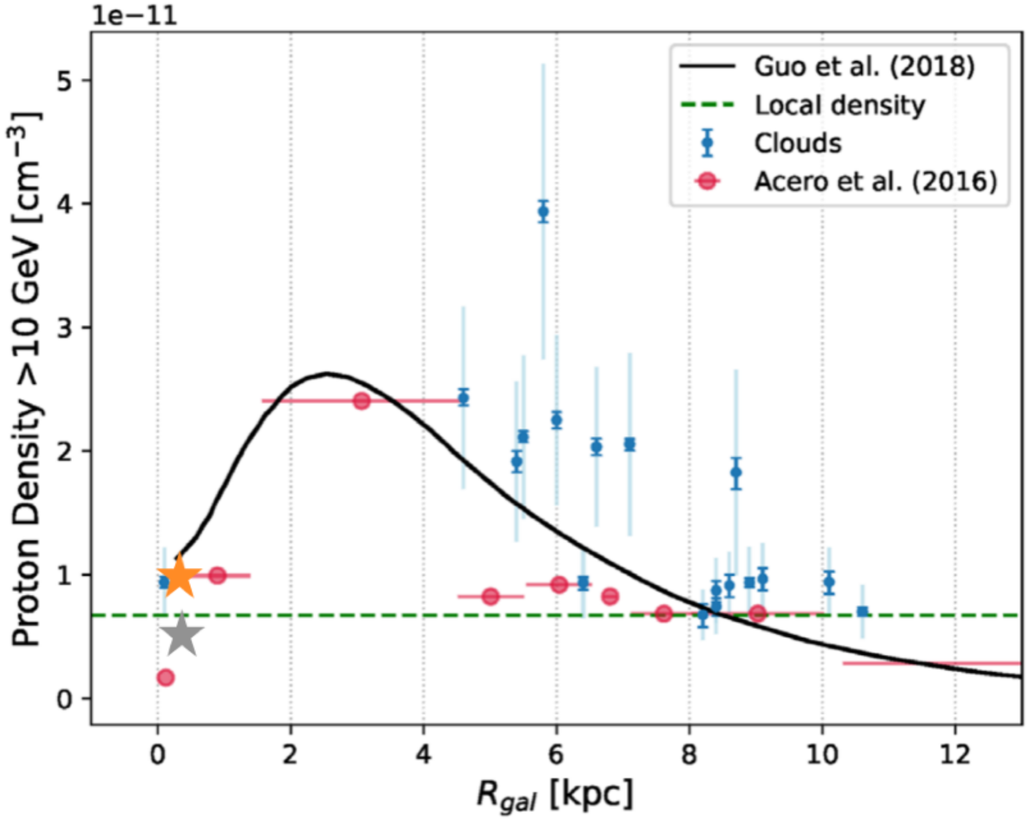
A power-law spectrum could give a good prediction over 4 orders of magnitude of energy.

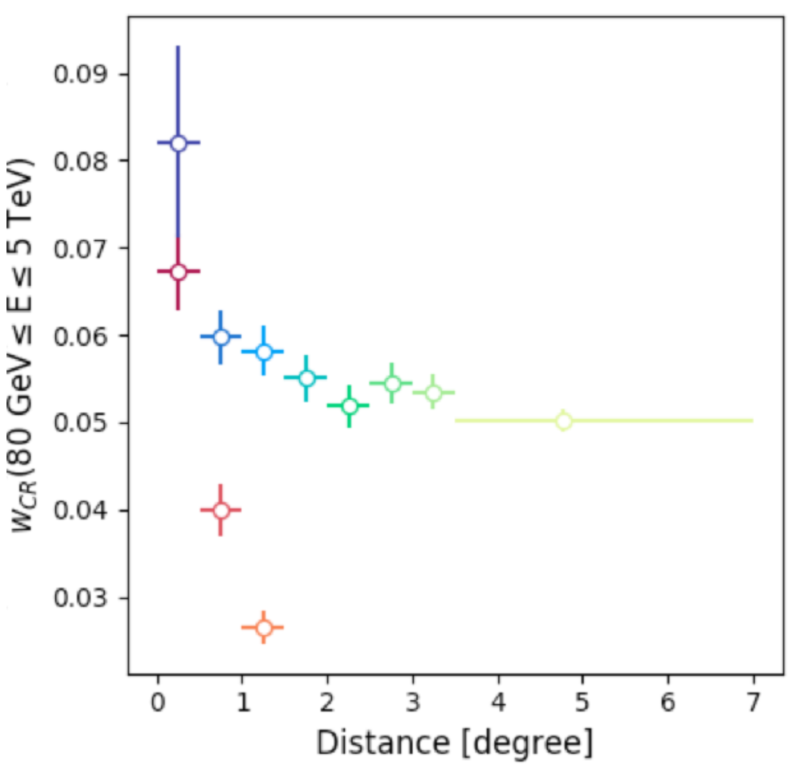
The effect of the GCE

Aharonian et al. 2020

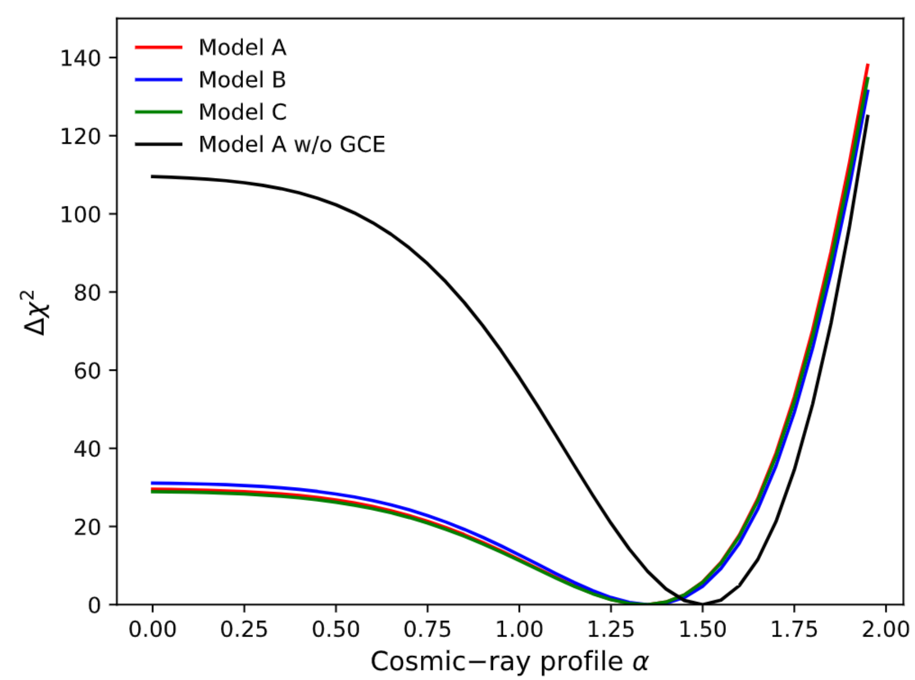


Without the GCE in the template fitting, the flux from the CMZ would be enhanced, and the derived cosmic-ray density would be consistent with that derived from the Sgr B complex.

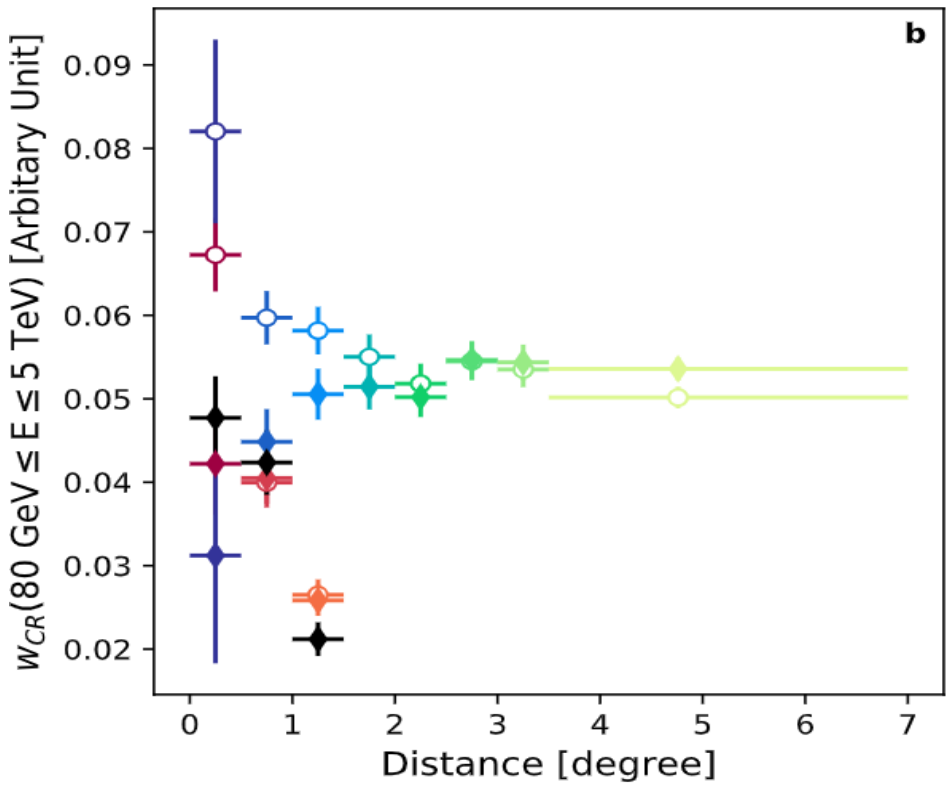




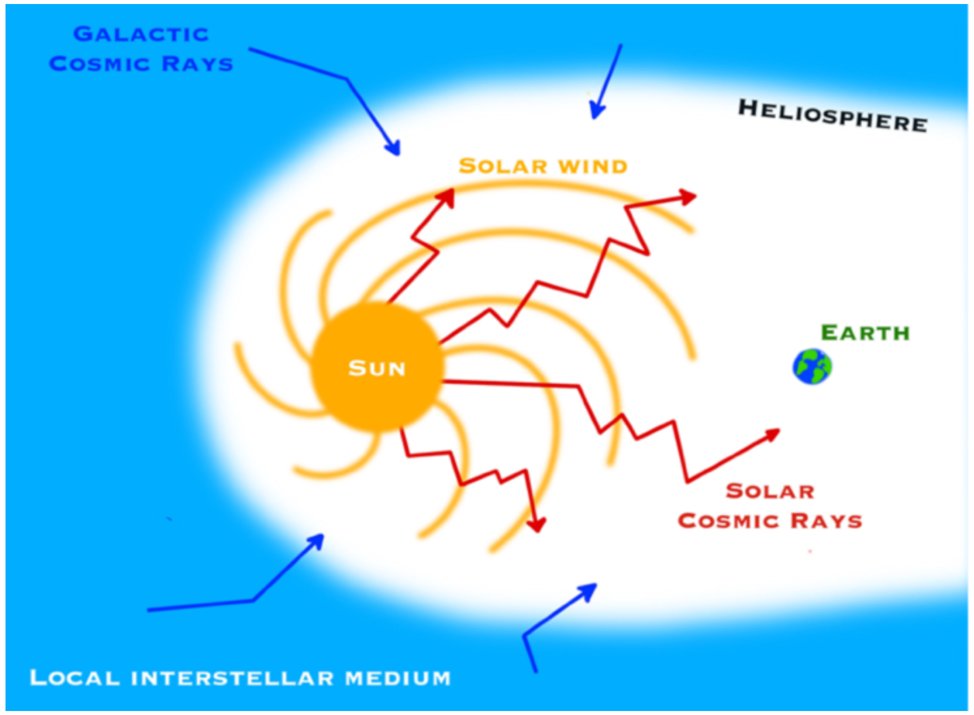
Without the GCE in the template fitting, cosmic-ray density derived from the innermost region would be enhanced, and the index of the spatial profile for the new component would get larger



CRs propagation in the CMZ



Credit: Sarah. A. Brands



$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 V_0 S - r^2 D_0 \frac{\partial S}{\partial r}\right) = \frac{q V_0 S}{r},$$

$V_0 \sim 500 \text{ km s}^{-1}$

$D_0 = 3 \times 10^{28} \text{ cm}^2 \text{ s}^{-1}$

CRs from outside of the CMZ

scaling relation of $\sim r^{0.8}$ for the CR density distribution

CRs from an central source

an approximate $r^{-1.5}$ profile of the CR density

Summary

- We identify a counterpart of the VHE accelerator in GeV-TeV energy range using the Fermi-LAT data
- There is a barrier that can effectively suppress the penetration of the particles from the cosmic-ray sea to the central molecular zone.

Thank you!