Istituto Nazionale di Fisica Nucleare

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Shedding (Gamma) Light on the Cosmic Ray Population in the Galactic Center Region

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OUTLINE

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The Galactic Center Region

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Inhomogeneous Cosmic Ray Diffusion: CR-sea scenario

Model testing: Galactic Ridge + SgrB + J1741-302

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Hot Gas in the Galactic Center - Credit: NASA/CXC/UCLA/MIT/M.Muno et al.

THE CONTEXT . . .

The nature of the very-high-energy gamma-ray diffuse emission measured by H.E.S.S. in the Galactic Center (GC) region is still unknown.

Among several interpretations, two main scenarios have been proposed to interpret H.E.S.S. results.

The first in which the emission arises from a cosmic-ray (CR) population diffusing out a local

PeVatron.

The second explains the signal as the “tip of the iceberg” of an inhomogeneous Galactic CR sea.

The latter scenario is motivated by recent analysis of the Galactic diffuse emission measured by Fermi-LAT as well as from Milagro and recent HAWC results .

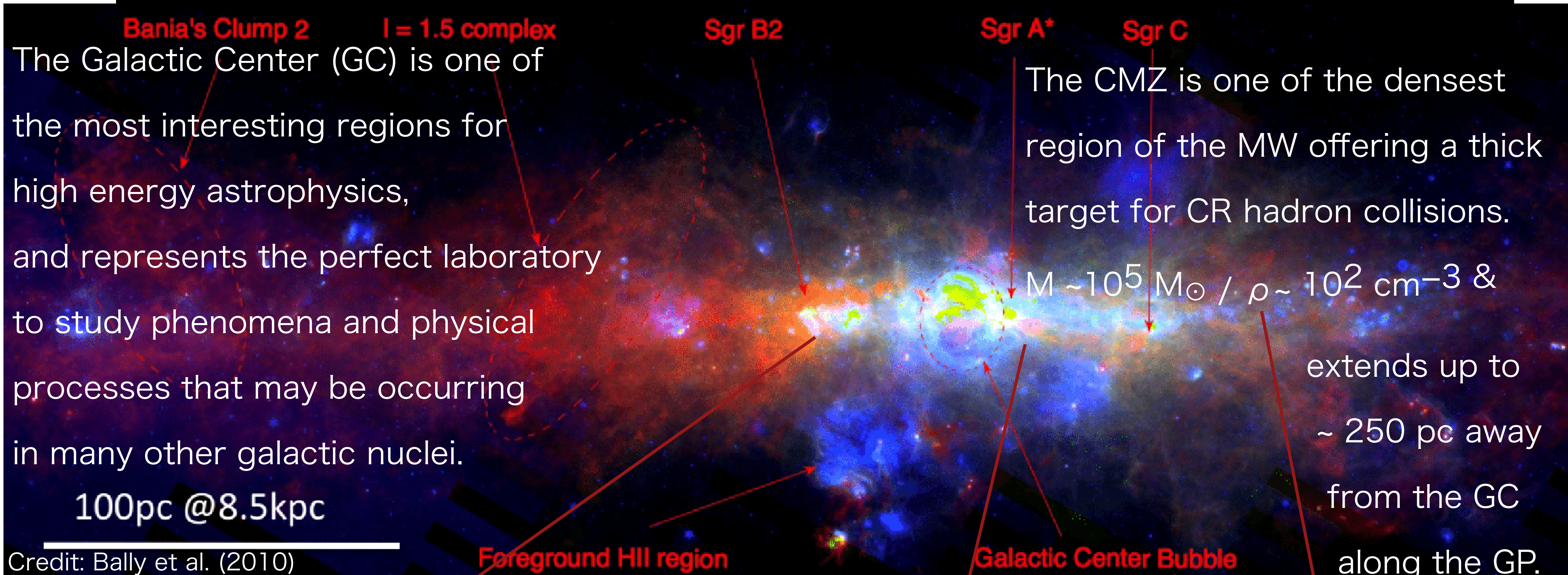
This scenario represents the extrapolation at the GC position of the diffuse emission tuned on local observations . . .

Credit: Ibraheem Mohammed

THE GALACTIC CENTER REGION

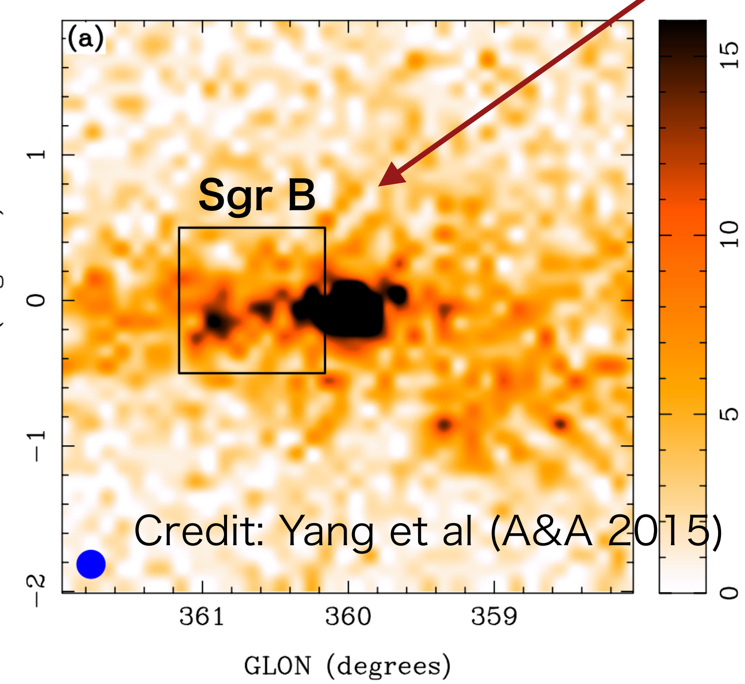
The Galactic Center (GC) is one of the most interesting regions for high energy astrophysics, and represents the perfect laboratory to study phenomena and physical processes that may be occurring in many other galactic nuclei.

The CMZ is one of the densest region of the MW offering a thick target for CR hadron collisions. $M \sim 10^5 M_\odot$ / $\rho \sim 10^2\ cm^{-3}$ & extends up to ~ 250 pc away from the GC along the GP.

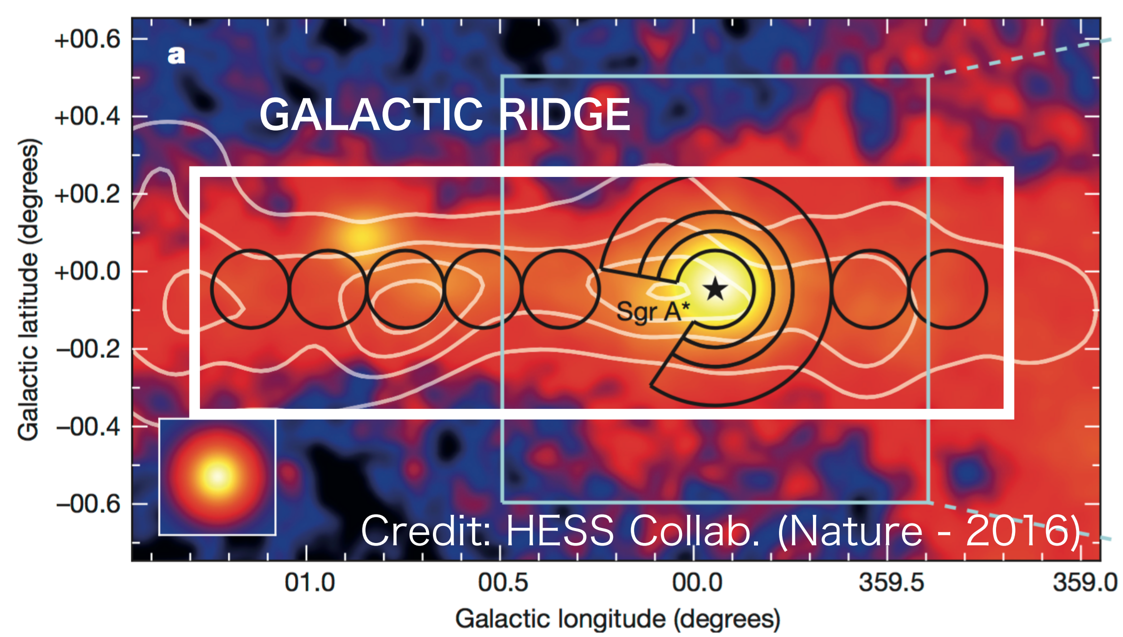


Credit: Bally et al. (2010)

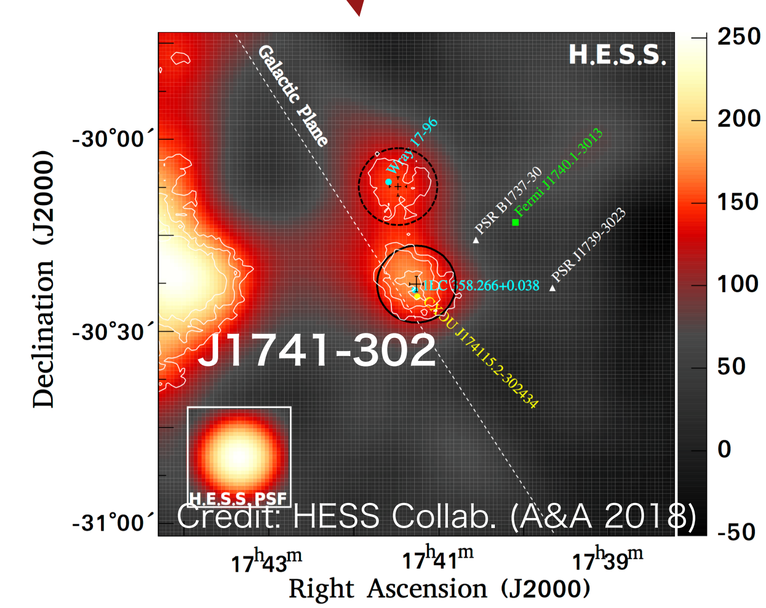
24μm, 70μm, 350μm



Credit: Yang et al (A&A 2015)

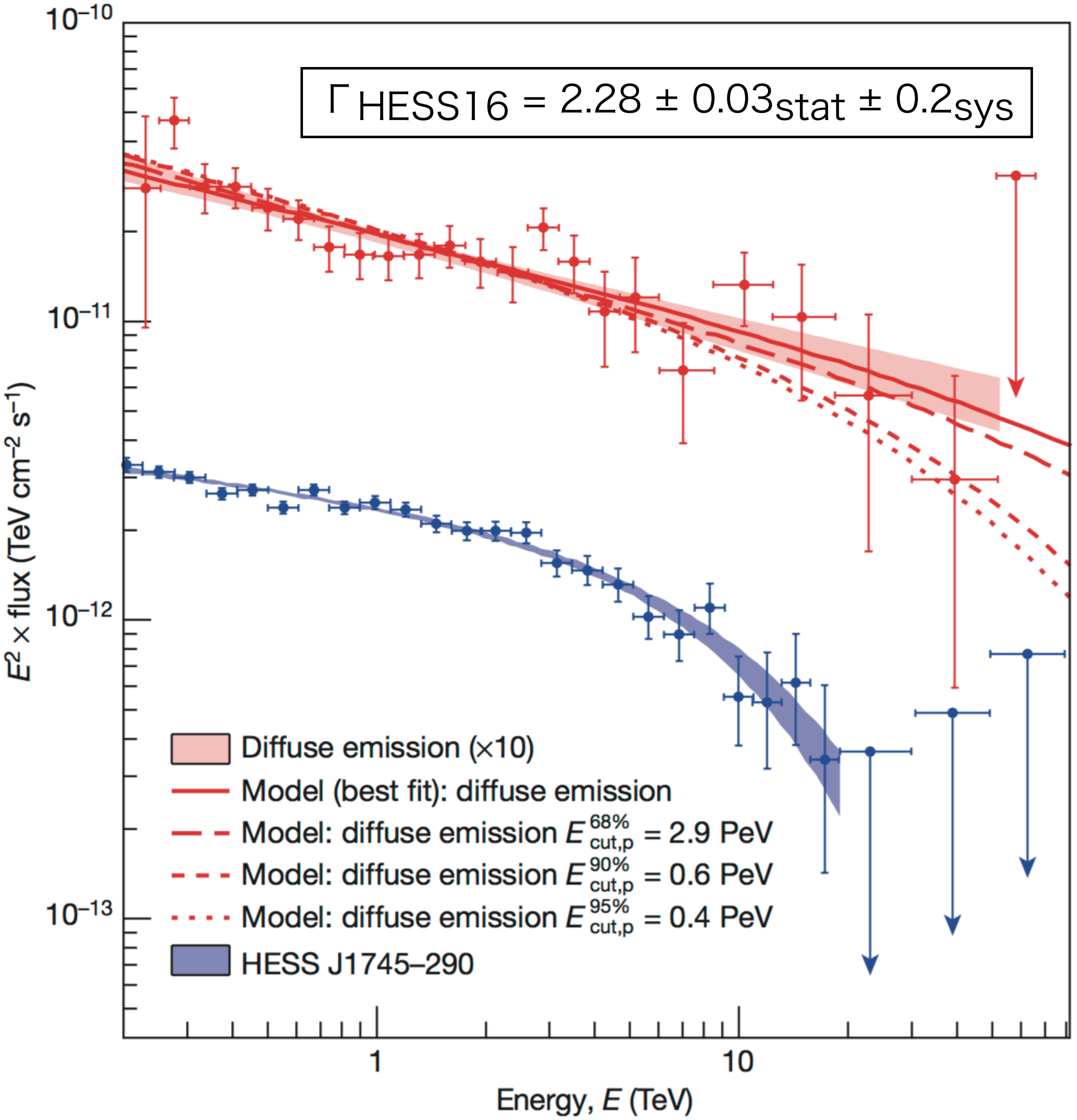


Credit: HESS Collab. (Nature - 2016)



Credit: HESS Collab. (A&A 2018)

H.E.S.S. MEASURAMENTS: PEVATRON SCENARIO



The diffuse emission from the CMZ is correlated with the gas distribution filling the region.

The observed spectrum is harder ($\Gamma \simeq 2.3$) than that measured at the Earth position ($\Gamma \simeq 2.7$).

A fresh accelerated (hard) CR hadron component was invoked to explain the emission (PeVatron).

Credit: H.E.S.S. Coll. (Nature 2016)

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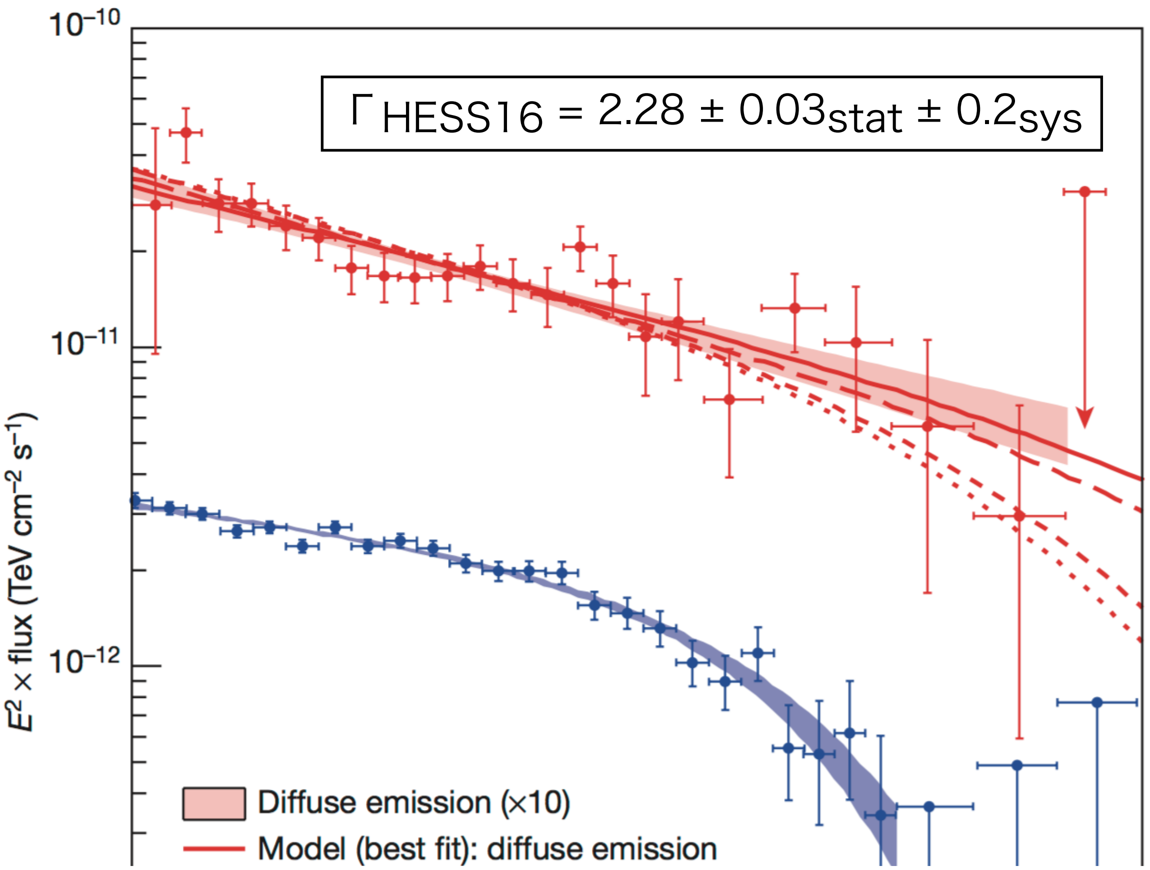

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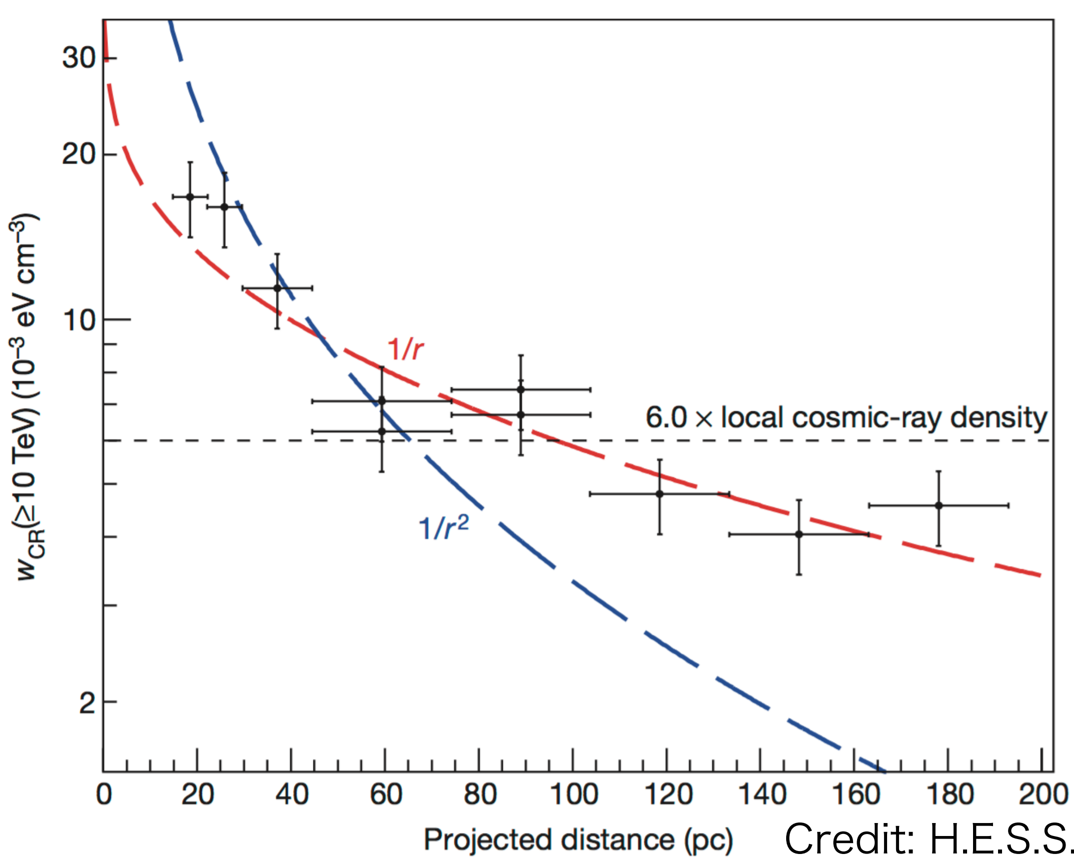


The inferred CR density profile is consistent with that expected from CR diffusing out a stationary source & continuous CRs injection in the CMZ (but is may also be compatible with a constant for R > 50 pc).

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

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

Credit: H.E.S.S. Coll. (Nature 2016)

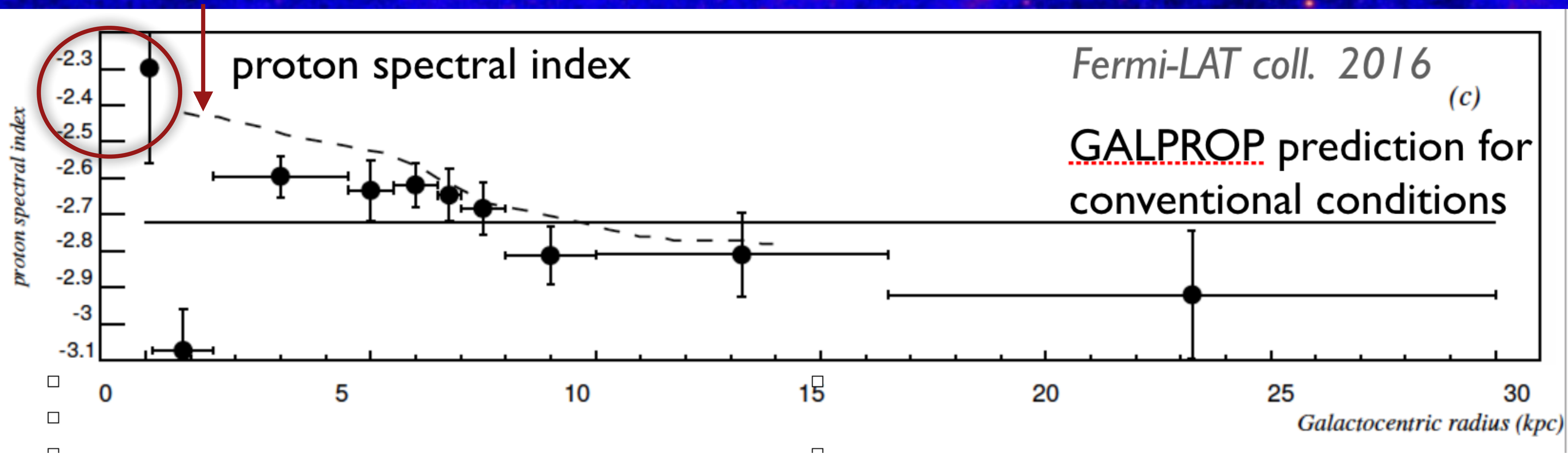
TOWARDS INHOMOGENEOUS CR DIFFUSION SCENARIO

Large-scale background detected by Fermi-LAT is explained in terms of the galactic CR populations (CR-sea) diffusing inside our Galaxy.
The so-called Gamma Model provides CRs undergo to inhomogeneous diffusion due to the linear dependence of diffusion coefficient with galactocentric distance & rigidity (Gaggero et al. - PRD 2015).
Such dependence is motivated by several independent analyses of Fermi-LAT data showing the spectral index of the γ-ray diffuse emission to increase from $\Gamma \sim -2.7$ to ~ -2.3 for R decreasing from 10 to 0 kpc.
Due to the large uncertanities of the proton spectral index in the inner galaxy, this hypothesis represents an extrapolation for R = 0 of the trend between 8 kpc < R < 3 kpc.

Dashed Line: Gaggero et al. (PRD 2015)

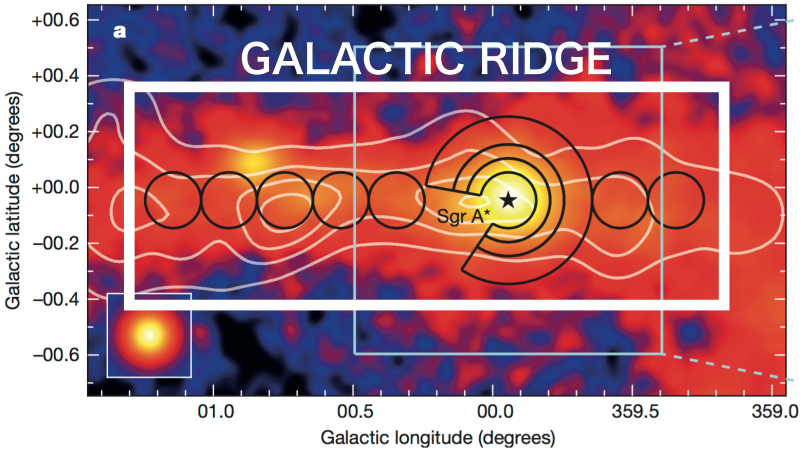
$$D(E) = D_0 \left(\frac{E}{E_0} \right)^{\delta(r)}$$

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

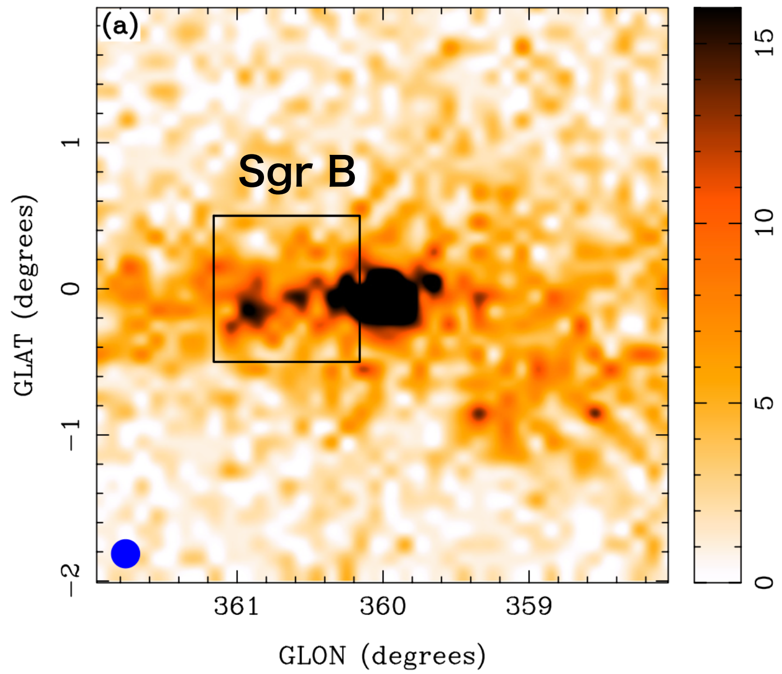


An additional hardening is present at 300 GeV/n, as observed by PAMELA, AMS-02, CREAM (Gaggero et al. - ApJ L. 2015).
This feature is able to reproduce the 15 TeV Milagro anomaly.

MODEL TESTING: GALACTIC RIDGE & SgrB

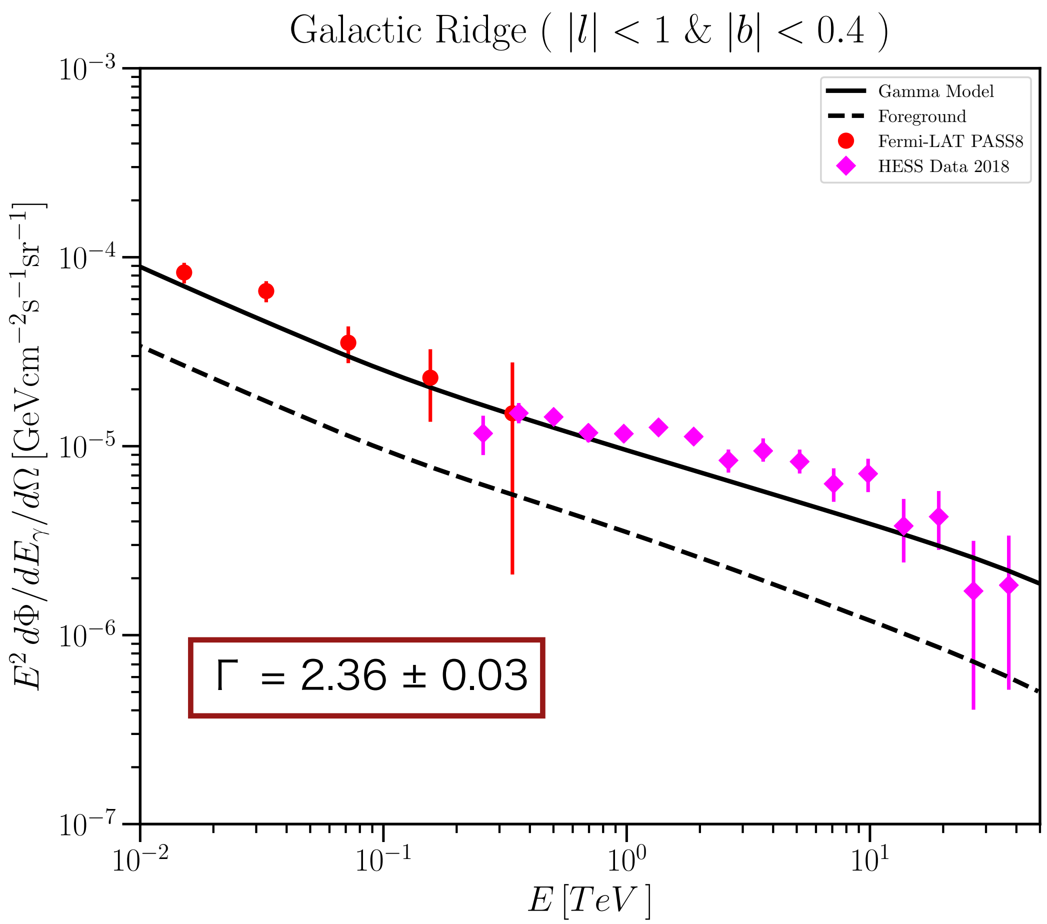


In order to extend the spectrum to few GeVs, Fermi-LAT analysis of ~10 y is computed subtracting FL8Y point-like sources.



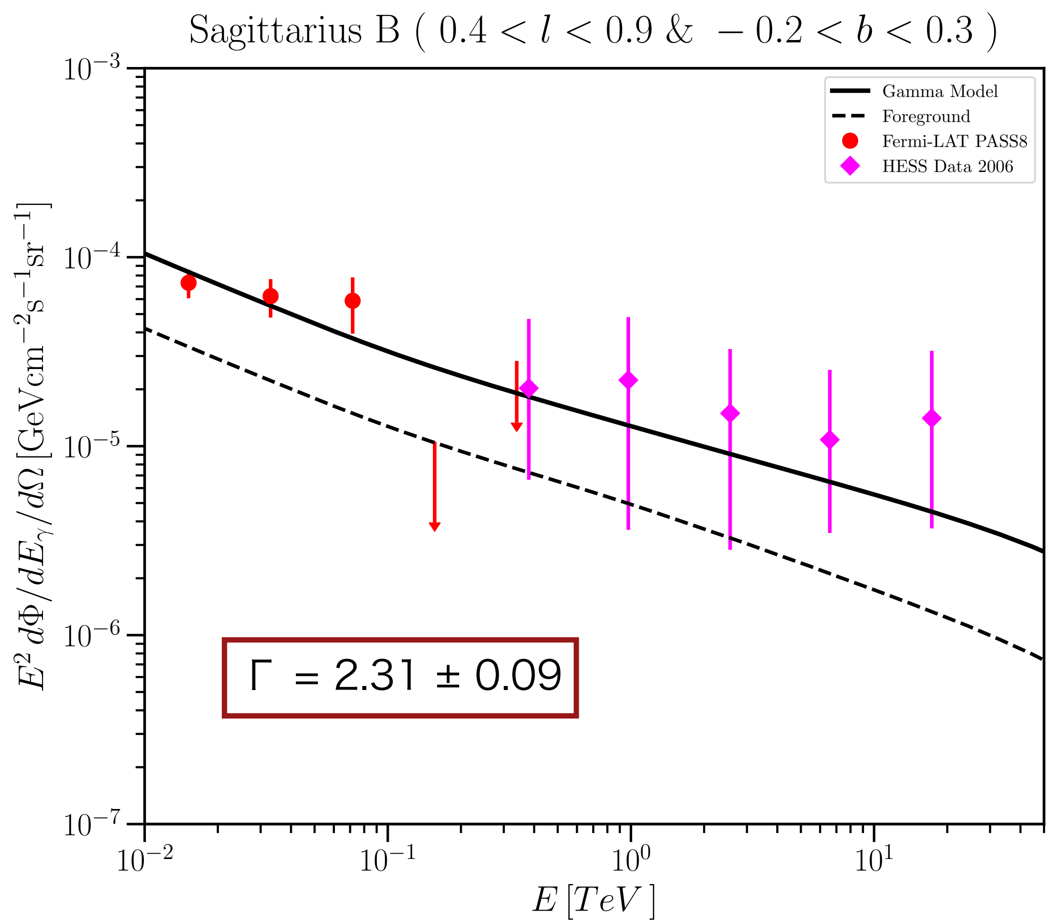
Gamma Model predicts the observed emission in both regions.

The absence of an additional feature might be the evidence against the presence of a new component in the CR population.

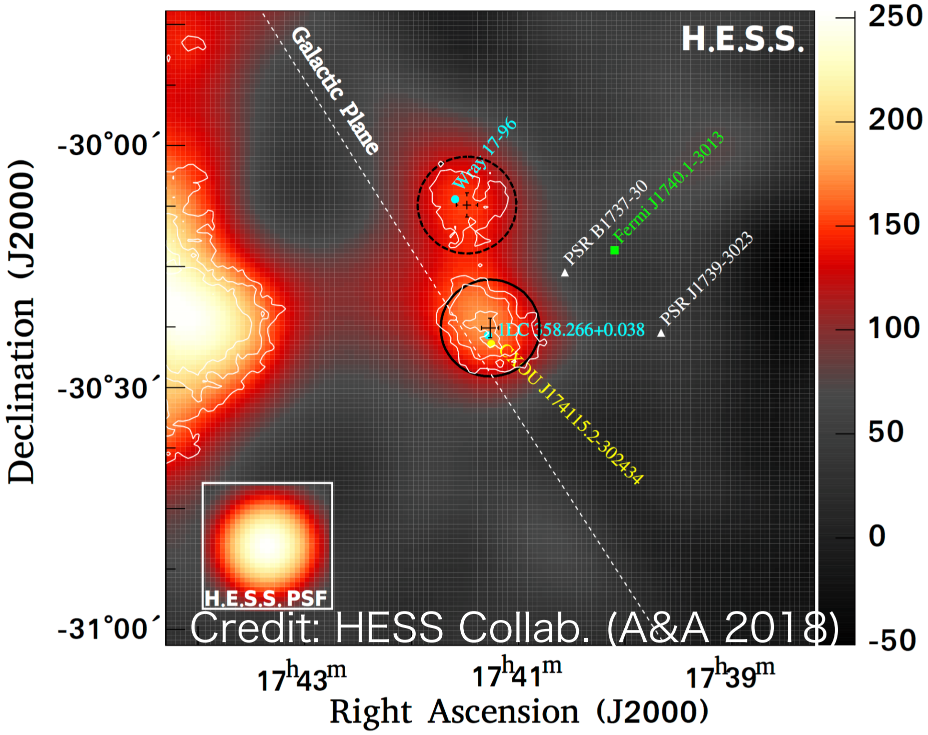


Gamma Model predictions with & without (dashed line) the contribution of the CMZ.

The latter represents our astrophysical background.



MOVING AWAY THE CMZ: J1741-302



l=-1.7°, distance 260 pc

Discovered by H.E.S.S. (A&A 2018).

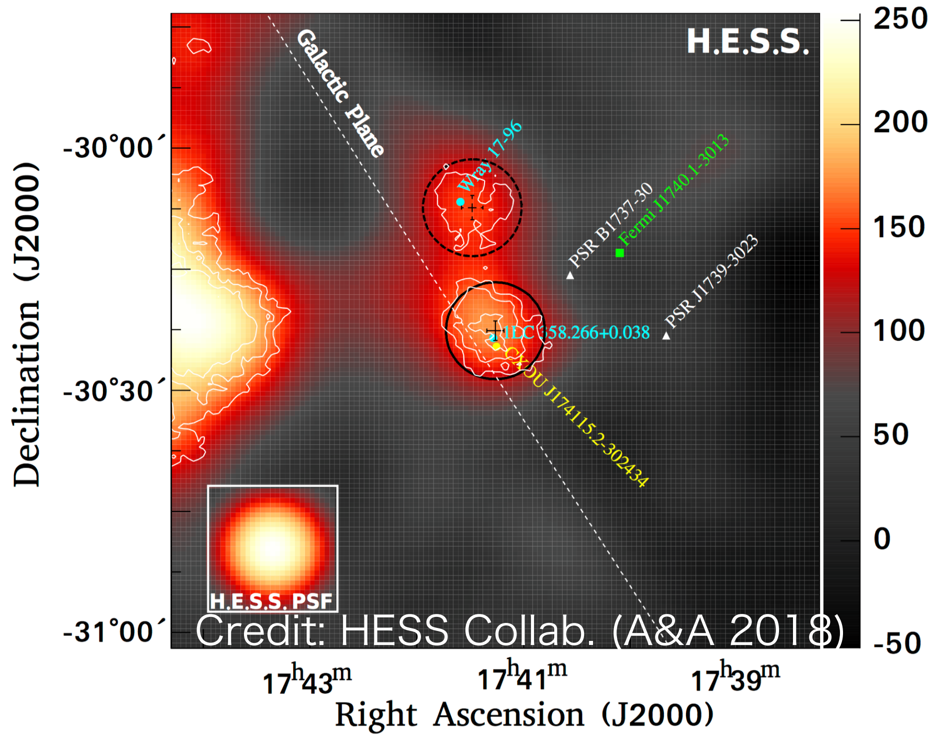
The energy spectrum extends up to10 TeV with no evidence of a cut off.

The Collaboration suggests that the parental particle population producing such emission extends up to tens of TeV (leptonic case) or hundreds of TeV (hadronic case).

Leptonic scenario: electrons with energies of hundreds of TeV, undergoing IC scattering off CMB or ambient radiation fields (relic PWN related to PSR B1737–30), or binary scenario related to the compact radio source 1LC 358.266+00.038, could explain the emission. The no evidence of HE γ-ray counterpart, X-ray emission from PWN, variability, and the point-like nature of the source disfavor the leptonic scenario.

Hadronic Scenario: the observed emission arises from the interactions of CR with the dense molecular cloud within the region. This represents the most plausible astrophysical (passive?) source associated with J1741-302.

MOVING AWAY THE CMZ: J1741-302



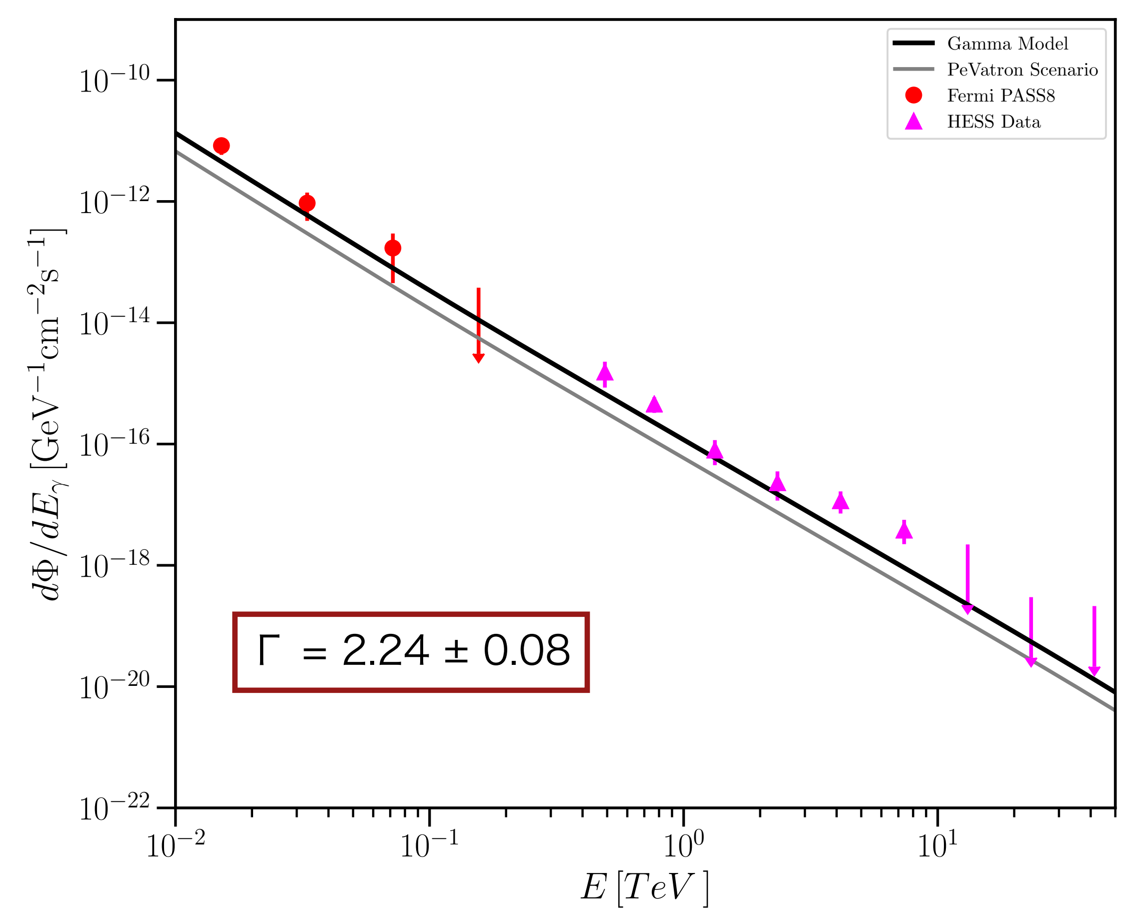
l=-1.7°, distance 260 pc

The most plausible source is the dense molecular cloud with M = 6.8 × 10^4 $M_\odot$

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

Gamma Model matches Fermi-LAT + H.E.S.S. data.

The absence of a prominent features in γ-ray spectrum disfavour the presence of a component due to CR acceleration in the Galactic Center region



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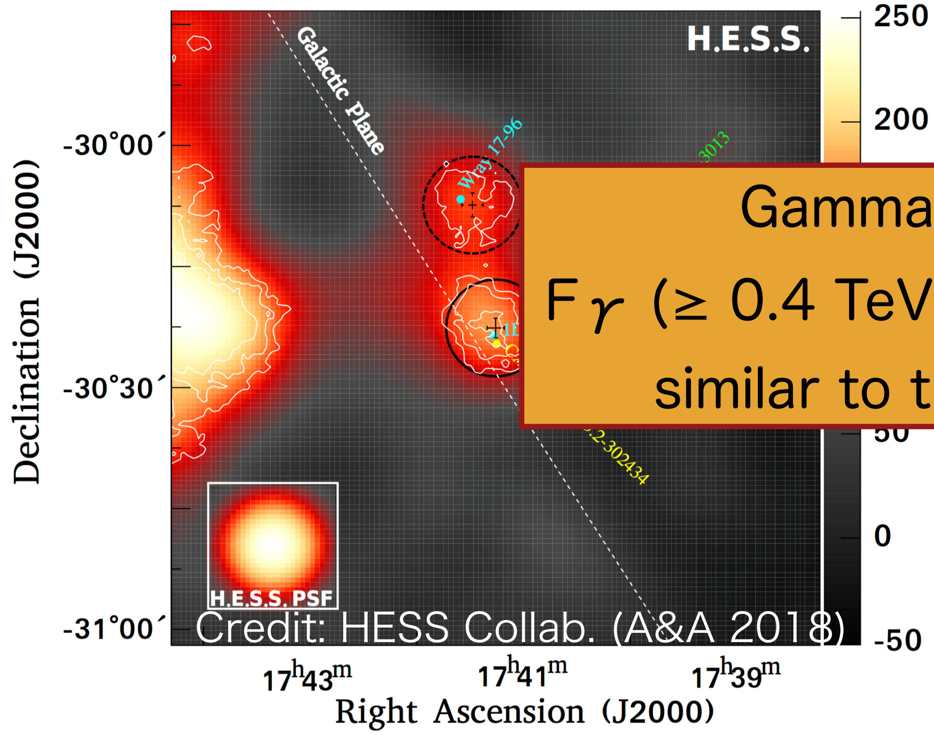
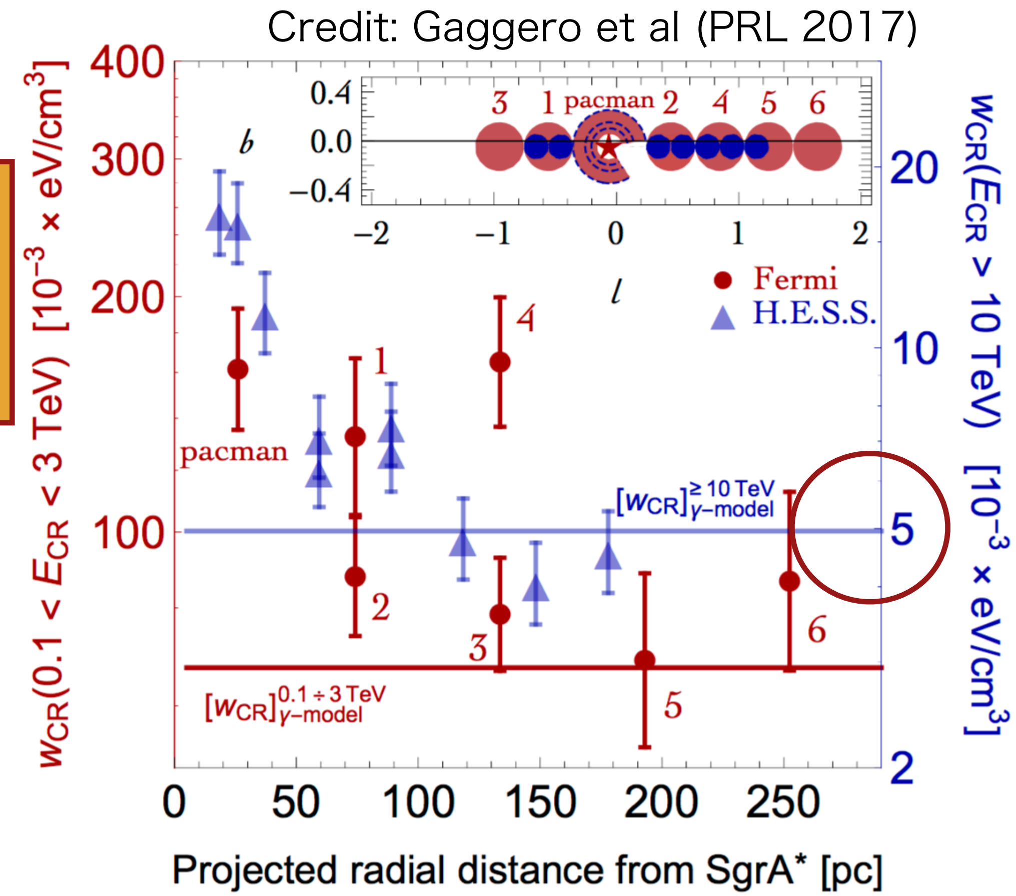


Gamma Model predicts a flux

F_γ ($\geq$ 0.4 TeV) $\simeq 5 \times 10^{-13}$ erg cm^{-2}s^{-1}

similar to that observed by H.E.S.S.

l=-1.7°, distance 260 pc

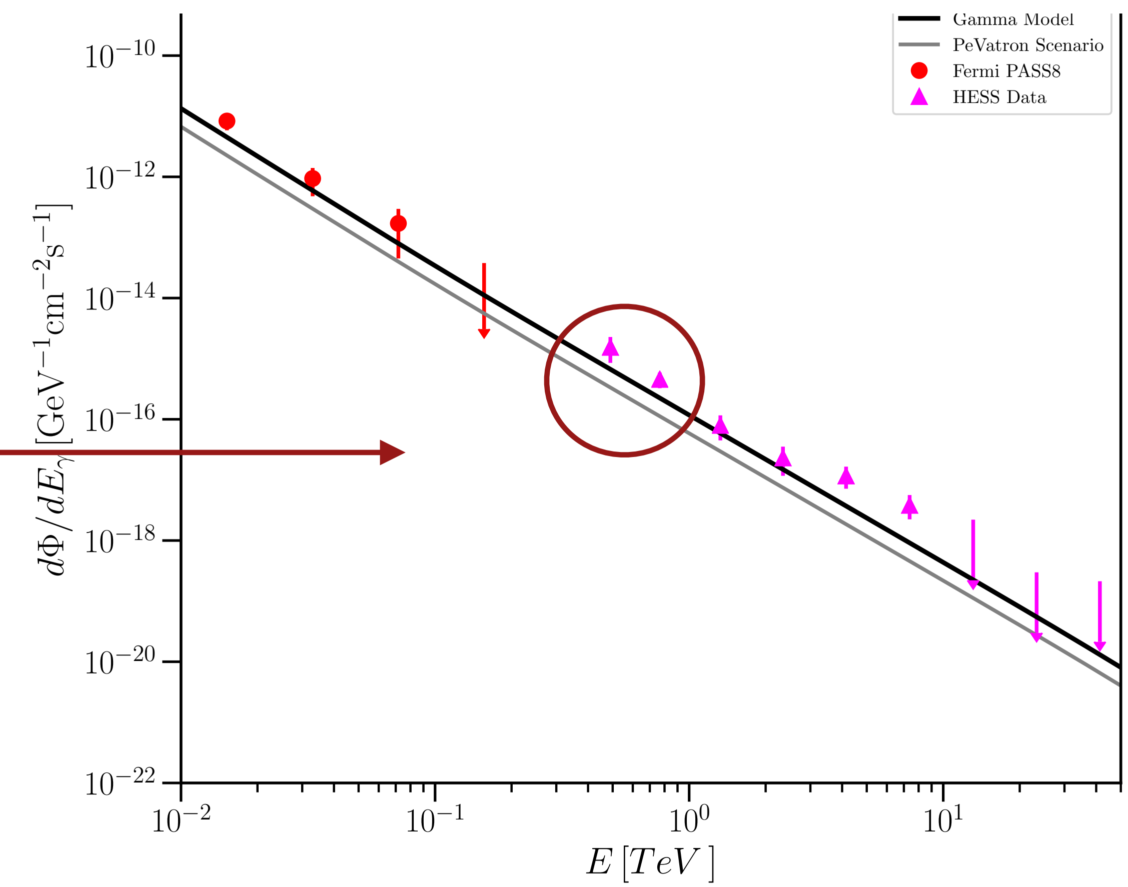


Using the CR density inferred by the H.E.S.S. collaboration

following 1/r profile . . .

PeVatron scenario provides w_{CR} less than half

the value predicted by f Gamma Model.



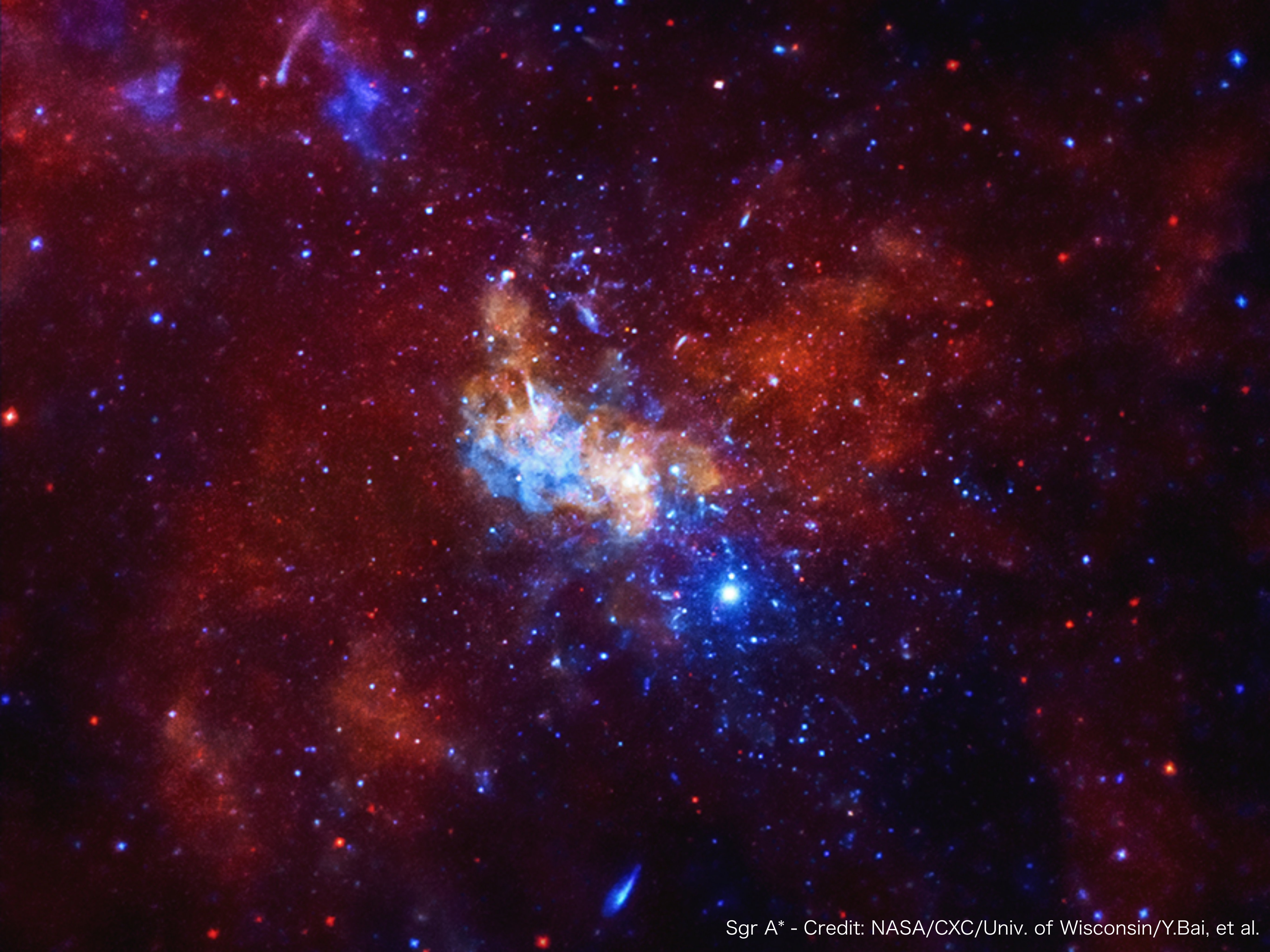
CONCLUSIONS

The diffuse γ-ray emission from the CMZ measured by H.E.S.S. and Fermi -LAT from few GeVs up to 50 TeV may be originated by the Galactic CR-sea if that is diffusing through our Galaxy inhomogeneously producing a harder spectrum in the Galactic Center. The CR-sea then shines in the Galactic Center because of the dense molecular clouds filling the region.

The large uncertainties on the gas density distribution and the dynamical description of the central region does not allow definitive conclusions.

Molecular clouds reside farther from the GC, inside the 1 kpc, may be the ideal targets to discriminate between the PeVatron and hard diffusion scenario.

The adoption of a more realistic 3D gas distribution maps in the models construction, and the upcoming Cherenkov Telescope Array (CTA) — thanks to the improved angular resolution and energy sensitivity — should be able to discriminate between PeVatron scenario and/or a steady-state CR background contribution to the γ-ray emission in the Galactic Center.



Sgr A* - Credit: NASA/CXC/Univ. of Wisconsin/Y.Bai, et al.