The Contribution of Cosmic Rays Interacting With Molecular Clouds to the Galactic Center Gamma-Ray Excess

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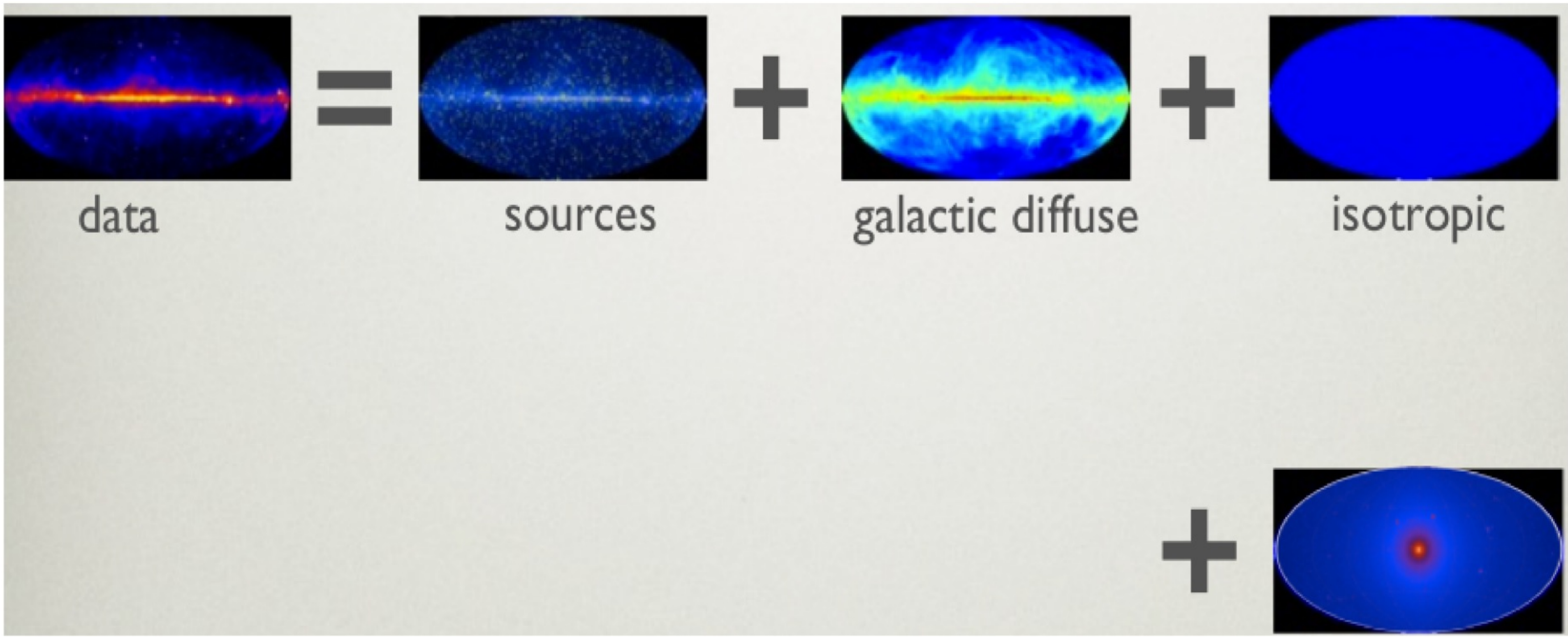
CG and O. Macias, Phys. Rev. D (2013)

O. Macias and CG, Phys. Rev. D (2014)

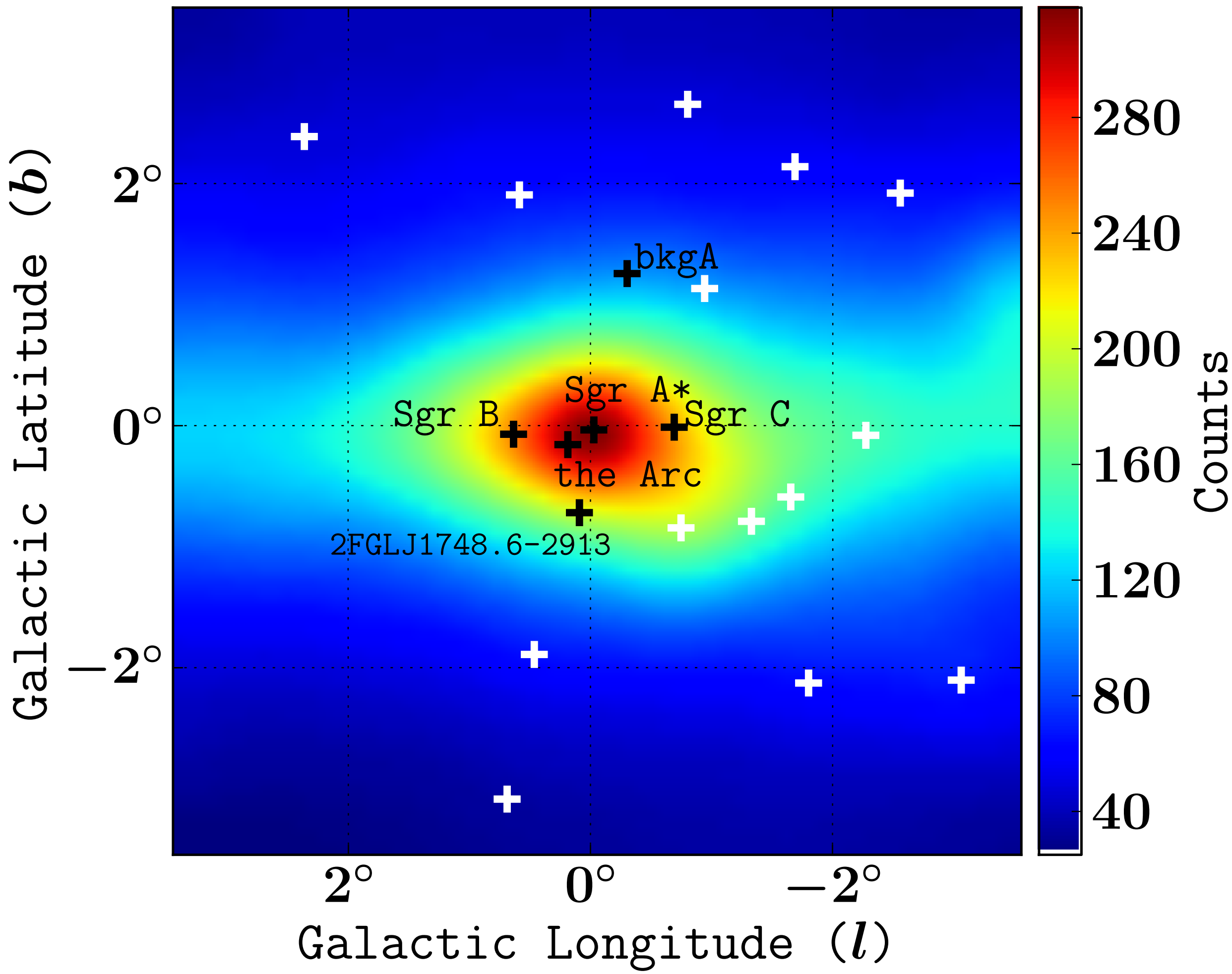
Fermi LAT Components



Dark Matter ?

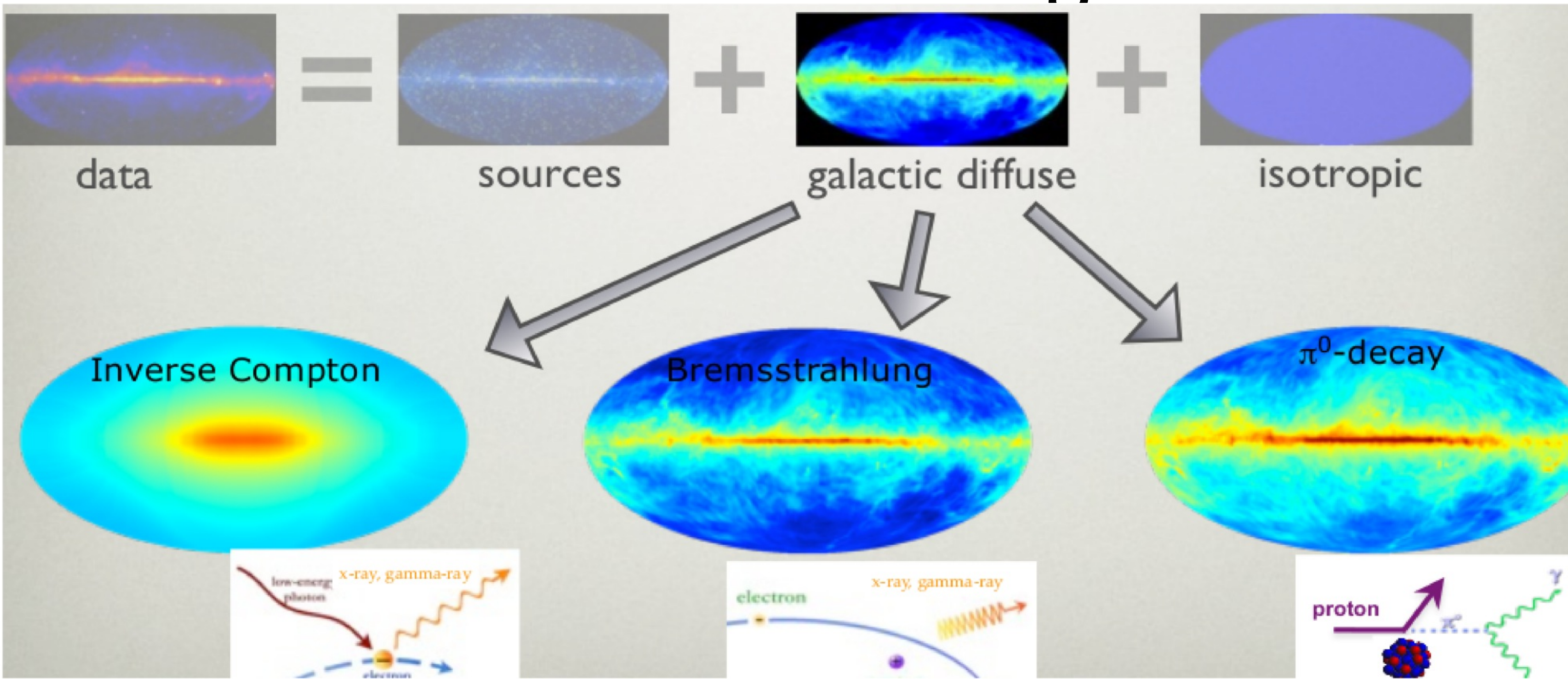
Excess Emission from Galactic Center

- Vitale et al. (2009)
- Confirmed by many others (Hooper, Linden, Abazajian, Kaplinghat, …) including CG and Macias (2013, 2014).



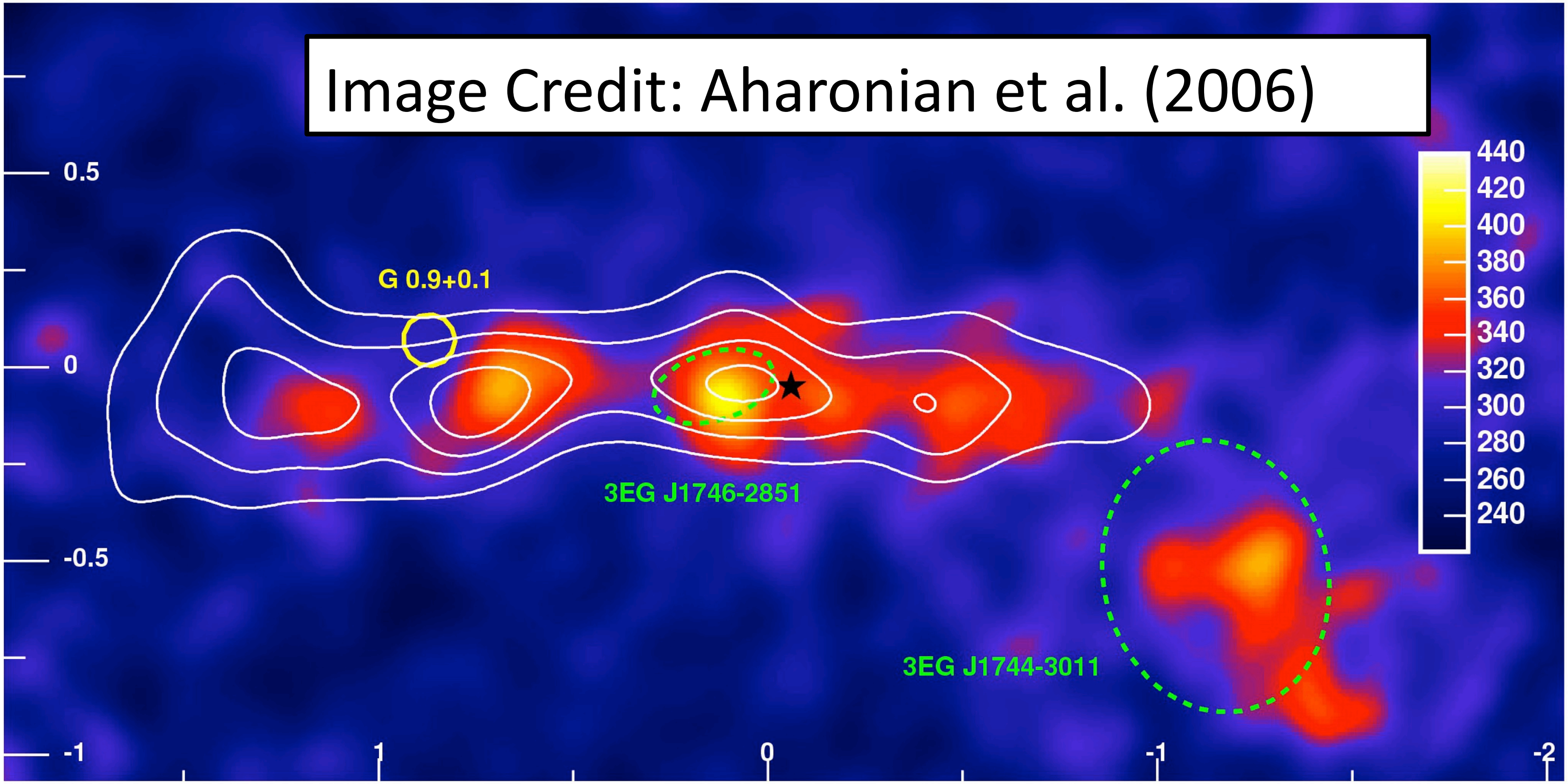
- Used Fermi-tools with 45 months of pass 7 data, and 300 MeV to 100 GeV energy range.

Diffuse Galactic Background



- Generated using gas column densities, and a GALPROP (Strong+2007) generated Inverse Compton (IC) intensity map.
- Effectively, assumes cosmic-ray population only varies on kpc scales.

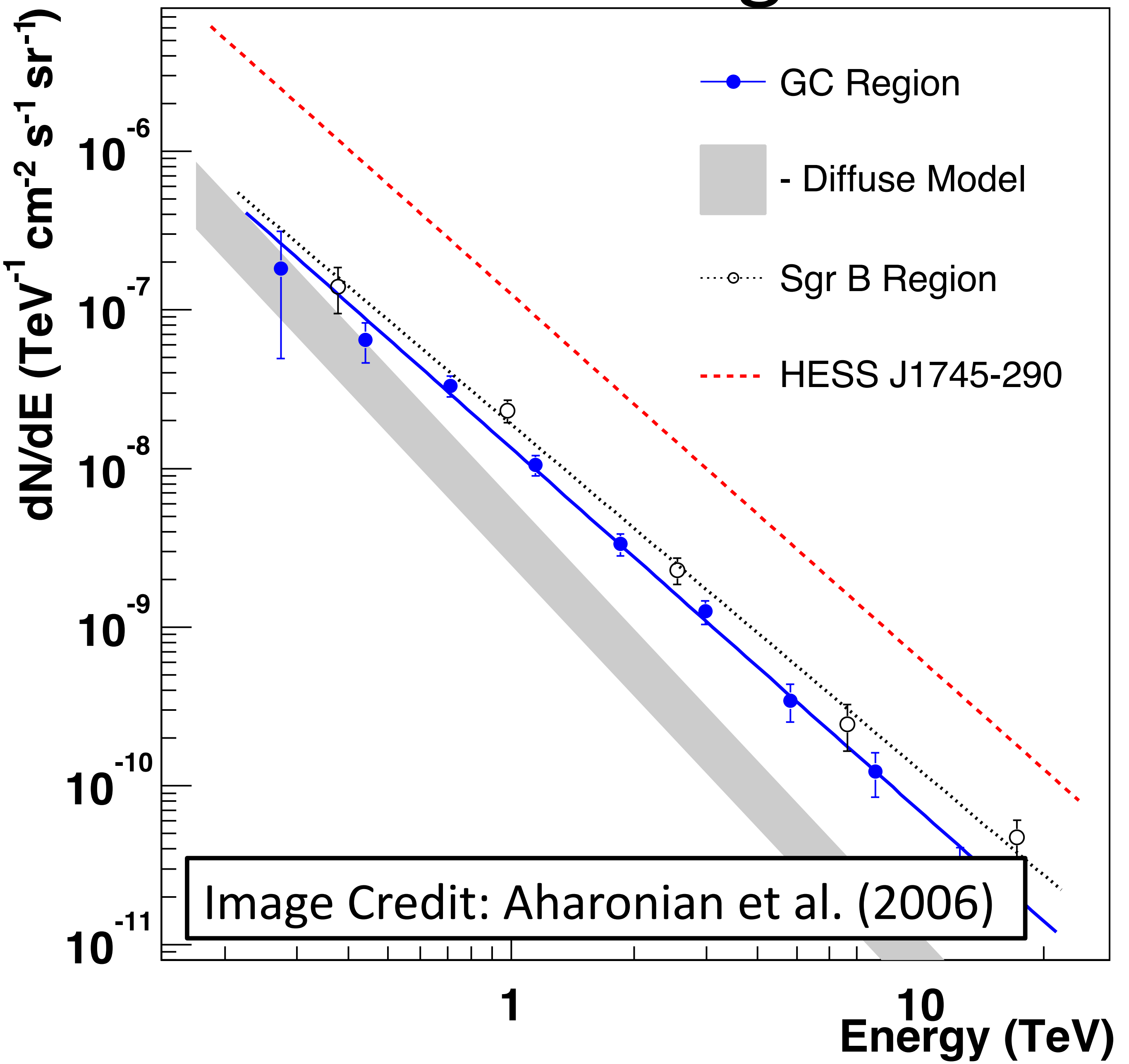
Galactic Center Ridge



- Ridge seen in HESS TeV gamma-ray data.
- White contour lines indicate the density of molecular gas, traced by its CS emission.

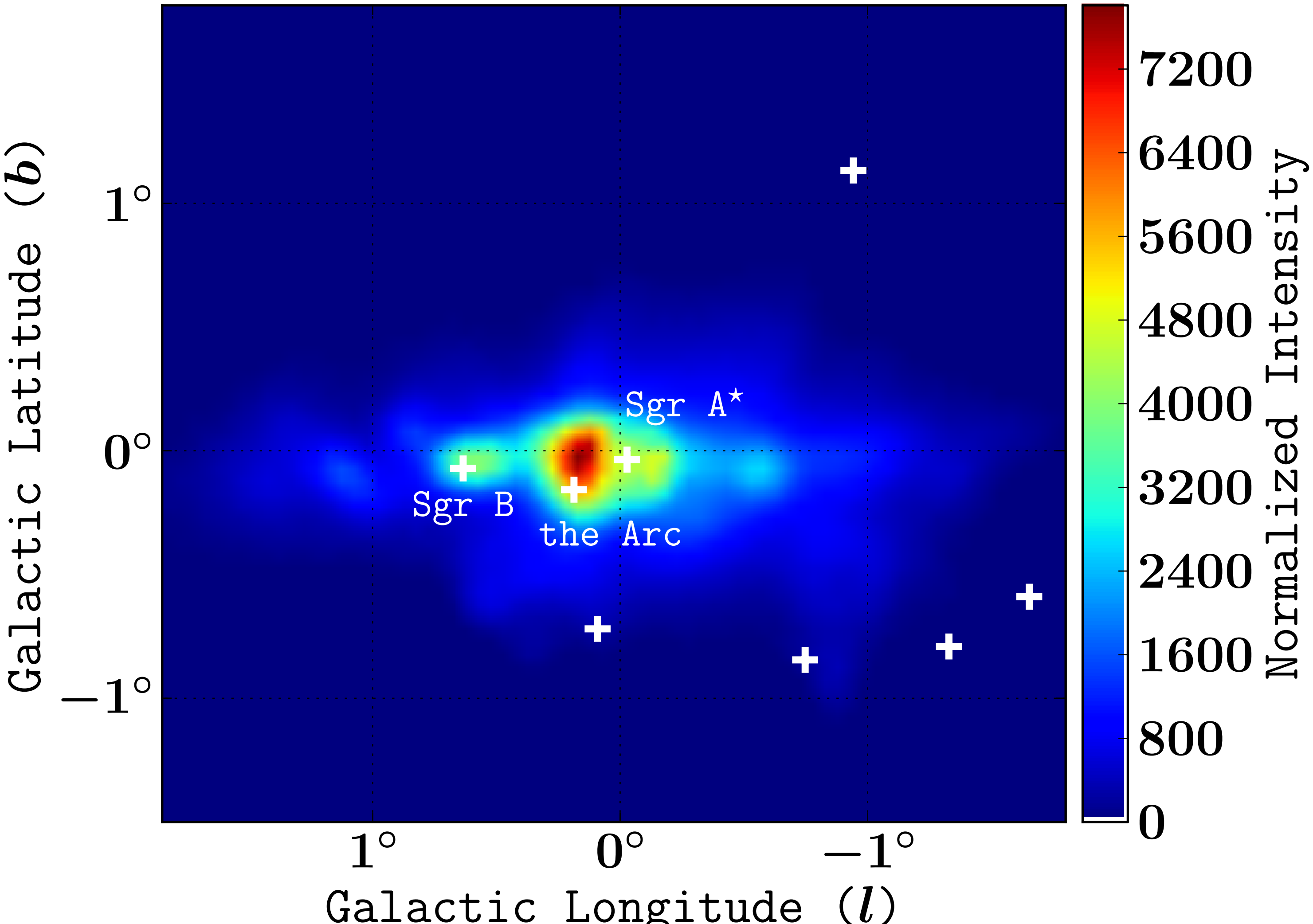
Galactic Center Ridge

Model: Cosmic-ray protons emitted from Sgr A* region, collide with molecular gas, produce pions which decay to give gamma-ray photons. Steady state by Crocker +2011 and Yusef-Zadeh +2012

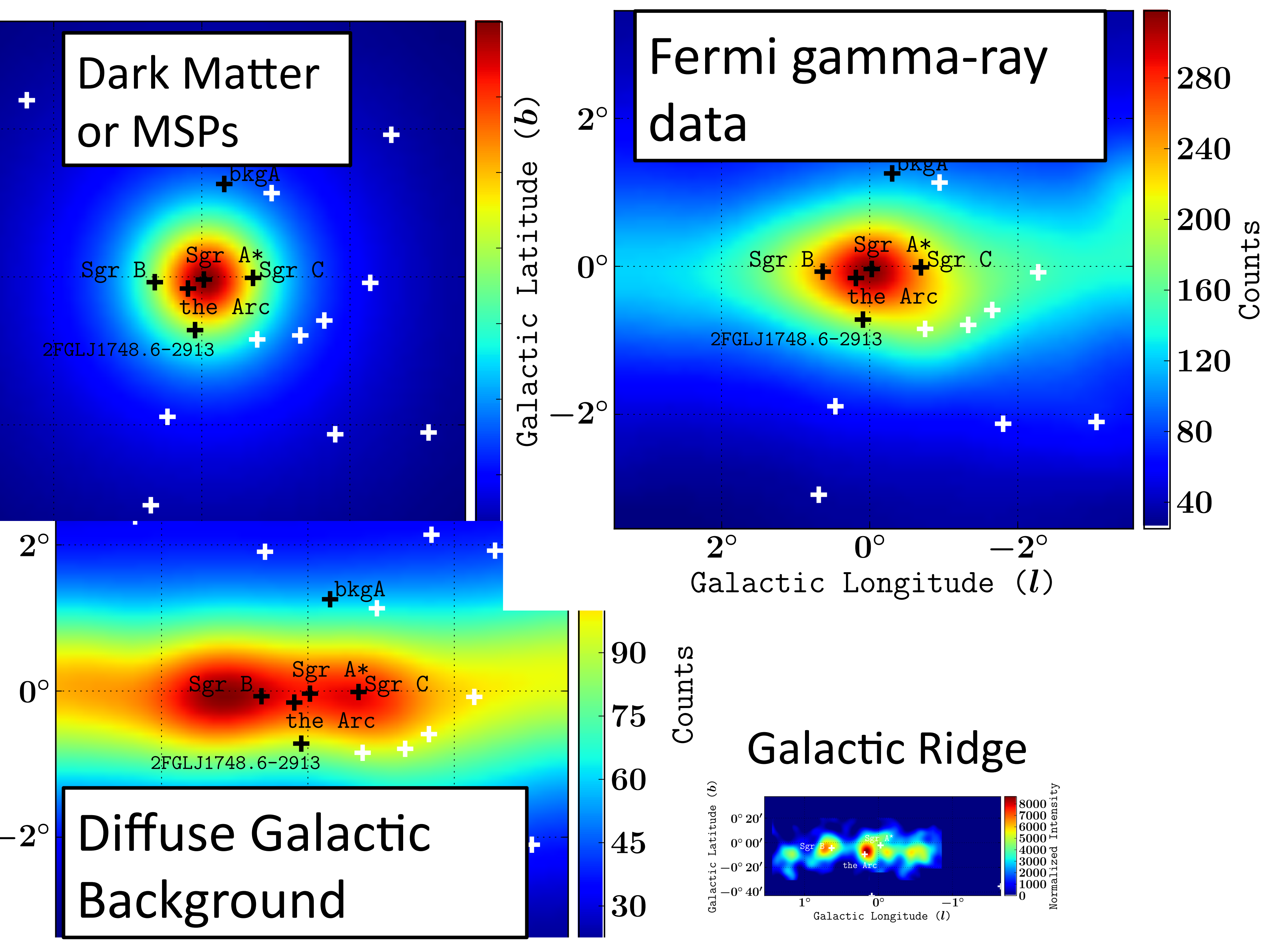


Galactic Center Ridge

- Radio data also shows a ridge like structure as can be seen in the 20cm emission map.



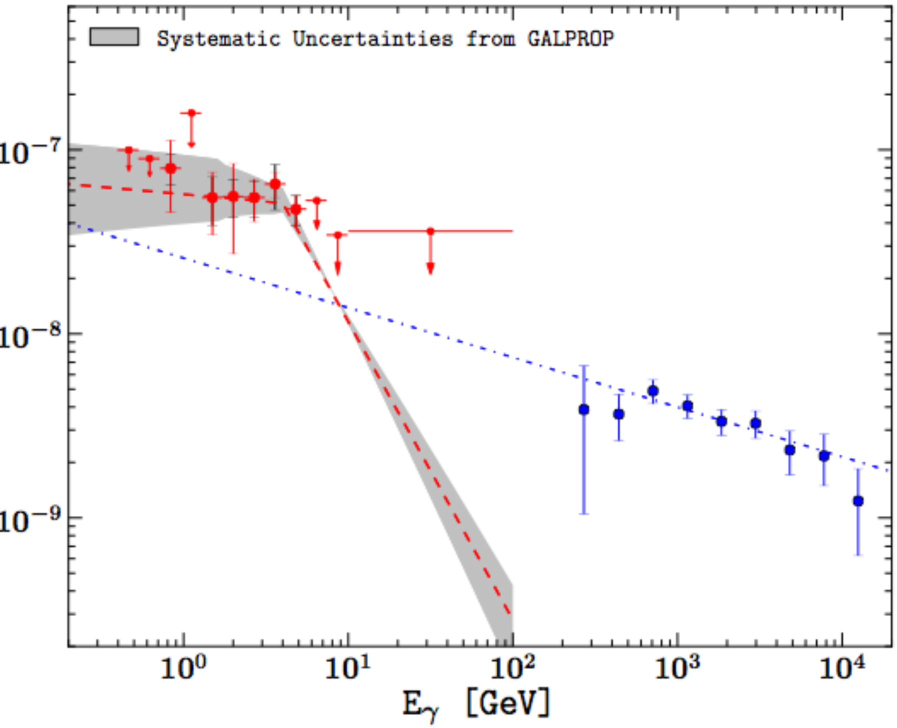
- This radio data can be explained by synchrotron emitting cosmic-ray electrons (Crocker+2011, Yusef-Zadeh+2012).



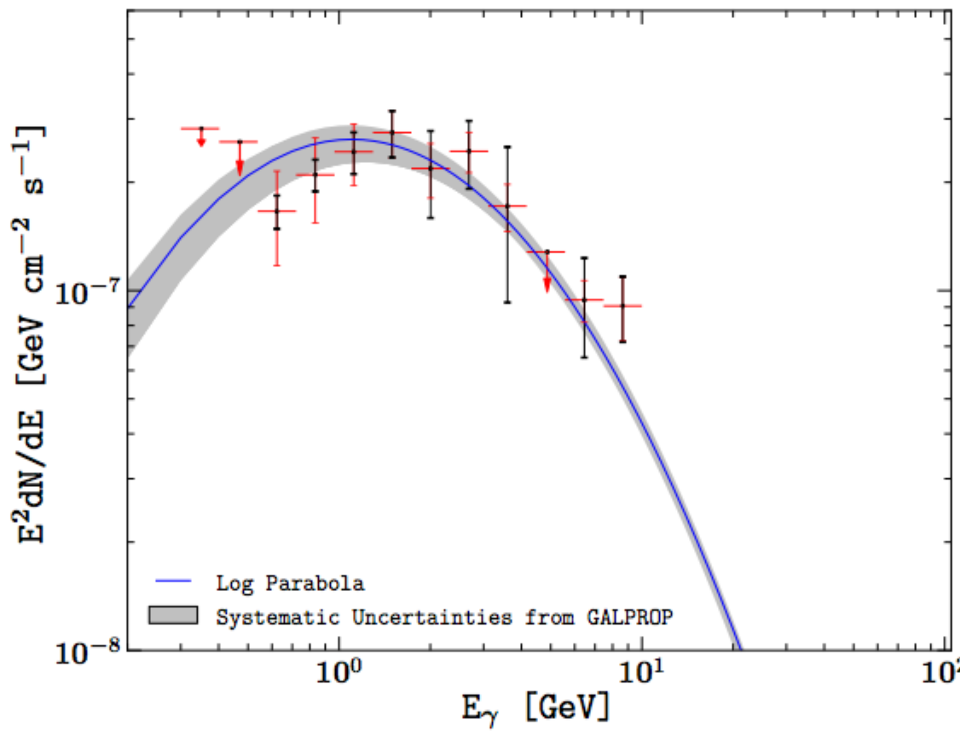
Dark Matter or MSPs
bkgA
Sgr A*
Sgr B
Sgr C
the Arc
2FGLJ1748.6-2913
Galactic Latitude (b)
Fermi gamma-ray data
2°
0°
−2°
Galactic Longitude (l)
280
240
200
160
120
80
40
Counts
Diffuse Galactic Background
90
75
60
45
30
Galactic Ridge
0° 20′
0° 00′
−0° 20′
−0° 40′
1°
−1°
8000
7000
6000
5000
4000
3000
2000
1000
0
Normalized Intensity

Spectra

Ridge

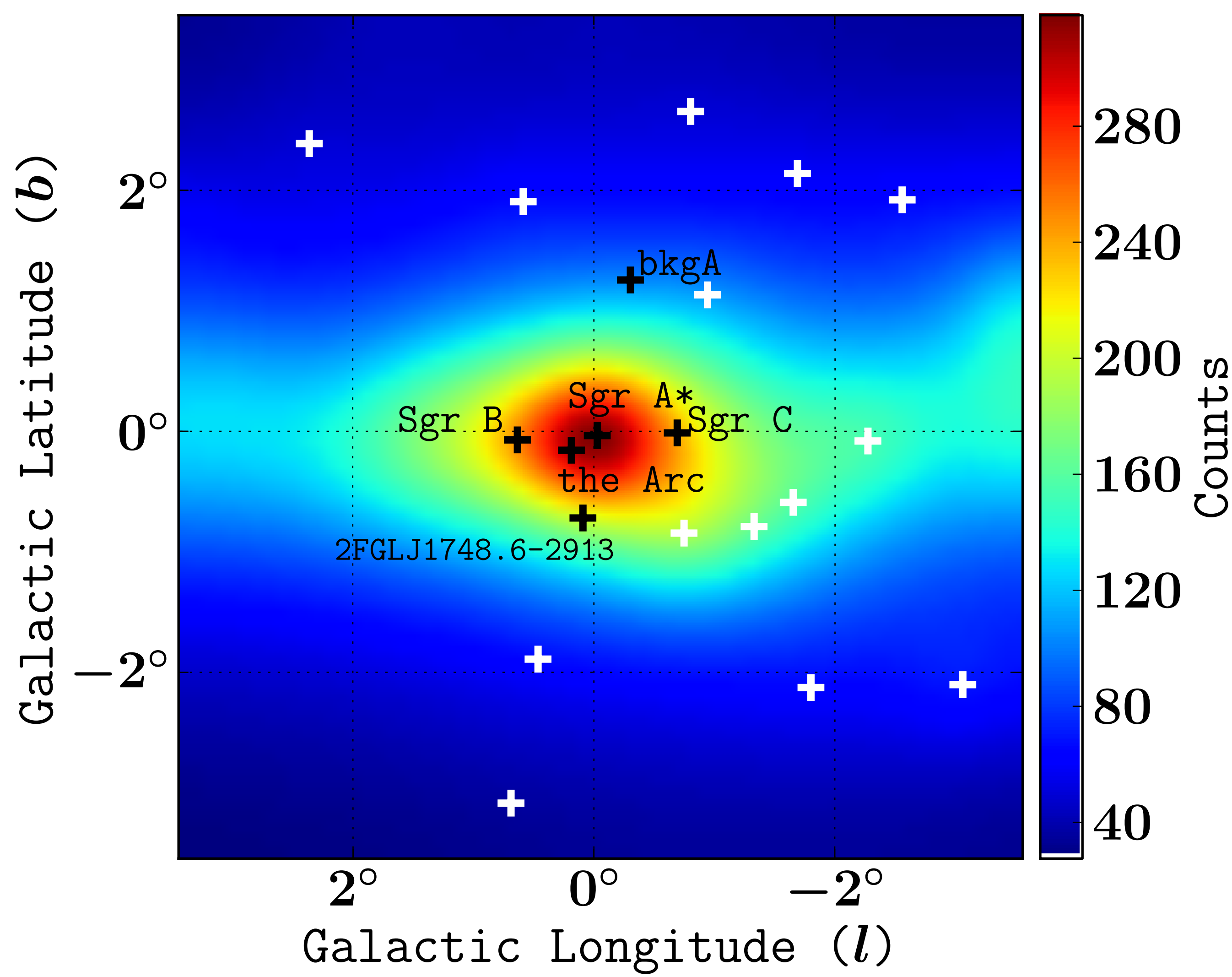


Spherically symmetric: radius$^{-2.4}$



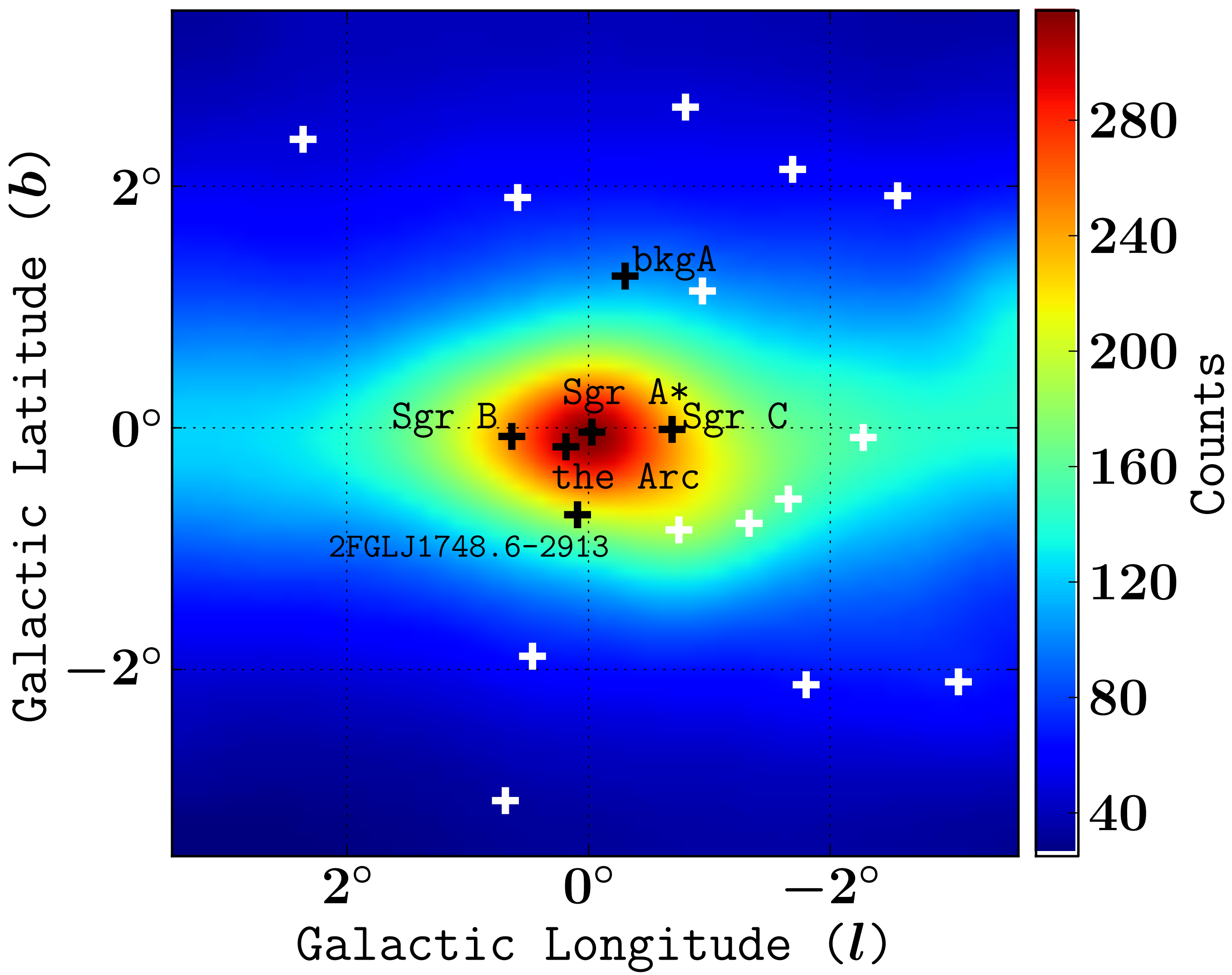
- Cosmic-ray models for the ridge: mainly pion decay (Crocker +2011) or mainly bremsstrahlung (Yusef-Zadeh+2012).
- Models for spherical component: dark matter annihilation (Hooper&Goodenough, 2009) or unresolved millisecond pulsars (MSPs) (Abazajian 2010).

Dark Matter Model



Model = DM (and/or MSPs) + point sources + diffuse Galactic background+extra-Galactic background

Data



Model = DM (and/or MSPs) + point sources + diffuse Galactic background+extra-Galactic background

Millisecond Pulsars

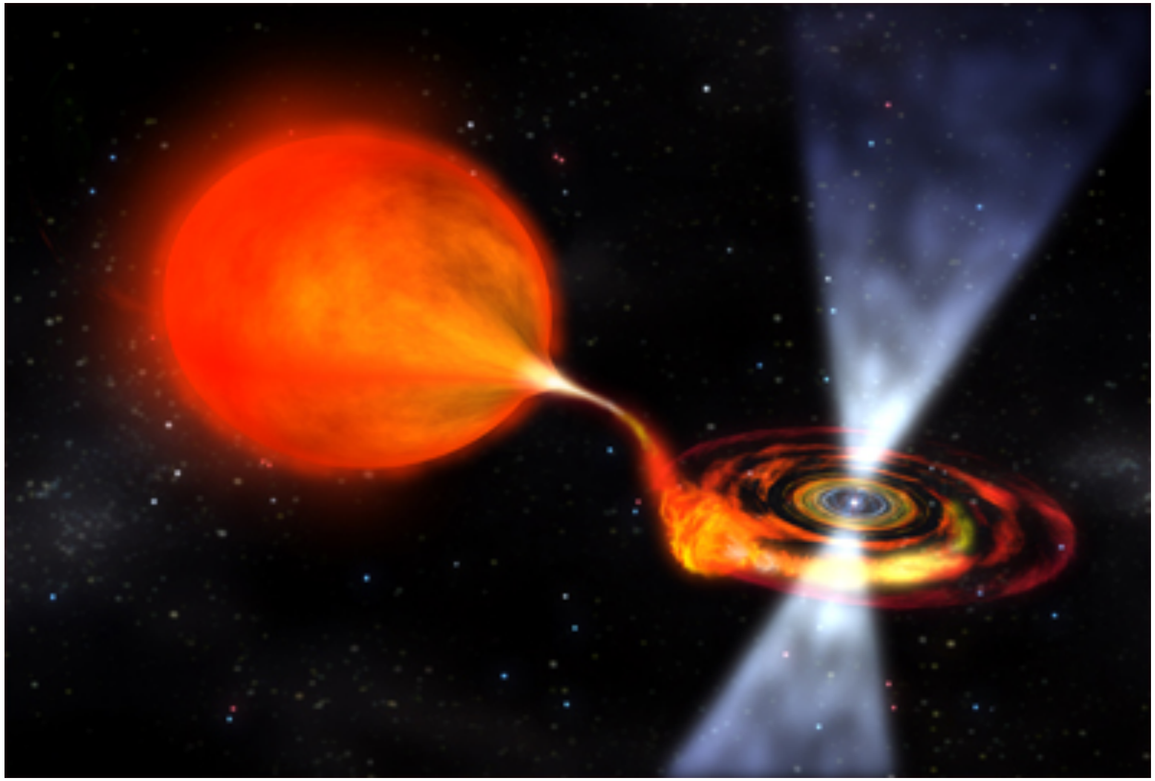


Image: NASA/Dana Berry.

- A unresolved population of millisecond pulsars, have the right spectral and spatial distribution to explain Galactic center excess (Abazajian and Kaplinghat (2012)).

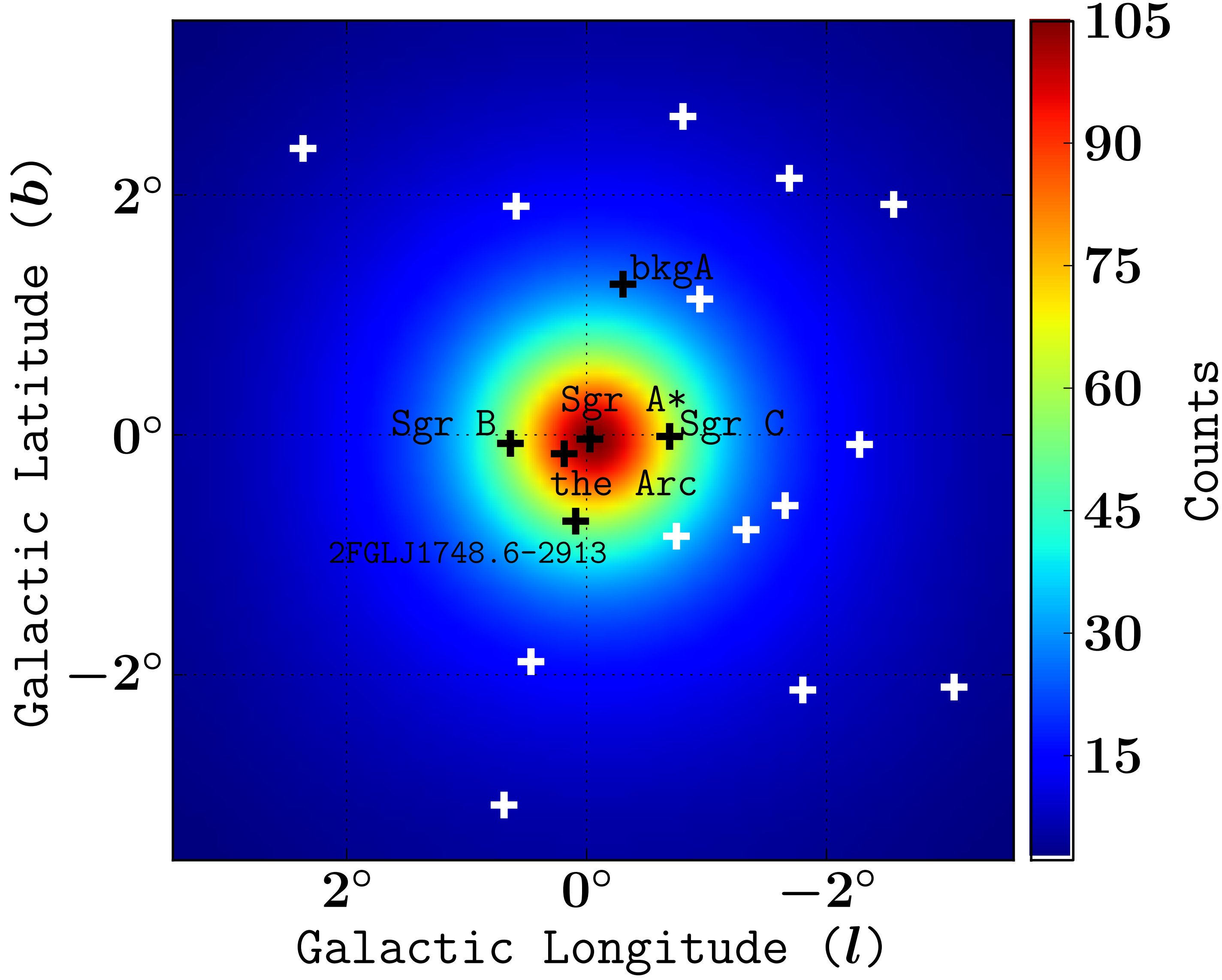
Millisecond Pulsar Spatial Distribution

- Abazajian and Kaplinghat (2012) compare with low mass X-ray binary (LMXB) populations, which should have a similar spatial profile as that of MSPs. LMXBs and MSPs are thought to be different phases of the same binary system.
- Observations targeting LMXBs in M31 show a sharp rise in the surface density within about an arcminute of the center. The inner “excess” is consistent with a population created by stellar encounters in the extremely high density environment in the central regions of the Galactic bulge (Voss and Gilfanov, 2007).
- Abazajian and Kaplinghat (2012) estimate a power-law index of -1.5 ± 0.2 for the projected M31 LMXB between 10 and 100 arcmin which corresponds to between 2 and 20 kpc from the center. The projected distribution corresponding to a model (which has $R^{-2.4}$ (where R is the projected radius), consistent with the surface density profile of the inner M31 LMXB population.

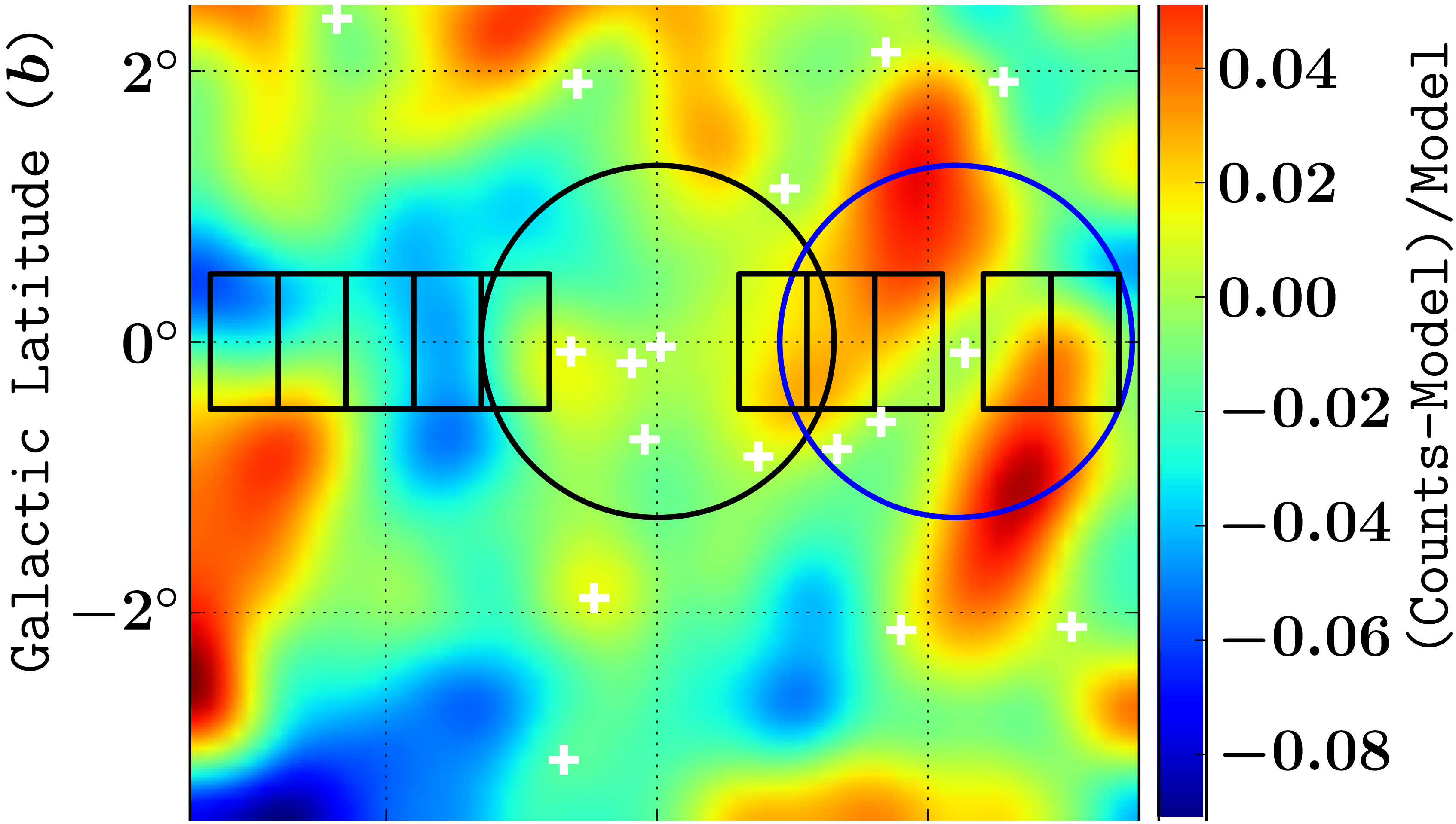
Millisecond Pulsar Spatial Distribution

- The LMXB population in the center of the Milky Way is less well determined. A study using INTEGRAL found too few LMXBs in the inner 1 degree radius to robustly infer a profile but there was slight evidence of steepening compared to the stellar profile in the LMXBs.

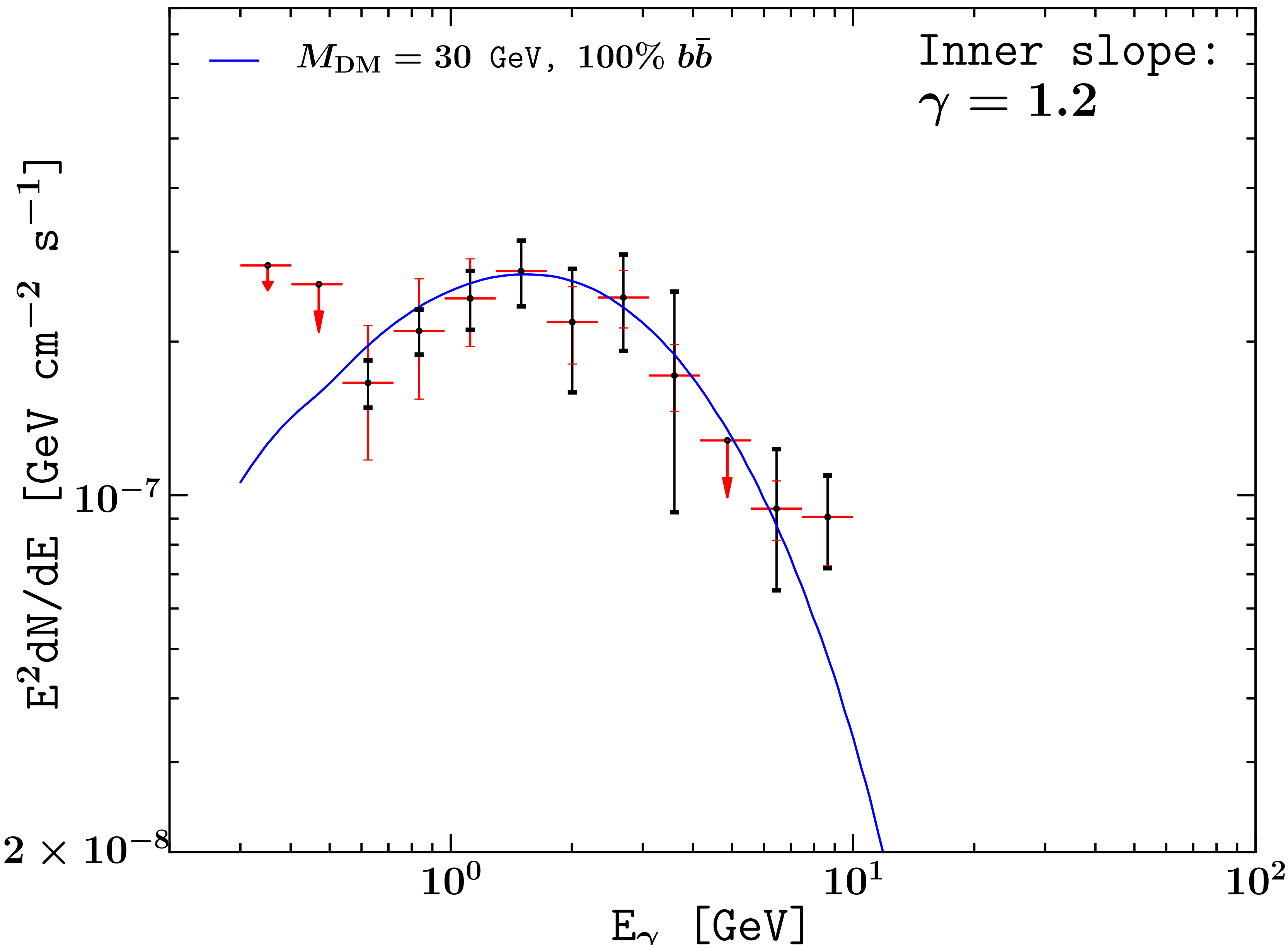
Dark Matter or MSPs



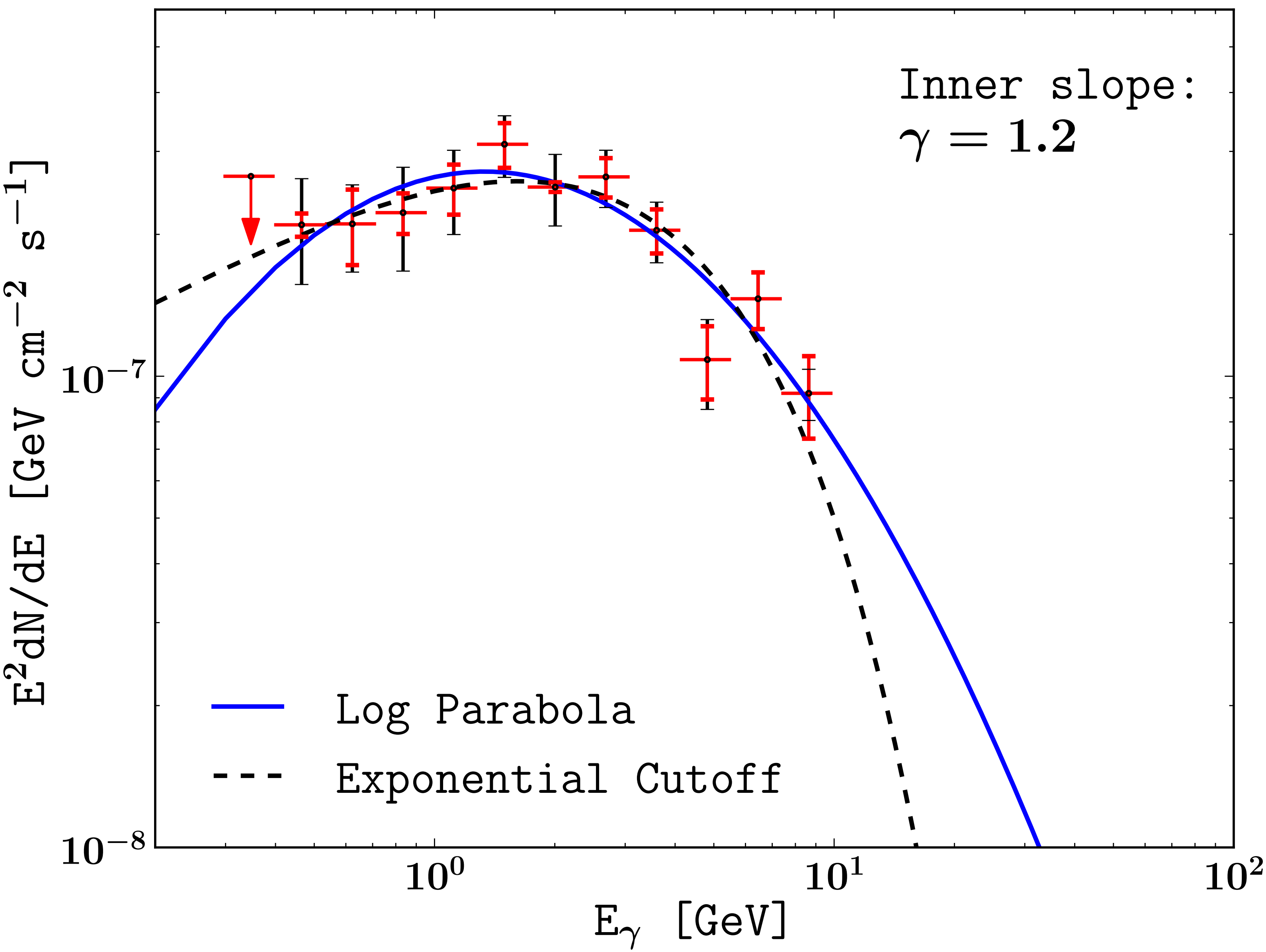
Spatial Systematic Errors

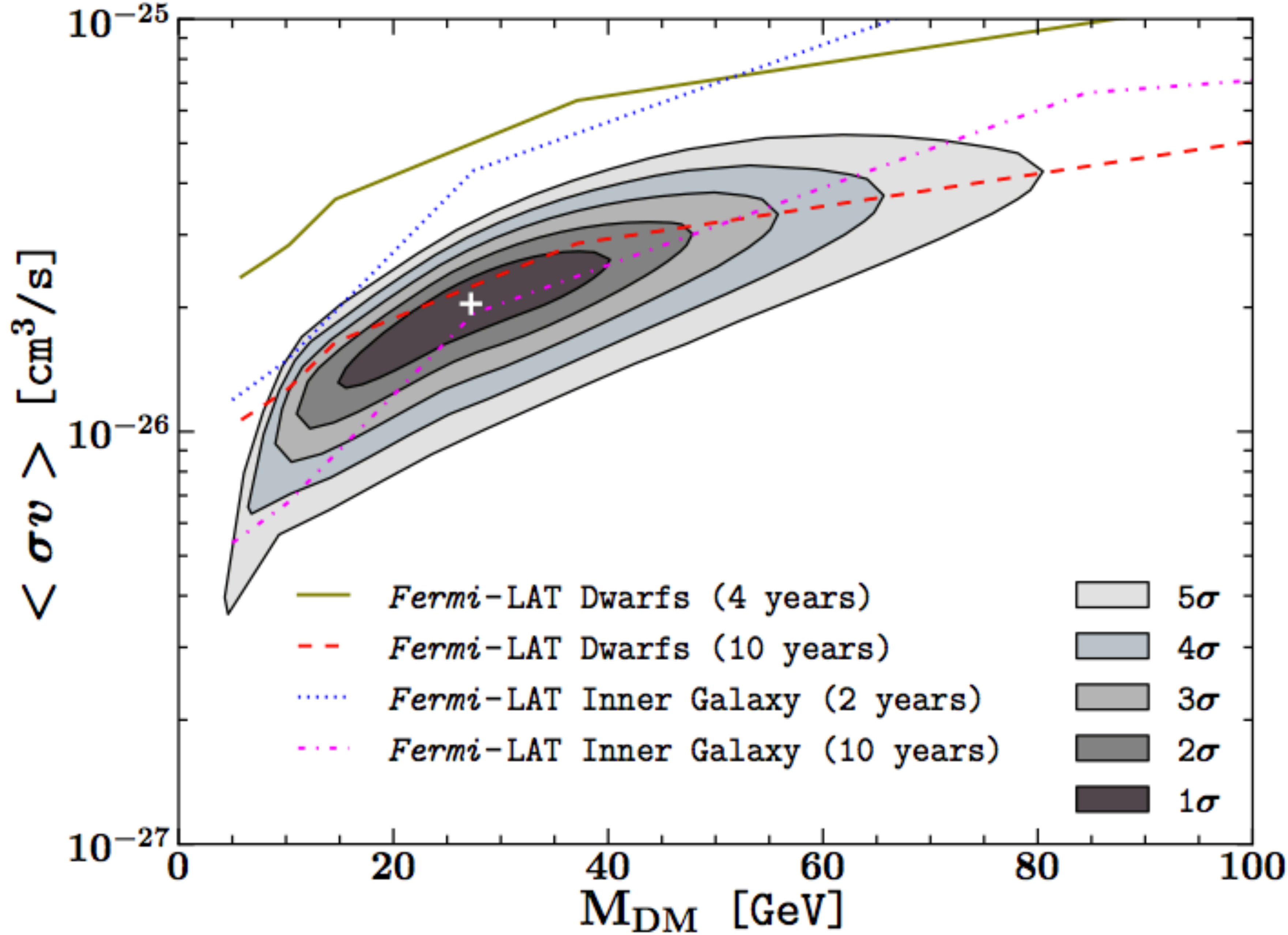


CDM Spectrum



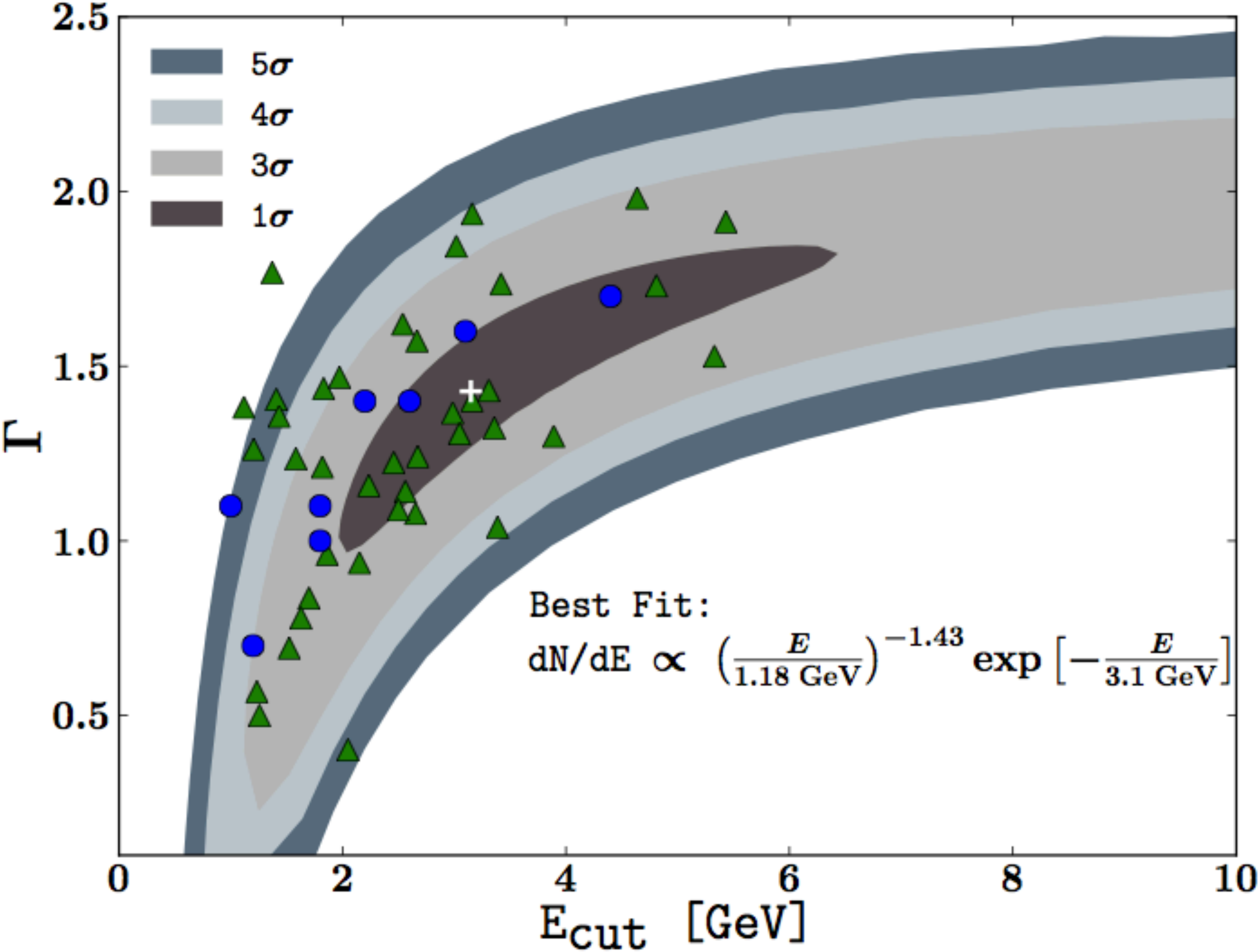
Millisecond Pulsar Spectrum



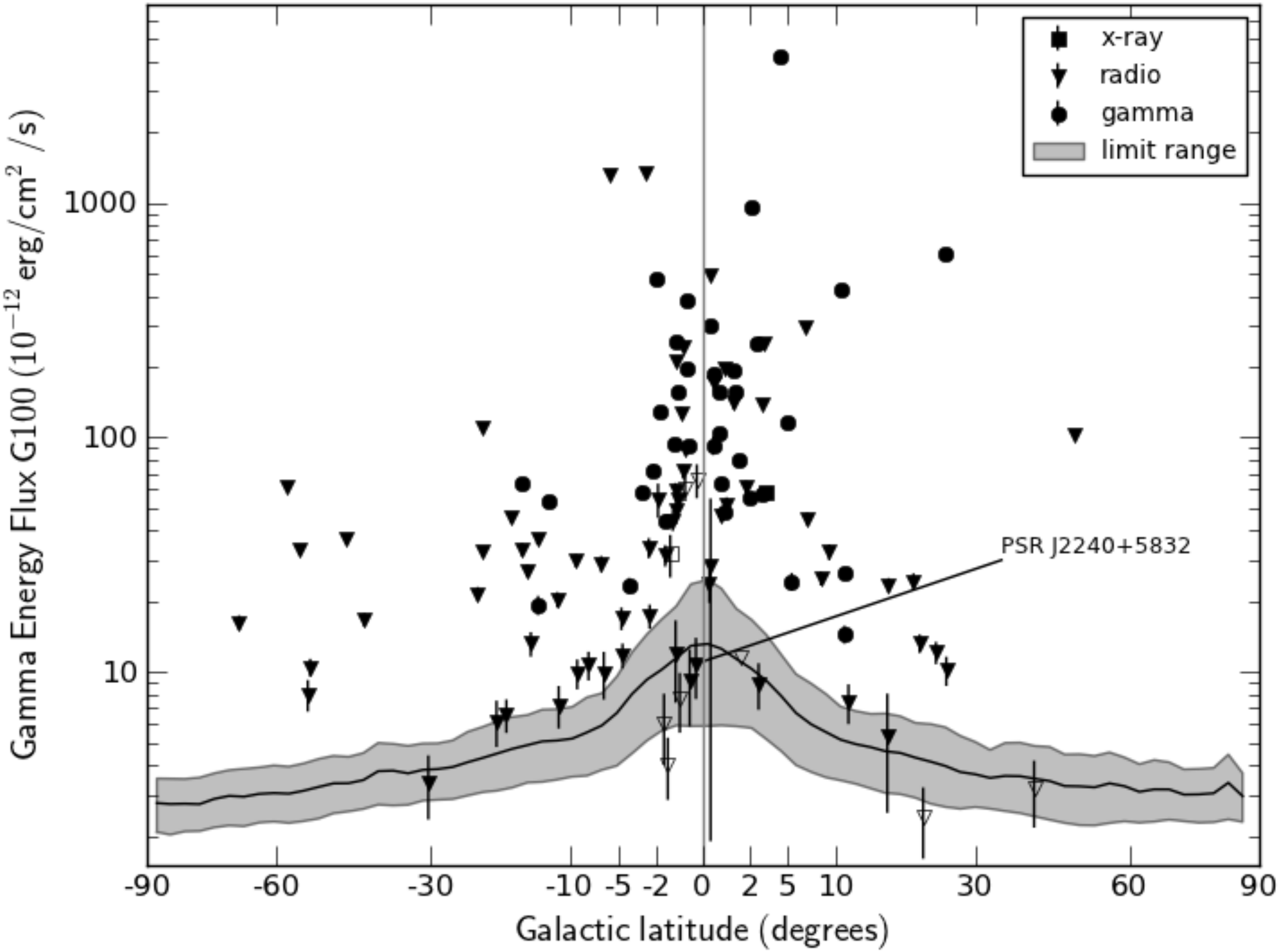


10^{-25}
10^{-26}
10^{-27}
$< \sigma v >$ [cm^3/s]
0
20
40
60
80
100
M_{DM} [GeV]
Fermi-LAT Dwarfs (4 years)
Fermi-LAT Dwarfs (10 years)
Fermi-LAT Inner Galaxy (2 years)
Fermi-LAT Inner Galaxy (10 years)
5σ
4σ
3σ
2σ
1σ

Millisecond Pulsars



Pulsar detection sensitivity



Credit: Fermi-LAT collaboration ApJ S 208, 17 (2013)

Millisecond Pulsars

- Based on the excess gamma-ray flux from the Galactic center and taking the average resolved MSP luminosity, we confirm about 1000 or more millisecond pulsars (MSPs) could account for the Galactic center excess emission.
- Faucher-Giguere & Loeb (2011) found that the encounter rate and stellar mass in the GC is similar to the globular cluster Terzan 5, which has a large population of MSPs. They estimated that the GC population could be as large as ~ 1200 total MSPs.
- Currently can't easily resolve MSPs in Galactic center due to dispersion effects. Need high frequency observations of around 14 GHZ or greater. It may be possible with the Square Kilometer Array (SKA).

Conclusions

- Analyzed Fermi-LAT Galactic center excess emission taking into account degeneracy with point sources and systematics in diffuse Galactic background.
- Galactic ridge template, from cosmic rays interacting with molecular clouds, improves fit but is too ridge like to explain majority of excess emission.
- Confirmed 30 GeV DM annihilating into quarks, with a thermal relic cross section is a good fit.
- Current and near future experiments unlikely to detect DM if mass of order 30 GeV and the DM annihilates predominantly into quarks.
- Found of order 1000 or more unresolved millisecond pulsars was also a good fit.
- SKA observations may eventually better constrain the millisecond pulsar explanation, if they observe ν>10 GHz$.