Gamma Ray Excess in the Milky Way

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290E Presentation
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Outline

- Galactic Center, Gamma Rays, & Dark Matter
- *Fermi* Gamma-Ray Space Telescope
- Results

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter

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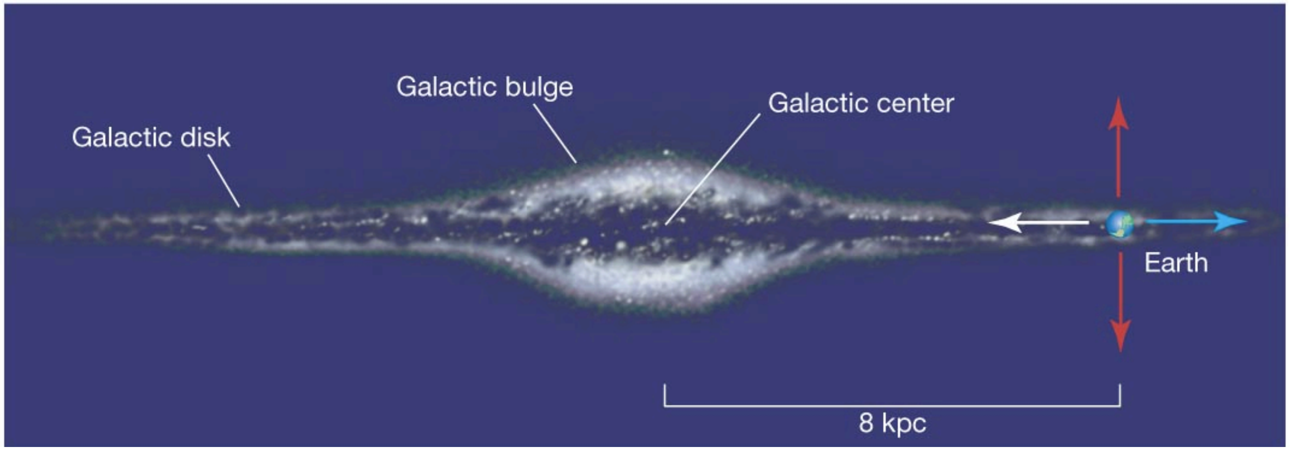
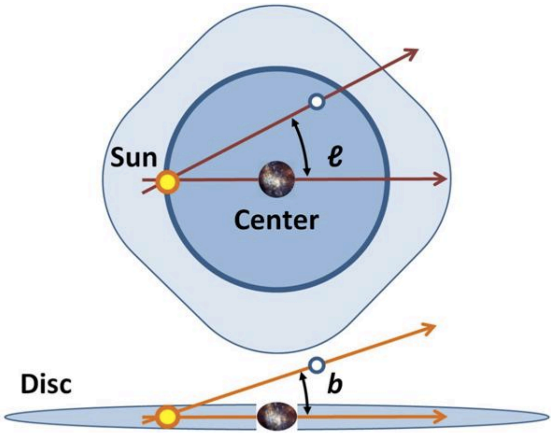
Dark matter annihilation in the Galactic Center as seen by the Fermi Gamma Ray Space Telescope

Dan Hooper[a,b,*], Lisa Goodenough[c]

Galaxy Terminology

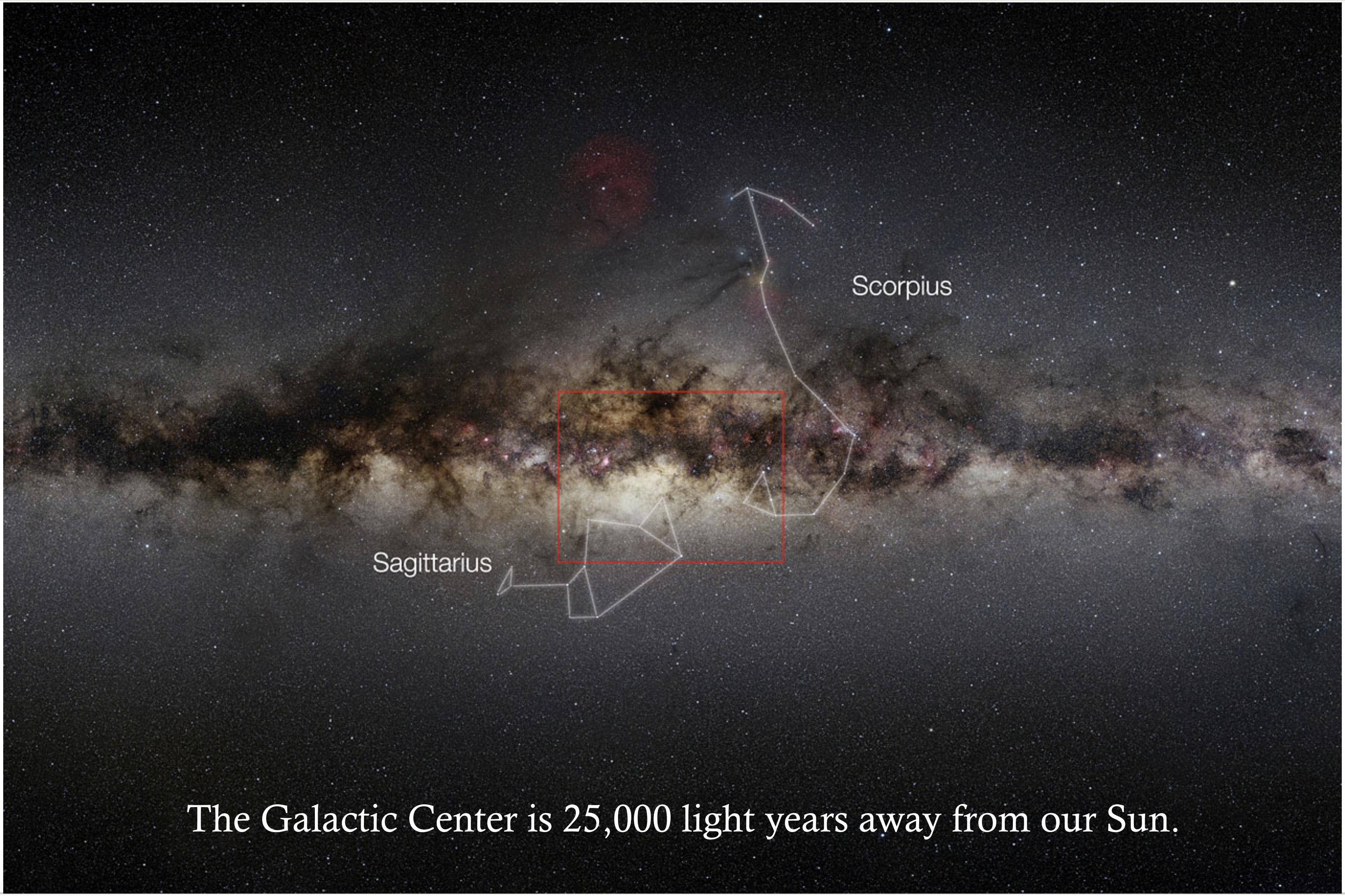


1 kpc = 3.26 light-years = $3.086*10^{19}$ meters



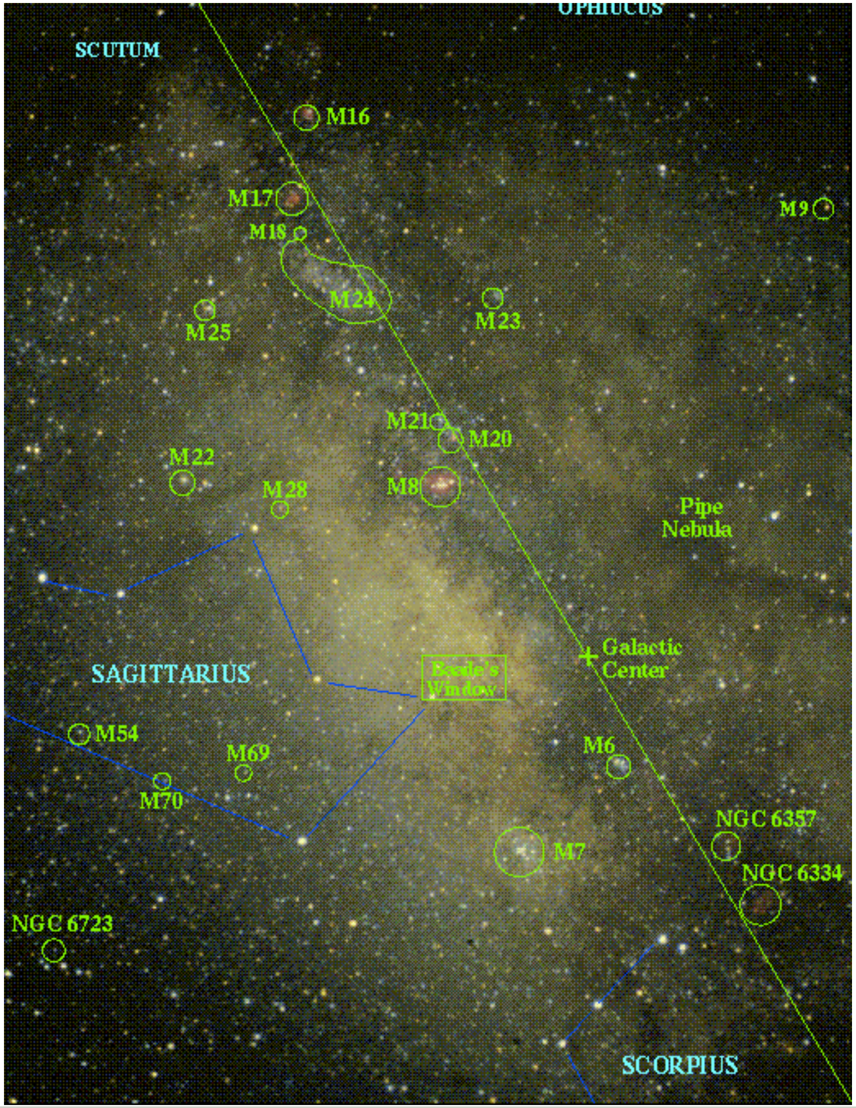
- The galactic coordinates use the Sun as the origin.
- Galactic longitude (l) is measured with primary direction from the Sun to the center of the galaxy in the galactic plane.
- Galactic latitude (b) measures the angle of the object above the galactic plane.

Galactic Center (I)

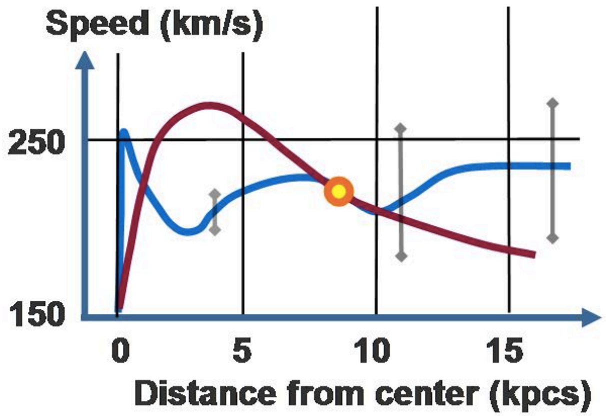


Galactic Center (II)

- The size of this image is about 10 by 15 degrees in size.
- For scale comparison, if you held a closed fist out at arm's length, it would cover 5 degrees on the sky.
  - Small signal space
- Large amounts of stellar dust between us and galactic center make it harder to study.

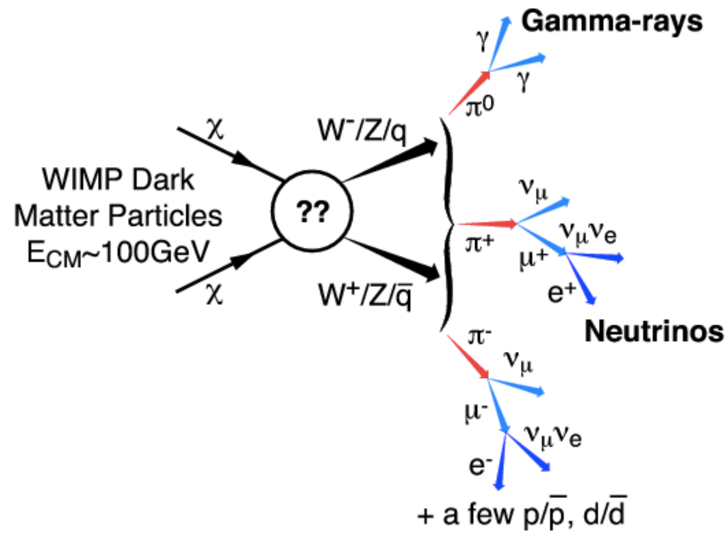


Dark Matter in Galaxies



- Galaxy rotation curve for the Milky Way. Vertical axis is speed of rotation about center. Observed curve of speed of rotation is blue line. Predicted curve is red line.
- We expect at larger distances for the velocity to slow, yet it does not. → dark matter?

- Most likely dark matter candidate is WIMPs
- If WIMPs annihilate, they can produce gamma rays which are identifiable from dense astrophysical background



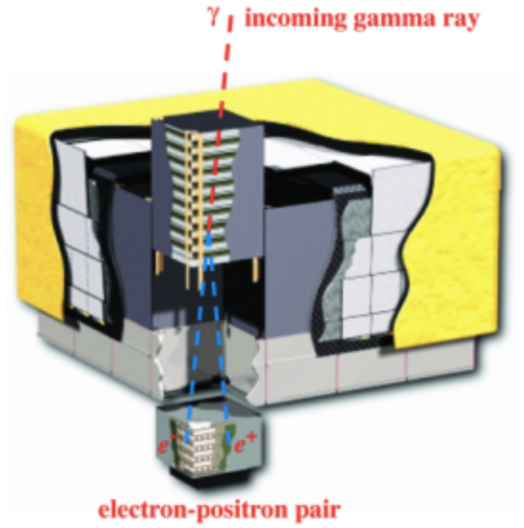
Analysis Chain

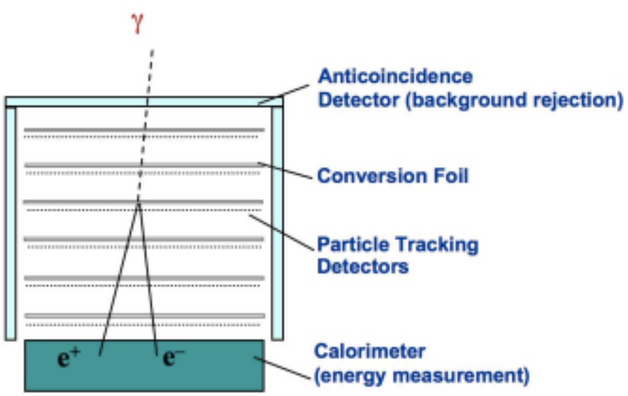
Fermi Large Area Telescope

- Fermi LAT is an imaging, high-energy gamma-ray telescope launched into near-earth orbit 11 June 2008
- Sensitive to gamma rays within an energy range of 20 MeV to more than 300 GeV
  - Such gamma rays are emitted only in the most extreme conditions by particles moving at the speed of light
- Field of view covers 20% of the sky at any time and it scans continuously, covering the whole sky every three hours
- gamma rays cannot be refracted by a lens or focused by a mirror → detected using the same technology as particle accelerators

Fermi Large Area Telescope

- Incoming gamma ray pass freely through the thin plastic anticoincidence detector
- They continue until they interact with an atom in one of the thin tungsten foils producing an electron and a positron.
- They proceed on, creating ions in thin silicon strip detectors.
  - The silicon strips alternate in the X and Y directions allowing the progress of the particles to be tracked.
- Finally the particles are stopped by a cesium iodide calorimeter which measure the total energy deposited → energy and direction of the gamma ray.





Gamma Ray & Dark Matter

- *Fermi* hopes to observe the flux of dark matter annihilation products, including gamma rays produced by the innermost volume of the Milky Way's halo.
- The flux of such gamma rays is described as:

$$\text{Flux} = \Phi_\gamma\left(E_\gamma,\psi\right) = \left(\frac{dN_\gamma}{dE_\gamma}\right)\frac{\langle\sigma v\rangle}{8\pi m_X^2}\int_{los}\rho^2\left(r\right)dl$$

gamma ray spectrum generated per annihilation

dark matter annihilation cross section

angle observed relative to the direction of the Galactic Center

dark matter mass

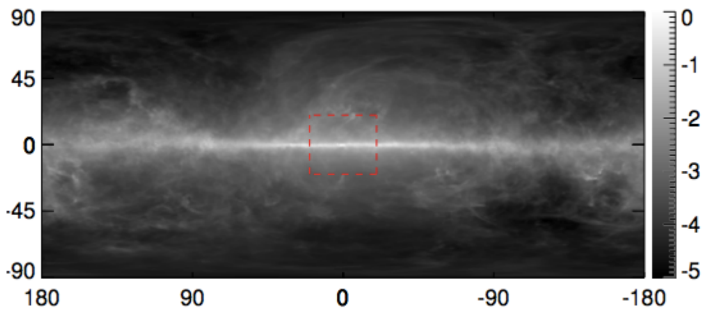
dark matter density as a function of distance to the Galactic Center

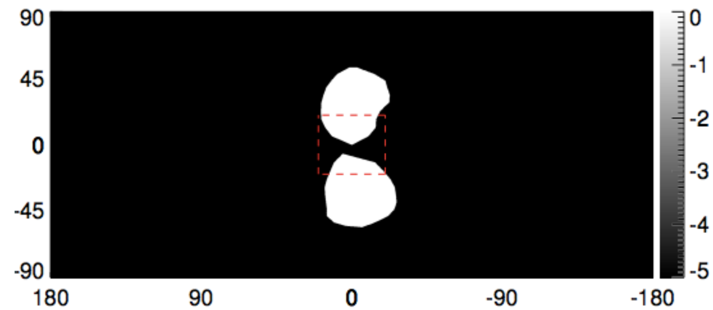
$$\rho \propto r^{-\gamma}$$

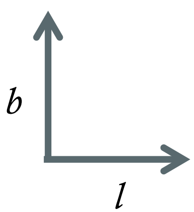
where γ is the inner slope of the halo

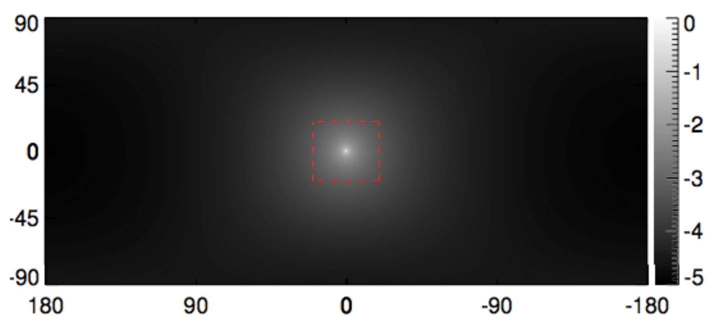
Modeling the Backgrounds

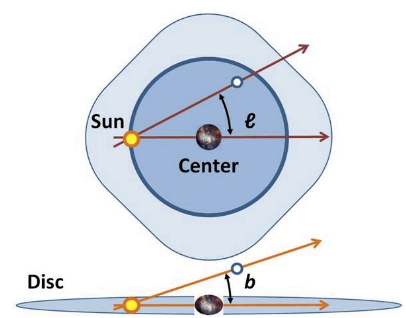
- Diffuse emission from the disk (top left) –inverse Compton, Bremsstrahlung, neutral pion decay.
- Emission from point sources – like Fermi Bubbles (top right)
- Dark Matter annihilation products (bottom)











red box indicates area of interest

Gamma Ray Emission Spectra

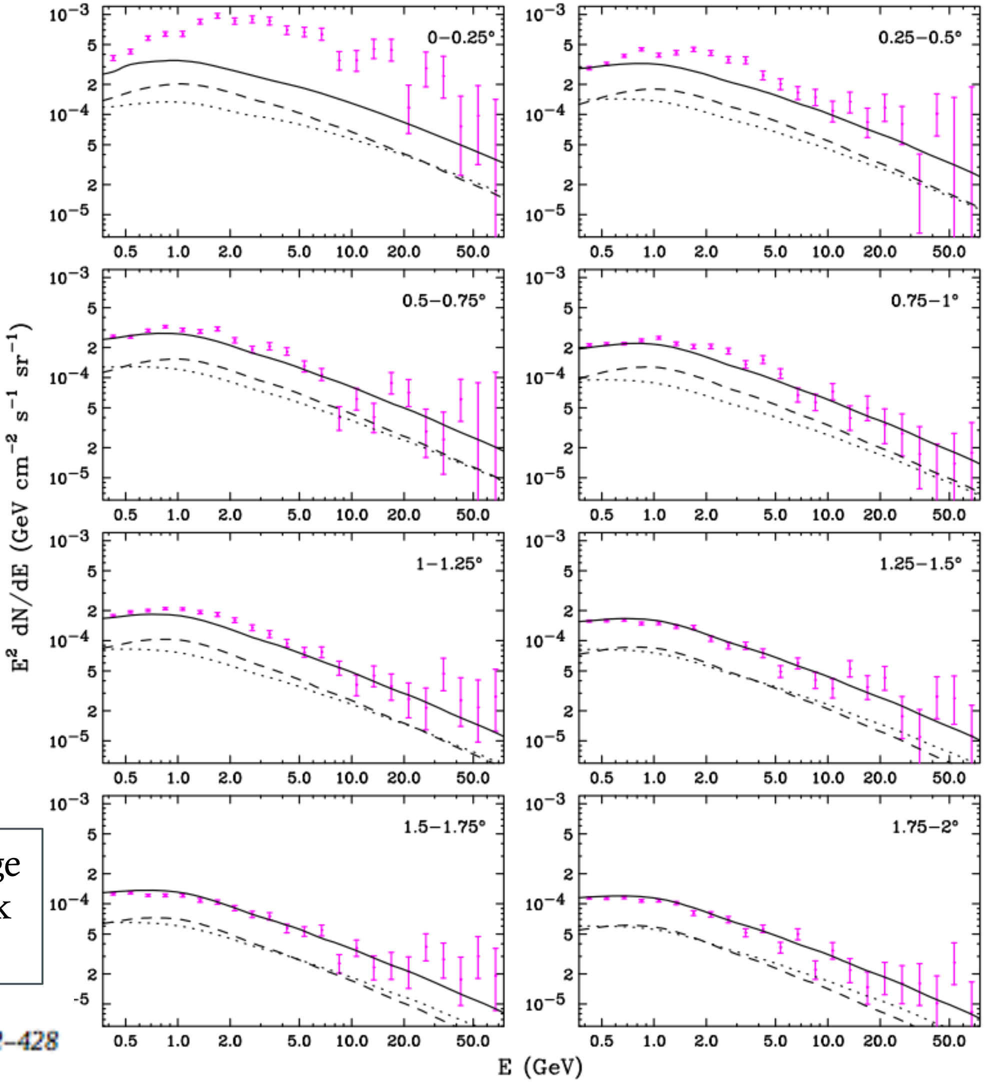
- Regions of Interest:
  - Galactic Center $|l| < 2^{o}$, $|b| < 2^{o}$
  - Galactic Disk $|l| > 2^{o}$

- Spectra are usually analyzed in multiple bins of various l and energy.

- Free parameter γ ranges from 1.1-1.3 depending upon the fit and analysis.
  - Recall, γ is the measure of the inner dark matter halo slope

Gamma Ray Emission Spectra

- Total observed gamma ray spectrum in various ranges of angular distance from the Galactic Center.
- Outside of 1.25° from Galactic Center, model describes data well.
- Closer to Galactic Center, the spectral shape of the observed emission is significantly different, peaking between 1-3 GeV
- Two years of data taken from 2008-2010.

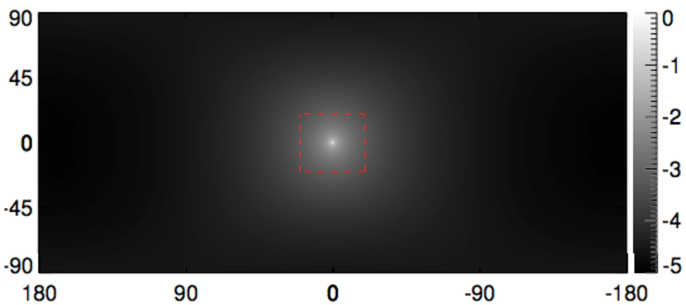


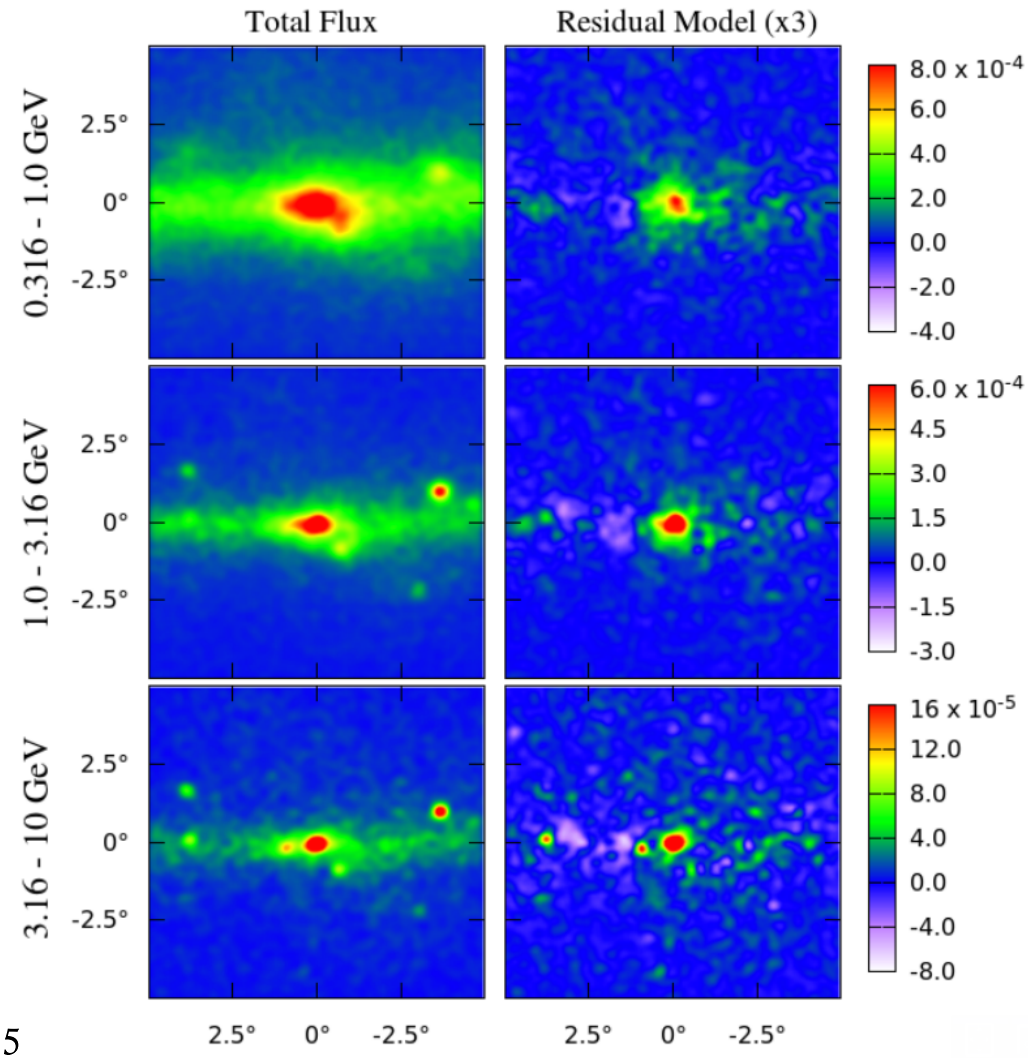
dotted: bulge
dashed: disk
solid: sum

D. Hooper, L. Goodenough / Physics Letters B 697 (2011) 412–428

Gamma Ray Emission Spectra – Dark Matter

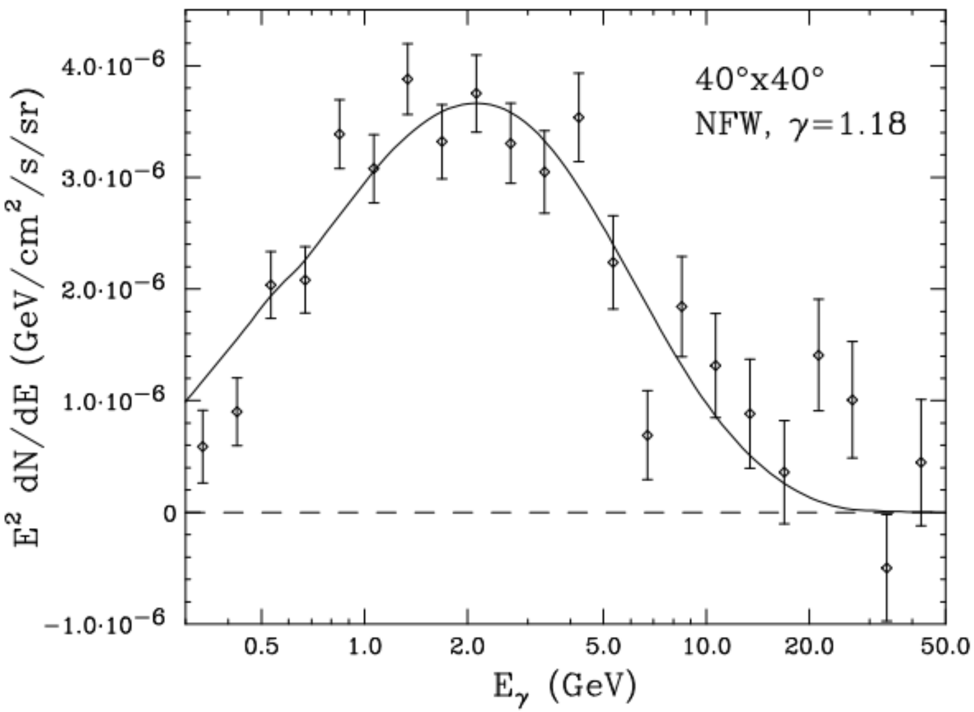
- Raw gamma ray maps (left) and the residual maps after subtracting the background models (right)
- Right frames clearly contain a significant central and spatially extended excess peaking at ~1-3 GeV.
- 5+ years of data





arXiv:1402.6703v2 [astro-ph.HE] 17 Mar 2015

Gamma Ray Emission Spectra – Dark Matter



- Spectrum of dark matter component, extracted from the fit.
- Shown for comparison is the spectrum predicted from a 43.0 GeV dark matter particle annihilating to *bb-bar* with a cross section of $\sigma v = 2.25 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}\ \times [(0.4\,\mathrm{GeV/cm}^3)/\rho_{\mathrm{local}}]^2$

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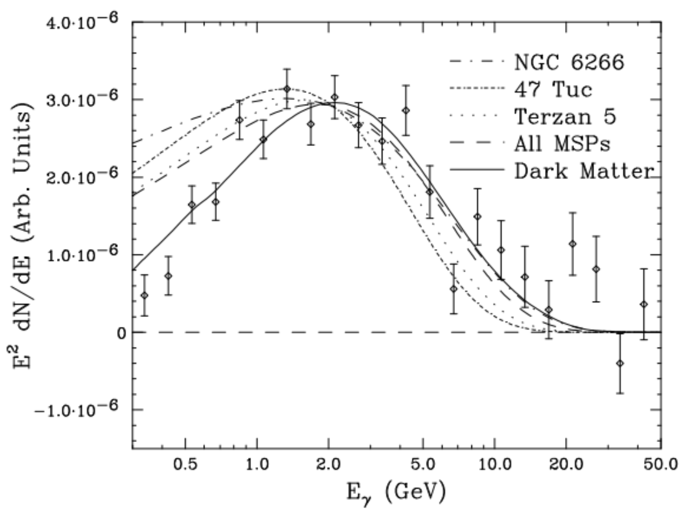
Is it dark matter?

- The other options considered were:
  - Millisecond Pulsars
  - Cosmic Ray outbursts from the Galactic Center
- Both of these alternative explanations were rejected due to characteristics of the data.
  - Cosmic Ray outbursts would not explain excess given that the diffuse emission background includes contributions from gas in Galactic Center.
  - Millisecond Pulsars are consistently softer than that of the observed excess at energies below ~1 GeV



Conclusion

- *Fermi* data has been available for several years, and multiple teams have analyzed the data.
- While the exact dark matter candidate varies based on statistical fluctuations in the fit, all can agree that:

"we have confirmed a robust and highly statistically significant excess, with a spectrum and angular distribution that is in excellent agreement with that expected from annihilating dark matter".

Einstein@Home