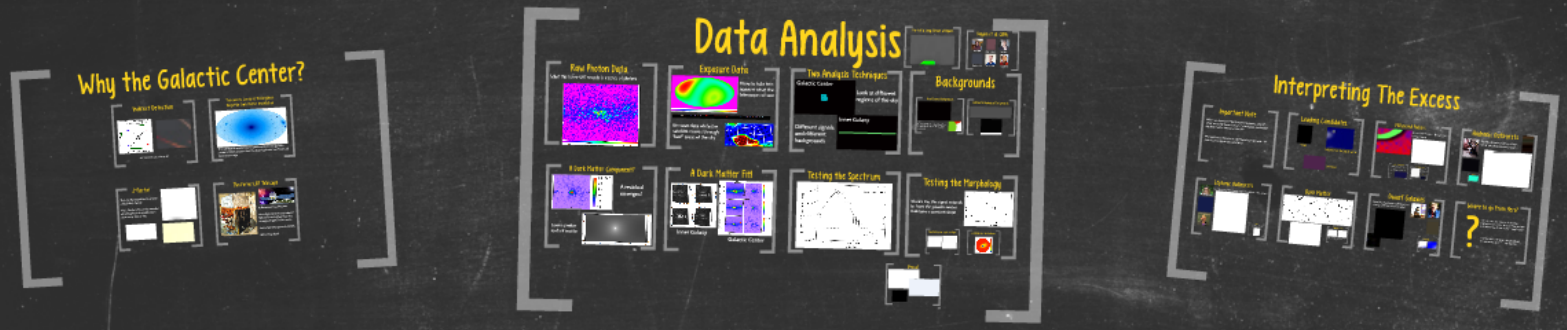
The Indirect Detection of Dark Matter in the Galactic Center

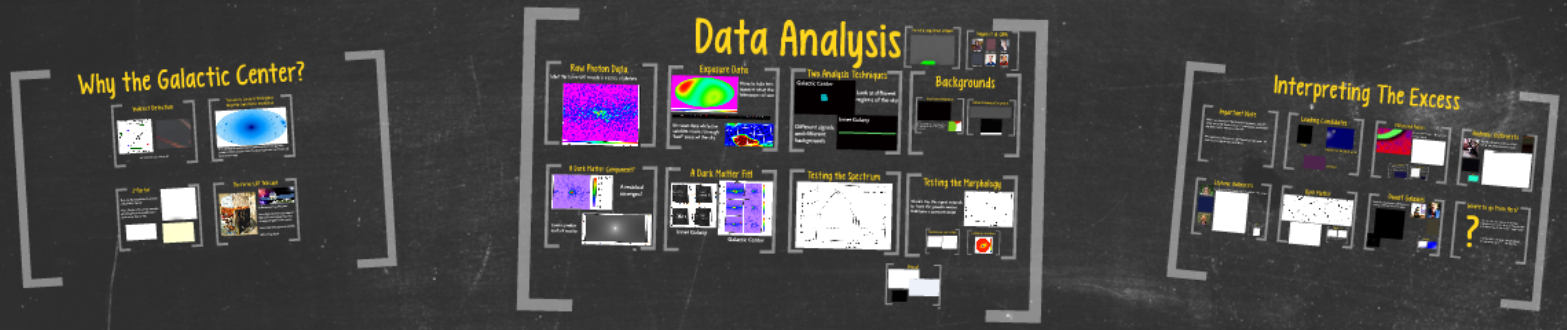


Tim Linden

Lecture 9

Fall 2014 Compton Lectures

The Indirect Detection of Dark Matter in the Galactic Center



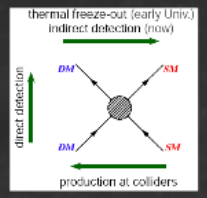
Tim Linden

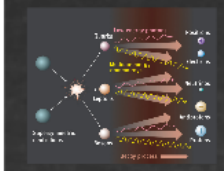
Lecture 9

Fall 2014 Compton Lectures

Why the Galactic Center?

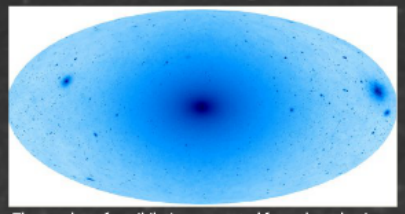
Indirect Detection





Our favorite images strike again!

The Galactic Center Is the Brightest Target for Dark Matter Annihilation

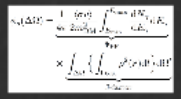


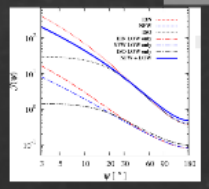
The number of annihilations expected from the galactic center is 100x greater than the dwarf galaxies we discussed two lectures ago

J-Factor

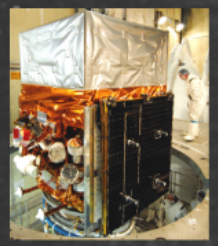
This can be quantified in a term called the J-factor:

The J-Factor tells us the number of astrophysical annihilations across any line of site





The Fermi-LAT Telescope



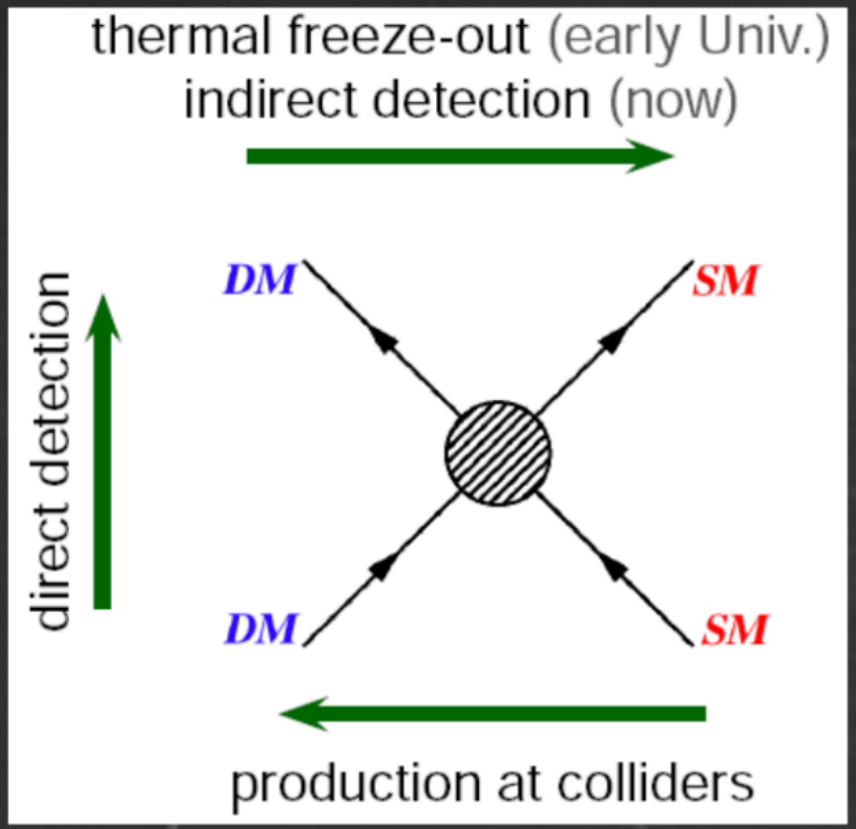
A Gamma-Ray detector:

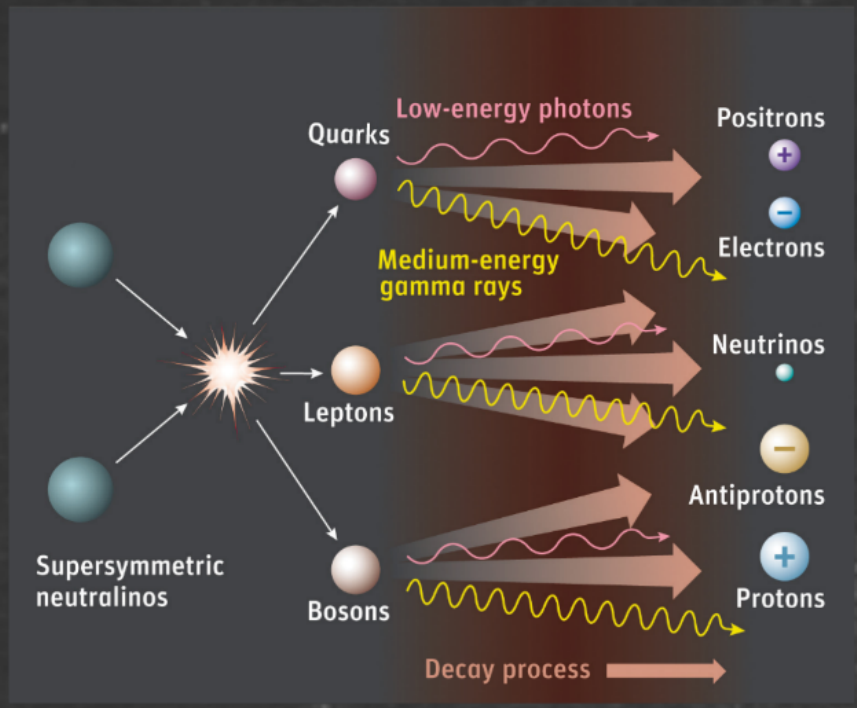
Sees light with energy about 1 billion times higher than the energy of light in this room.

Launched into space in 2008.

Still taking data!

Indirect Detection





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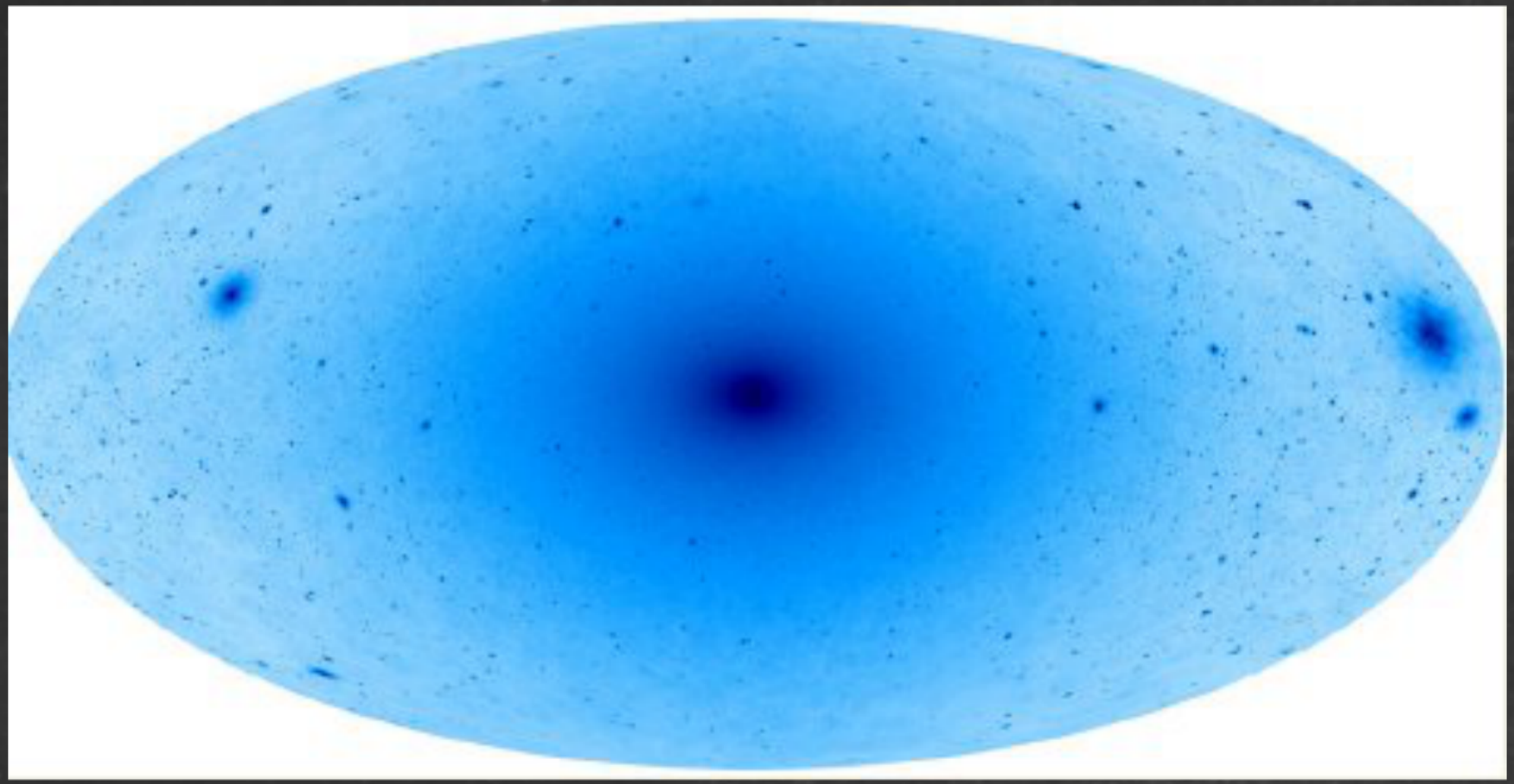

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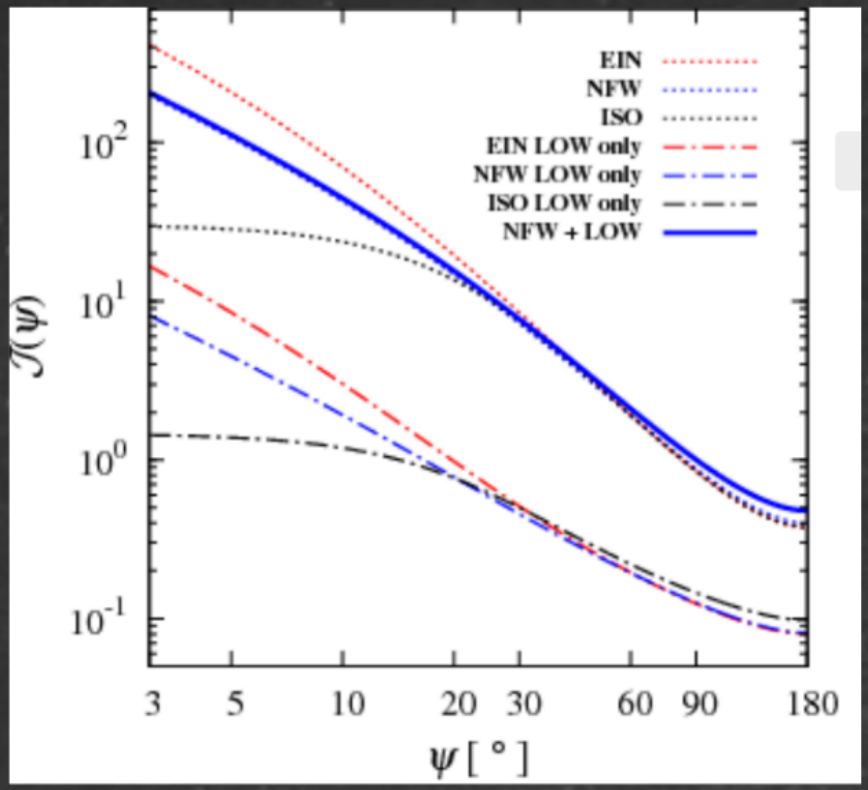

$$\phi_s(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\int_{E_{\rm min}}^{E_{\rm max}}\frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}{\rm d}E_\gamma}_{\Phi_{\rm PP}} \times \underbrace{\int_{\Delta\Omega}\left\{\int_{\rm l.o.s.}\rho^2(\boldsymbol{r}){\rm d}l\right\}{\rm d}\Omega'}_{\text{J-factor}}$$

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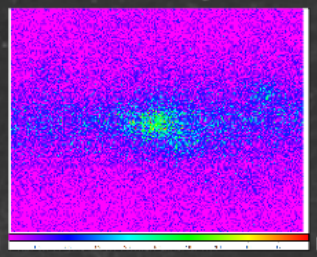
Data Analysis

Part of a Long Stream of Papers

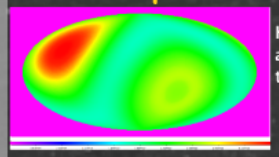
Daylan et al. (2014)

Raw Photon Data

What the Fermi-LAT records is a series of photons

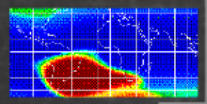


Exposure Data



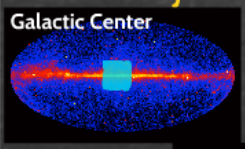
Have to take into account what the telescope can see

Remove data while the satellite moves through "bad" areas of the sky



Two Analysis Techniques

Galactic Center



Look at different regions of the sky

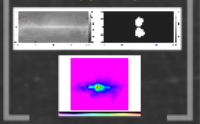
Different signals and different backgrounds

Inner Galaxy

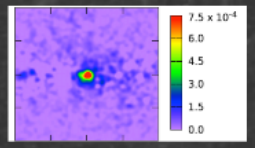
Backgrounds

Point Source Backgrounds

Diffuse Astrophysical Backgrounds



A Dark Matter Component?



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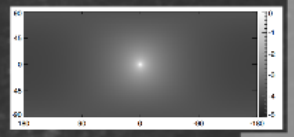
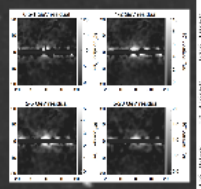
Looks similar to dark matter



A Dark Matter Fit!



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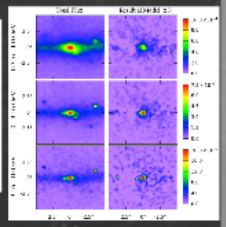
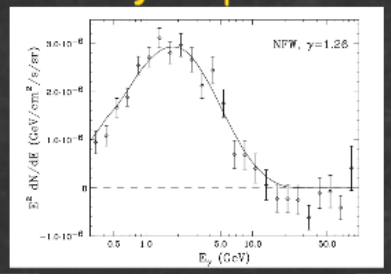


Galactic Center

Testing the Spectrum



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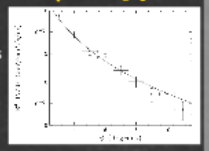
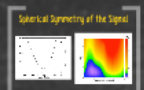
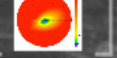
It looks like this signal extends far from the galactic center. Maintains a constant slope



Spherical Symmetry of the Signal



Centeredness of the Excess

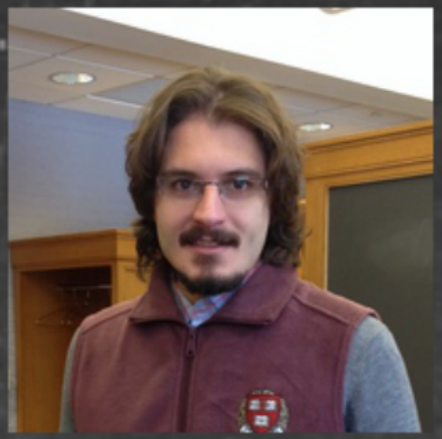


Press!

Part of a Long Stream of Papers

- Goodenough & Hooper (2009) arXiv:0910.2998
- Hooper & Goodenough (2011, PLB 697 412) arXiv:1010.2752
- Hooper & Linden (2011, PRD 84 12) arXiv:1110.0006
- Abazajian & Kaplinghat (2012, PRD 86 8) arXiv:1207.6047
- Hooper & Slatyer (2013, PDU 2 118) arXiv:1302.6589
- Gordon & Macias (2013, PRD 88 8) arXiv:1306.5725
- Macias & Gordon (2014, PRD 89 6) arXiv:1312.6671
- Abazajian et al. (2014, PRD 90 2) arXiv:1402.4090
- Daylan et al. (2014) arXiv:1402.6703
- Calore et al. (2014) arXiv:1409.0042

Daylan et al. (2014)



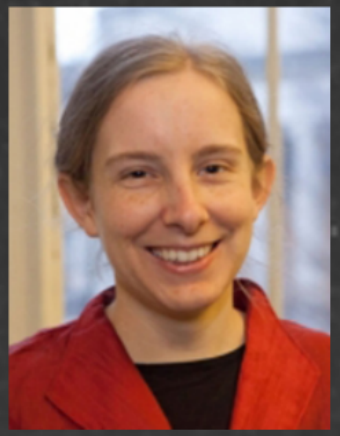
Tansu Daylan

Doug Finkbeiner

Dan Hooper

Stephen Portillo

Nicholas Rodd



Tracy Slatyer

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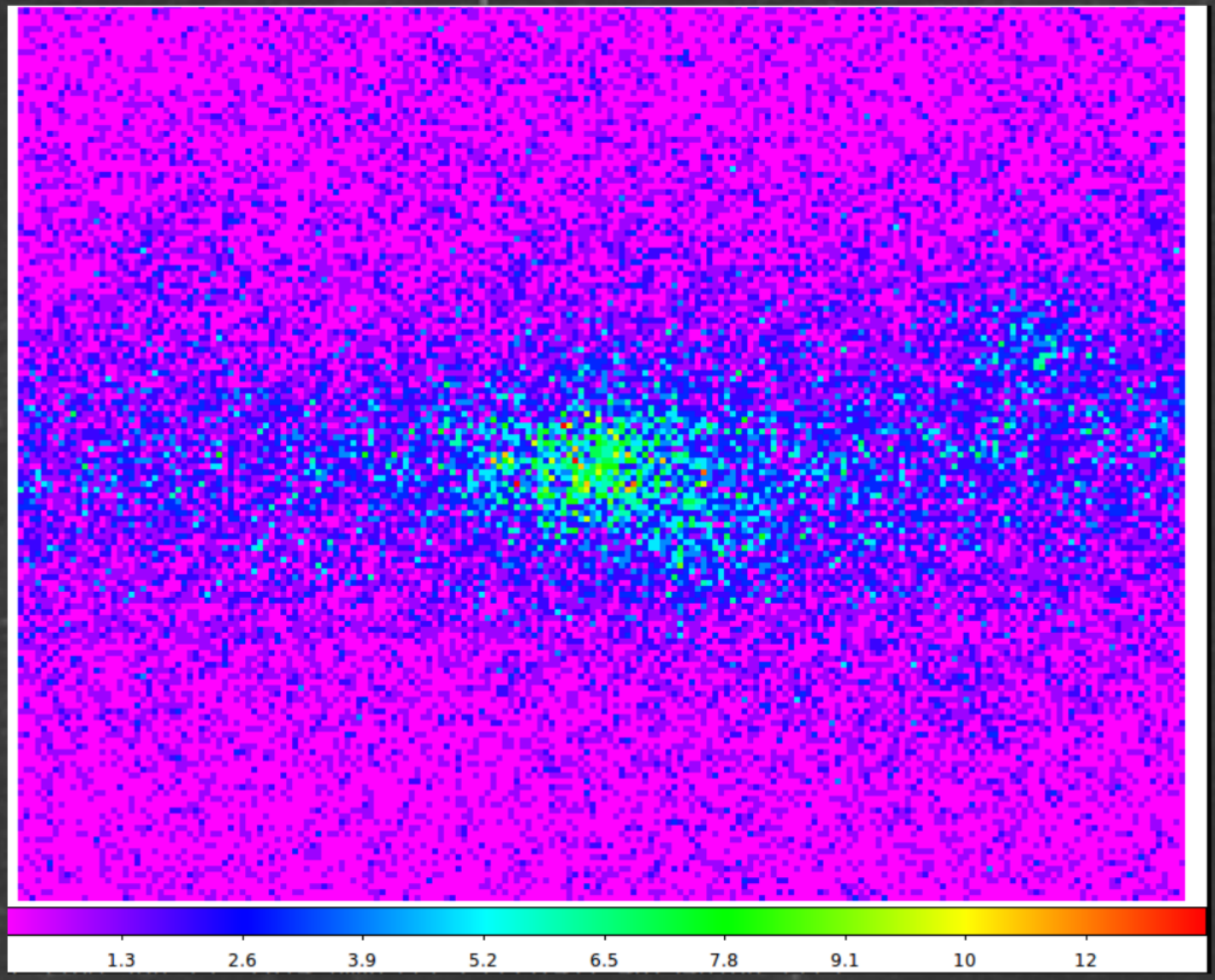

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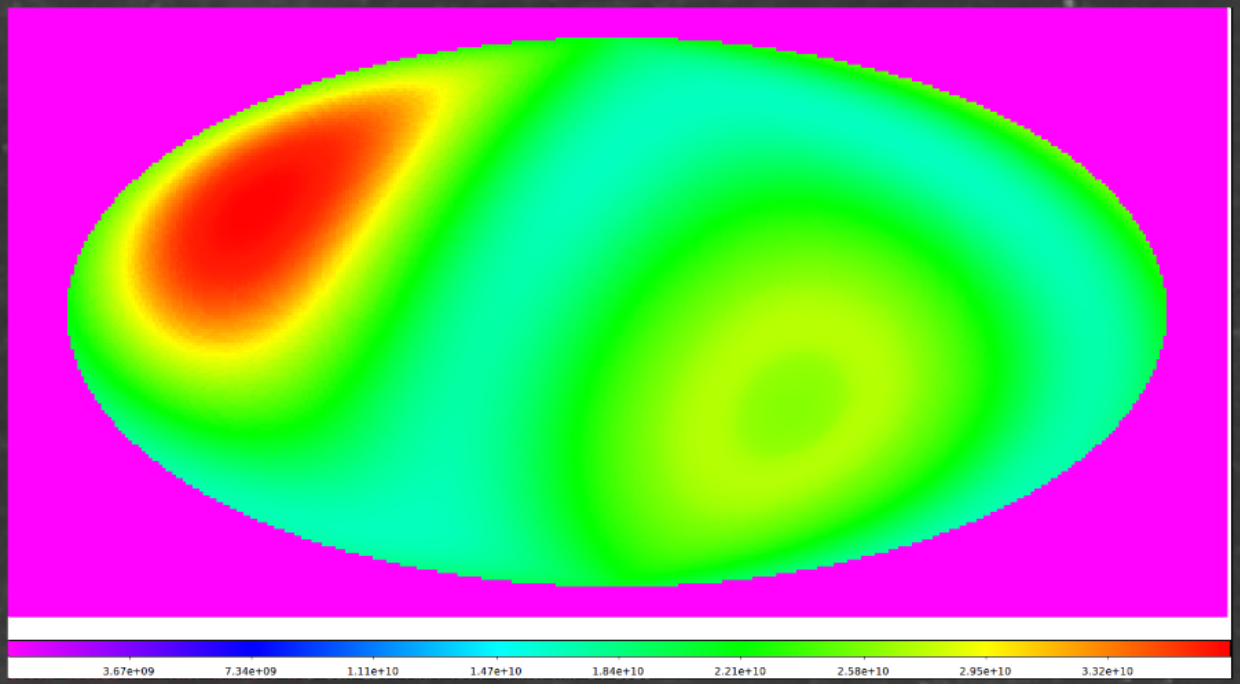

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.$fileouttime.fits
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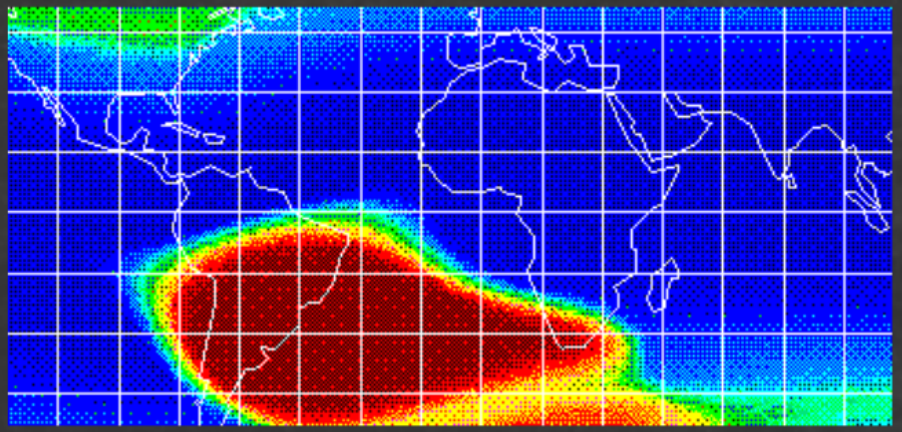

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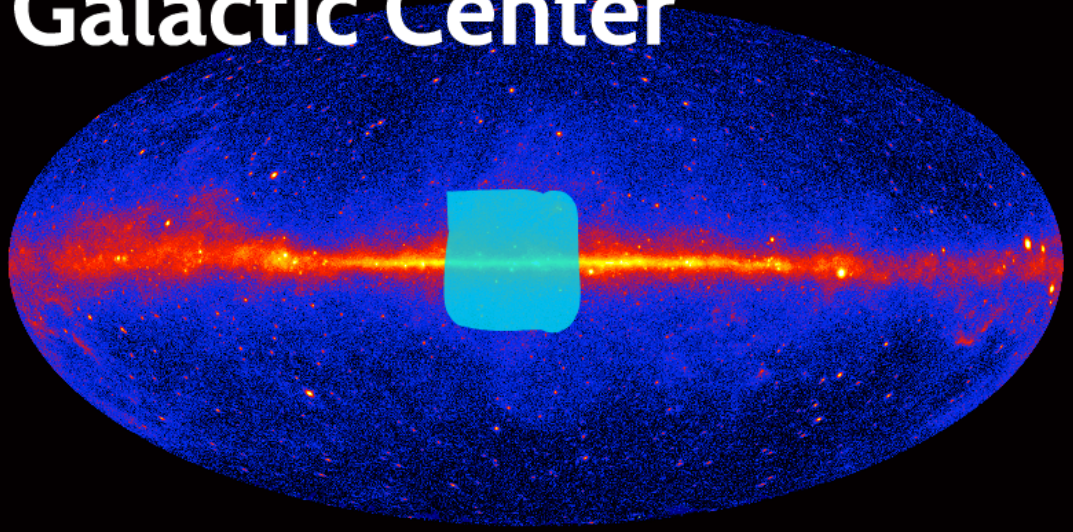

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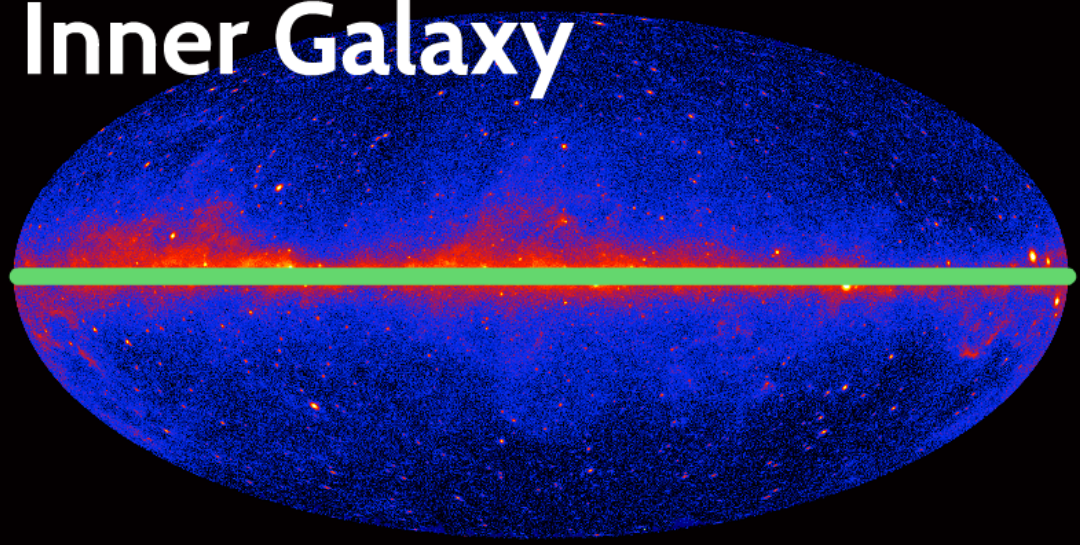
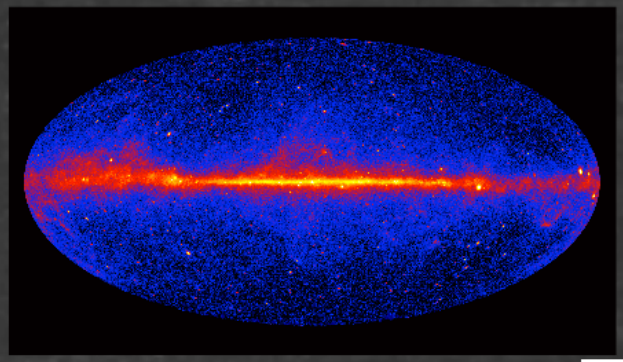


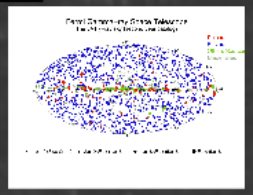
Different signals and different backgrounds

Backgrounds

Point Source Backgrounds



Fermi-LAT has detected more than 2300 point sources - those aren't dark matter



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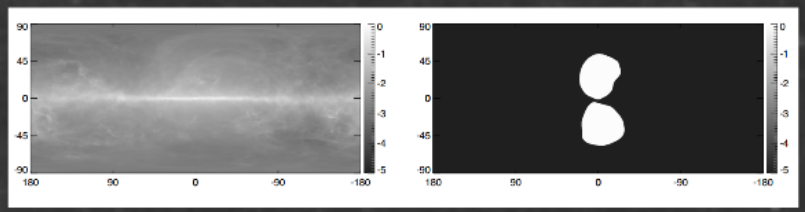

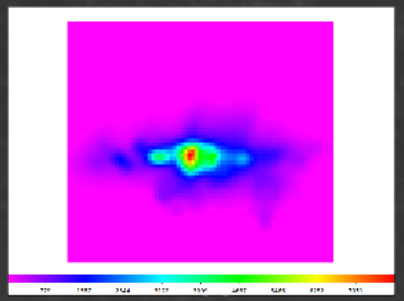

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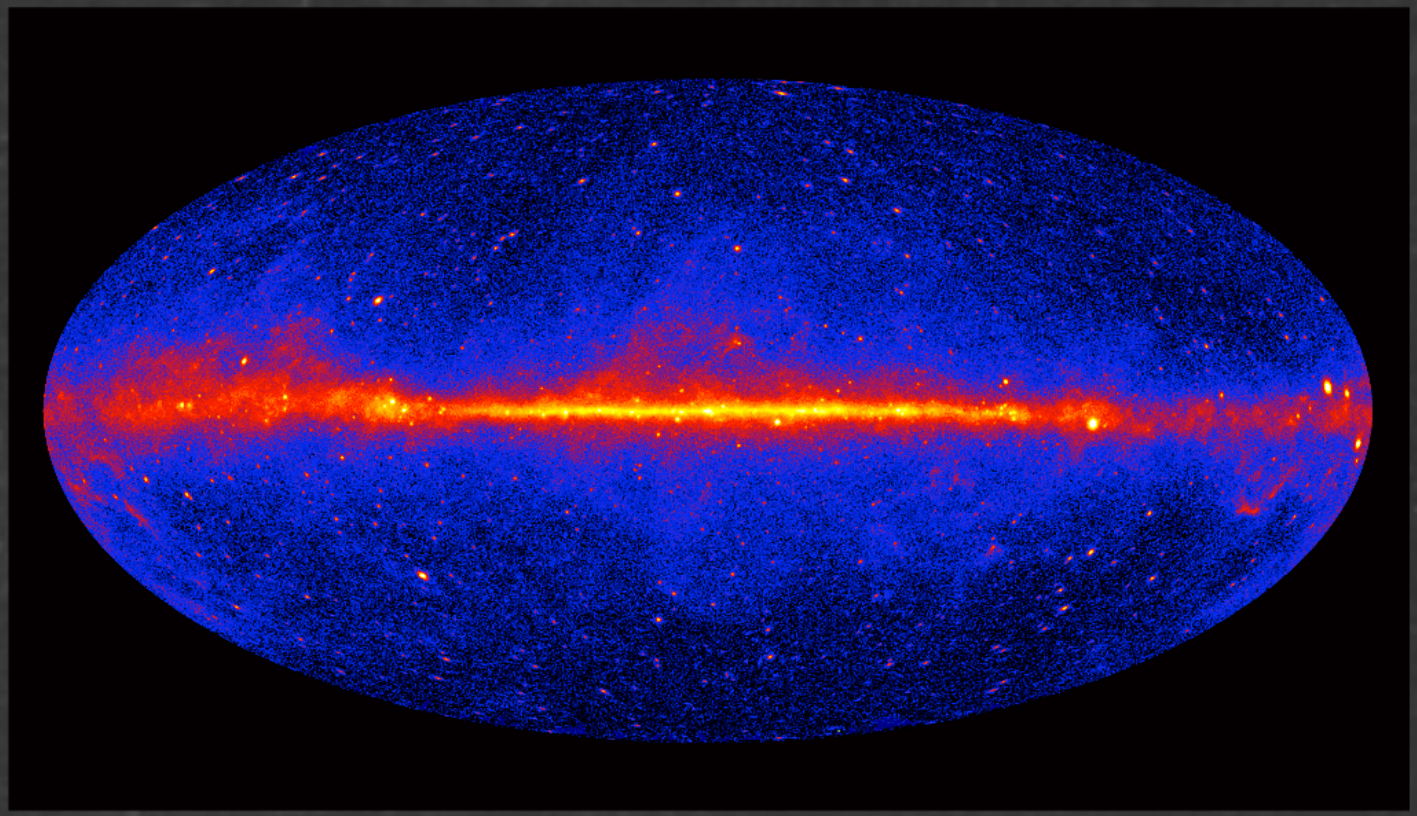

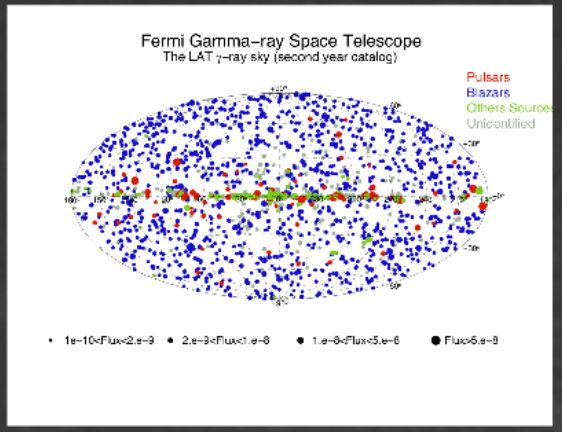

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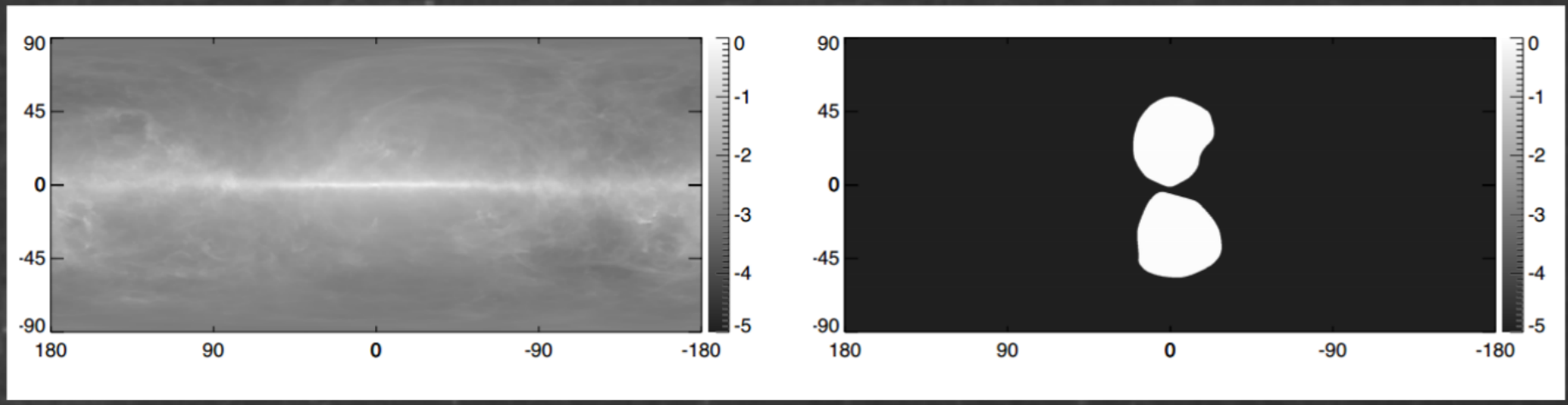

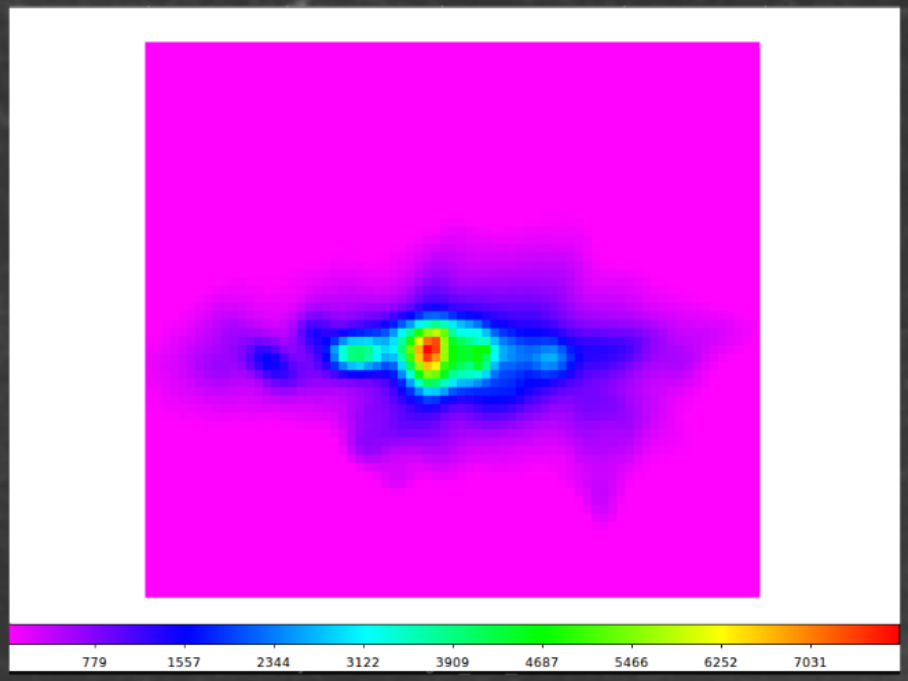

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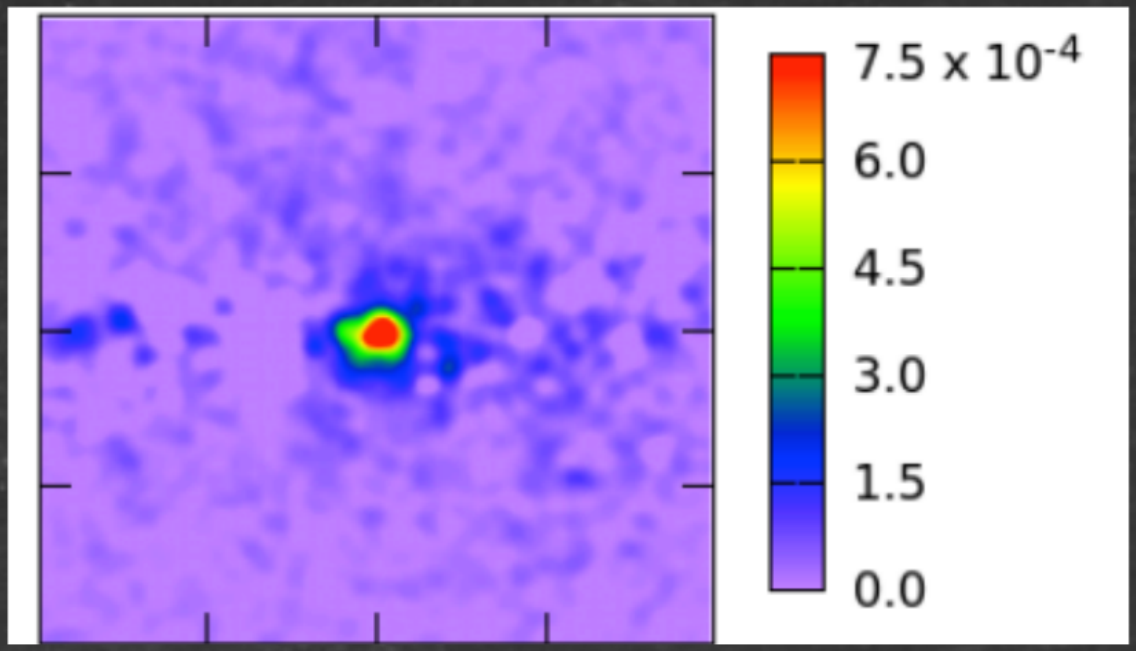

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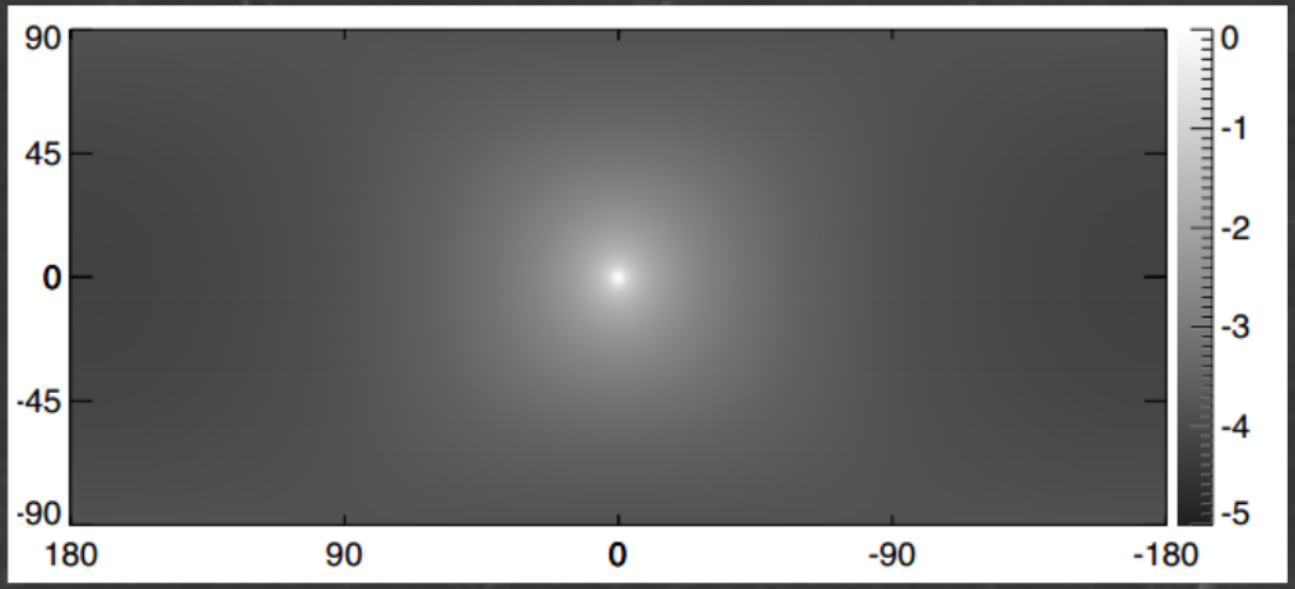

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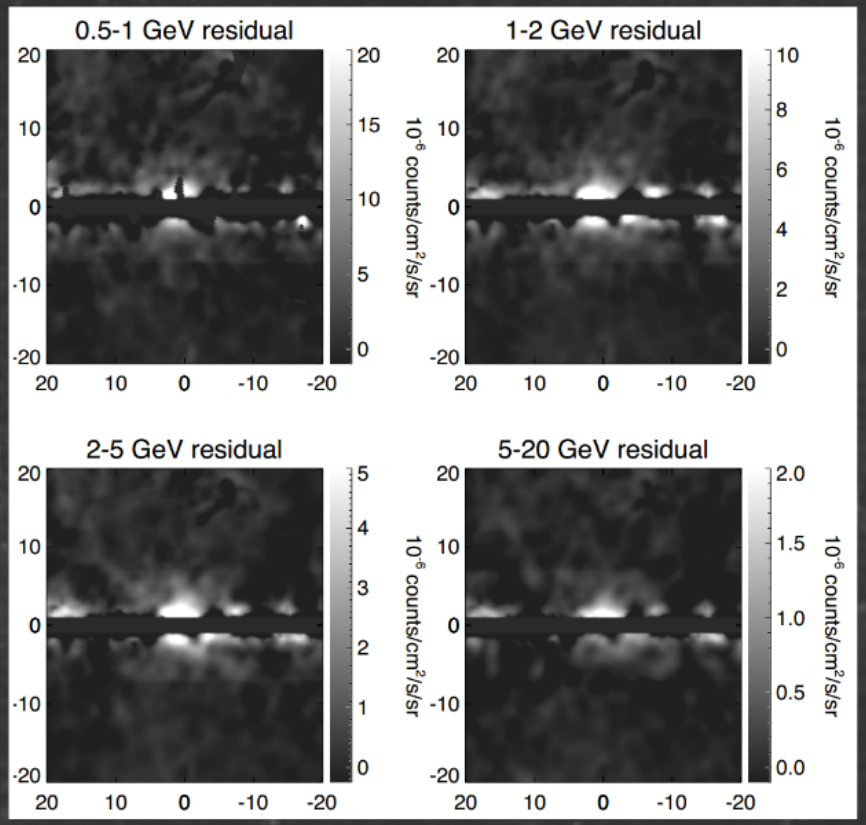

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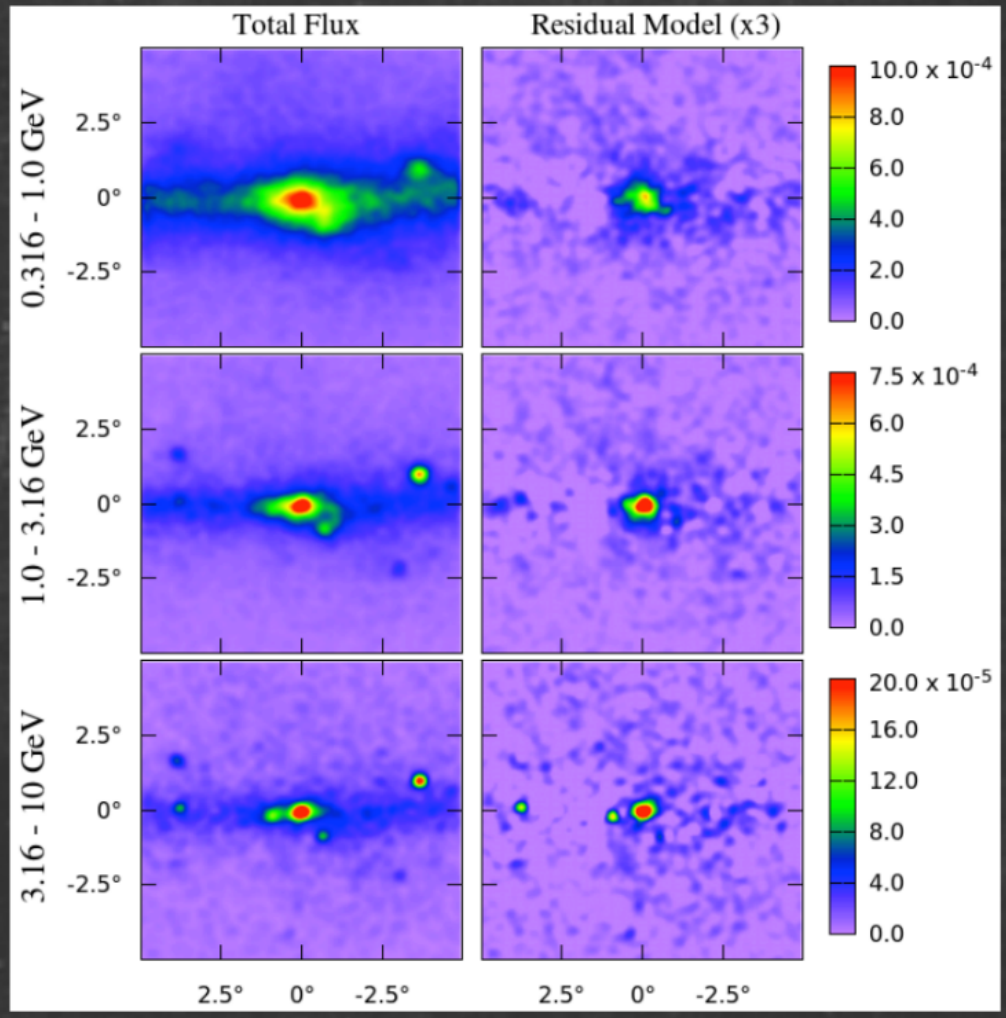
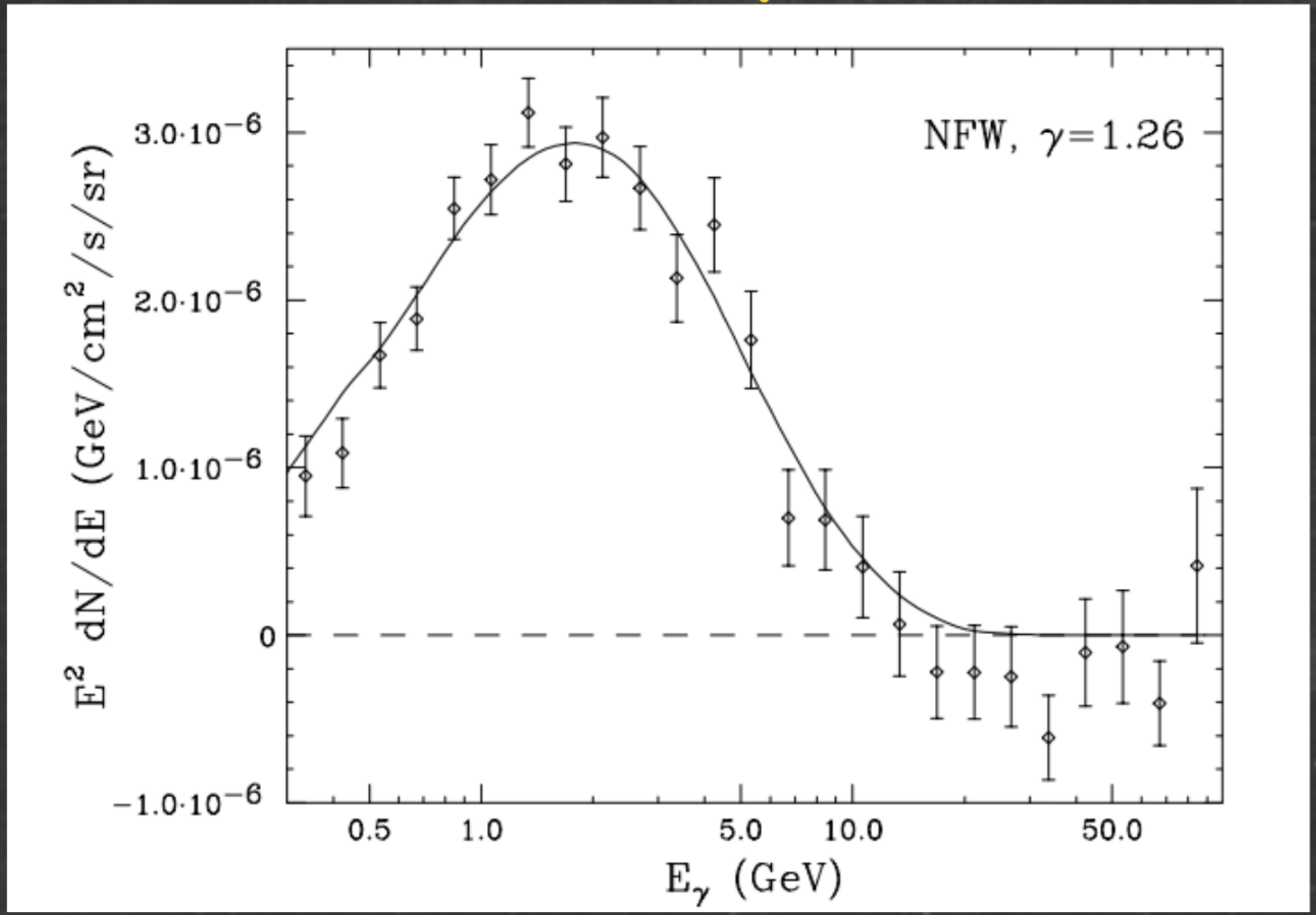


Galactic Center

Testing the Spectrum



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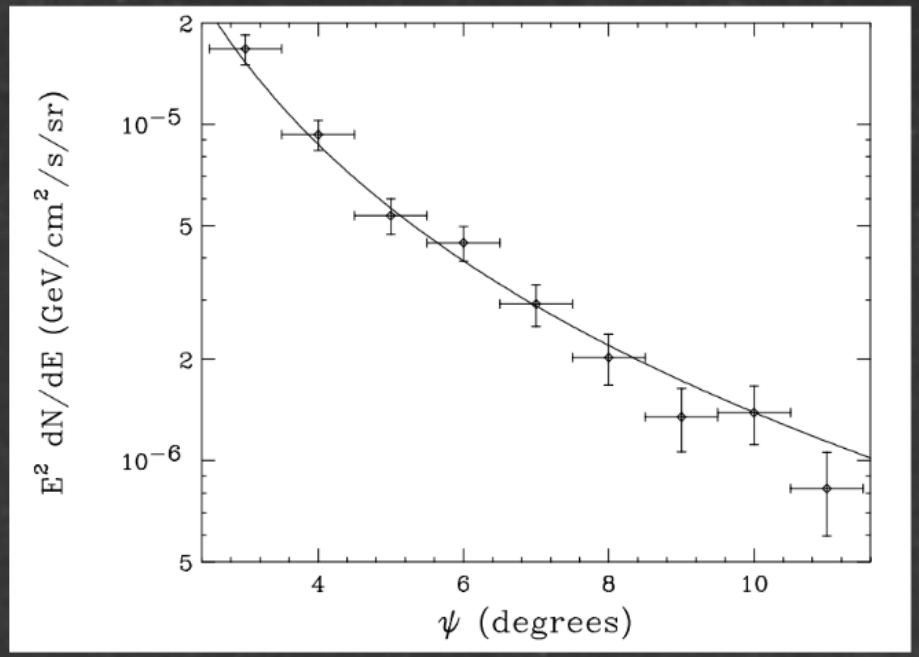
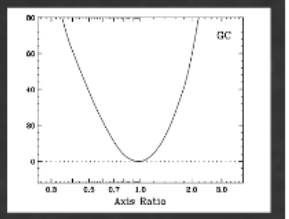
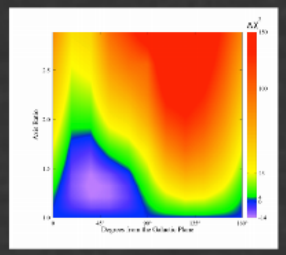
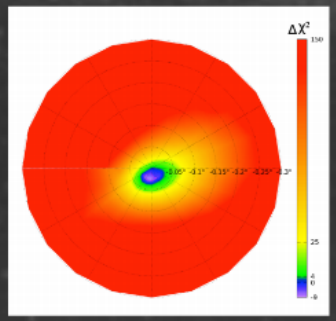


Spherical Symmetry of the Signal





Centered-ness of the Excess



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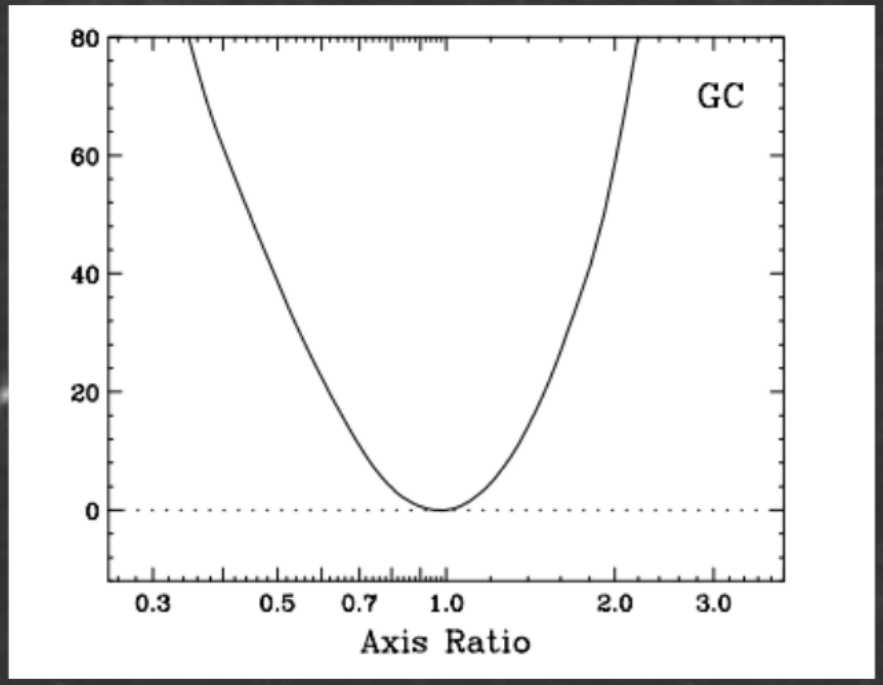

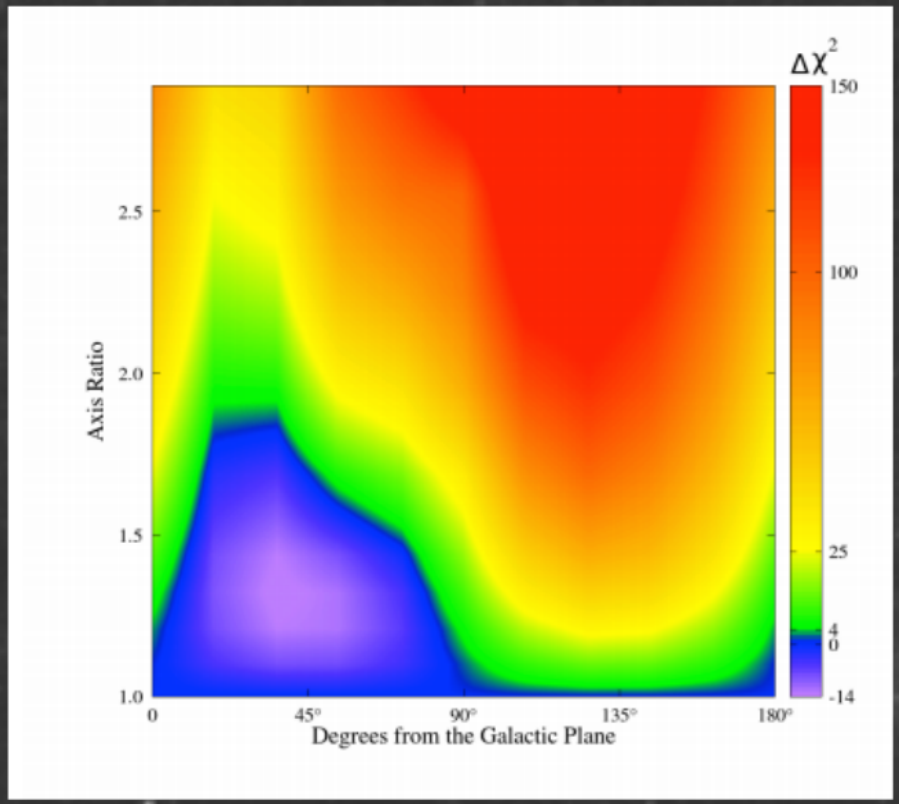

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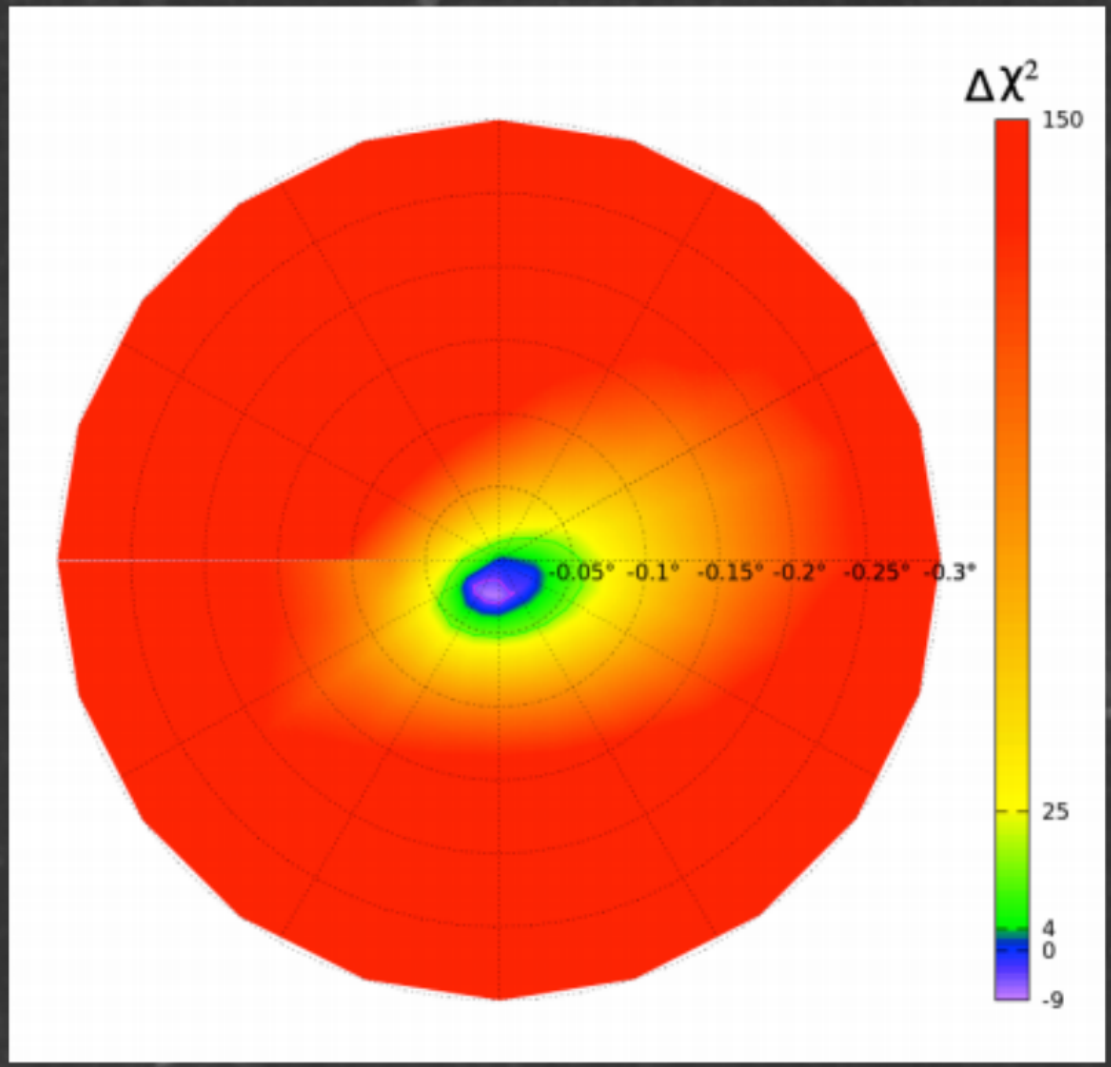

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Space

Dark matter looks more and more likely after new gamma-ray analysis

Scientists describe as 'extremely interesting' new analysis that makes case for gamma rays tracing back to Wimp particles

Natalie Wolchover for Quanta magazine

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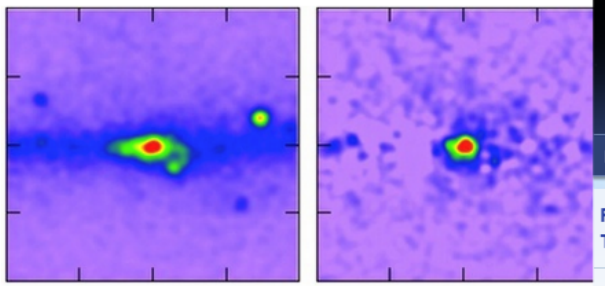
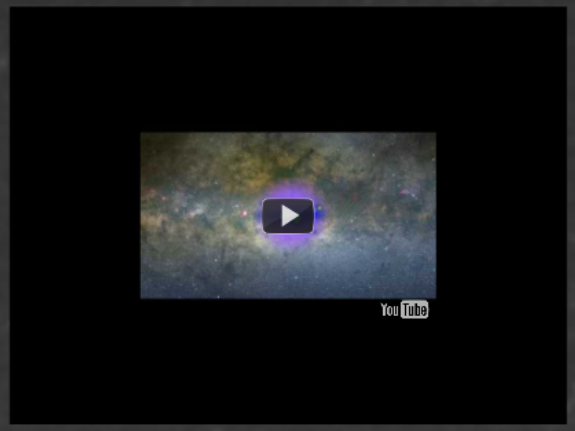


Maps of gamma rays from the center of the Milky Way galaxy, before (left) and after signals from known sources were removed, reveal an excess that is consistent with the distribution of dark matter. Photograph: Day et al/Quanta magazine



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Fermi Gamma-Ray Space Telescope

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Fermi Data Tantalize With New Clues To Dark Matter **April 3, 2014**

A new study of gamma-ray light from the center of our galaxy makes the strongest case to date that some of this emission may arise from dark matter, an unknown substance making up most of the material universe. Using publicly available data from NASA's Fermi Gamma-ray Space Telescope, independent scientists at the Fermi National Accelerator Laboratory (Fermilab), the Harvard-Smithsonian Center for Astrophysics (CfA), the Massachusetts Institute of Technology (MIT) and the University of Chicago have developed new maps showing that the galactic center produces more high-energy gamma rays than can be explained by known sources and that this excess emission is consistent with some forms of dark matter.

"The new maps allow us to analyze the excess and test whether more conventional explanations, such as the presence of undiscovered pulsars or cosmic-ray collisions on gas clouds, can account for it," said Dan Hooper, an astrophysicist at Fermilab in Batavia, Ill., and a lead author of the study. "The signal we find cannot be explained by currently proposed alternatives and is in close agreement with the predictions of very simple dark matter models."

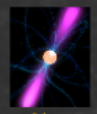
Interpreting The Excess

Important Note

When we have said "dark matter improves the fit" - what we really mean is that - "a template motivated by dark matter improves the fit"

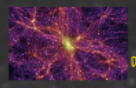
We now know there is an additional component - we just need to figure out what it is!

Leading Candidates



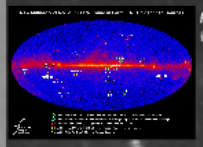
Pulsars

Outbursts from The Galactic Center

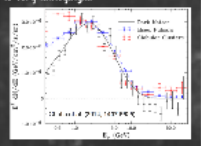


Dark Matter

Millisecond Pulsars

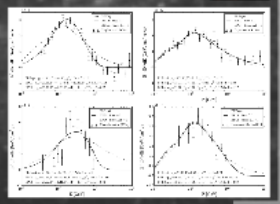


As a dark matter fan -- this spectrum is very annoying...



Hadronic Outbursts

Could a massive outburst from Sgr A* produce the emission?



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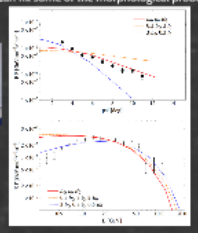

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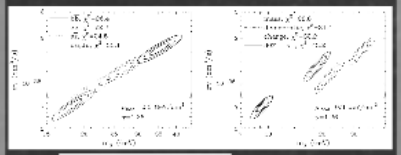

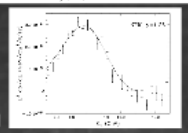

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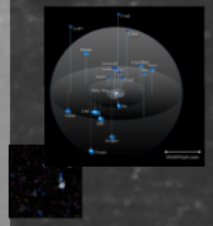

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If we knew what it was we were doing, it would not be called research, would it?" - Albert Einstein

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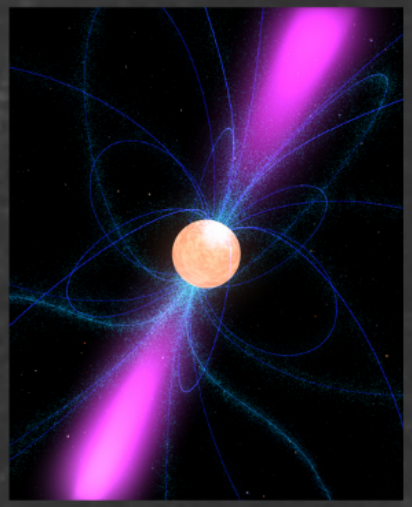

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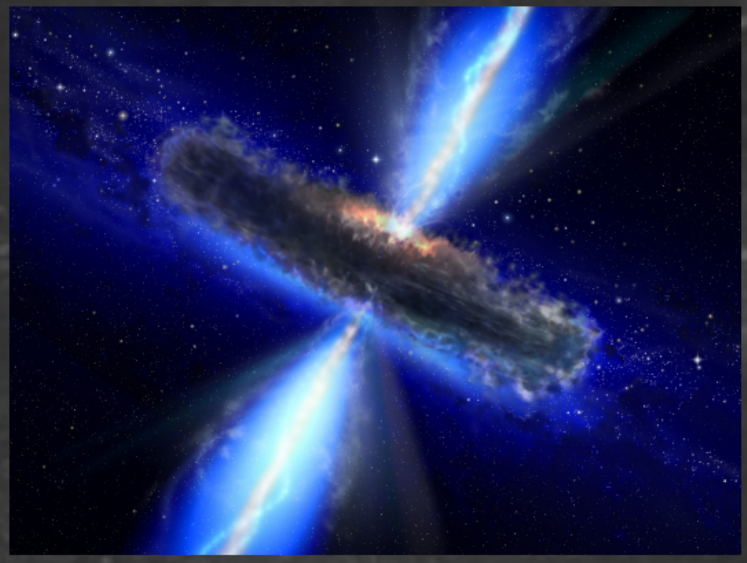

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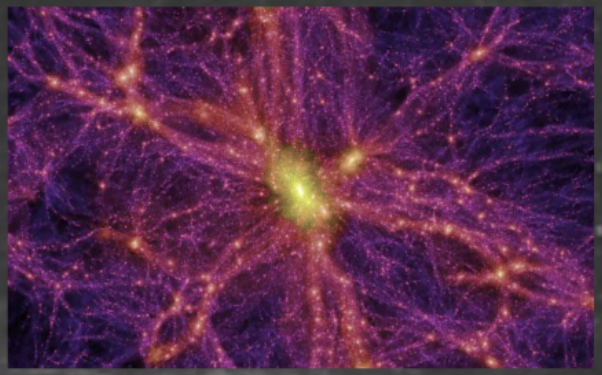

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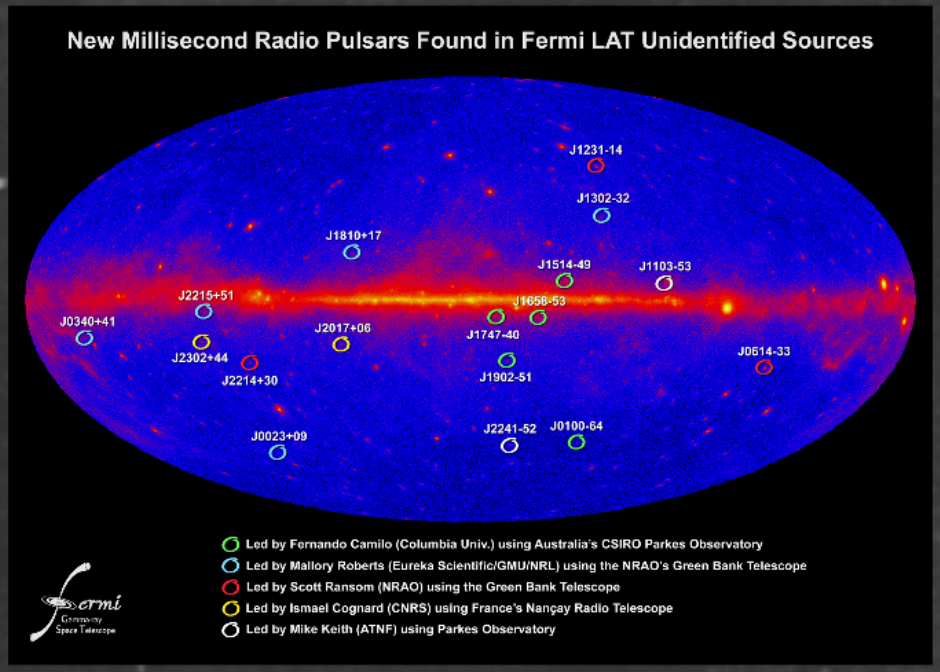

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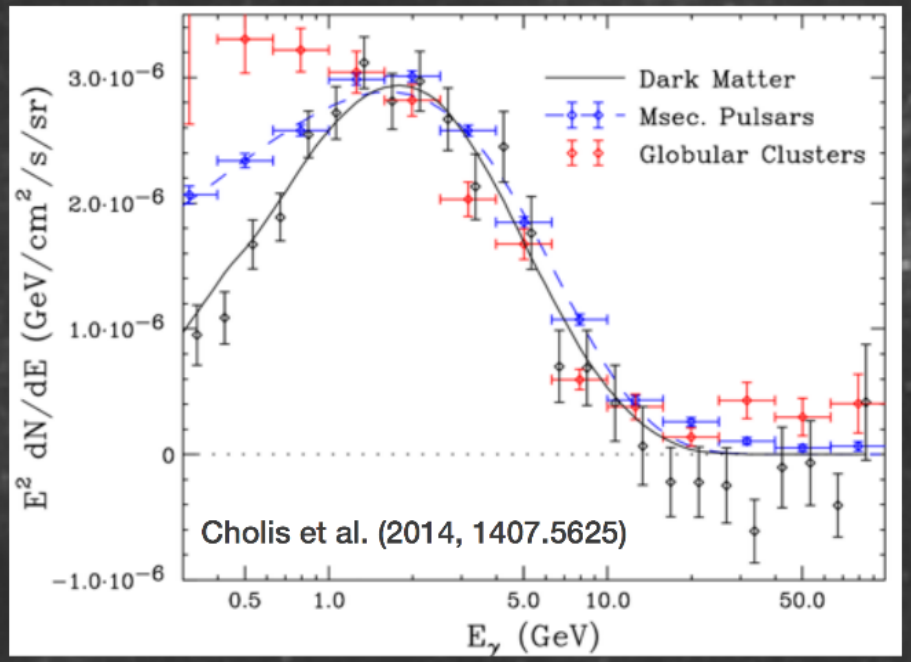

Why Not Millisecond Pulsars

If Millisecond Pulsars make up all of the emission in the galactic center, we should have seen some by now.

Instead, we actually see no millisecond pulsars very close to the galactic center.

Why?

Missing Pulsar Problem

Up until 2013, no pulsars had been discovered at the galactic center.

It was possible that the high density of electrons near the galactic center was smearing out the signal, making them impossible to see.

Then we found one.....

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Astronomers Discover a Magnetar at the Galactic Center

August 16, 2013 Space

Artist's impression of PSR J1745-2900, a pulsar with a very high magnetic field ("magnetar") in direct vicinity of the central source of our Galaxy, a supermassive black hole of approximately 4 million times the mass of our sun. Measurements of the pulsar imply that a strong magnetic field exists in the vicinity around the black hole. MPIfR/Ralph Eatough.

An international team of astronomers has discovered a magnetar at the center of the Milky Way galaxy.

Astronomers have discovered a magnetar at the center of our Milky Way. This pulsar has an extremely strong magnetic field and enables researchers to investigate the direct vicinity of the black hole at the heart of the galaxy. An international team of scientists

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Mysterious Missing Pulsars May Have Gotten Wrapped in Dark Matter and Turned Into Black Holes

BY MARCUS WOO 11.03.14 | 6:30 AM | PERMALINK

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The core of the Milky Way at a distance of some 26,000 light years from Earth. NASA/CXC/UMass/D. Wang et al./STScI/JPL-Caltech/SSC/S.Stolovy

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SPACE PHOTO OF THE DAY

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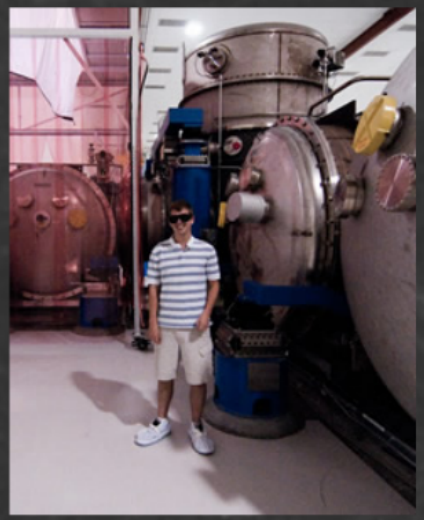

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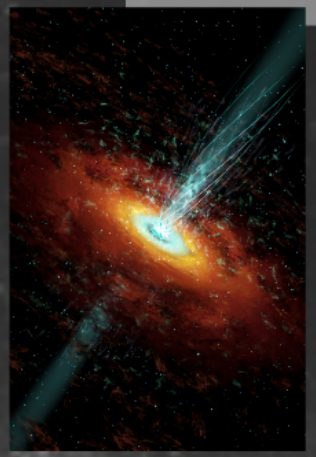

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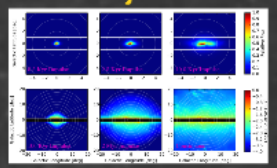
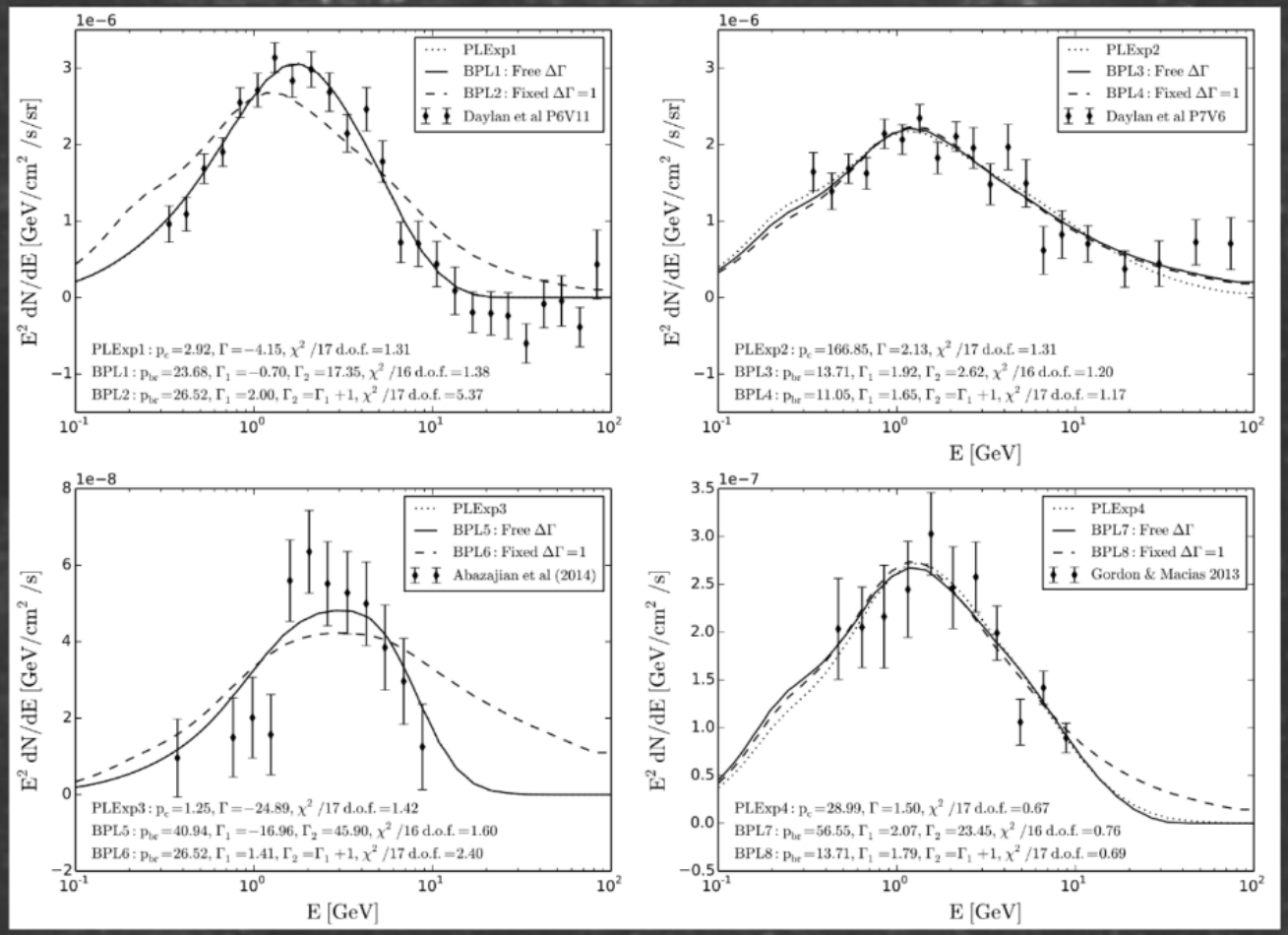


Not very spherical, doesn't fit the excess well



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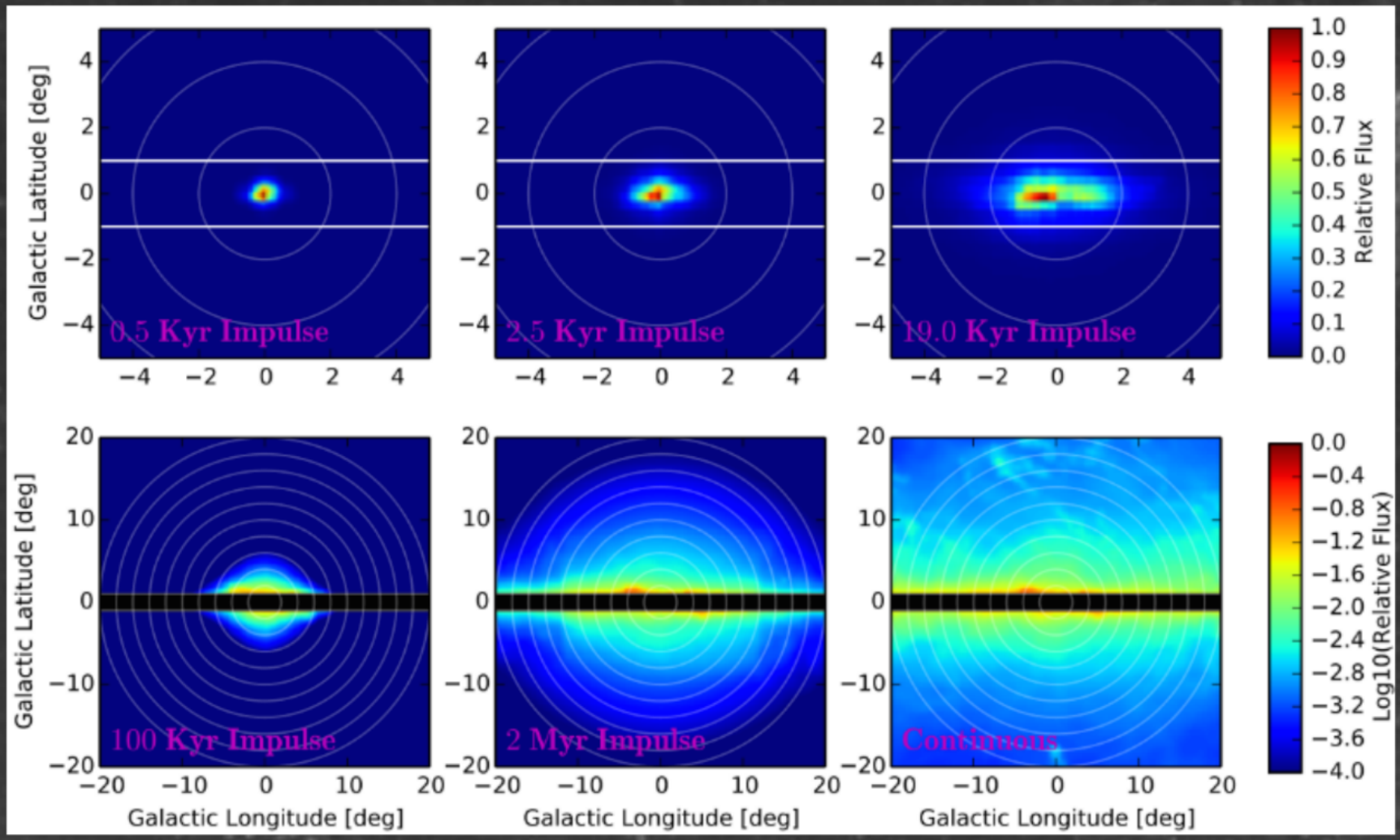

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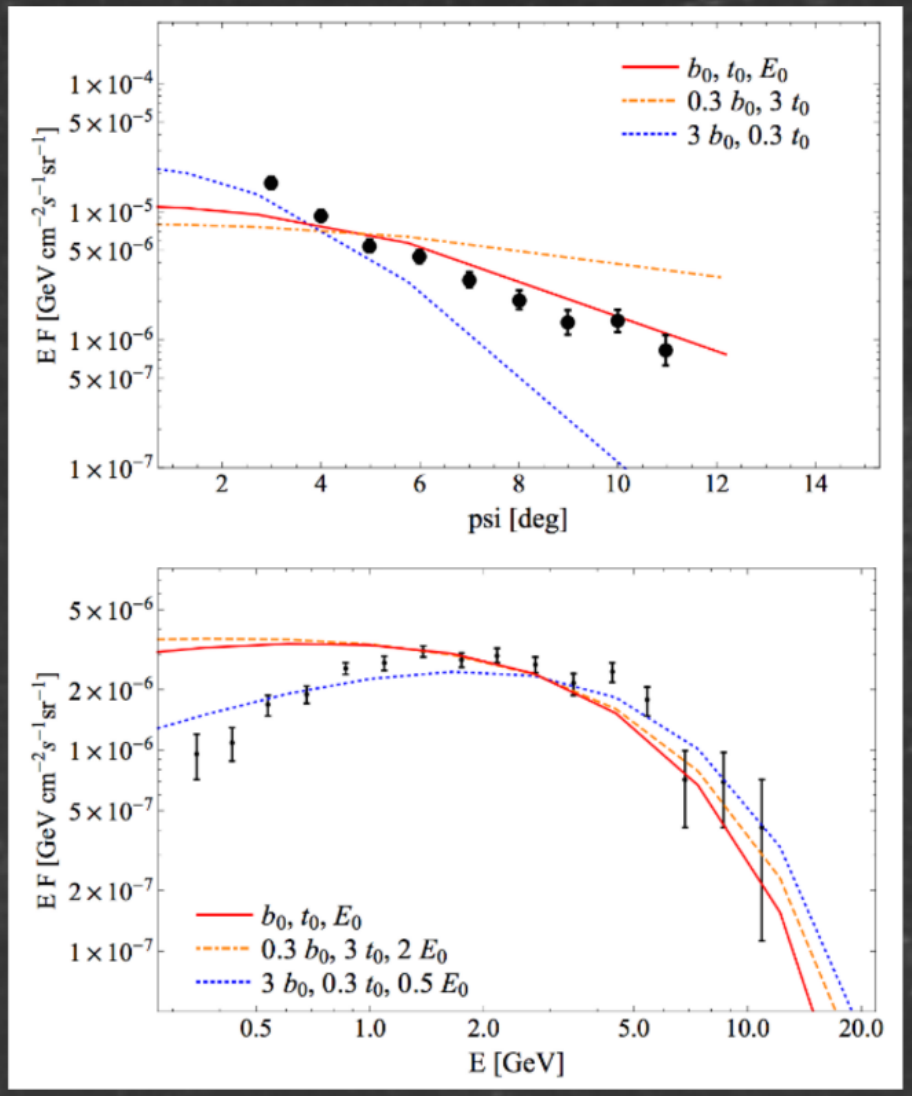

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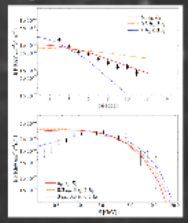
Electron Cooling is very efficient. Hard to get the correct spectrum to stay constant as you travel farther from the galactic center



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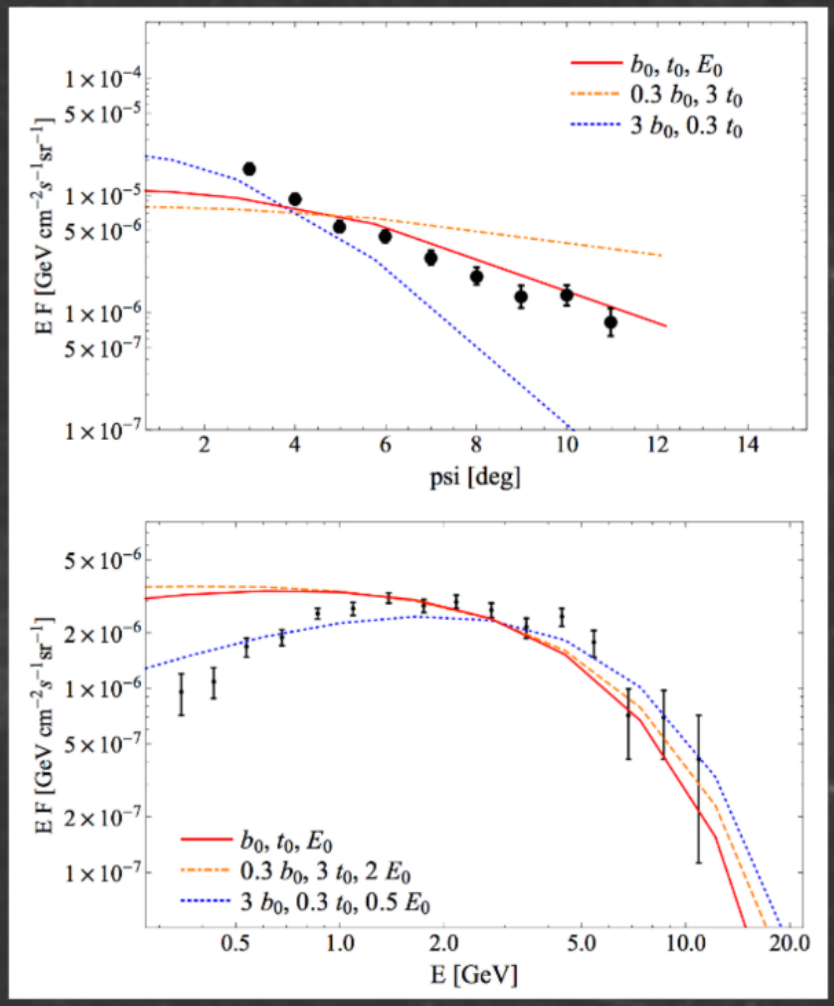

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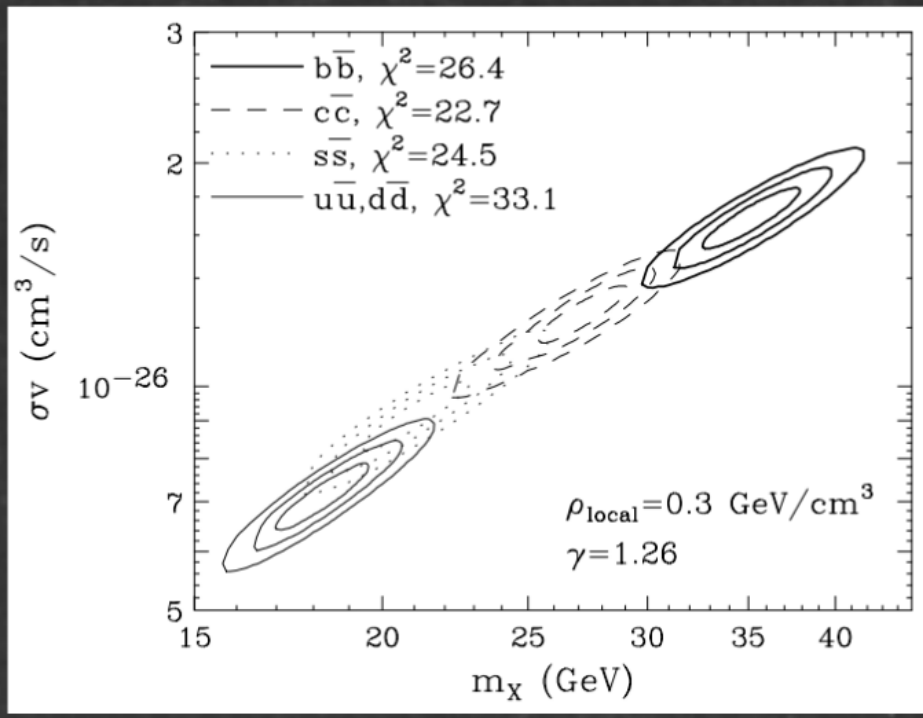
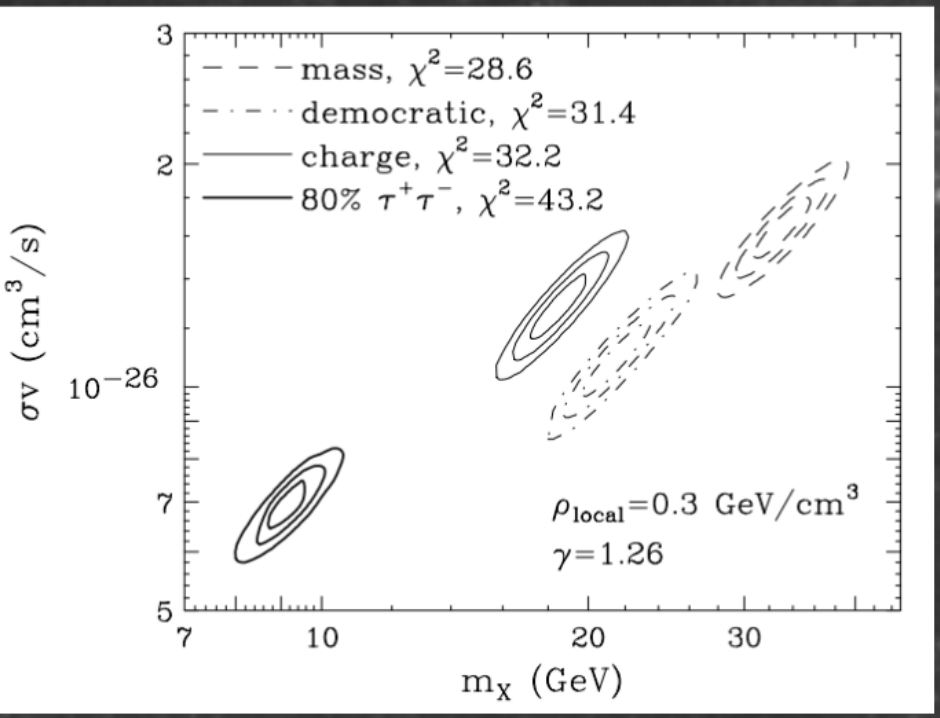
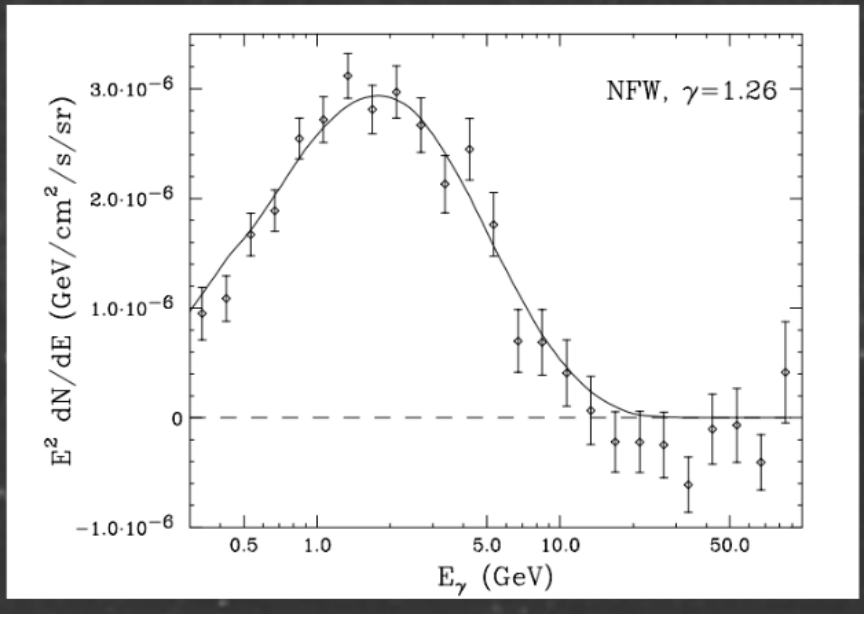
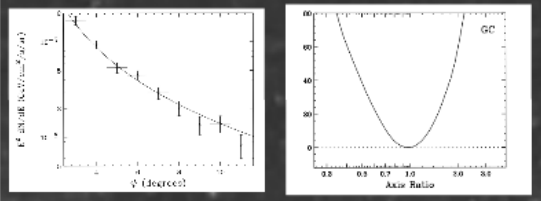




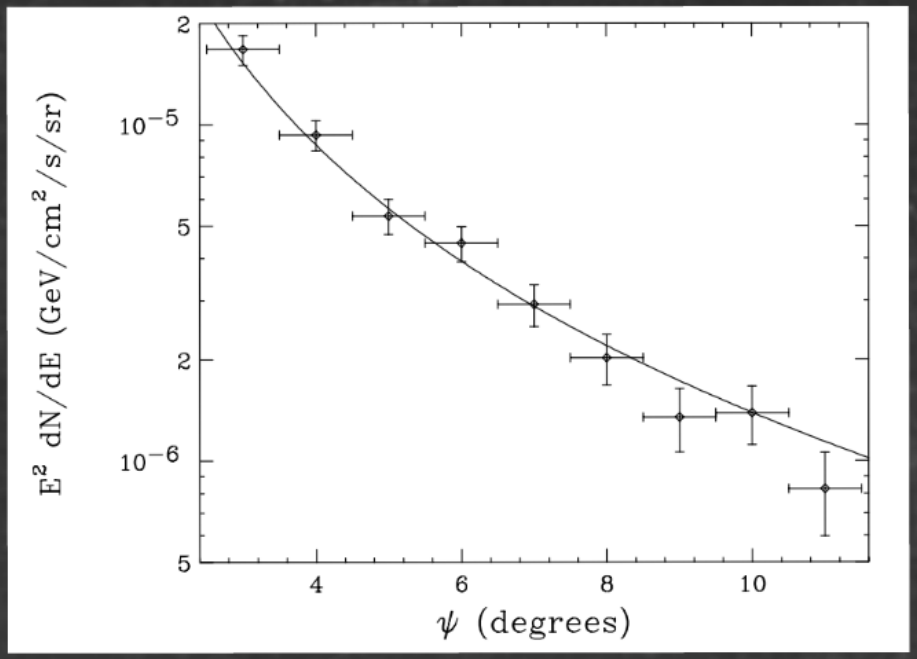


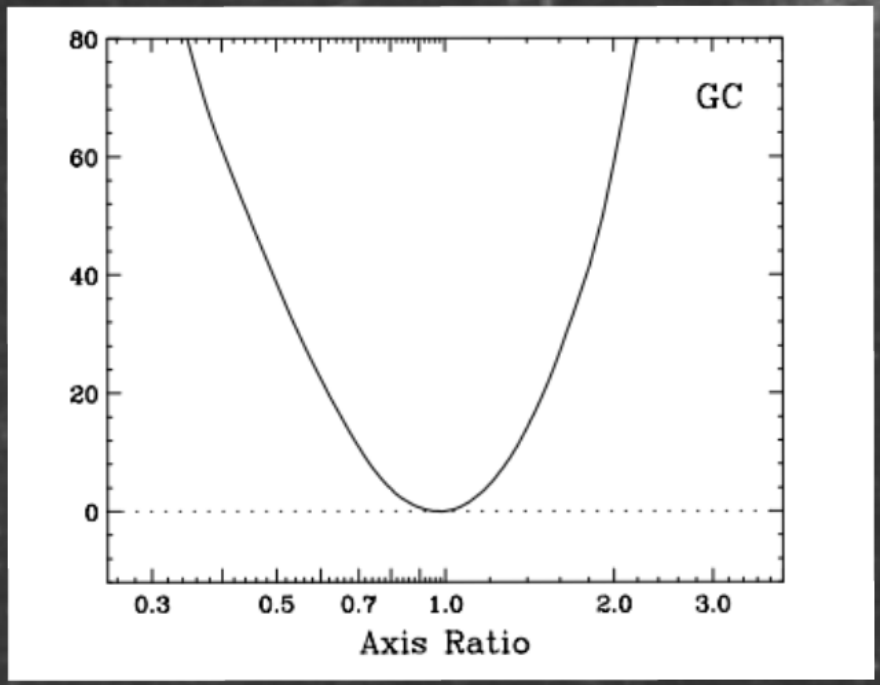
Morphological Fits



The spherical symmetry and radial distribution of the signal closely resembles a dark matter source.

Morphological Fits





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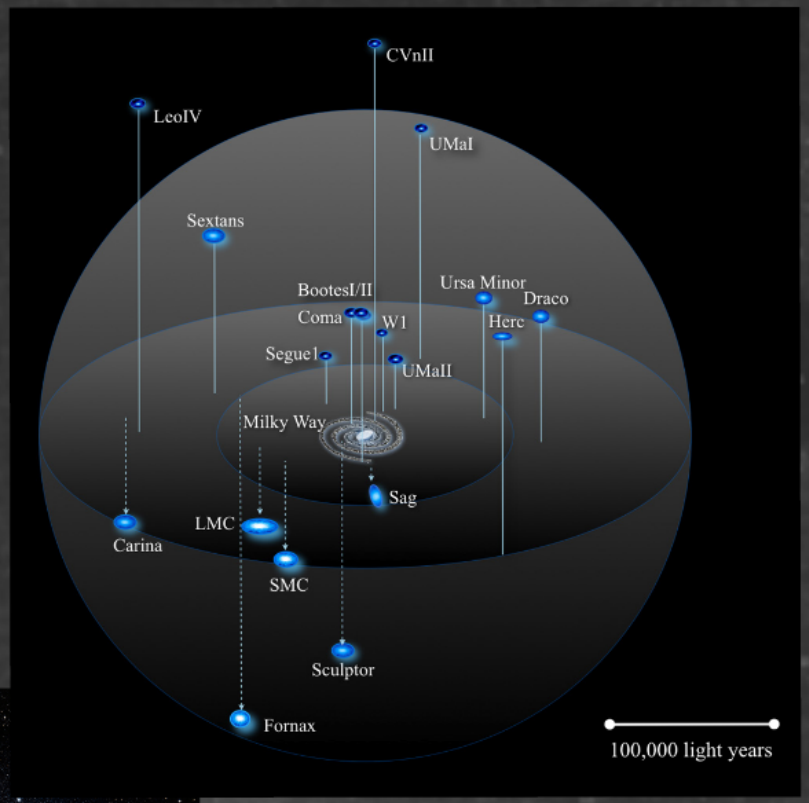
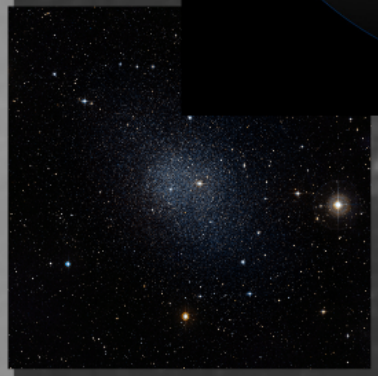
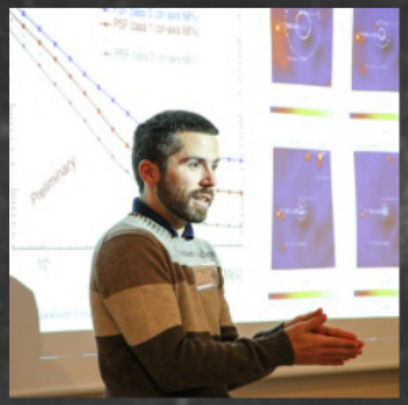
Fermi dwarf galaxies could provide a strong confirmation of the signal







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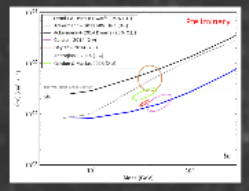

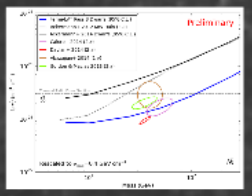

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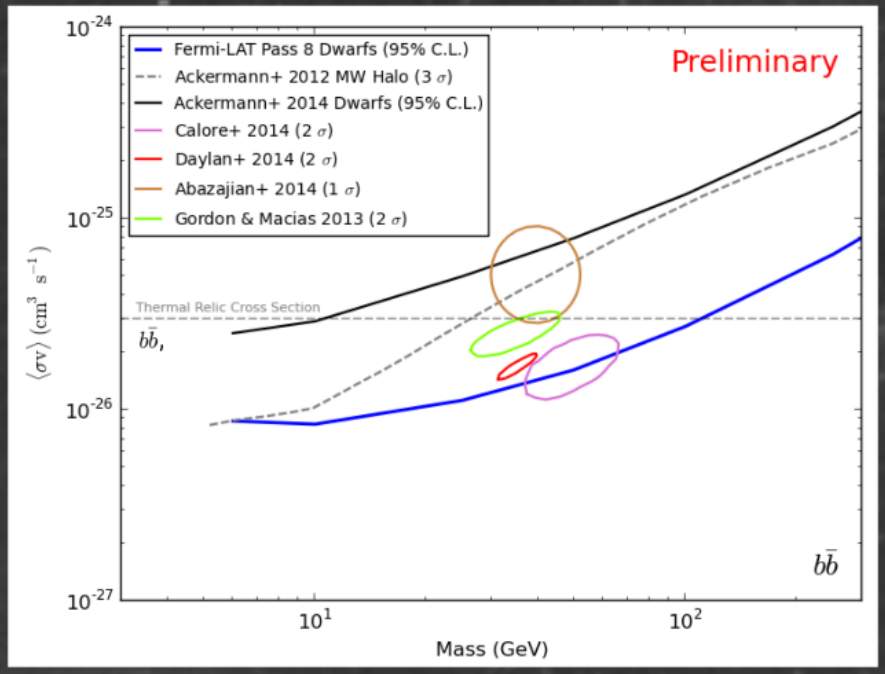
Fermi-LAT Pass 8 Dwarfs (95% C.L.)
Ackermann+ 2012 MW Halo (3 σ)
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Calore+ 2014 (2 σ)
Daylan+ 2014 (2 σ)
Abazajian+ 2014 (1 σ)
Gordon & Macias 2013 (2 σ)
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Thermal Relic Cross Section
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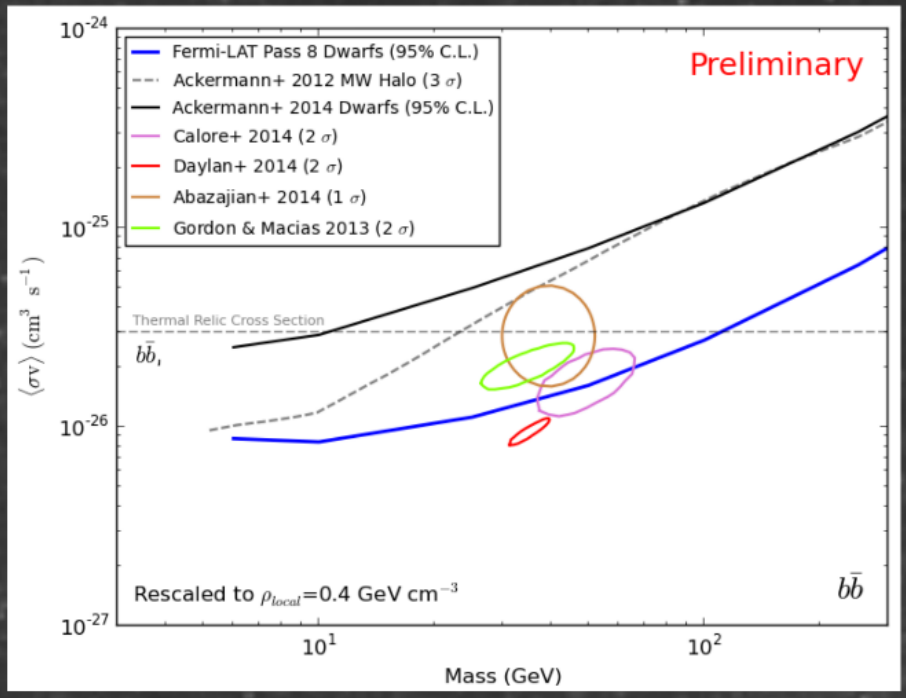
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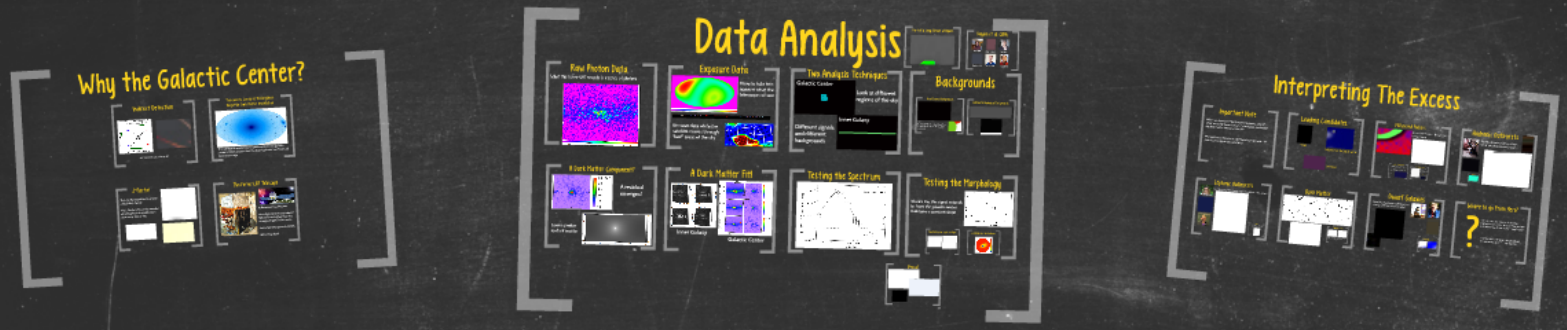
The Indirect Detection of Dark Matter in the Galactic Center



Tim Linden

Lecture 9

Fall 2014 Compton Lectures