A Compelling Case for Annihilating Dark Matter

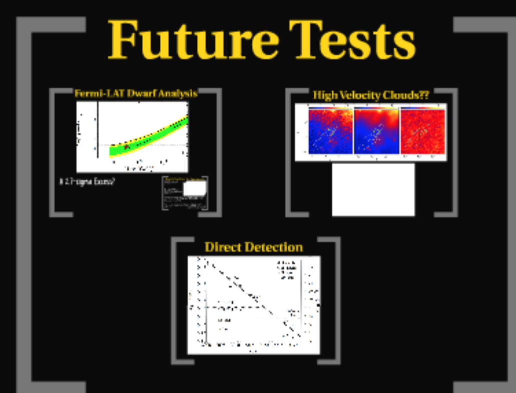
Tim Linden

along with:
Tansu Daylan, Doug Finkbeiner, Dan Hooper, Stephan Portillo, Nick Rodd, Tracy Slatyer

arXiv: 1402.6703

University of Hong Kong - October 17, 2014

It's a compelling case
-- but what is next?



Thank you for attending!

Any Questions?

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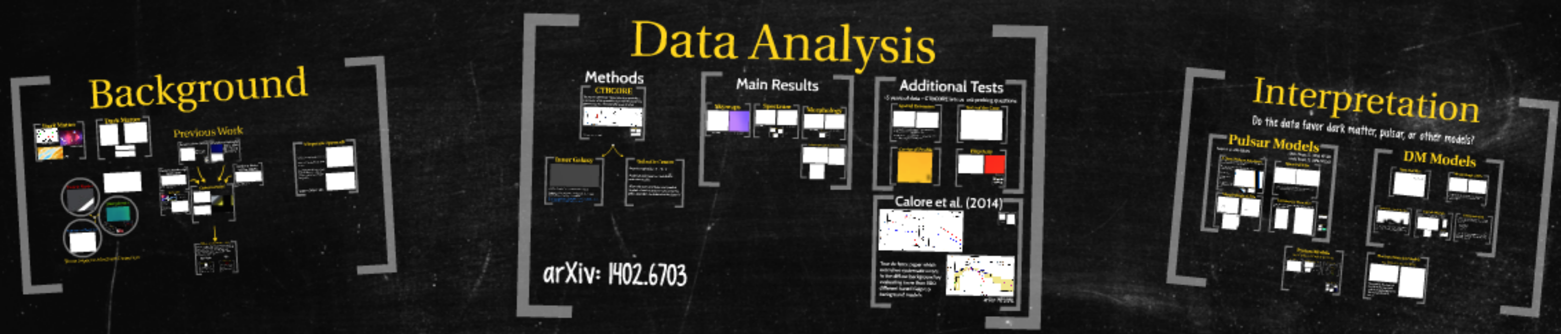

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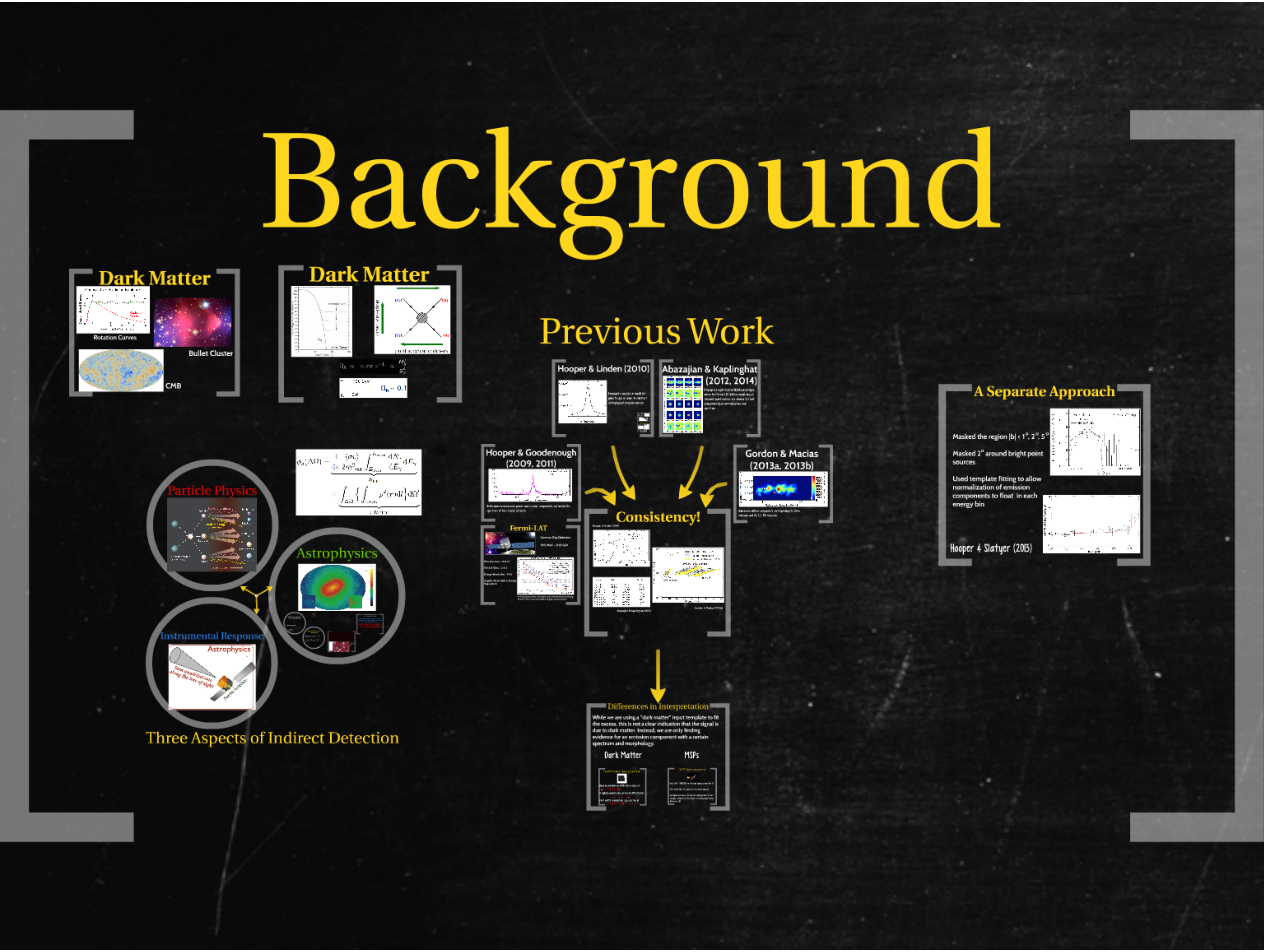
Background
Dark Matter
Rotation Curves
Bullet Cluster
CMB
Dark Matter
$\Omega_h \sim 0.1$
Particle Physics
Astrophysics
Instrumental Response
Astrophysics
Three Aspects of Indirect Detection
Previous Work
Hooper & Linden (2010)
Abazajian & Kaplinghat (2012, 2014)
Hooper & Goodenough (2009, 2011)
Gordon & Macias (2013a, 2013b)
Fermi-LAT
Consistency!
Differences in Interpretation
While we are using a "dark matter" input template to fit the excess, this is not a clear indication that the signal is due to dark matter. Instead, we are only finding evidence for an emission component with a certain spectrum and morphology.
Dark Matter
MSPs
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Masked the region |b| < 1°, 2°, 5°
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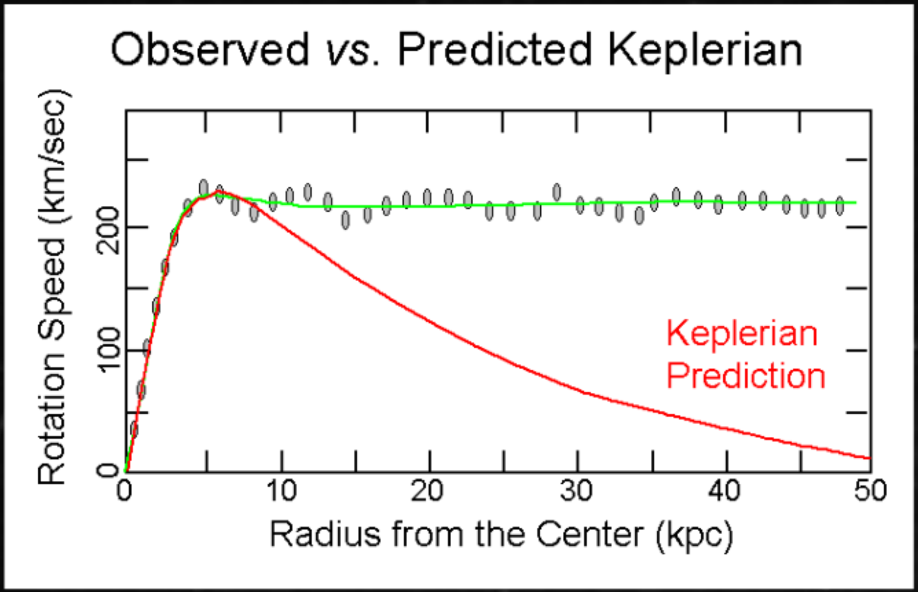
Used template fitting to allow normalization of emission components to float in each energy bin
Hooper & Slatyer (2013)

Dark Matter



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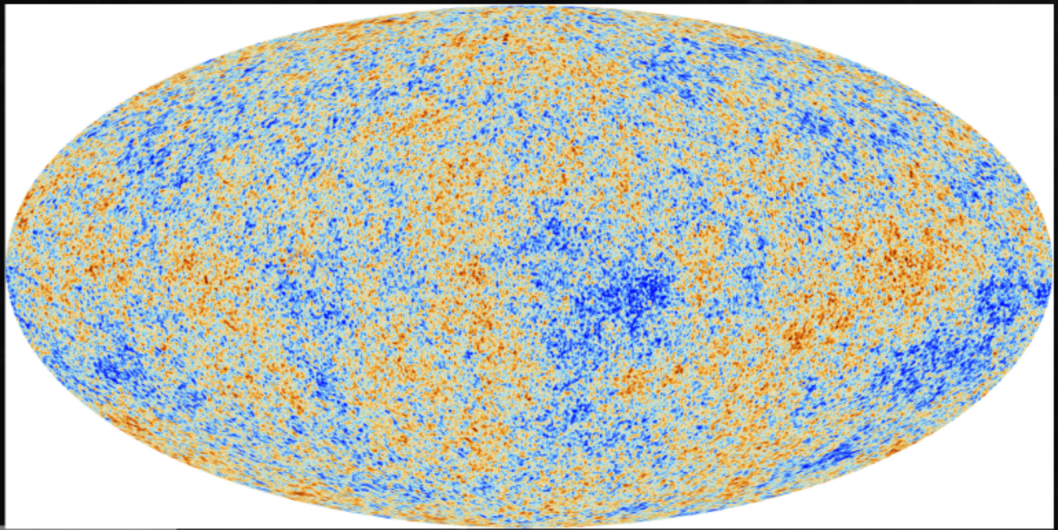

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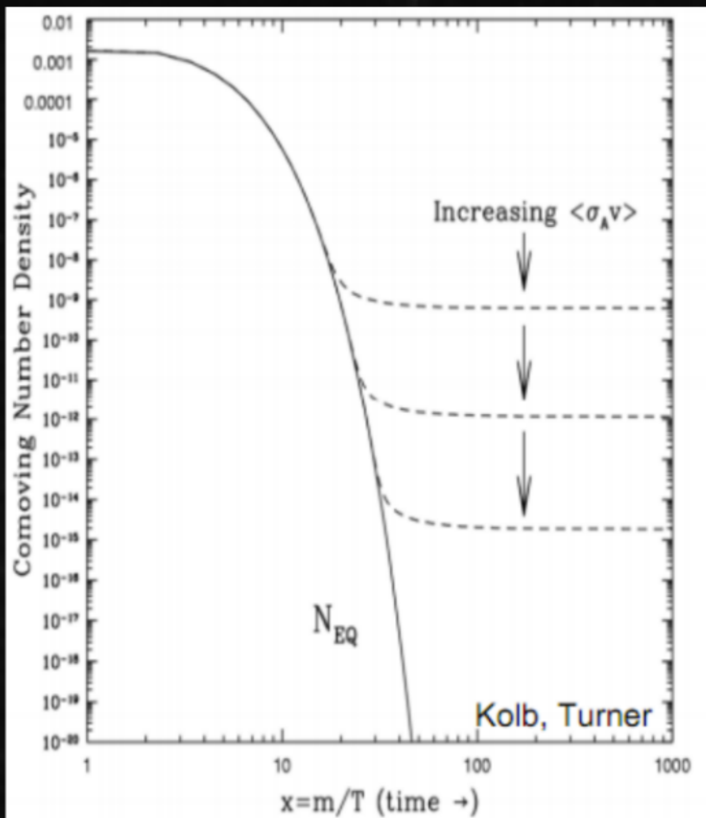
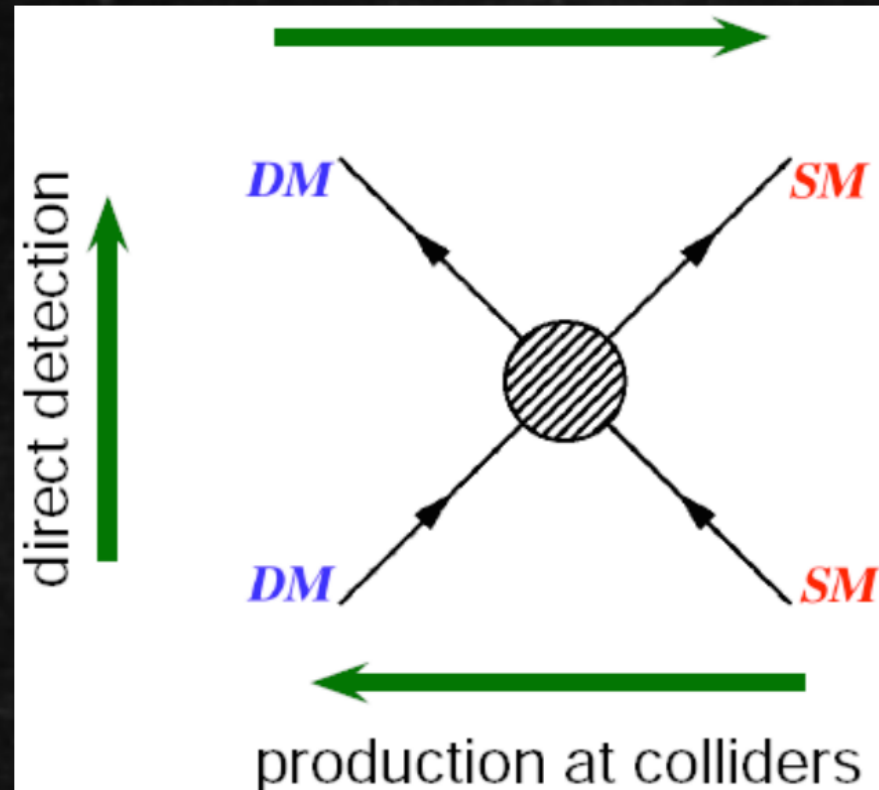




$$\Omega_h \propto \langle \sigma v \rangle^{-1} \propto \frac{M_X^2}{g_X^4}$$

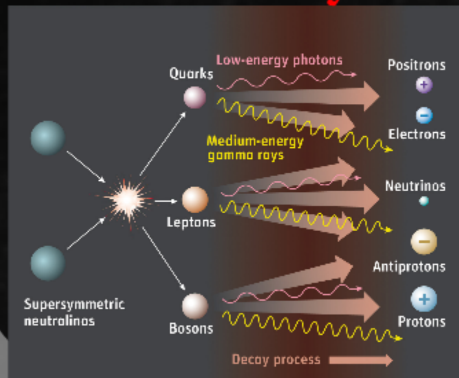
$M_X{}^2$ = 100 GeV

$\Omega_h \sim 0.1$

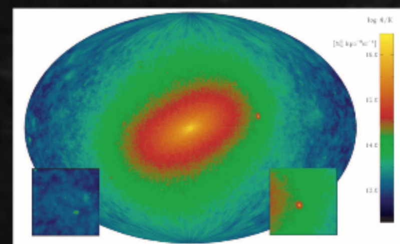
$g_X{}^4$ = 0.6

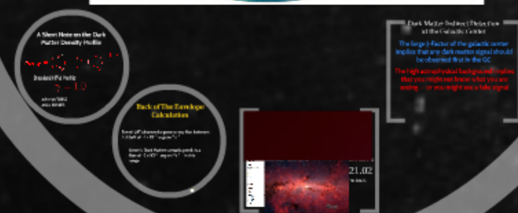
$$\phi_s(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\int_{E_{\rm min}}^{E_{\rm max}}\frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}{\rm d}E_\gamma}_{\Phi_{\rm PP}} \times \underbrace{\int_{\Delta\Omega}\left\{\int_{\rm l.o.s.}\rho^2(\boldsymbol{r}){\rm d}l\right\}{\rm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

Particle Physics

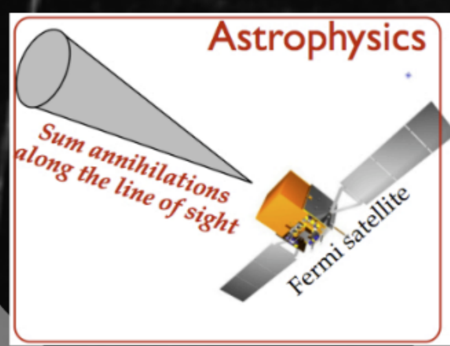


Astrophysics





Instrumental Response



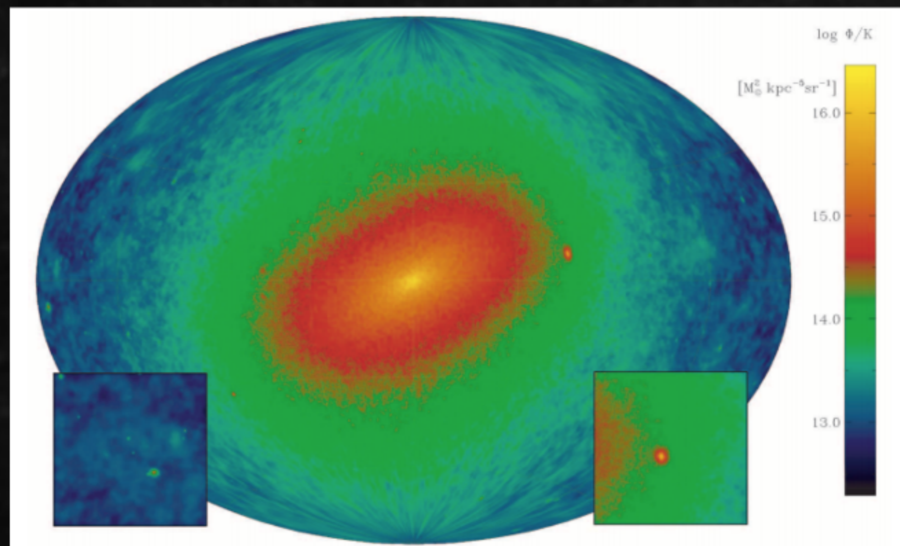
Three Aspects of Indirect Detection

utrinos

rotons

Protons

Astrophysics



A Short Note on the Dark Matter Density Profile

$$\rho_{NFW} = \left(\frac{r}{r_s}\right)^{-\gamma} \left(1 + \frac{r}{r_s}\right)^{-3+\gamma}$$

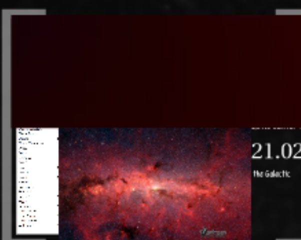
Standard NFW Profile:

$$\gamma = 1.0$$

Back of The Envelope Calculation

Fermi-LAT observed a gamma-ray flux between 1-3 GeV of ~1 x 10 [illegible] erg cm^{-2} s^{-1}

Generic Dark Matter scenario predicts a flux of ~2 x 10 [illegible] erg cm^{-2}s^{-1} in this range



Dark Matter Indirect Detection at the Galactic Center

The large J-Factor of the galactic center implies that any dark matter signal should be observed first in the GC

The high astrophysical background implies that you might not know what you are seeing -- or you might see a fake signal

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astro-ph/9508025
arXiv: 0809.0898

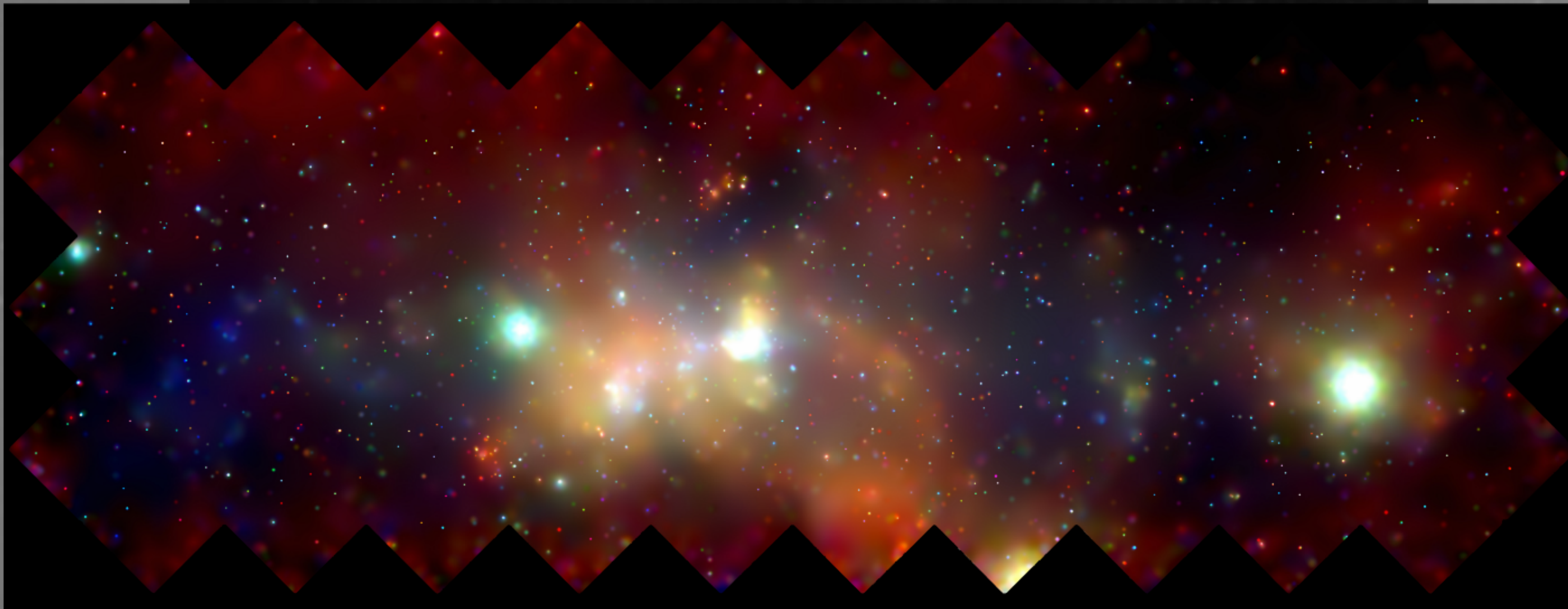
Bac

Back of The Envelope Calculation

Fermi-LAT observed a gamma-ray flux between 1-3 GeV of ~1×10^{-10} erg cm^{-2} s^{-1}

Generic Dark Matter scenario predicts a flux of ~2×10^{-11} erg $cm^{-2} s^{-1}$ in this range

Profile Dependence



Canes Venatici II
Canis Major
Carina
Coma Berenices
Draco
Fornax
Hercules
Leo I
Leo II
Leo IV
Leo V
Pisces II
Sagittarius
Sculptor
Segue 1
Segue 2
Sextans
Ursa Major I
Ursa Major II
Ursa Minor
Willman 1

21.02

the Galactic

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Previous Work

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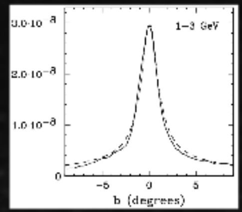

Employed a analytical model for galactic gas in order to subtract astrophysical emission sources

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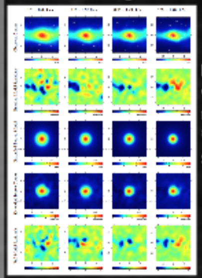

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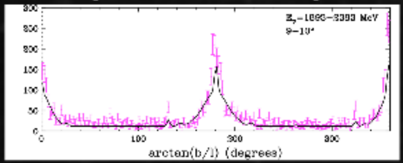

Broke down emission into planer and circular components, extracted the spectrum of the circular emission

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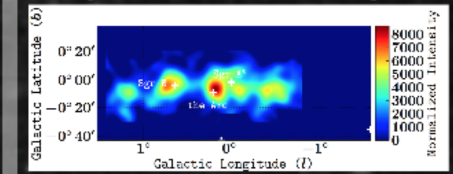


Added new diffuse components corresponding to 20cm emission and H.E.S.S. TeV emission

Fermi-LAT

Gamma-Ray Detector:

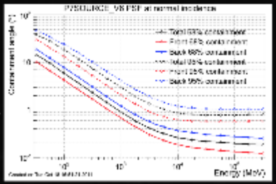
100 MeV - 300 GeV

Effective Area = 0.8 m^2

Field of View = 2.4 sr

Energy Resolution ~ 10%

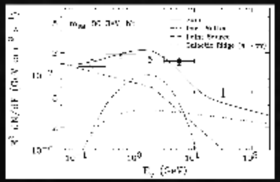
Angular Resolution is Energy Dependent



In the galactic center, we restrict ourselves to front converting events, which have much better angular reconstruction

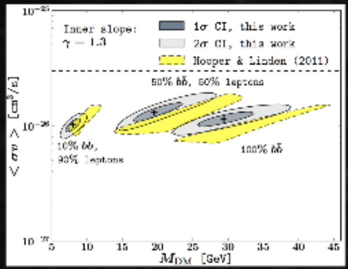
Consistency!

Hooper & Linden (2011)



channel, m_χ	TS_{α}	$-\ln \mathcal{L}$	$\Delta \ln \mathcal{L}$
$b\bar{b}$, 10 GeV	[illegible]	[illegible]	156.5
$b\bar{b}$, 30 GeV	3400.3	139658.4	411.8
$b\bar{b}$, 100 GeV	1305.1	[illegible]	189.3
$b\bar{b}$, 300 GeV	[illegible]	[illegible]	13.3
$b\bar{b}$, 1 TeV	27.5	140089.2	48.3
$b\bar{b}$, 2.5 TeV	[illegible]	[illegible]	[illegible]
$\tau^+\tau^-$, 10 GeV	1628.7	139787.7	292.5
$\tau^+\tau^-$, 30 GeV	[illegible]	[illegible]	[illegible]
$\tau^+\tau^-$, 100 GeV	4.10	140134.4	48.3

Abazajian & Kaplinghat (2012)



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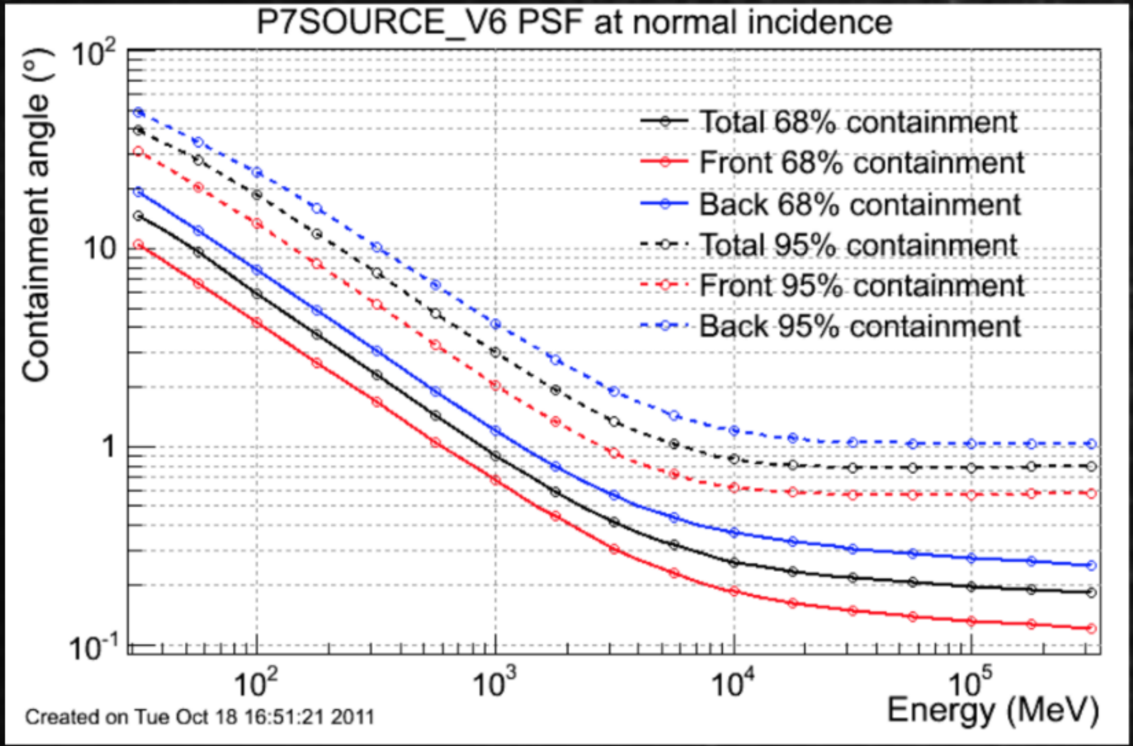

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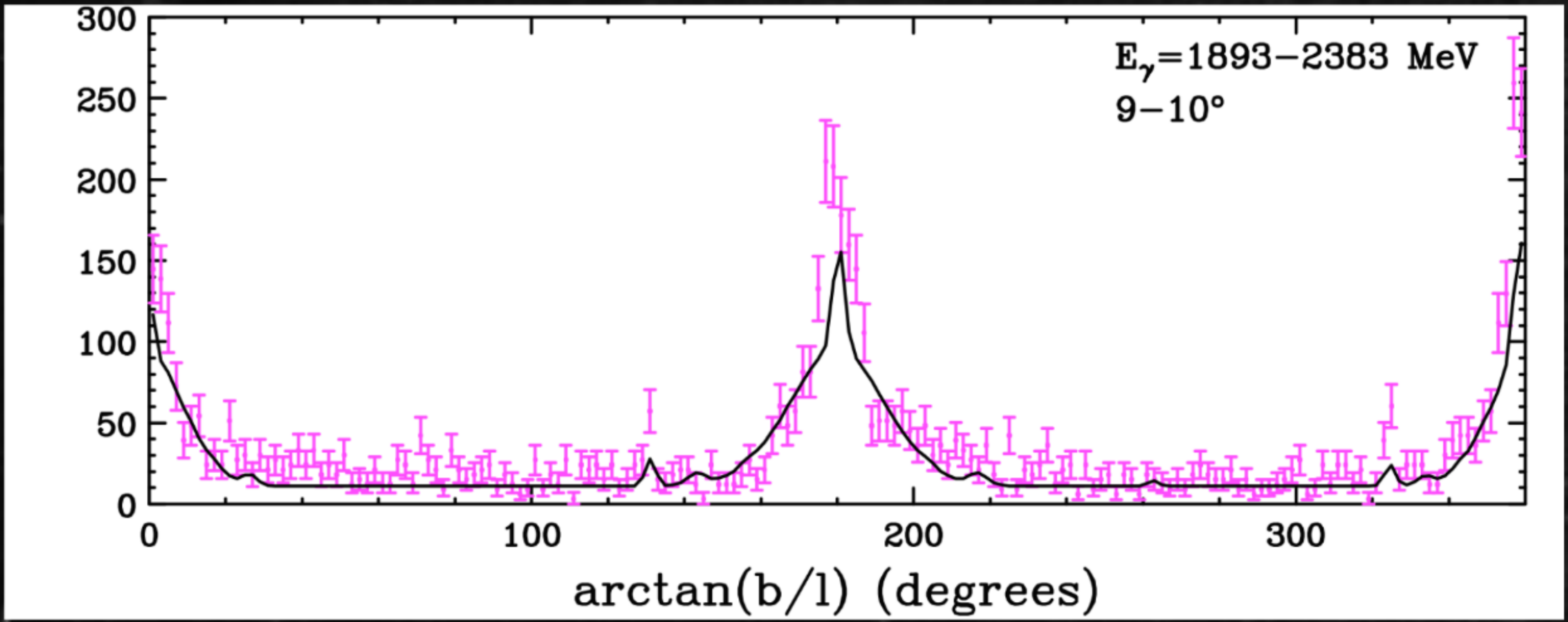

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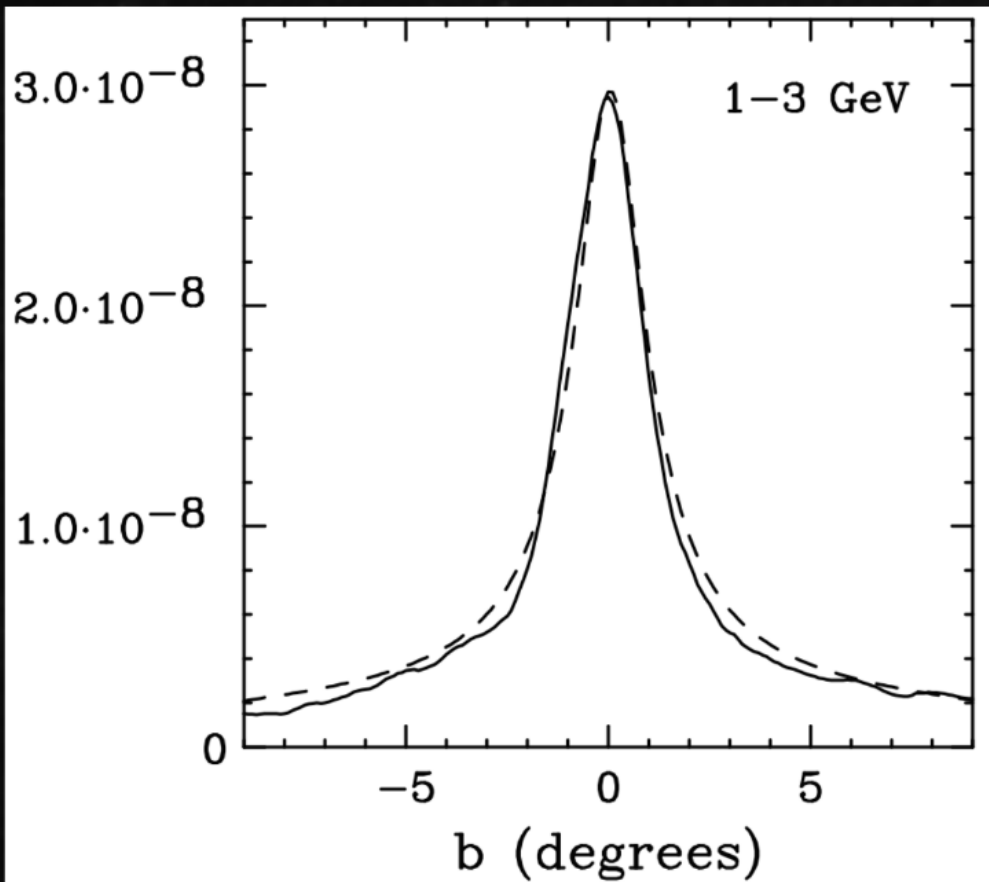

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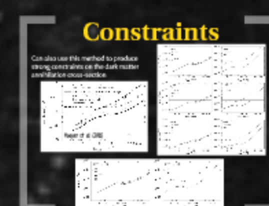

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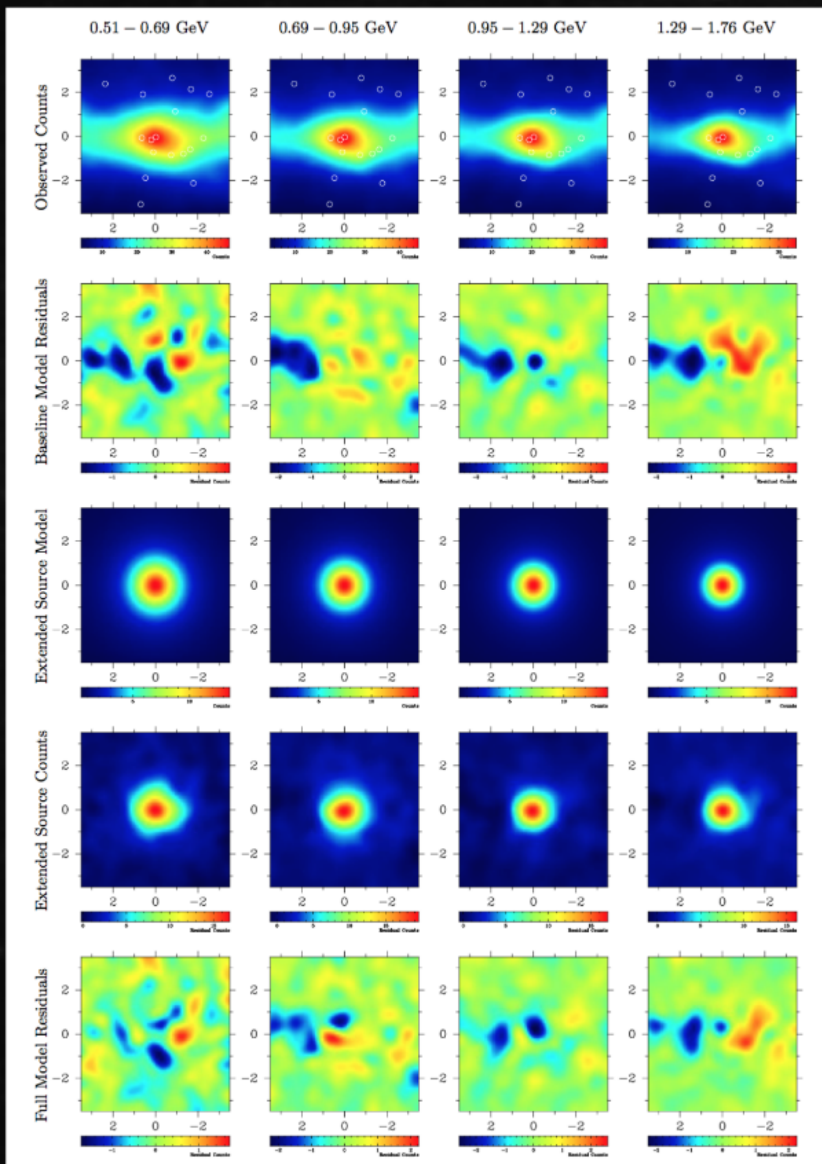

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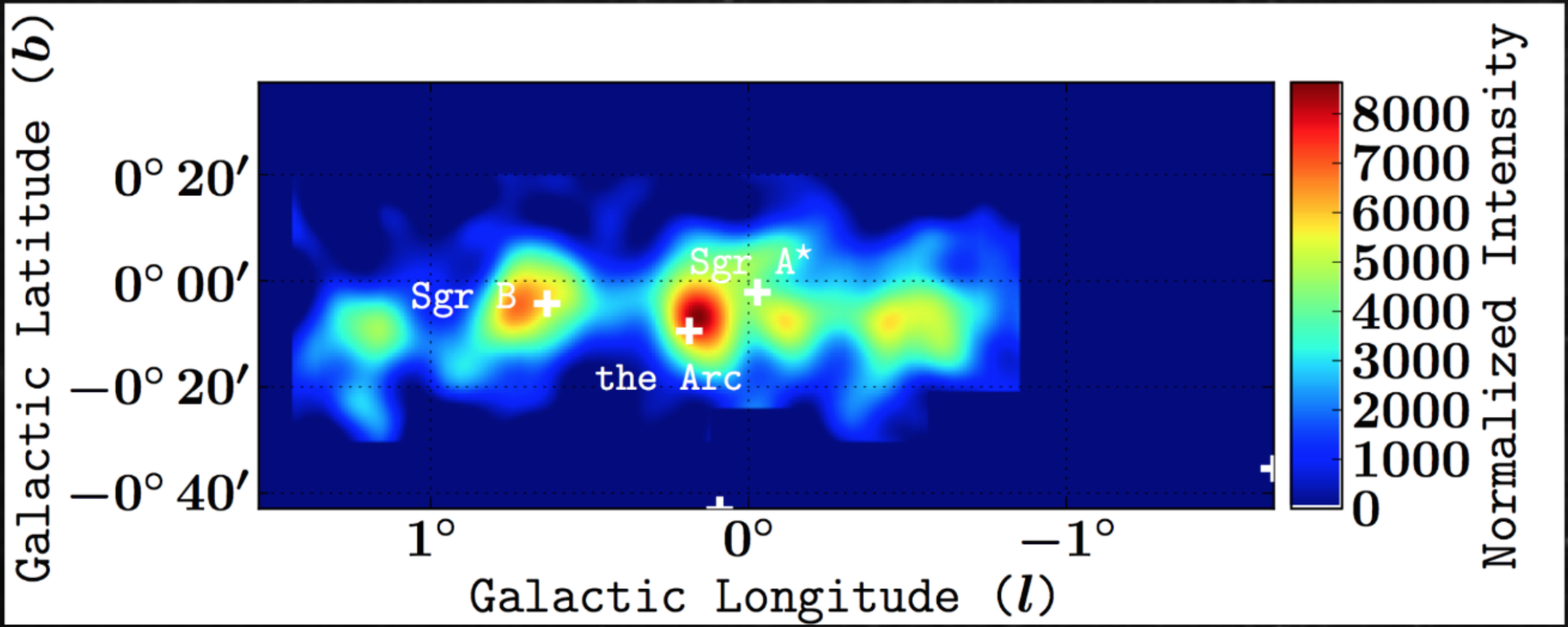

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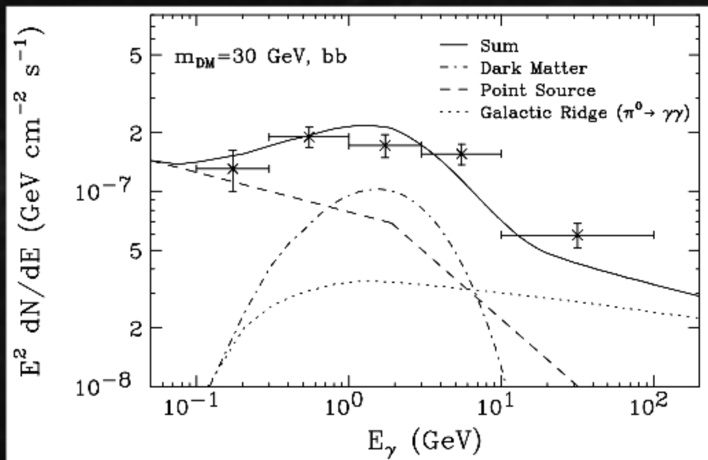

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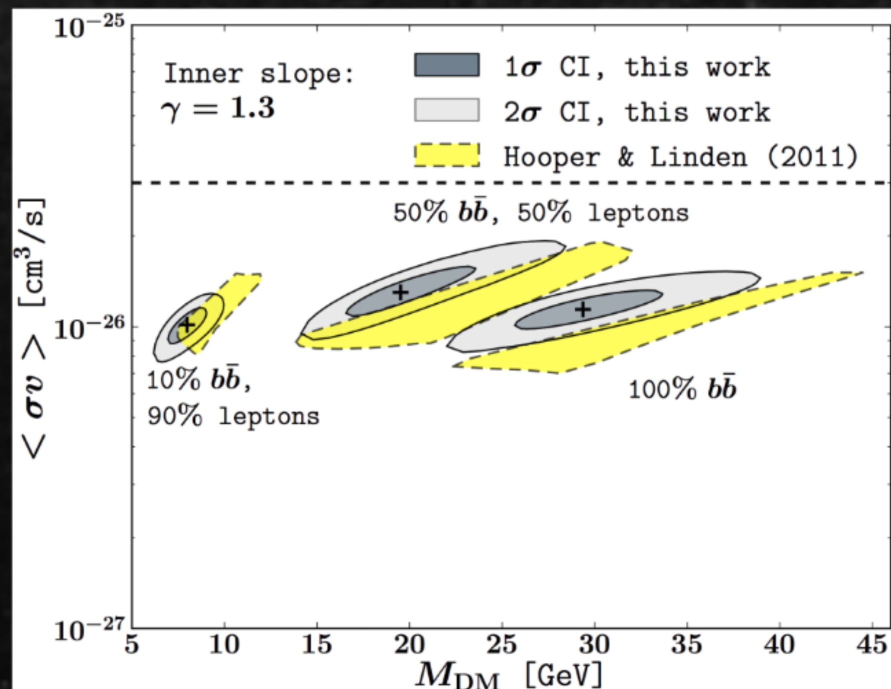

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Differences in Interpretation

While we are using a "dark matter" input template to fit the excess, this is not a clear indication that the signal is due to dark matter. Instead, we are only finding evidence for an emission component with a certain spectrum and morphology.

Dark Matter

Dark Matter Interpretation

Need an annihilating WIMP with a mass of:

$25 - 50\ \mathrm{GeV};\ b\bar{b}$ $8 - 12\ \mathrm{GeV};\ \tau^+\tau^-$

A slightly adiabatically contracted NFW Profile:

$\gamma = 1.1 - 1.3$

Dark matter annihilation cross-section of

$1.5 - 2.5 \times 10^{-26}\ \mathrm{cm^3 s^{-1}}$

MSPs

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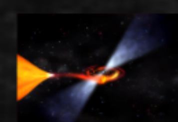

Need 2000 - 4000 MSPs in the inner degree around the GC

MSPs must follow the square of the stellar density

Average pulsar spectrum must be slightly harder at low-energies, compared to the pulsars currently observed by the Fermi-LAT

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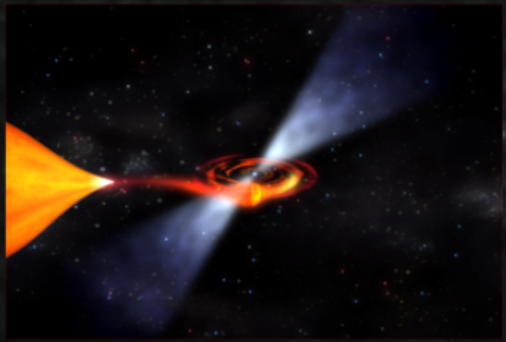

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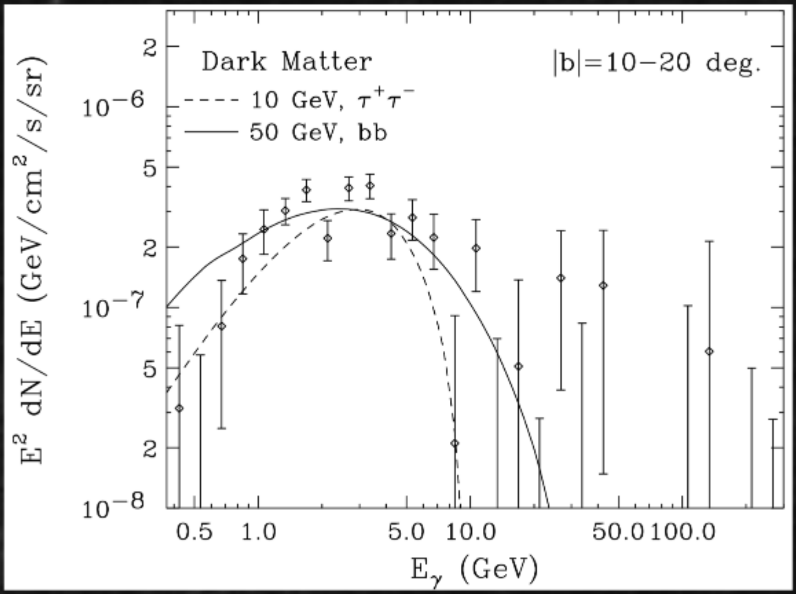

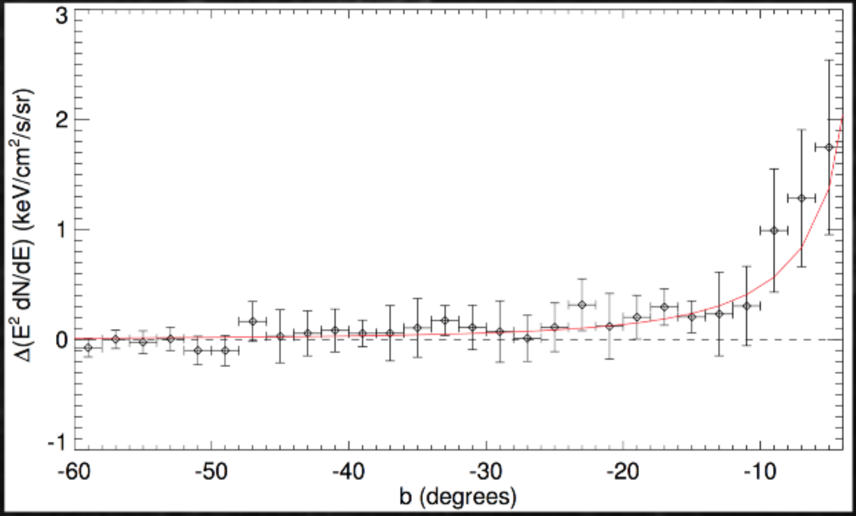

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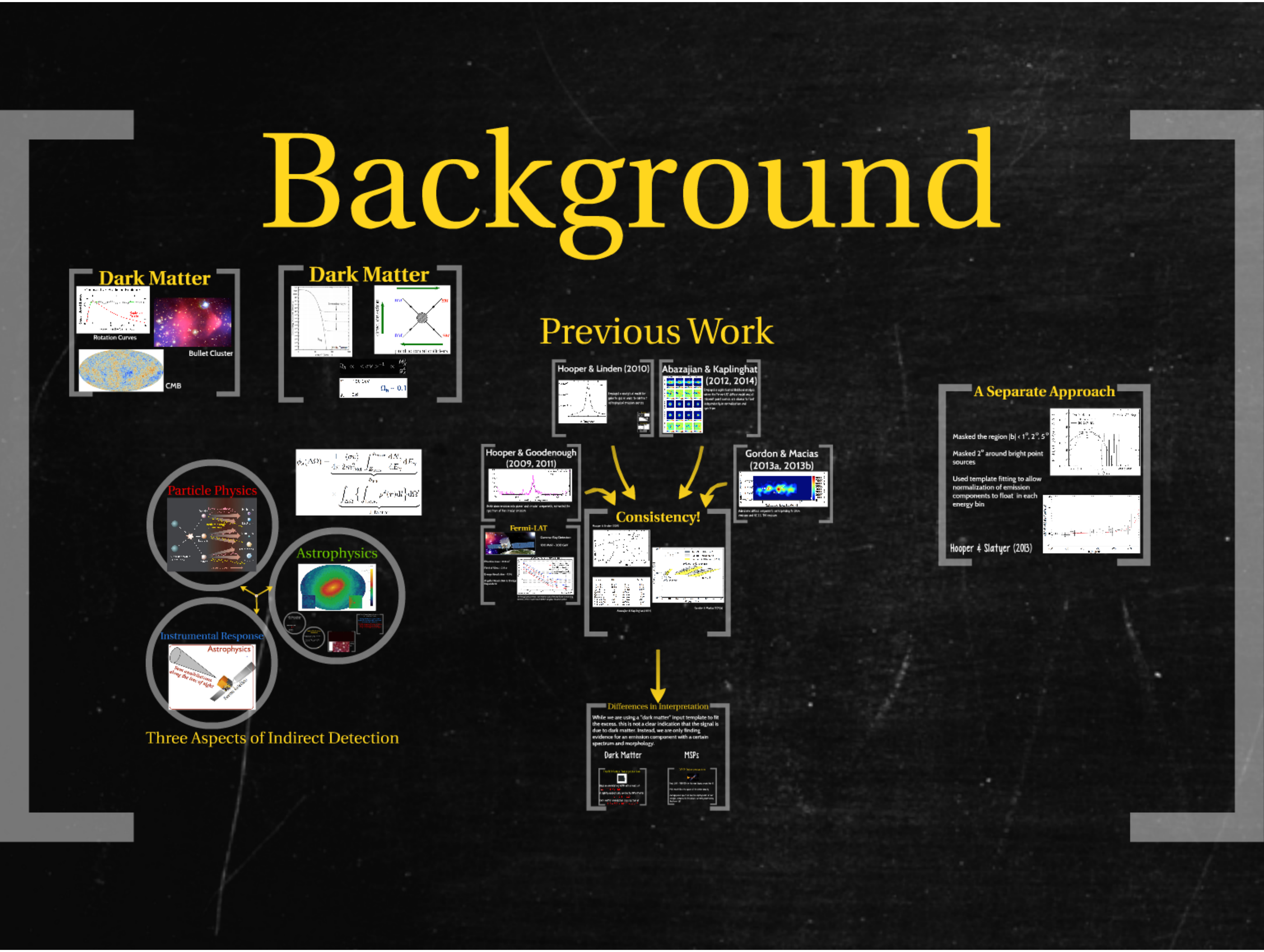
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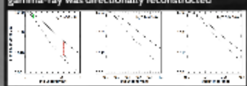
Data Analysis

Methods

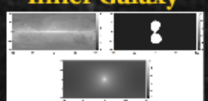
CTBCORE

The Fermi-LAT PASS 7 Data Selection provides a parameter which quantifies how well the incoming gamma-ray was directionally reconstructed



Portillo & Finkbeiner (2014)

Inner Galaxy



Mask |b| < 1° and a 2° radius around all 1FGL Sources

Employ models for the diffuse emission, isotropic emission, Fermi bubbles and a dark matter template

Allow the normalization of each component to float independently in 25 energy bins from 300 MeV to 100 GeV

Galactic Center

Examine region |b| < 5°, |l| < 5°

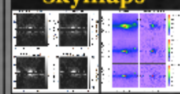
Model all point sources and diffuse emission models

Allow the normalizations and spectral models of each source to vary using the *gtlike* algorithm to determine the best fit

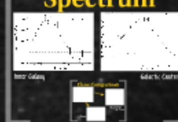
arXiv: 1402.6703

Main Results

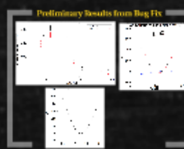
Skymaps



Spectrum



Morphology



Additional Tests

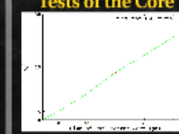
>5 years of data + CTBCORE lets us ask probing questions

Spatial Extension

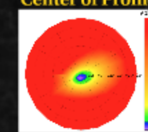
Inner Galaxy - Spatial Extension out to at least 11°, maybe as far as 15° depending on binning

Galactic Center - Spatial Extension out to at least 5°, cutoff due to region exceeding ROI

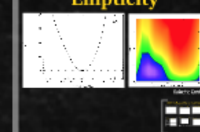
Tests of the Core



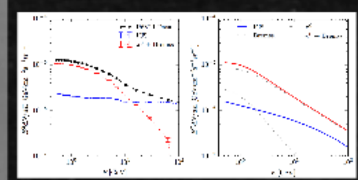
Center of Profile



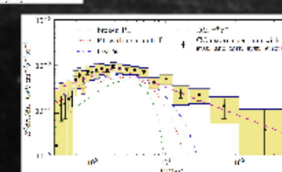
Ellipticity



Calore et al. (2014)



Tour de force paper which examines systematic errors in the diffuse background by evaluating more than 300 different tuned Galprop background models



arXiv: 1409.0042

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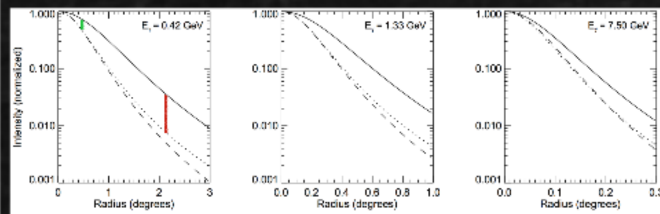
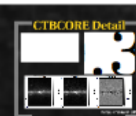
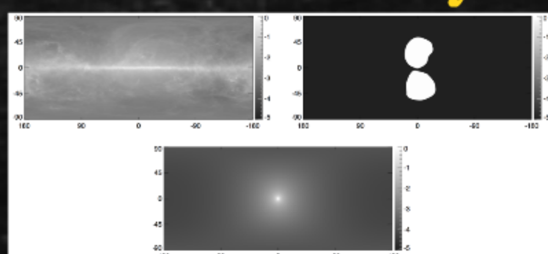




Portillo & Finkbeiner (2014)

Inner Galaxy



Mask $|b| < 1^\circ$ and a 2° radius around all 1FGL Sources

Employ models for the diffuse emission, isotropic emission, Fermi bubbles and a dark matter template

Allow the normalization of each component to float independently in 25 energy bins from 300 MeV to 100 GeV

Galactic Center

Examine region $|b| < 5^\circ$, $|l| < 5^\circ$

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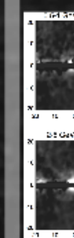

CTBCORE

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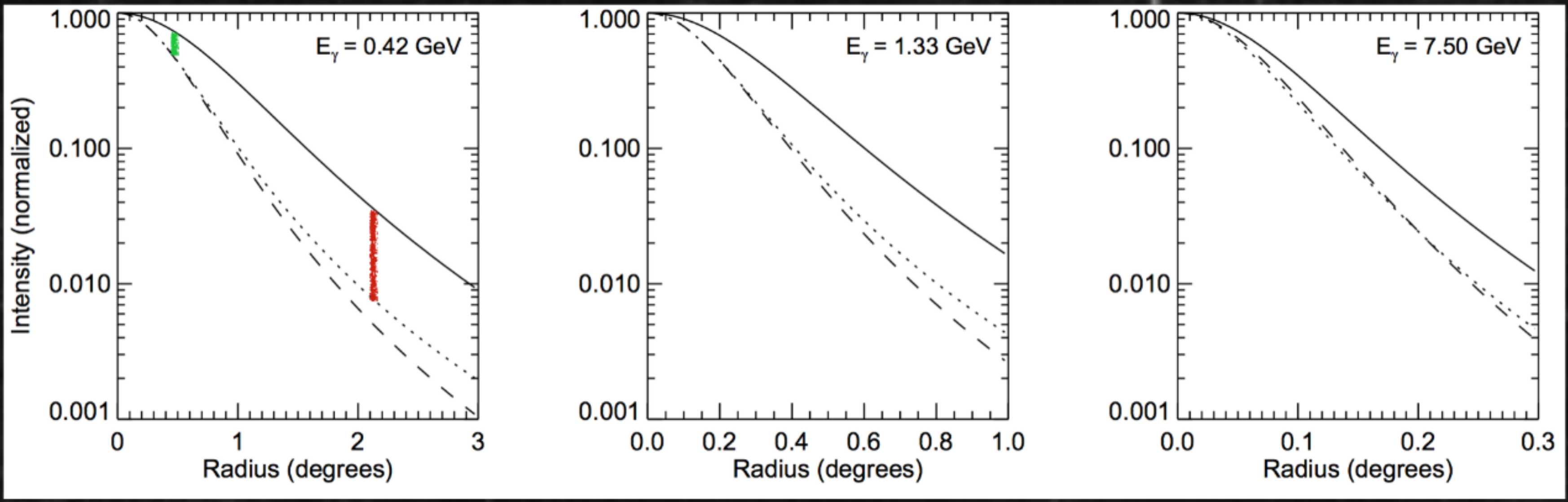

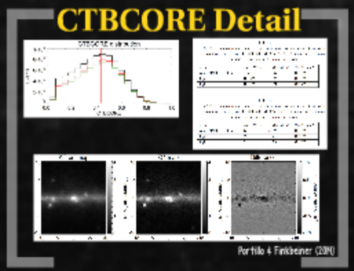

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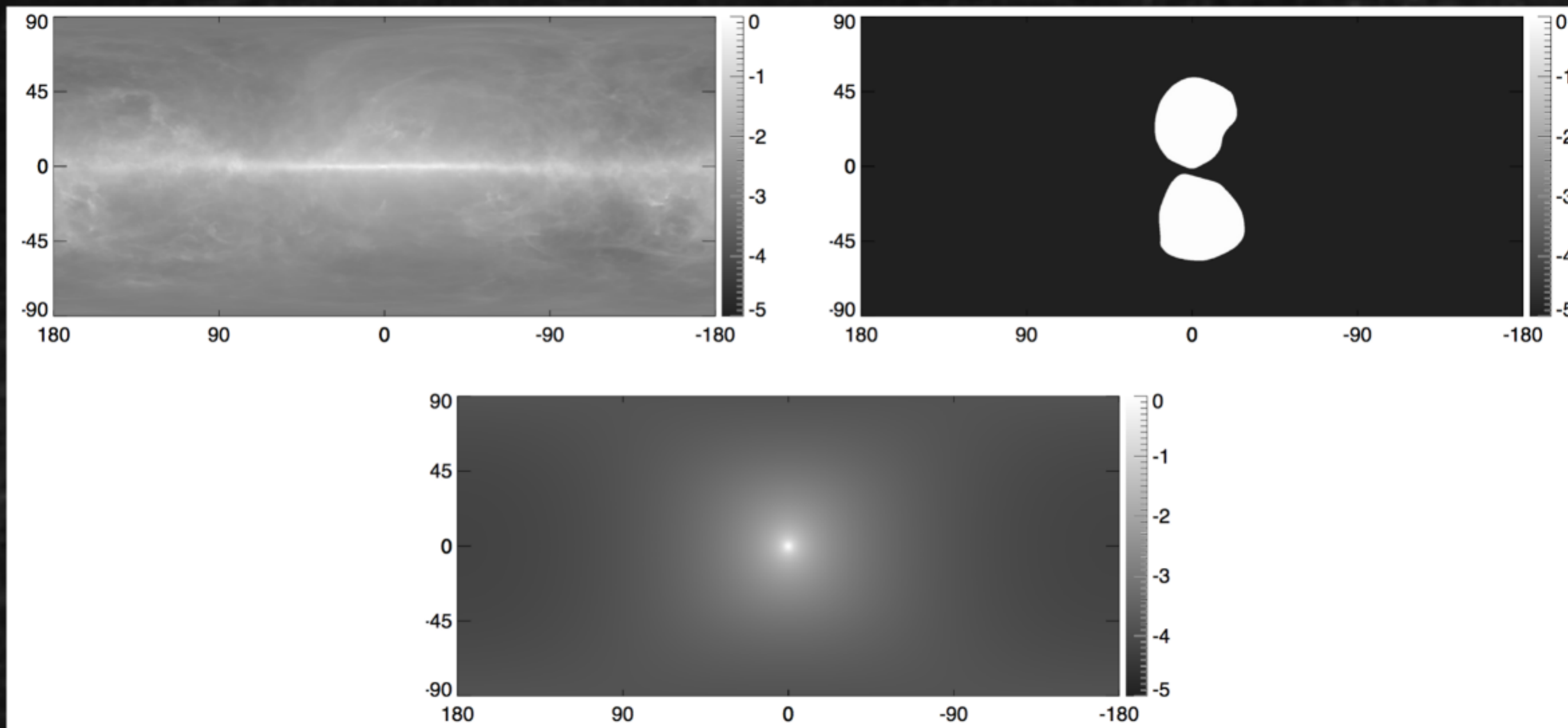

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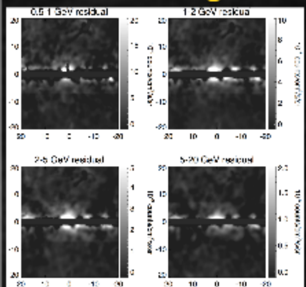
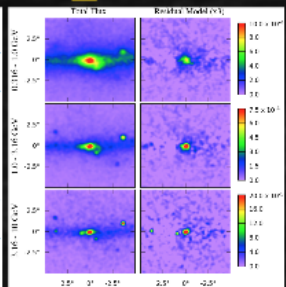
Main Results

Skymaps

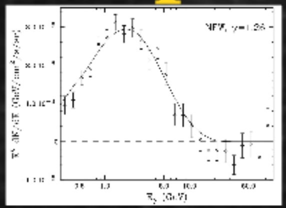


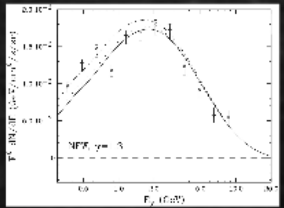


Inner Galaxy

Galactic Center

Spectrum

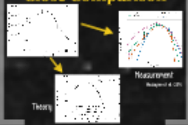




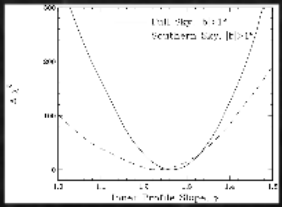
Inner Galaxy

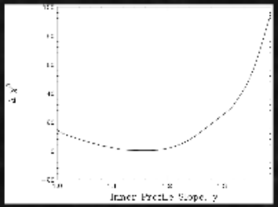
Galactic Center

Close Comparison



Morphology

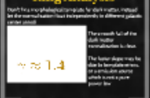




Inner Galaxy

$\gamma \approx 1.26$

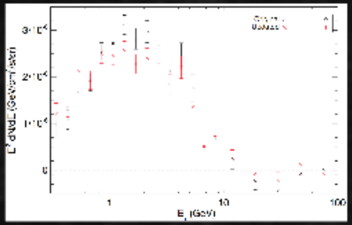
Ring Analysis

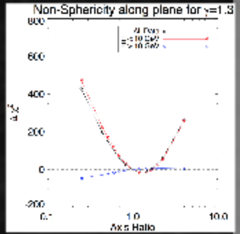


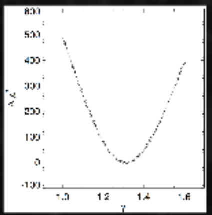
Galactic Center

$\gamma \approx 1.17$

Preliminary Results from Bug Fix







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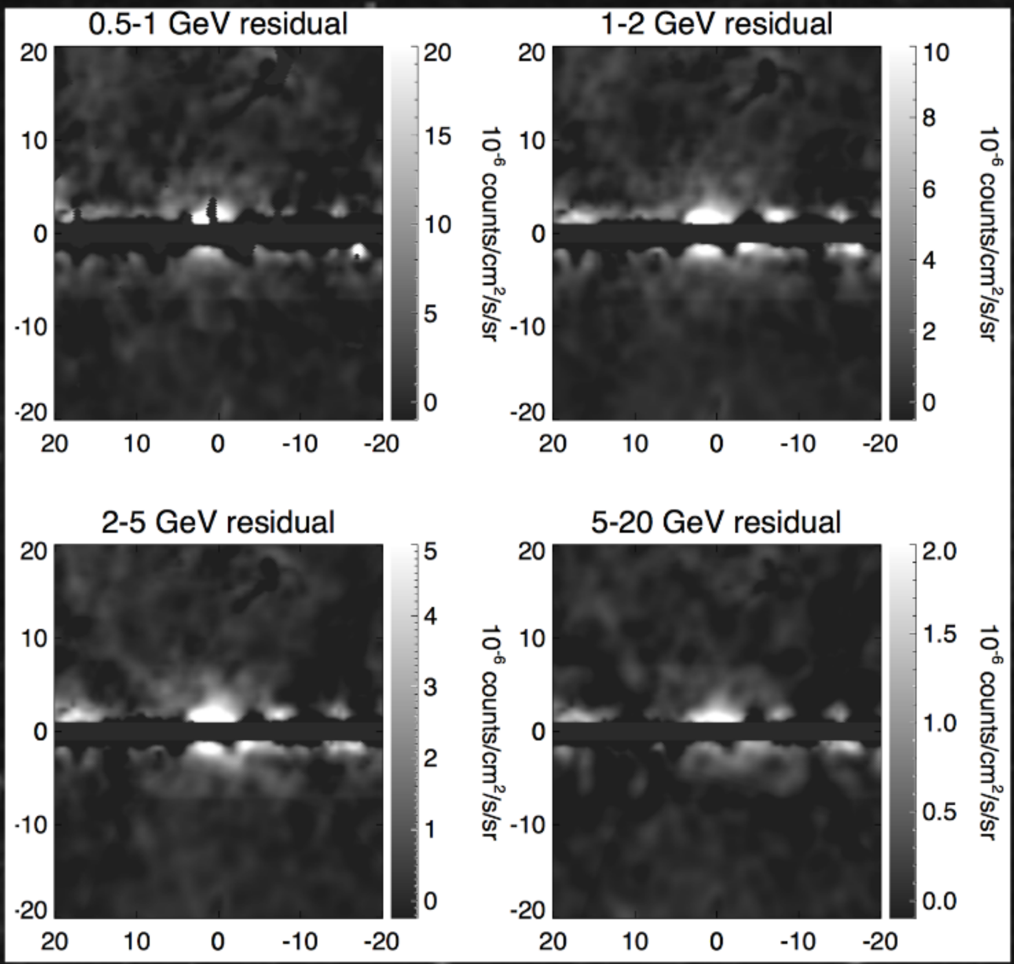

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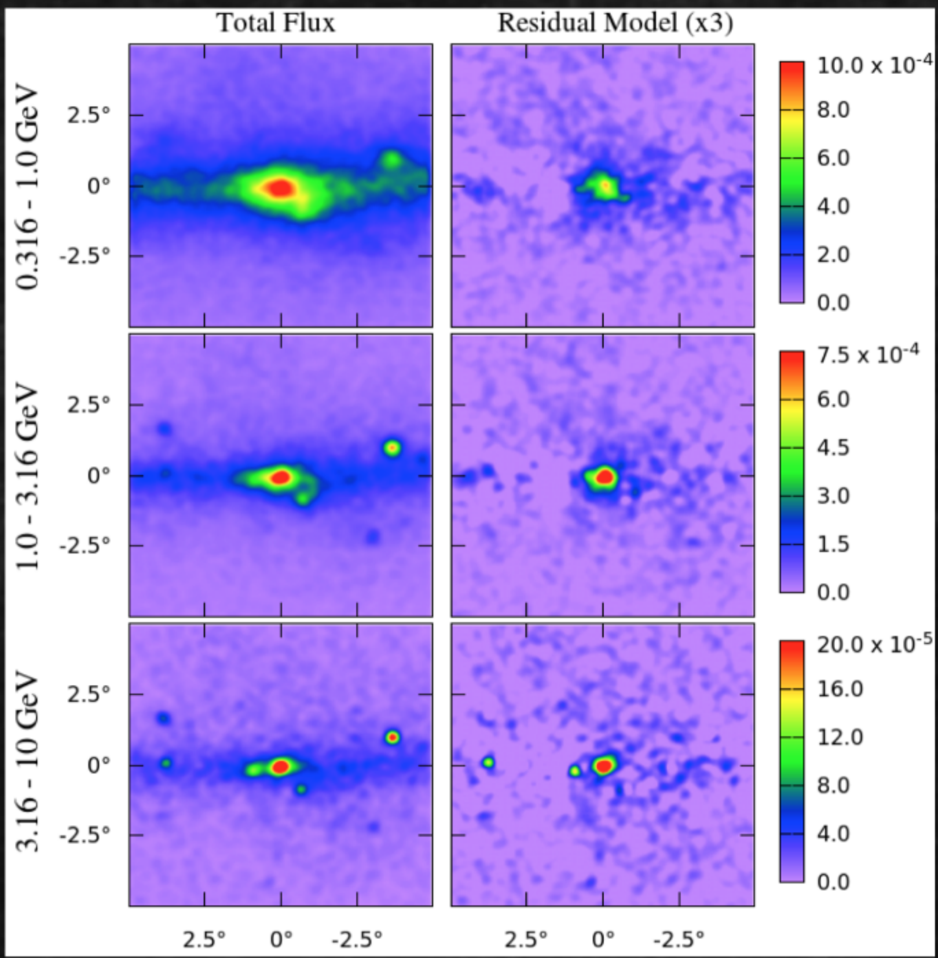
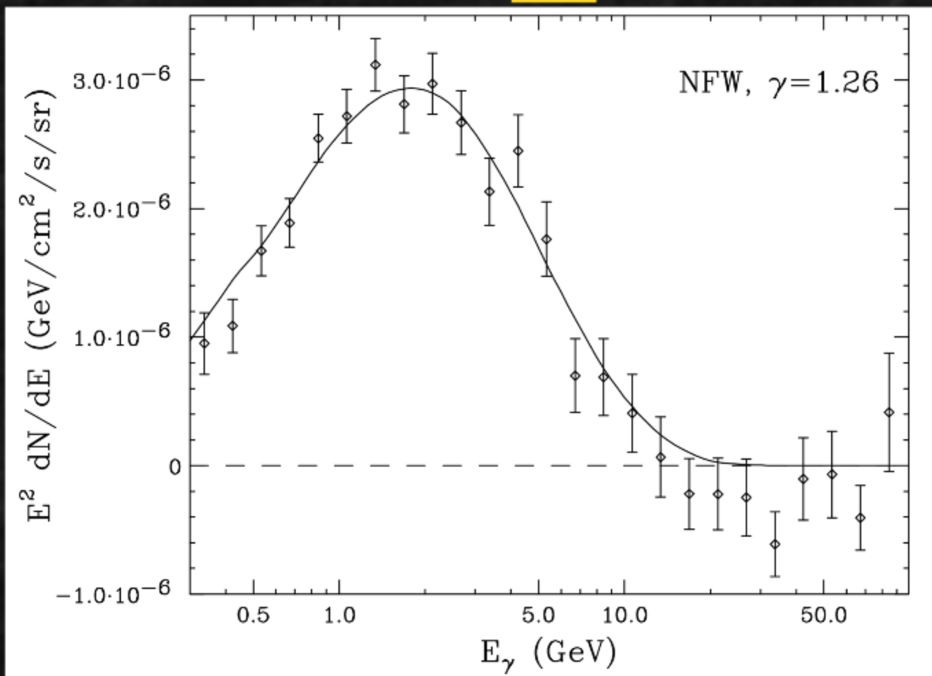


Galactic Center

Spectrum



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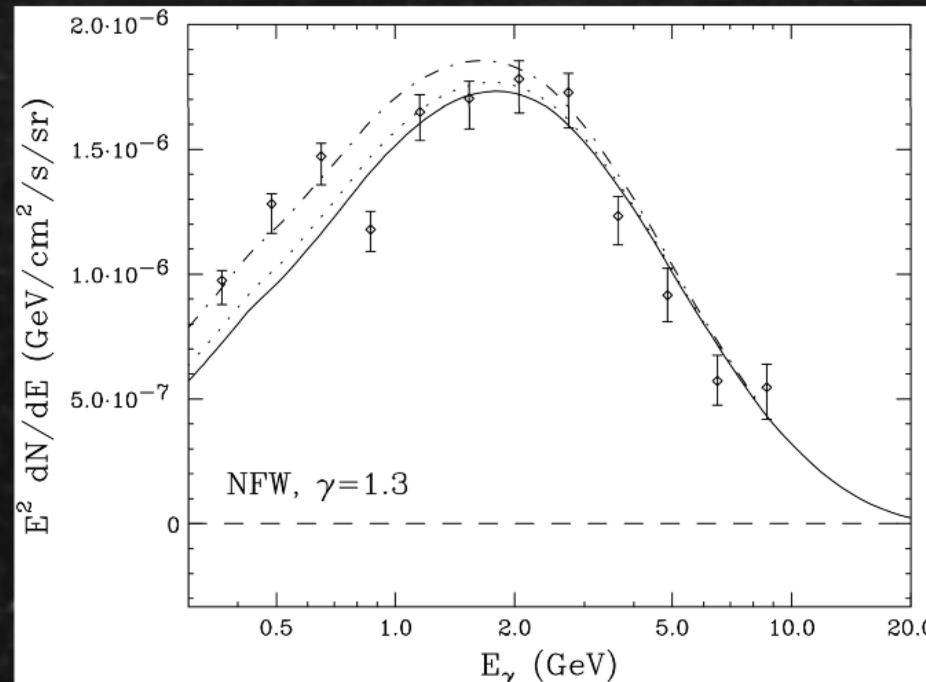

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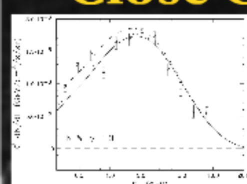
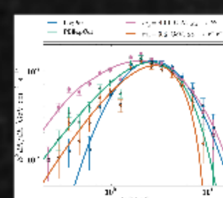
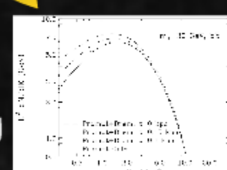




Measurement

Abazajian et al. (2014)

Theory



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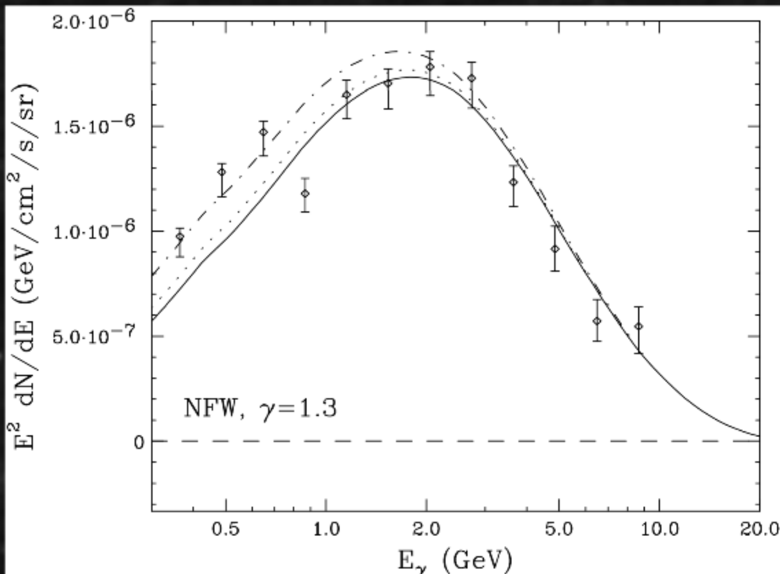

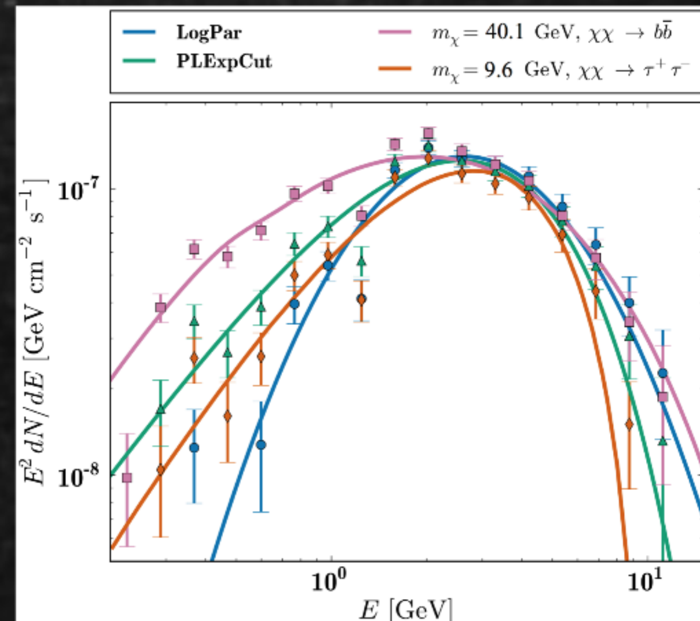

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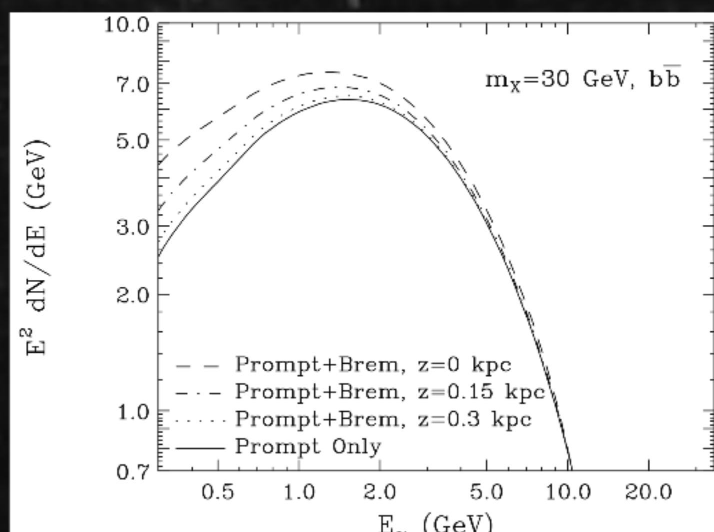

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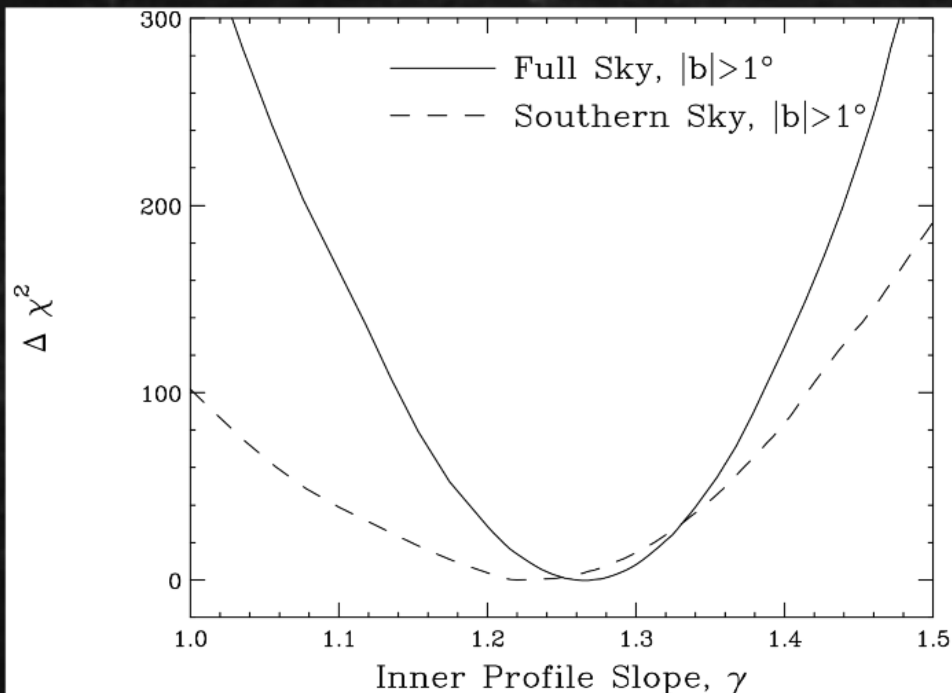

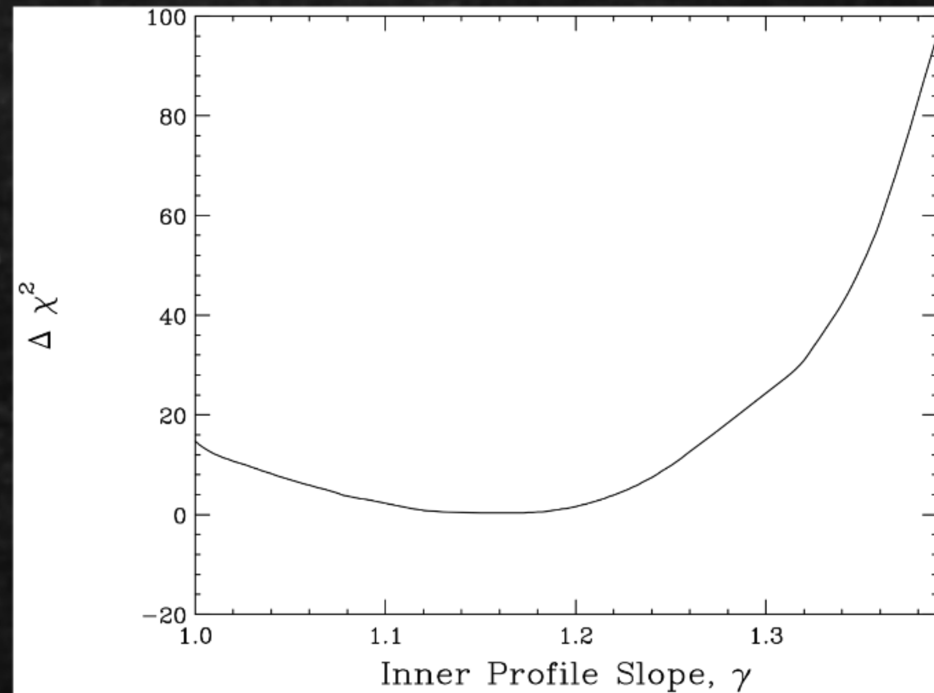

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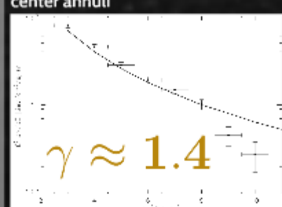
$\gamma \approx 1.26$

Ring Analysis

Don't fix a morphological template for dark matter, instead let the normalization float independently in different galactic center annuli



The smooth fall of the dark matter normalization is clear.

The faster slope may be due to template errors, or a emission source which is not a pure power law

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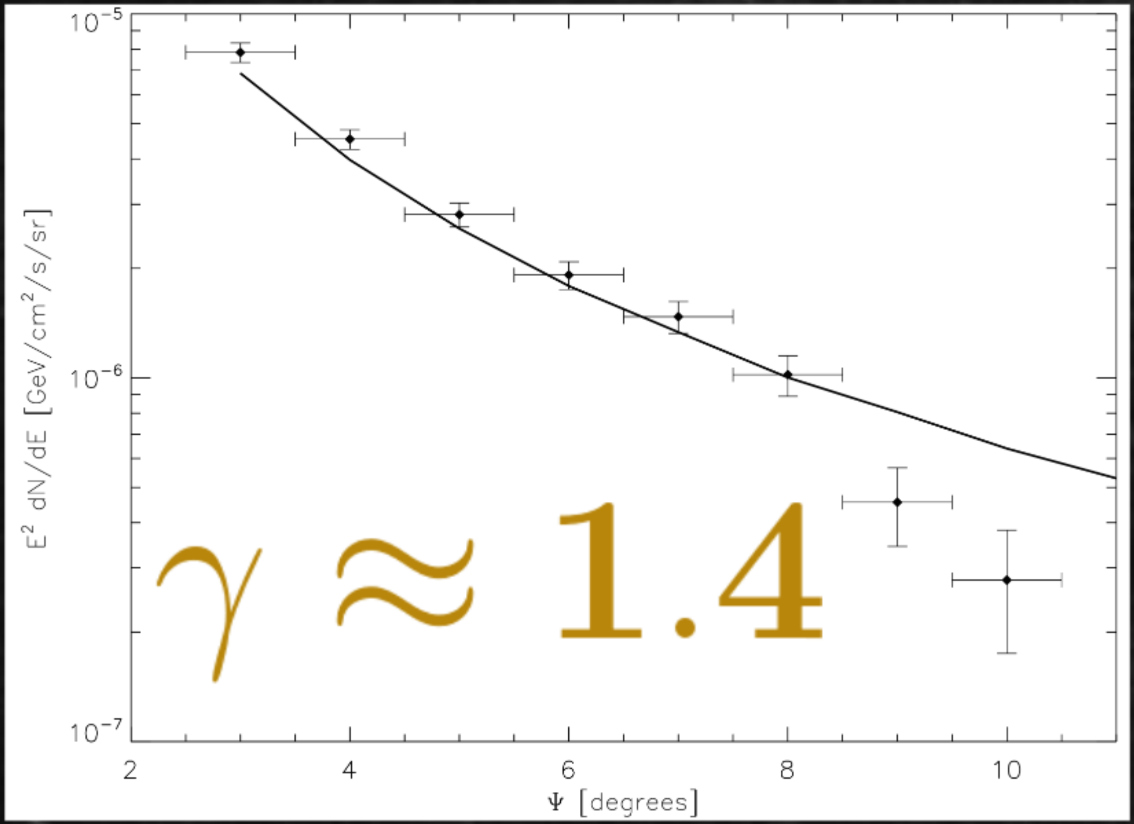

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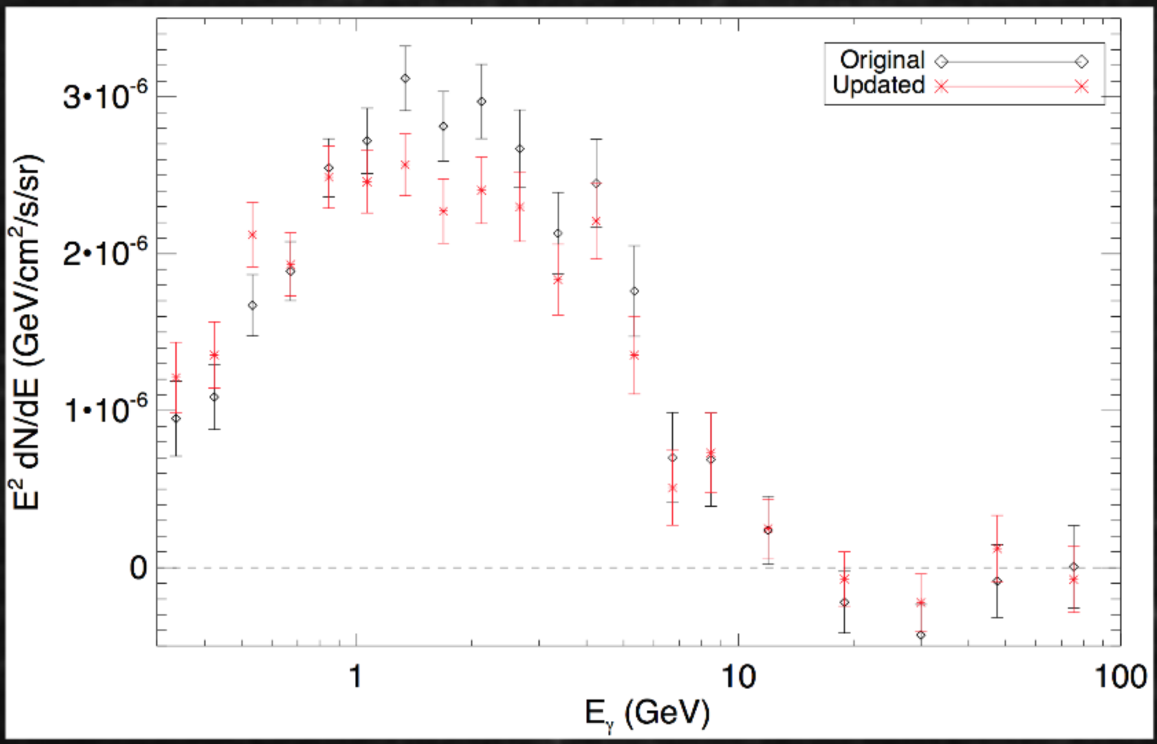
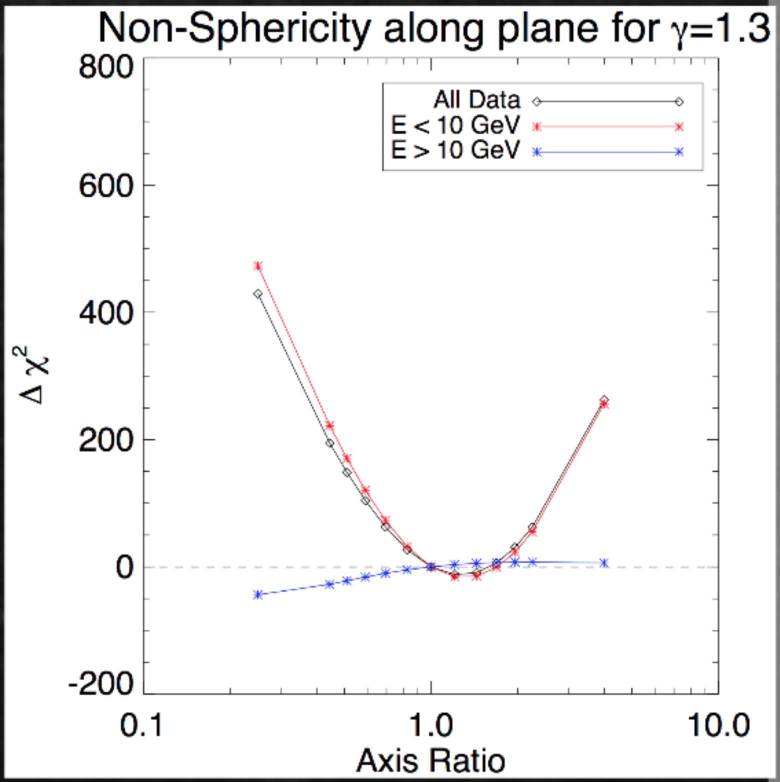
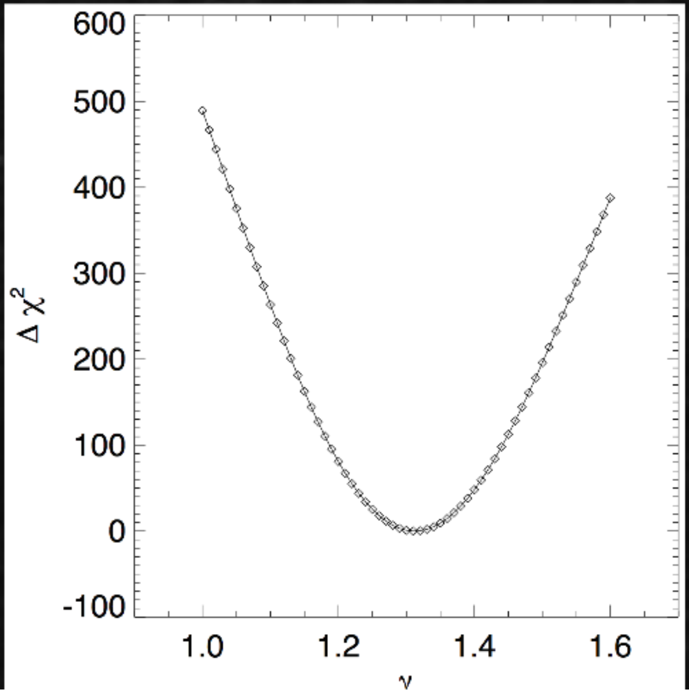


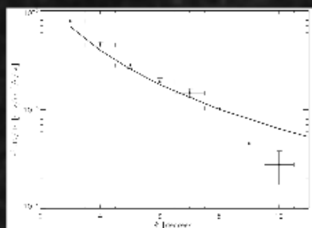


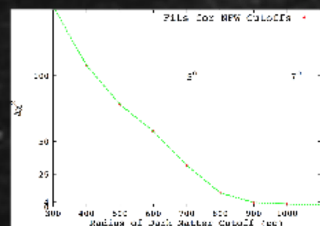


Additional Tests

>5 years of data + CTBCORE lets us ask probing questions

Spatial Extension





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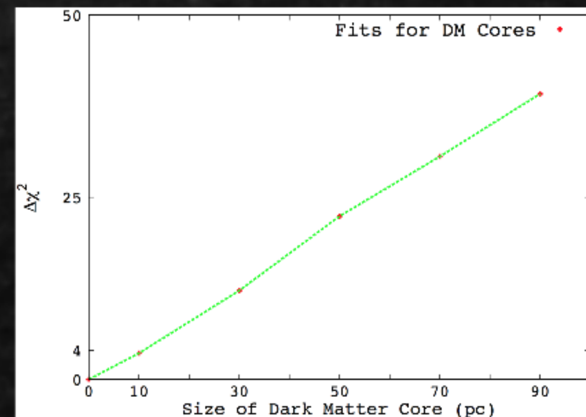
Tests of the Core



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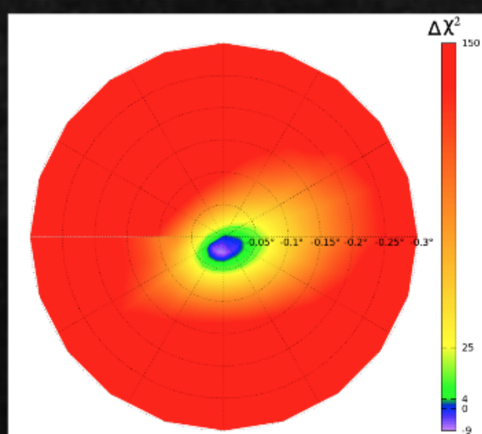
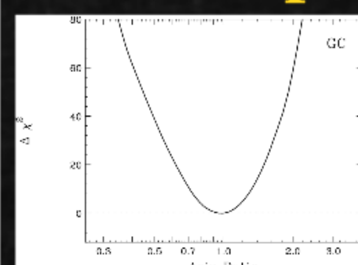
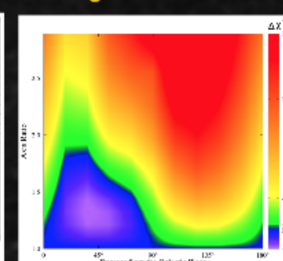


Ellipticity





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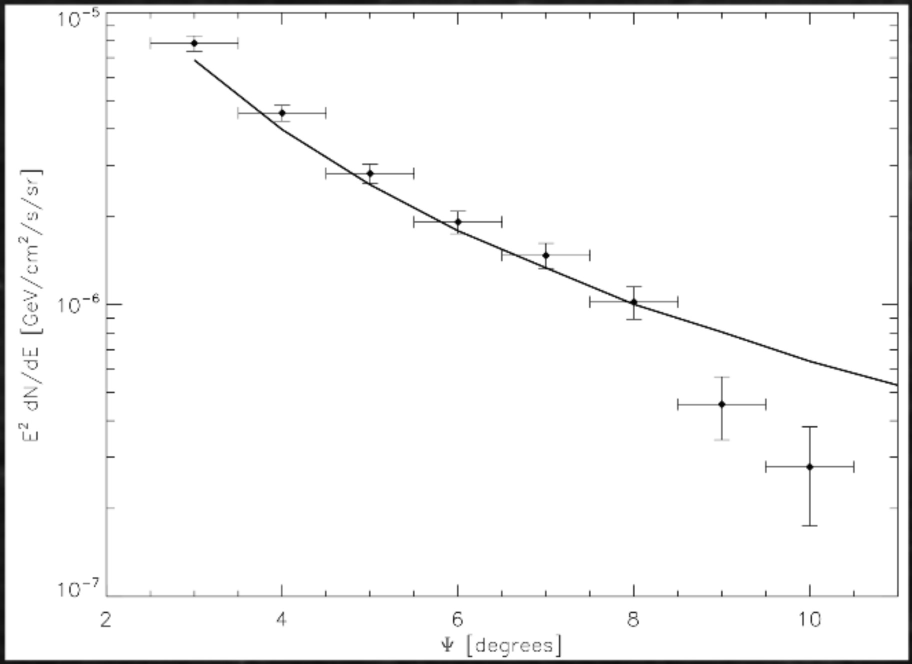

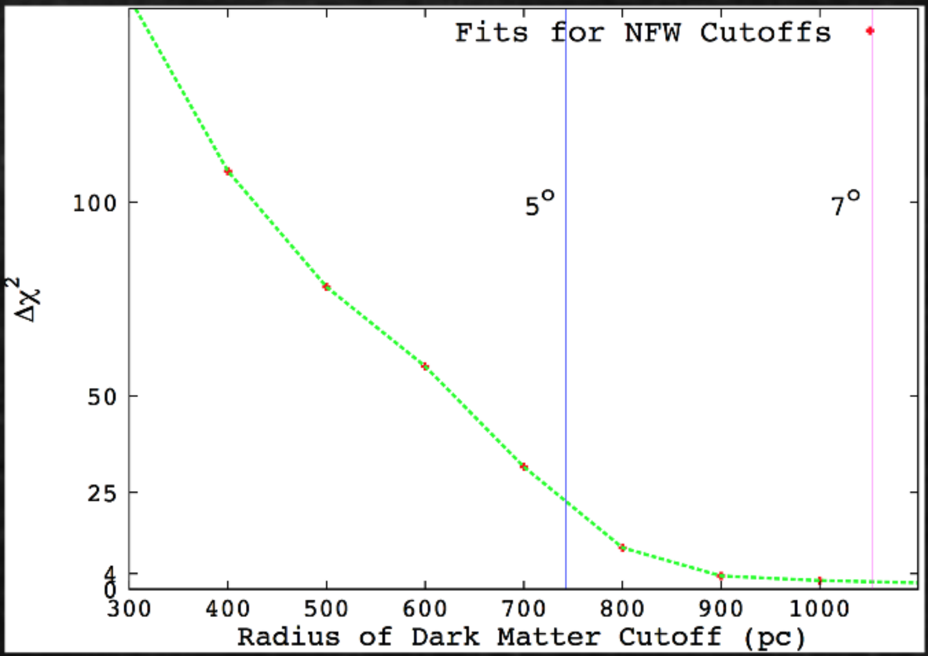

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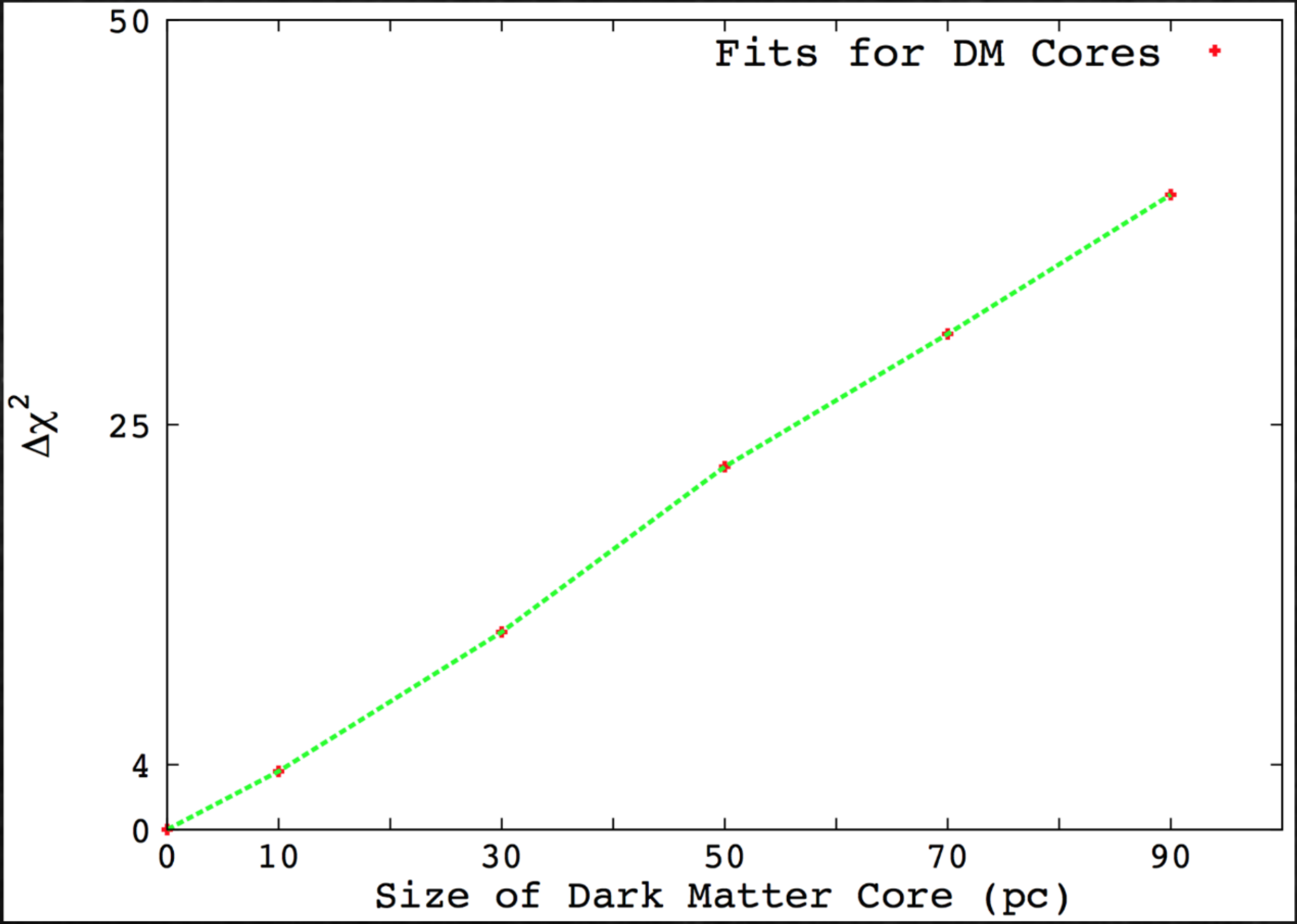

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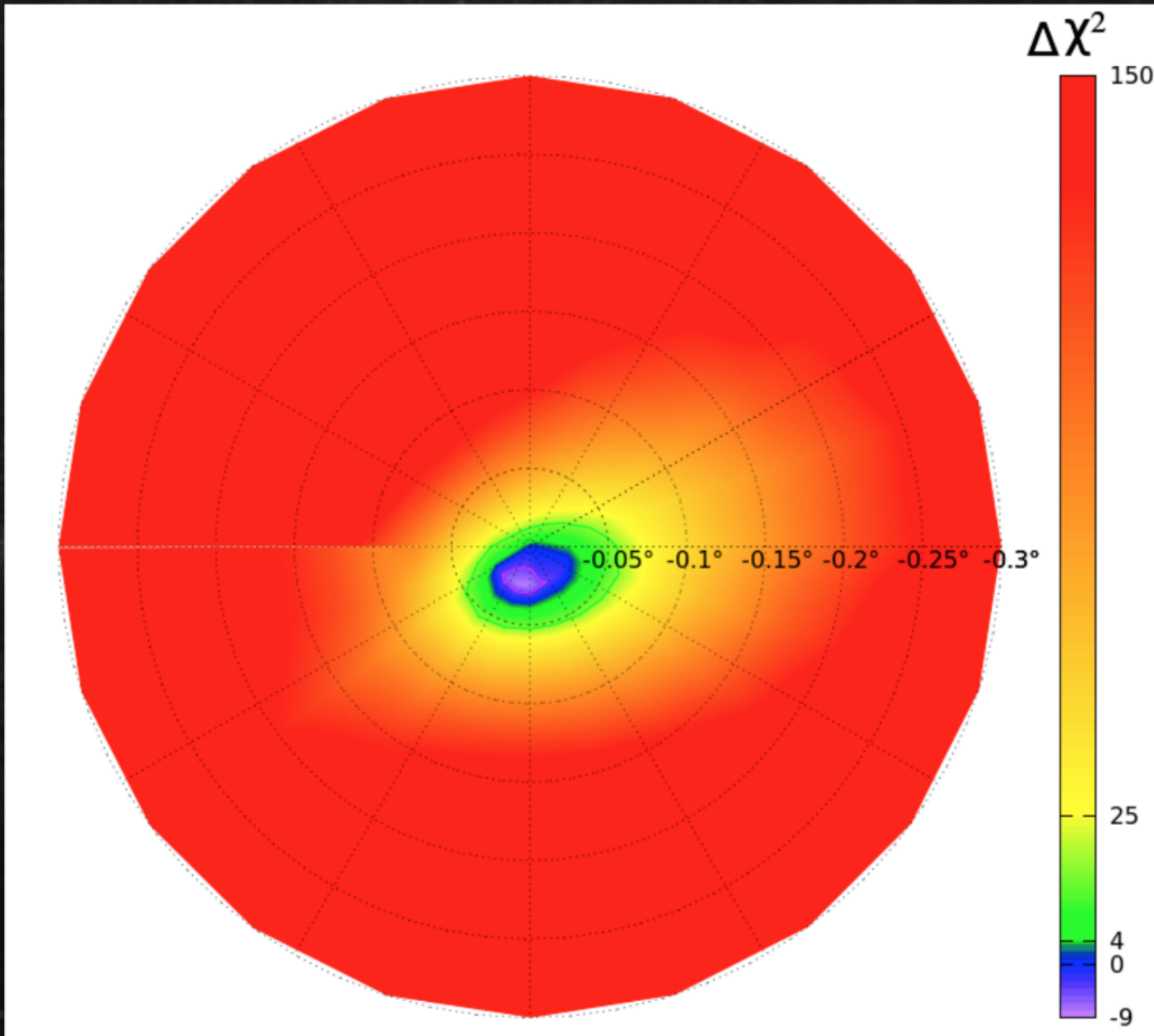

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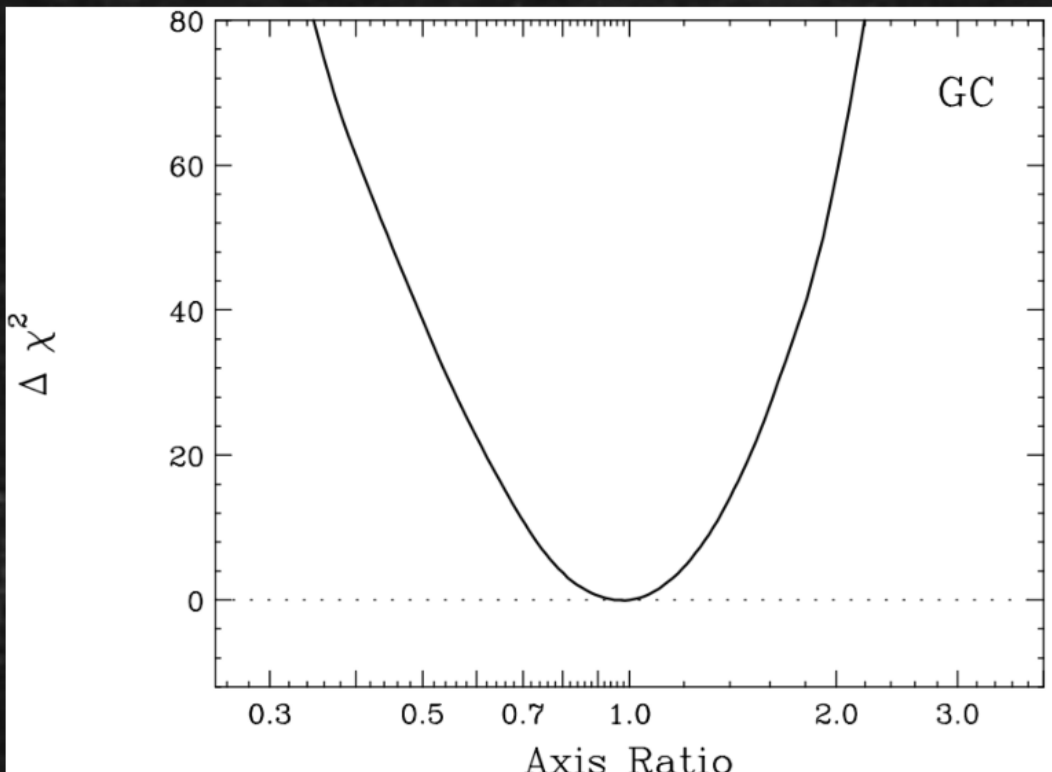

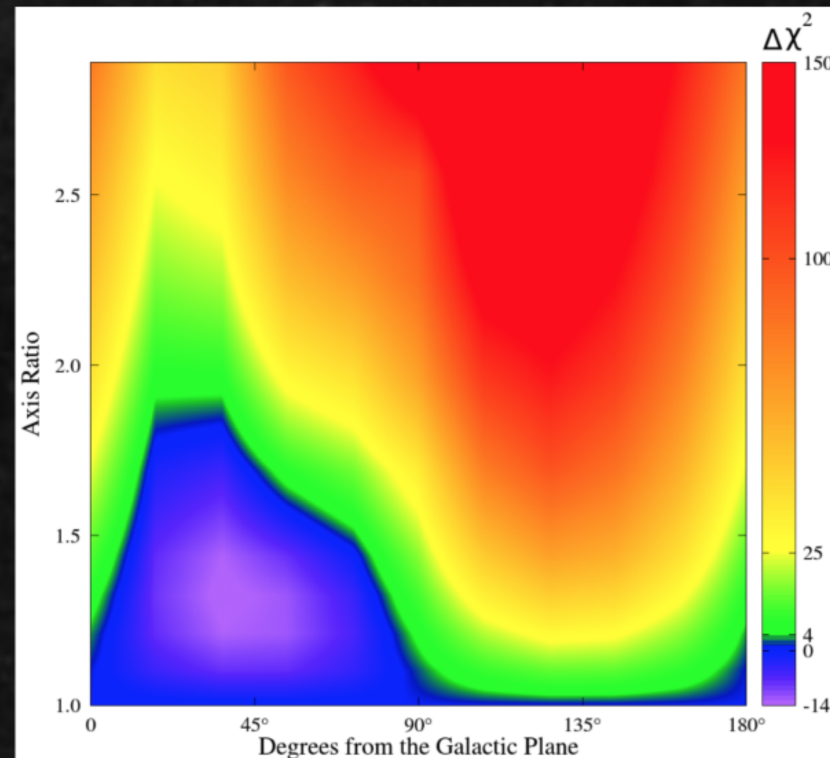

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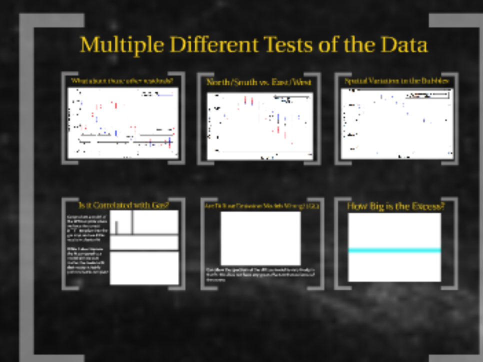
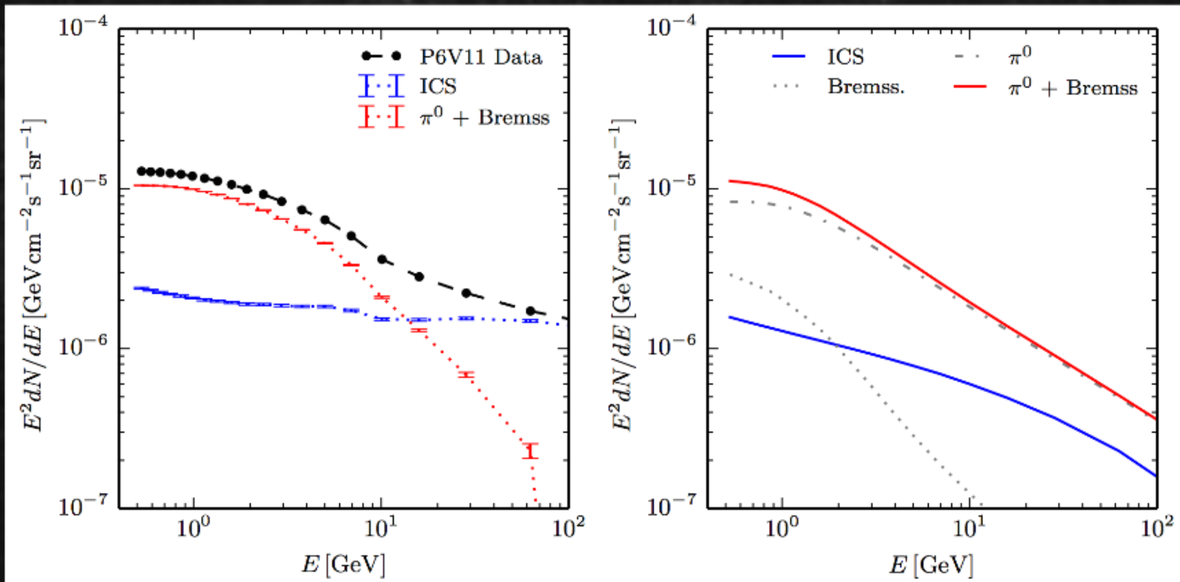
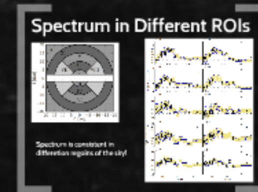
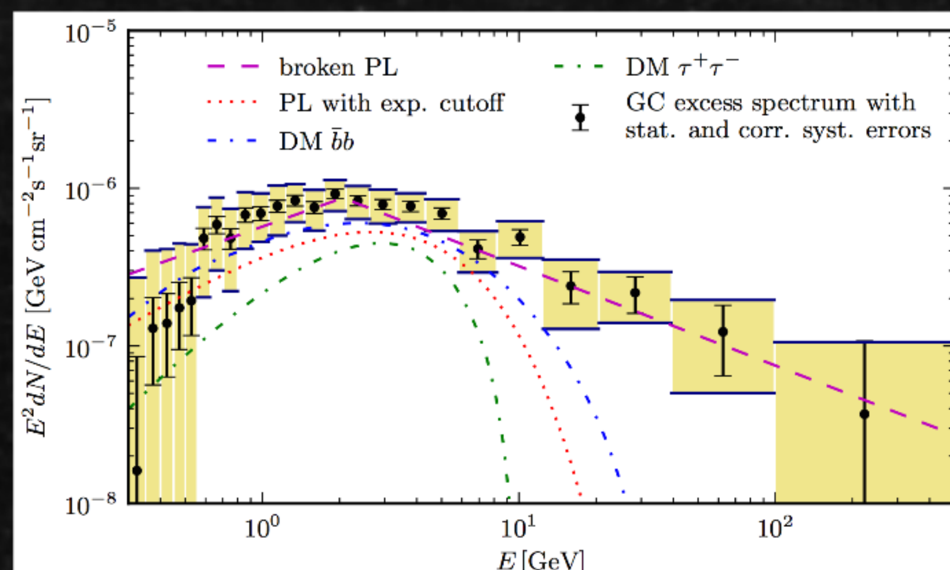


Calore et al. (2014)





Tour de force paper which examines systematic errors in the diffuse background by evaluating more than 300 different tuned Galprop background models



arXiv: 1409.0042

Data Analysis

Methods

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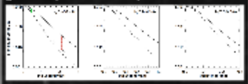

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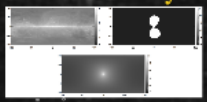

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arXiv: 1402.6703

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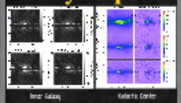
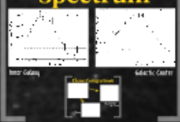
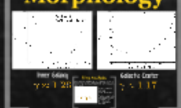


Spectrum



Morphology



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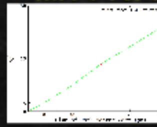

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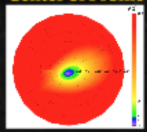

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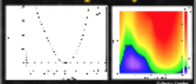

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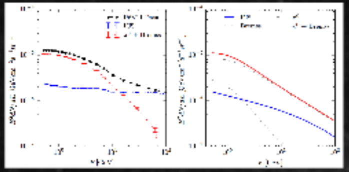

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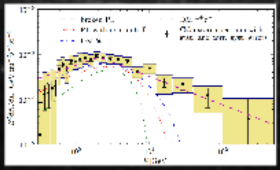


arXiv: 1409.0042

Interpretation

Do the data favor dark matter, pulsar, or other models?

Pulsar Models

Hooper et al. (2013) 1305.0830

Cholis, Hooper, TL (2014a) 1407.5583
Cholis, Hooper, TL (2014b) 1407.5625

A New Pulsar Analysis

We want to answer the question - what does the average pulsar observed by the Fermi-LAT look like?

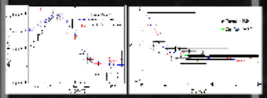
Then we can calculate the diffuse emission from the undetected fraction

5.6 years data

P7 Reprocessed Photons

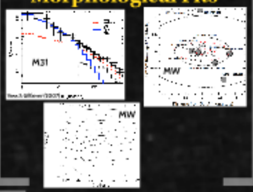
15 logarithmic energy bins (100 MeV - 100 GeV)

Spectral Fits



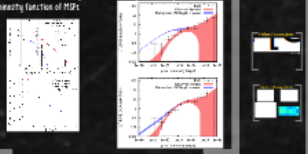
A reanalysis of MSP emission finds an average MSP spectrum which is significantly softer than the GC excess

Morphological Fits



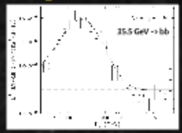
Luminosity Function

5 years of Fermi-LAT data gives us the ability to actually measure the luminosity function of MSPs



DM Models

Spectral Fits



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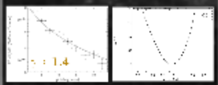

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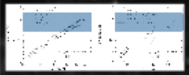

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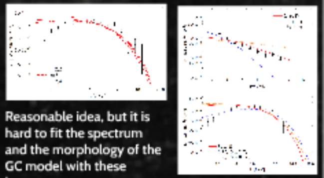
Proton Models

e.g. Carlson & Profumo (2014)

Electron Emission Models

e.g. Petrovic et al. (2014)



Reasonable idea, but it is hard to fit the spectrum and the morphology of the GC model with these bursts.

Pulsar Models

Hooper et al. (2013) 1305.0830

Cholis, Hooper, TL (2014a) 1407.5583

Cholis, Hooper, TL (2014b) 1407.5625

A New Pulsar Analysis

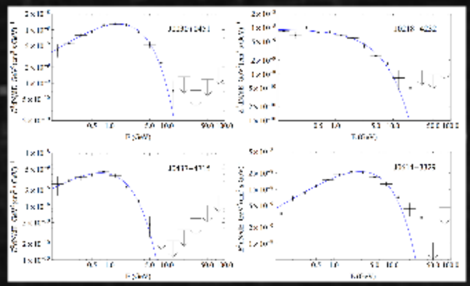
We want to answer the question - what does the average pulsar observed by the Fermi-LAT look like?

Then we can calculate the diffuse emission from the undetected fraction

5.6 years data

P7 Reprocessed Photons

15 logarithmic energy bins (100 MeV - 100 GeV)



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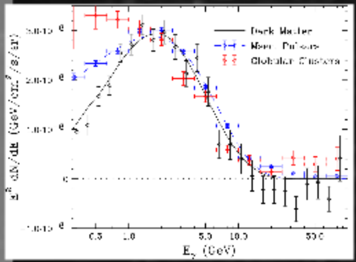

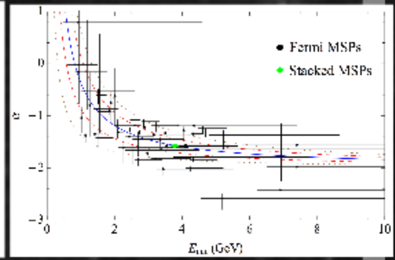

A reanalysis of MSP emission finds an average MSP spectrum which is significantly softer than the GC excess

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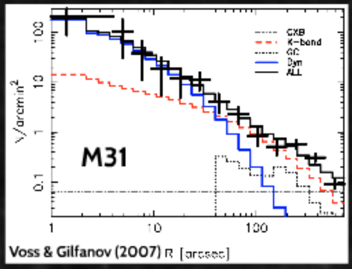

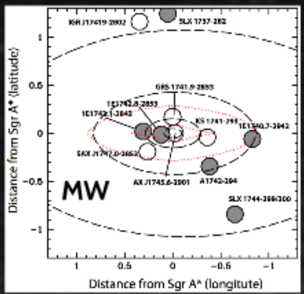

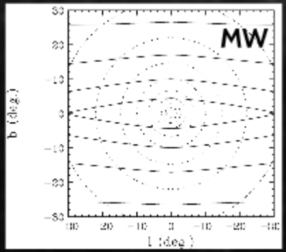

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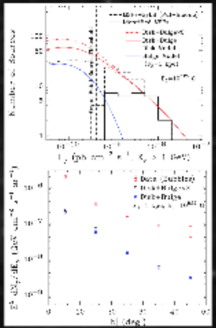
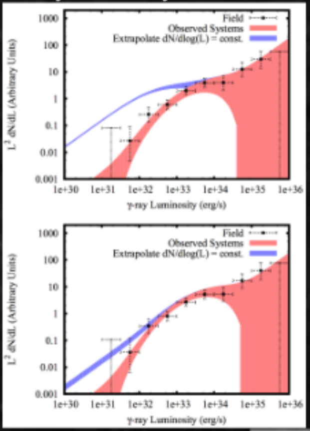
5 years of Fermi-LAT data gives us the ability to actually measure the luminosity function of MSPs





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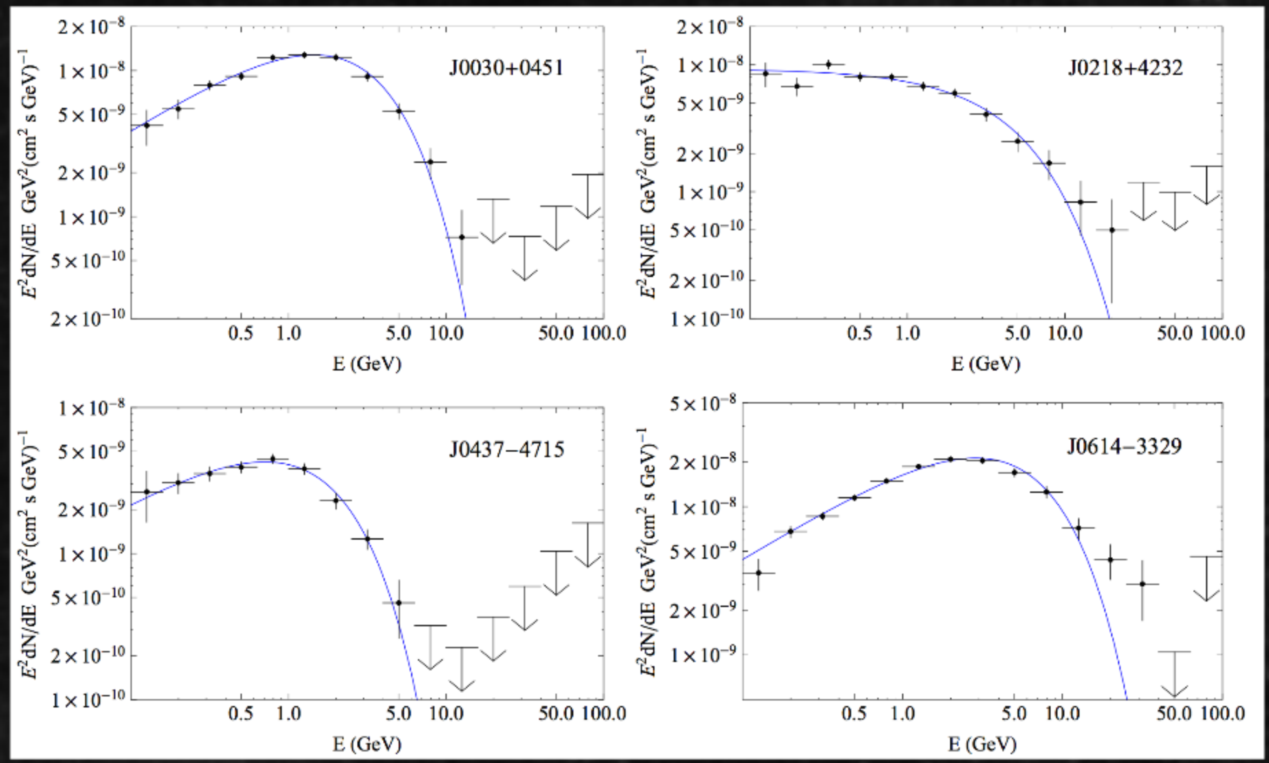
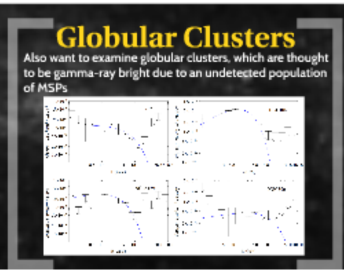
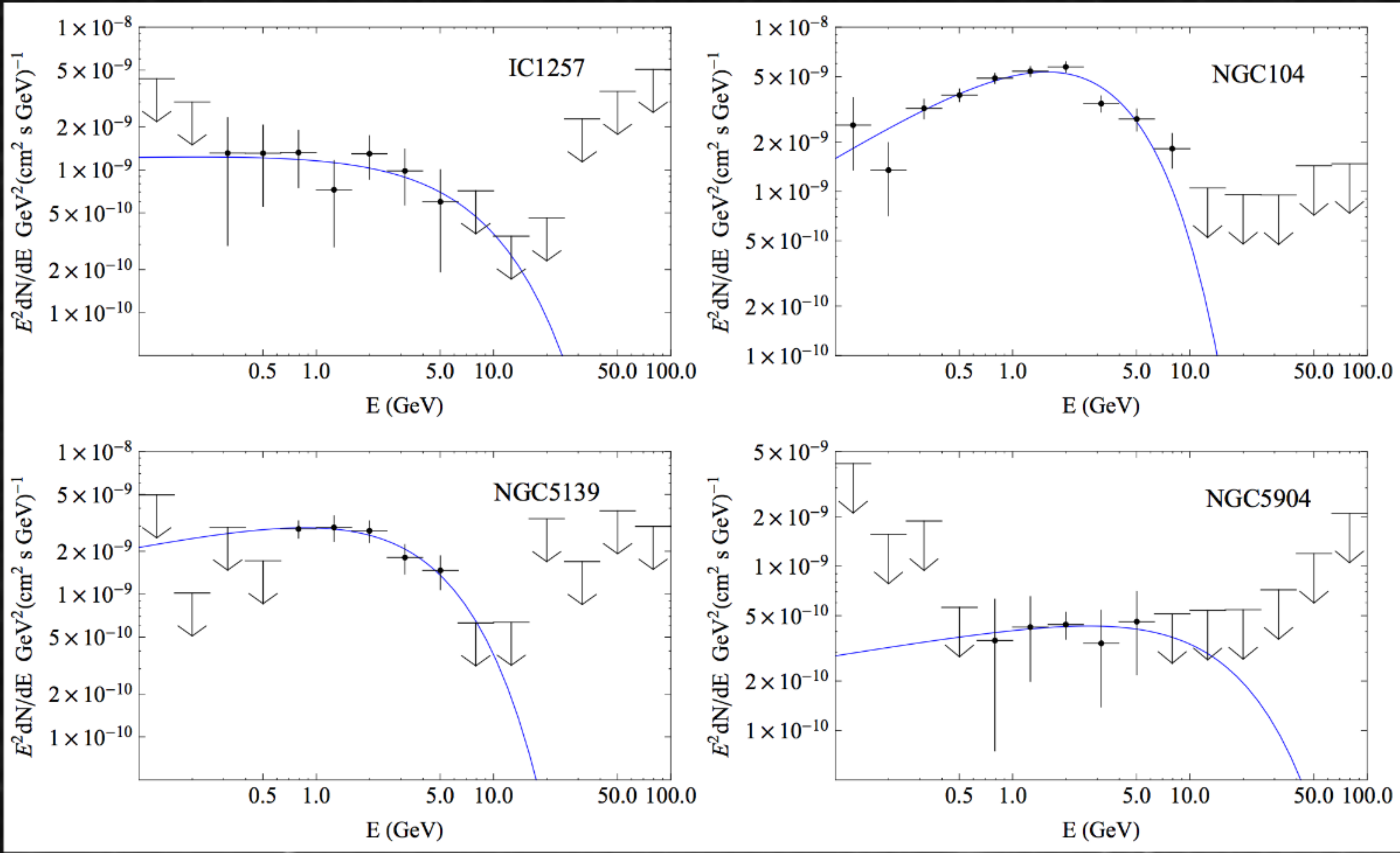




Globular Clusters

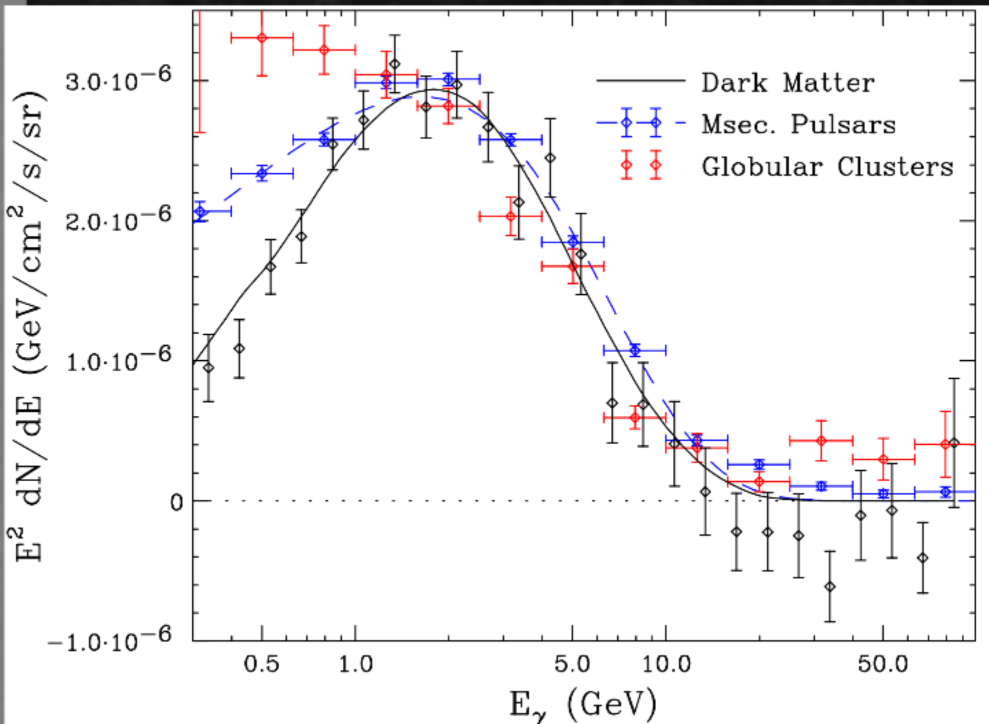
Also want to examine globular clusters, which are thought to be gamma-ray bright due to an undetected population of MSPs

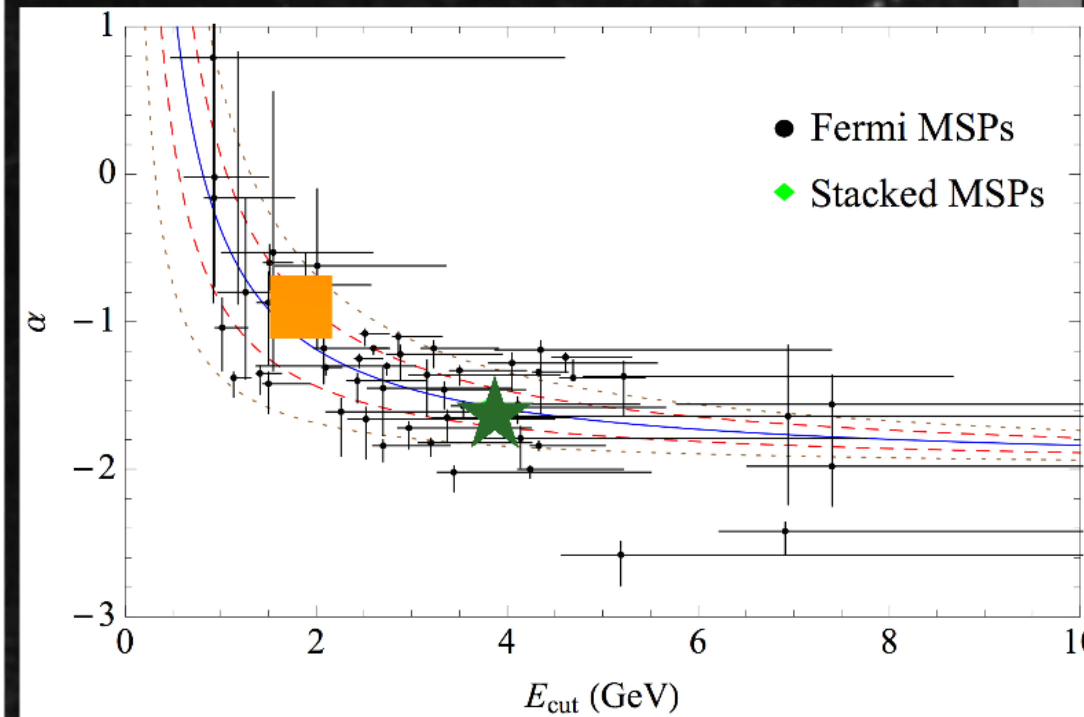


Best Fit Tables

Name	A (cm^{-2} s^{-1})	α	α_{low}(68%)	α_{high}(68%)	E_{cut} (GeV)	$E_{cut_{low}}$(68%)	$E_{cut_{high}}$(68%)	χ^2/dof
J0023+0923	4.30×10^{-9}	-1.04	-1.33	-0.84	1.02	0.94	1.28	1.43
J0030+0451	1.57×10^{-8}	-1.31	-1.36	-1.30	2.10	2.06	2.27	0.94
J0034-0534	2.06×10^{-9}	-1.72	-1.86	-1.68	2.97	2.85	4.25	0.76
J0101-6422	2.49×10^{-9}	-1.40	-1.55	-1.35	2.43	2.32	3.16	2.23
J0102+4839	1.78×10^{-9}	-1.65	-1.82	-1.60	3.37	3.22	4.65	1.59
J0218+4232	2.19×10^{-9}	-2.00	-2.06	-1.98	4.24	4.11	5.22	1.49
J0307+7443	7.20×10^{-9}	-0.92	-1.08	-0.83	1.57	1.51	1.82	0.15
J0340+4130	3.70×10^{-9}	-1.18	-1.31	-1.13	3.23	3.10	3.91	1.15
J0437-4715	9.29×10^{-9}	-1.38	-1.51	-1.34	1.14	1.106	1.32	0.52
J0533+6759	1.11×10^{-9}	-1.28	-1.47	-1.21	4.05	3.81	5.57	0.80
J0605+3757	3.13×10^{-9}	-0.16	-0.88	+0.74	1.18	0.83	1.77	0.49
J0610-2100	1.25×10^{-9}	-1.66	-1.93	-1.58	2.52	2.33	4.50	0.93
J0613-0200	4.04×10^{-9}	-1.57	-1.66	-1.54	3.54	3.42	4.14	0.74
J0614-3329	1.25×10^{-8}	-1.34	-1.37	-1.33	4.33	4.27	4.63	2.32
J0737-3039A	1.66×10^{-10}	-1.64	-2.24	-1.16	6.94	3.96	22.90	0.12
J0751+1807	2.39×10^{-9}	-1.22	-1.40	-1.16	2.88	2.74	3.95	1.13
J1024-0719	2.37×10^{-9}	-0.02	-0.76	+1.02	0.94	0.62	1.50	0.28
J1124-3653	1.96×10^{-9}	-1.46	-1.59	-1.41	3.340	3.173	4.19	1.27
J1125-5825	1.14×10^{-11}	-1.85	-1.99	-1.74	200	20	>1000	1.10
J1137+7528	7.53×10^{-13}	-2.02	-2.30	-1.85	191	76.5	325	0.38
J1142+0119	6.99×10^{-10}	-1.19	-1.62	-1.13	4.35	3.87	7.40	0.19
J1231-1411	2.30×10^{-8}	-1.18	-1.22	-1.17	2.60	2.56	2.77	1.54

Spectral Fits





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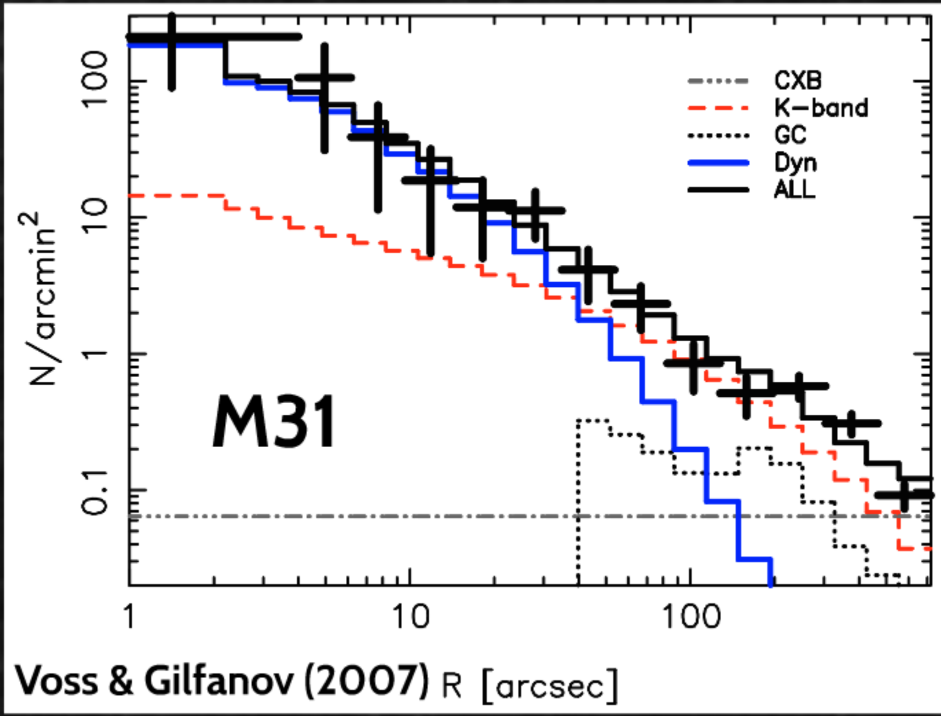

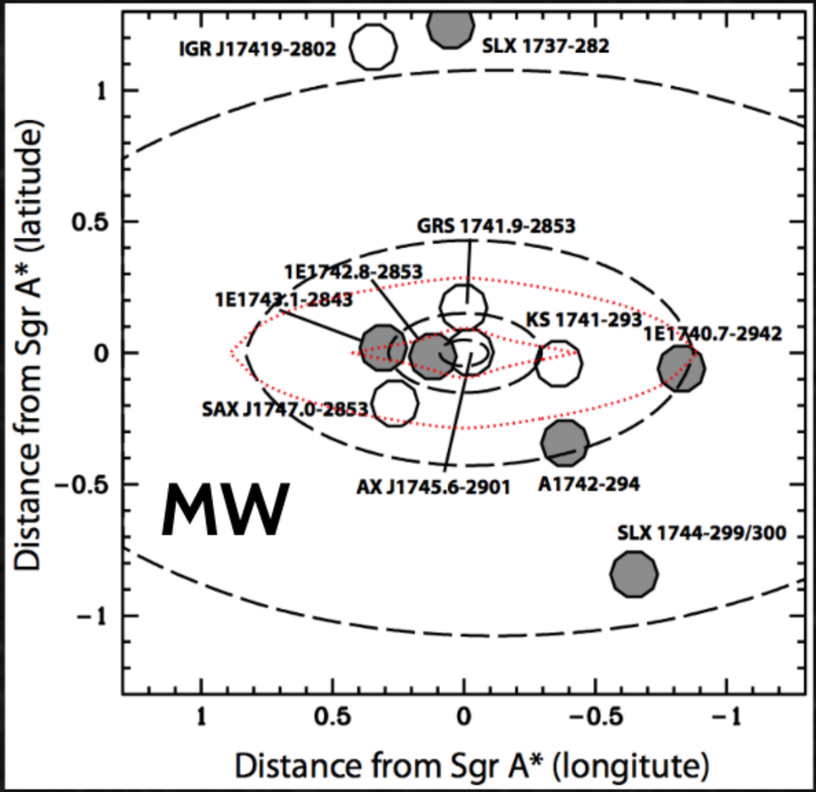

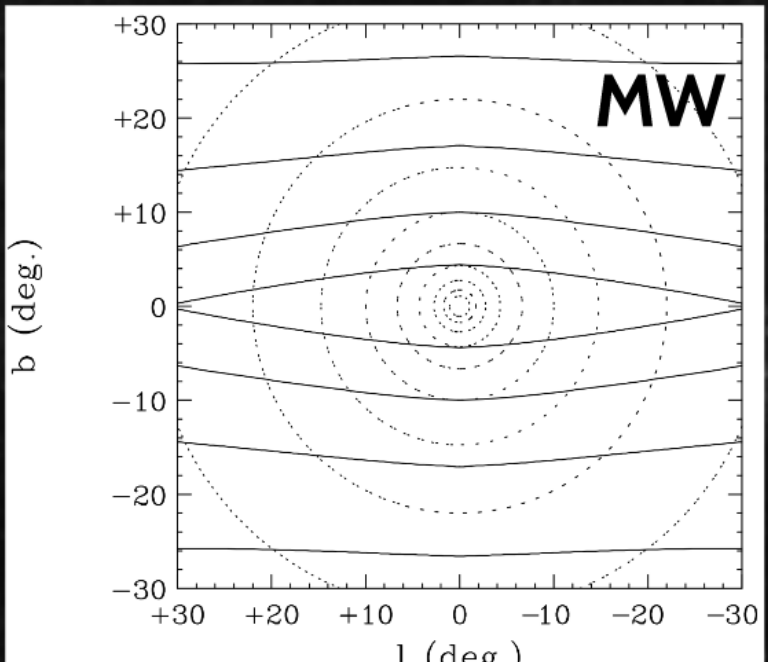

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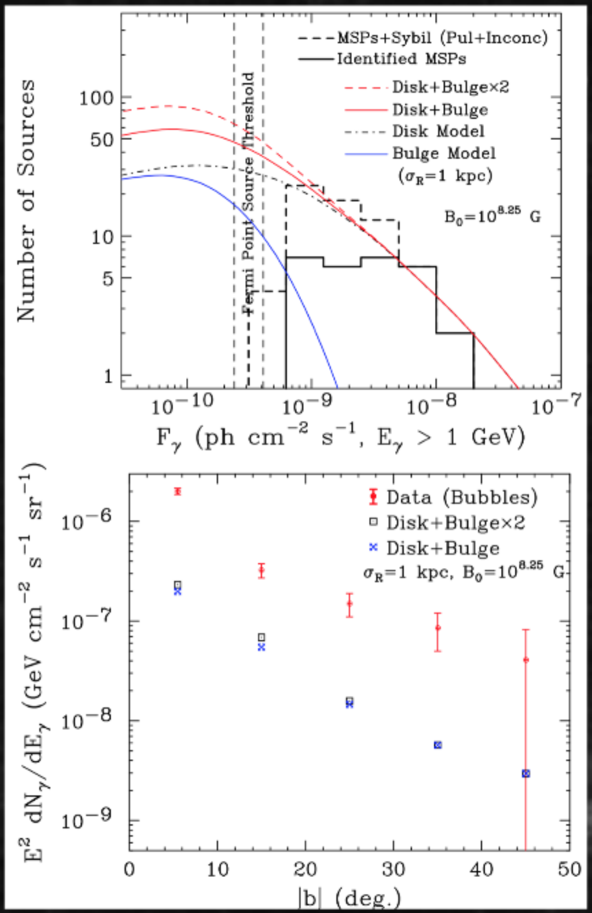

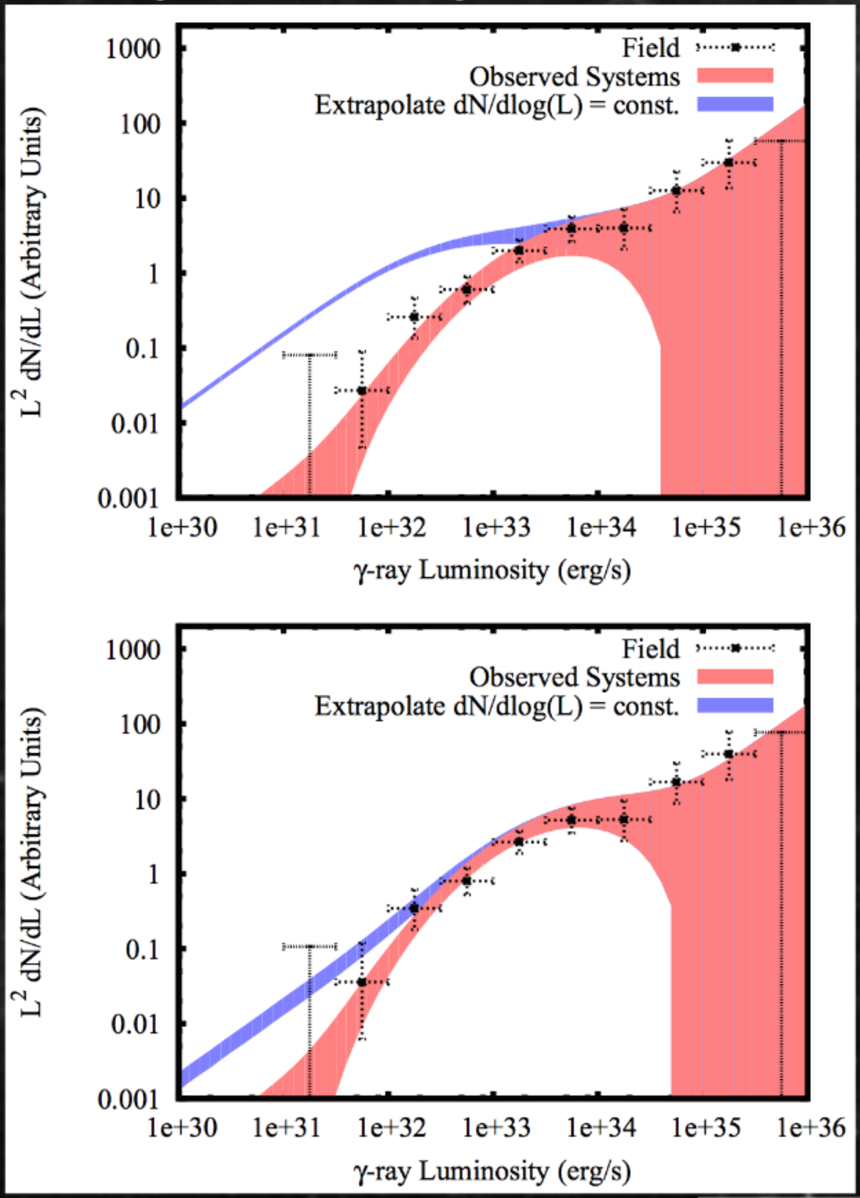

DM Models

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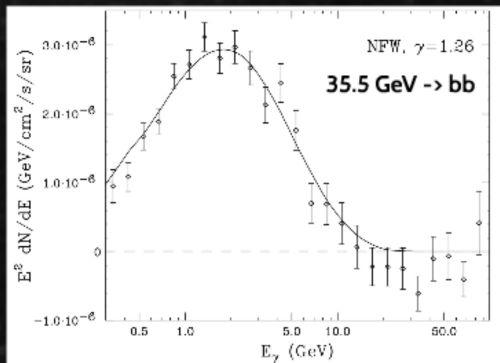

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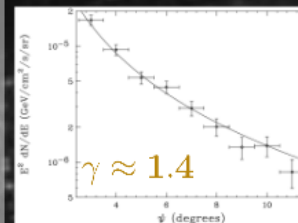

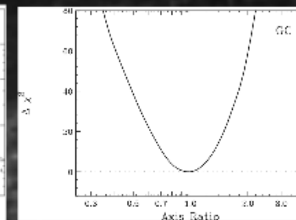

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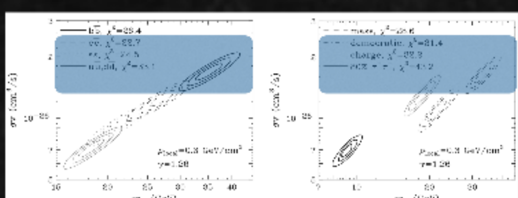

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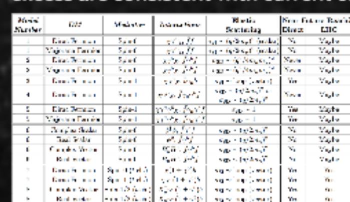

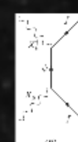

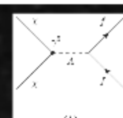

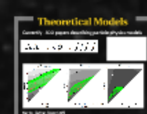

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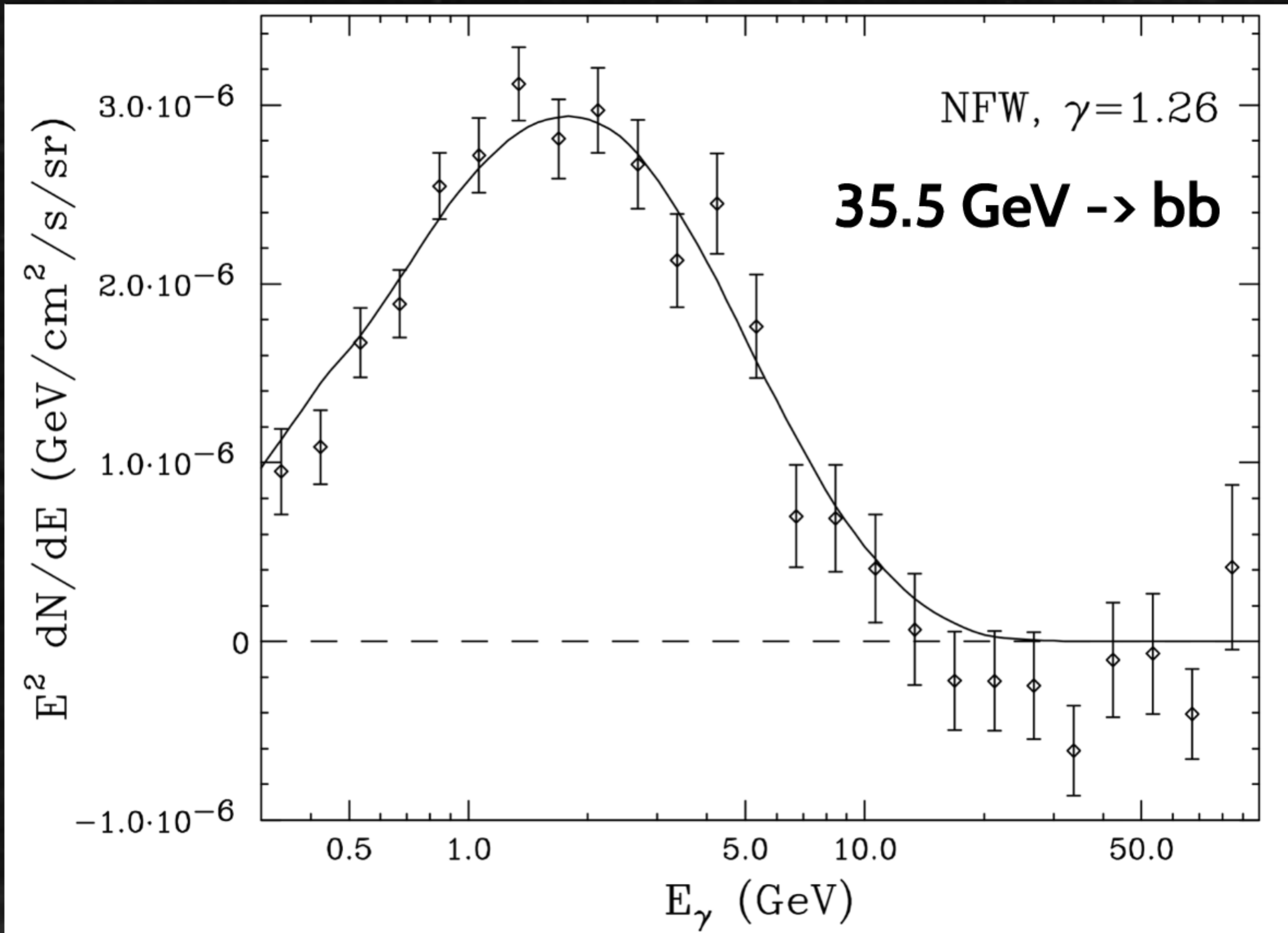

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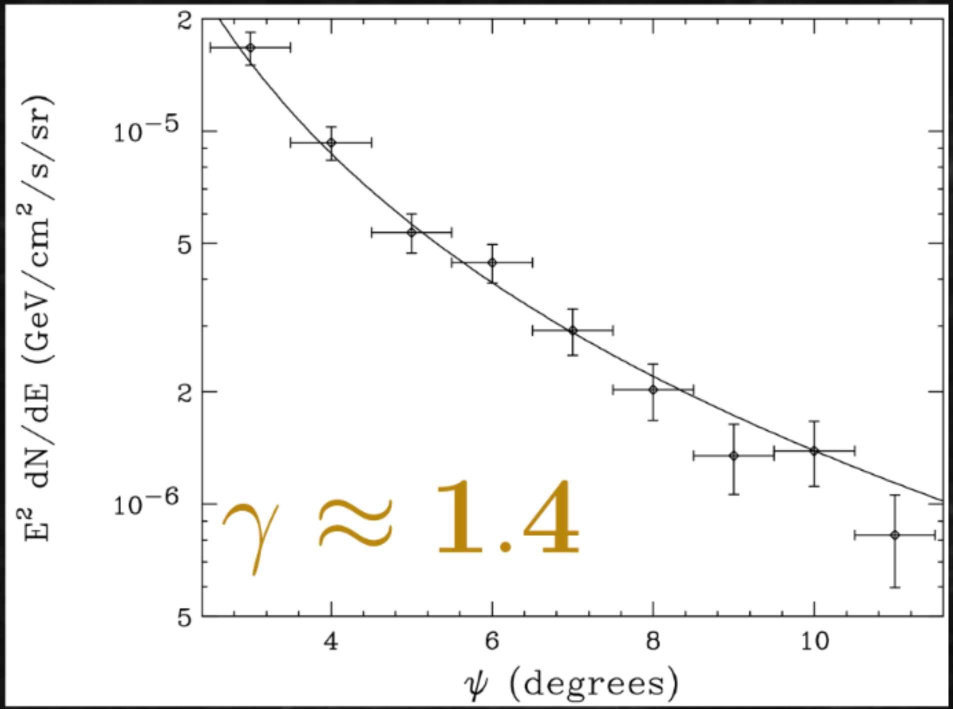

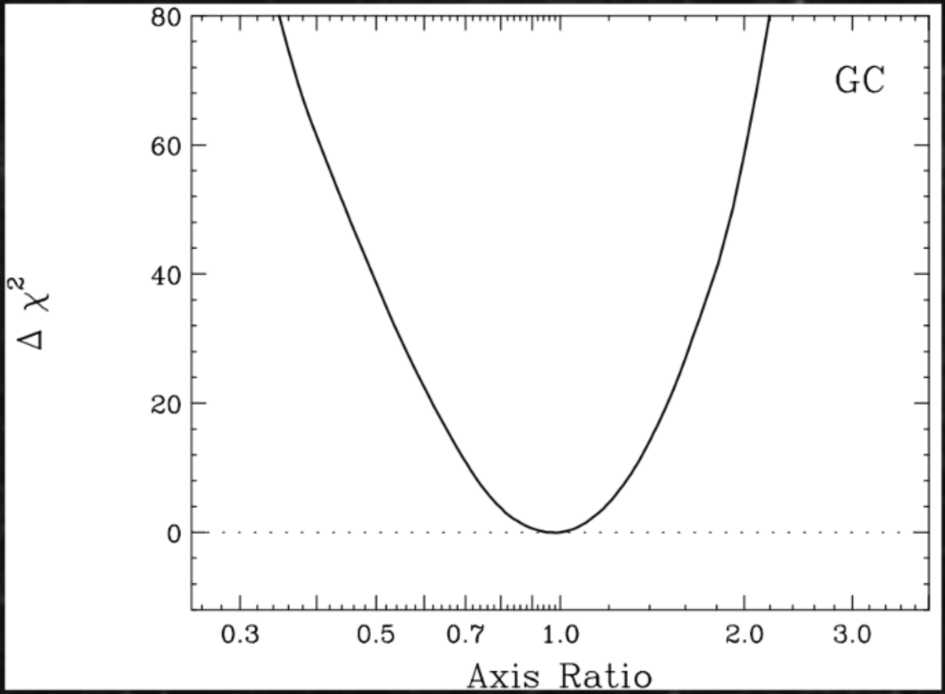

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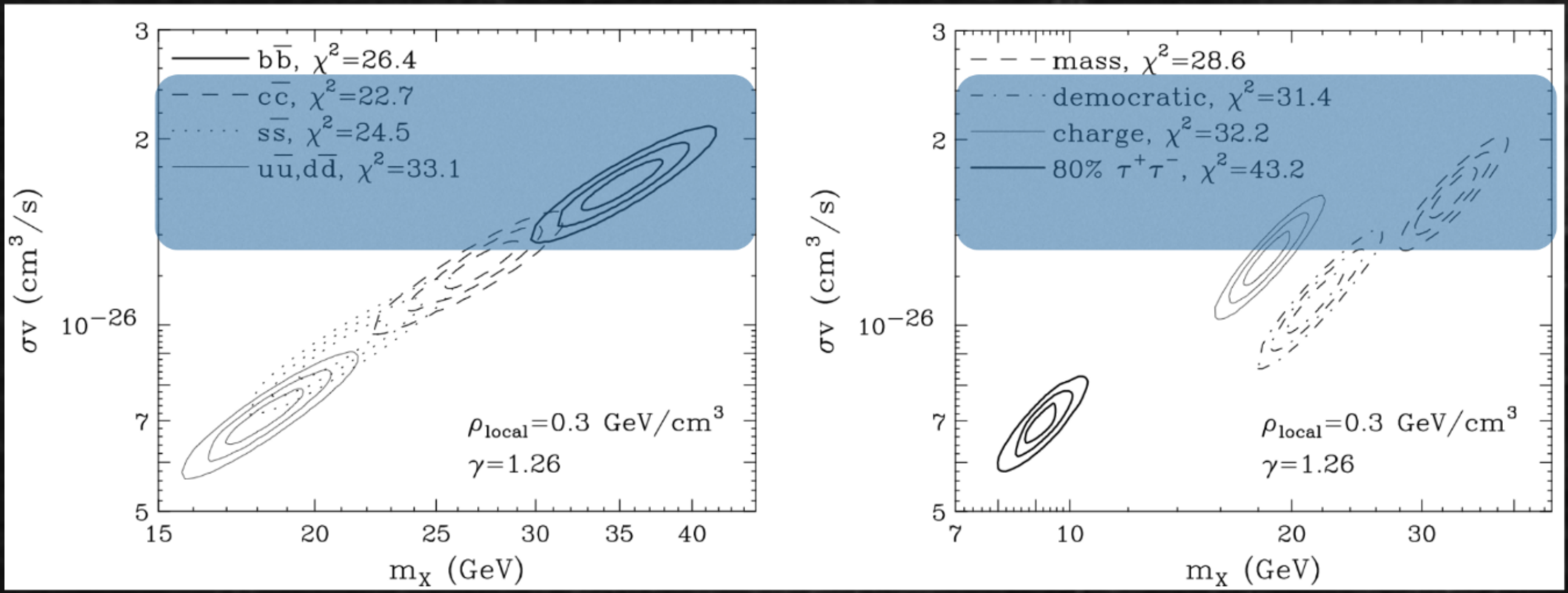

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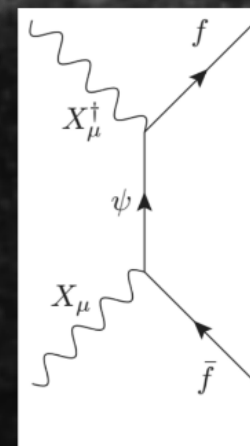
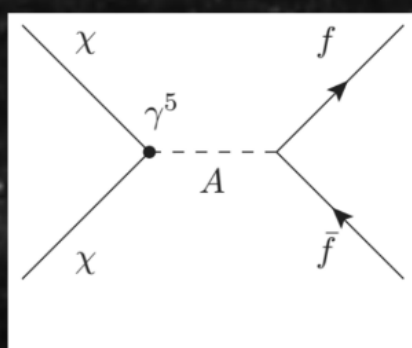
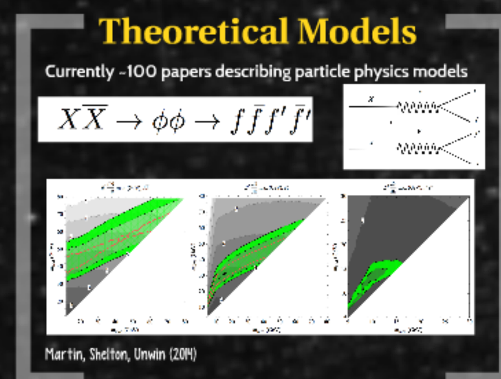
Model Number	*DM*	*Mediator*	*Interactions*	Elastic Scattering	Near Future Reach? Direct	LHC
1	Dirac Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}f$	$\sigma_{SI} \sim (q/2m_\chi)^2$ (scalar)	No	Maybe
1	Majorana Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}f$	$\sigma_{SI} \sim (q/2m_\chi)^2$ (scalar)	No	Maybe
2	Dirac Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}\gamma^5 f$	$\sigma_{SD} \sim (q^2/4m_n m_\chi)^2$	Never	Maybe
2	Majorana Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}\gamma^5 f$	$\sigma_{SD} \sim (q^2/4m_n m_\chi)^2$	Never	Maybe
3	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\chi,\ \bar{b}\gamma_\mu b$	$\sigma_{SI} \sim$ loop (vector)	Yes	Maybe
4	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$ or $\sigma_{SD} \sim (q/2m_\chi)^2$	Never	Maybe
5	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{SD} \sim 1$	Yes	Maybe
5	Majorana Fermion	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{SD} \sim 1$	Yes	Maybe
6	Complex Scalar	Spin-0	$\phi^\dagger\phi,\ \bar{f}\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	No	Maybe
6	Real Scalar	Spin-0	$\phi^2,\ \bar{f}\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	No	Maybe
6	Complex Vector	Spin-0	$B^\dagger_\mu B^\mu,\ \bar{f}\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	No	Maybe
6	Real Vector	Spin-0	$B_\mu B^\mu,\ \bar{f}\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	No	Maybe
7	Dirac Fermion	Spin-0 (*t*-ch.)	$\bar{\chi}(1 \pm \gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	Yes	Yes
7	Dirac Fermion	Spin-1 (*t*-ch.)	$\bar{\chi}\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	Yes	Yes
8	Complex Vector	Spin-1/2 (*t*-ch.)	$X^\dagger_\mu\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	Yes	Yes
8	Real Vector	Spin-1/2 (*t*-ch.)	$X_\mu\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	Yes	Yes



(8)



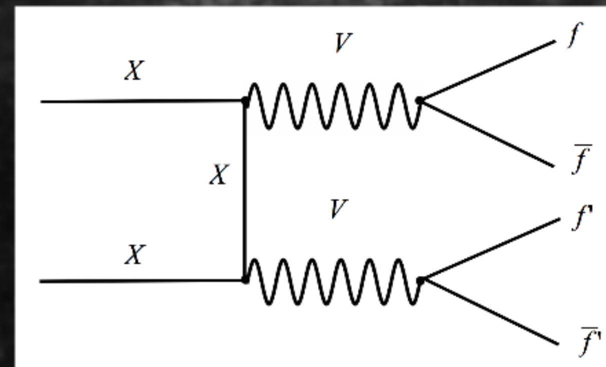
(1)

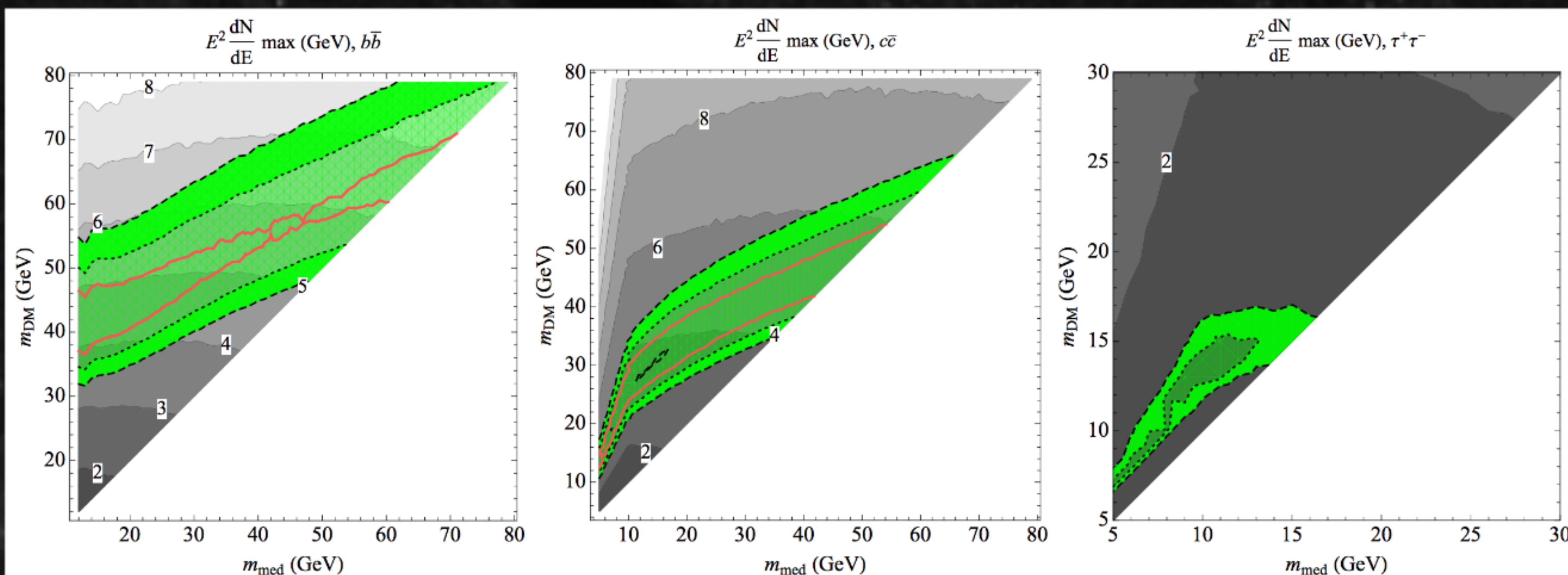


Theoretical Models

Currently ~100 papers describing particle physics models

$$X\overline{X} \to \phi\phi \to f\bar{f}f'\bar{f}'$$





Martin, Shelton, Unwin (2014)

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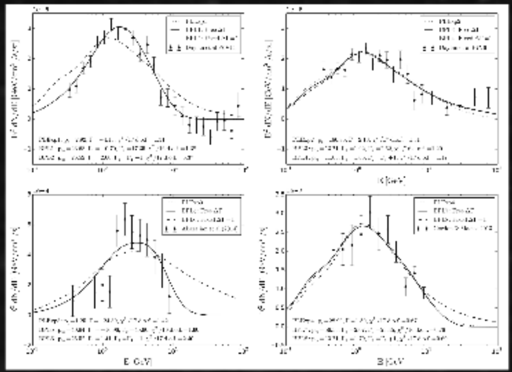
Spectral Problems



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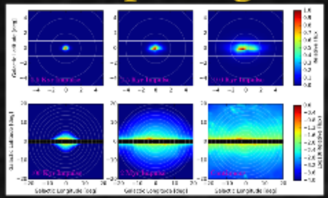
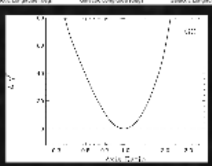


While very young systems appear to be somewhat spherically symmetric, those old enough to cover the ~10° extentsion of the data are highly enlongated along the plane



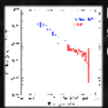
This is strongly excluded by our models

Data Analysis

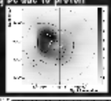
Eric Carlson and Stefano Profumo kindly provided the output of their models, and we calculated the TS of these fits to the data (in the GC analysis) as follows:

0.5 kyr	TS = 33
2.5 kyr	TS = 43
19 kyr	TS = 14
100 kyr	TS = 0
2 Myr	TS = 0
7.5 Myr Continuous:	TS = 0
Linear Combination	TS=51
Dark Matter:	TS = 315

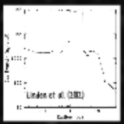
Extension of the GC Source

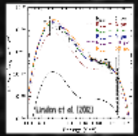


Has long been posited that the Fermi-LAT and H.E.S.S. GC source might be connected, and may be due to proton emission from the central source

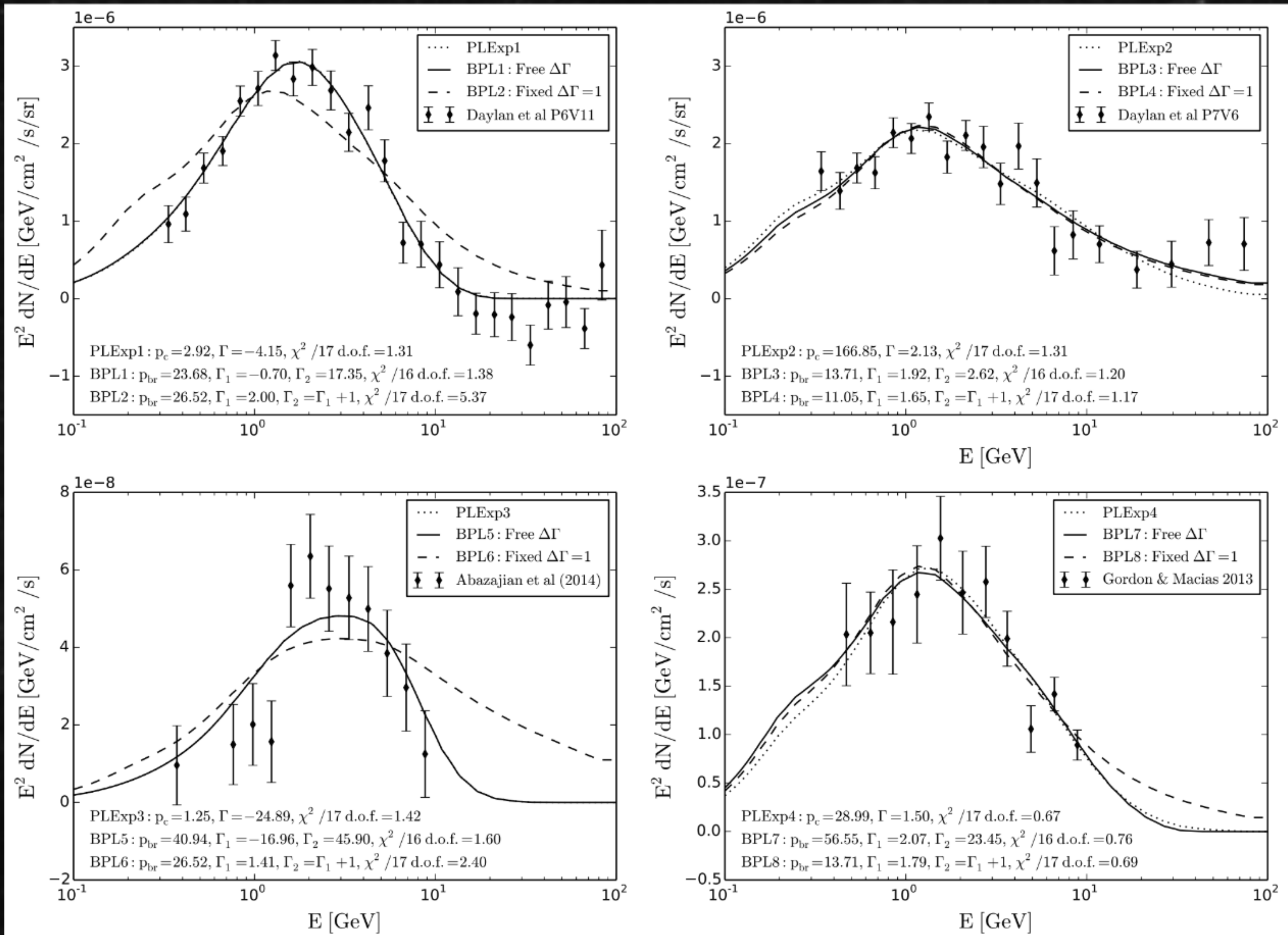


One problem is that the H.E.S.S. source appears to be point-like, and the H.E.S.S. angular resolution is better than that of the Fermi-LAT

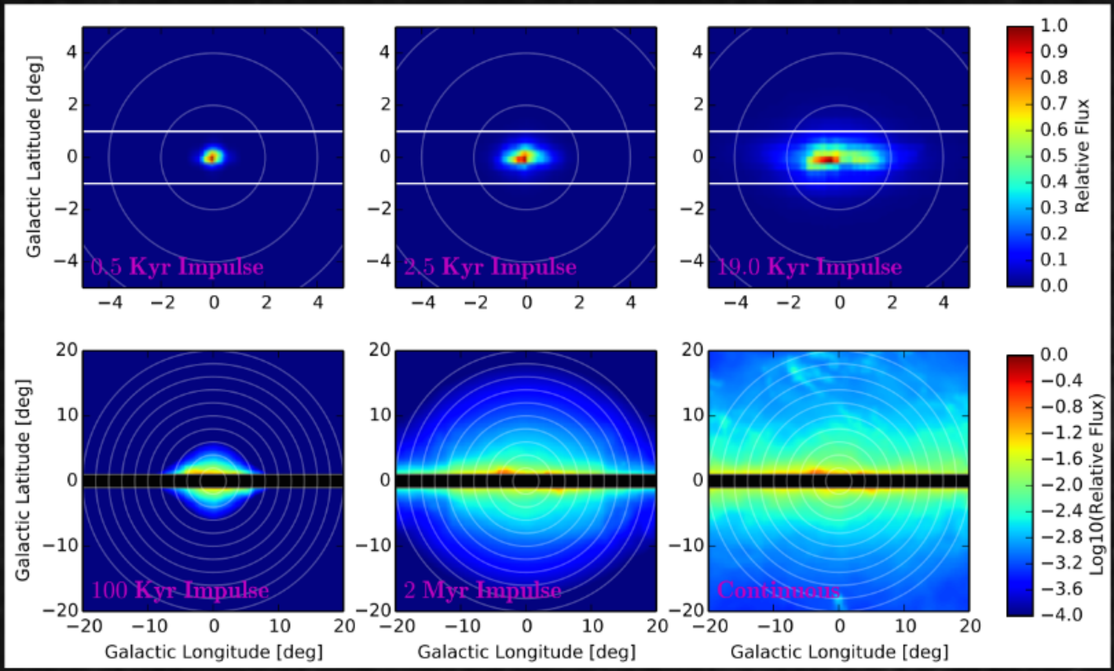


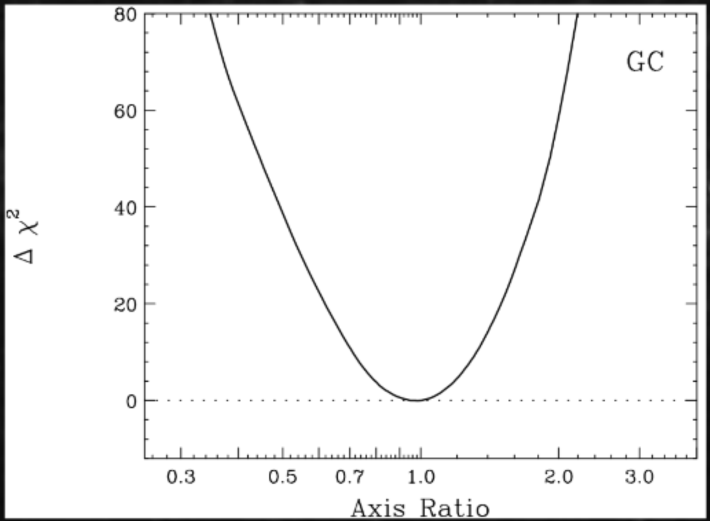


Spectral Problems



Morphological Problems





While very young systems appear to be somewhat spherically symmetric, those old enough to cover the ~10° extentsion of the data are highly enlongated along the plane

This is strongly excluded by our models

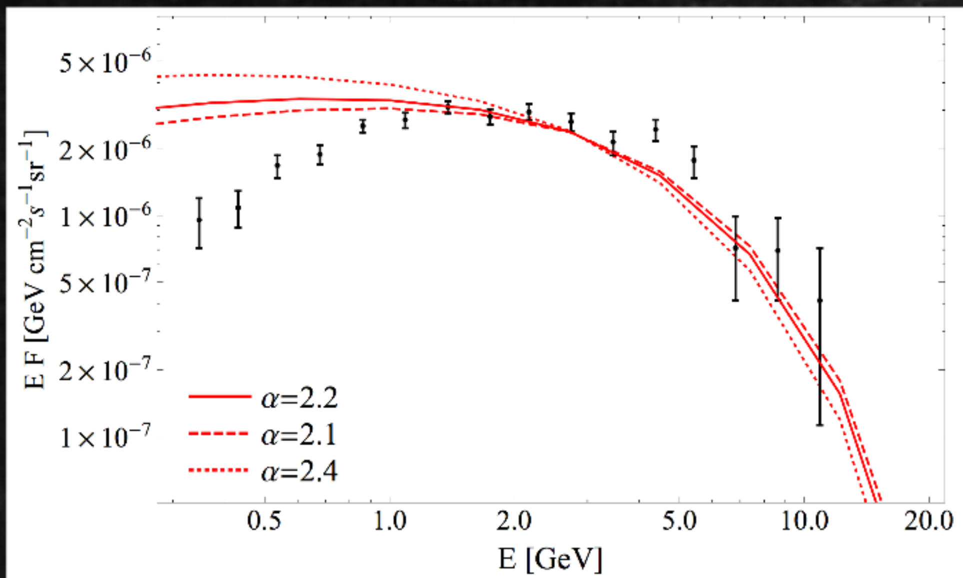
Data Analysis

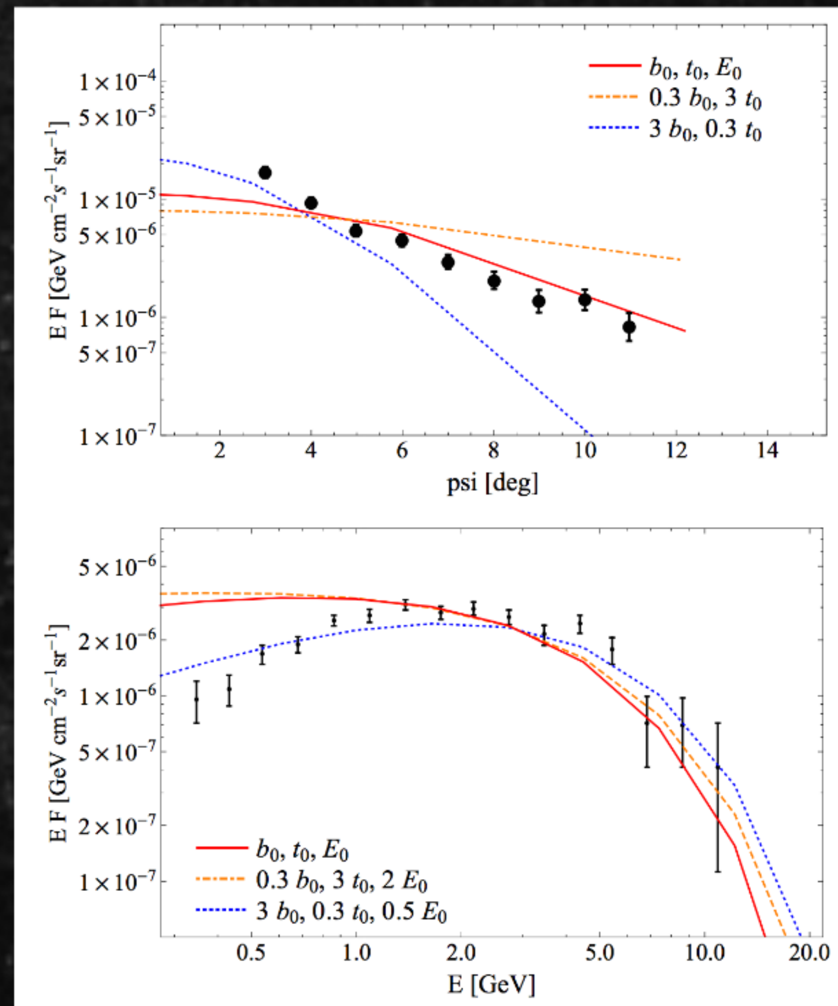
Eric Carlson and Stefano Profumo kindly provided the output of their models, and we calculated the TS of these fits to the data (in the GC analysis) as follows:

0.5 kyr	TS = 33
2.5 kyr	TS = 43
19 kyr	TS = 14
100 kyr	TS = 0
2 Myr	TS = 0
7.5 Myr Continuous:	TS = 0
Linear Combination	TS=51
Dark Matter:	TS = 315

Electron Emission Models

e.g. Petrovic et al. (2014)





Reasonable idea, but it is hard to fit the spectrum and the morphology of the GC model with these bursts.

Interpretation

Do the data favor dark matter, pulsar, or other models?

Pulsar Models

Hooper et al. (2013) 1305.0830

Cholis, Hooper, TL (2014a) 1407.5583
Cholis, Hooper, TL (2014b) 1407.5625

A New Pulsar Analysis

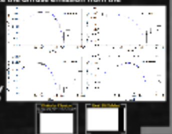
We want to answer the question - what does the average pulsar observed by the Fermi-LAT look like?

Then we can calculate the diffuse emission from the undetected fraction

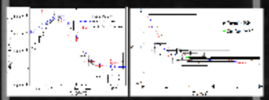
5.6 years data

P7 Reprocessed Photons

15 logarithmic energy bins (100 MeV - 100 GeV)

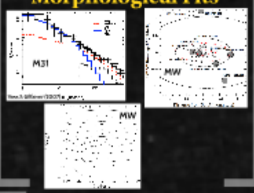


Spectral Fits



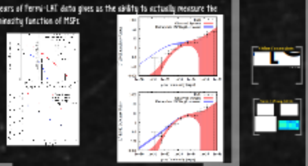
A reanalysis of MSP emission finds an average MSP spectrum which is significantly softer than the GC excess

Morphological Fits



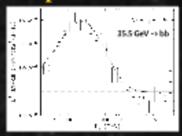
Luminosity Function

5 years of Fermi-LAT data gives us the ability to actually measure the luminosity function of MSPs

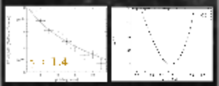


DM Models

Spectral Fits

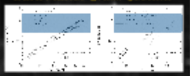


Morphological Fits



The signal exhibits both a smooth power-law falloff (in 3D) and also spherical symmetry around the position of Sgr A*

Dark Matter Cross-Section



The Excess is fit by simple dark matter models annihilating at the thermal cross-section. There is no need for Sommerfeld enhancement, or other particle physics fixes

Particle Models

Half of all tree level diagrams which explain the excess are consistent with current constraints

Interpretation

You can compare the simplicity of this scenario with previous results that were interpreted as dark matter annihilation

- Positron Excess
- DAMA/LIBRA
- 130 GeV Line

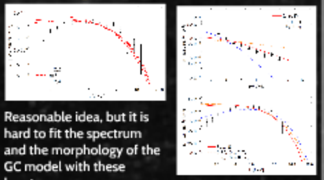
This excess is hugely statistically significant, it is well fit by simple dark matter models, and there are no clear astrophysical interpretations of the data

Proton Models

e.g. Carlson & Profumo (2014)

Electron Emission Models

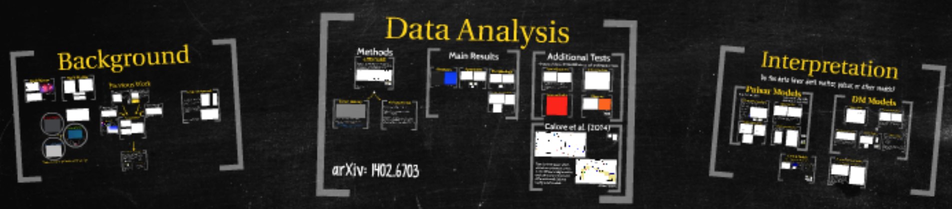
e.g. Petrovic et al. (2014)



Reasonable idea, but it is hard to fit the spectrum and the morphology of the GC model with these bursts.

A Compelling Case for Annihilating Dark Matter

Tim Linden

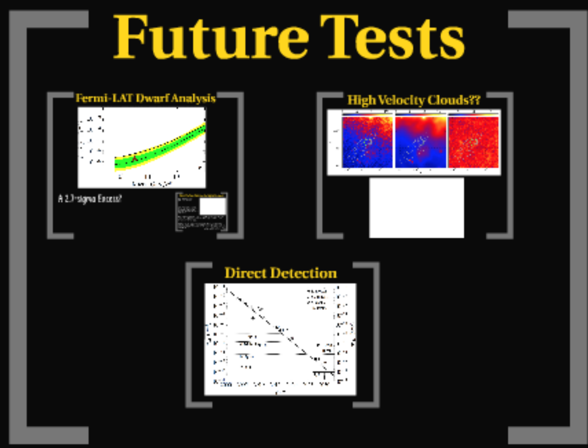


along with:
Tansu Daylan, Doug Finkbeiner, Dan Hooper, Stephan Portillo, Nick Rodd, Tracy Slatyer

arXiv: 1402.6703

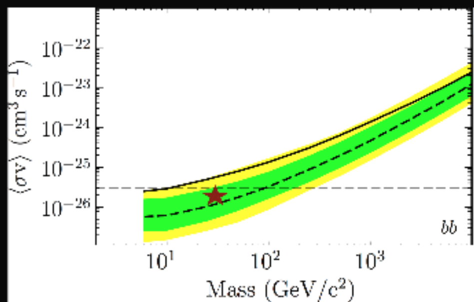
University of Hong Kong - October 17, 2014

It's a compelling case -- but what is next?

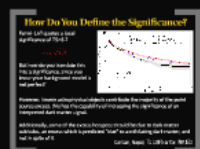


Future Tests

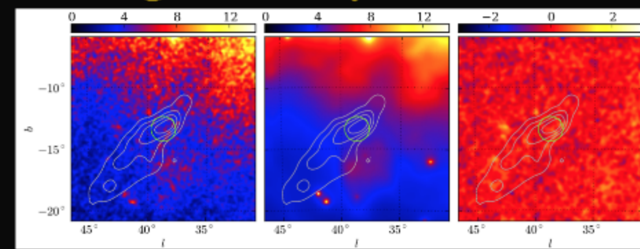
Fermi-LAT Dwarf Analysis

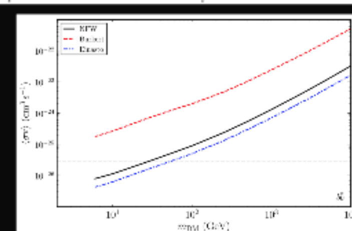


A 2.7-sigma Excess?

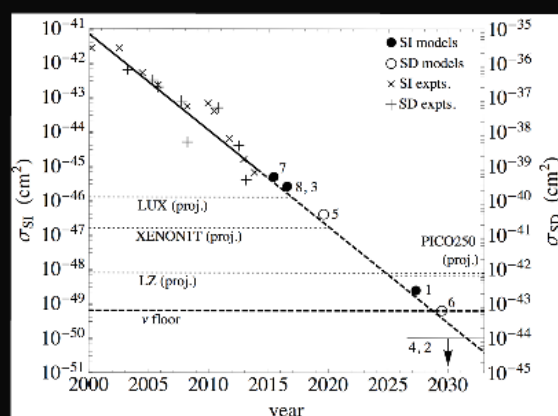


High Velocity Clouds??

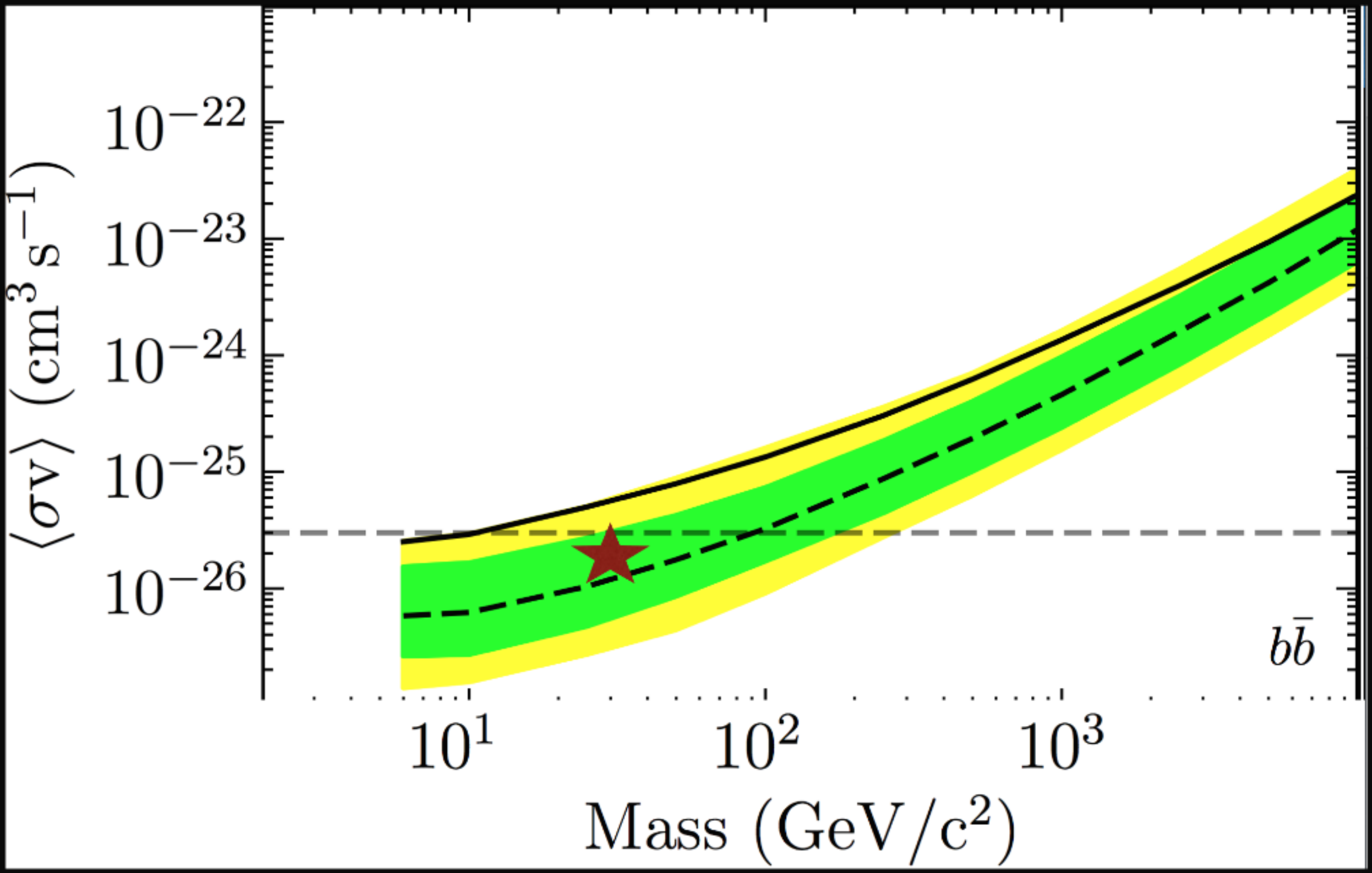




Direct Detection



Fermi-LAT Dwarf Analysis



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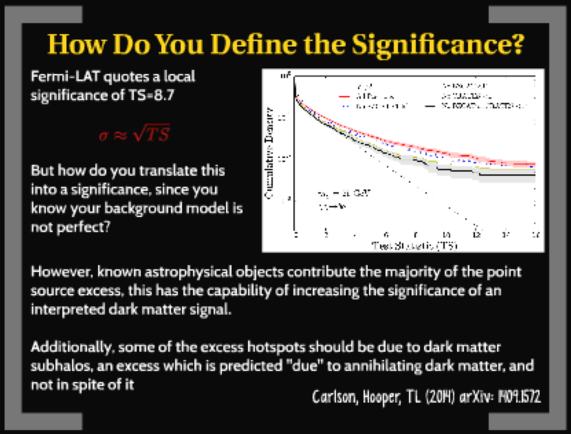
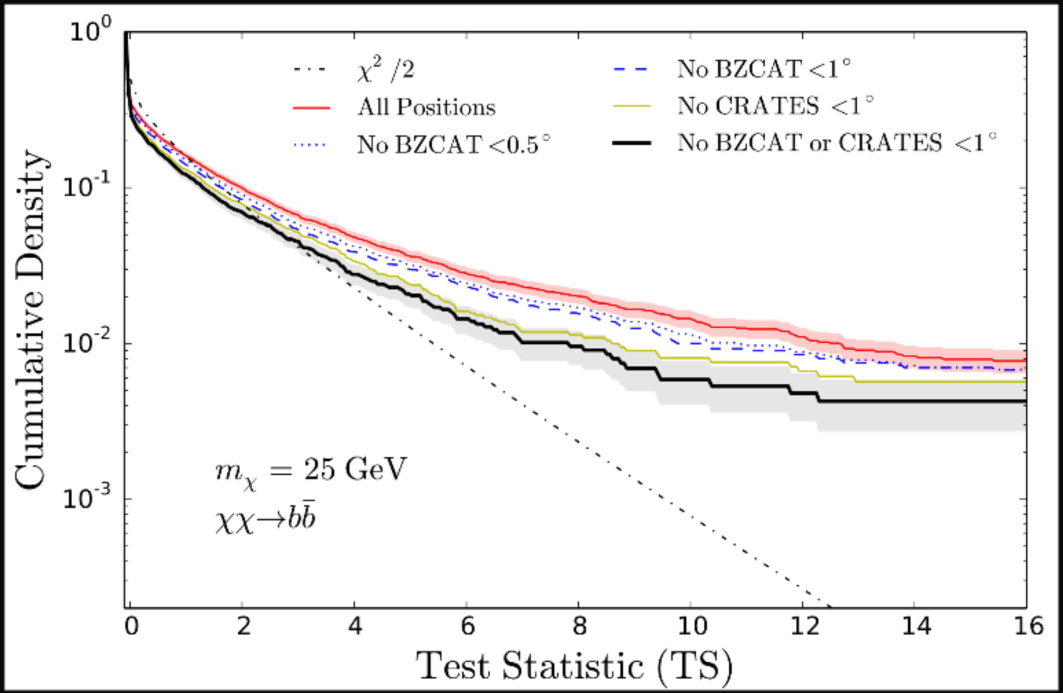


How Do You Define the Significance?

Fermi-LAT quotes a local significance of TS=8.7

$$\sigma \approx \sqrt{TS}$$

But how do you translate this into a significance, since you know your background model is not perfect?

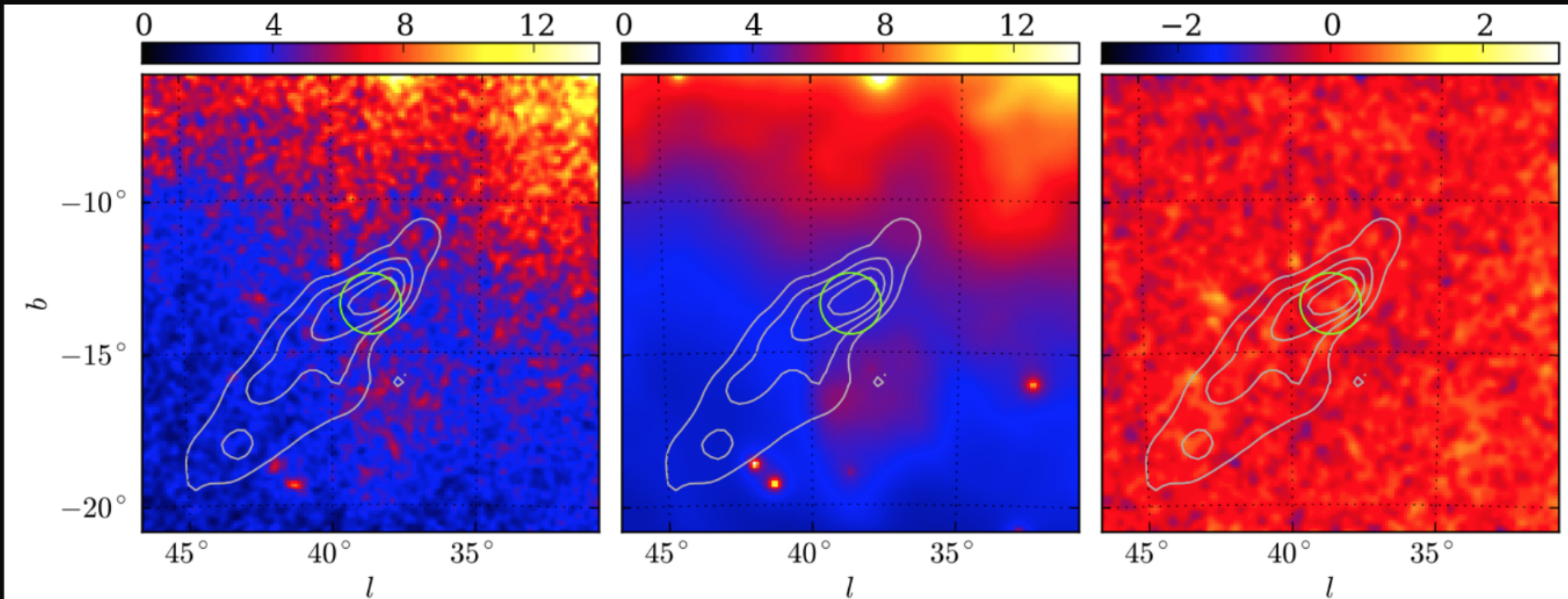


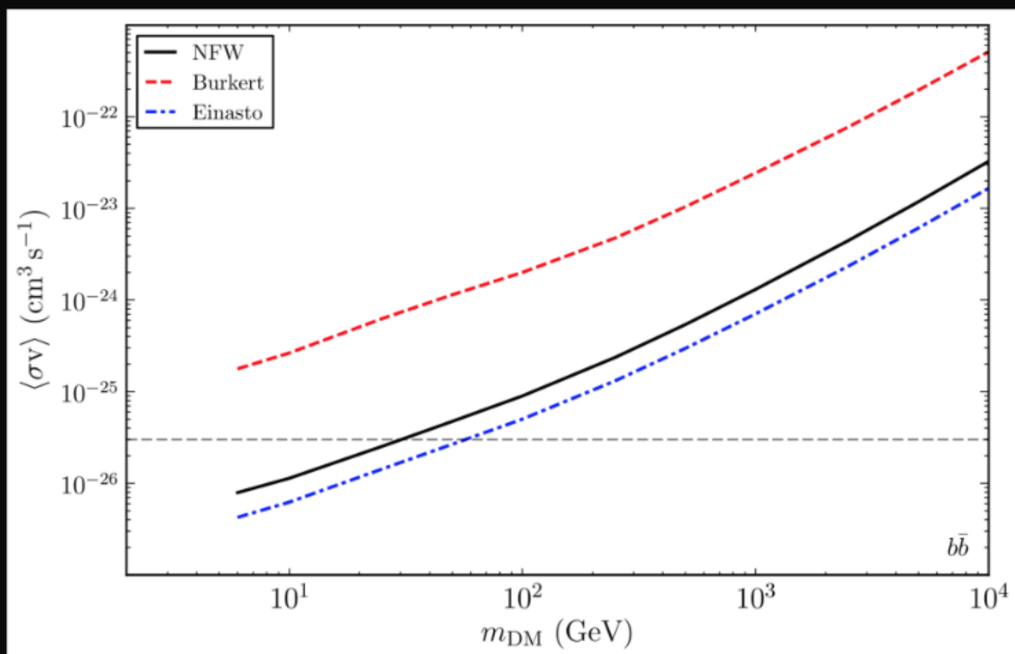
However, known astrophysical objects contribute the majority of the point source excess, this has the capability of increasing the significance of an interpreted dark matter signal.

Additionally, some of the excess hotspots should be due to dark matter subhalos, an excess which is predicted "due" to annihilating dark matter, and not in spite of it

Carlson, Hooper, TL (2014) arXiv: 1409.1572

High Velocity Clouds??





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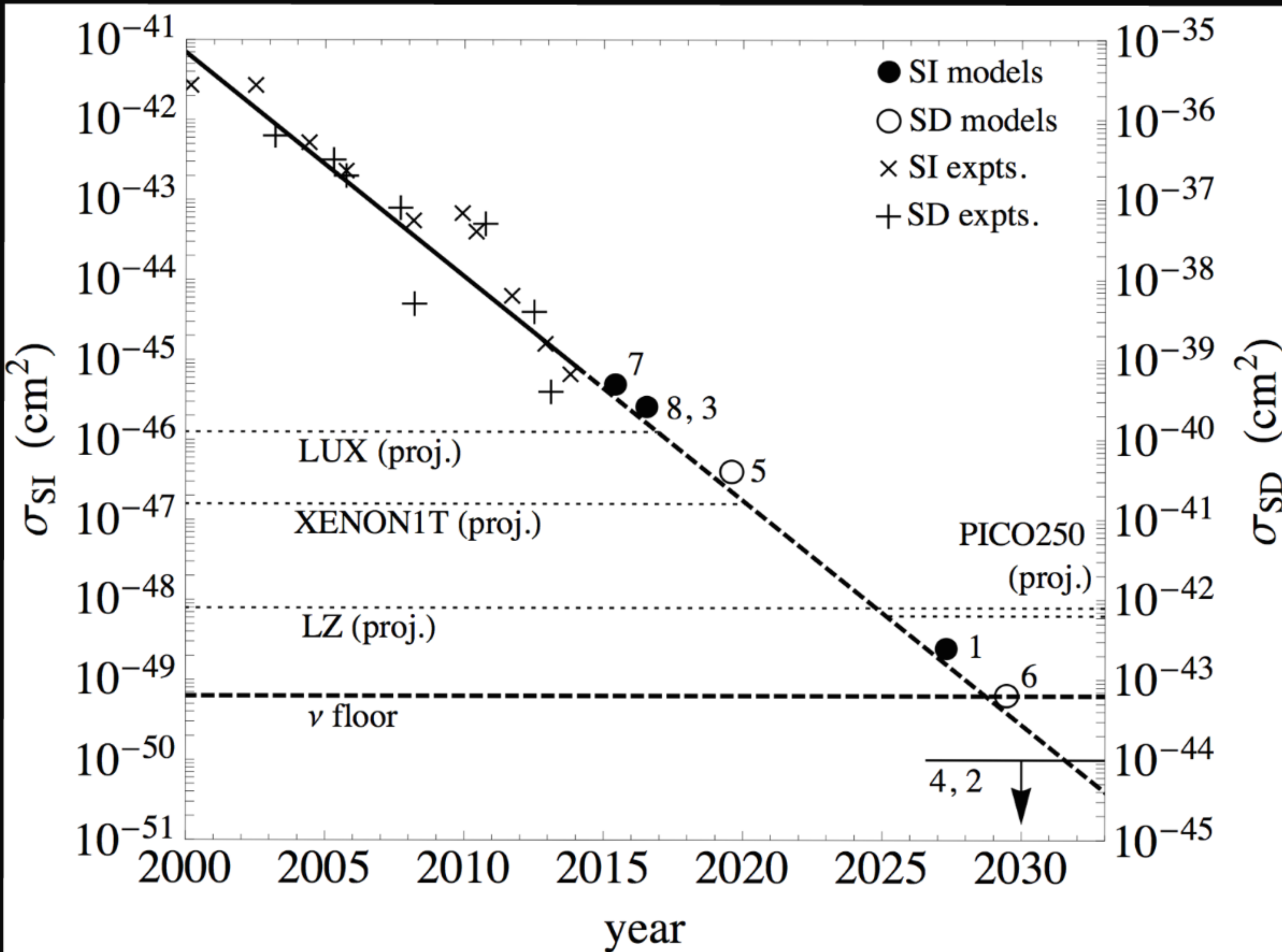

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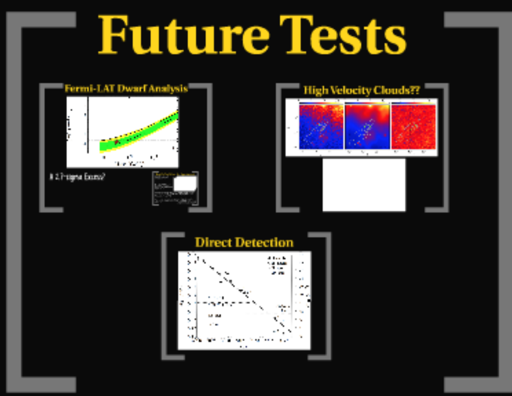

Thank you for attending! **Any Questions?**