Fermi Gamma-ray Space Telescope

Search for Gamma-ray Emission from Dark Matter Annihilation in the SMC with the Fermi-LAT

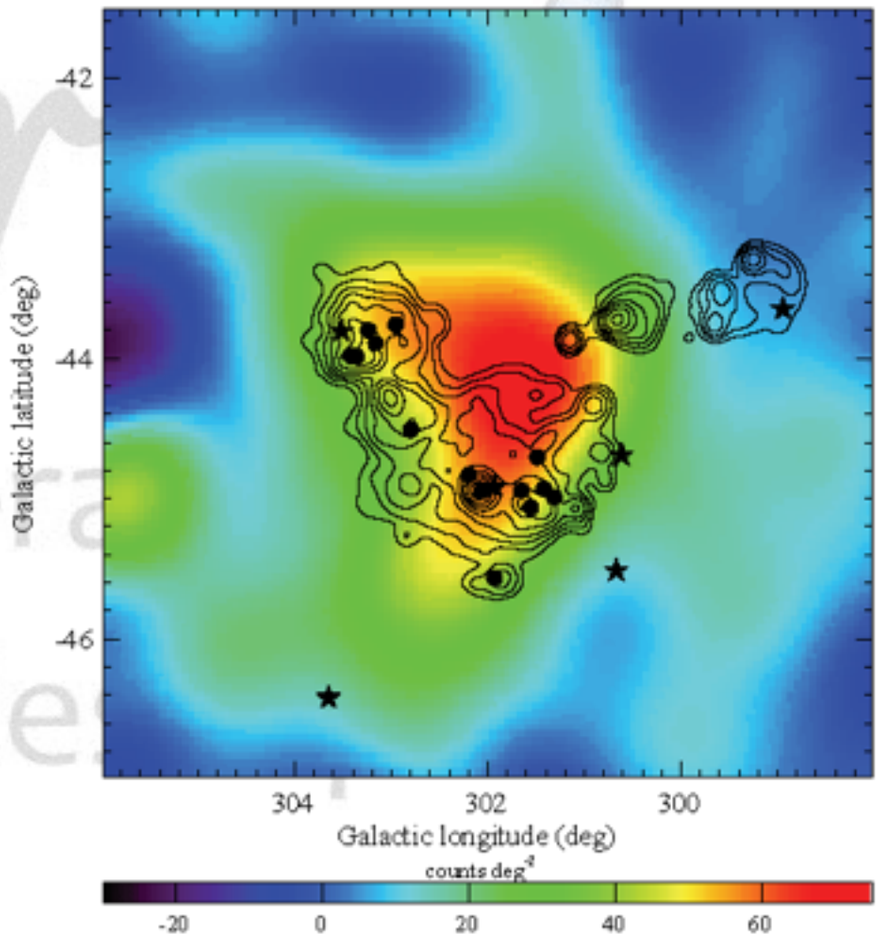
R. Caputo, UCSC
on behalf of the
Fermi-LAT Collaboration,
A. M. Brooks and M. R. Buckley

Fermi Symposium
13 November 2015

SCIPP

Today's Program in 5 Acts

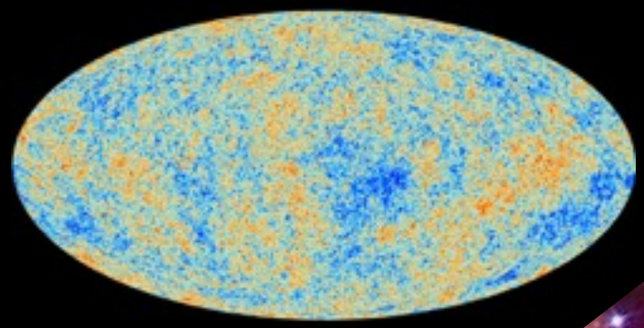
- **Part I: Modeling of the Dark Matter distribution**
  - **Rotation Curves, N-body simulations**
- **Part II: Modeling the Conventional Astrophysical Sources in the SMC**
  - **Cosmic-ray emissivity**
- **Part III: The Fermi-LAT Analysis**
  - **Correlation between DM and astrophysics**
- **Part IV: Results**
- **Part V: Summary/Conclusions**

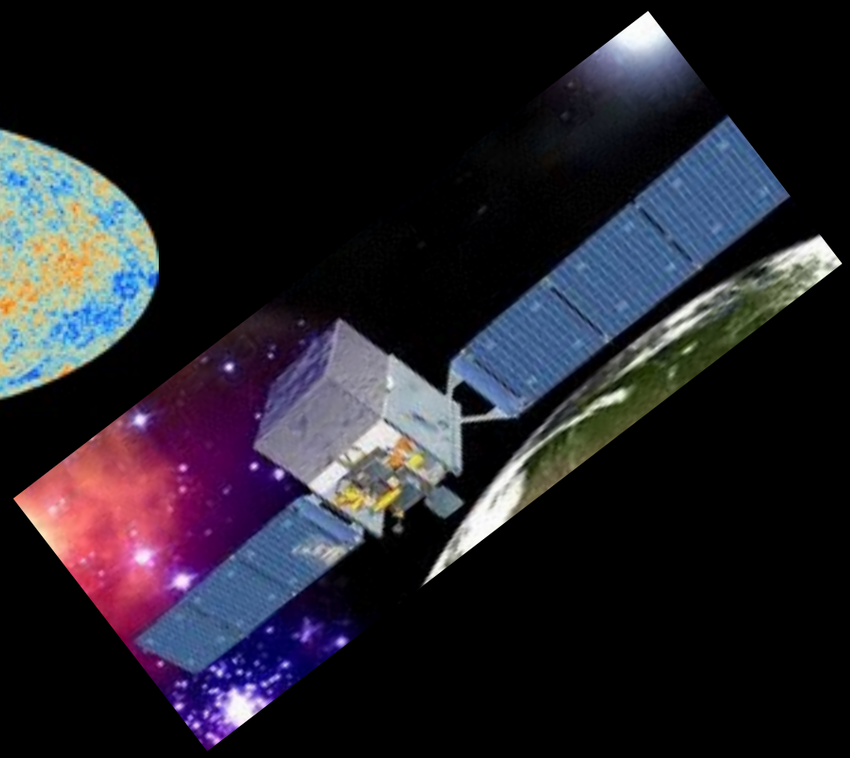


Fermi-LAT Collaboration, A&A 523, A46 (2010)

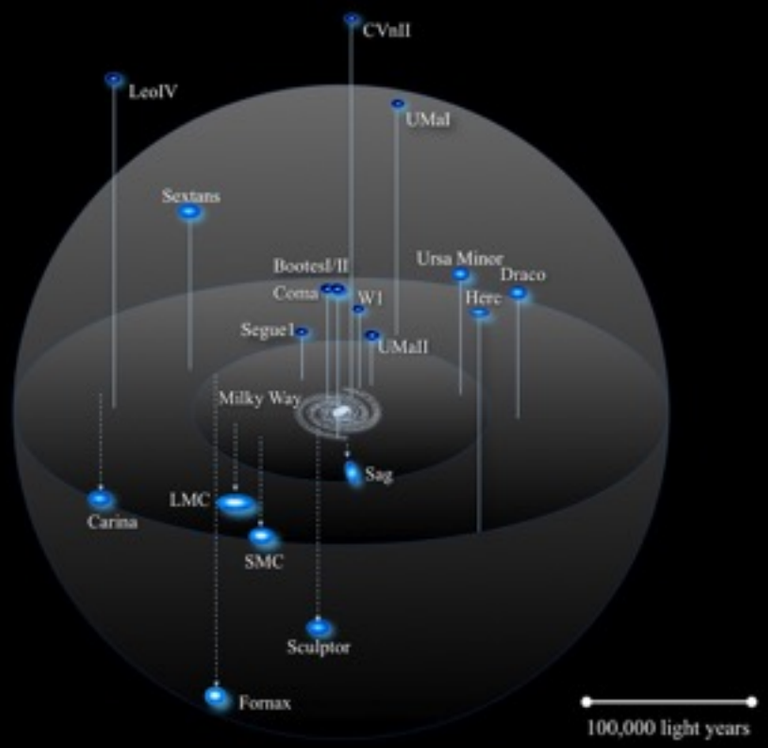
Prelude: A Brief Introduction

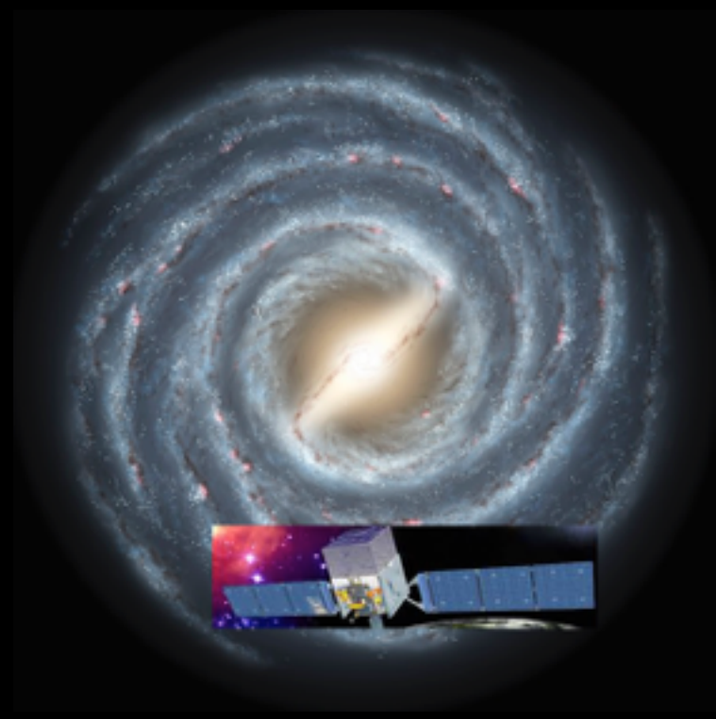
Why Dark Matter?





Why the SMC?





Prelude: A Brief Introduction

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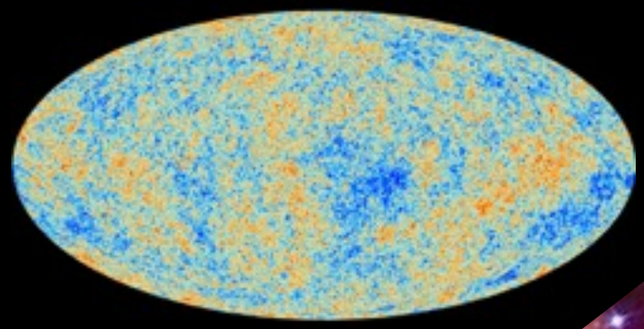
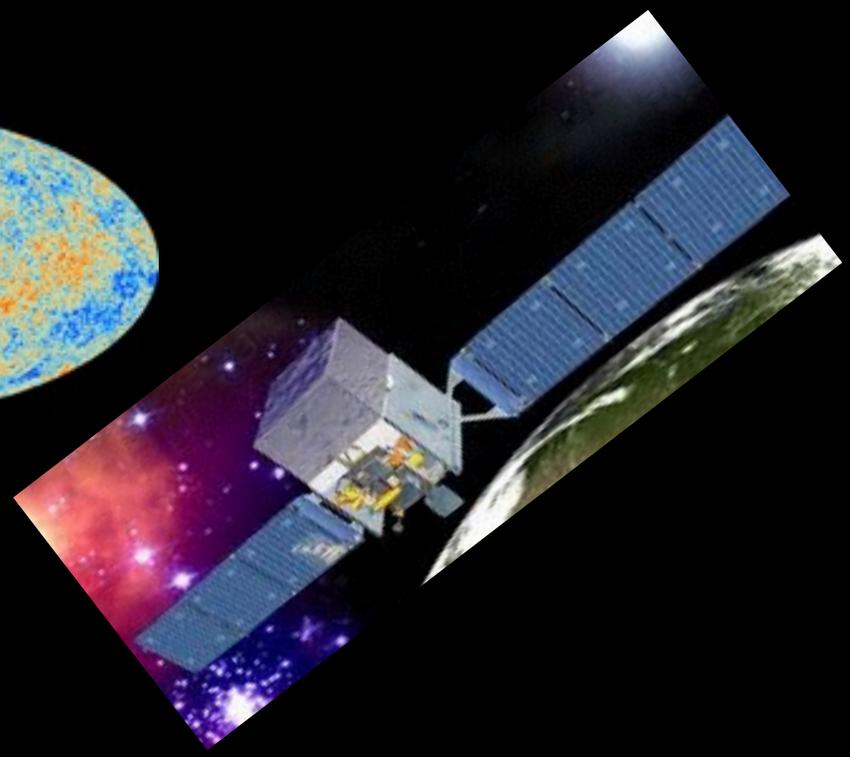
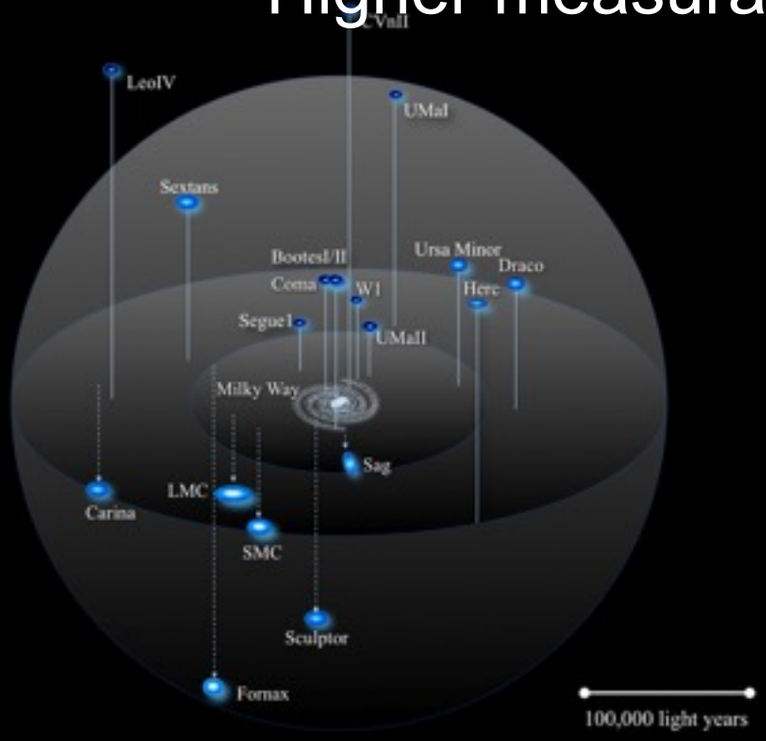


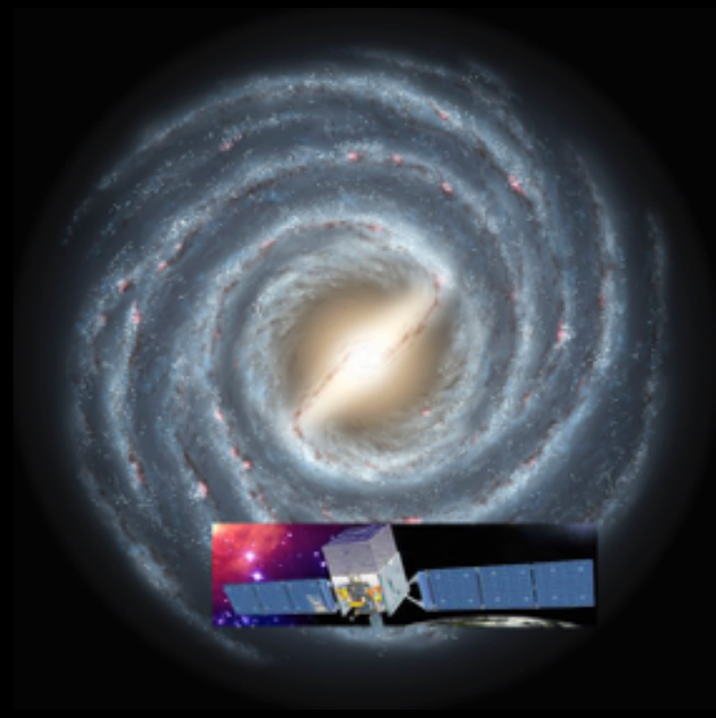


Why the SMC?

— High density of dark matter —

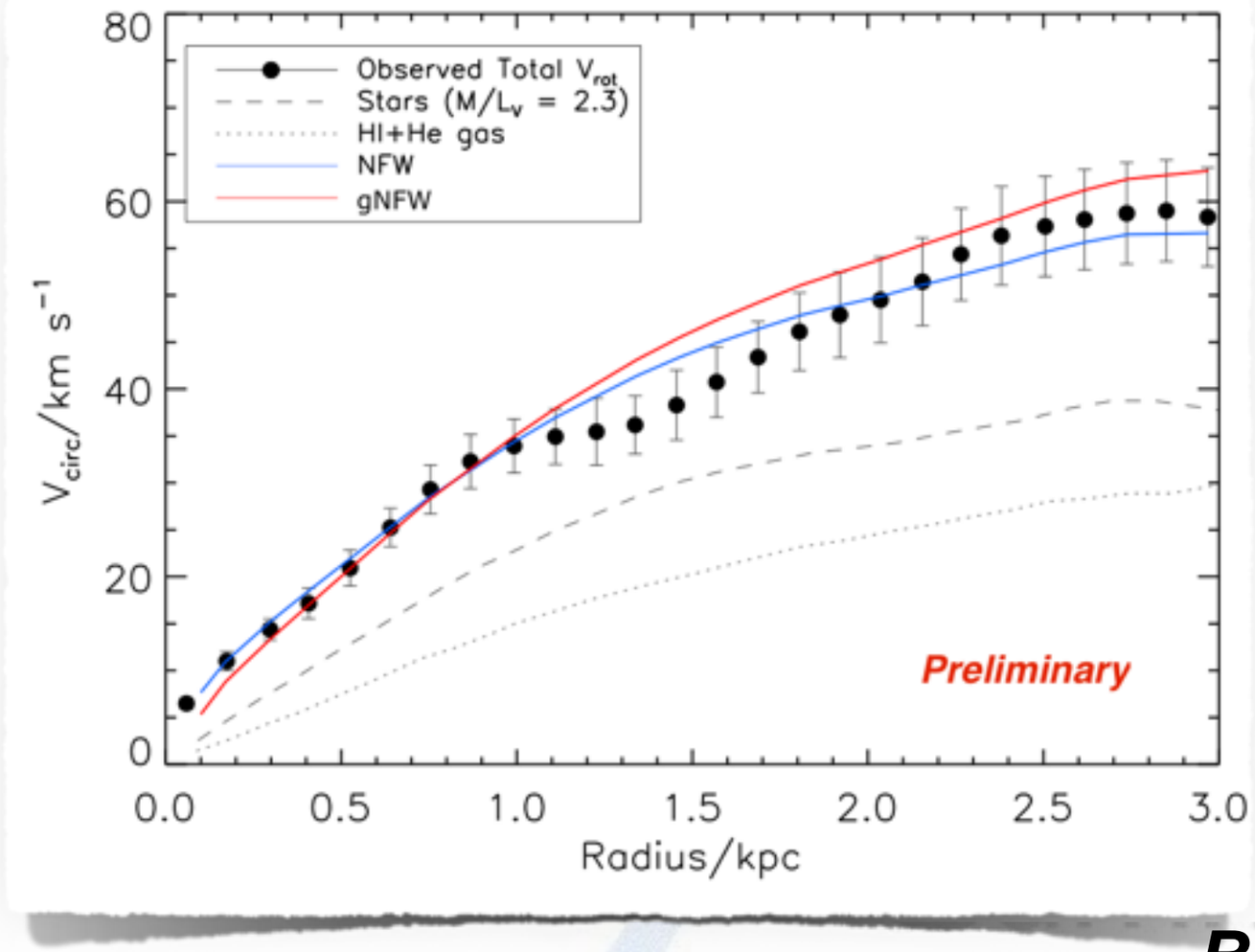
Fewer astrophysical sources than GC/LMC
Higher measurable signal (J-factor) than dwarf spheroidal galaxies
Part of the dark matter picture





Part I: Modeling the Dark Matter Distribution

SMC Rotation Curve



Results: rotation curve + N-body simulations

Fit	gNFW	NFW
α	1.80±0.35	1
β	2.65±0.06	3
γ	0.69±0.14	1
r_s [kpc]	5	5.1
ρ_0 [$M_\odot$/kpc^3]	7.0x10^6	4.1x10^6
J [GeV^2/cm^5]	4.56x10^{19}	1.13x10^{19}
$\log_{10}$ J	19.7±0.2	19.1±0.2

Best for N-body and Rotation

Second best for Rotation

Generalized NFW density profile:

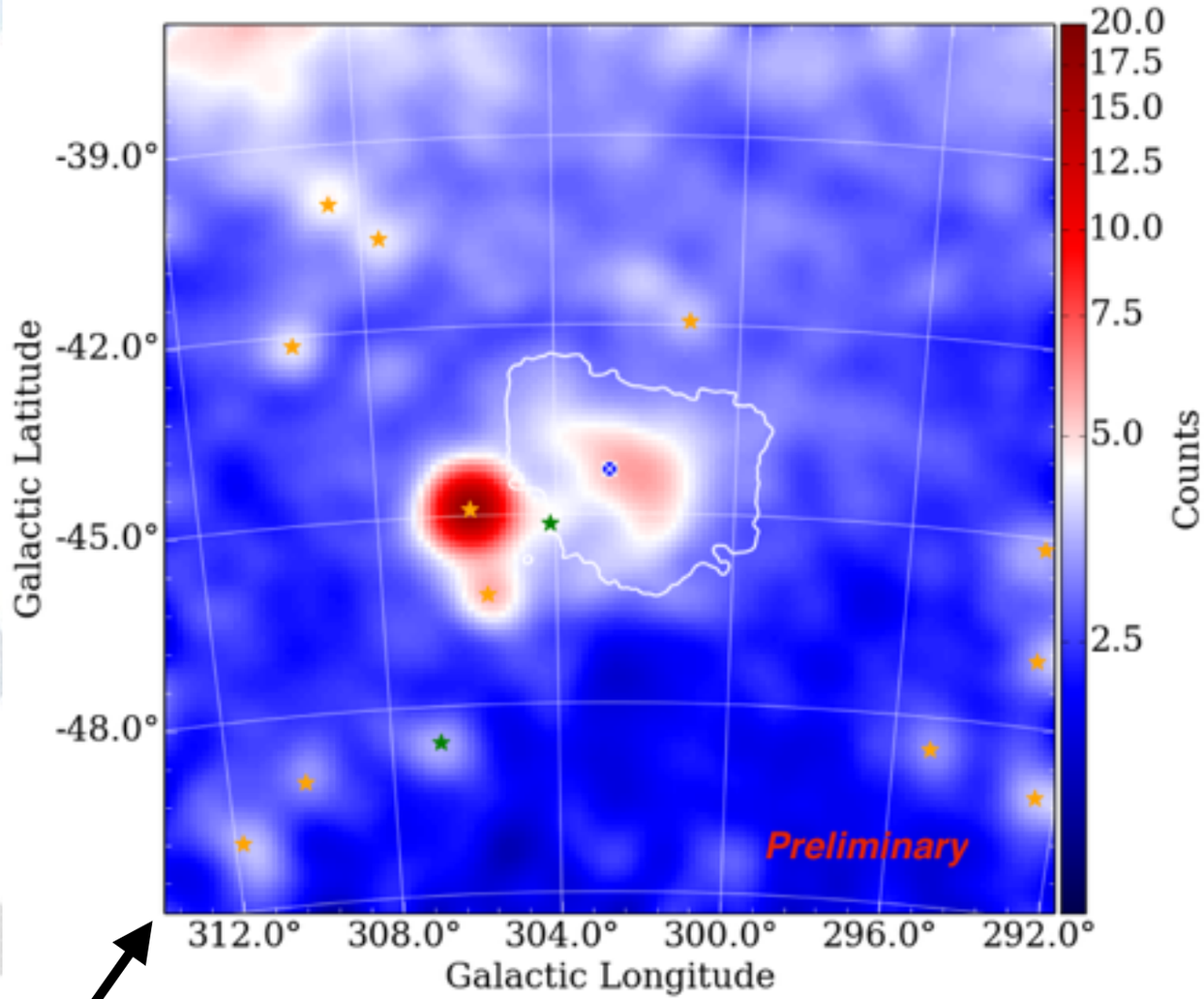
$$\rho(r) = \frac{\rho_0}{\left(\frac{r}{r_S}\right)^{\gamma}\left[1+\left(\frac{r}{r_S}\right)^{\alpha}\right]^{\frac{\beta-\gamma}{\alpha}}}\Theta(r_{\max}-r)$$

Bekki & Stanimirovic, MNRAS (2009) 395 (1)

Di Cintio et al., MINRAS (2013) 437 415

Part II: Modeling the Astrophysical Sources

Selection	Criteria
Observation Period	2008 Aug. 4 to 2014 Aug. 5
MET (s)	239557414 to 428903014
Energy Range (GeV)	0.5 to 500
Fit Region	10°×10° centered (ℓ,b)=(302°.80, -44°.30)
Zenith Range	θ_z<100°



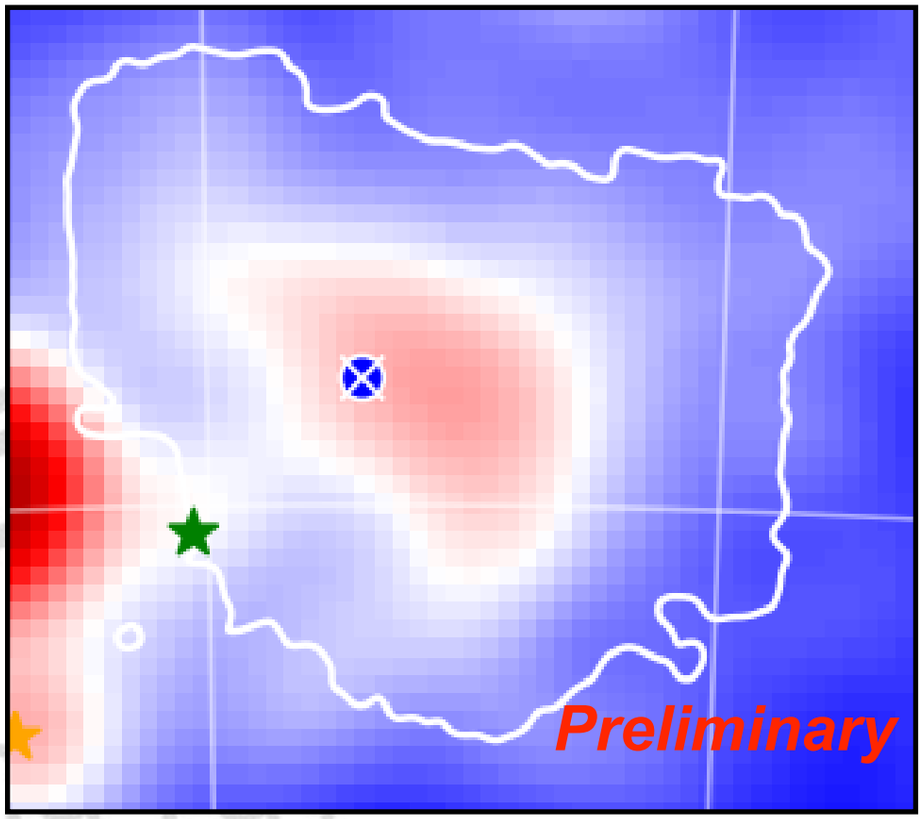
1 new point source,
1 re-centered (3FGL J0021.66835),
and SMC (white outline)

SMC Modeling

Emissivity model (LMC*): gamma-rays come from cosmic rays interacting with interstellar gas in the SMC

2D Gaussian emissivity profile multiplied by gas column density → Best fit to LAT data (1 component)

2D Gaussian (alternative)



* M. R. Buckley *et. al*, Phys. Rev. D 91, 102001 (2015) arXiv:1502.01020 [astro-ph.HE]

Part III: The Fermi-LAT Analysis

SMC DM Fits

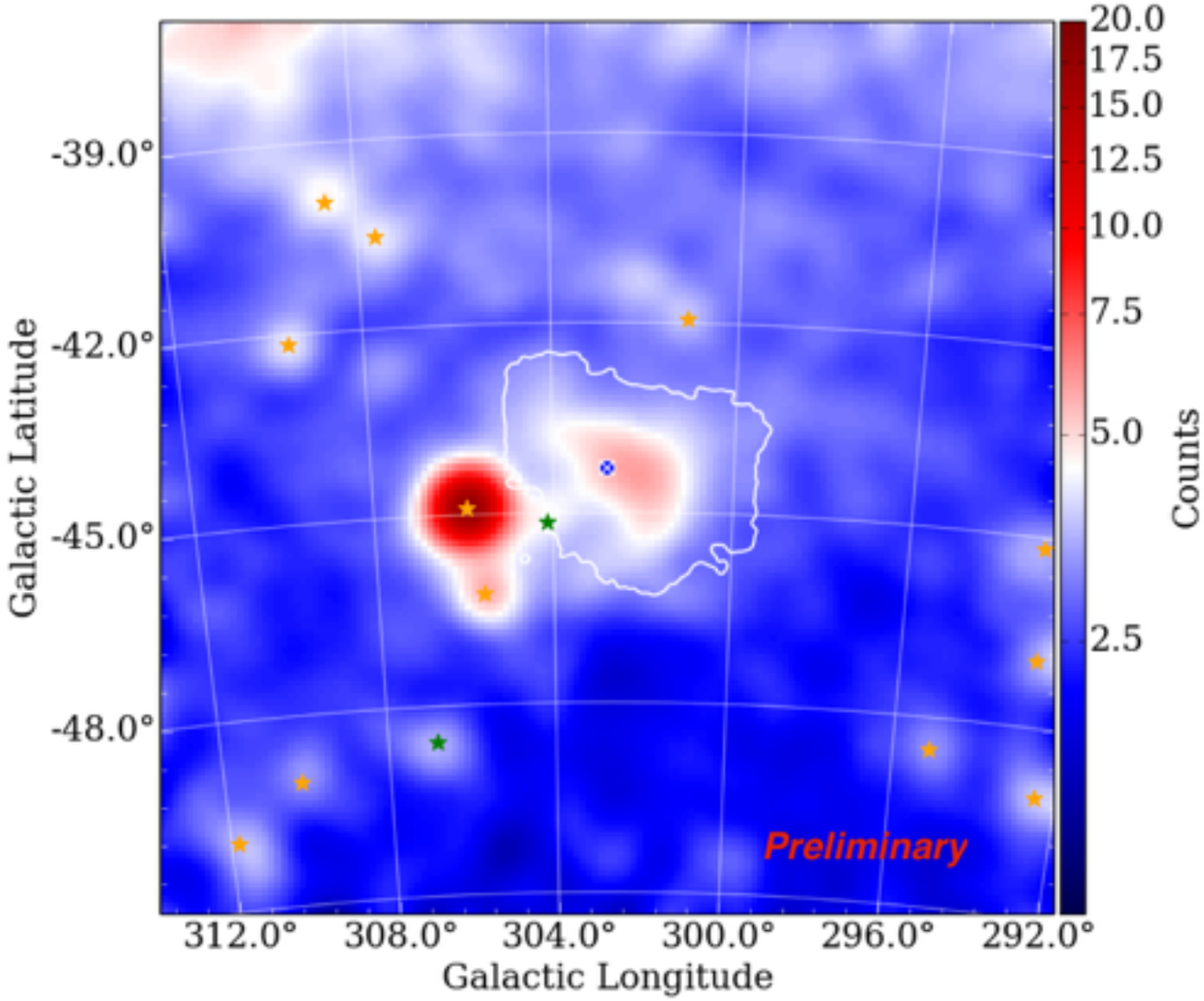
Broadband fit (standard binned Poisson Likelihood)

- normalizations of diffuse and point sources
- DM: power law index ($\Gamma = 2$)*

Scan likelihood of assumed DM signal (energy bin-by-bin)

- background normalizations fixed
- free component: DM normalization

Identify degeneracies…

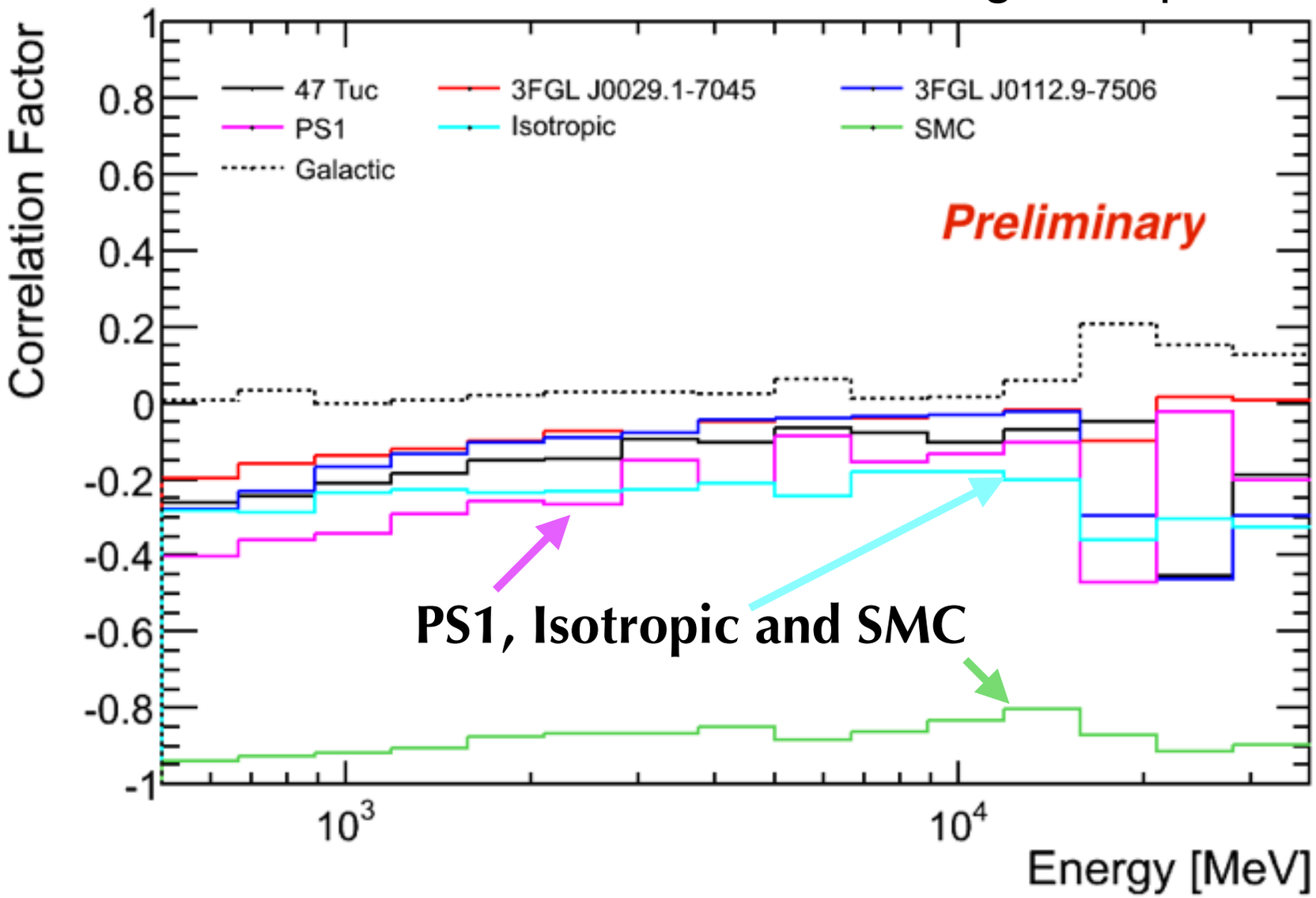


* **Fermi-LAT Collaboration, 2014, Phys. Rev. D, 89, 042001 arXiv:1310.0828 [astro-ph.HE]**

Part III: The Fermi-LAT Analysis

Correlations between SMC and DM template

gNFW profile



float 10σ nominal value

Correlation Factor (ρ) calculated using covariance matrices

*See talk by E. Charles on Wednesday

Part IV: Results

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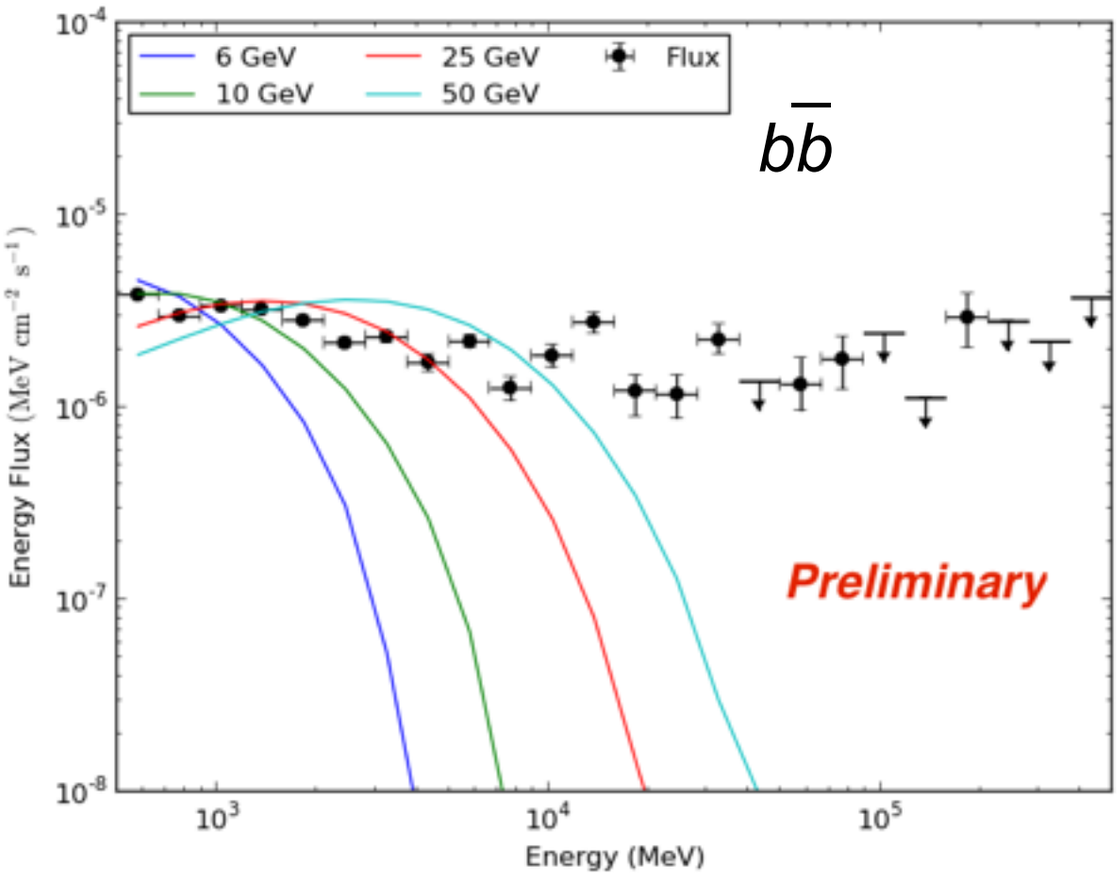
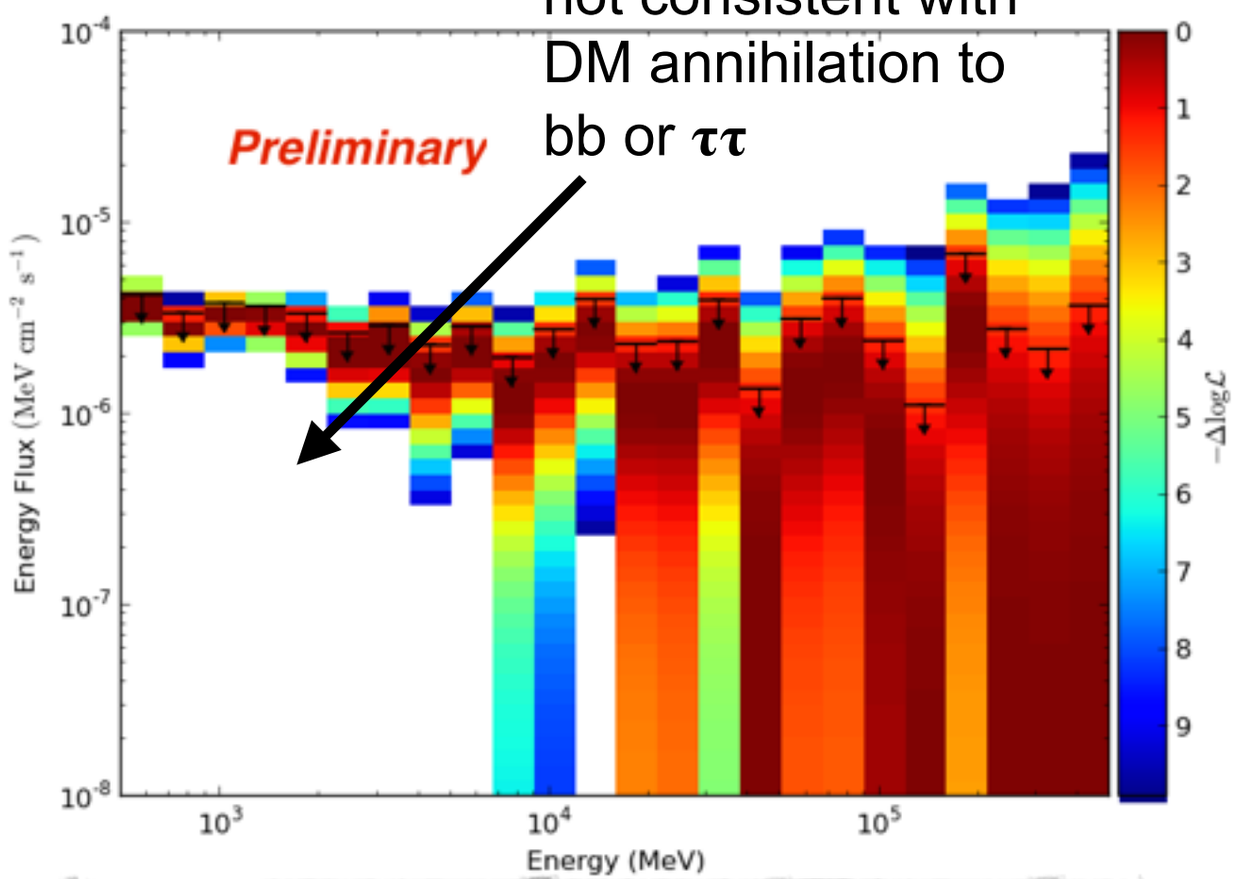
Assume ***all*** gamma rays are from DM annihilation
Remove the SMC model…



Shape of excess not consistent with DM annihilation to bb or $\tau\tau$



All gamma-rays from SMC are *not* from DM annihilation (excluded by dsphs)

	bb	$\tau\tau$
6 GeV:	2.4×10^{-25} cm^3/s,	3.0×10^{-25} cm^3/s
10 GeV:	3.3×10^{-25} cm^3/s,	5.2×10^{-25} cm^3/s
25 GeV:	8.2×10^{-25} cm^3/s,	1.4×10^{-25} cm^3/s
50 GeV:	1.8×10^{-24} cm^3/s,	2.8×10^{-24} cm^3/s

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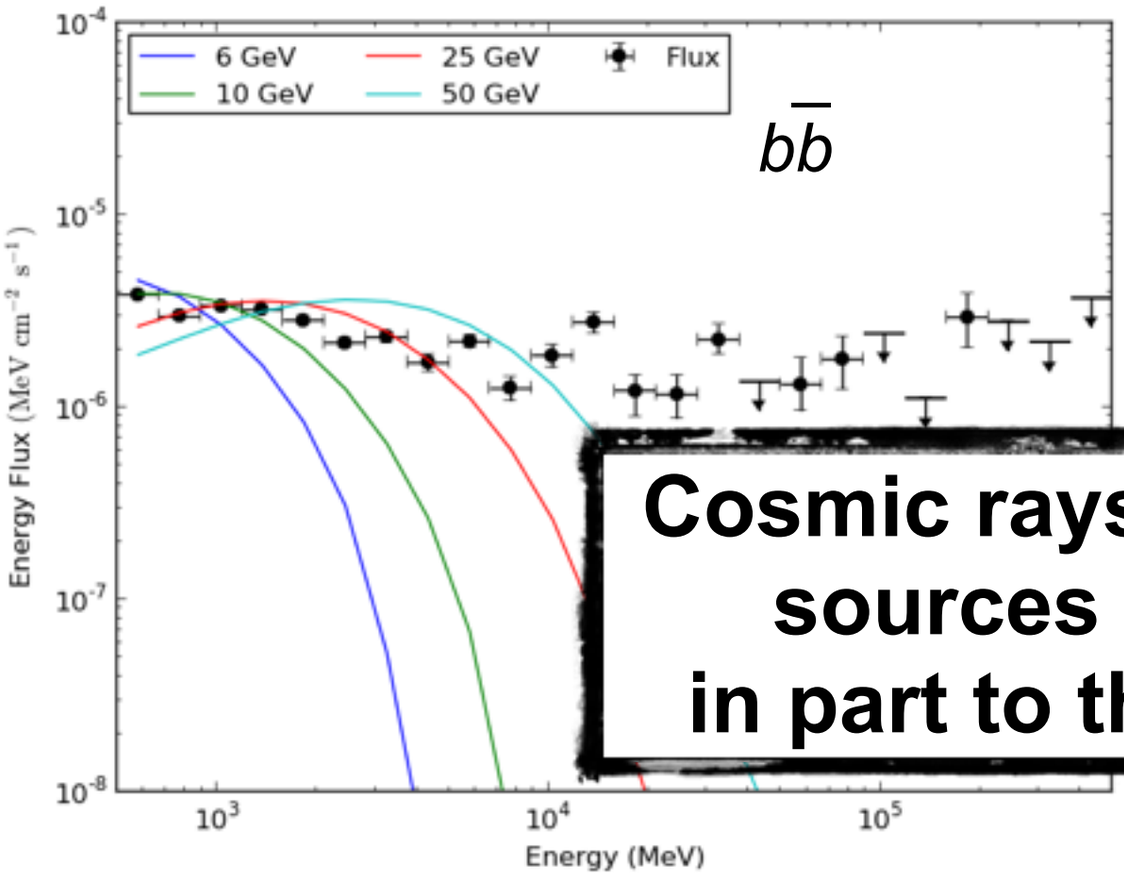

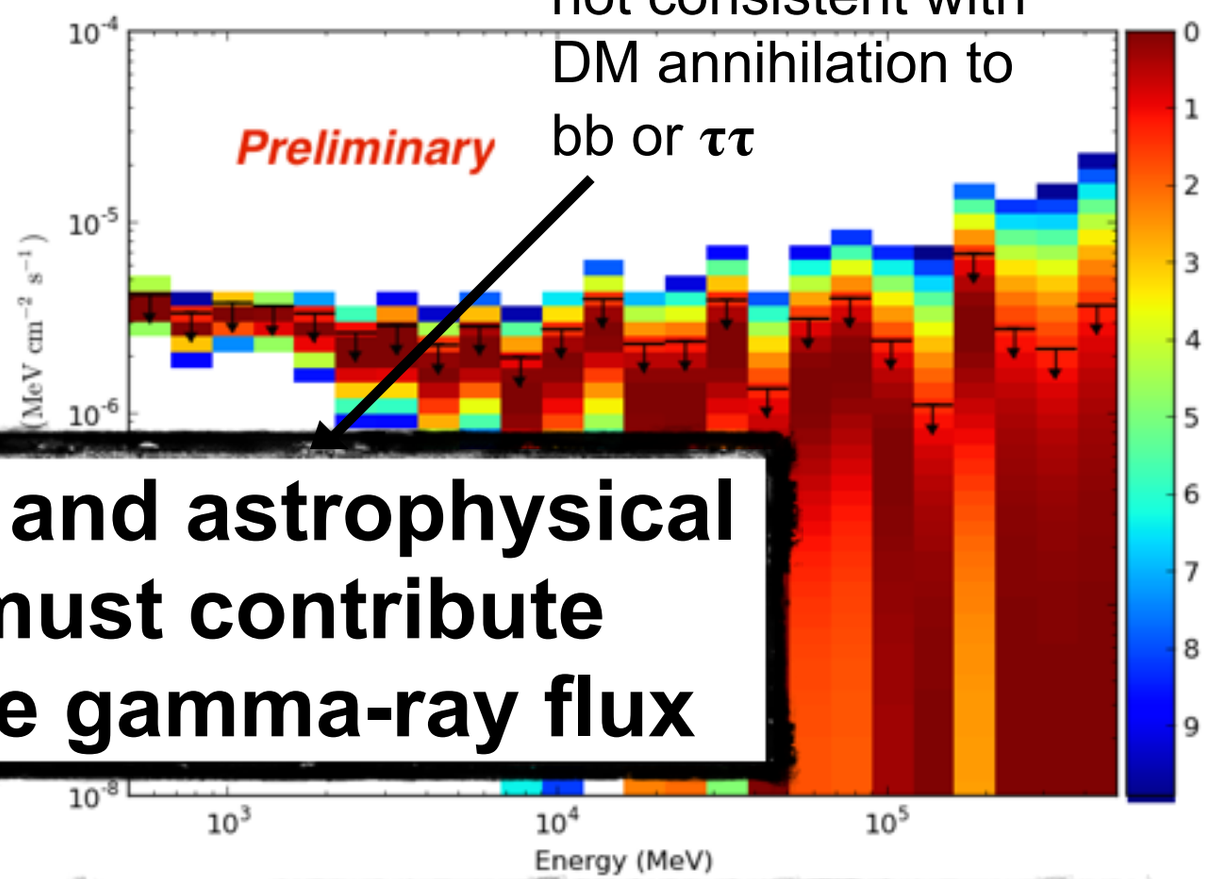

Shape of excess not consistent with DM annihilation to bb or $\tau\tau$

Cosmic rays and astrophysical sources must contribute in part to the gamma-ray flux

All gamma-rays from SMC are *not* from DM annihilation (excluded by dsphs)

	bb	$\tau\tau$
6 GeV:	2.4×10^{-25} cm^3/s,	3.0×10^{-25} cm^3/s
10 GeV:	3.3×10^{-25} cm^3/s,	5.2×10^{-25} cm^3/s
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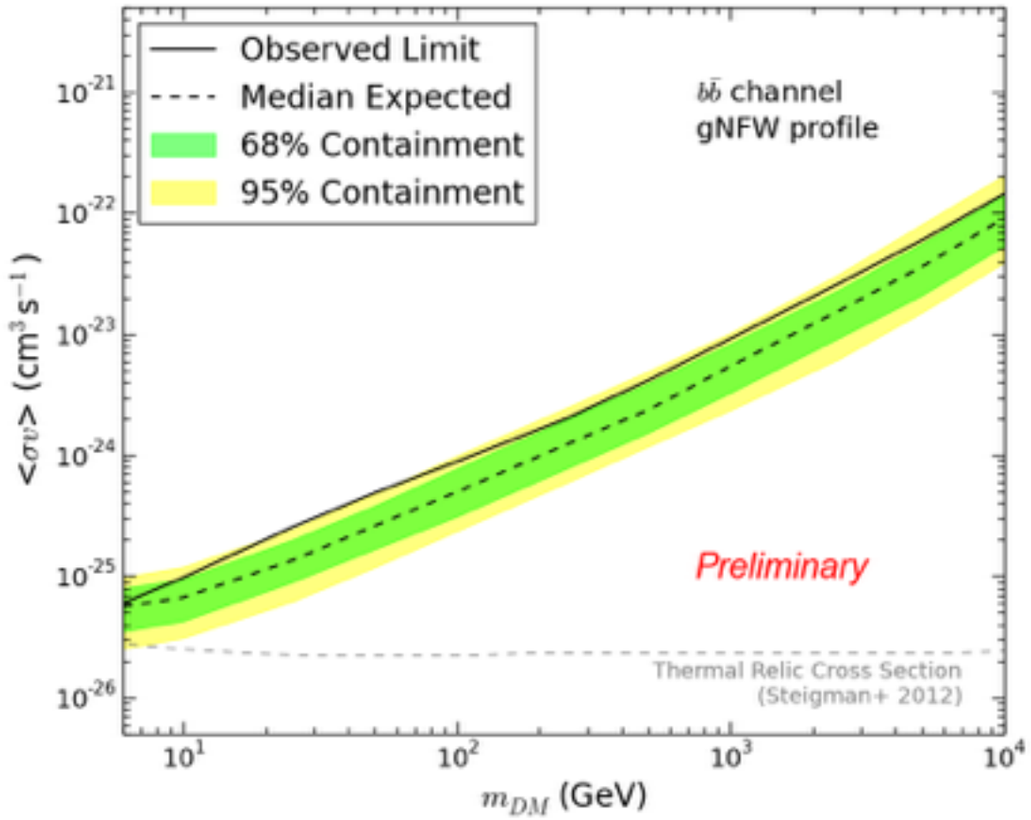
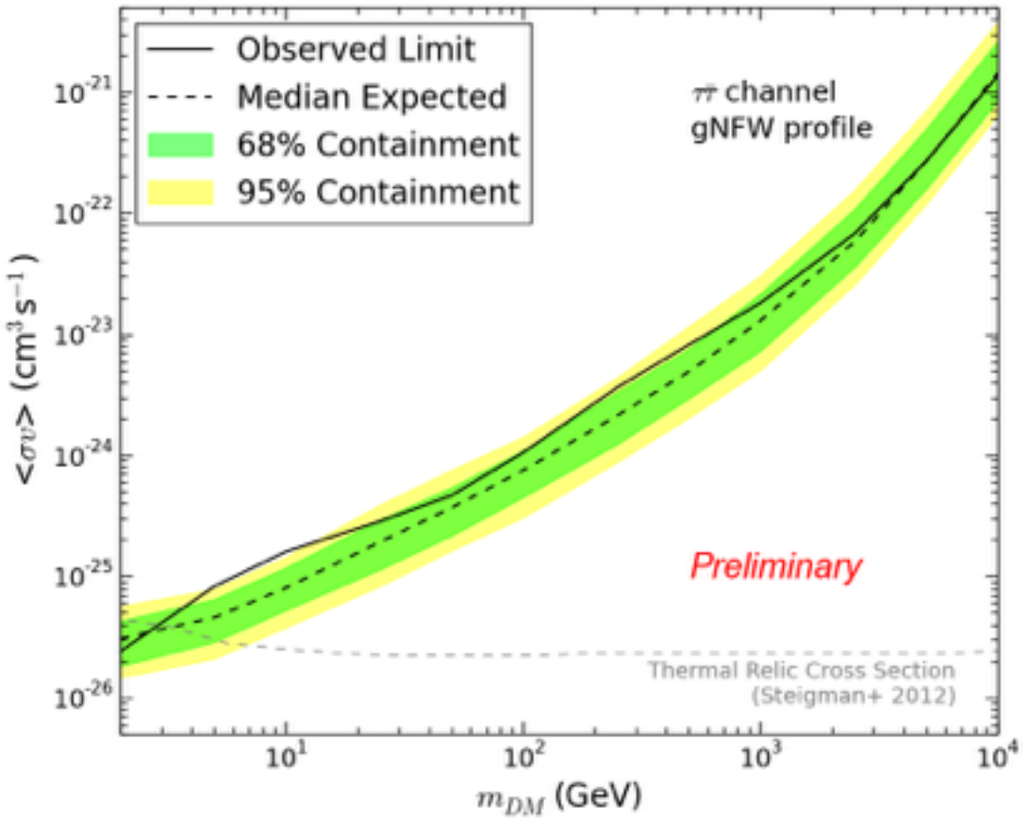
Part IV: Results

- **95% CL upper limits assuming a generalized NFW (gNFW) - best fit**
  - **bands from 100 MC trials**
  - **thermal relic shown is from Steigman *et. al* (2012)**





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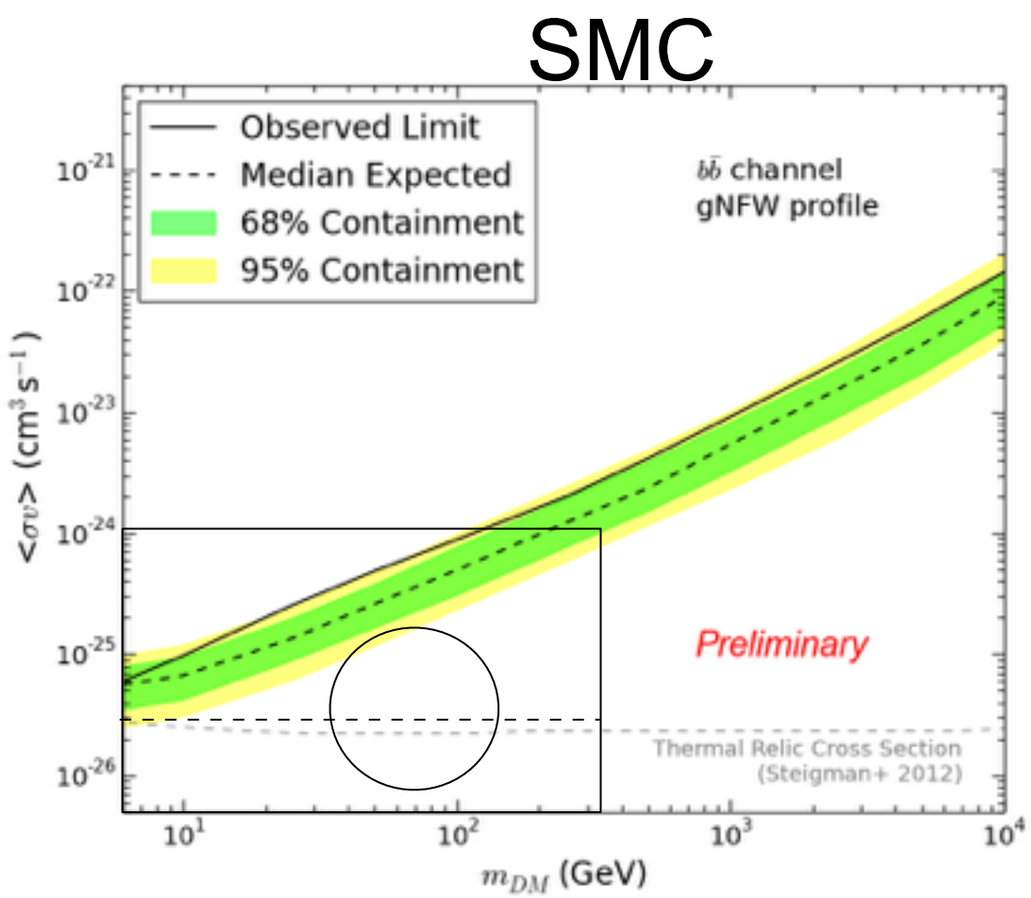

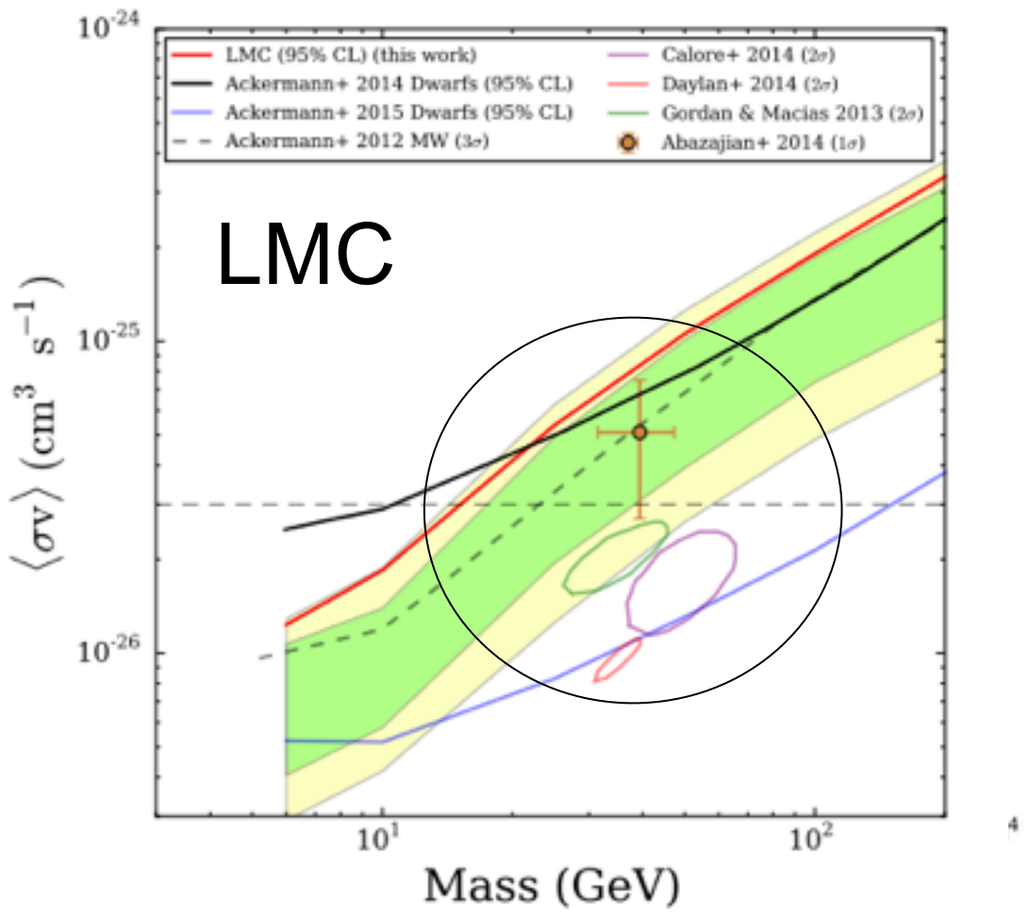

*** M. R. Buckley *et. al*, Phys. Rev. D 91, 102001 (2015) arXiv:1502.01020 [astro-ph.HE]**

Part IV: Results

- 95% CL upper limits assuming a standard NFW
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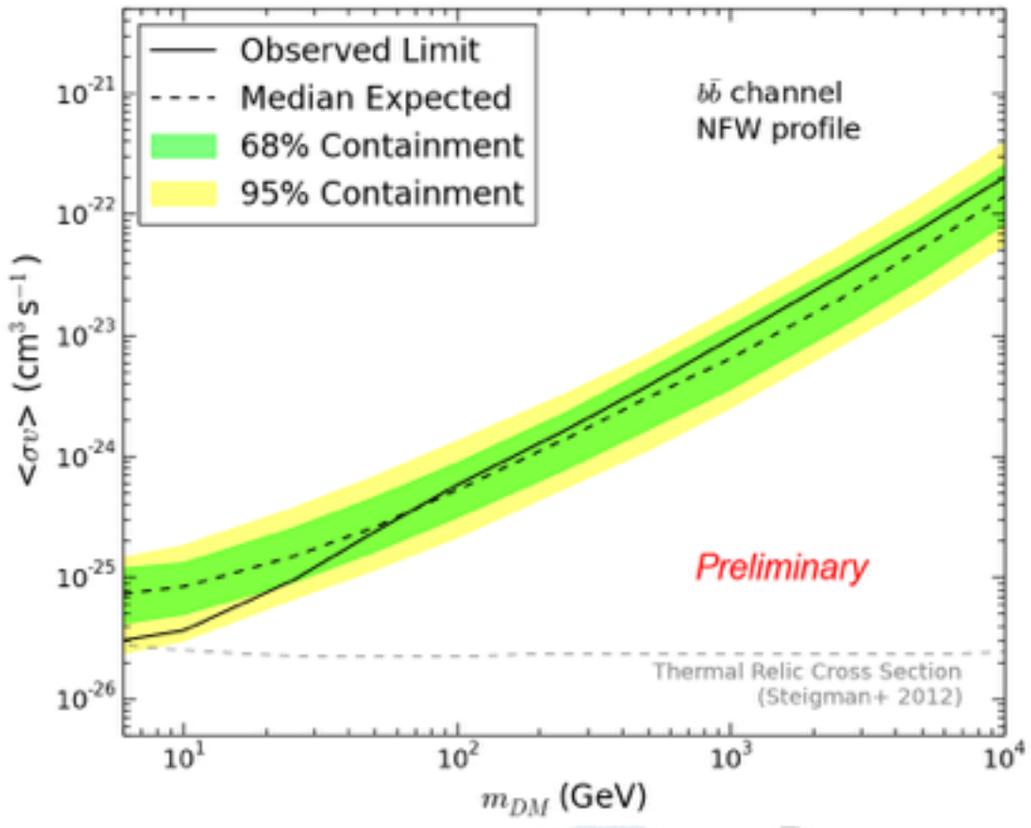

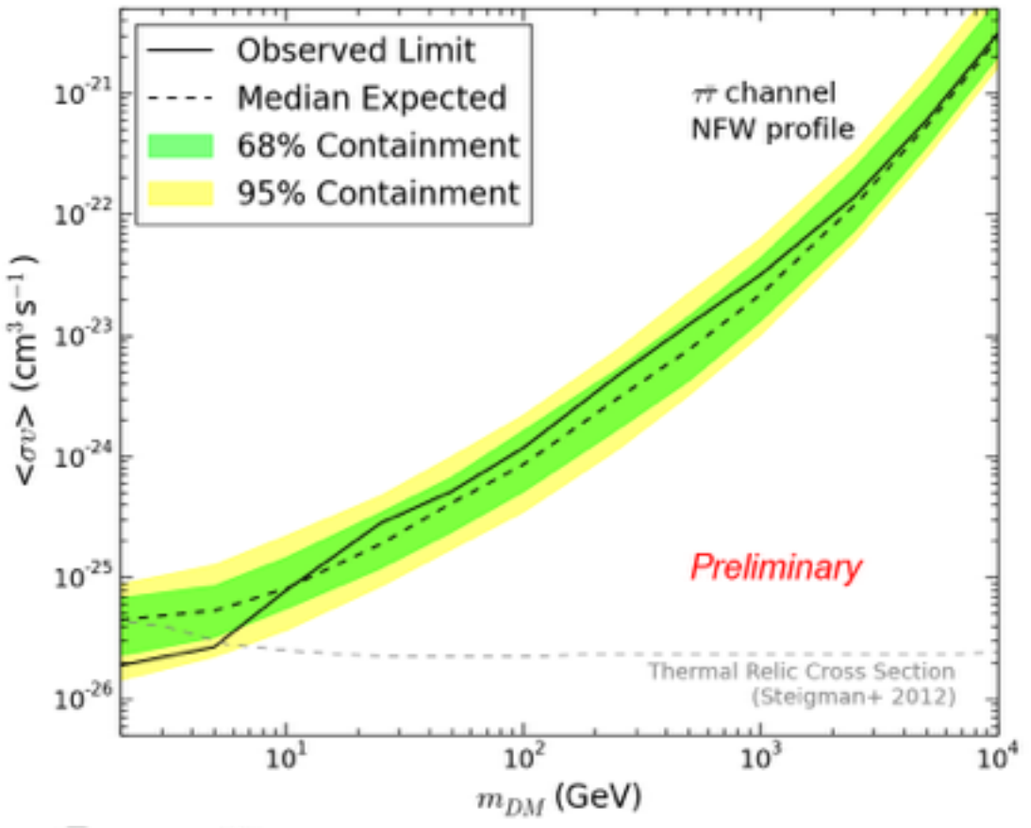

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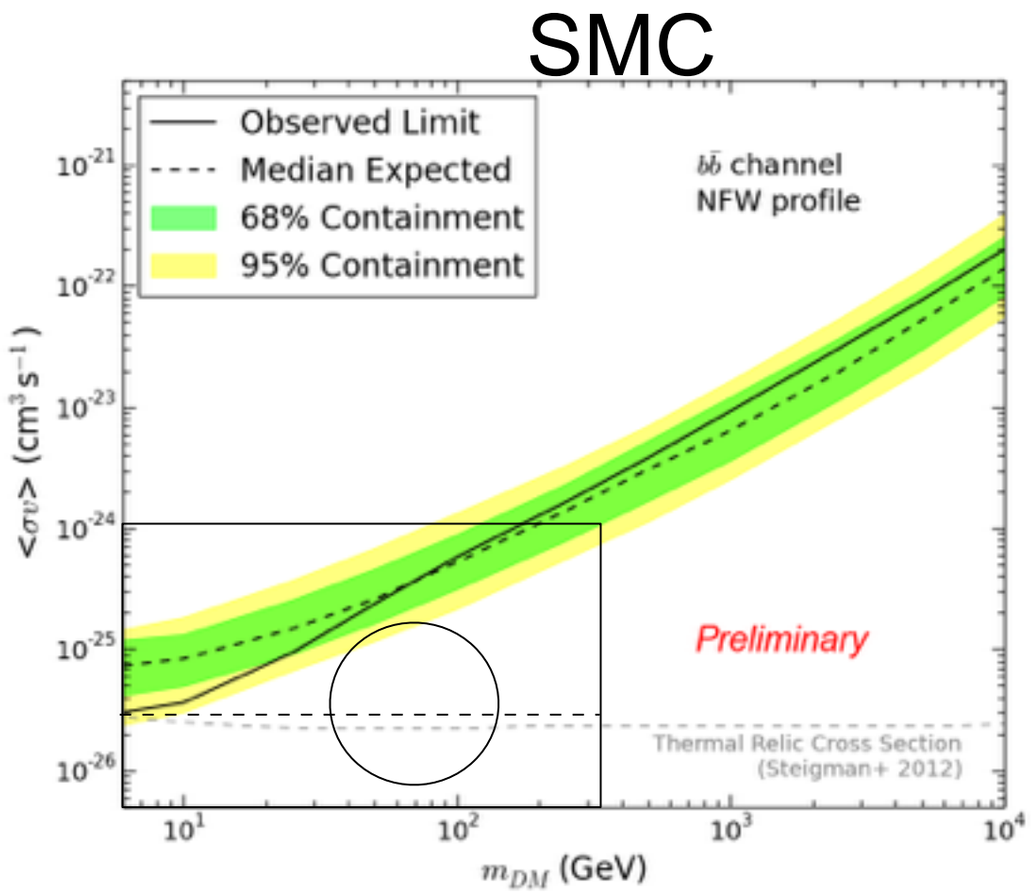
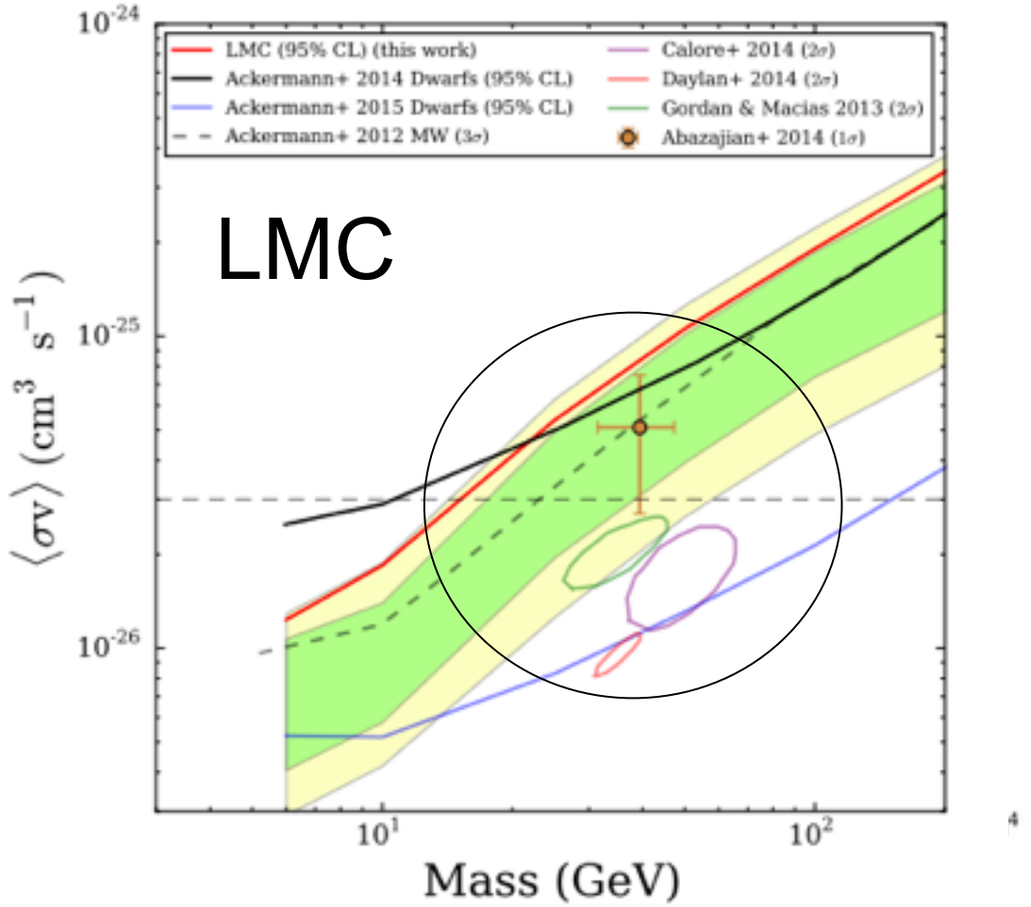




*** M. R. Buckley *et. al*, Phys. Rev. D 91, 102001 (2015) arXiv:1502.01020 [astro-ph.HE]**

Part V: Discussion and Conclusions

- **SMC is a complementary target to search for dark matter**
  - **Contains a large amount of dark matter: Rotation curve, N-body simulations**
  - **Annihilation signal larger than the brightest dwarfs (less than GC and LMC)**
  - **Lower astrophysical background than GC and LMC (higher than dwarfs)**

- **Astrophysics in the SMC**
  - **Physical Emissivity model**
  - **bonus: found a new point source**

- **Fermi-LAT analysis**
  - **6 years of data, >500 MeV**
  - **High correlation between SMC models and dark matter template**

Part V: Discussion and Conclusions

- **What we found**
  - **Background consistent with no-dark matter simulation**
  - **High correlation weakens limits**
  - **No evidence of dark matter annihilation**
  - **$\langle\sigma v\rangle$ limits near the thermal relic**

- **Where we can improve**
  - **Better models of both the dark matter template and the baryonic background**
  - **More accurate simulations of the Magellanic system**
    - **results of stellar surveys (HST)**
  - **Cosmic-ray propagation in the SMC**

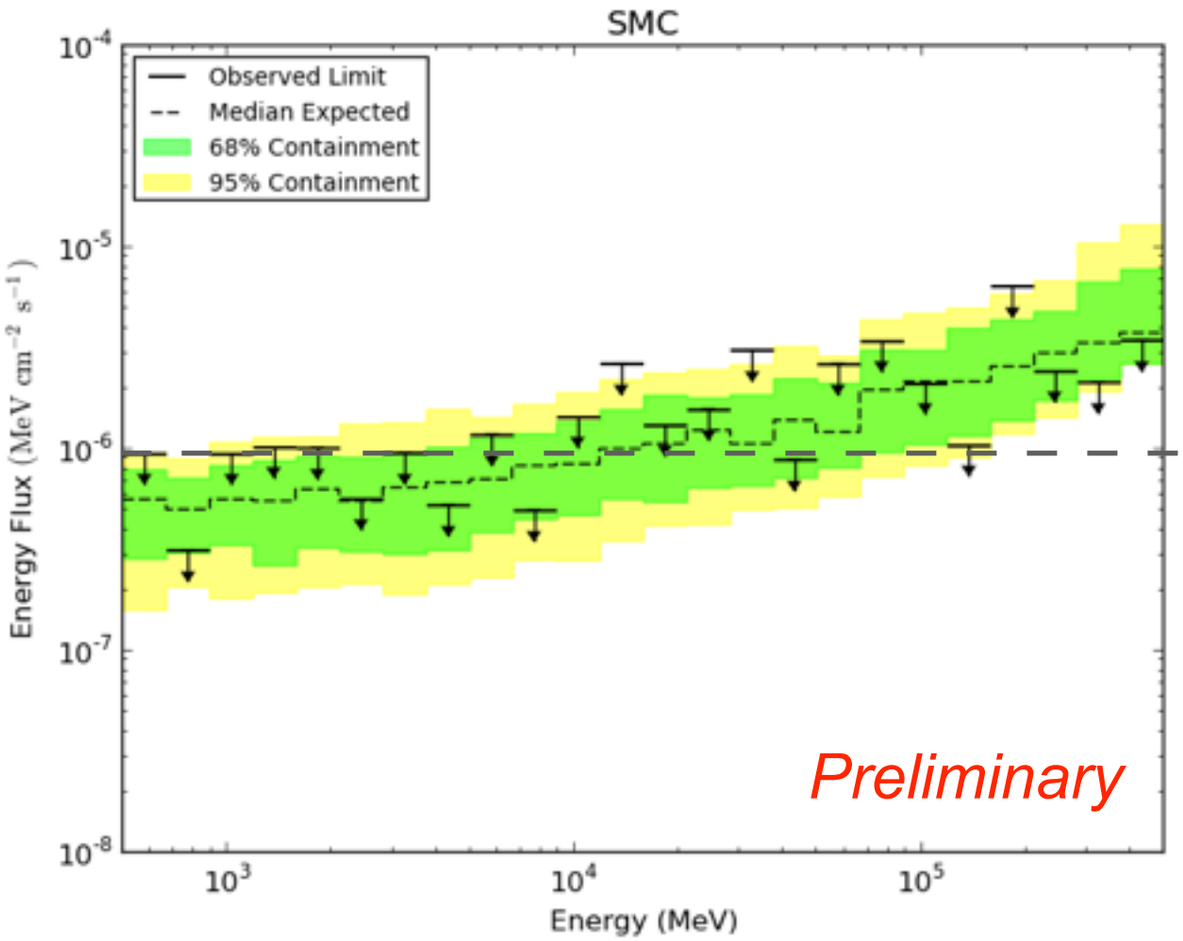
- **The LMC/SMC System is an important target for indirect dark matter searches**

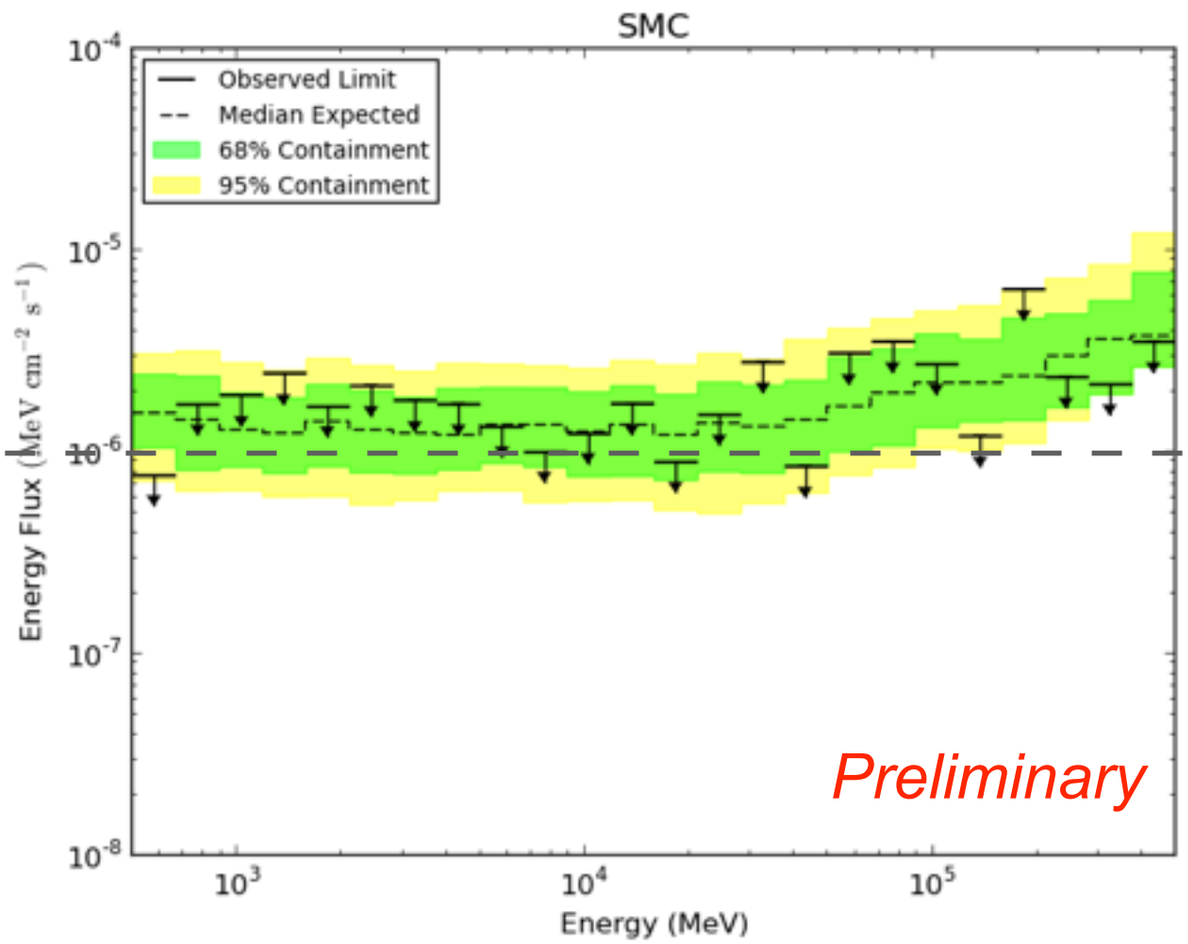
Thank you!

¡Backups!

Correlations

- **With and without letting the SMC/Iso Diffuse float in $10\sigma_{stat}$ within bin-by-bin fit**





Generated SMC Flux Upper Limits

Bands from 100 MC trials

Part III: The Fermi-LAT Analysis

- b_{eff} Study
  - beff~actual background
  - insight into correlation i.e.: Σ ~1: completely degenerate

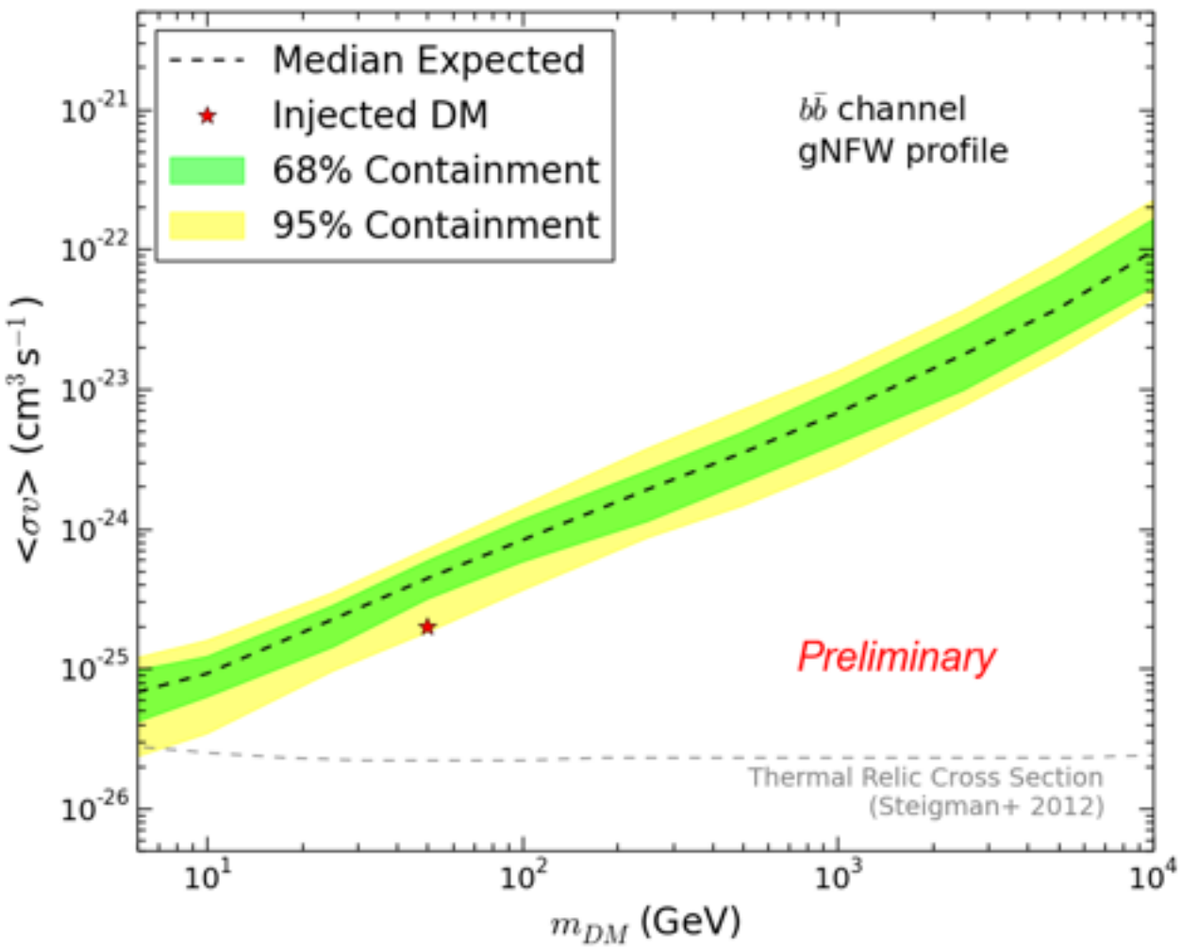
$$b_{\mathrm{eff}} = \frac{N}{\sum_k \frac{P^2_{\mathrm{sig,k}}(\mu)}{P_{\mathrm{bkg,k}}(\theta)} - 1}$$

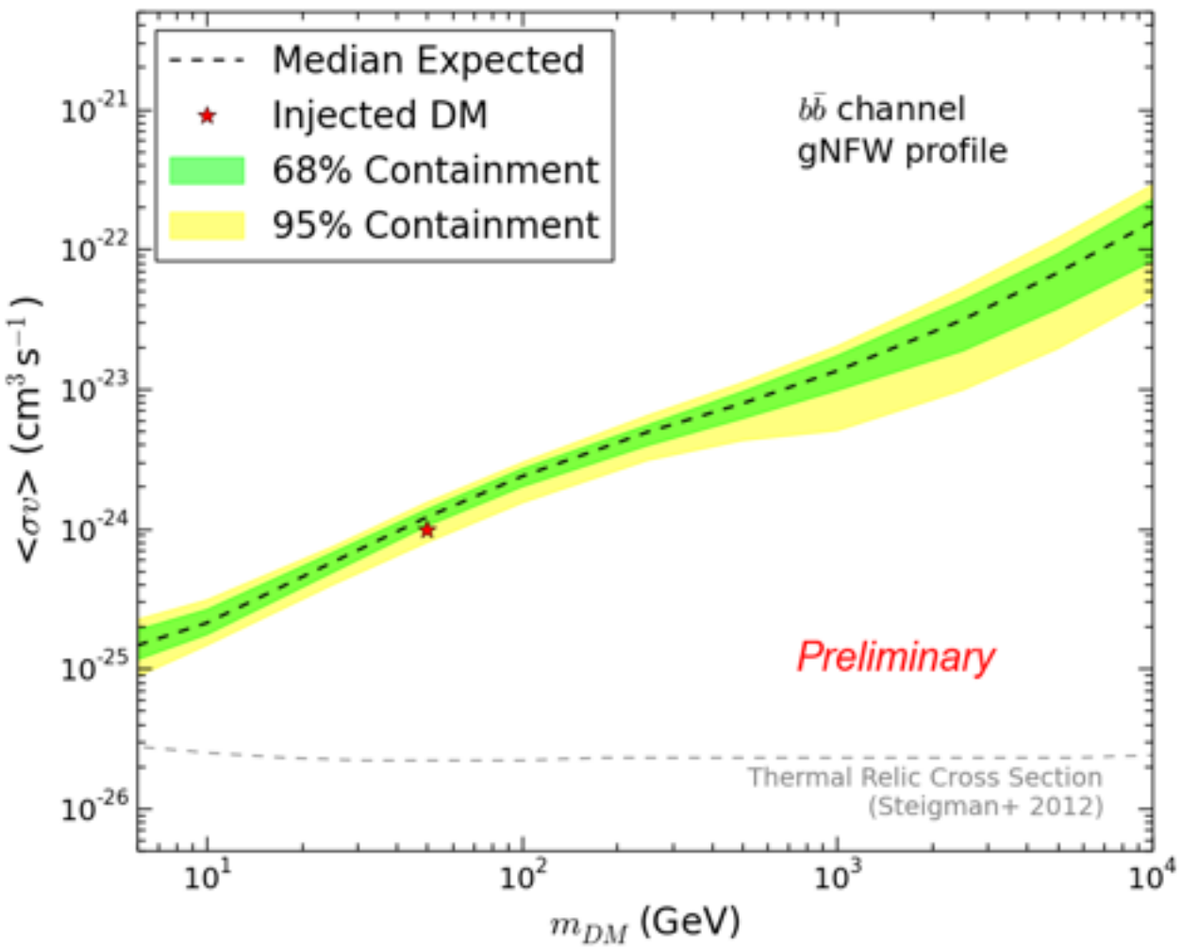
name	b_{eff}	Σ term
iso diff	5100	2.7
gal diff	6400	3.8
SMC	140	15
PS1	81.7	1.3
47 Tuc	0.0043	510000
J0021	0.02	44000
SMC+iso	21600	1.5
Total	25300	2.25

sum of sources: 32000

Part III: The Fermi-LAT Analysis

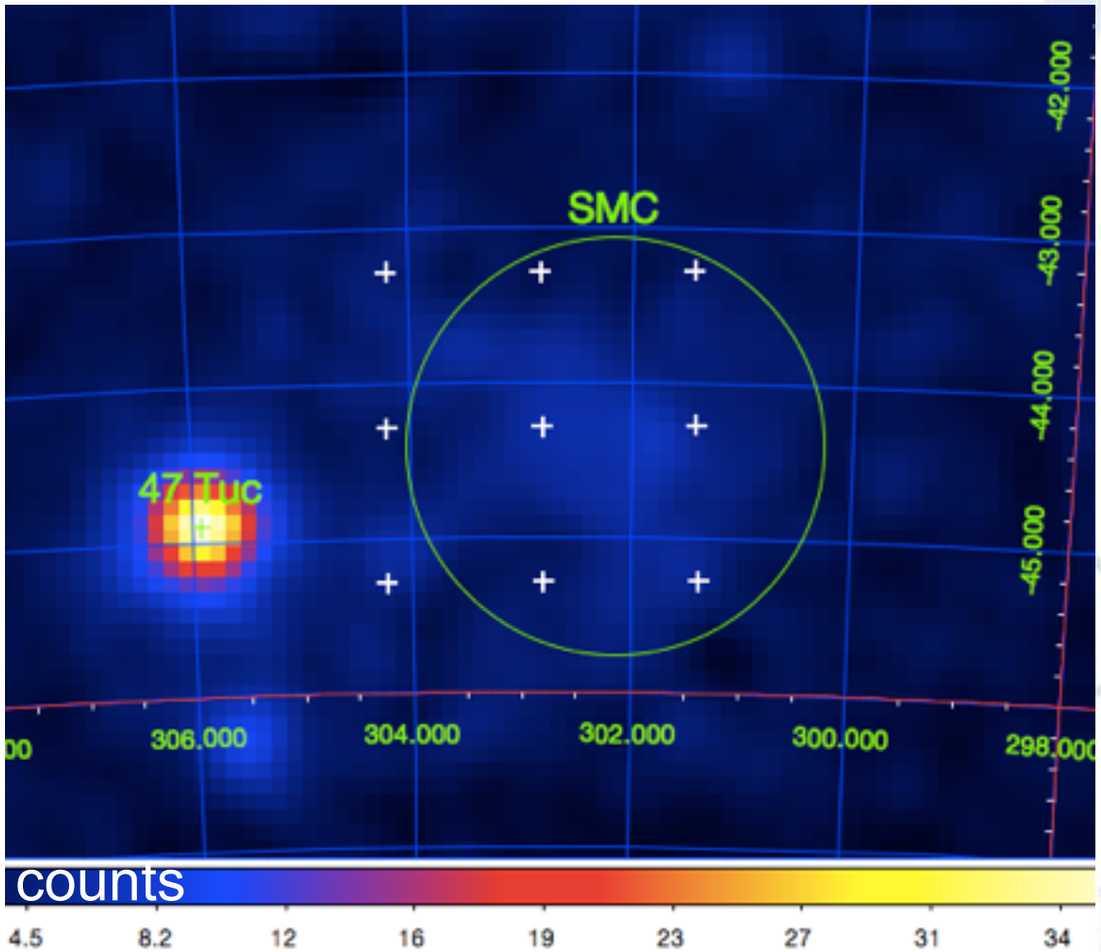
- **Coverage Study**
  - **injected 50 GeV $b\bar{b}$ DM @ $\langle\sigma v\rangle = 2\times10^{-25}$ (1×10^{-24}) cm^3/s**
  - **limits don't exclude injected DM**



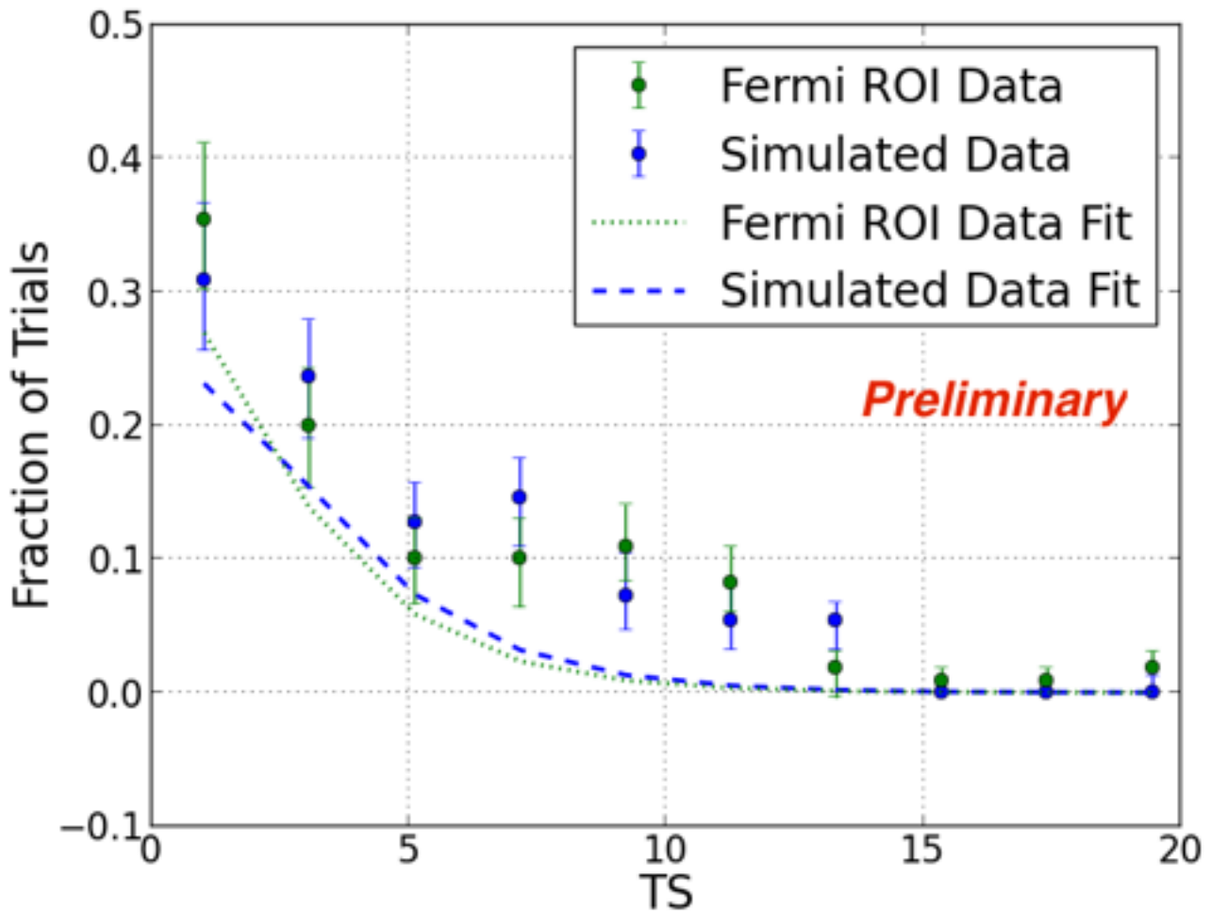


Part III: The Fermi-LAT Analysis

Understanding the background…



Scan the region around the SMC kinematic center with DM template



TS follows a χ^2 distribution with 1 d.o.f.
Small TS excess occurs at points near 47 Tuc

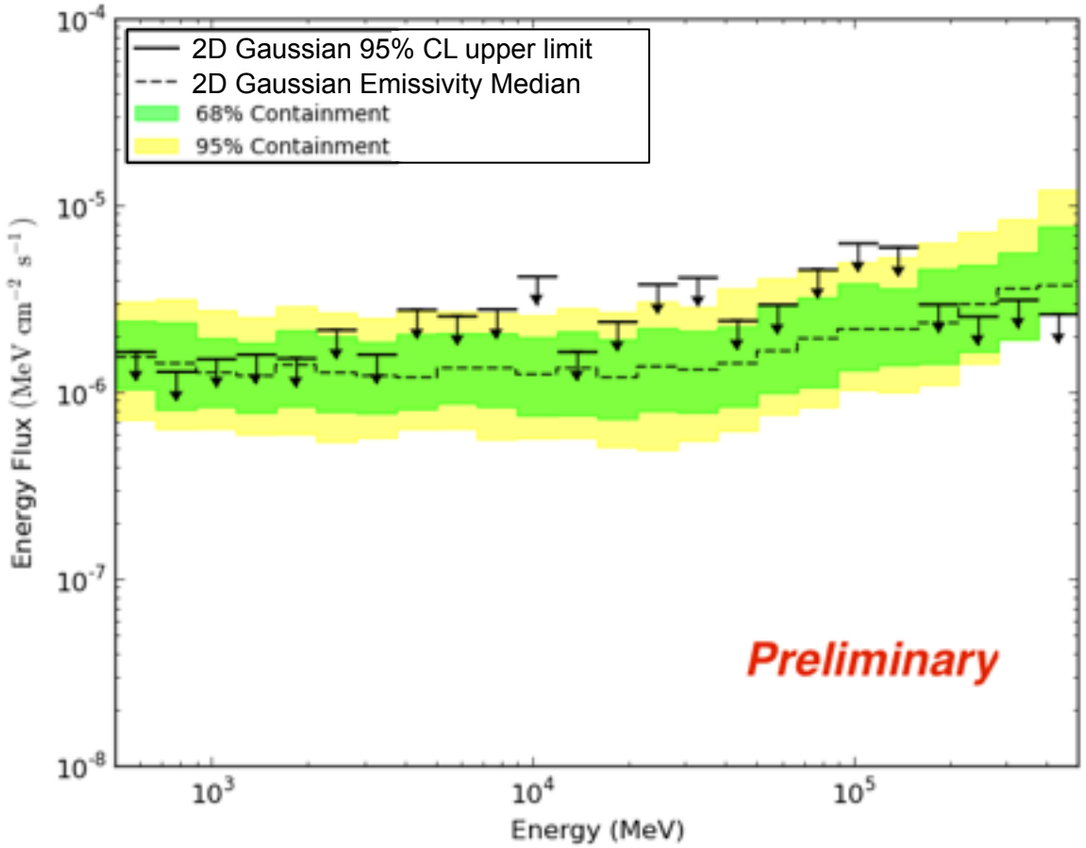
Part III: The Fermi-LAT Analysis

- **Alternative models of the SMC**
  - **Perform same analysis to determine flux upper limits**

- **MC only study**
  - **2D Gaussian compared with the 2D Gaussian emissivity**

- **Flux upper limits**
  - **At or below 95% CL Emissivity band**

SMC 2D Model (MC) on Baseline SMC Model Bands



No SED Constrain

- **Limits assuming an gNFW - NO SED constrain**
  - **bands from 100 MC trials**