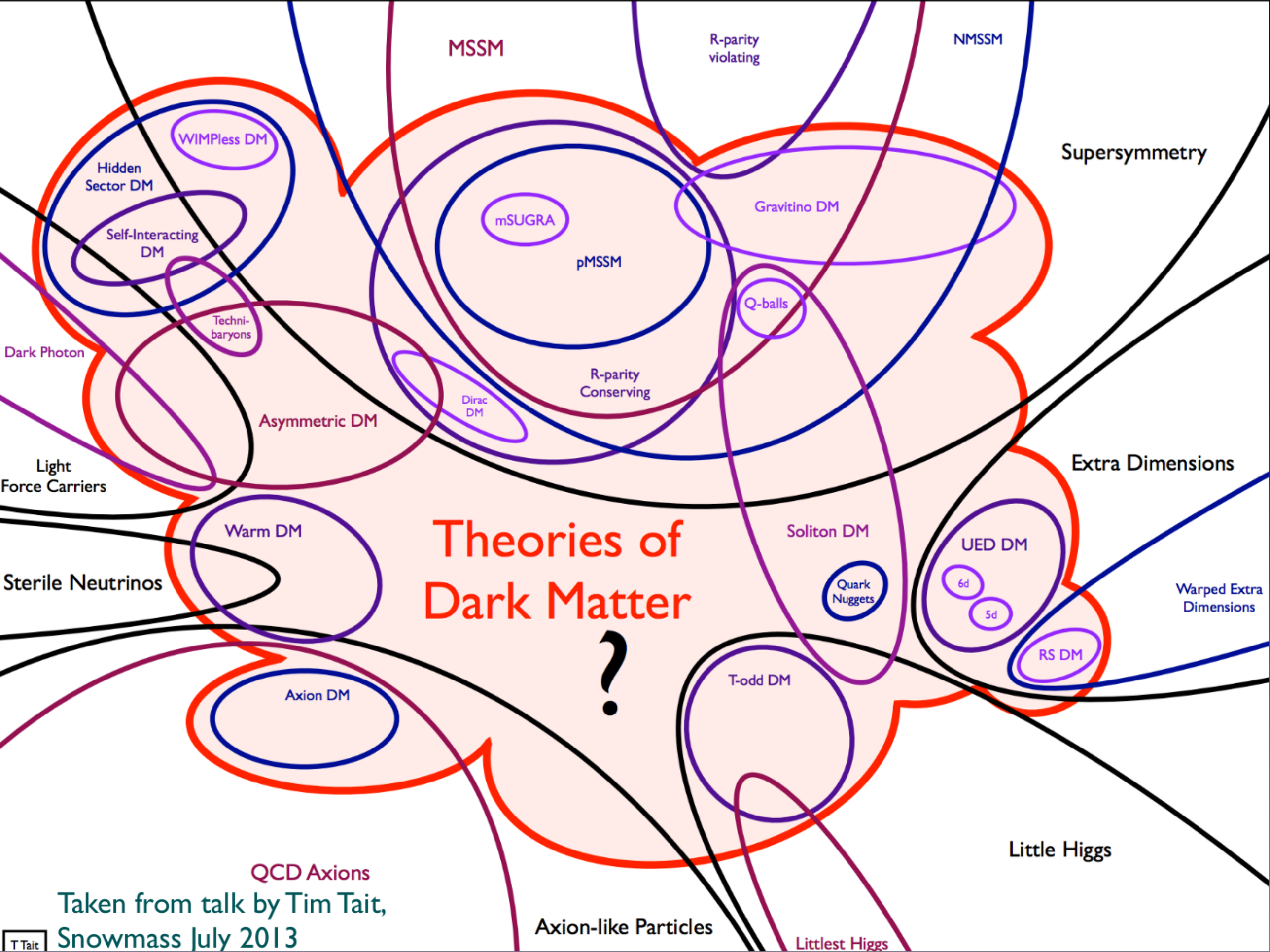
Strong constraints on thermal relic dark matter from Fermi-LAT observations of the Galactic Center

Ryan Keeley

16th Marcel Grossmann Meeting

July 09 2021

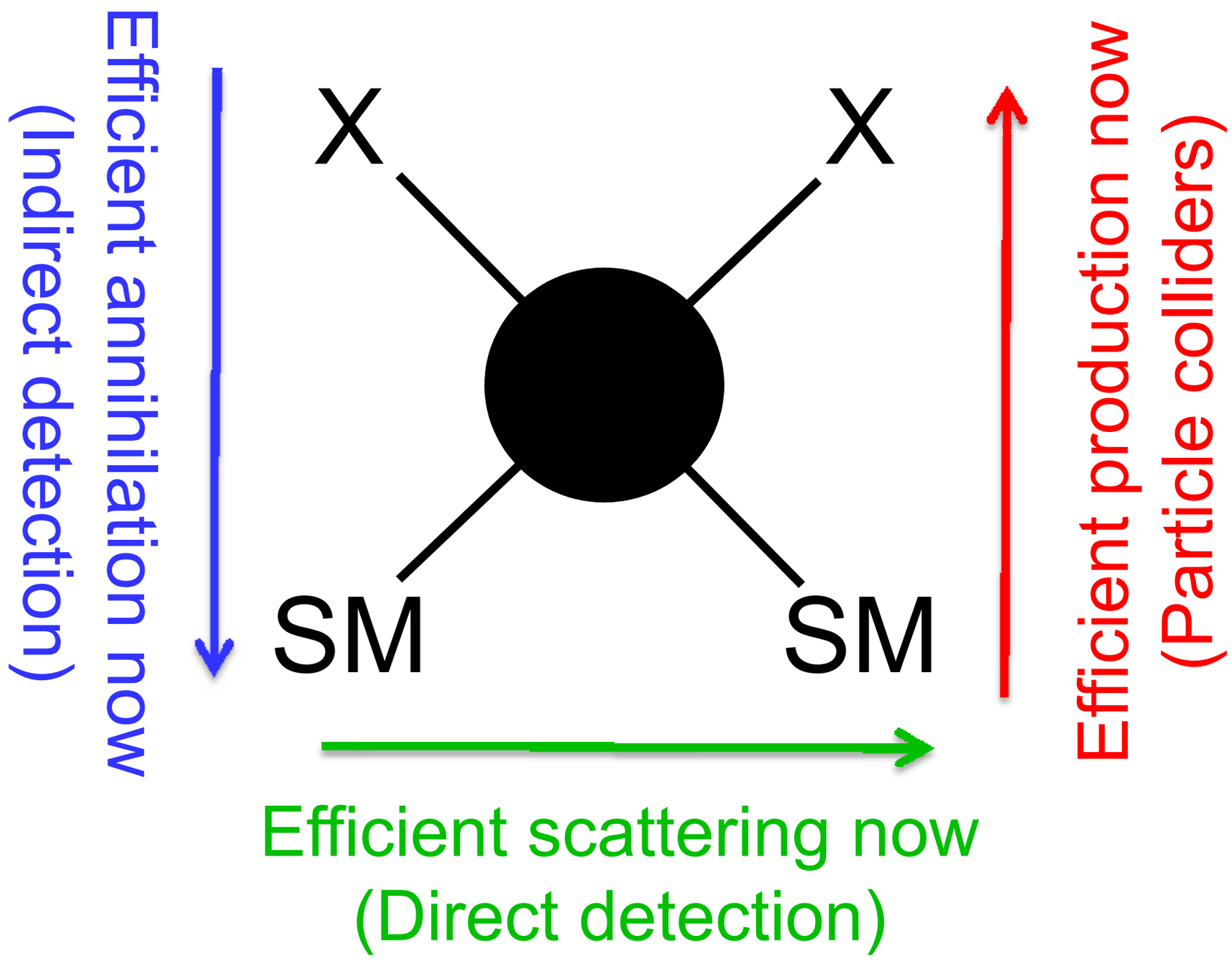
Cosmology Group at
Korea Astronomy and Space Science Institute



Taken from talk by Tim Tait, Snowmass July 2013

T Tait

Detection



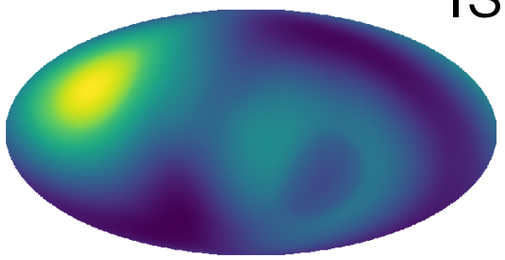
Jonathan Feng (2008)

Fermi Gamma-Ray Space Telescope

- Since 2008
- Covers the sky every 3 hours
- Giant calorimeter in space
- 20 MeV to 300 GeV

Galactic Center Review

Isotropic



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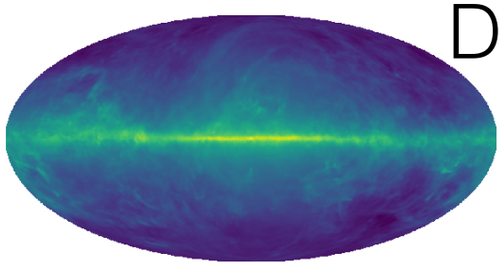
Diffuse: π0 + ICS



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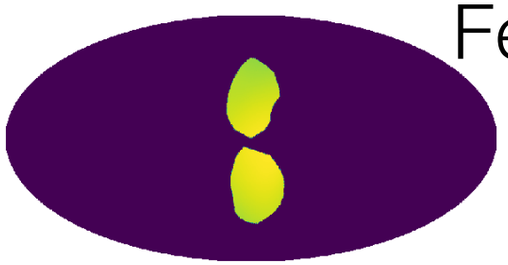
Fermi Bubbles



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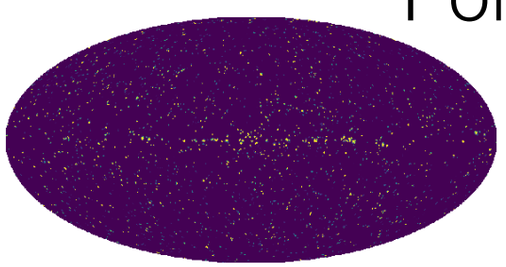
Point Sources



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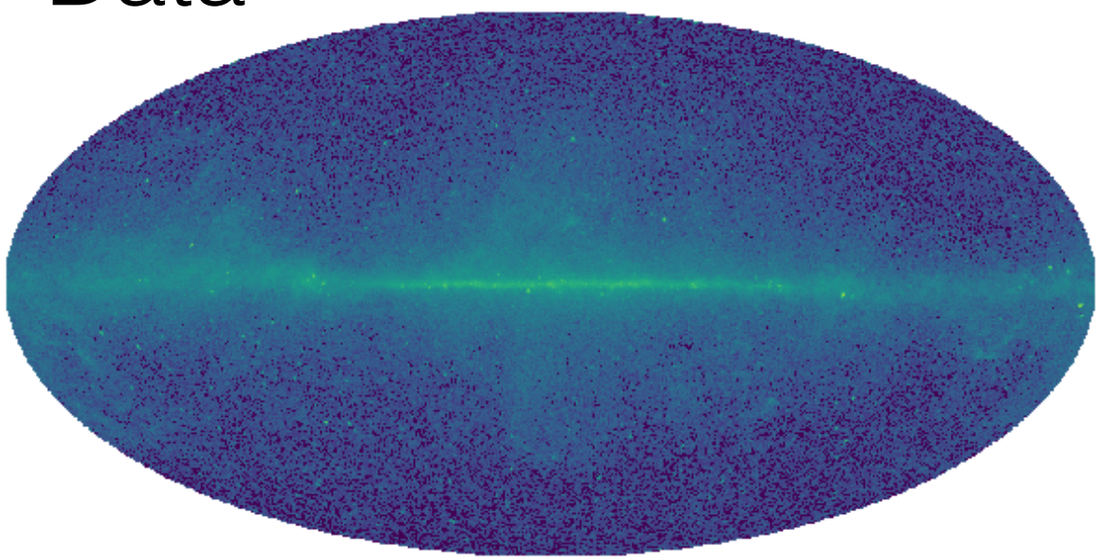
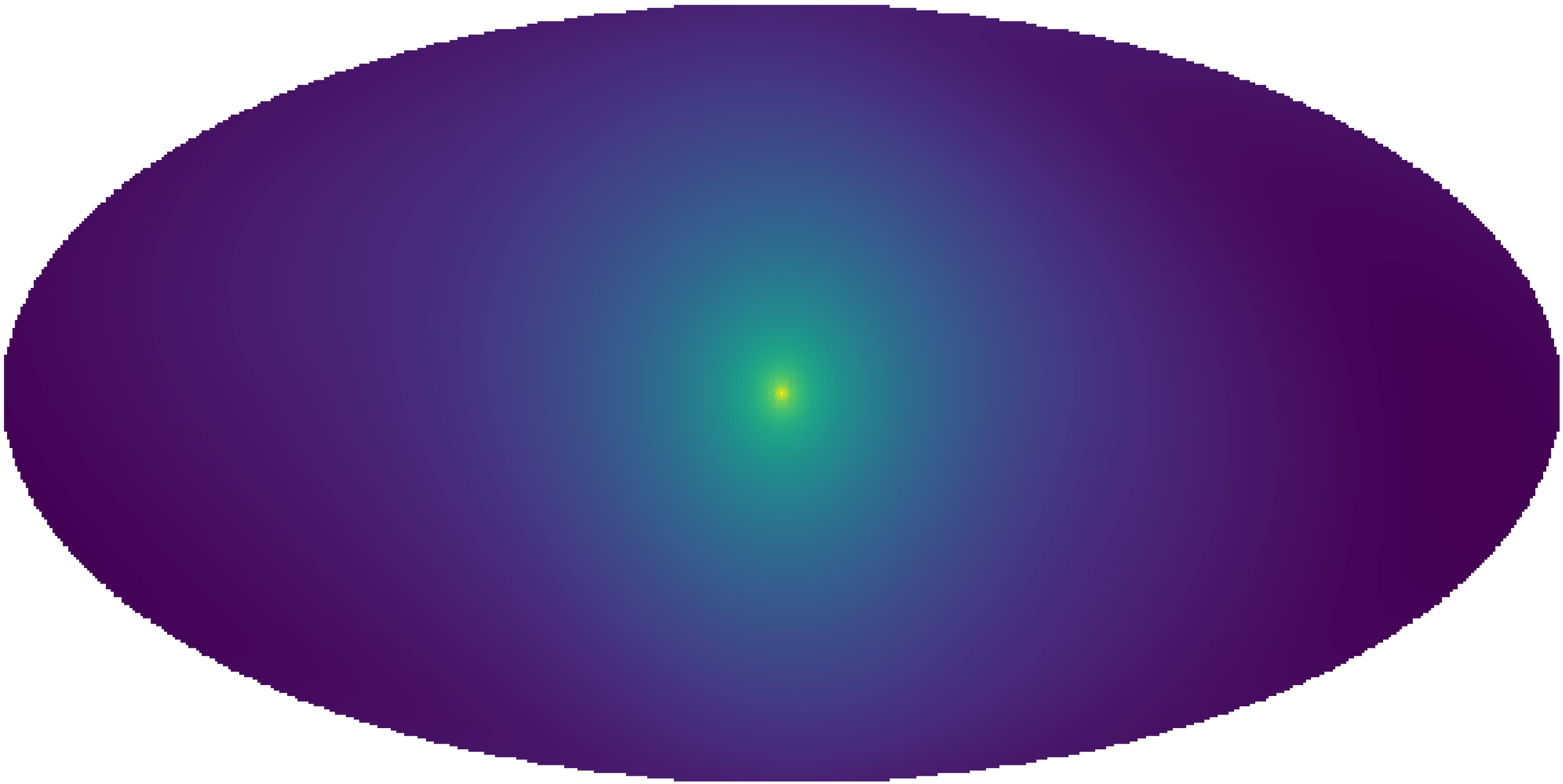
Data

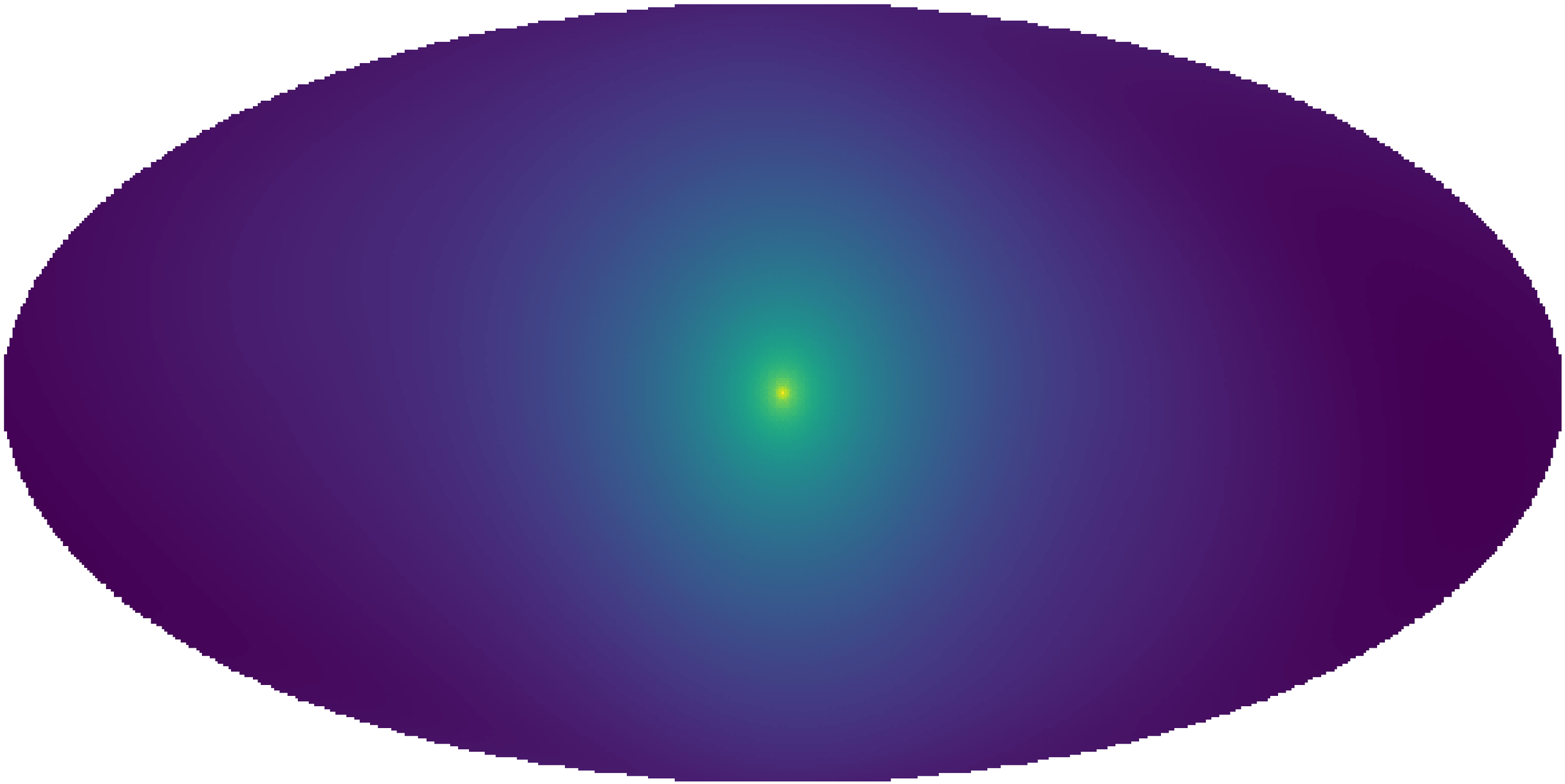


Galactic Center Excess



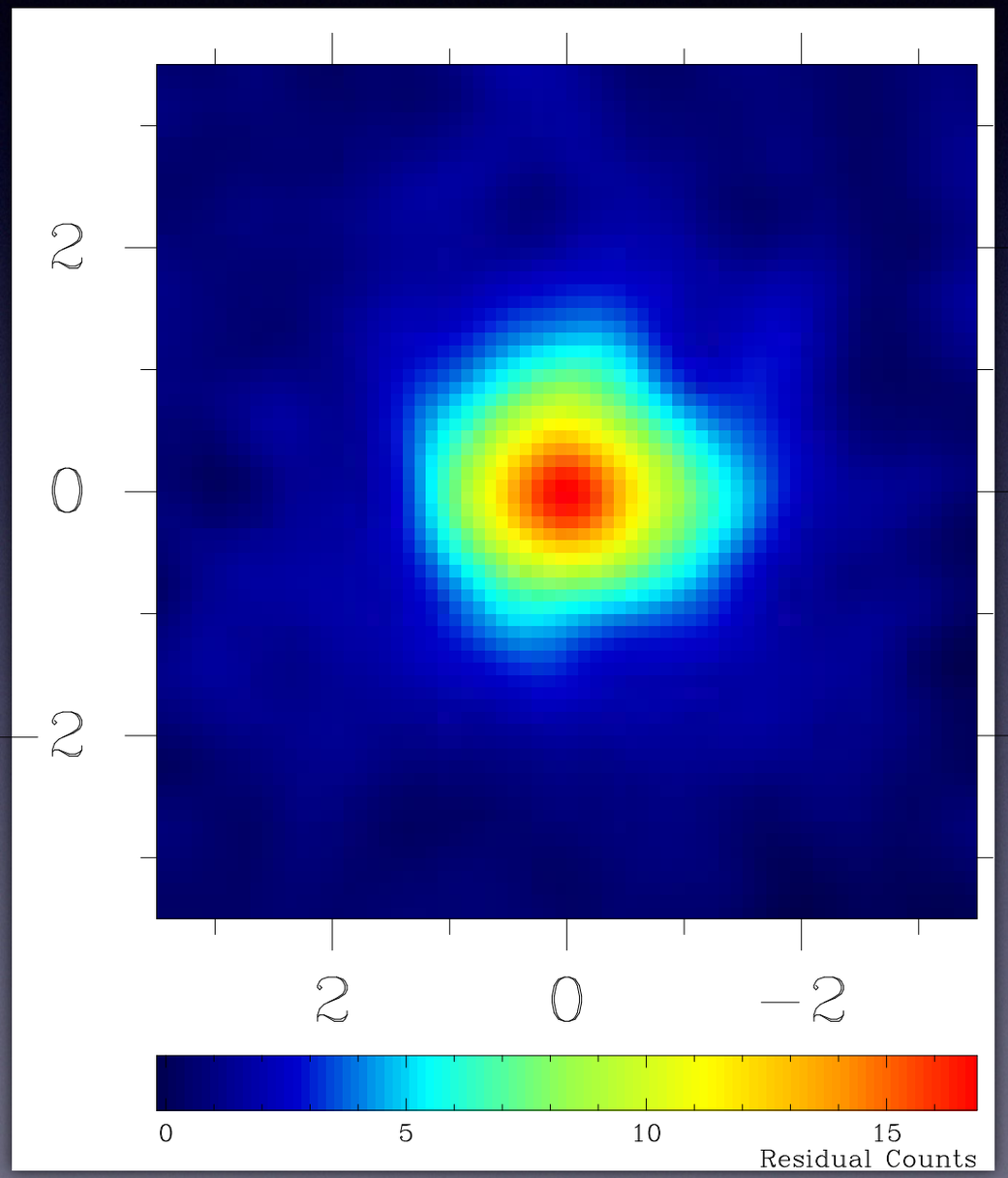
Galactic Center Excess

DM Annihilation?



DM Interpretation

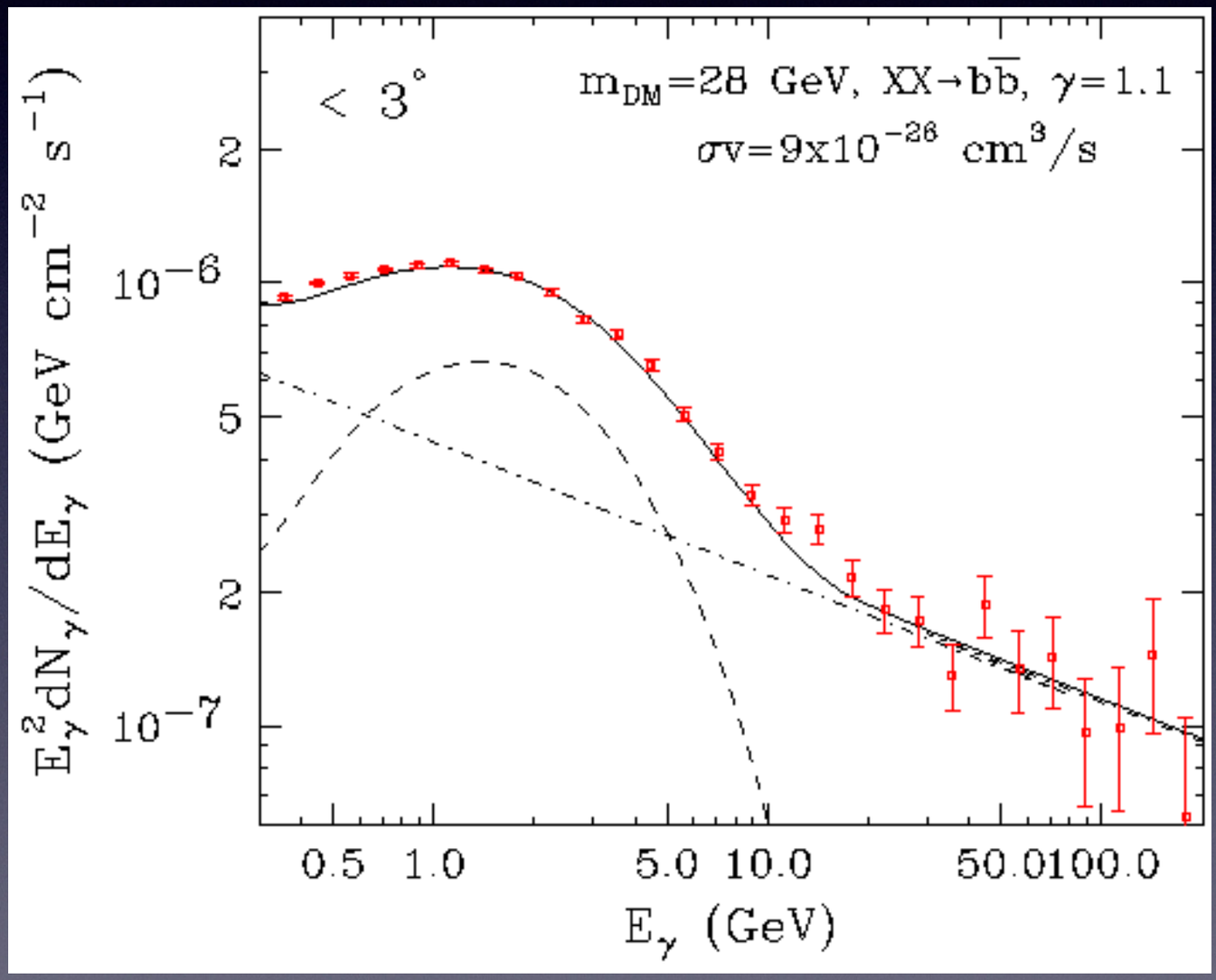
- 3 lines of evidence
- Roughly spherically symmetric / NFW-gamma~1.2



Abazajian & Kaplinghat 2012

DM Interpretation

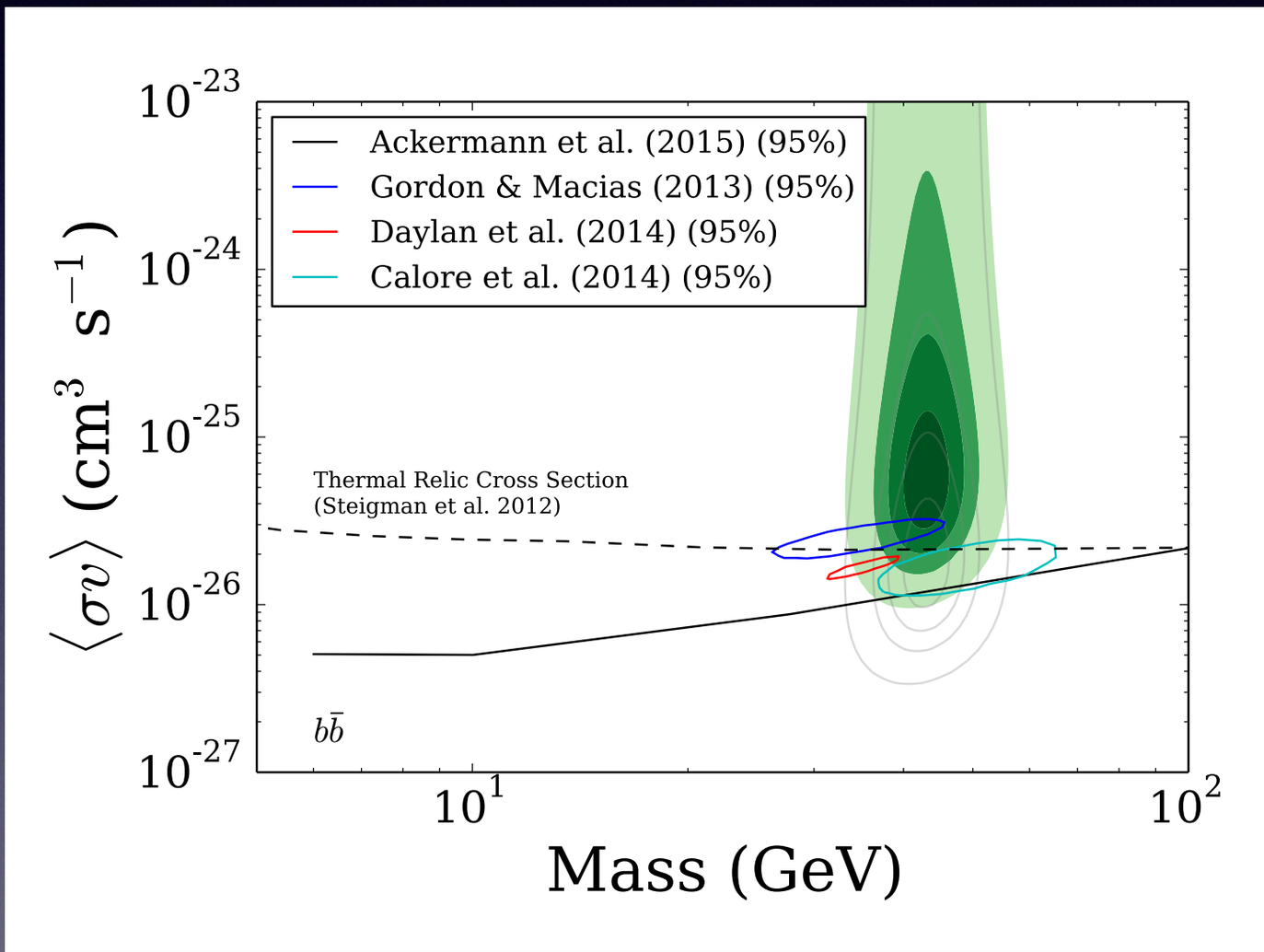
- 3 lines of evidence
- Roughly spherically symmetric / NFW-gamma~1.2
- Peaks at a few GeV (Annihilating WIMP of 10s to 100s GeV)



Goodenough and Hooper 2009

DM Interpretation

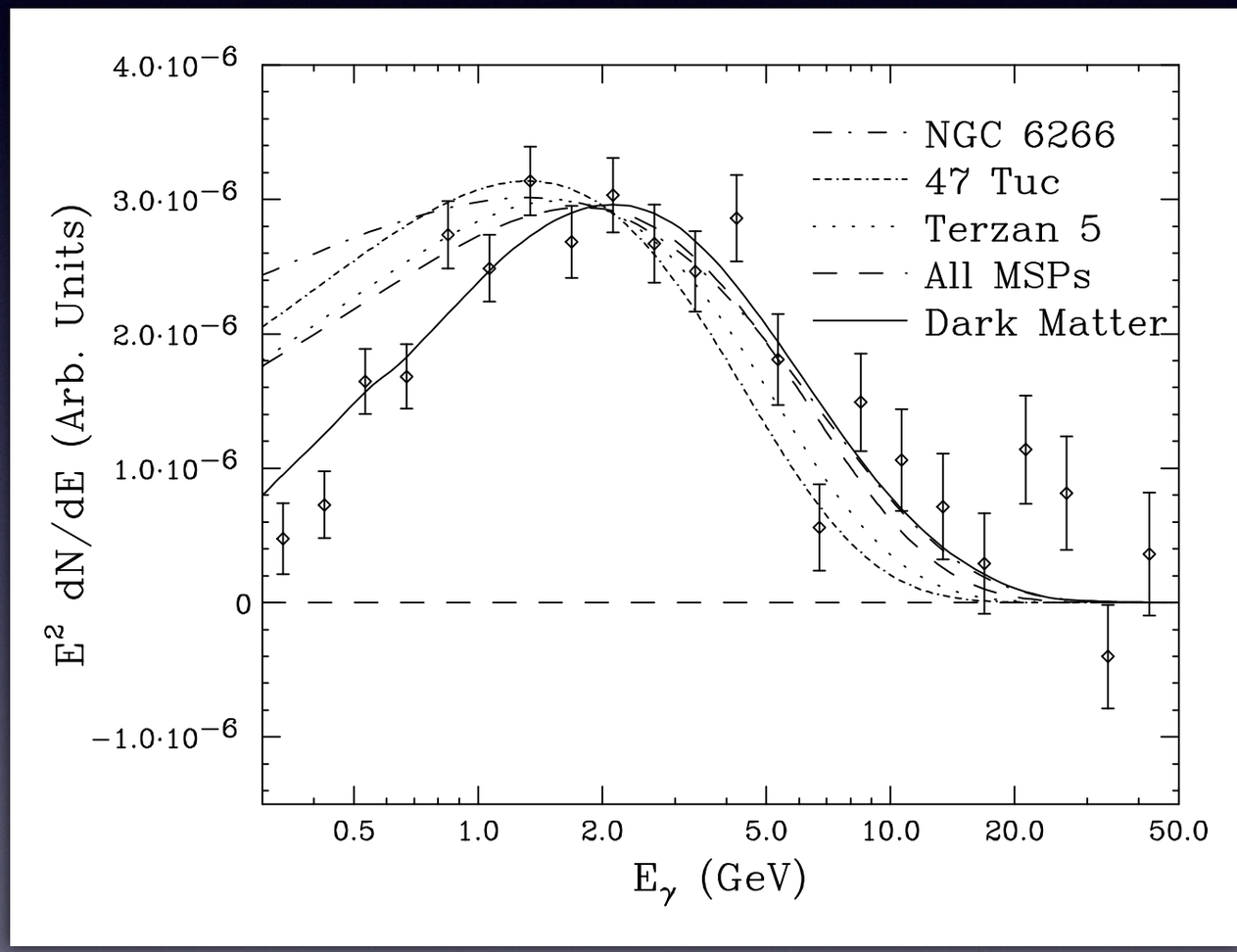
- 3 lines of evidence
- Roughly spherically symmetric / NFW-gamma~1.2
- Peaks at a few GeV
- Right flux for thermal cross section



Abazajian and Keeley 2015

Alternative Explanation:
Pulsars

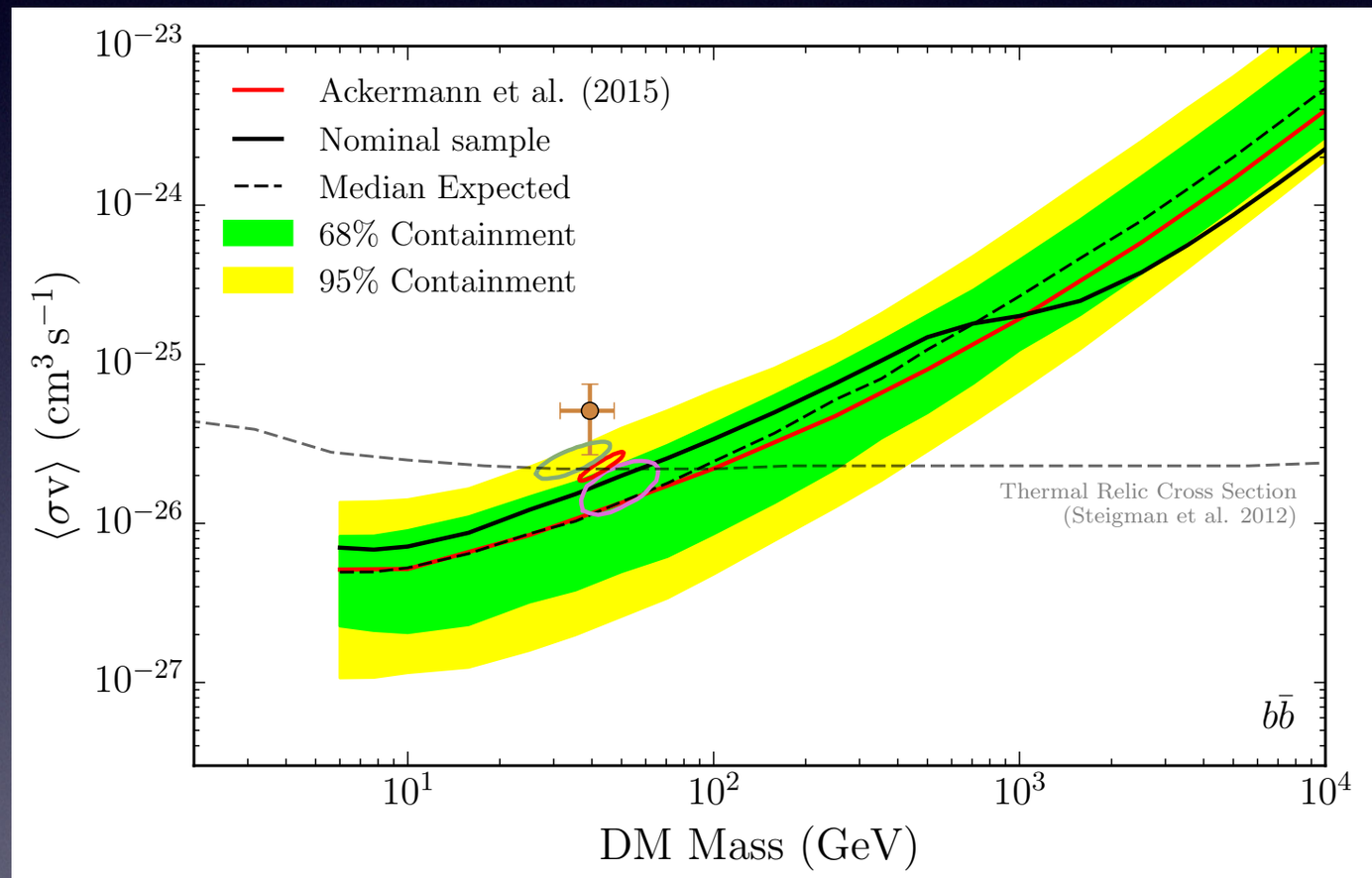
- However,
- Even before GCE was seen, known that pulsars could be confused for a DM signal.
- WIMPs and pulsars have similar spectra



Daylan et al 2014

Pulsar Interpretation

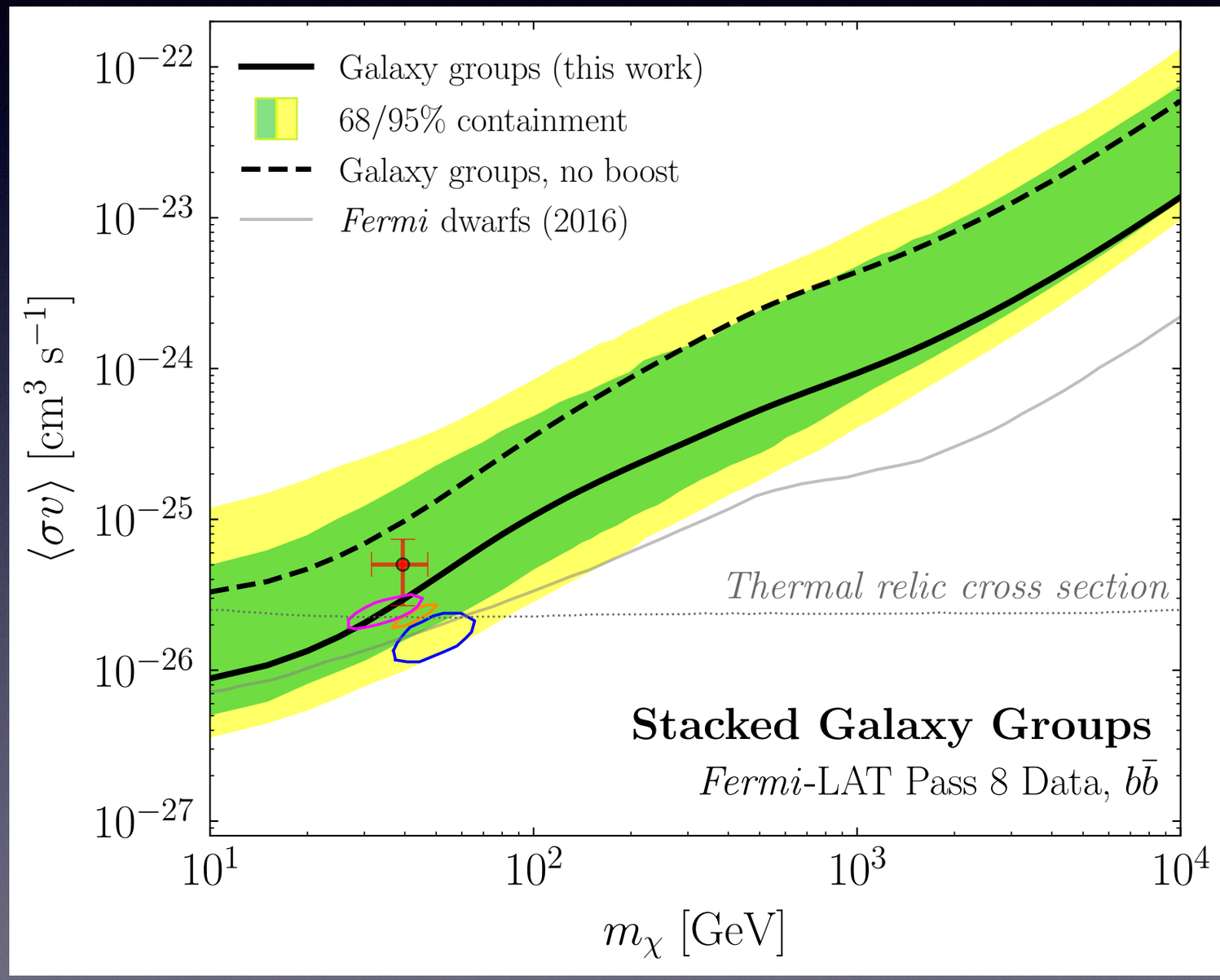
- No signal in the MW dwarfs
- Rules out GCE parameter space



Albert et al 2017, Keeley et al 2017

Pulsar Interpretation

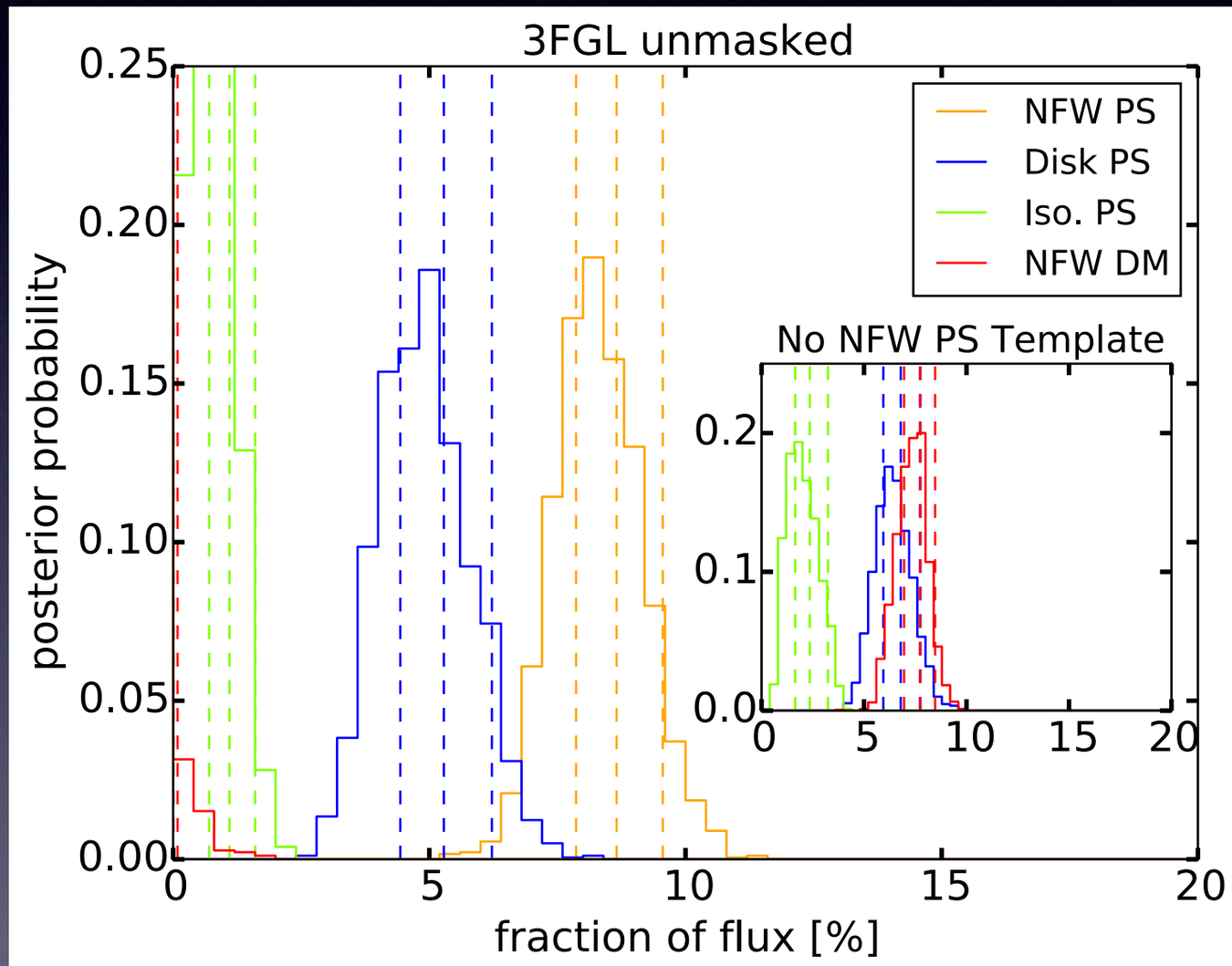
- No gamma ray excess seen in galaxy groups



Lisanti et al 2018

Pulsar Interpretation

- Non-Poissonian Template Fitting (NPTF)
- Test to see if data is consistent with unresolved point sources
- Depends on how diffuse emission is modeled
- Signal can be confused for mis-modeling of extended emission

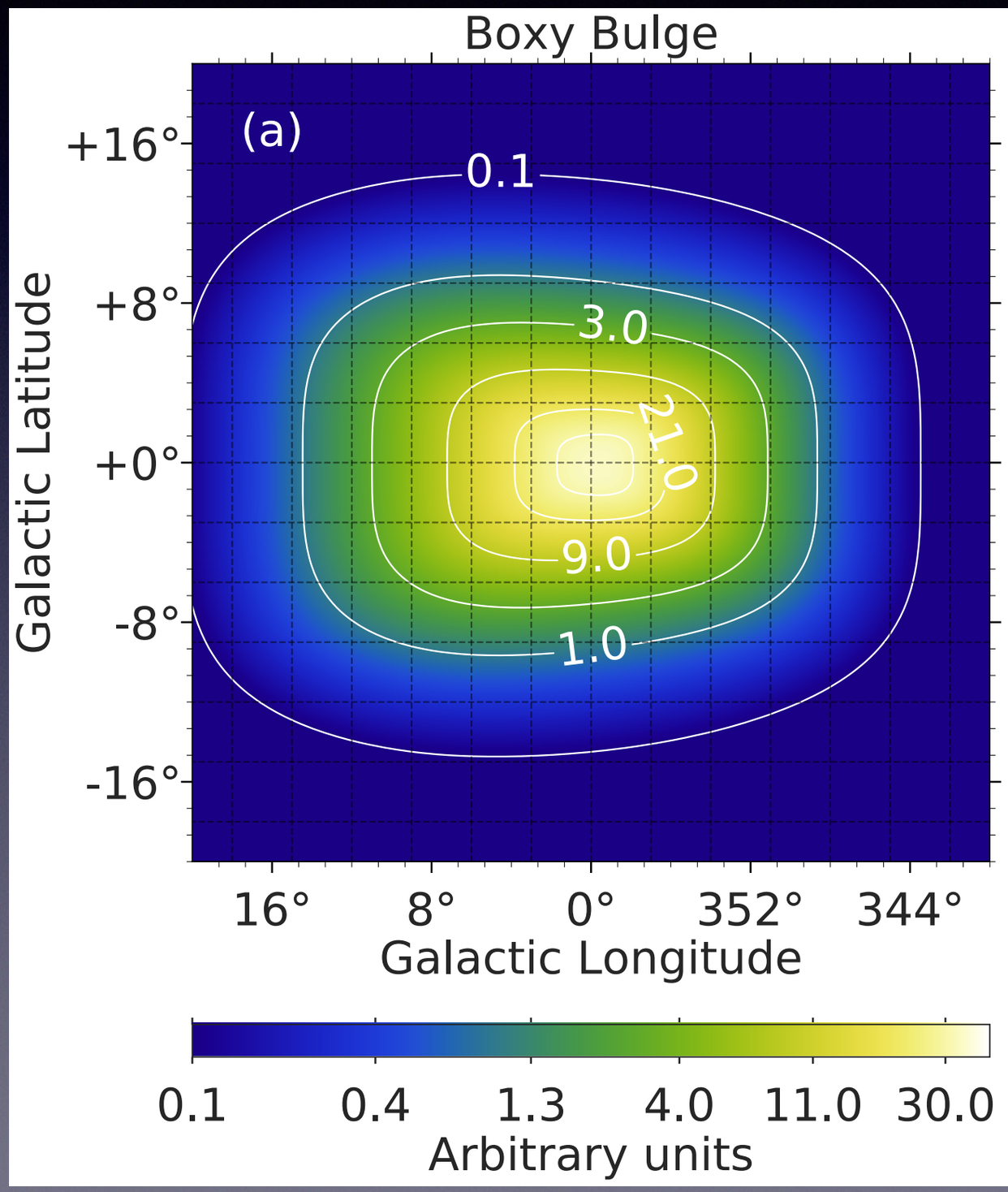


Lee et al 2015

Pulsar Interpretation

- Bulge template generated from stellar density maps
- Pulsars trace stellar density
- shape seen in simulations of Galactic bar+bulge
- GCE prefers bulge template to spherical NFW

Abazajian et al 2020



DM or Pulsars

Dark Matter

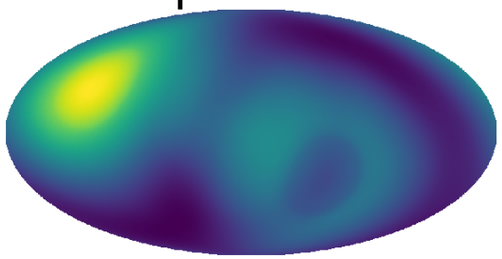
- Peaks at few GeV
- Shape of spherical NFW^2 γ=1.2 profile
- Thermal cross-section

Pulsars

- Peaks at few GeV
- Not seen in dwarfs
- Not seen in groups
- Small scale power
- ***More consistent with non-spherical bulge***

Galactic Center Review

Isotropic



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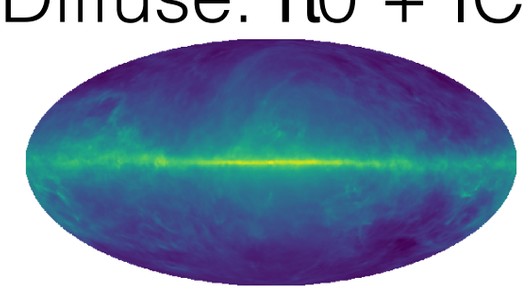
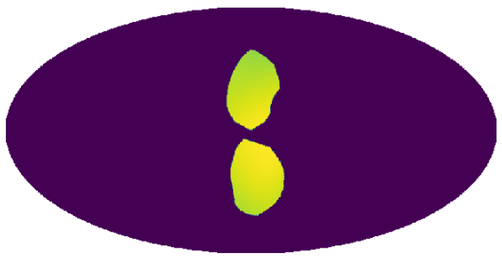
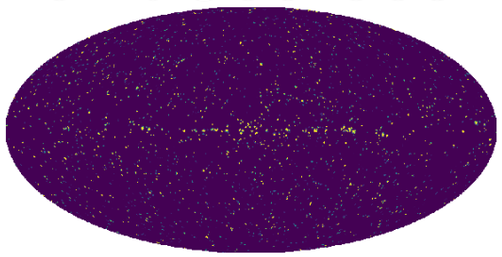


Fermi Bubbles



Point Sources



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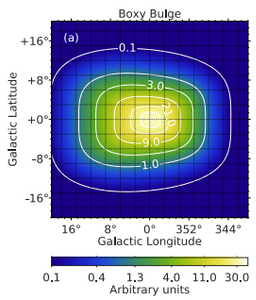
Bulge



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Data

Data is *fully* explained

Statistics

- Want $P(\langle\sigma v\rangle, m_\chi | D)$
- Poisson Statistics

$$\mathscr{L}(D|M) = \Pi_i \mathscr{L}(D_i|M) = \Pi_i \mu_i^{N_i} e^{-\mu_i}/N_i!$$

- 15 energy bins between 0.667 and 158 GeV - each independent (no assumption about spectra)
- Marginalize over backgrounds

$$\mathscr{L}_i(F_{DM,i}|D_i) = \int \overrightarrow{dF_{b,i}}\, \mathscr{L}_i(F_{DM,i}, \overrightarrow{F_{b,i}}|D_i)$$

Dark Matter Math

$$\frac{d\Phi}{dE} = \frac{\langle \sigma v \rangle}{8\pi} \frac{J}{m_\chi^2} \frac{dN}{dE}$$

$$P(\langle \sigma v \rangle, m_\chi \,|\, D) = \int dJ \; P(\langle \sigma v \rangle, m_\chi, J \,|\, D) P(J)$$

$$J = \int d\Omega \int ds \; \rho^2(r(s, \Omega))$$

$$\rho(r) = \rho_\odot \left(\frac{R_\odot}{r} \right)^\gamma \left(\frac{r_s + R_\odot}{r_s + r} \right)^{3-\gamma}$$

NFW parameters

$\rho_\odot = 0.28 \pm 0.08\ \mathrm{GeV/cm^3}$

- Taken from velocities of local stars into and out of the plane

$R_s = 26 \times 10^{\pm 0.14}\ \mathrm{kpc}$

- Derived from the concentration mass relation (from simulations)

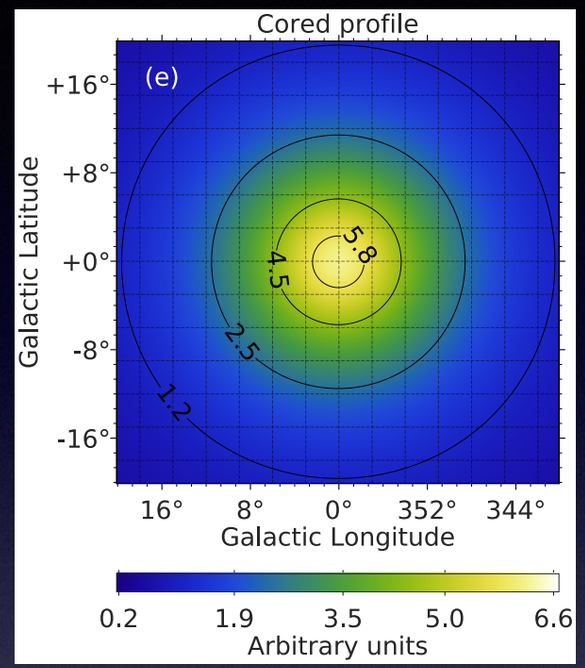
$\gamma : 0.5 - 1.5$

- Previously from gamma-ray data - now iterate over possible values

Additional Profiles

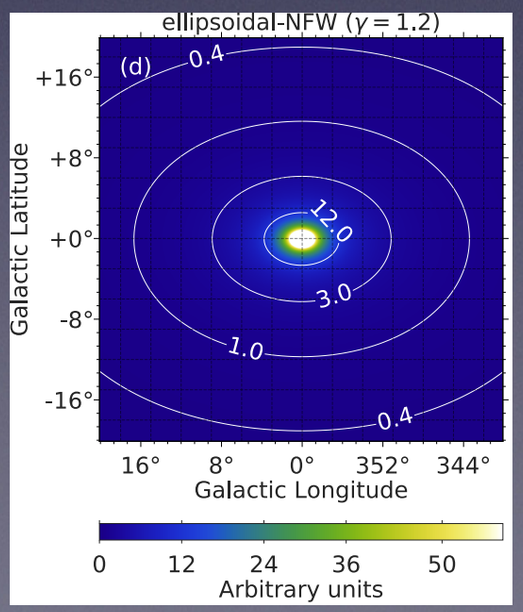
- Additional profiles Motivated by SIDM simulations
- Read Profile 1 kpc sized core

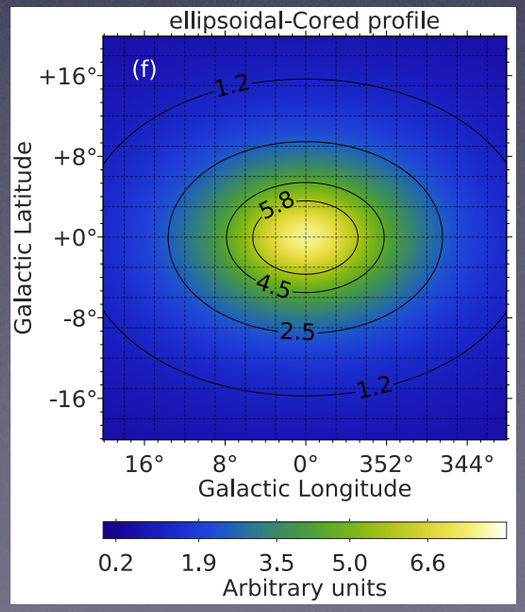
$$M_c(r) = M_{\mathrm{NFW}}(r)\tanh(r/r_c)$$



- Ellipsoidal versions of NFW & Read profiles

$$r^2 = x^2 + y^2 + z^2 \rightarrow r^2 = x^2 + y^2 + 0.8z^2$$





Consistency Checks!

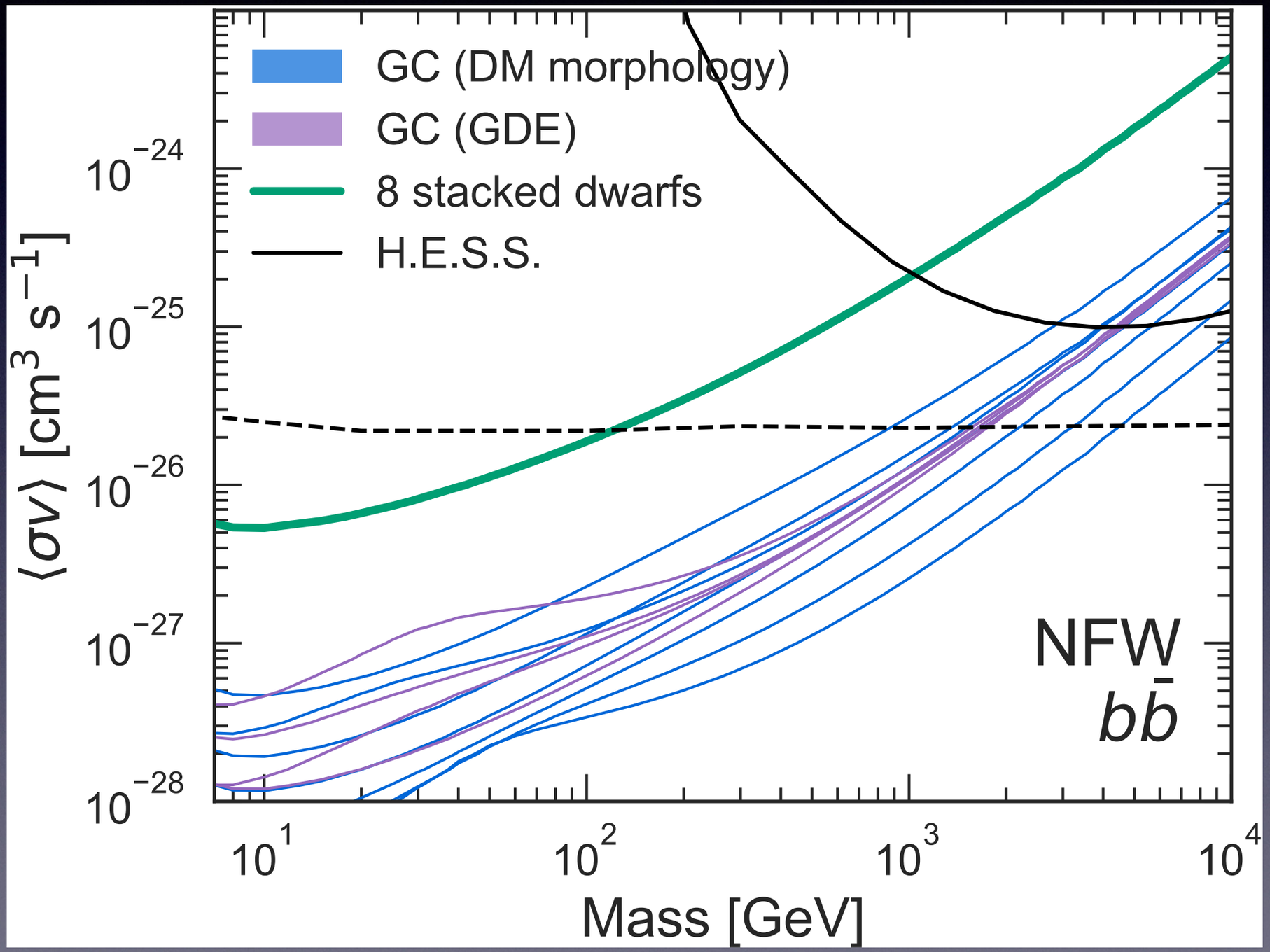
Diffuse Emission

- Interpolated gas maps
- E(B-V) with 2 mag-cut
- IC 3D (6 rings)
- IC 2D (central source of electrons)

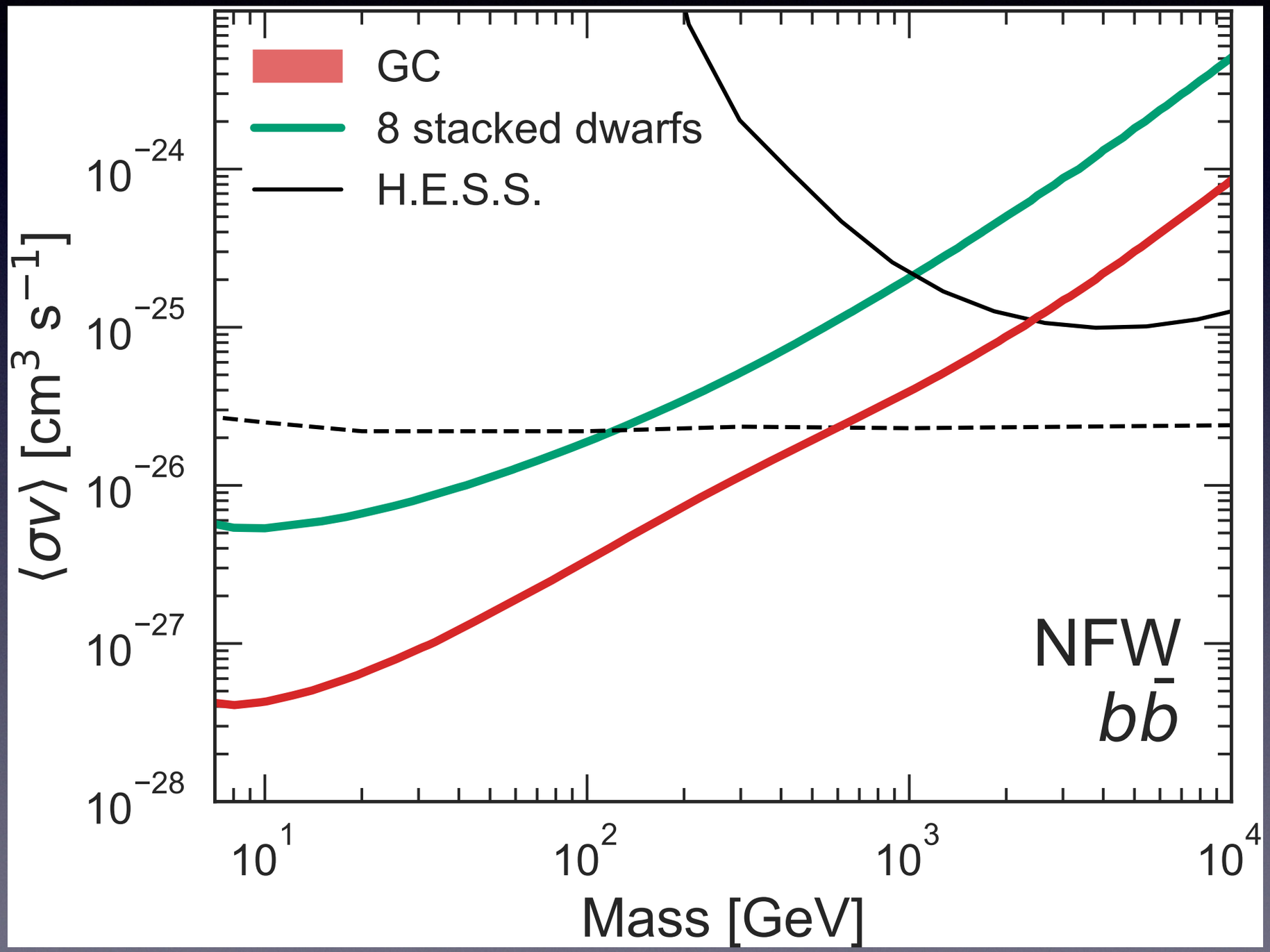
DM profiles

- NFW - γ
- Read profile
- Triaxial NFW
- Triaxial Read

Robust Limits



Conservative Limits



Conclusions

- Fermi sees an excess of gamma rays (Galactic Centre Excess)
- We show DM is not the explanation for the GCE (unfortunately)
- From GCE data, we show WIMPs with m_χ < 300 -1 TeV are ruled out
- Hunt for DM continues!