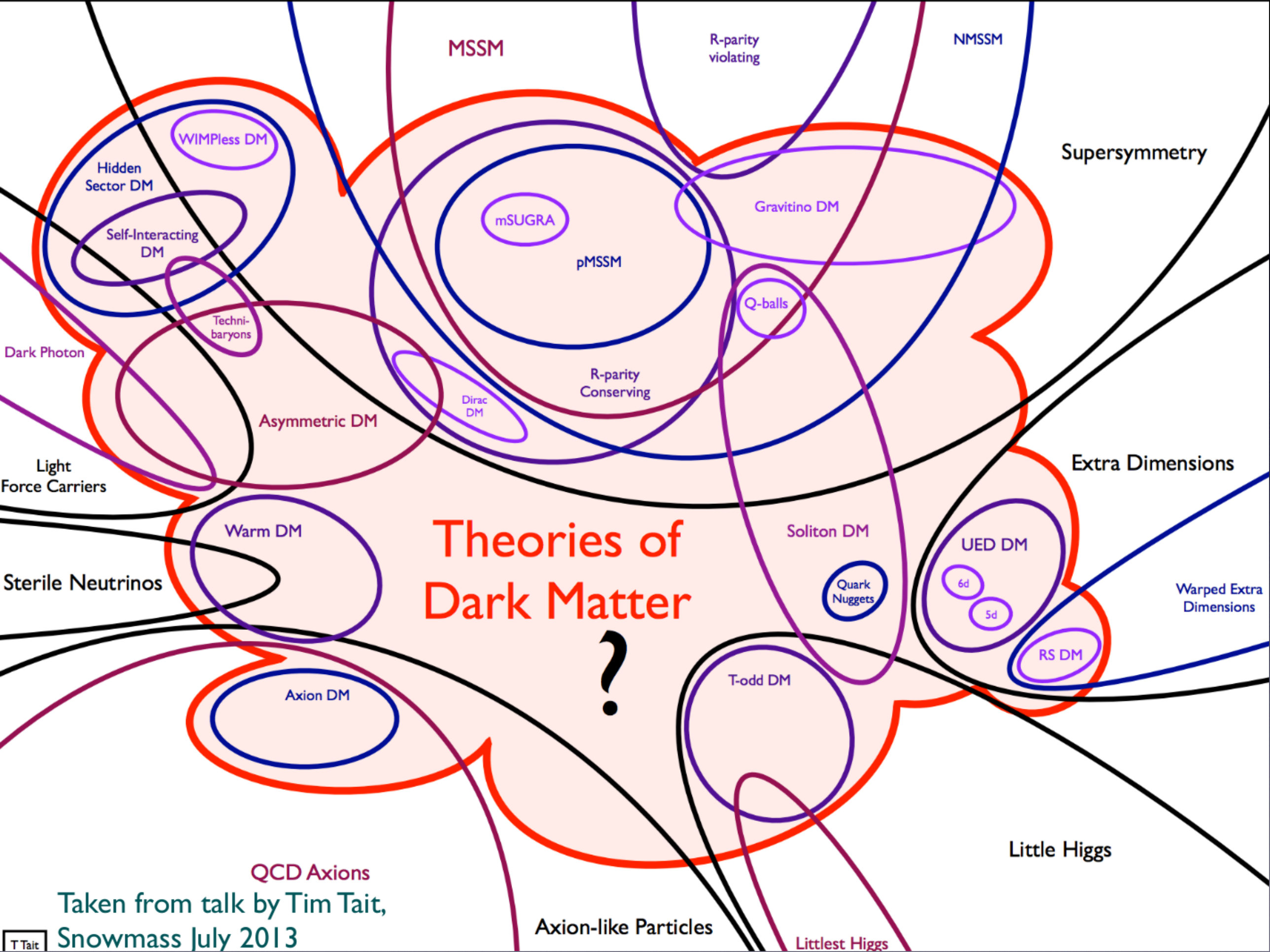
Strong constraints on thermal relic dark matter from Fermi-LAT observations of the Galactic Center

Ryan Keeley

APS DPF 2021

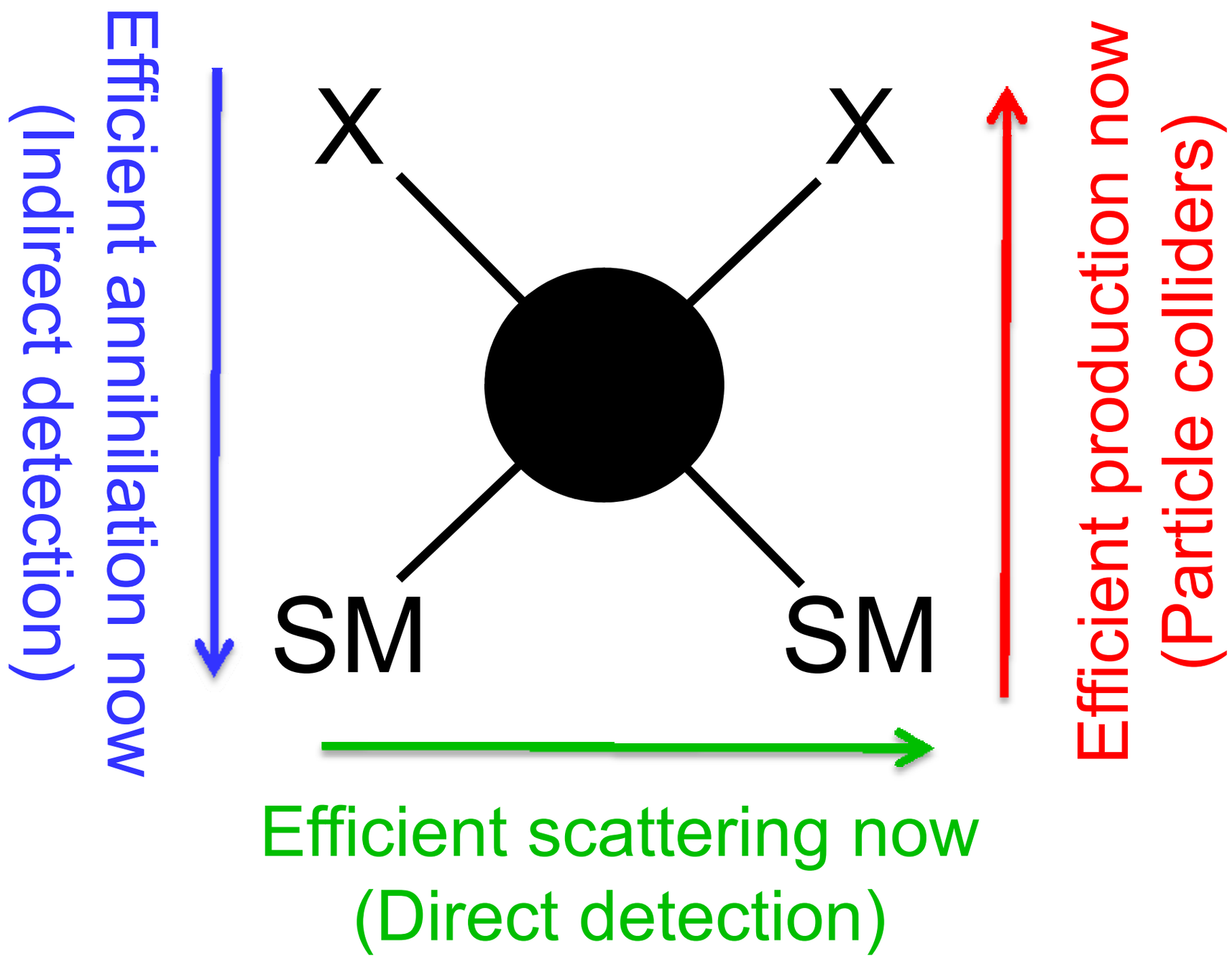
July 14 2021



Taken from talk by Tim Tait, Snowmass July 2013

T Tait

Detection



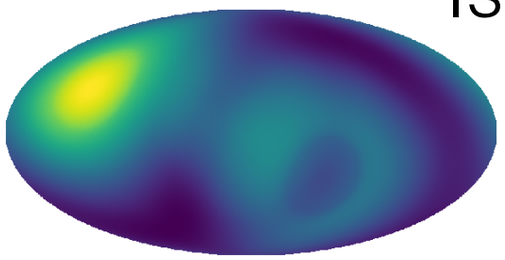
Jonathan Feng (2008)

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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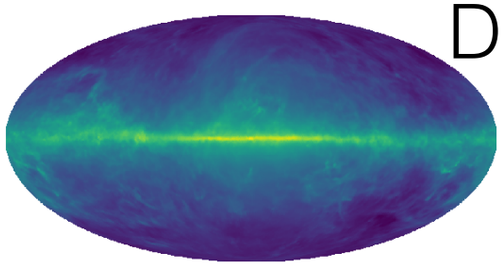
Diffuse: π0 + ICS



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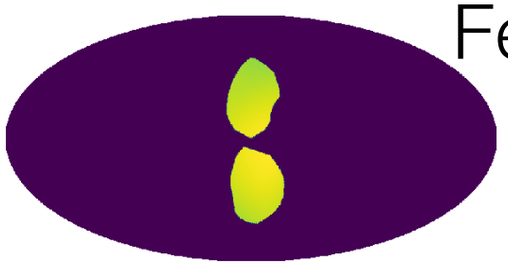
Fermi Bubbles



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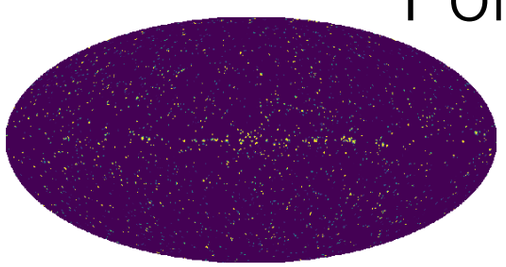
Point Sources



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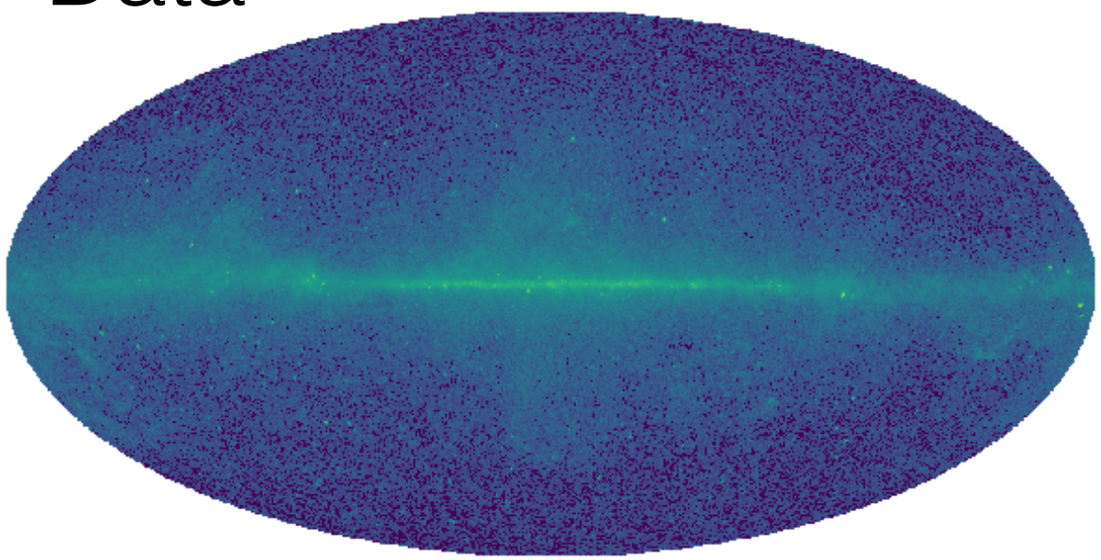
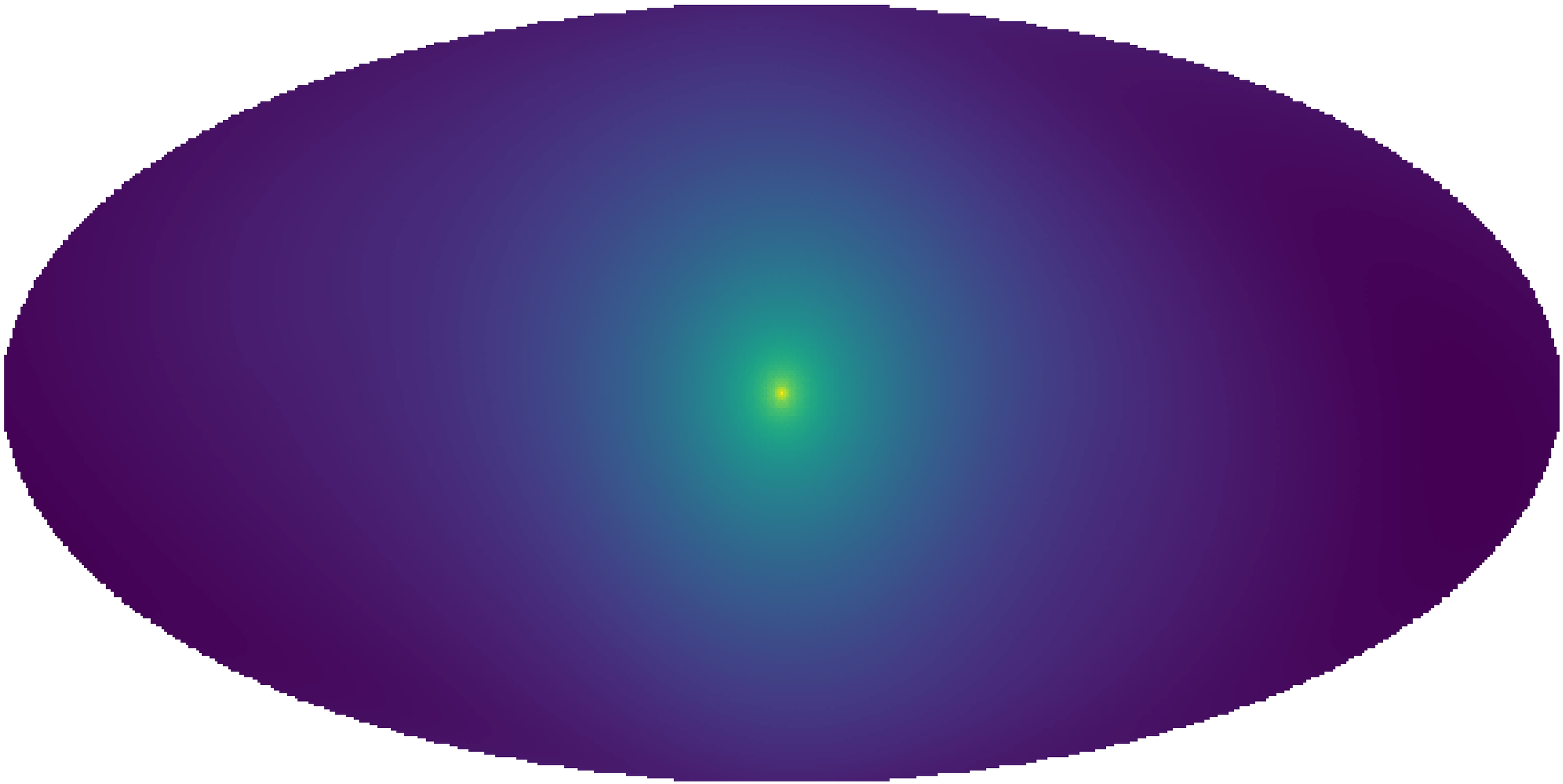
Data

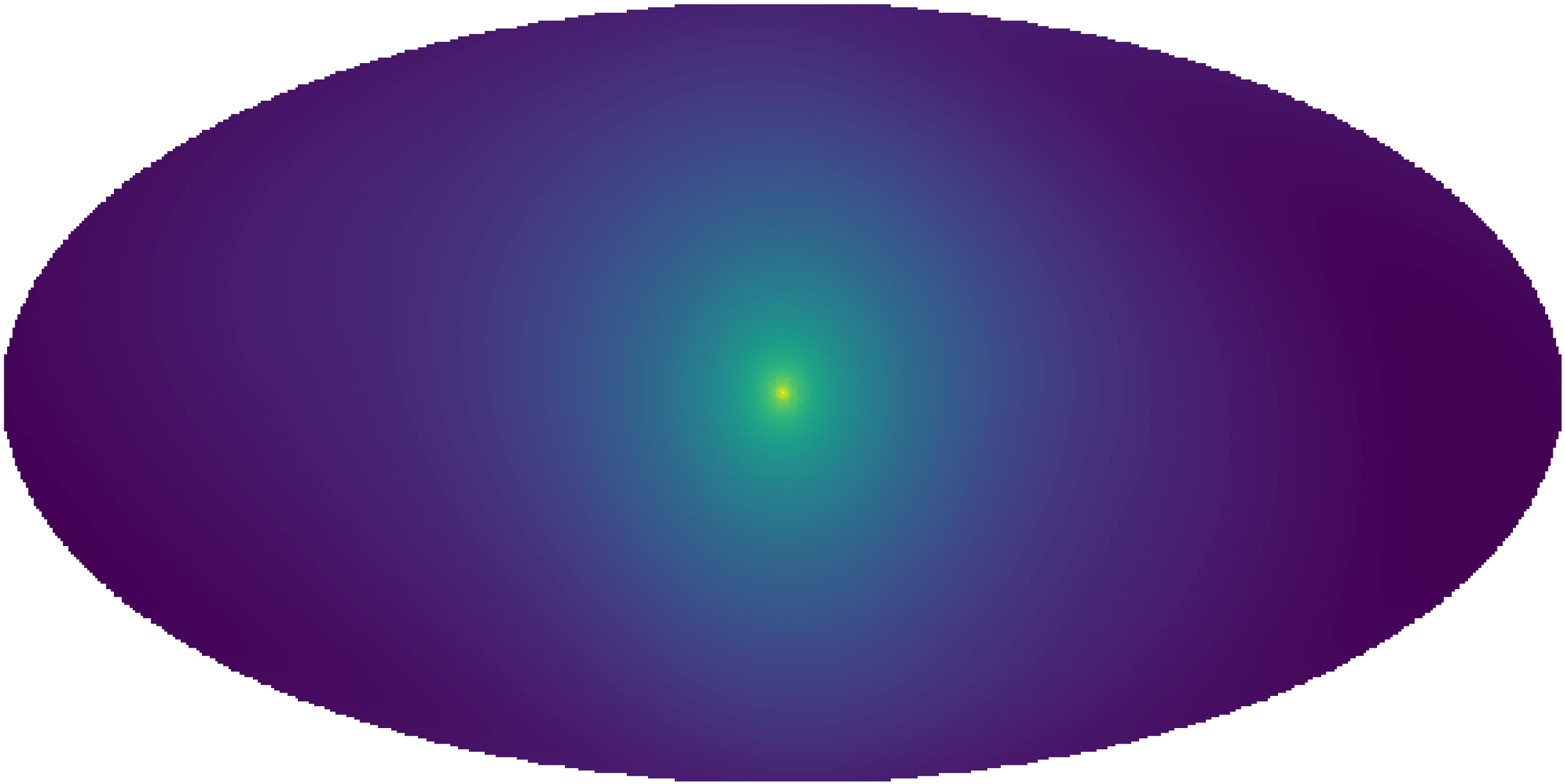


Galactic Center Excess



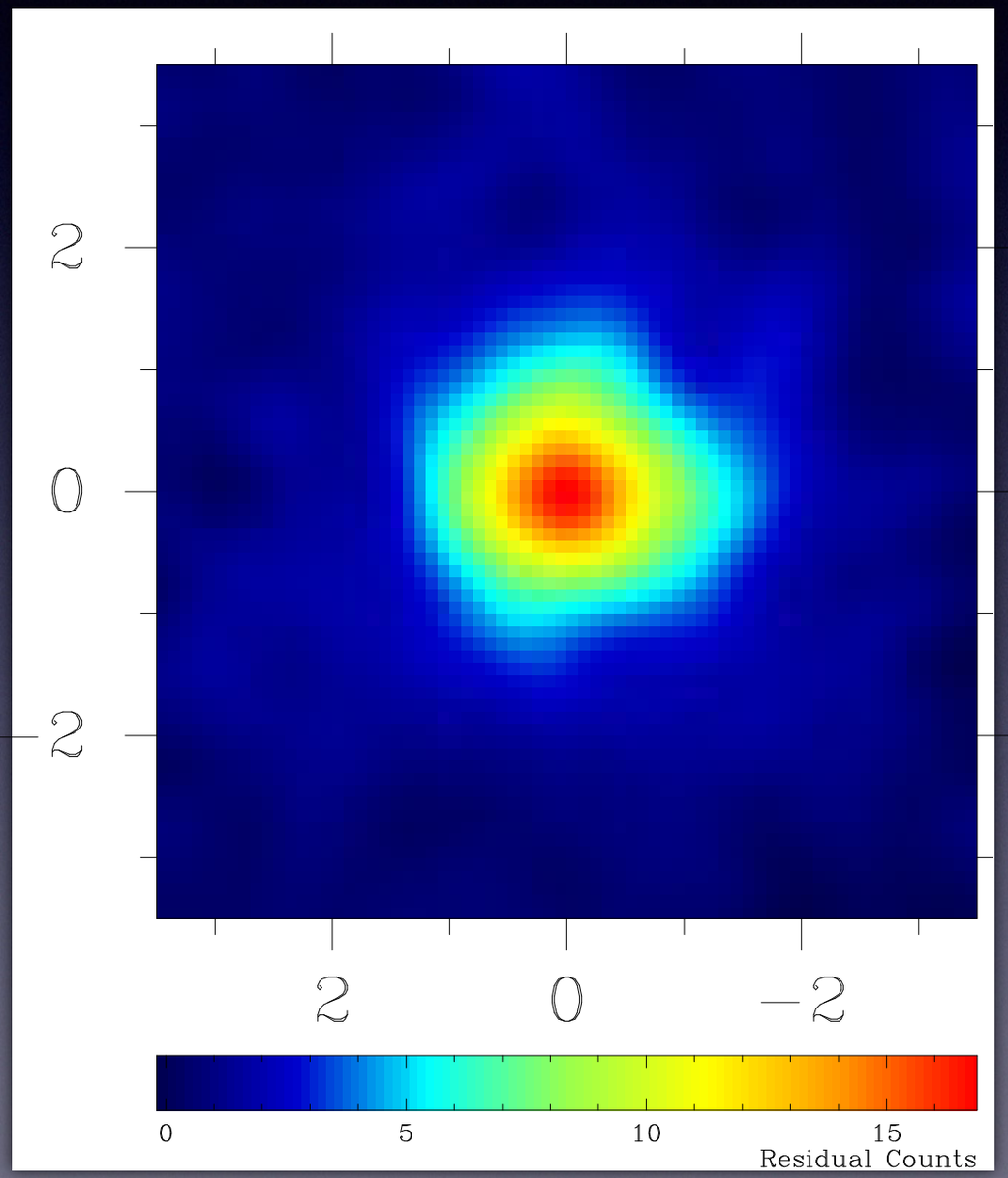
Galactic Center Excess

DM Annihilation?



DM Interpretation

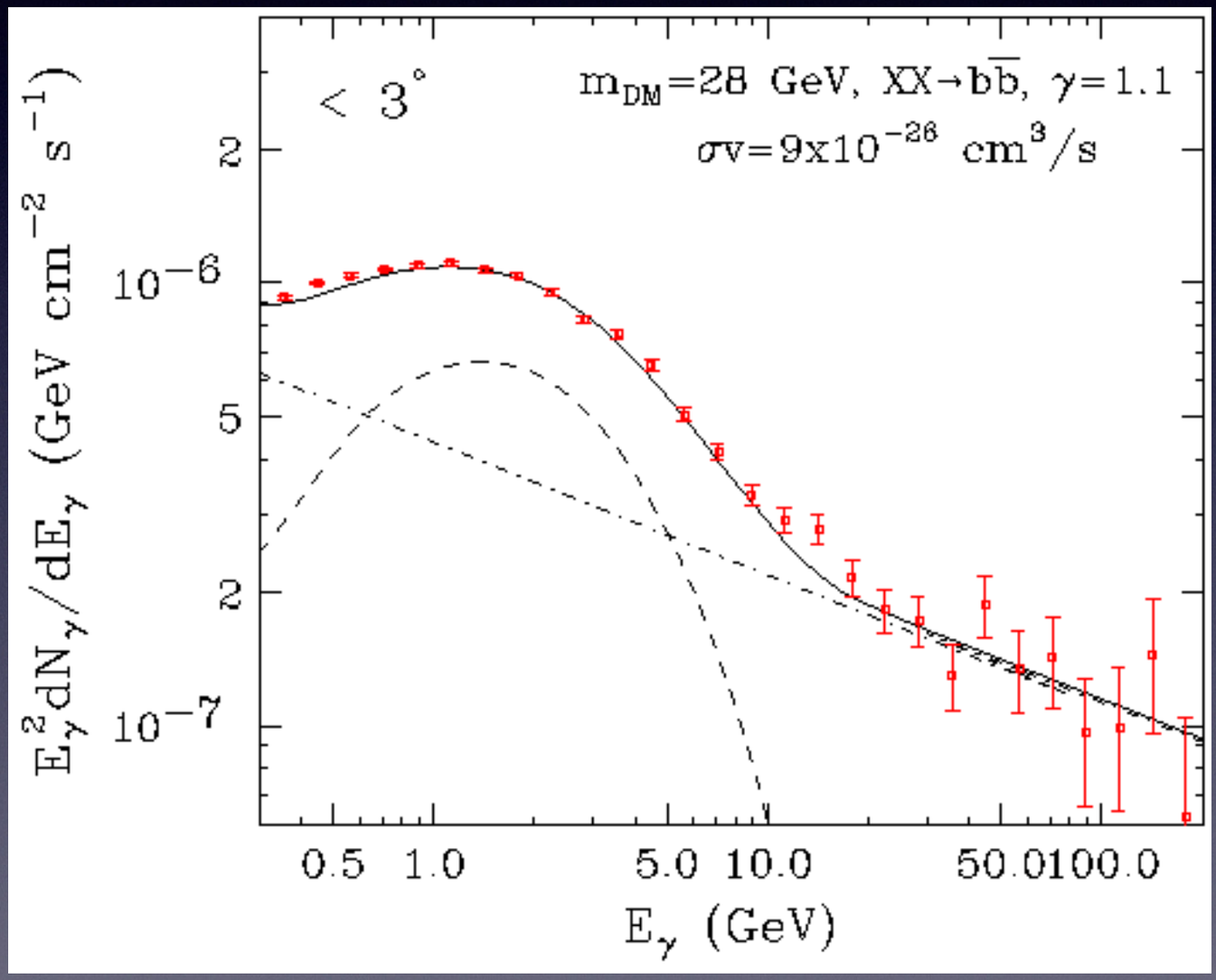
- 3 lines of evidence
- Roughly spherically symmetric / NFW-gamma~1.2



Abazajian & Kaplinghat 2012

DM Interpretation

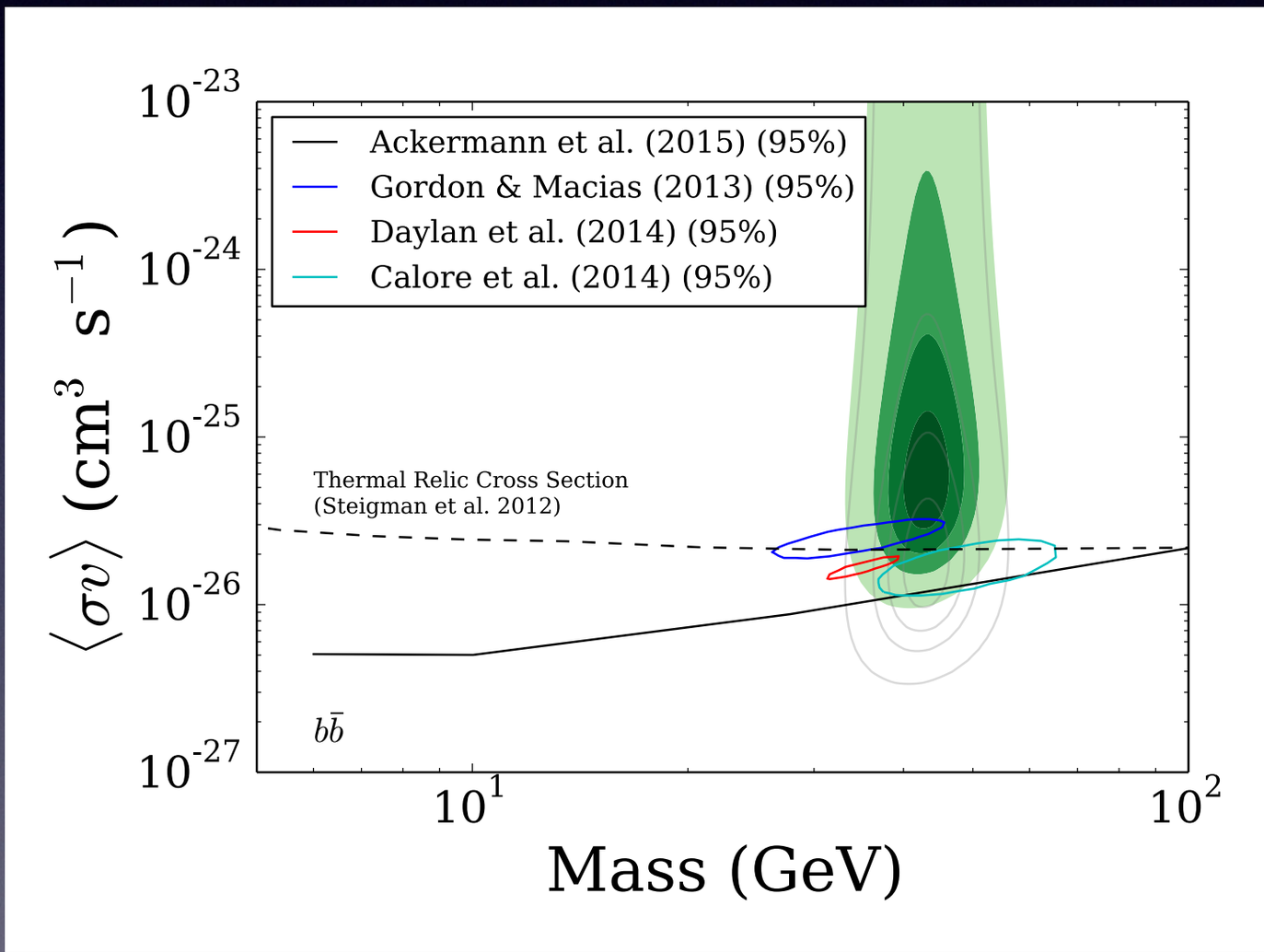
- 3 lines of evidence
- Roughly spherically symmetric / NFW-gamma~1.2
- Peaks at a few GeV (Annihilating WIMP of 10s to 100s GeV)



Goodenough and Hooper 2009

DM Interpretation

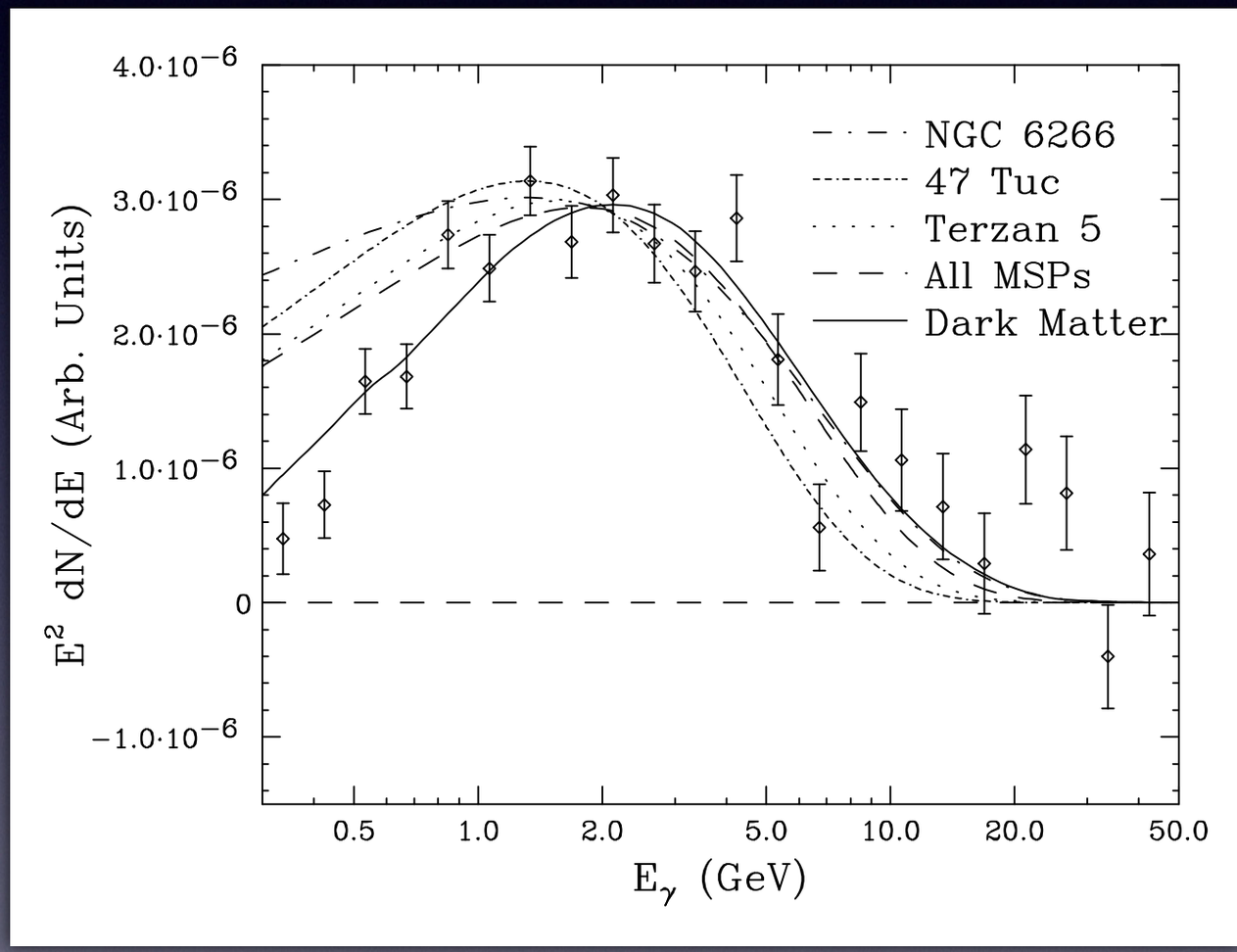
- 3 lines of evidence
- Roughly spherically symmetric / NFW-gamma~1.2
- Peaks at a few GeV
- Right flux for thermal cross section



Abazajian and Keeley 2015

Alternative Explanation:
Pulsars

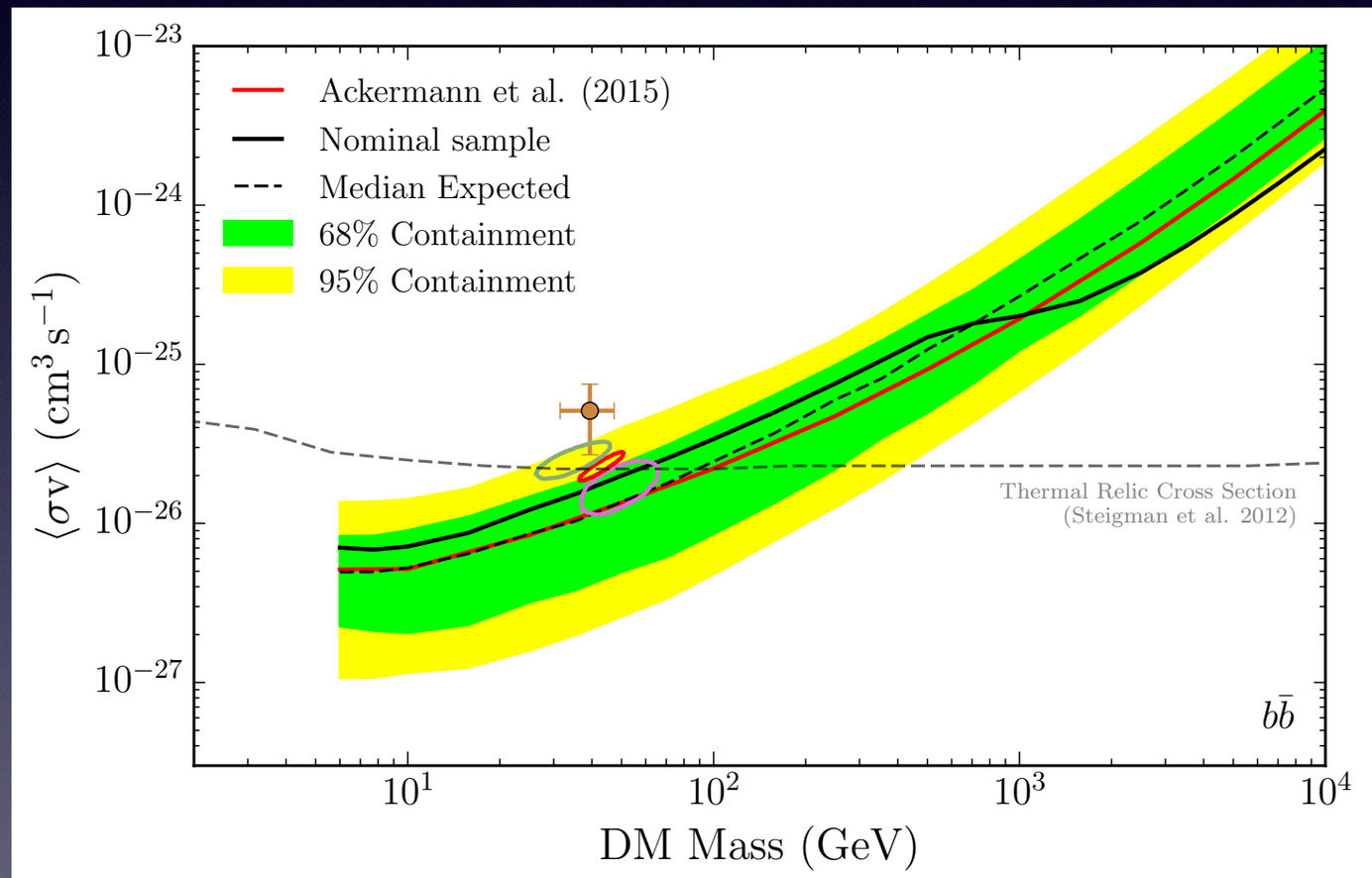
- However,
- Even before GCE was seen, known that pulsars could be confused for a DM signal.
- WIMPs and pulsars have similar spectra



Daylan et al 2014

Pulsar Interpretation

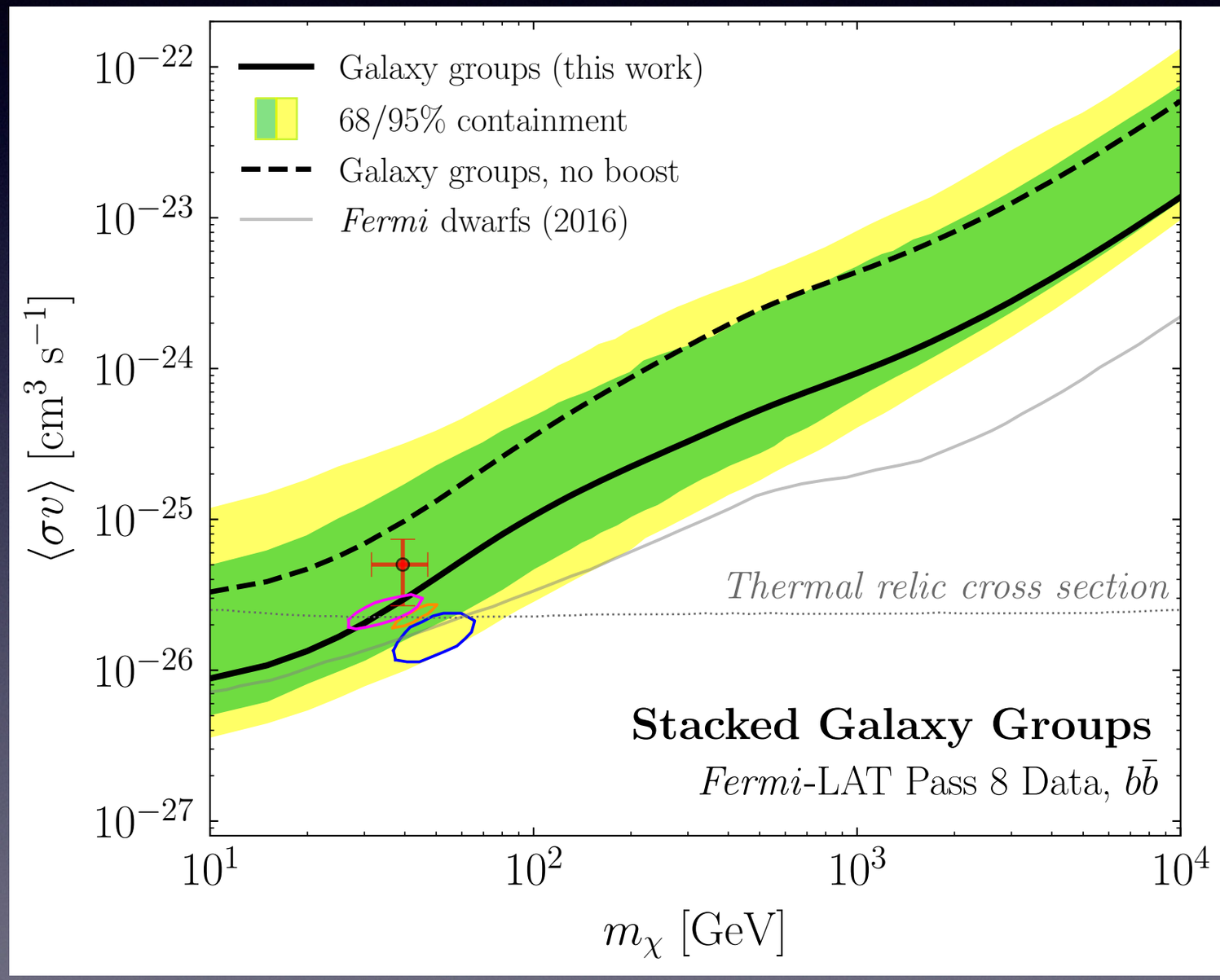
- No signal in the MW dwarfs
- Rules out GCE parameter space



Albert et al 2017, Keeley et al 2017

Pulsar Interpretation

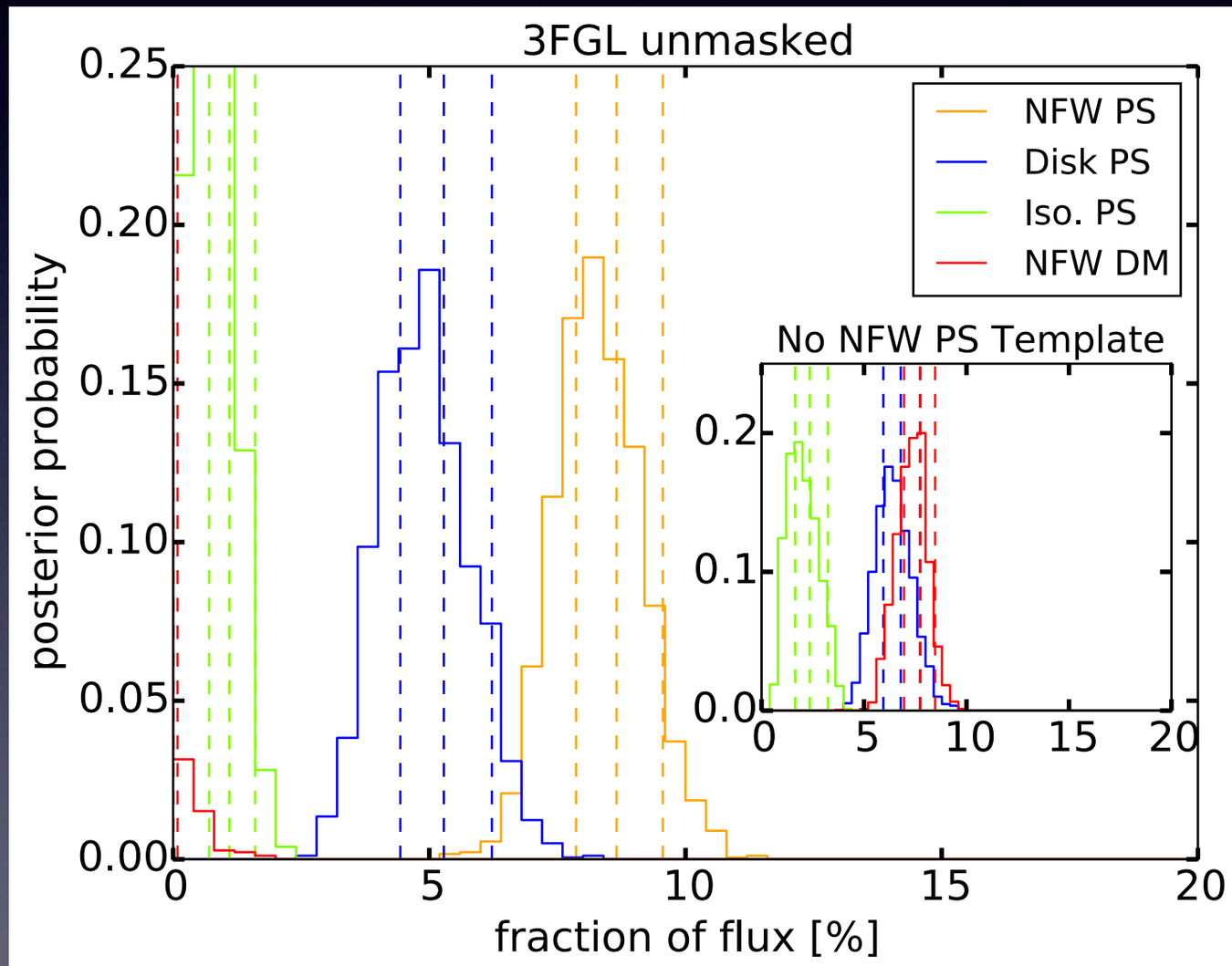
- No gamma ray excess seen in galaxy groups



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

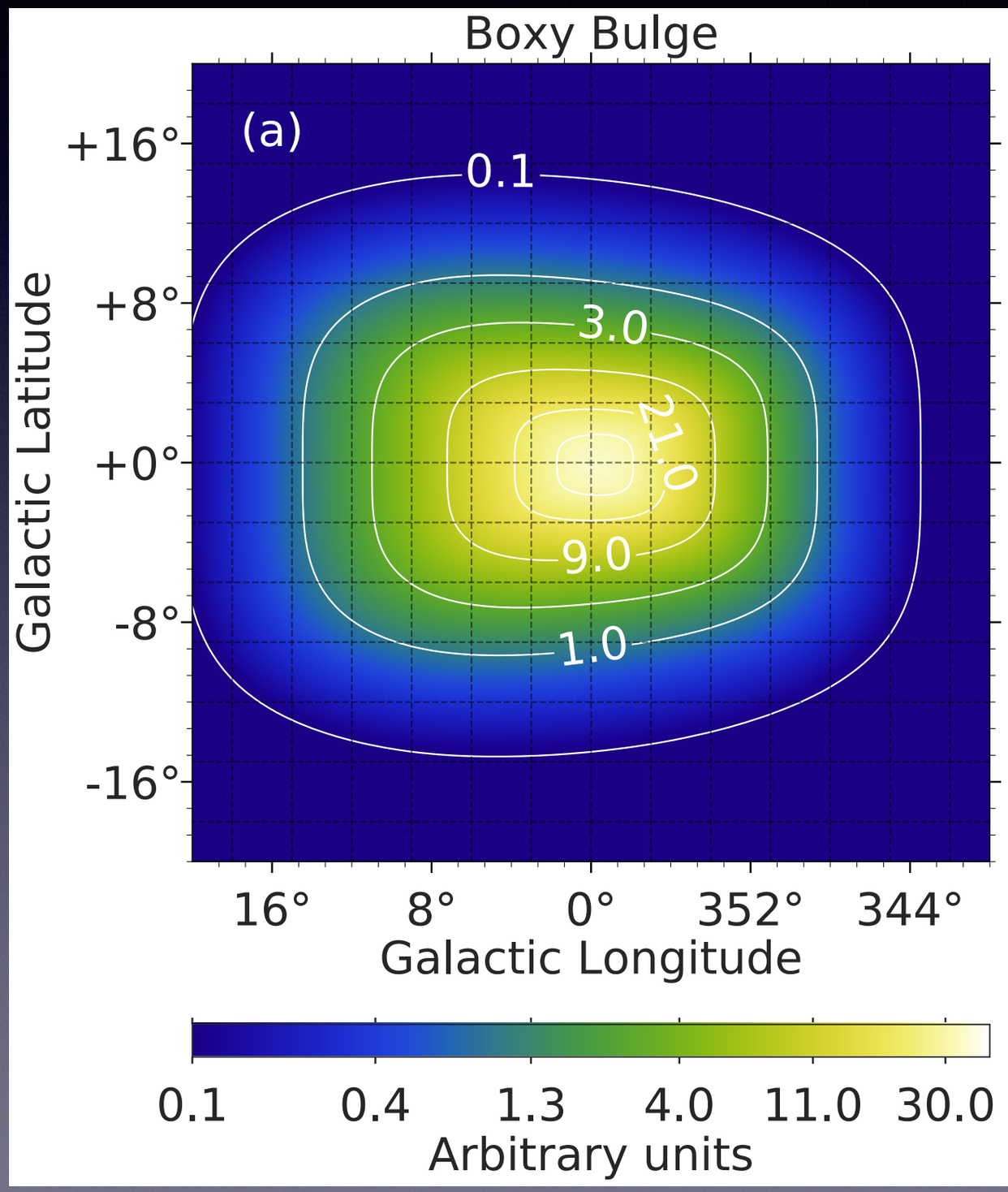


Lee et al 2015

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

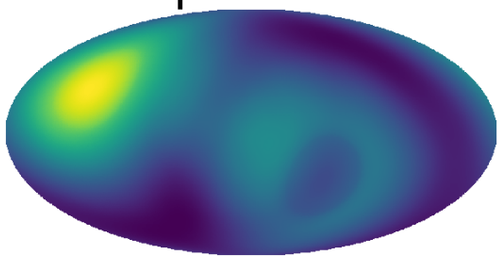
- Peaks at few GeV
- Shape of spherical NFW^2 γ=1.2 profile
- Thermal cross-section

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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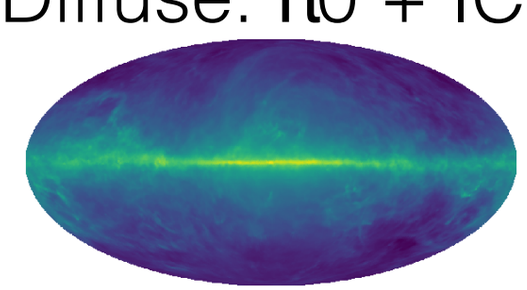
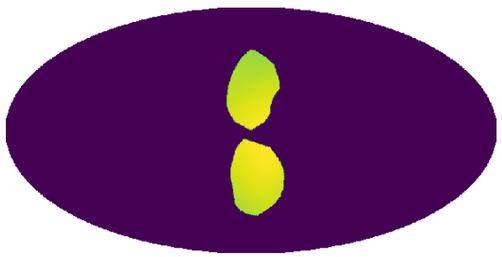


Fermi Bubbles



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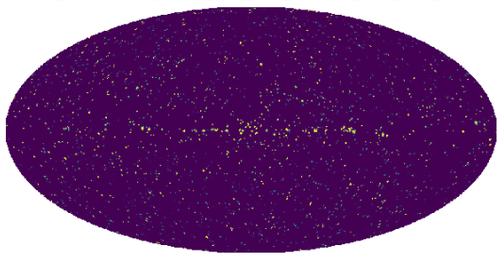

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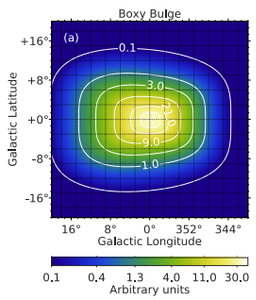
Bulge



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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)

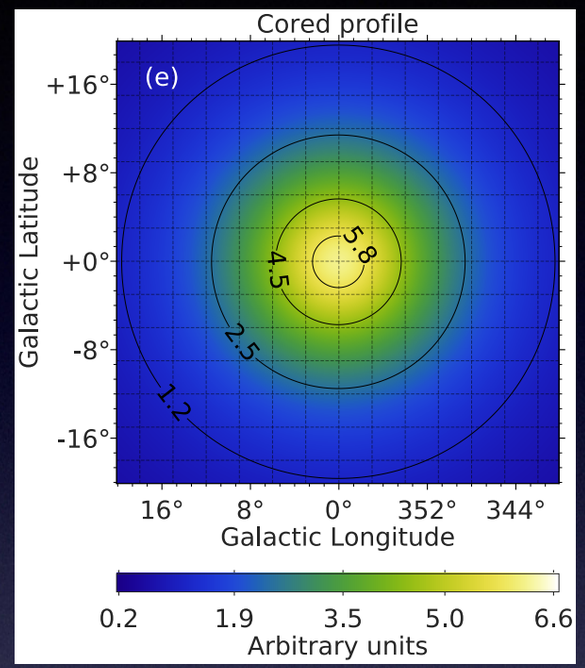
$\gamma : 0.5 - 1.5$

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

Additional Profiles

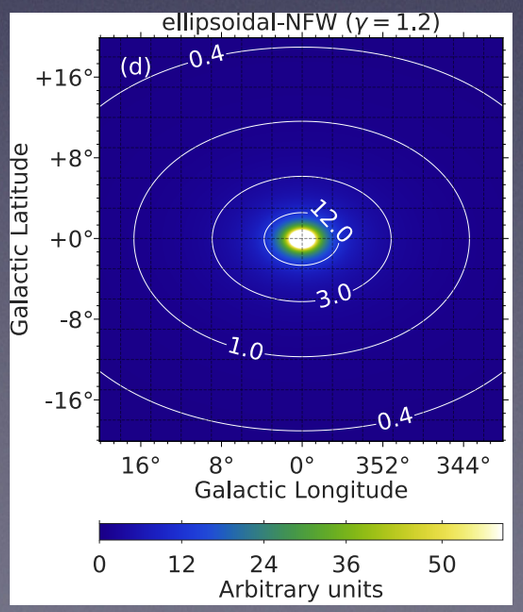
- Additional profiles Motivated by SIDM simulations
- Read Profile 1 kpc sized core

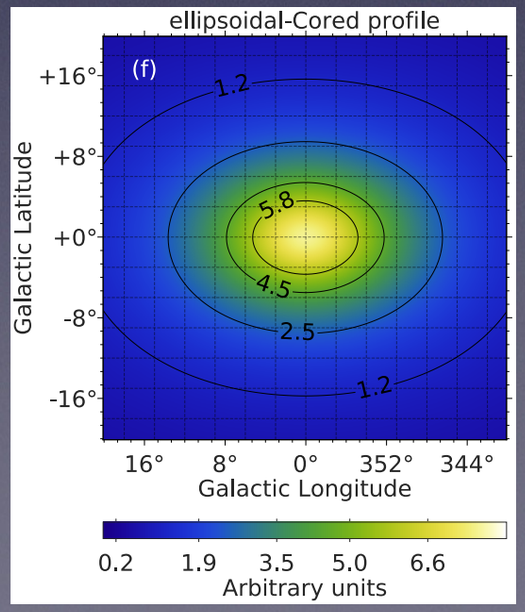
$$M_c(r) = M_{\mathrm{NFW}}(r)\tanh(r/r_c)$$



- 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!

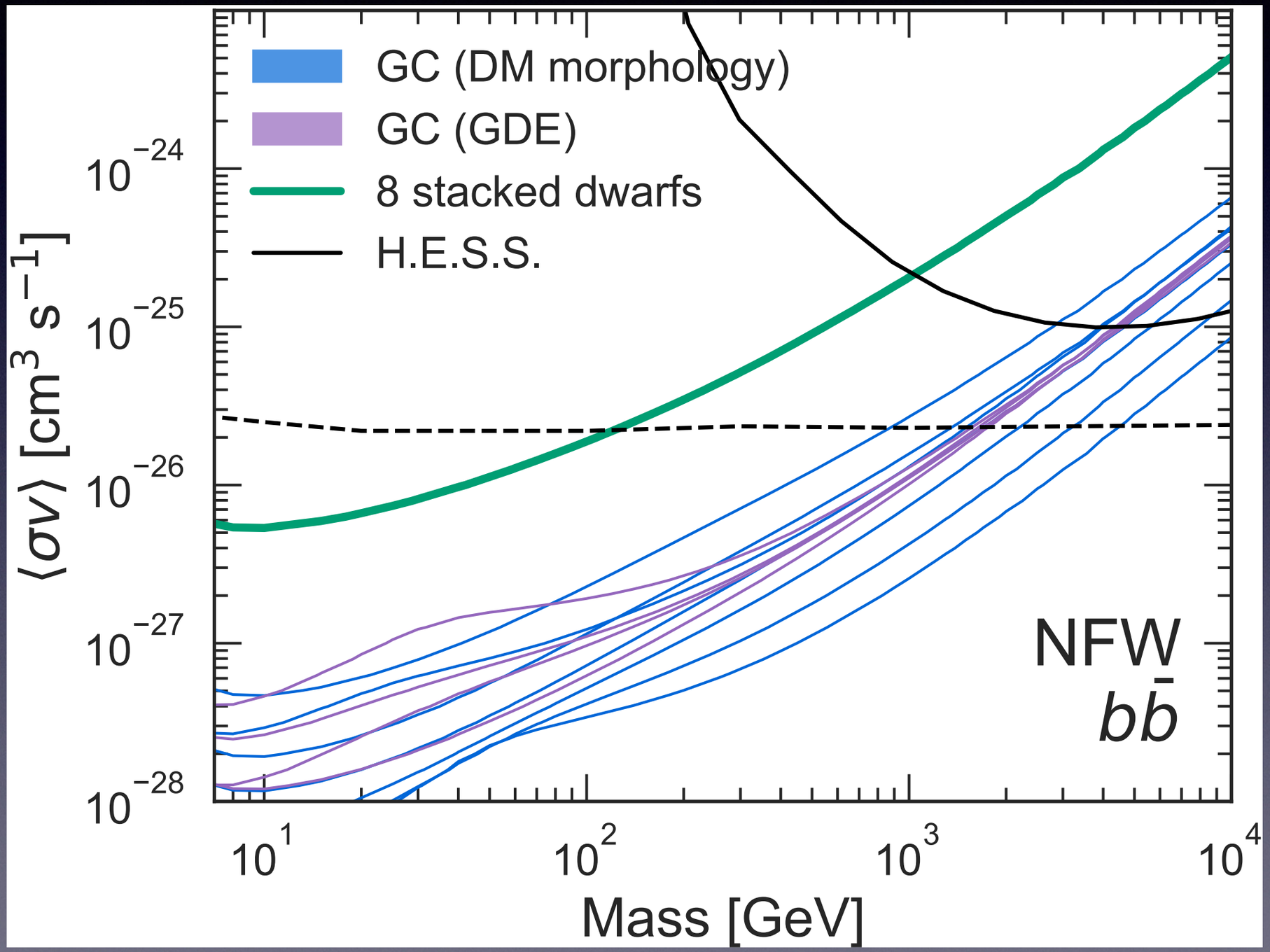
Diffuse Emission

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

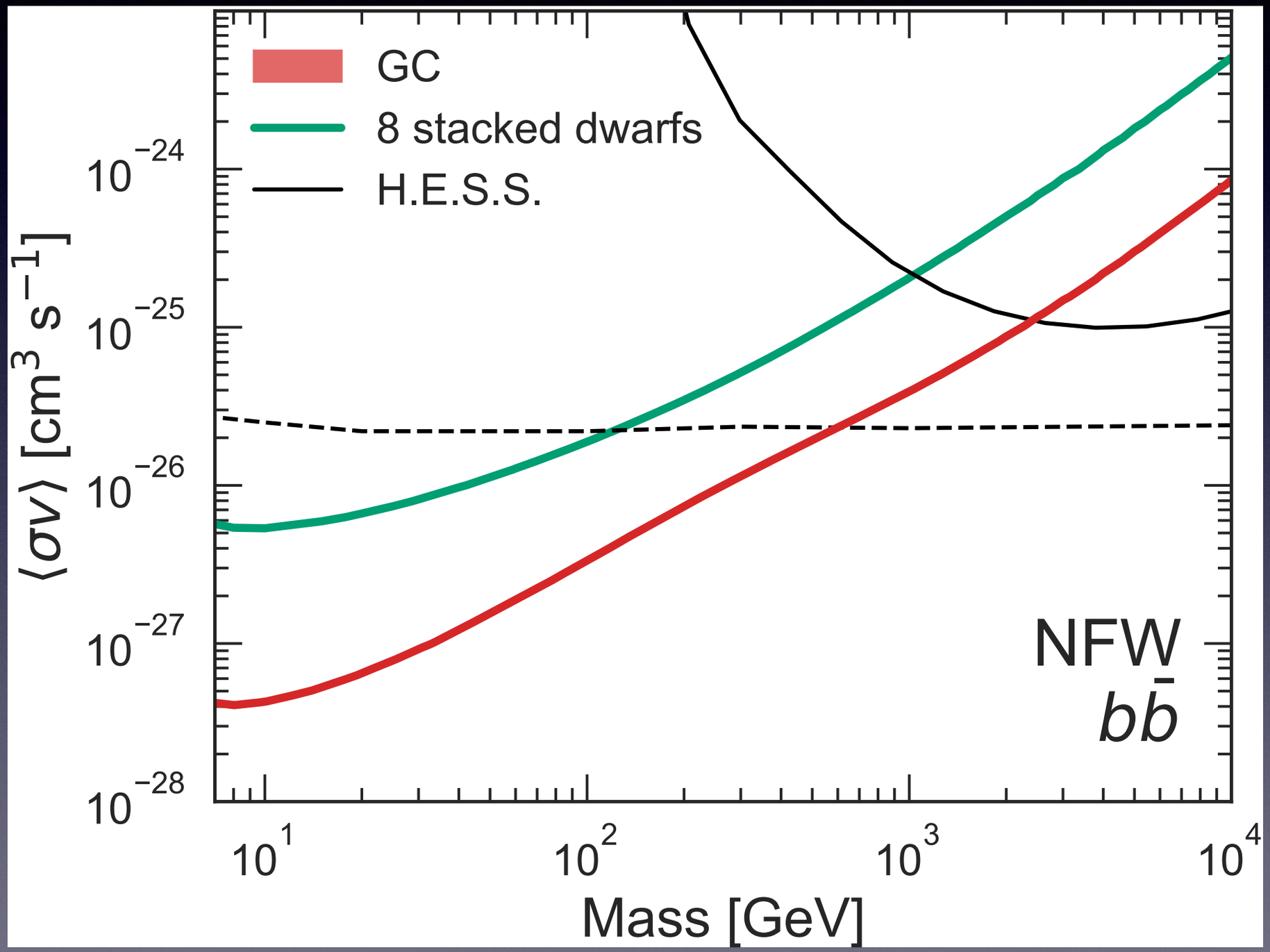
DM profiles

- 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!