Dark Matter
Overview: Gamma-Rays

Kevork Abazajian
University of California, Irvine

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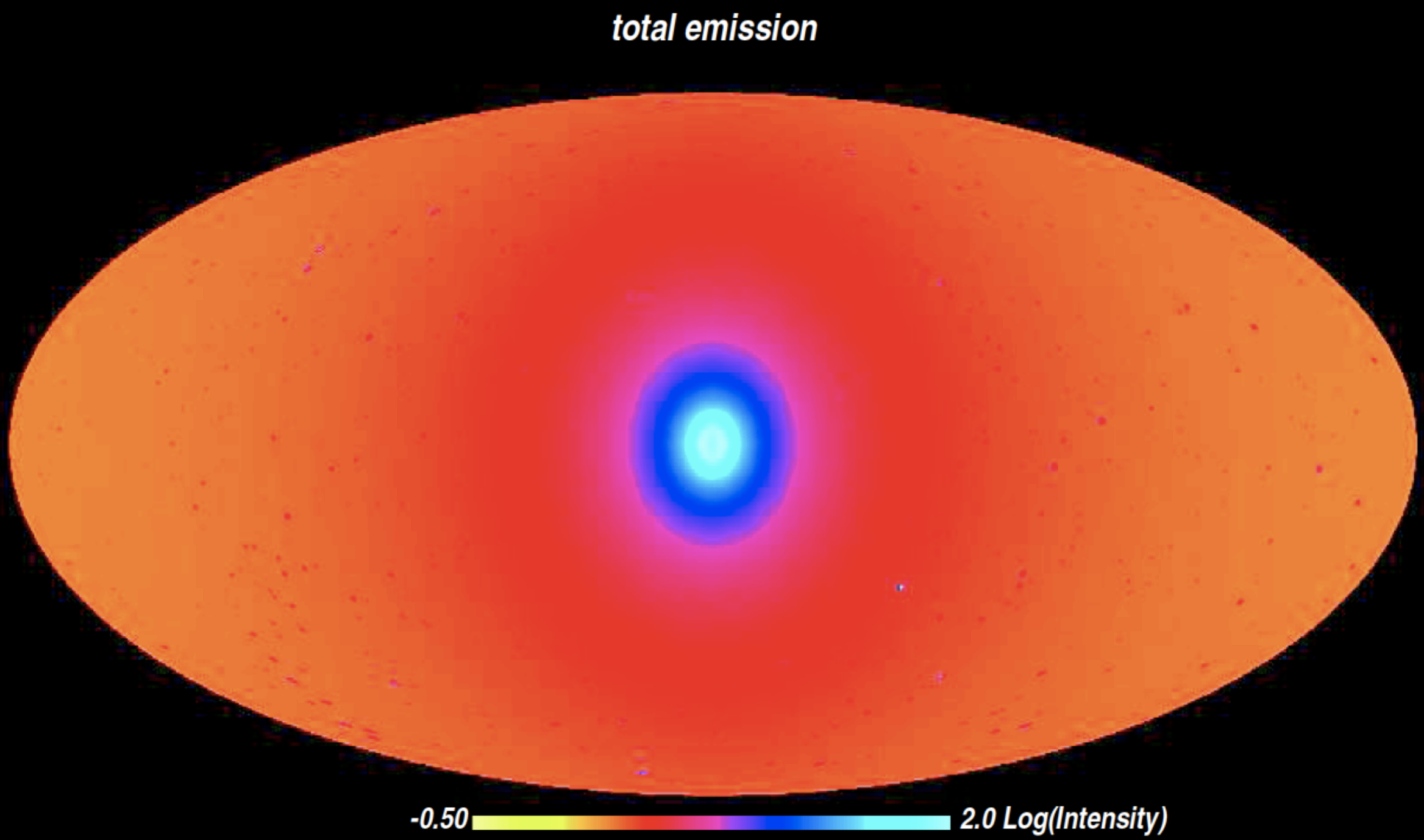
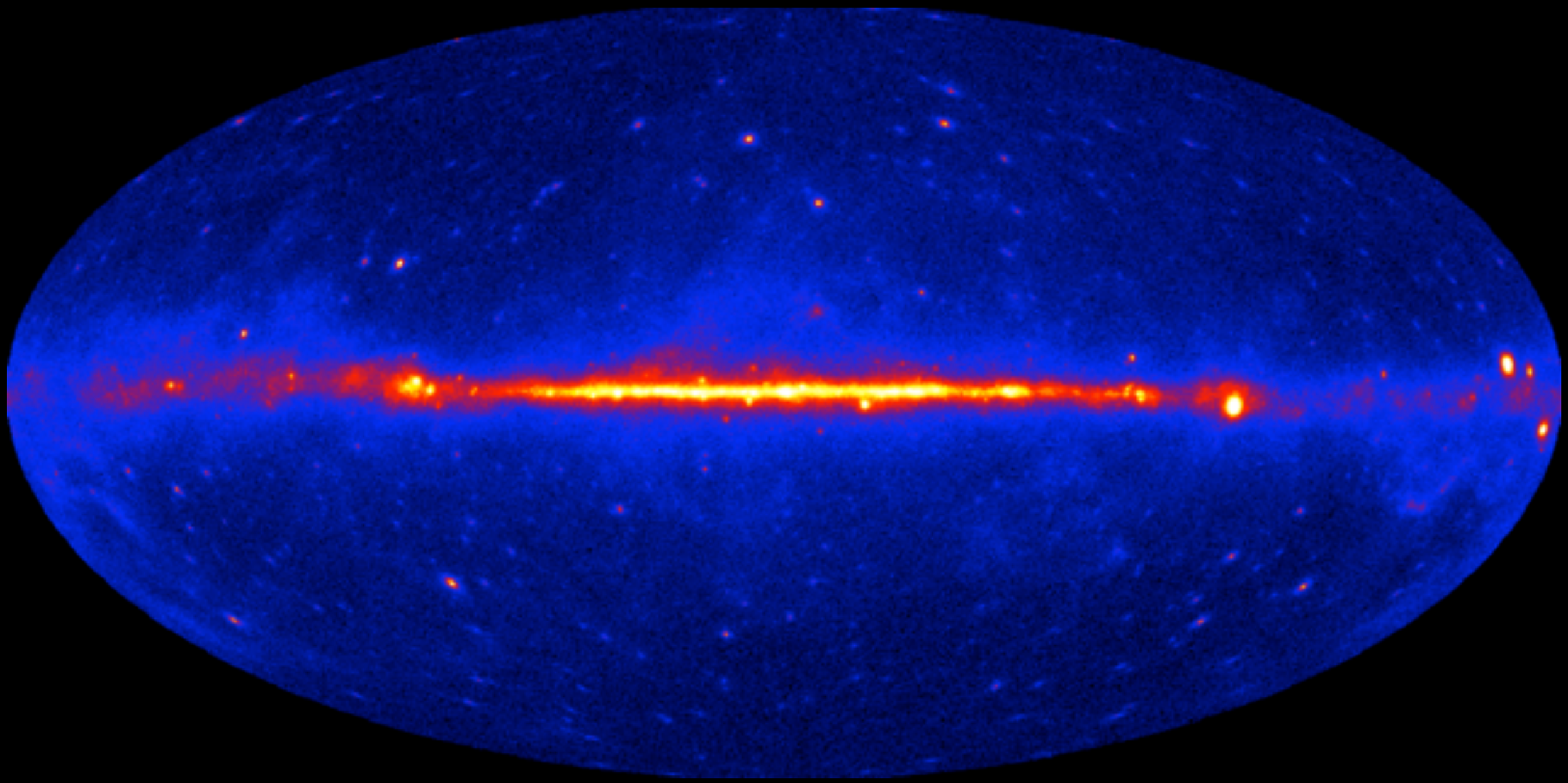
CDM to γ-ray: the potential dark matter sky

$$X_{\rm DM} + X_{\rm DM} \to Y^+ + Y^-, \quad X_{\rm DM} + X_{\rm DM} \to \gamma + \gamma$$

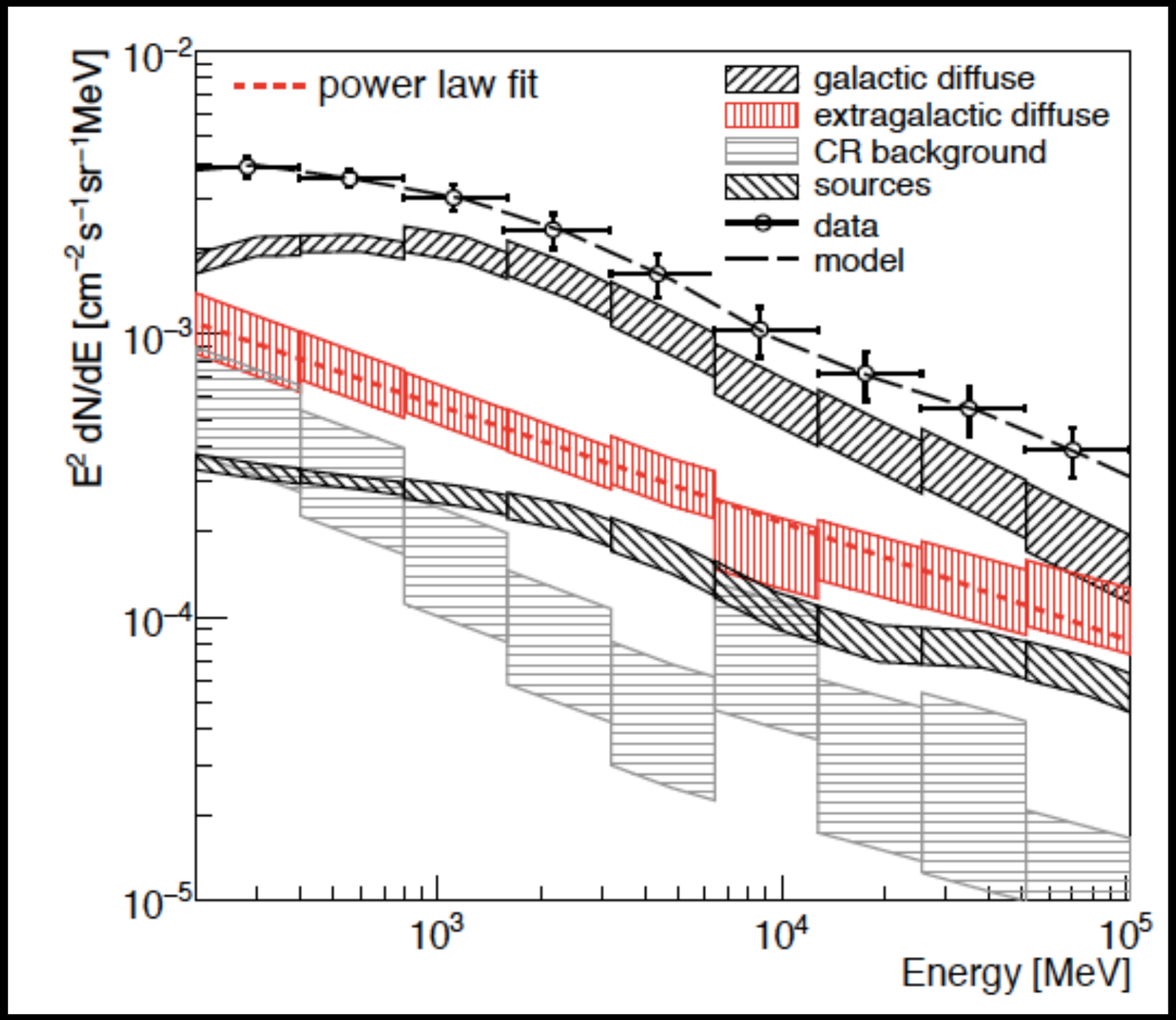


Springel et al 2008

The Observed Fermi-LAT Gamma-Ray Sky

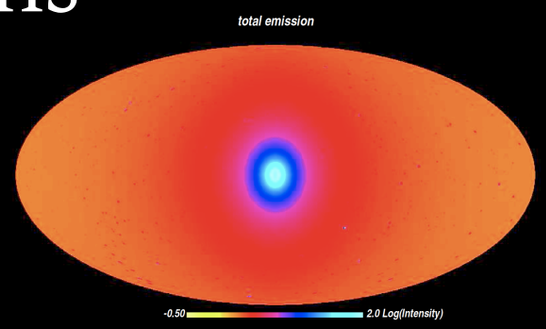


The Observed All-Sky γ-ray Spectrum



The Fermi-LAT collaboration (A.A. Abdo et al.) JCAP, arXiv:1002.3603

DM Annihilation:
Galactic and Extragalactic Contributions



Galactic:

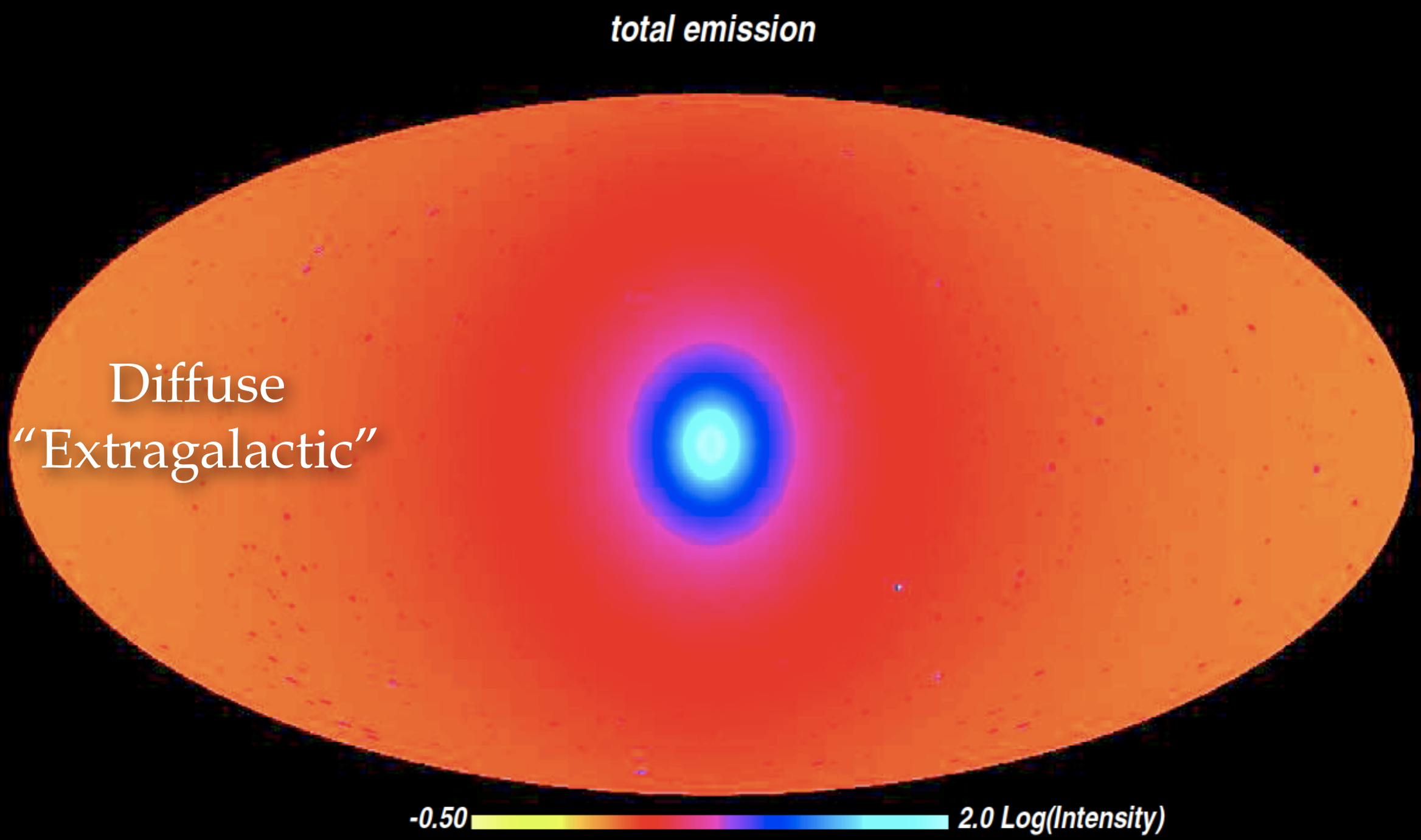
$$\frac{d\Phi_\gamma}{dE} = \frac{\langle \sigma_A v \rangle}{2} \frac{\mathcal{J}_{\Delta\Omega}}{J_0} \frac{1}{4\pi m_\chi^2} \frac{dN_\gamma}{dE}$$

$$\mathcal{J}(b,\ell) = \mathrm{J}_0 \int_{x_{\min}}^{x_{\max}} \rho^2 \left(r_{\mathrm{gal}}(b,\ell,x)\right) dx$$

Extragalactic:

$$\frac{d\Phi_\gamma}{dE} = \frac{\langle \sigma_A v \rangle}{2} \frac{c}{4\pi H_0} \frac{(f_{\mathrm{DM}}\Omega_m)^2 \rho_{\mathrm{crit}}^2}{m_\chi^2} \int_0^{z_{\mathrm{up}}} \frac{f(z)(1+z)^3}{h(z)} \frac{dN_\gamma(E')}{dE'} e^{-\tau(z,E')} dz$$

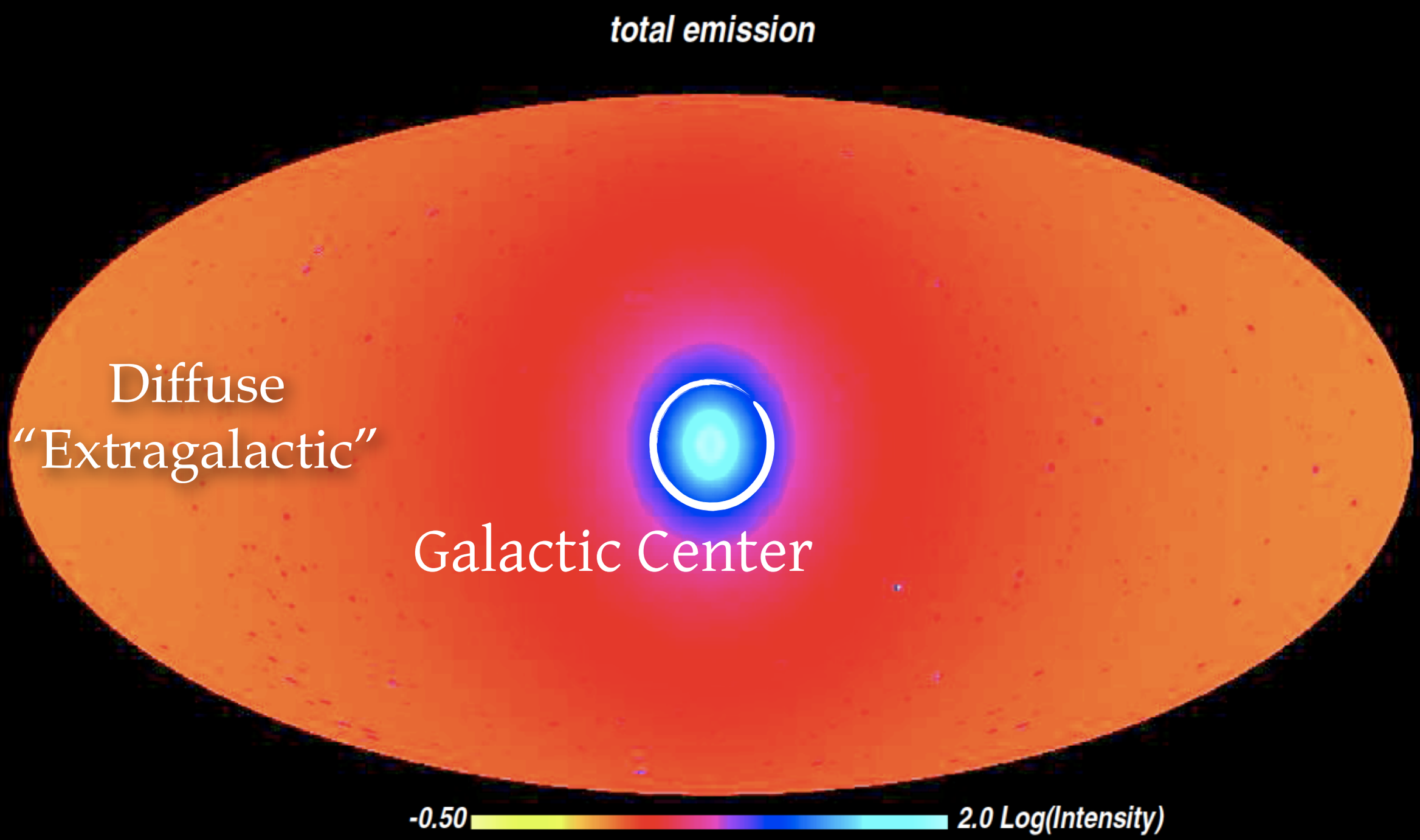
Galactic Contribution Over All-sky



Diffuse
"Extragalactic"

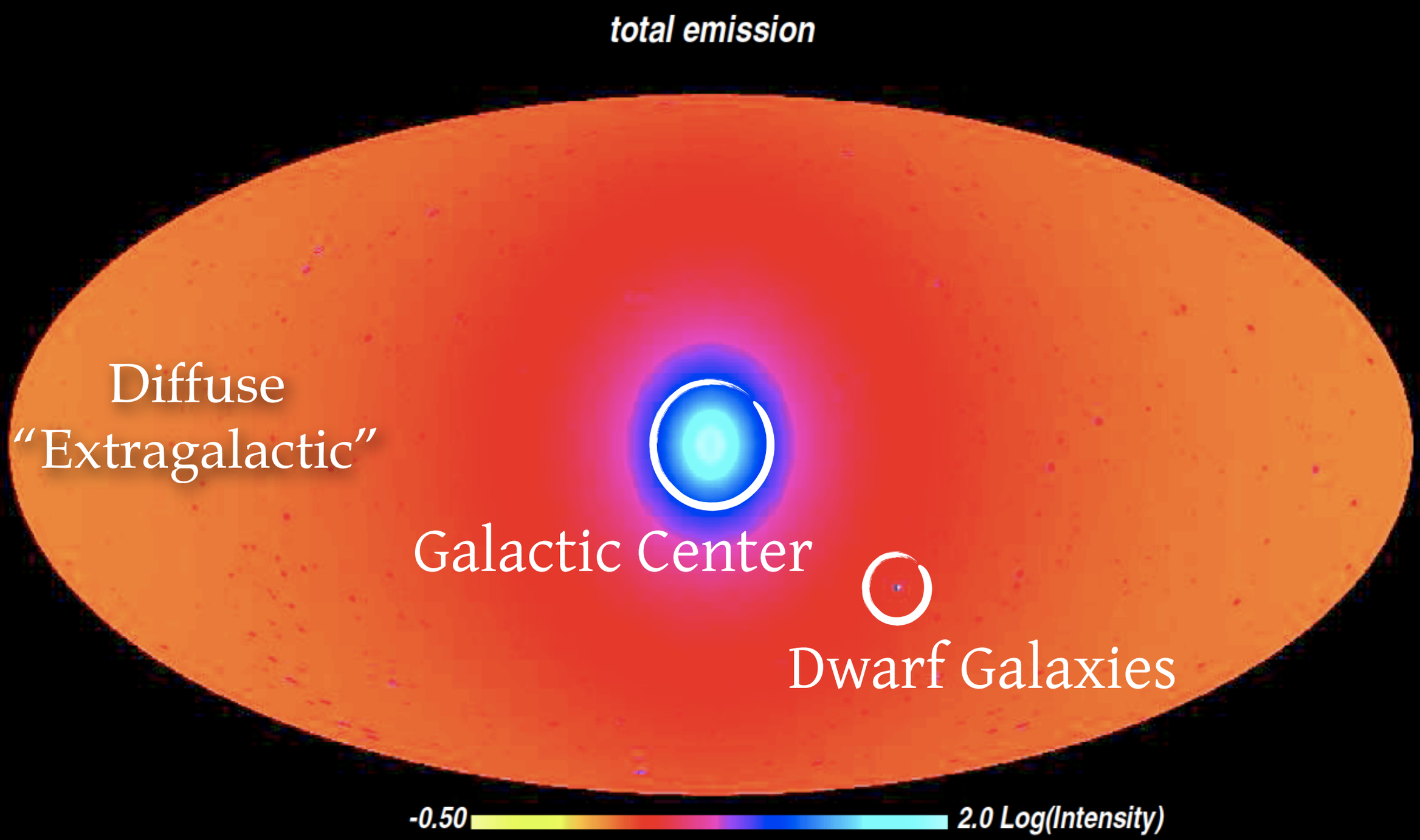
Springel et al 2008

Galactic Contribution Over All-sky



Springel et al 2008

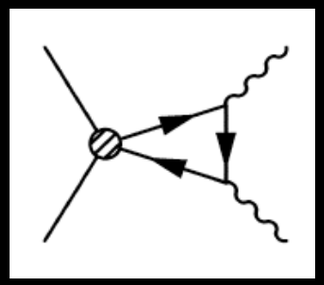
Galactic Contribution Over All-sky

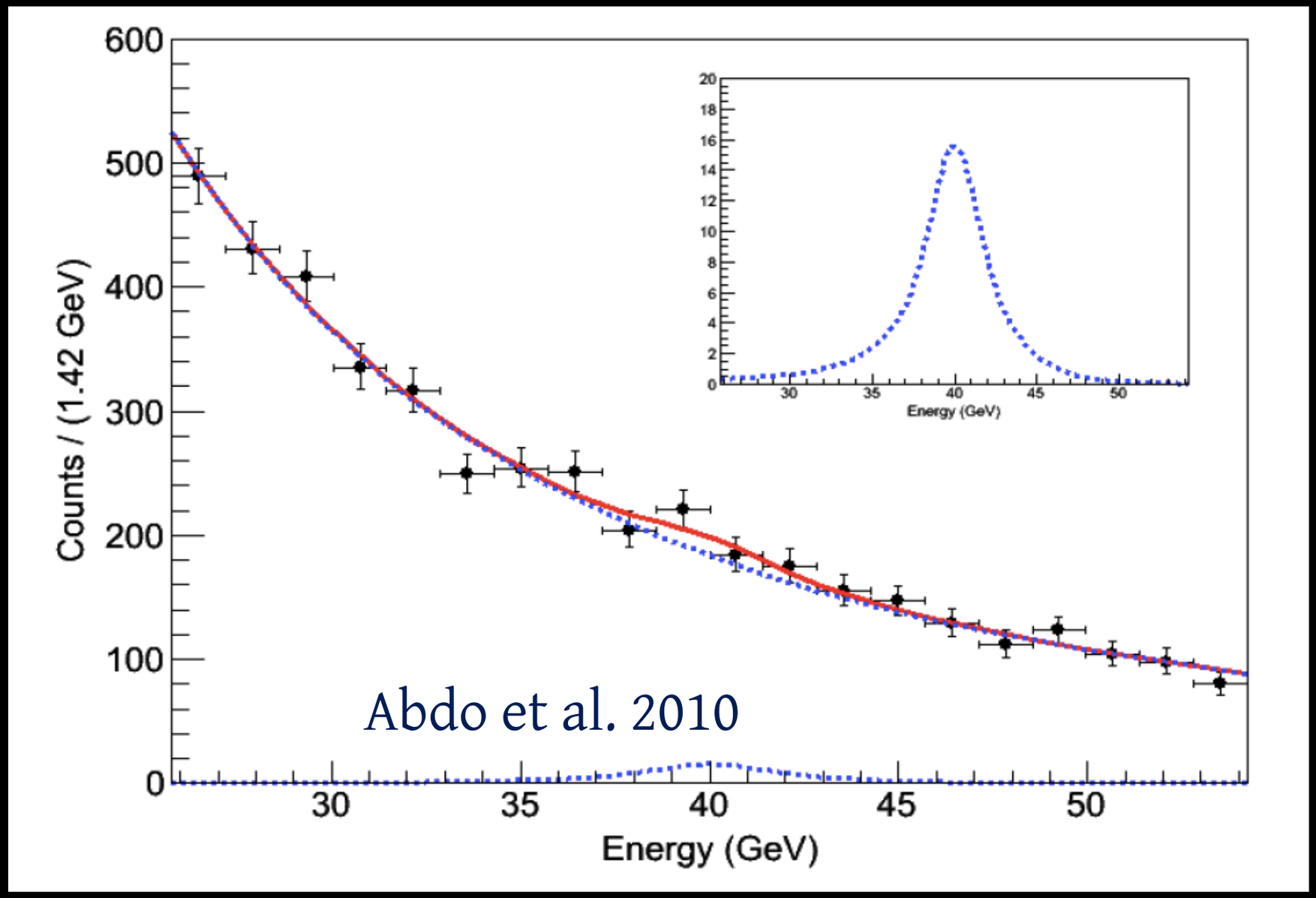


Springel et al 2008

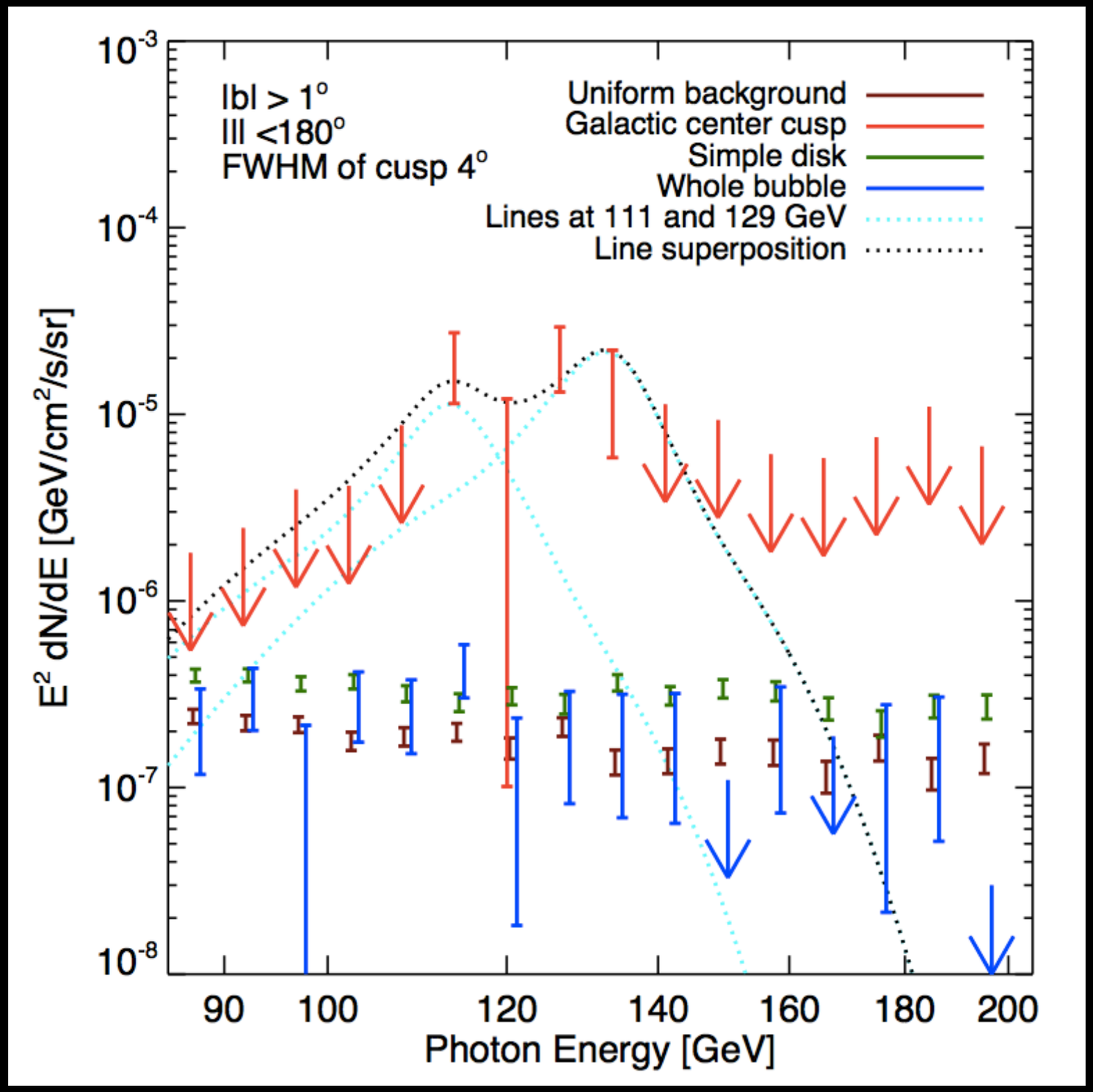
The Smoking Gun? -- A Gamma-ray Line

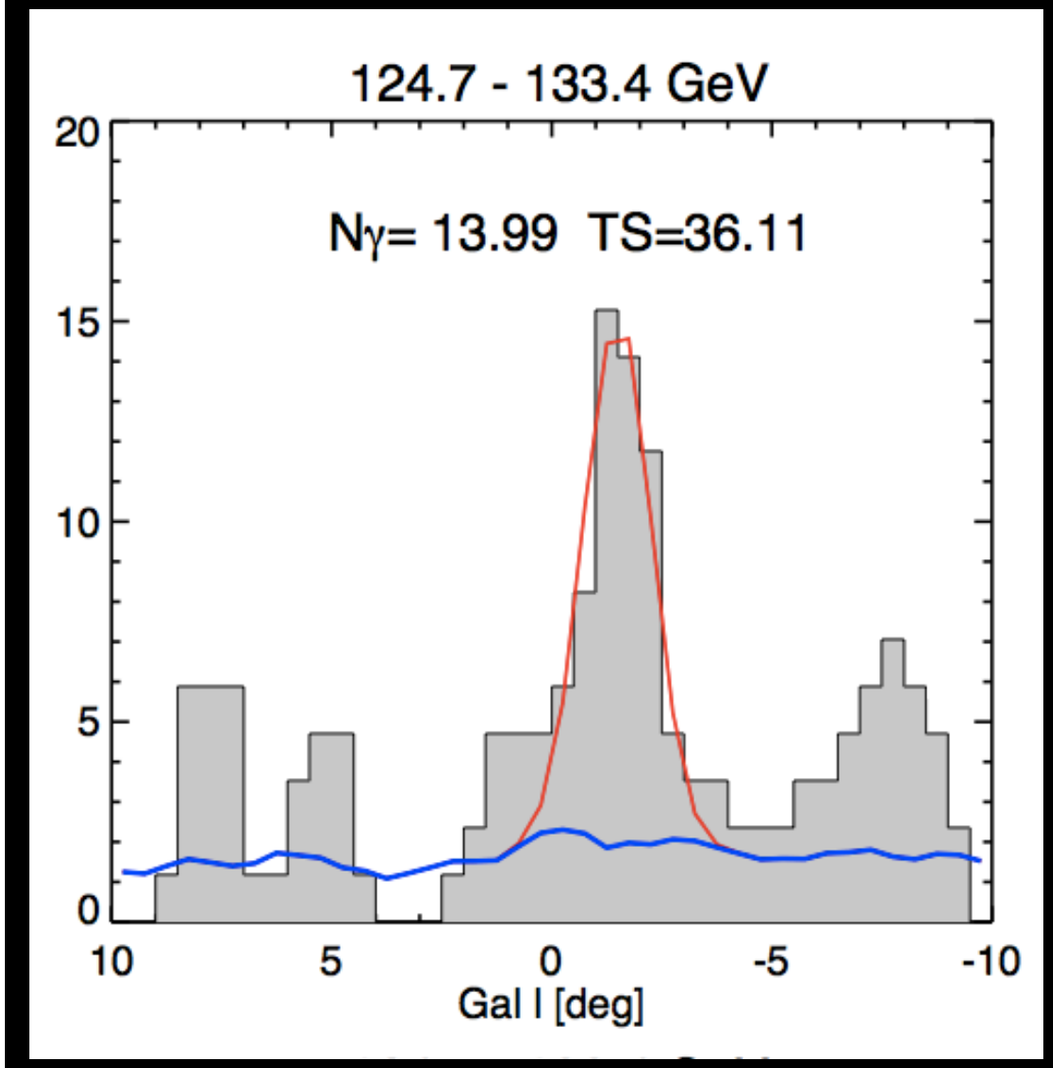
$$X_{\mathrm{DM}} + X_{\mathrm{DM}} \to 2\gamma$$





Smoking Gun in the GC Seen?





Weniger, 2012; Su & Finkbeiner, 2012; Temple et al. 2012

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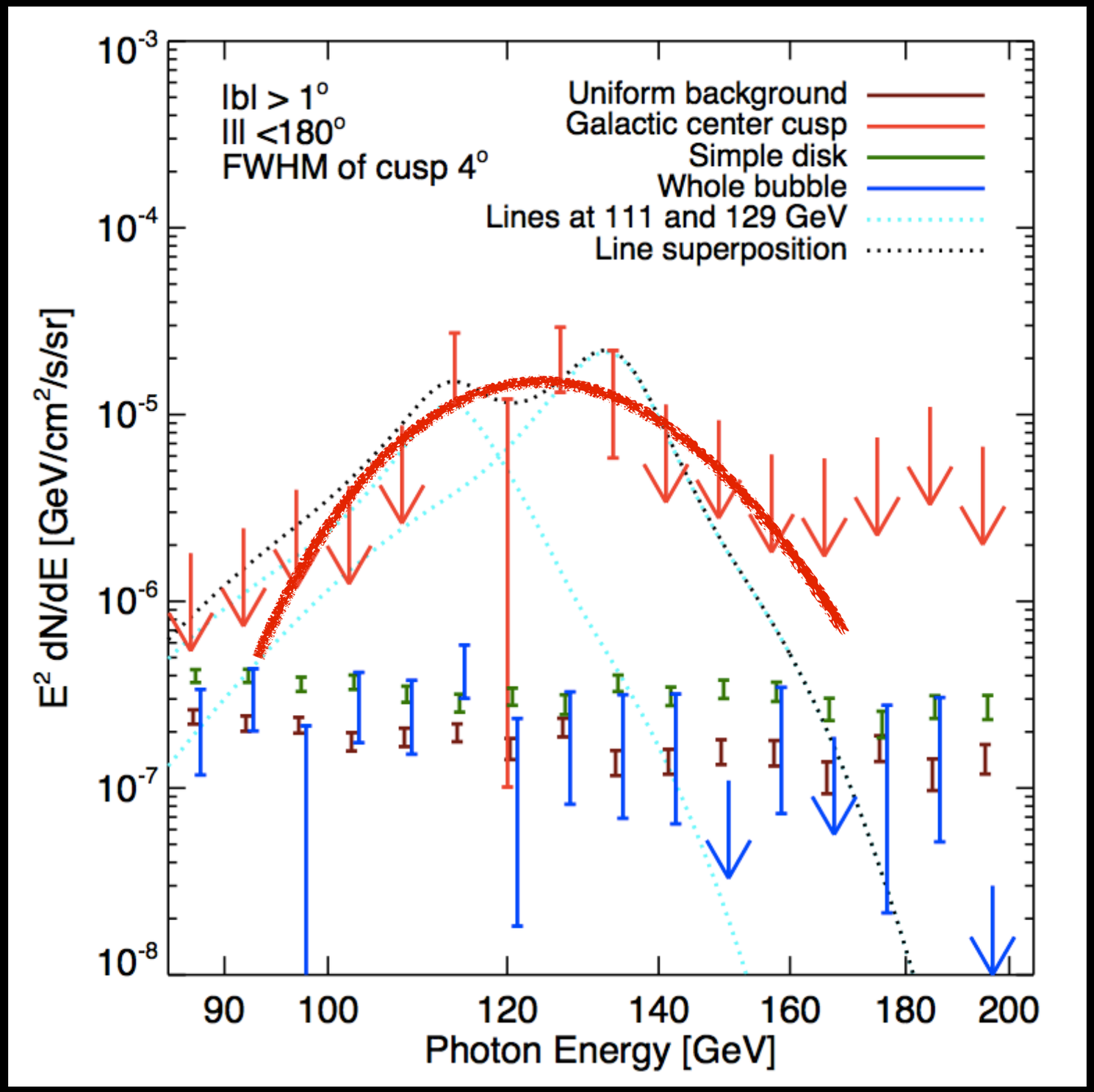
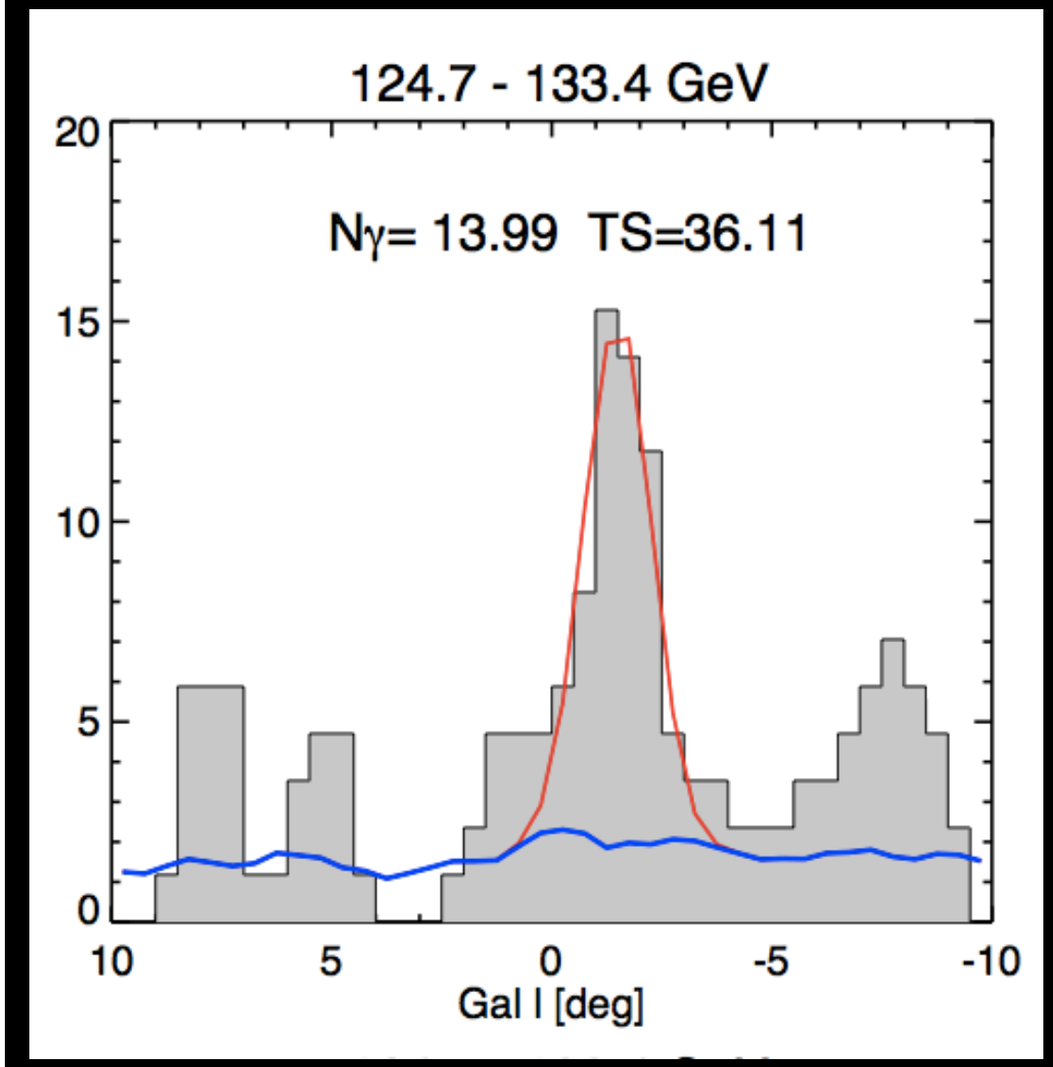
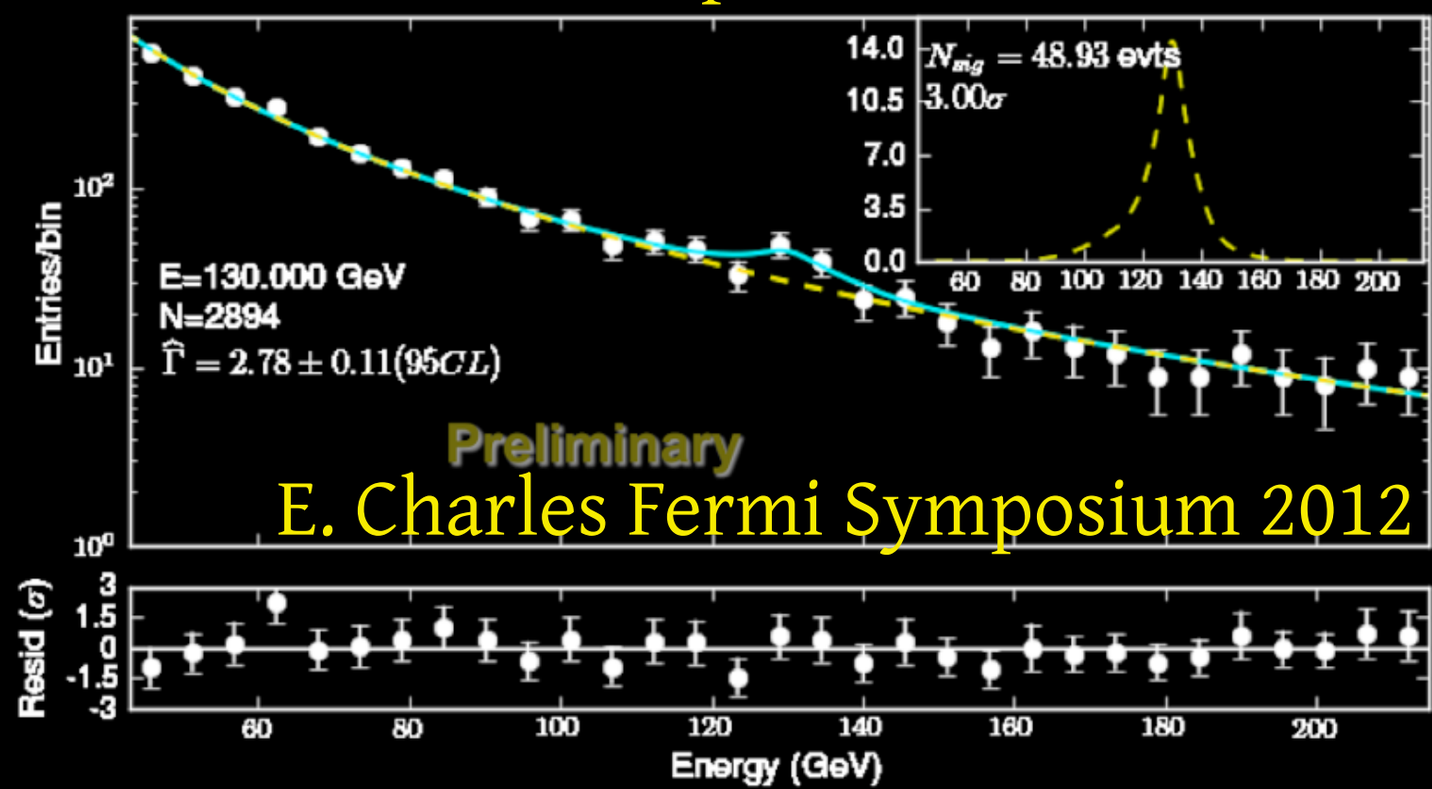




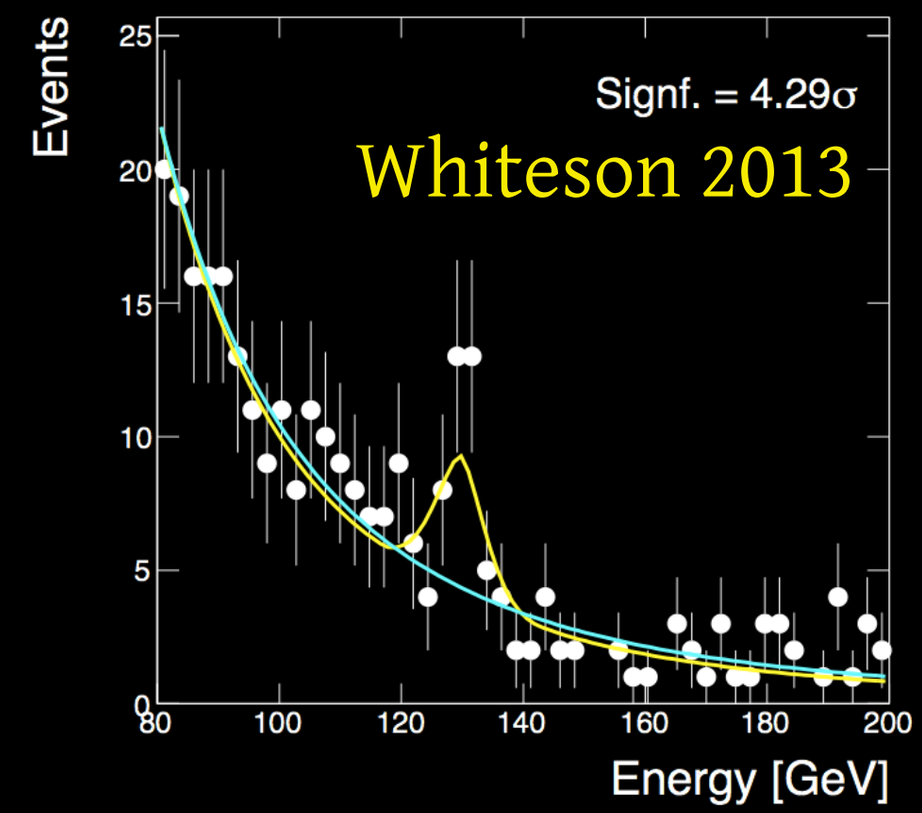
Weniger, 2012; Su & Finkbeiner, 2012; Temple et al. 2012

Is the GC line real?

Seen in Earth's limb photons...

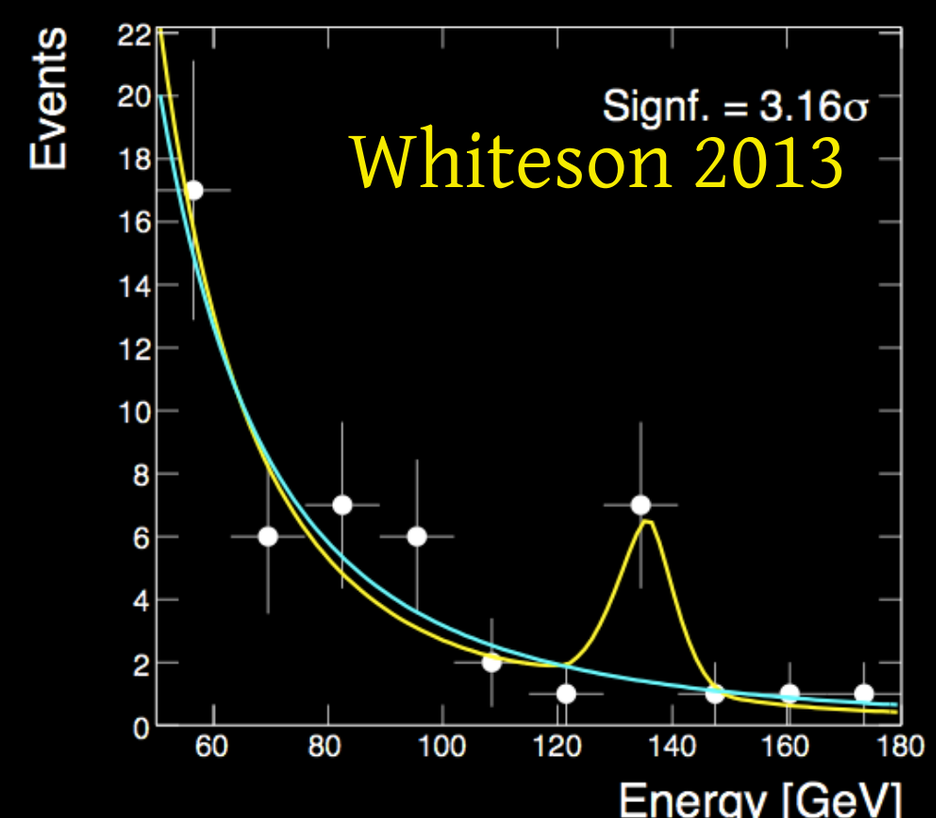


E. Charles Fermi Symposium 2012



Whiteson 2013

Seen toward the Sun...



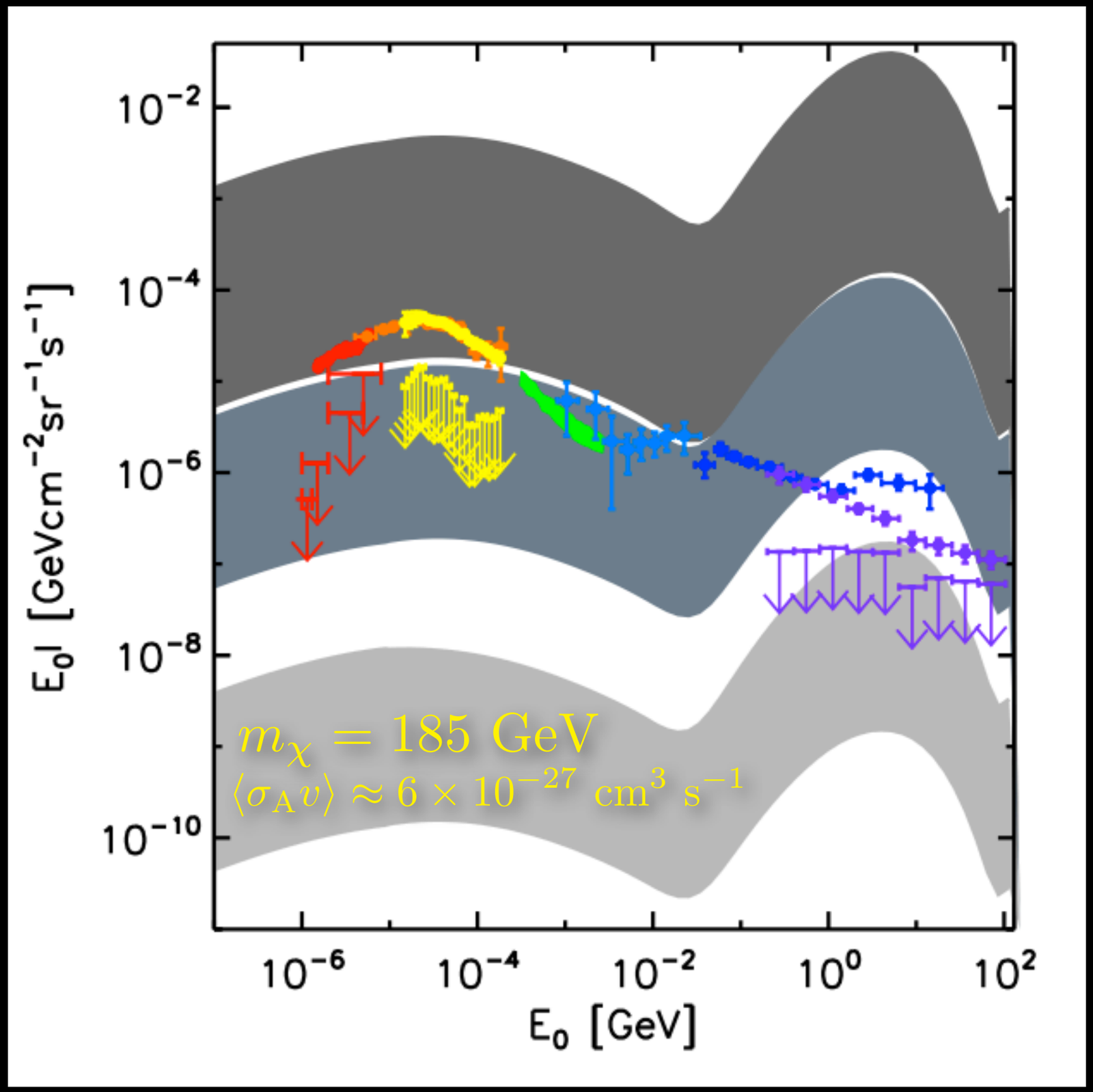
Whiteson 2013

& line photons are correlated with instrumental zenith angle

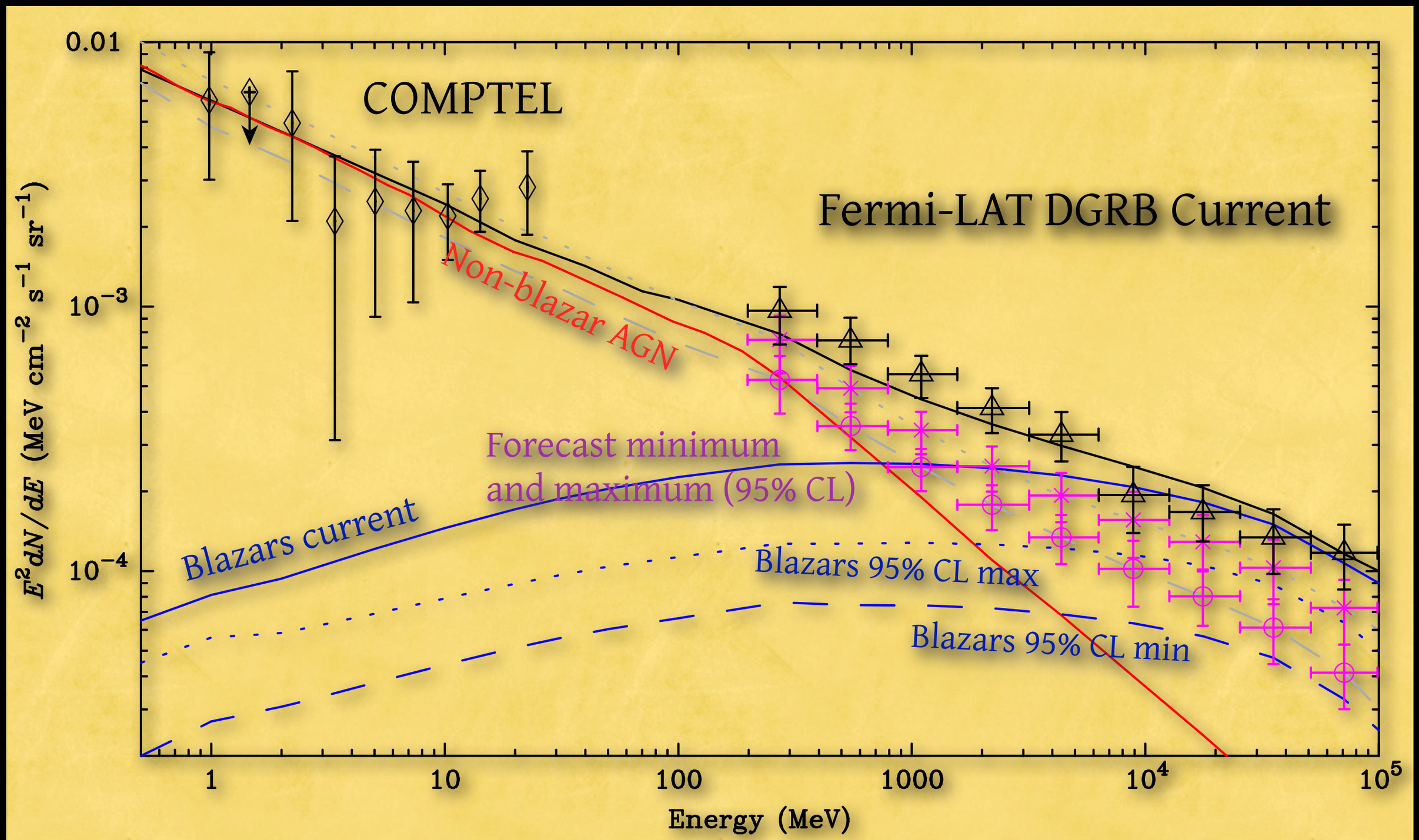
Conservative Diffuse Background Constraints

- Varied extragalactic contribution models within numerically-inferred ranges
- Included Inverse-Compton component at lower energies

Zavala et al 2011



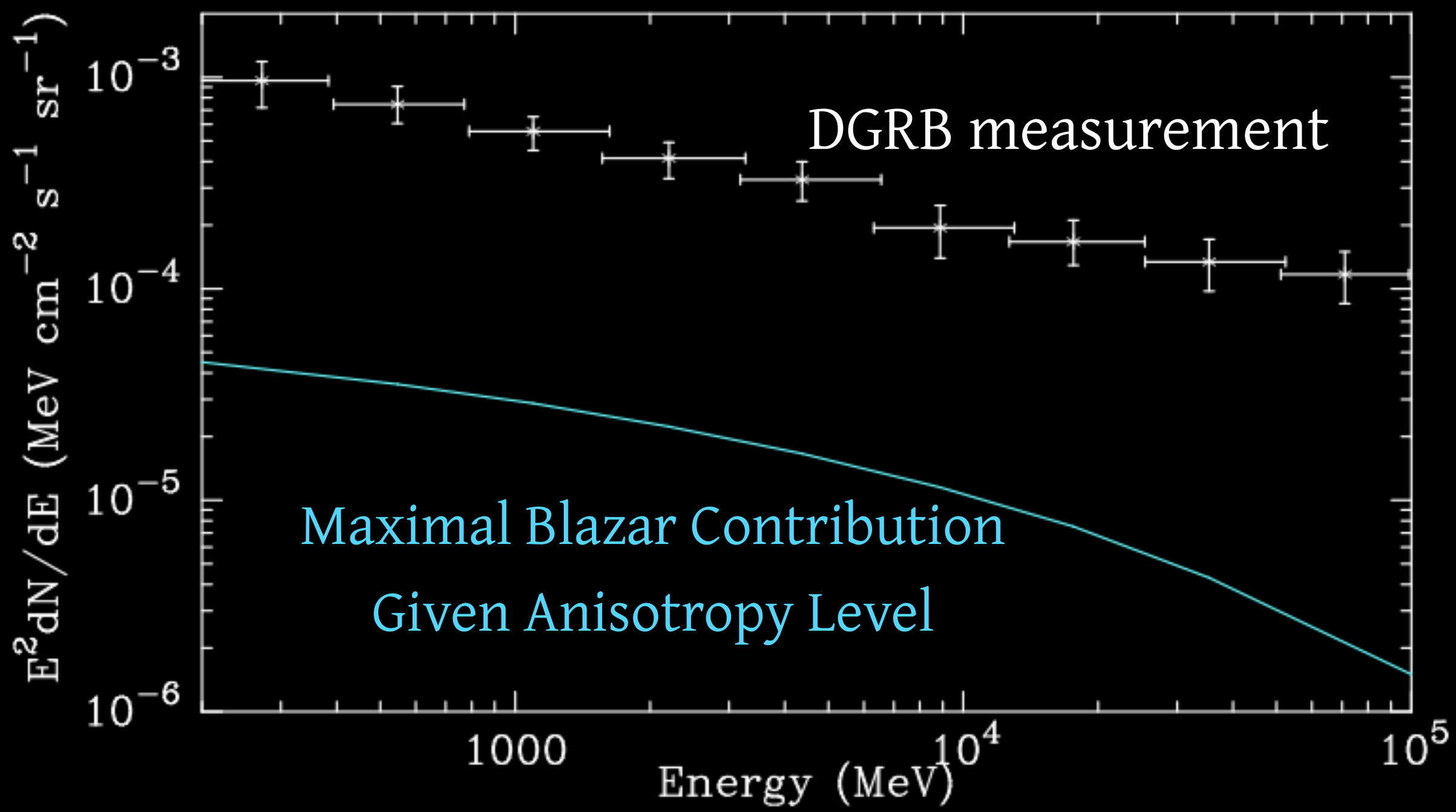
Forecasts for Fermi-LAT's DGRB: LDDE Blazar models



Abazajian, Blanchet & Harding, 2011

Diffuse γ-ray background from Blazars Limited by Anisotropy

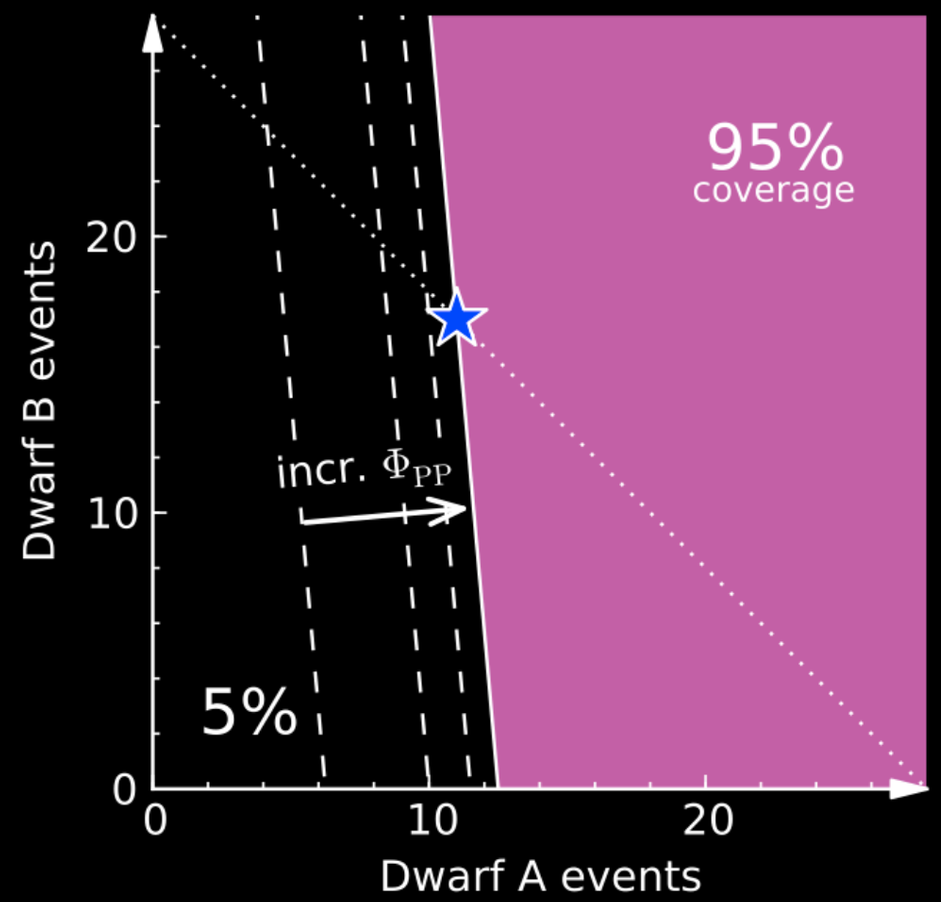
Measurement: Ackermann et al 2012

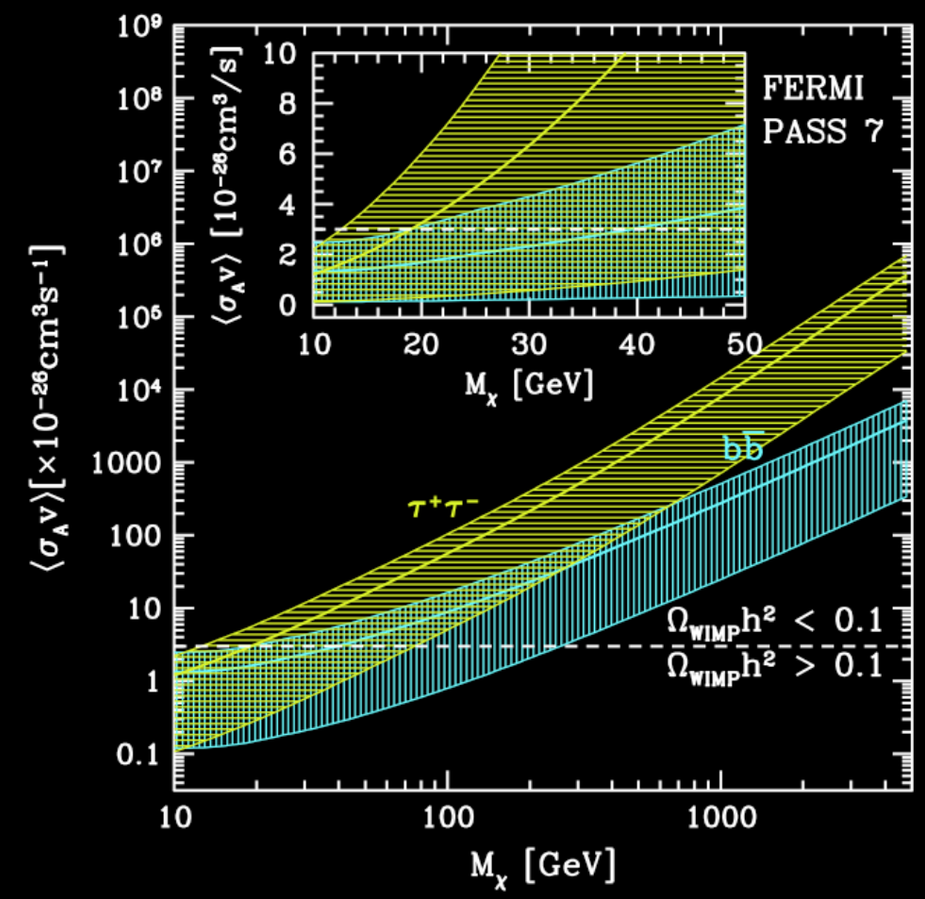


dN/dF: Cuoco, Siegal-Gaskins, Komatsu 2012
LDDE: Harding & Abazajian, 2012

Best Current Limit at Low Masses: Stacking Dwarf Galaxies

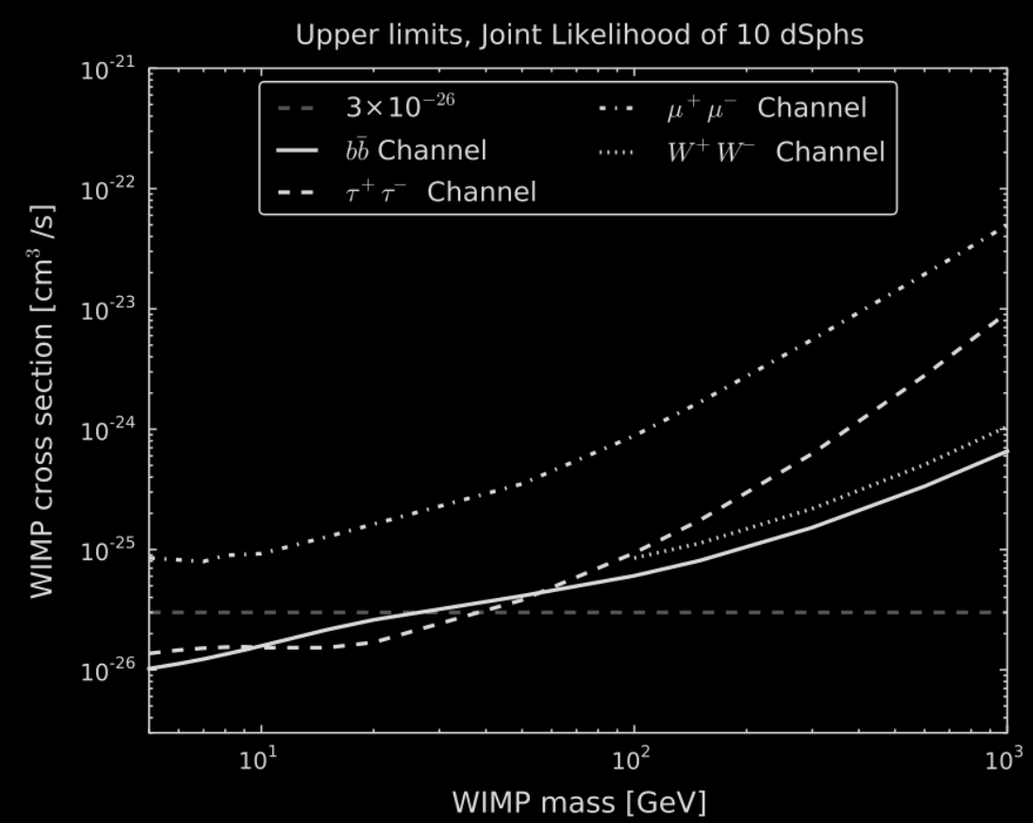
Frequentist, Pass 7





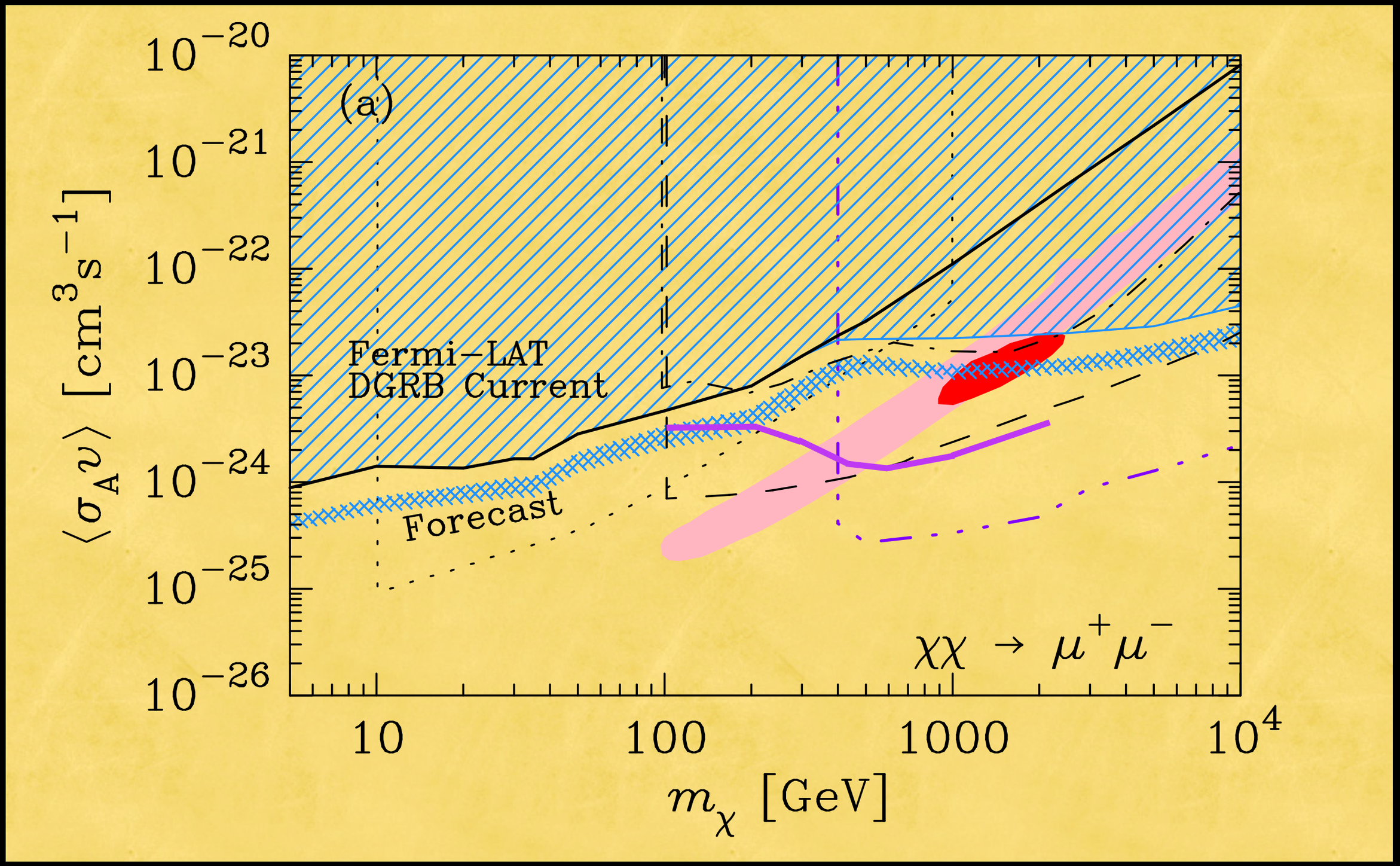
Geringer-Sameth & Koushiappas 2011

Bayesian, Pass 6v3



Fermi-Collab. Ackermann et al. 2011

Annihilation Channel Gamma-ray Constraint
Status & Forecasts



Abazajian, Blanchet & Harding 2012

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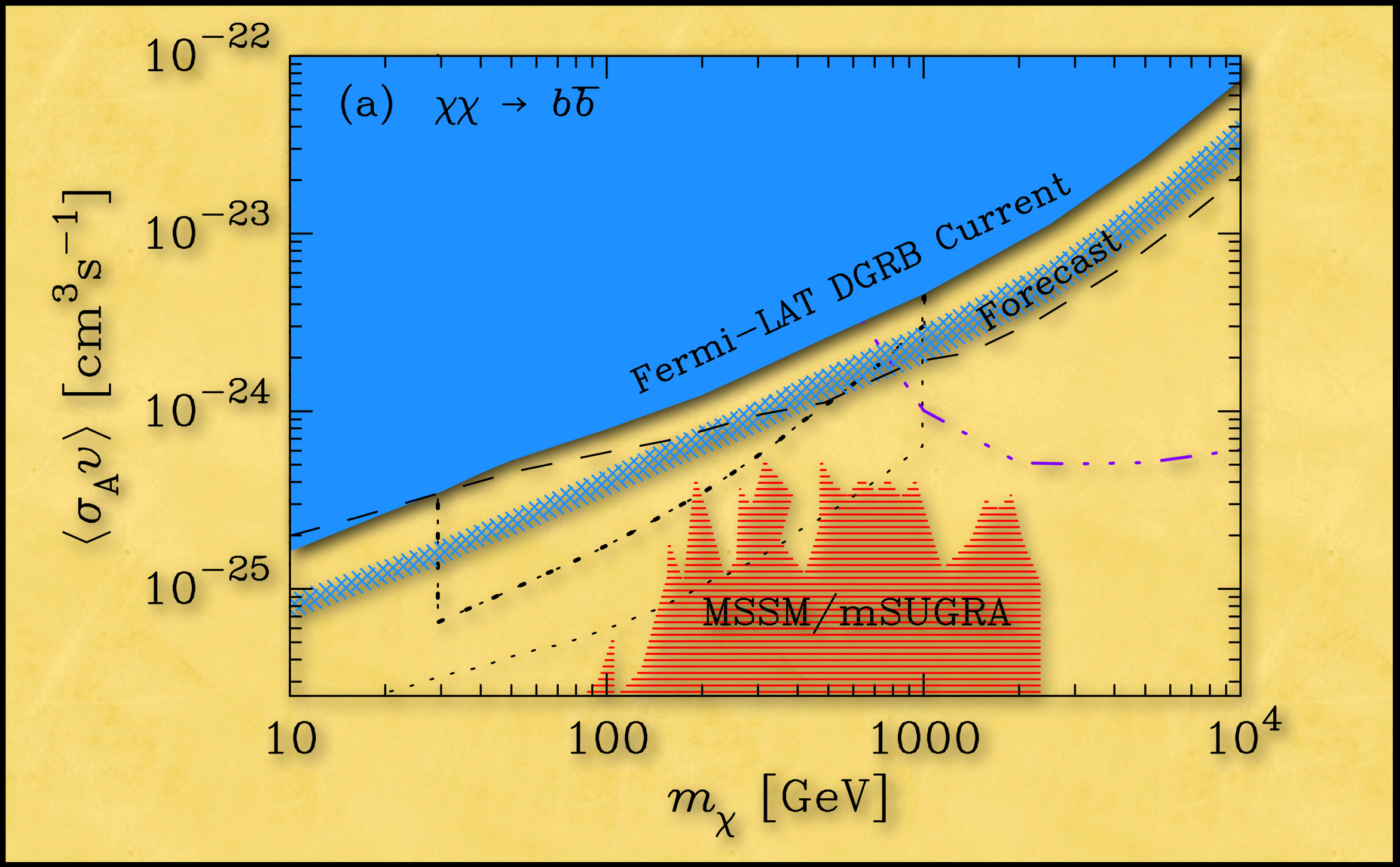

Abazajian, Blanchet & Harding 2012

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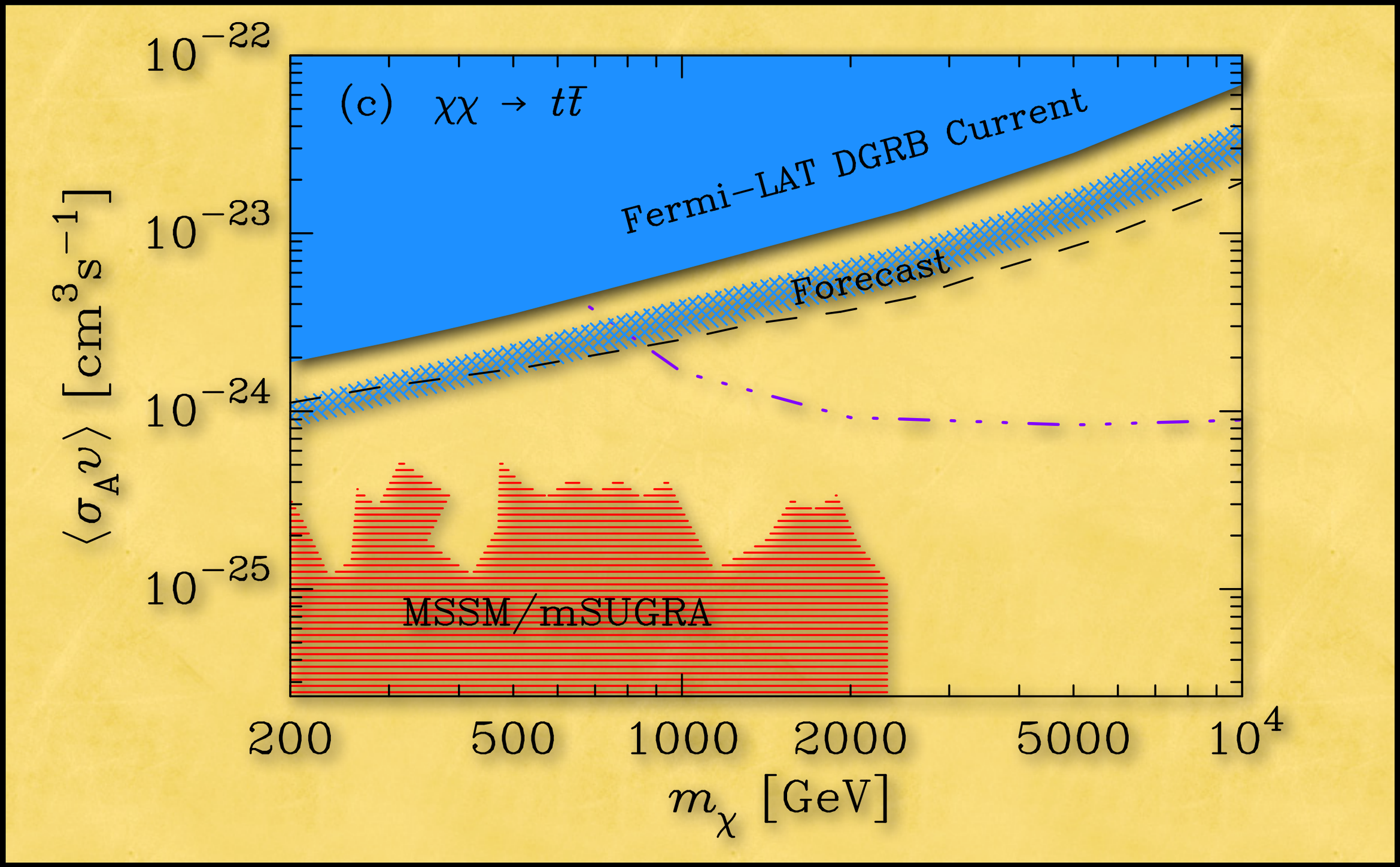

Abazajian, Blanchet & Harding 2012

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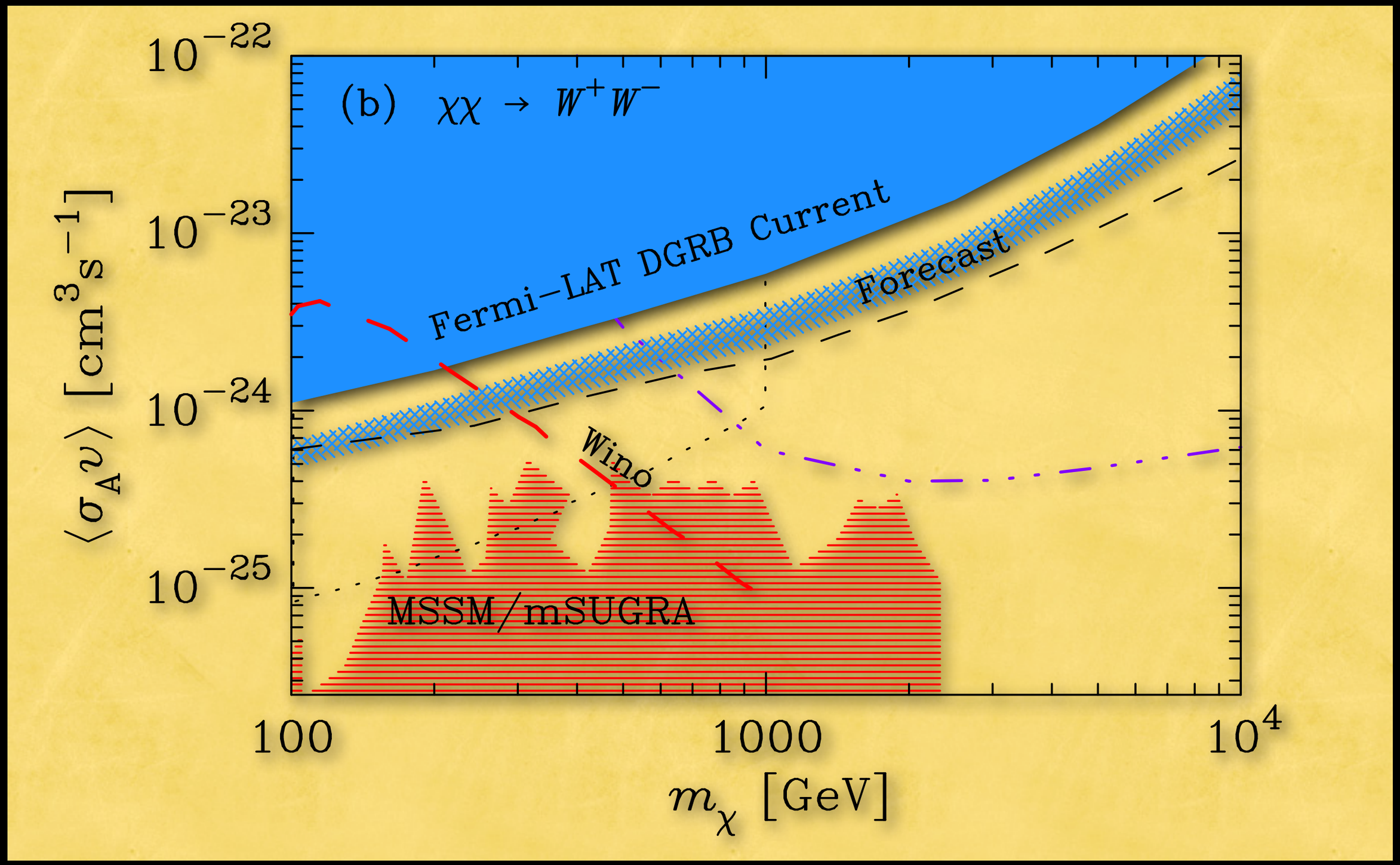

Abazajian, Blanchet & Harding 2012

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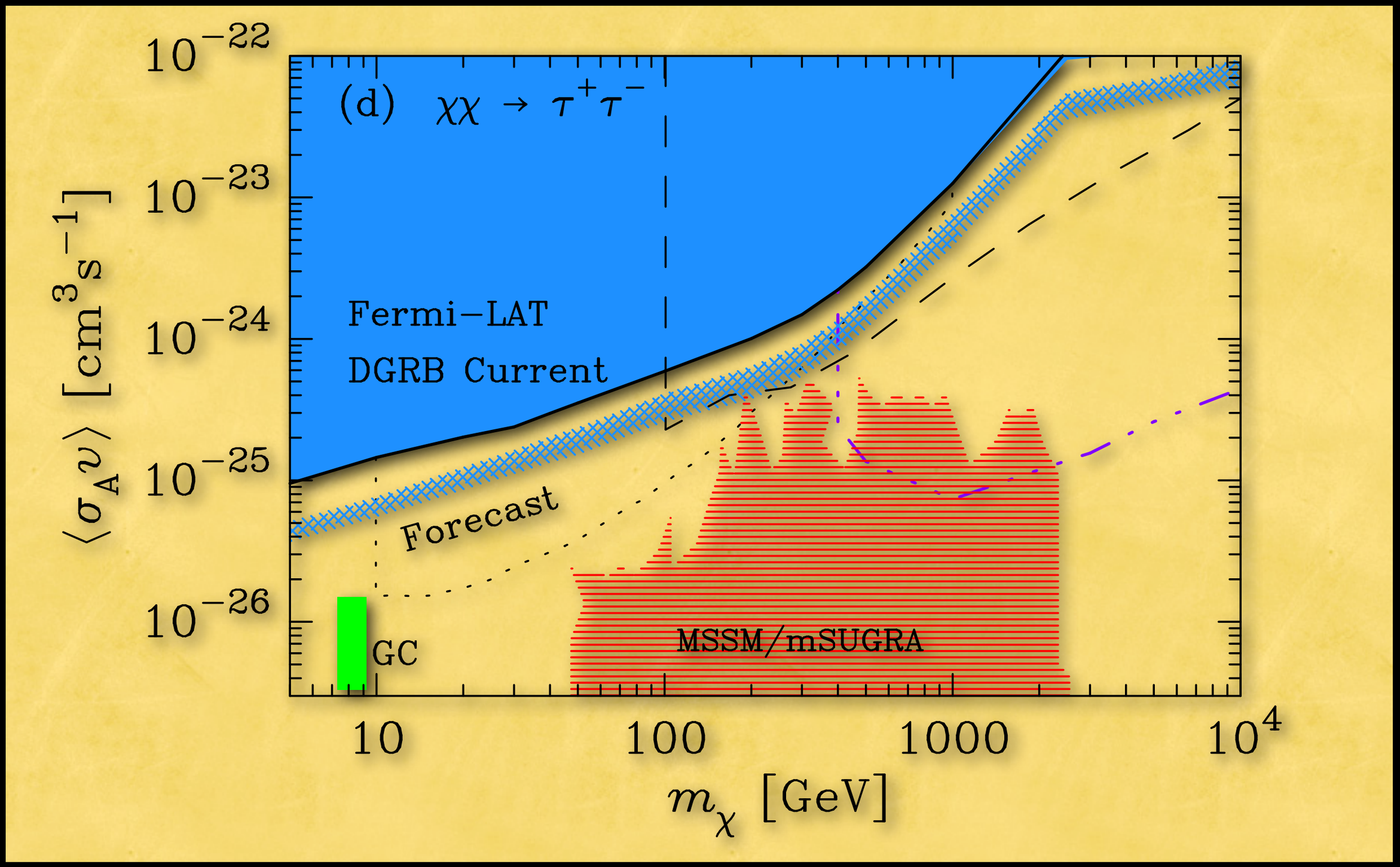
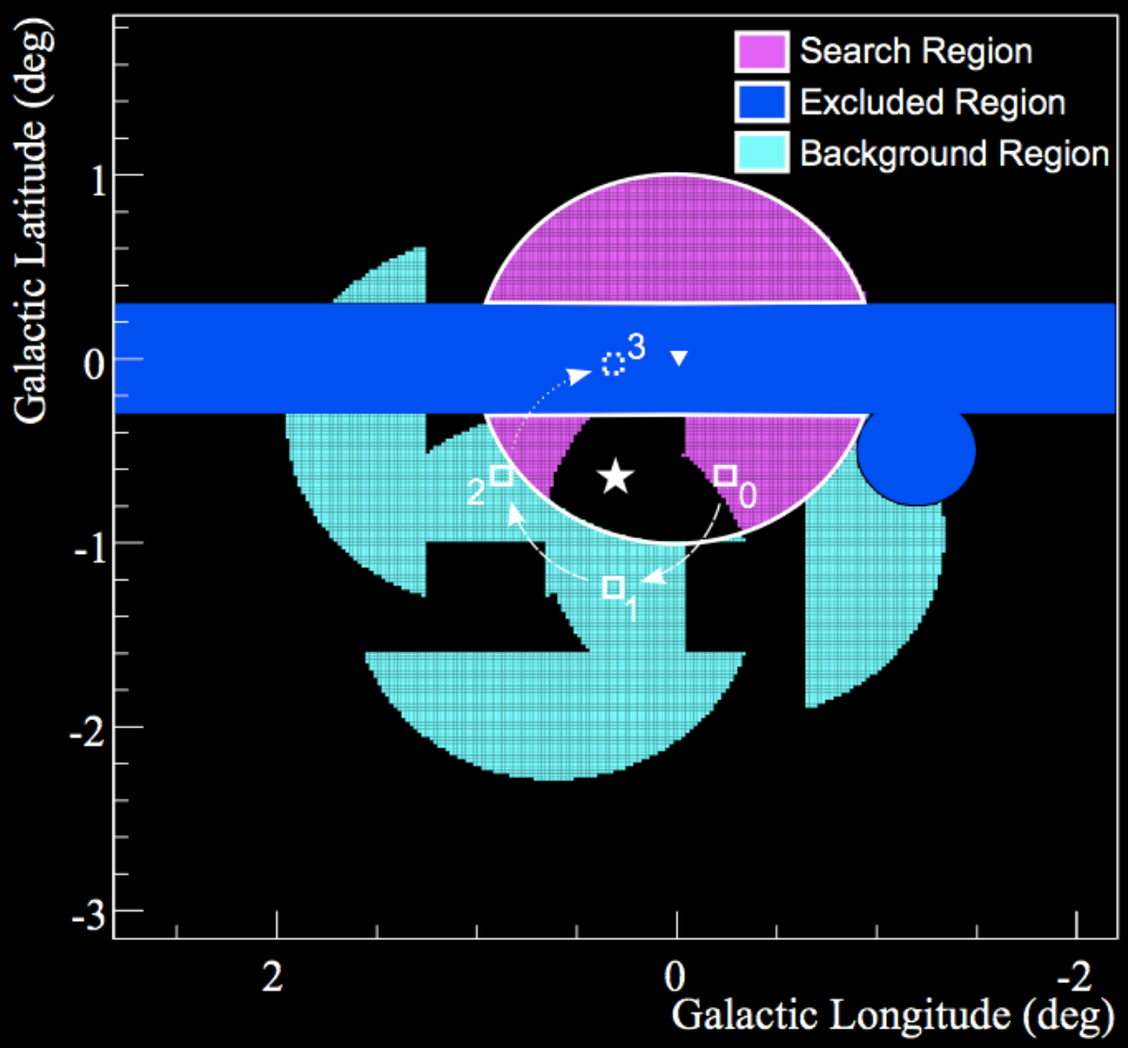


Abazajian, Blanchet & Harding 2012

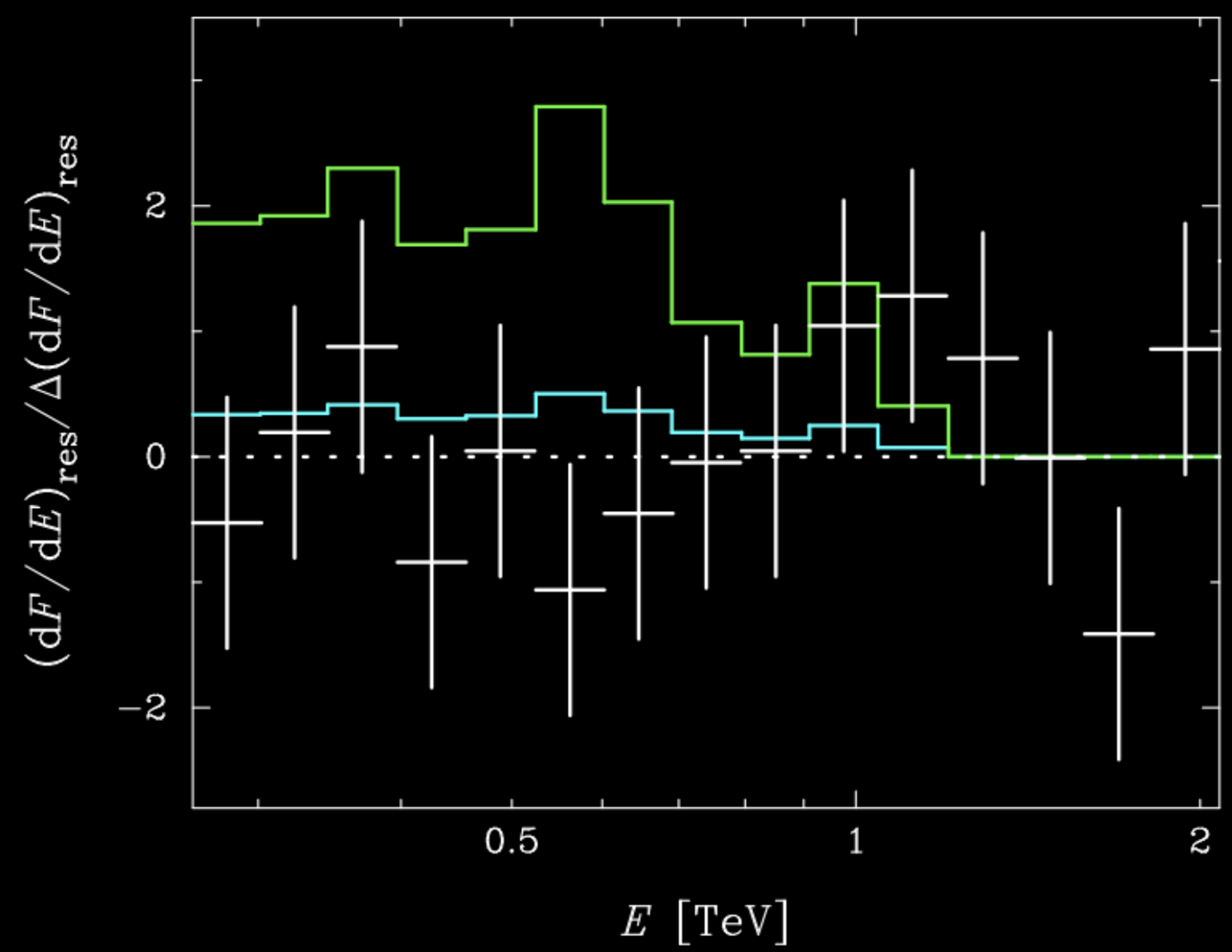
Best Current Limit at High DM Masses: High Energy Stereoscopic System (HESS) Gamma-Ray Telescope observation of GC

Southern Hemisphere (Namibia) location allows for extended observations of the Galactic Center

Residual Spectrum Toward the Galactic Center

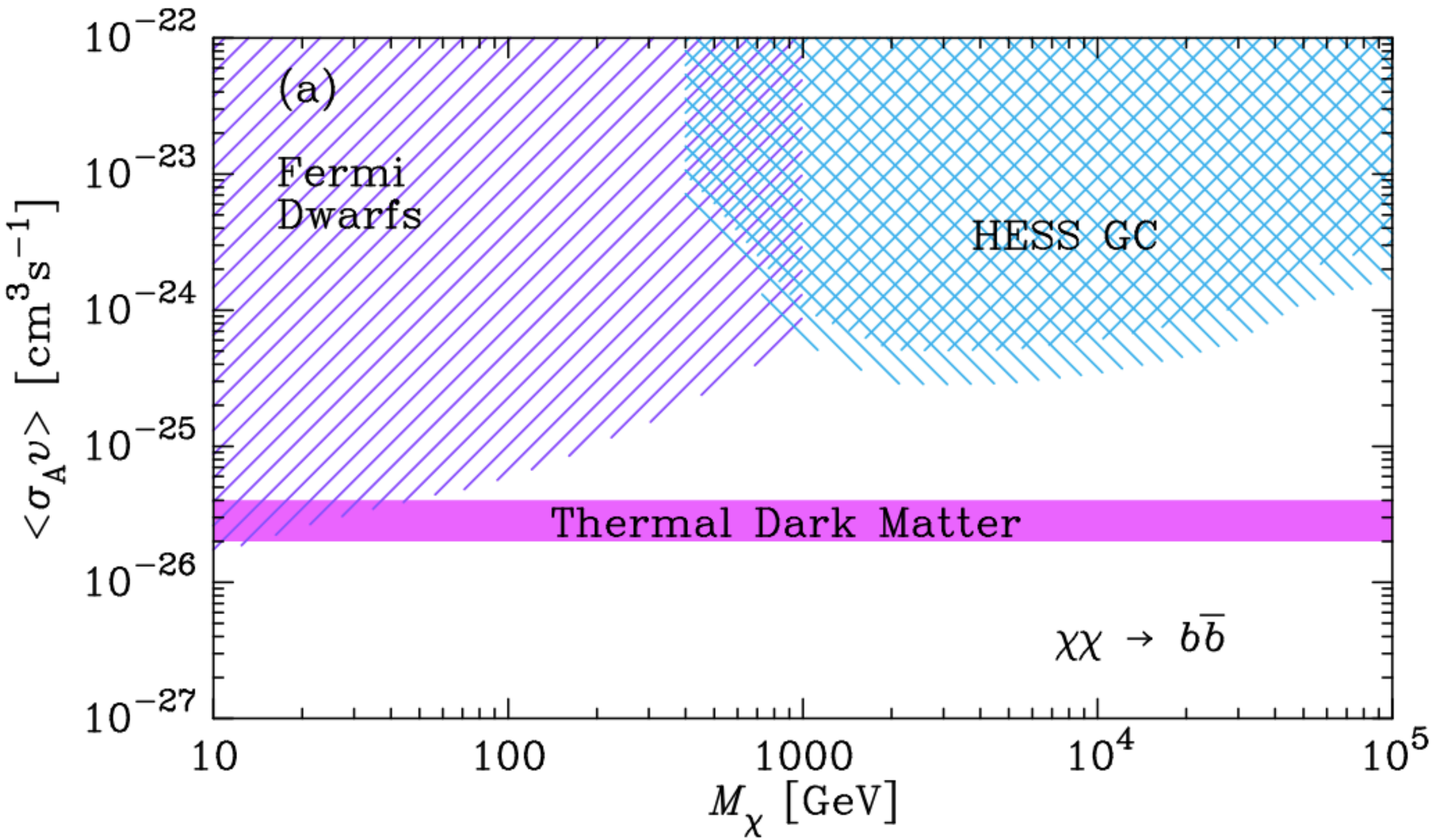


Abramowski et al 2011

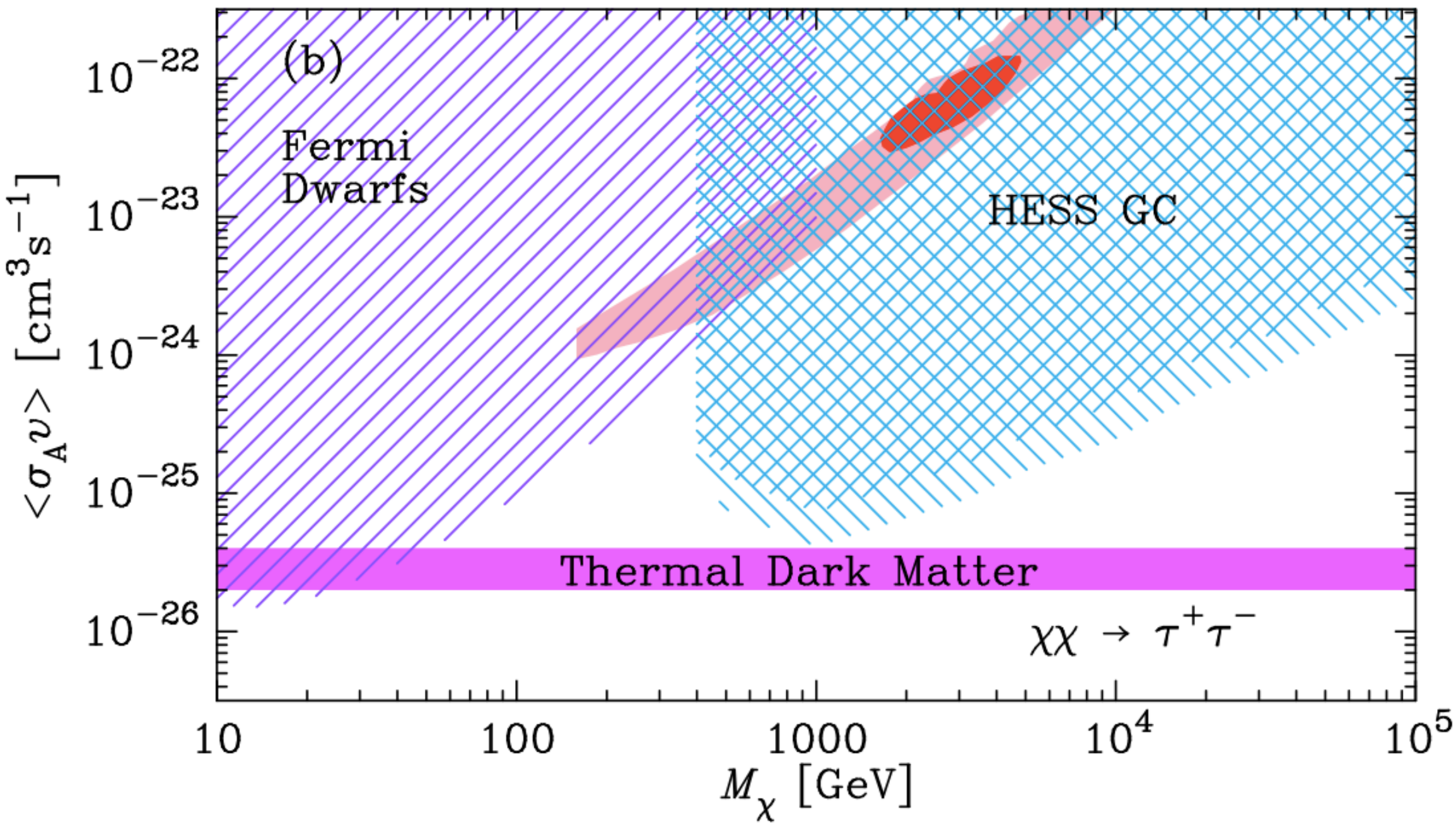


Abazajian & Harding 2012

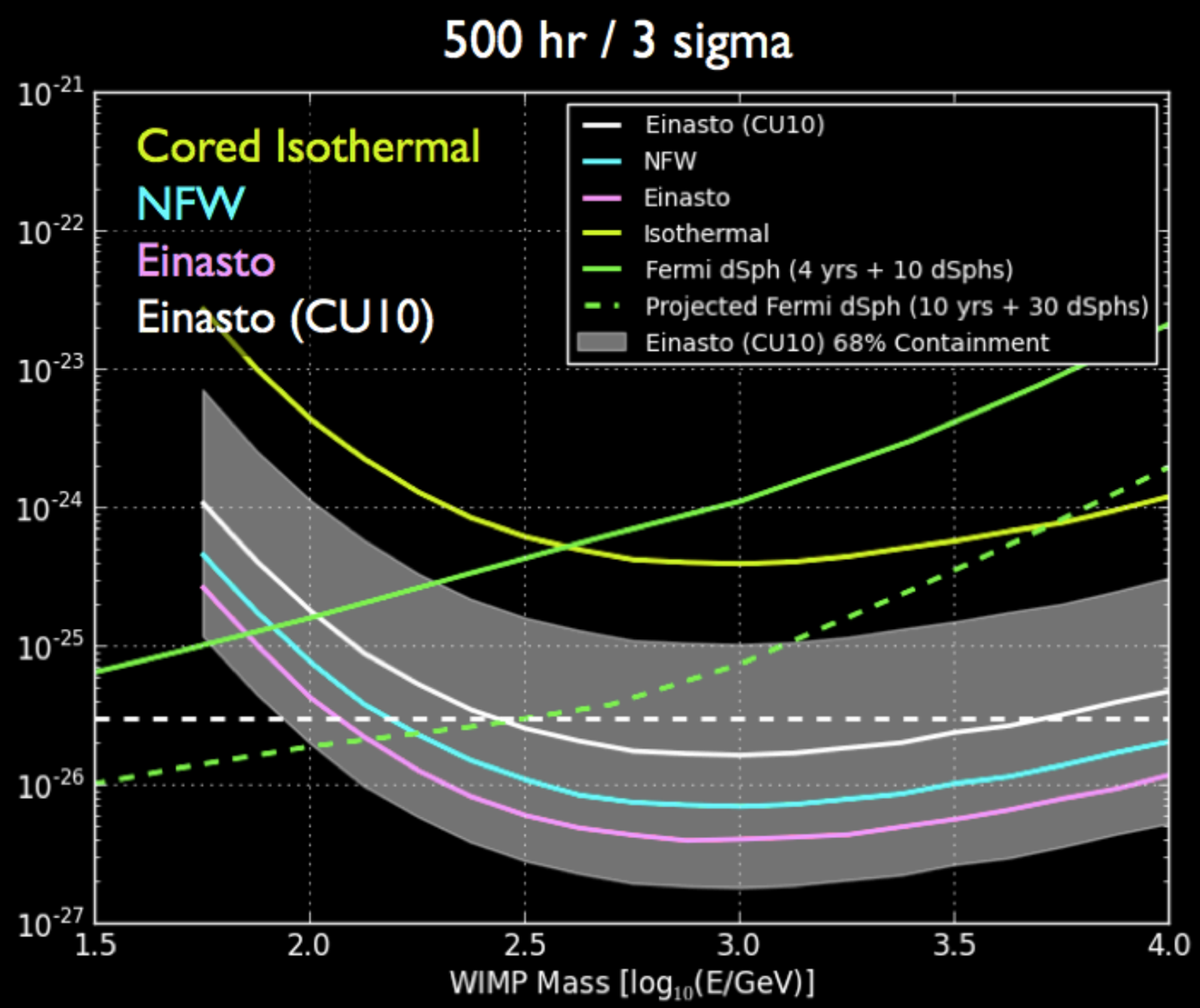
The Best Current Constraints: Fermi-LAT Dwarf Stacking & HESS GC



The Best Current Constraints: Fermi-LAT Dwarf Stacking & HESS GC



HESS GC to CTA GC: Forecasts



Matthew Wood, Aspen 2013

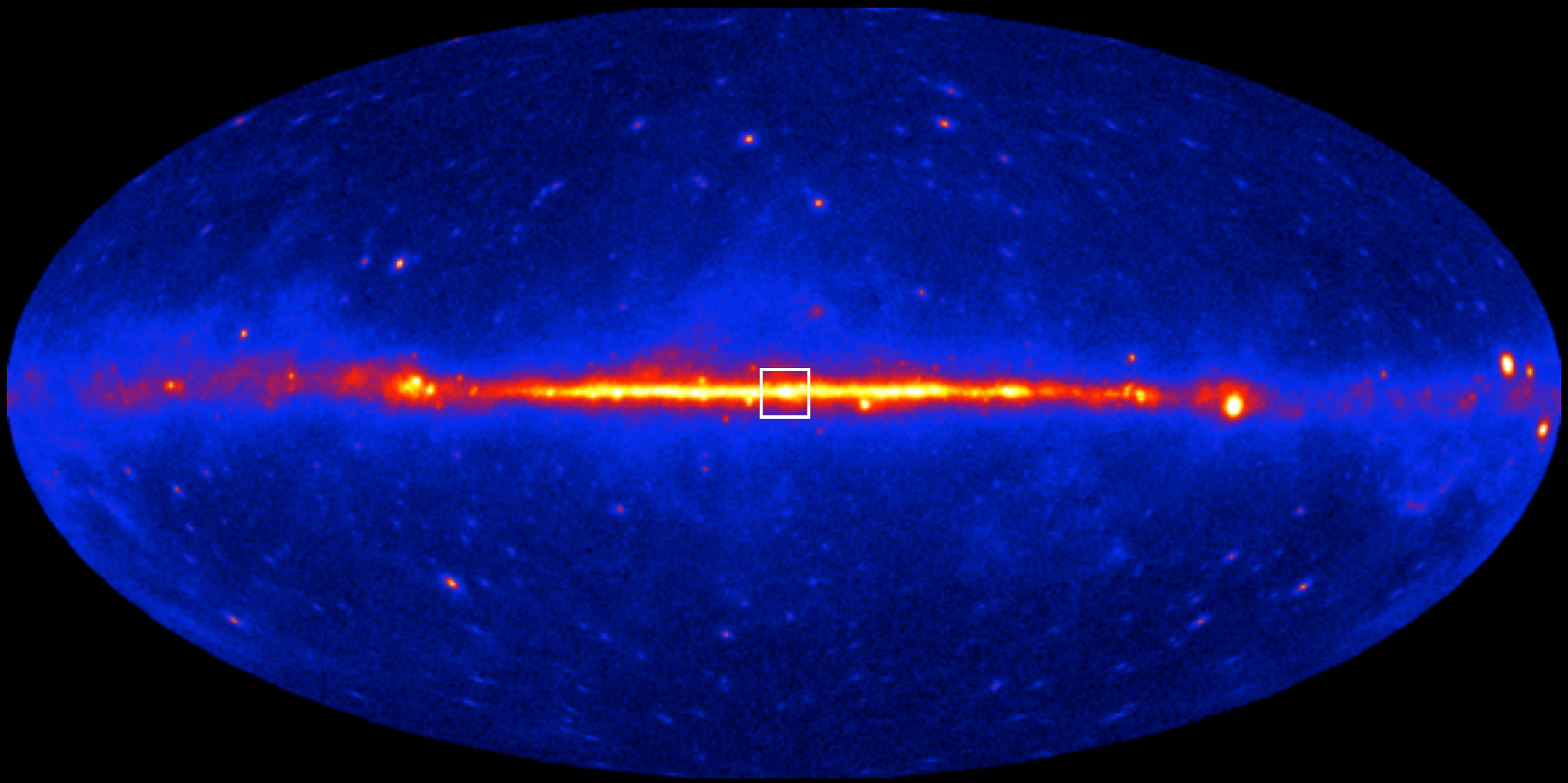
- Constraining Inner MW Halo Structure requires robust numerical simulations

- Numerical simulations of MW-size halos that show "isothermal" or cores at a scale of ~2 to ~3 from force-softening length.

Not the same level of rigor in these simulations as that establishing the NFW-like profile in DM-only simulations

(Abazajian & Harding 2012)

Galactic Center should be the brightest DM annihilation



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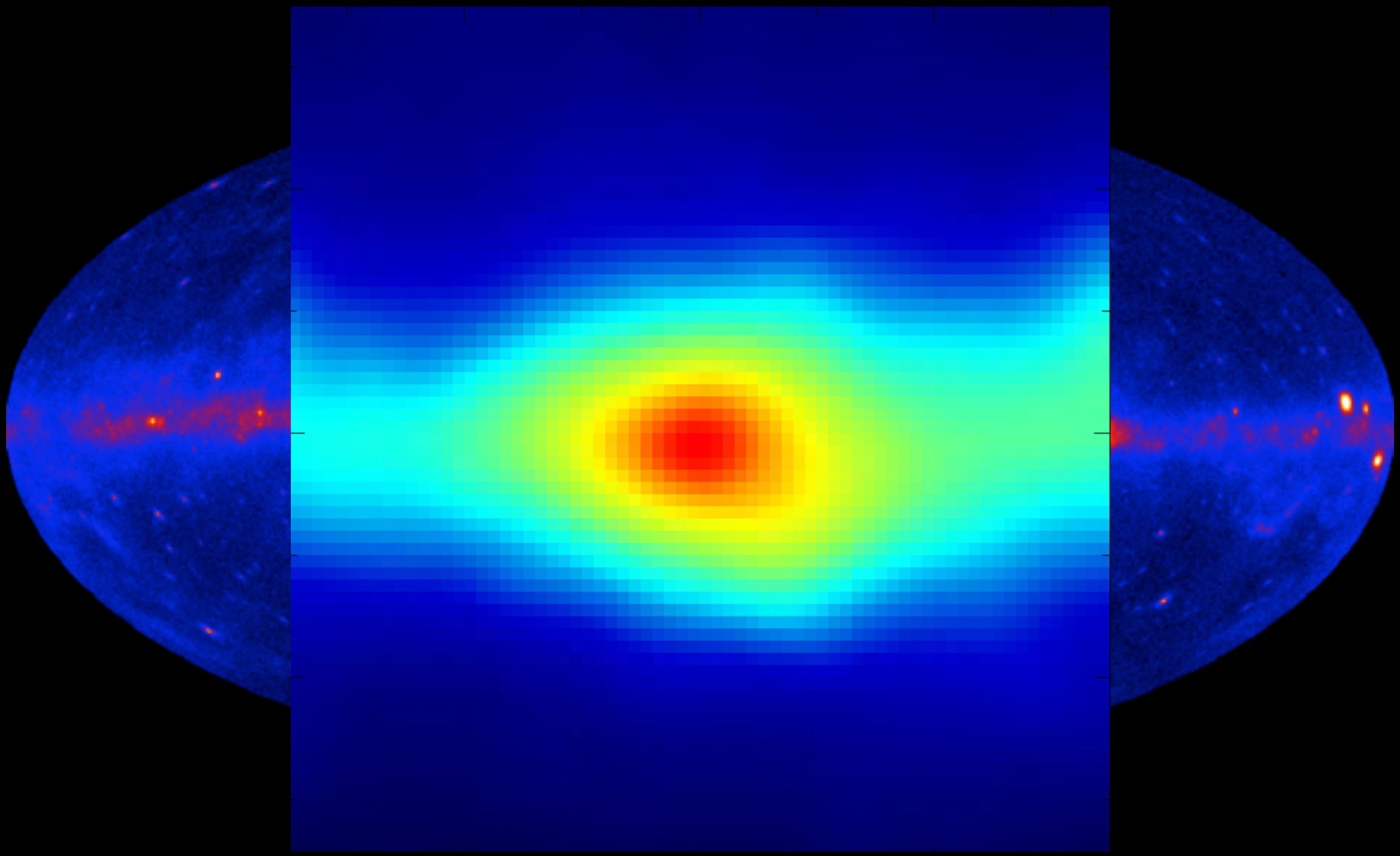
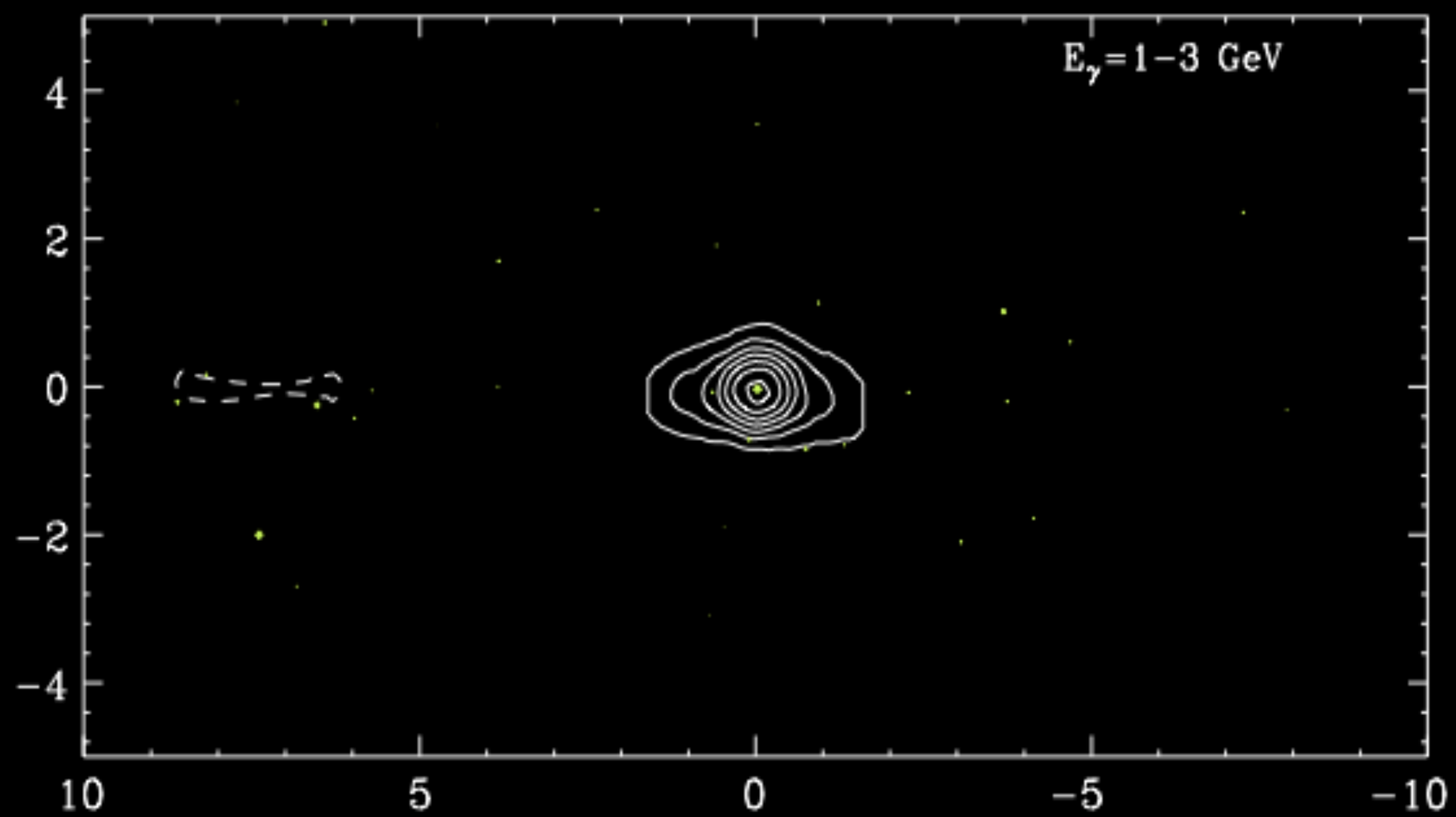


Dark Matter Annihilation in the Galactic Center?

in the continuum



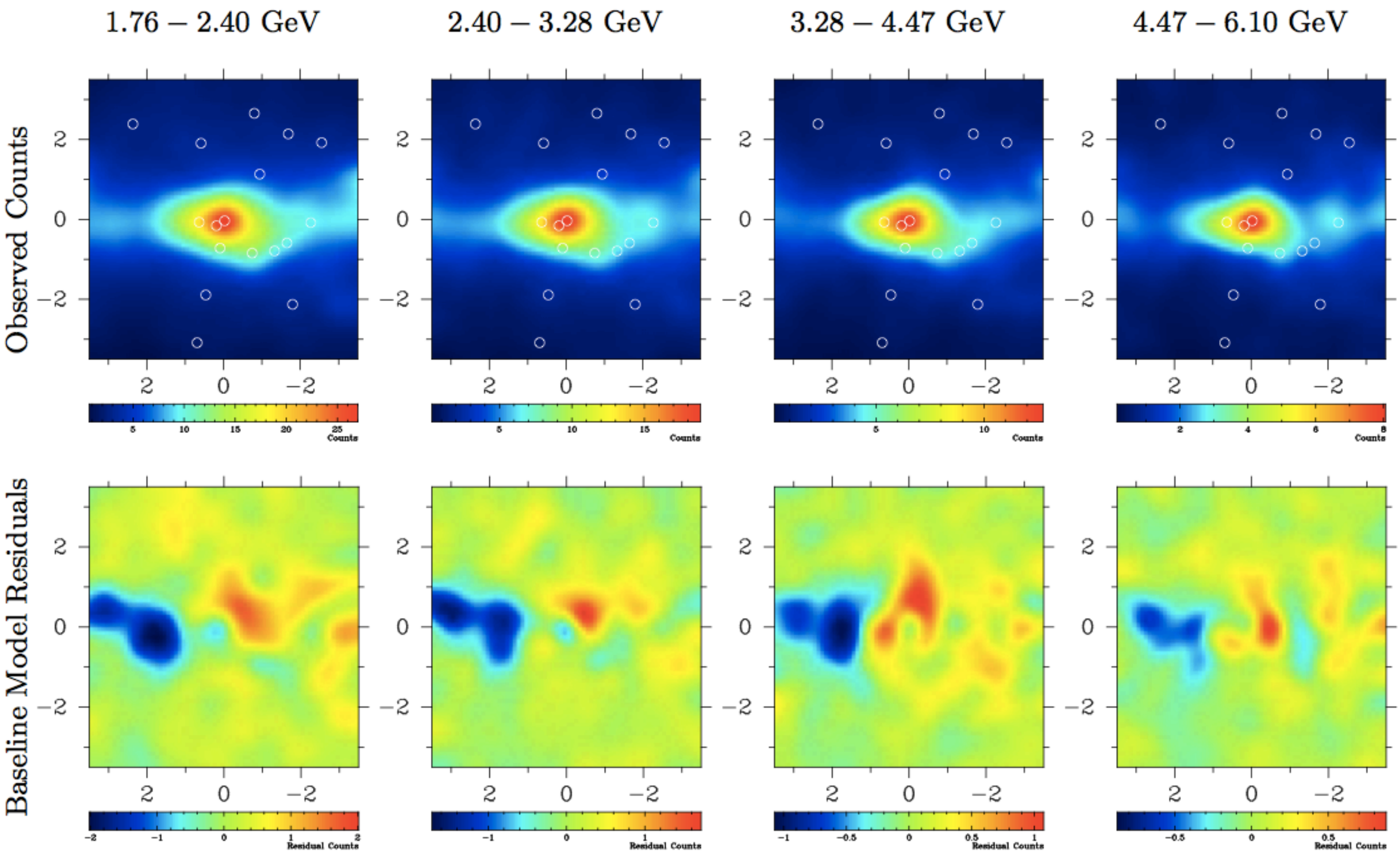
Yes it's extended!

Hooper & Goodenough, 2010
Hooper & Linden, 2011

No, it's point sources!

Boyarsky et al. 2011

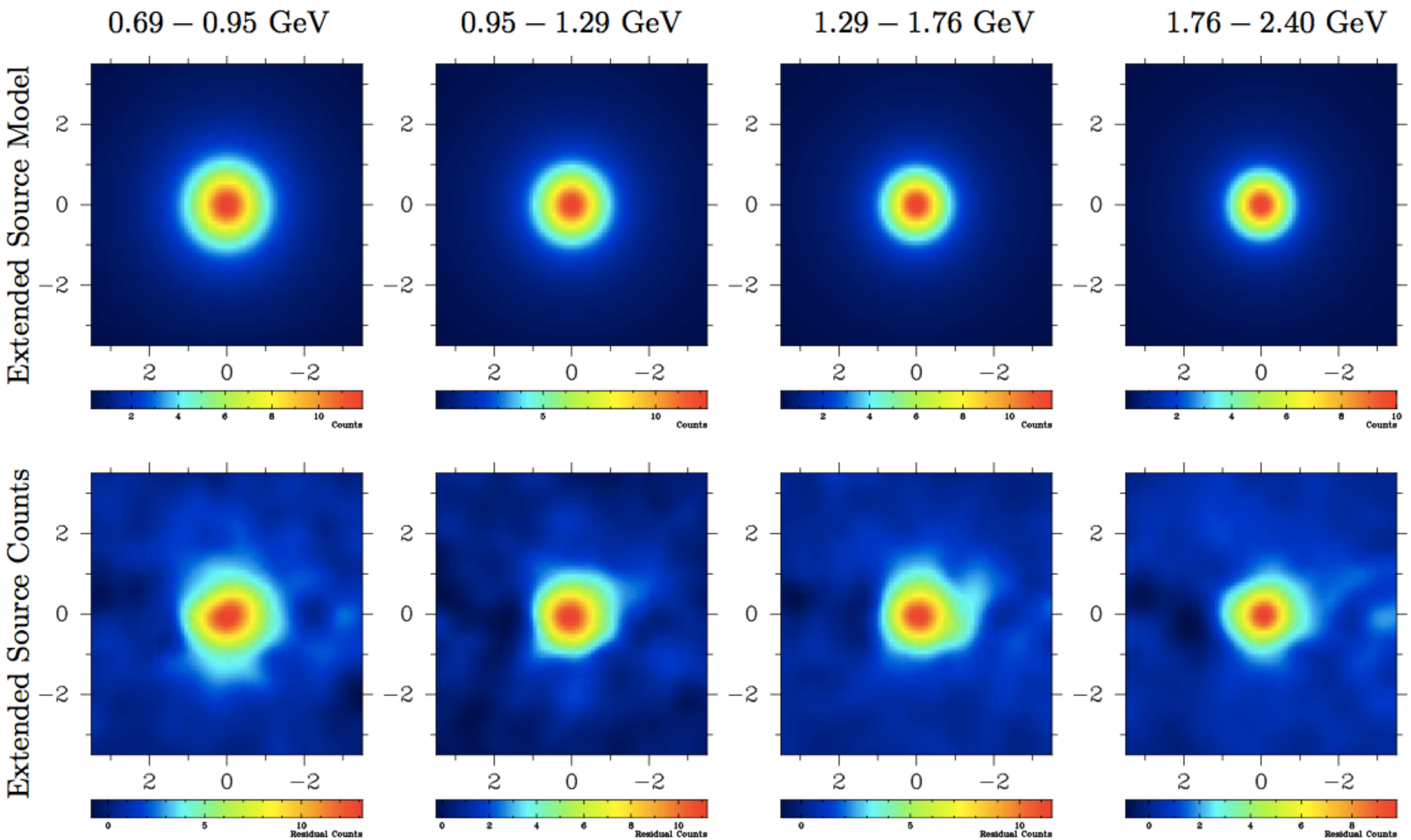
Fermi-LAT 2 Year Point Sources and Diffuse Galactic & Extragalactic Fit Subtraction



Dark Matter in the Galactic Center?

$m_\chi = 30$ GeV
NFW $\gamma = 1.2$

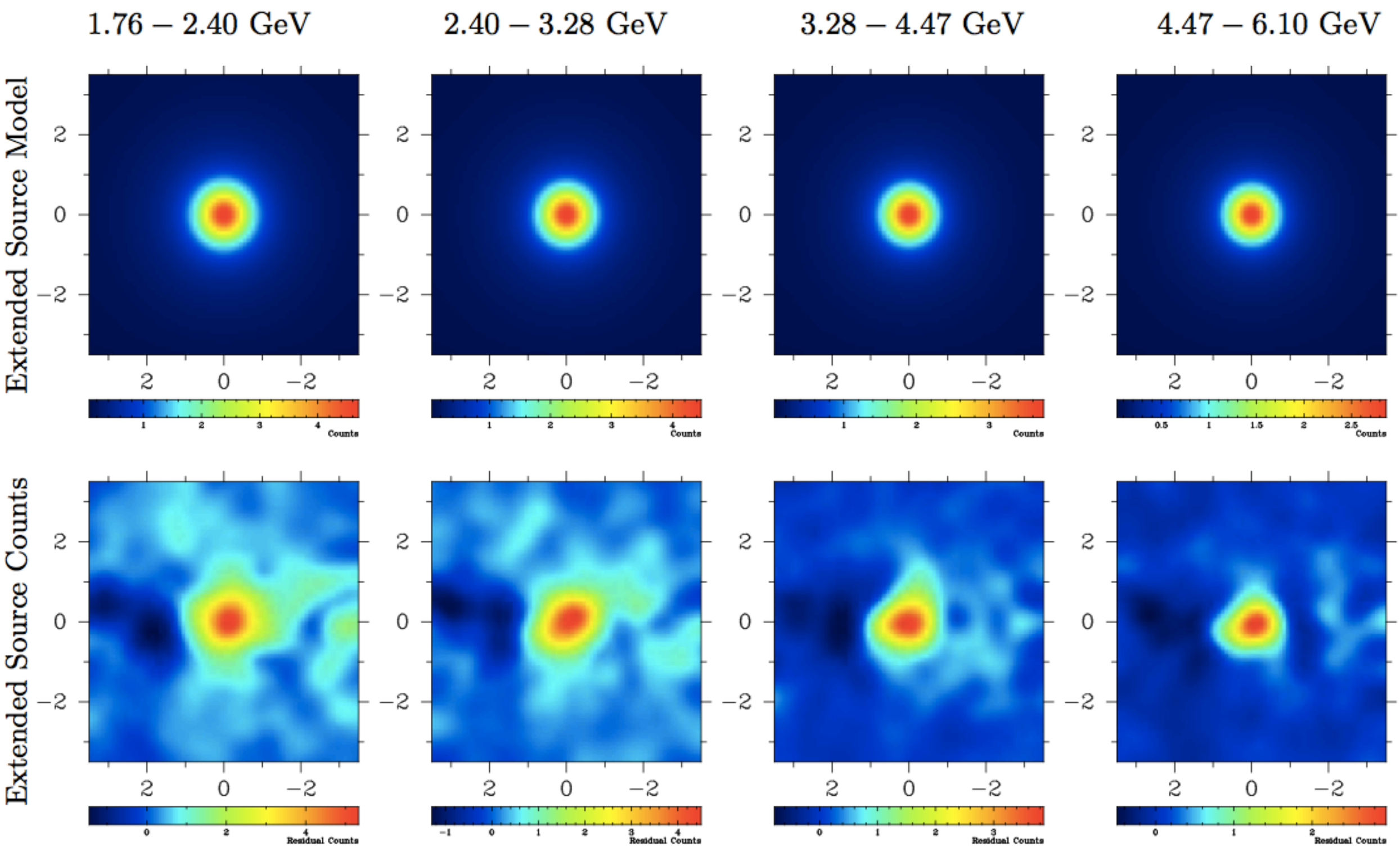
$\mathrm{TS}_{\mathrm{true}} = 2\Delta \ln \mathcal{L} = 824,\ 28.7\sigma,\ p = 4 \times 10^{-181}$



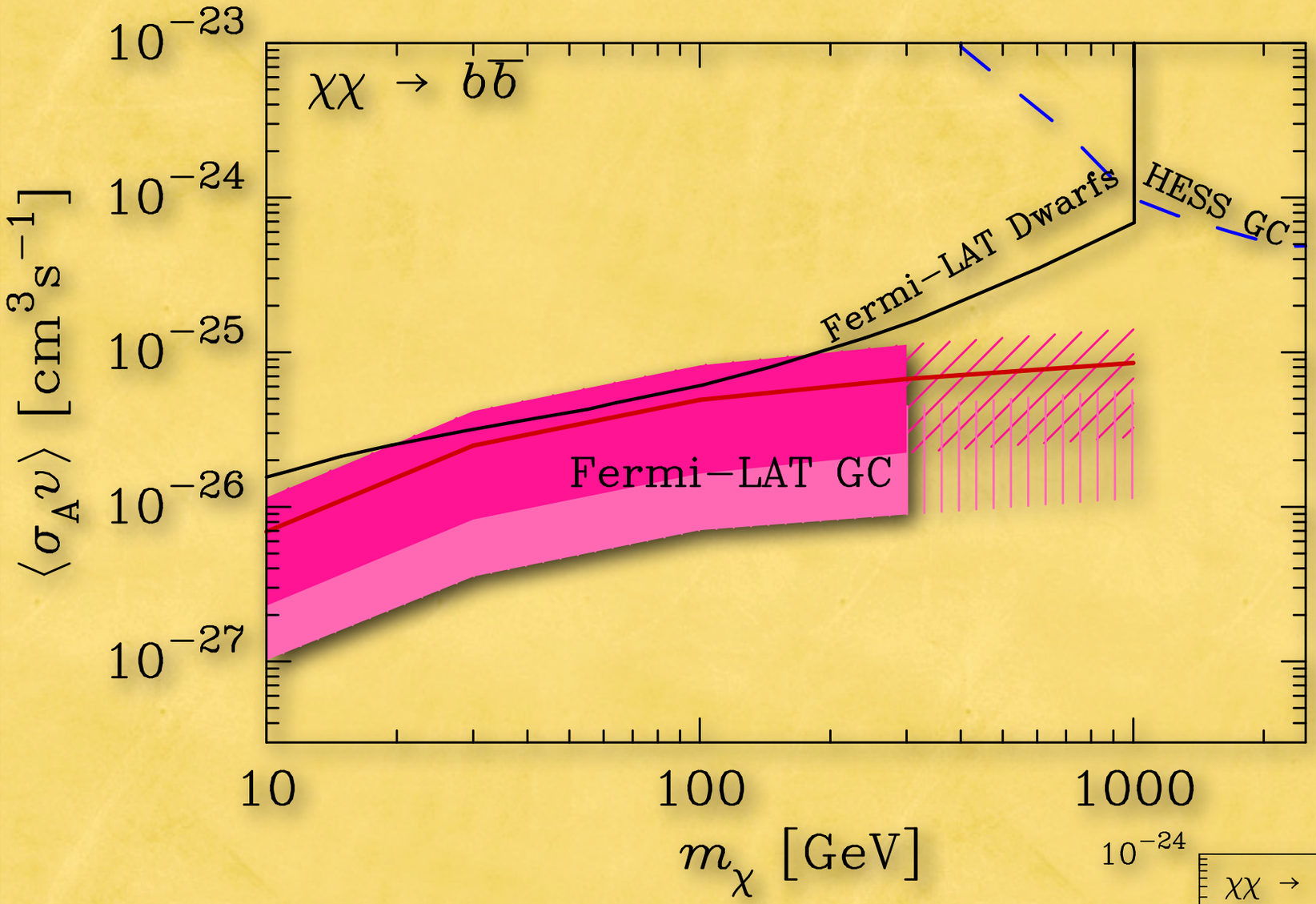
$m_\chi = 100$ GeV

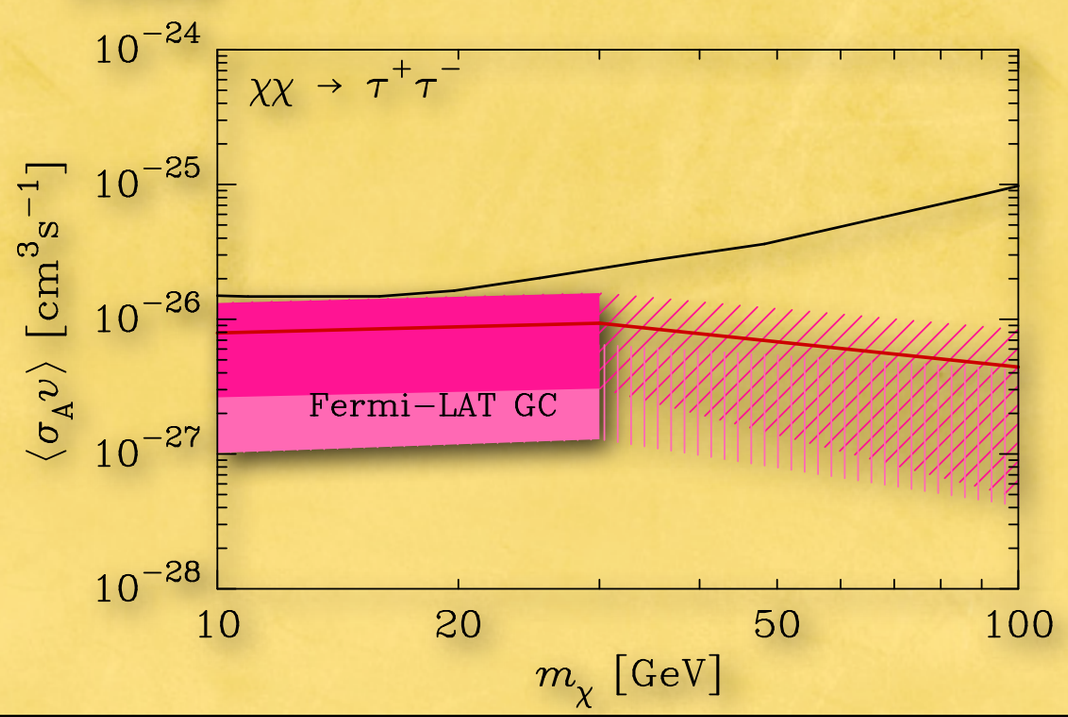
NFW $\gamma = 1.2$

$\mathrm{TS}_{\mathrm{true}} = 2 \ln \mathcal{L} = 378;\ 19.4\sigma,\ p = 3 \times 10^{-84}$



Signal Parameters: *corrected!*





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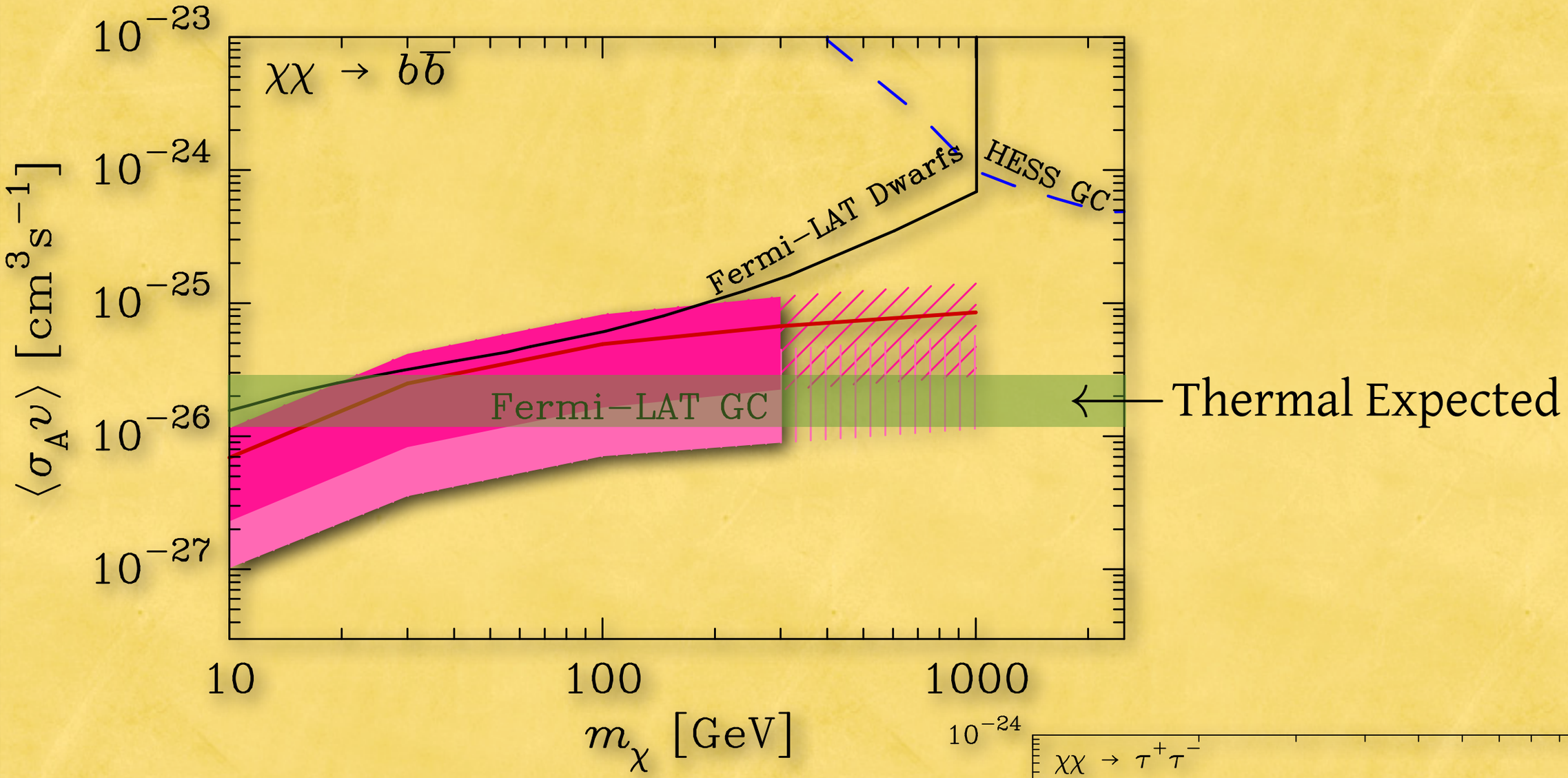

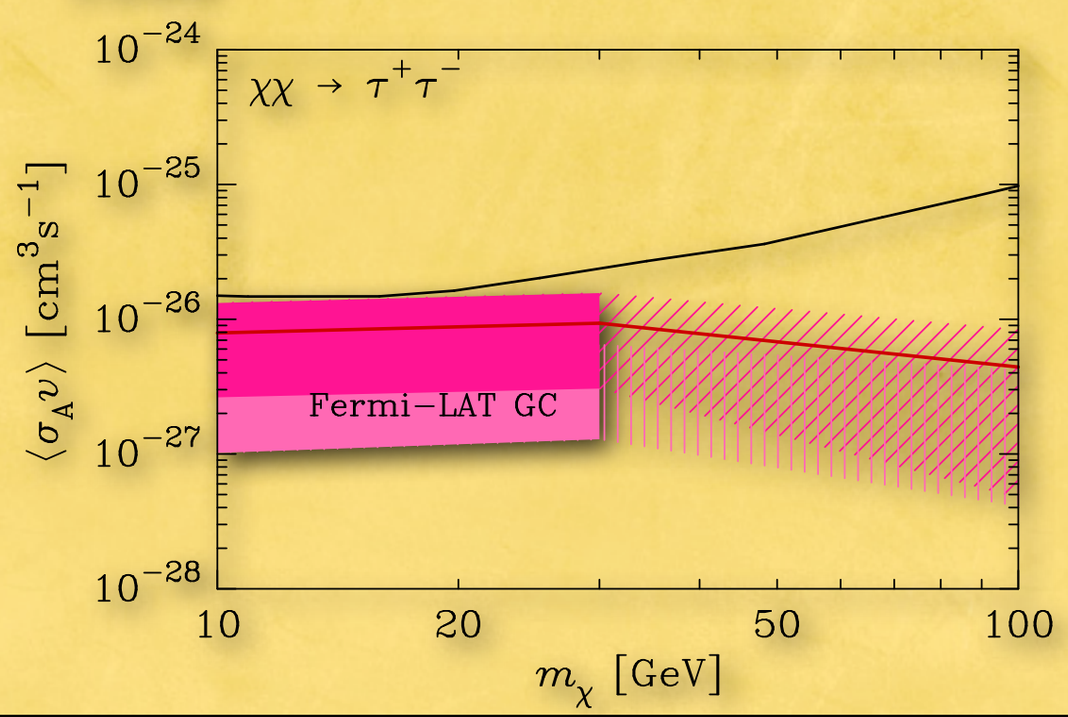

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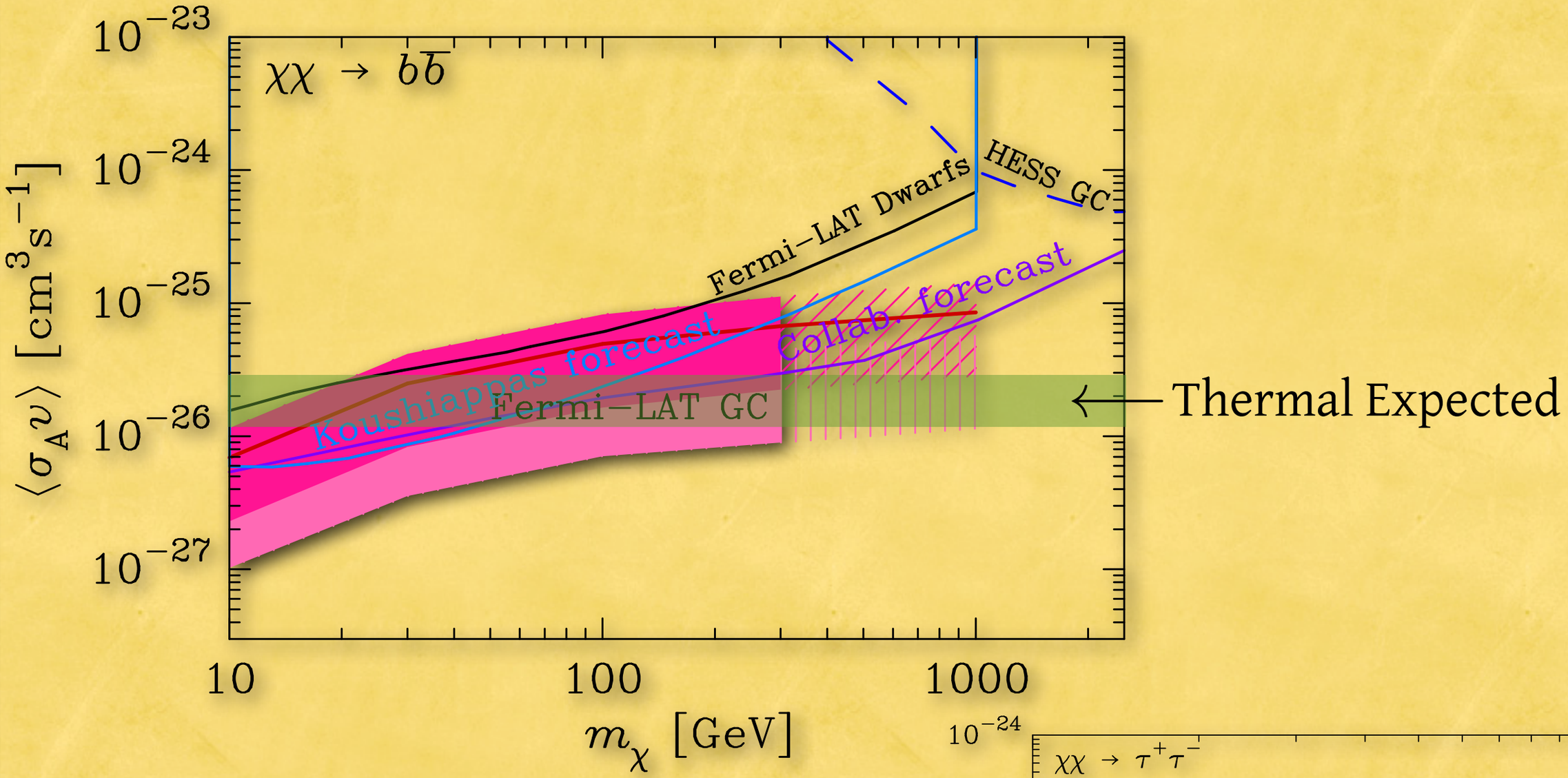
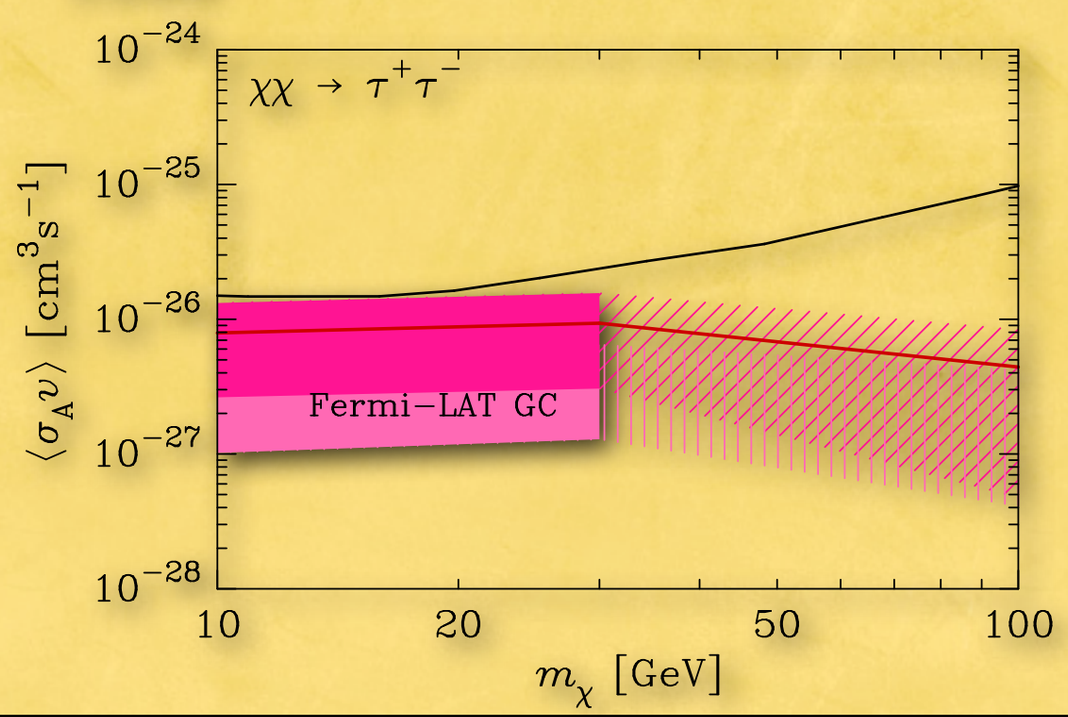
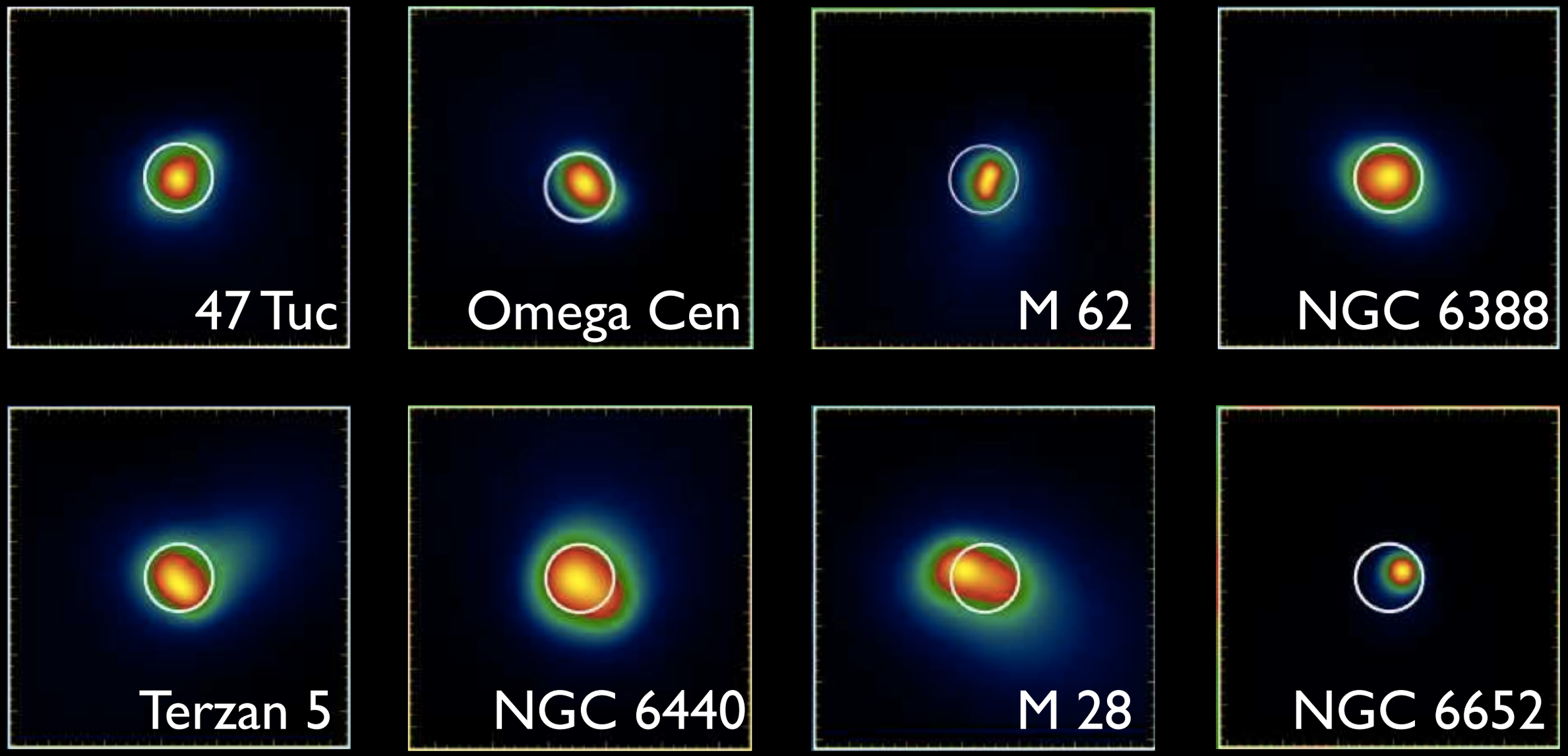


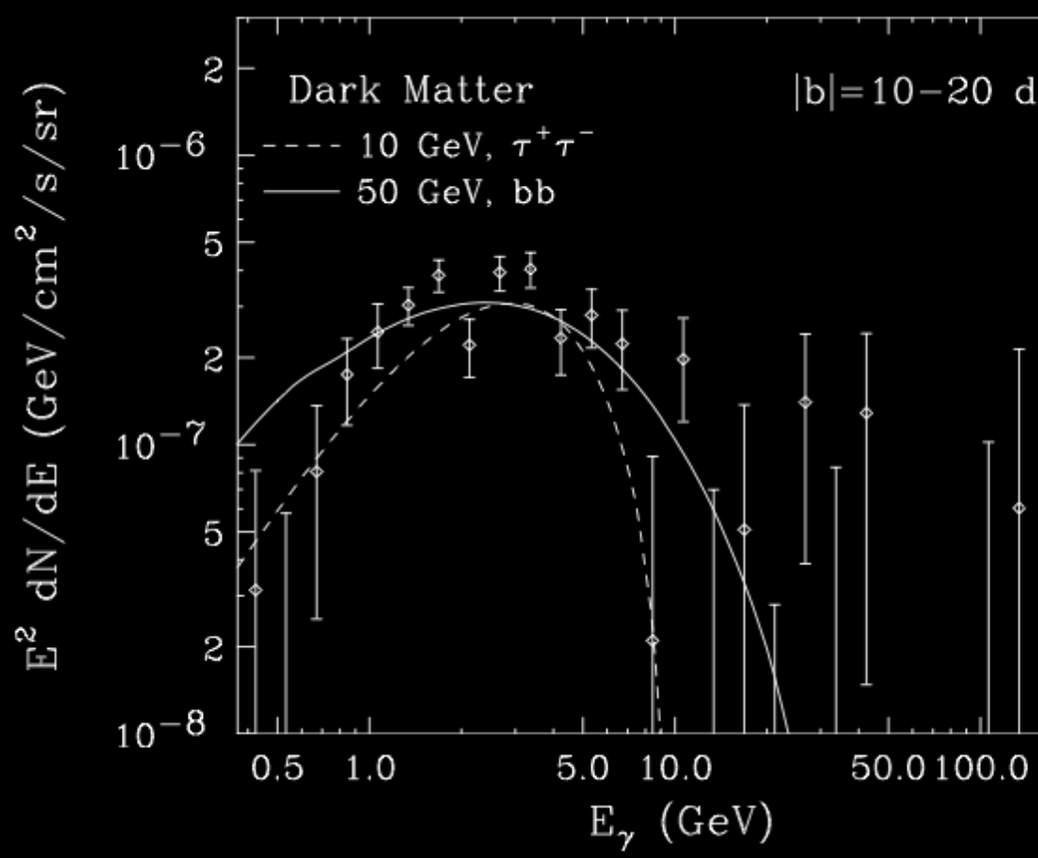


Is it dark matter?
Millisecond Pulsars in Stellar & Globular Clusters



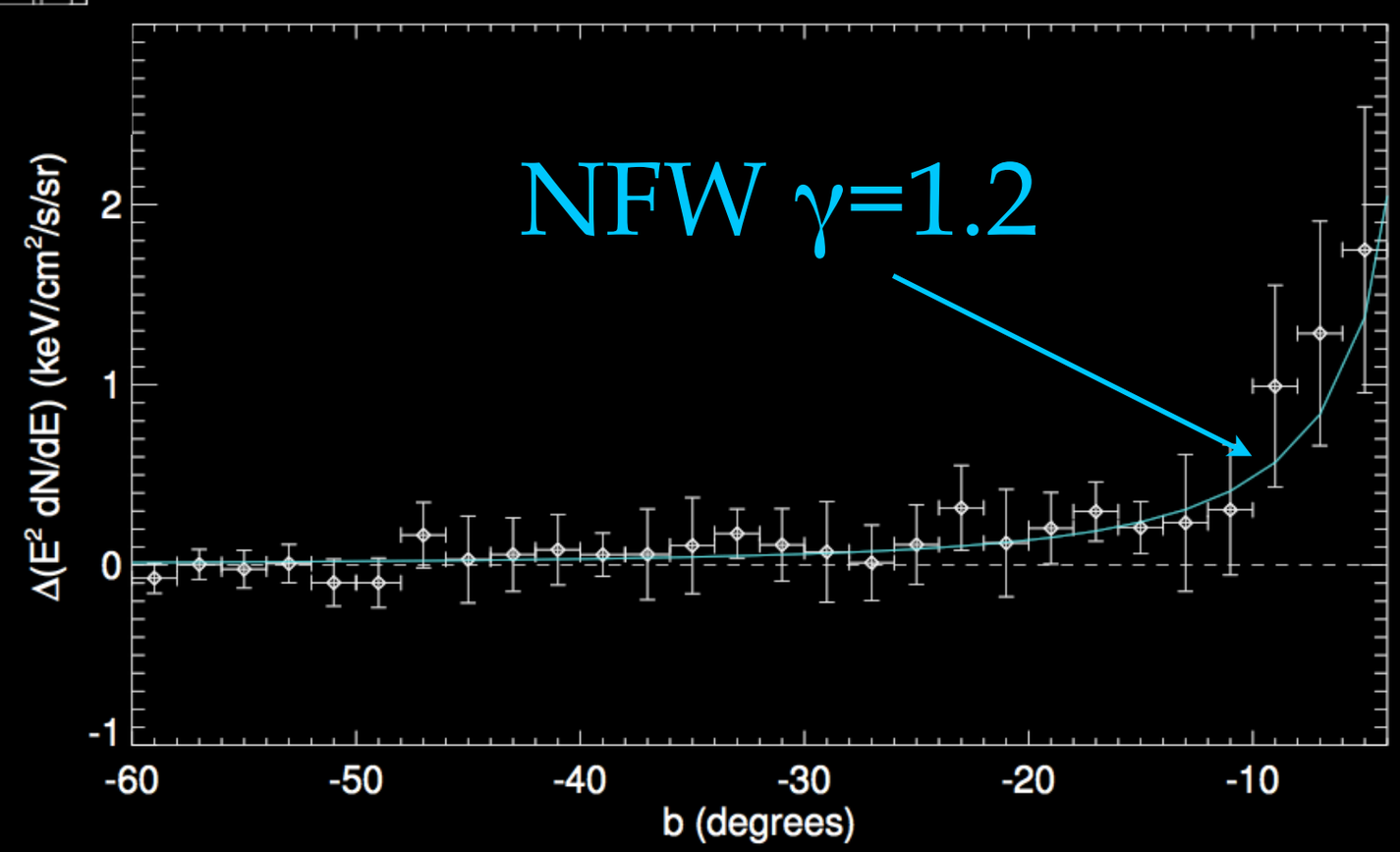
- Requires the flux from the GC MSPs to be ~200 times that in Omega Cen - reasonable stellar mass is ~800 times
- Requires ~1000 MSPs in the GC region - again reasonable scale
- Requires a centrally concentrated density profile $n \sim r^{-2.6}$, which is seen for the central density distribution of LMXBs in M31 (see also Wharton et al 2012)

Detection of Extended Halo Annihilation?!

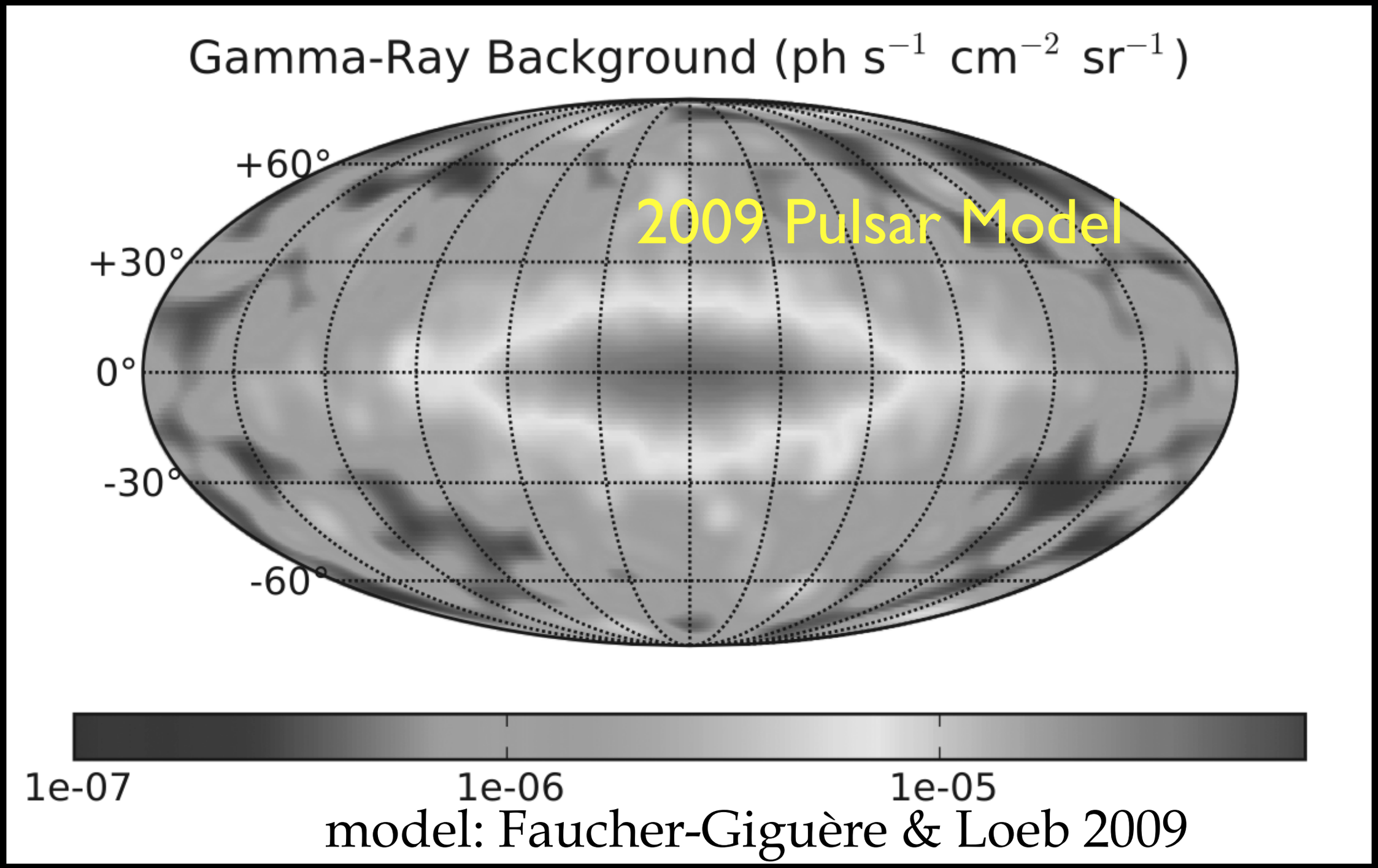


Recent work sees a flux in the Galactic γ-ray bubbles that is consistent with GC annhilation in flux, spectrum, and morphology (NFW γ=1.2)

Hooper & Slatyer 2013



Diffuse Emission from MSPs?



model: Faucher-Giguère & Loeb 2009

anisotropy constraints: Siegal-Gaskins et al. 2009

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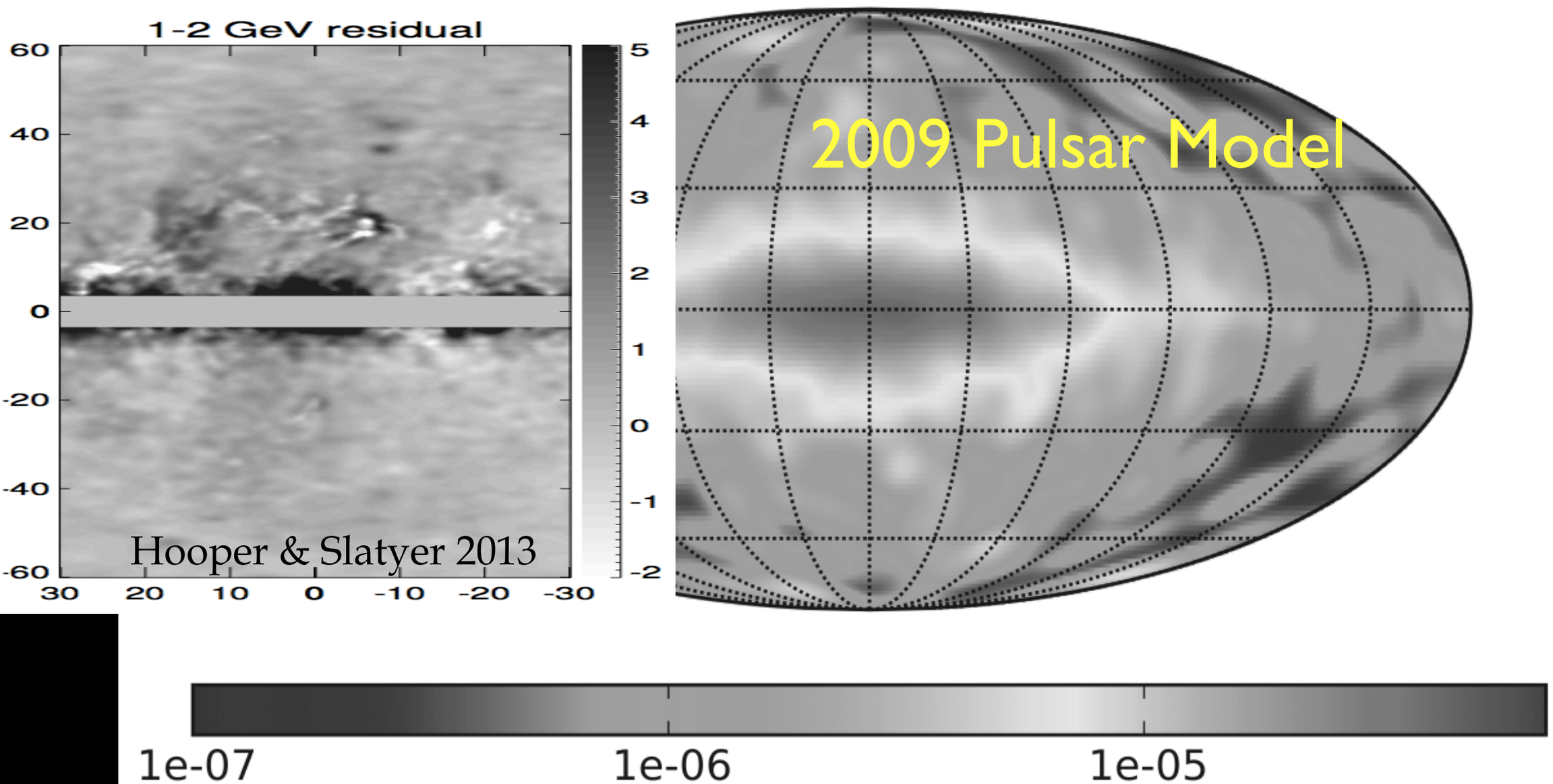

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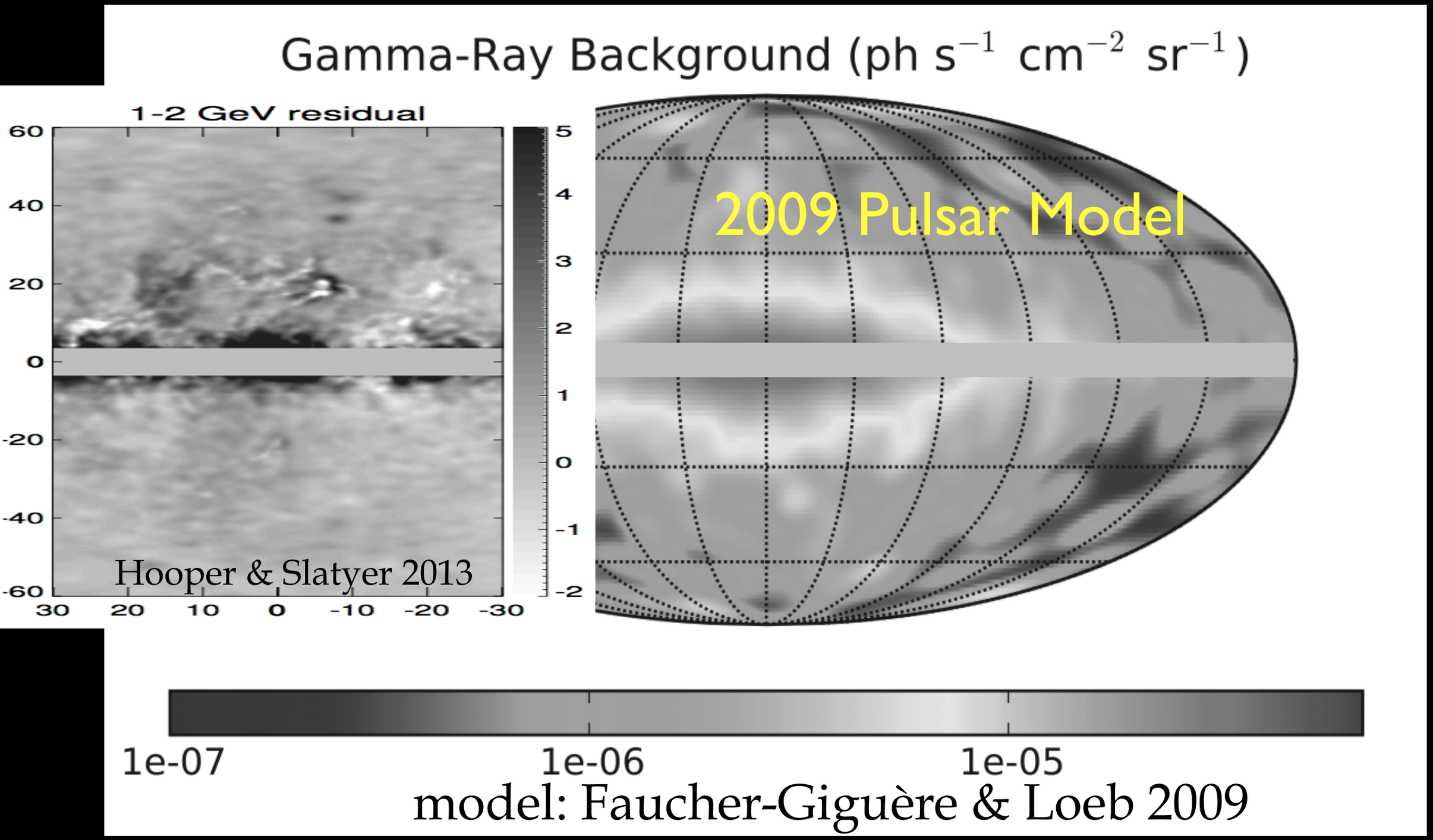
anisotropy constraints: Siegal-Gaskins et al. 2009

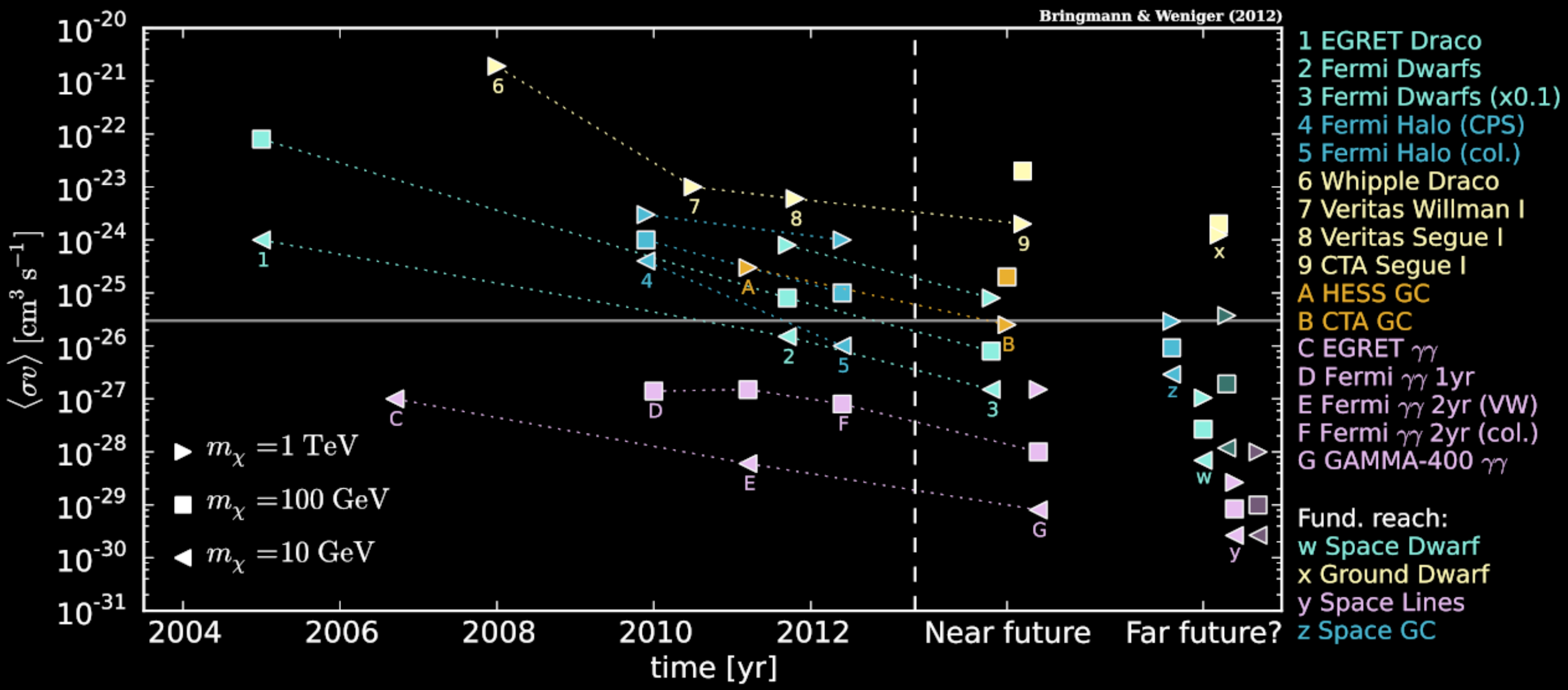
Diffuse Emission from MSPs?



model: Faucher-Giguère & Loeb 2009

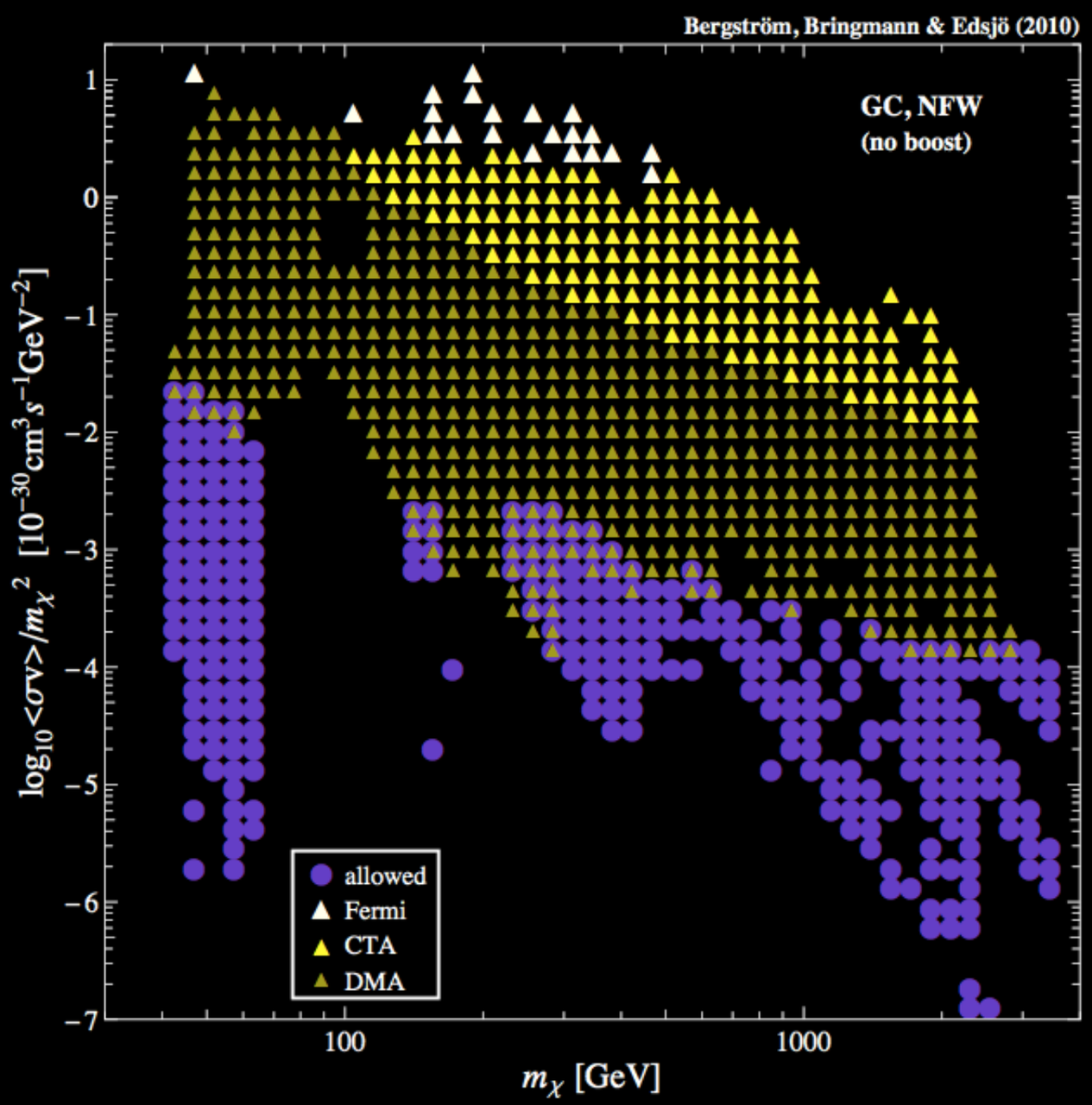
anisotropy constraints: Siegal-Gaskins et al. 2009

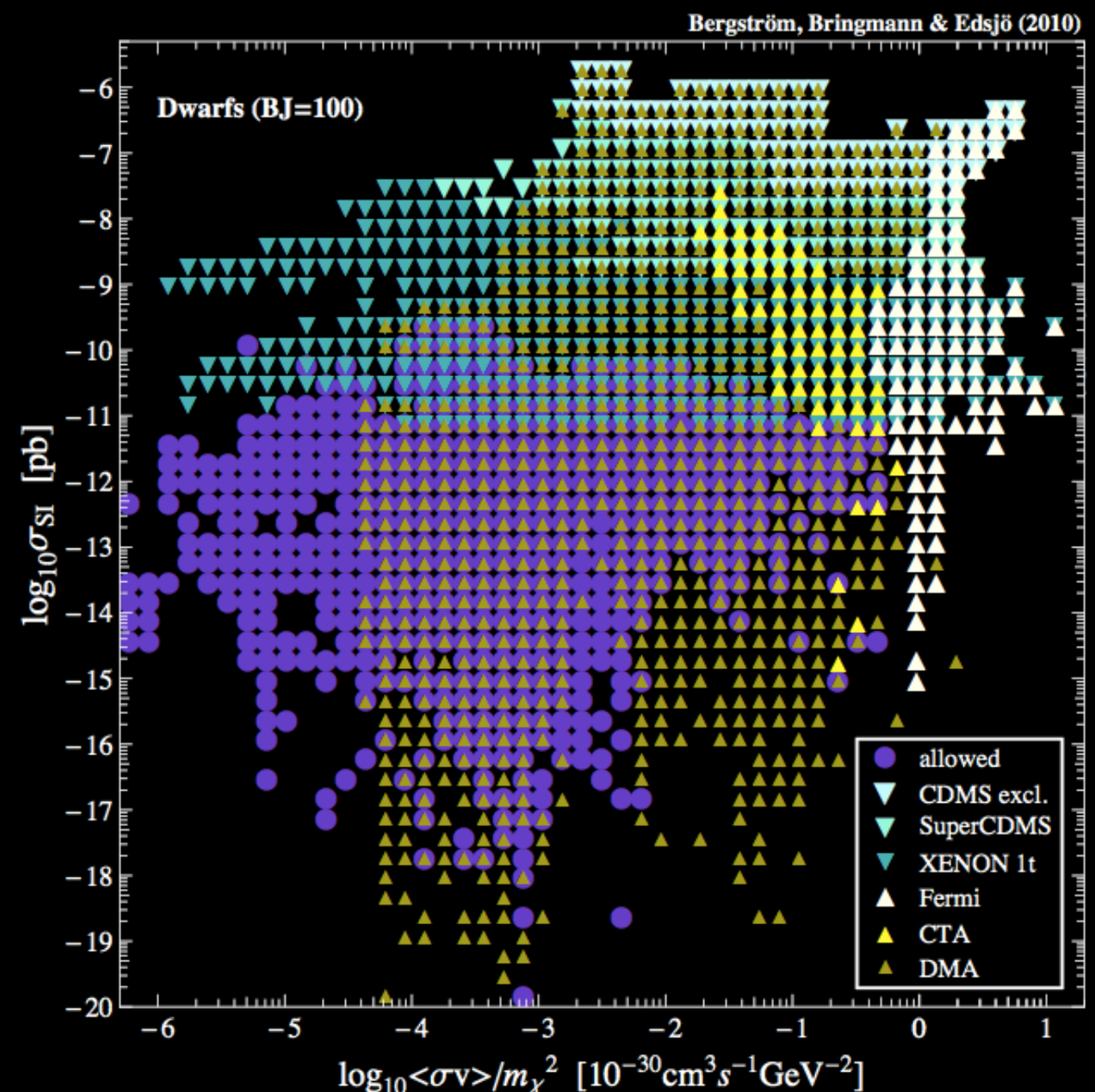
Status & Forecast Prospects - Another View



Bringmann & Weniger, 2012

Current, Forecast Complementarity: cMSSM case





⬆ Bergström, Bringmann & Edsjö, 2010

See also: Cotta et al. 2012, Ripken et al. 2011

Summary

- Current constraints are just touching upon the canonical thermal WIMP cross-section
- Potential continuum signals in the GC & bubbles are exciting!

- Future efforts will be the continuation of the Fermi-LAT searches, VERITAS, HESS-II, CTA, and GAMMA-400
- There exists significant complementarity with direct searches and LHC collider efforts