SEARCHING FOR DARK MATTER ANNIHILATION IN THE MILKY WAY HALO AT HIGH LATITUDES

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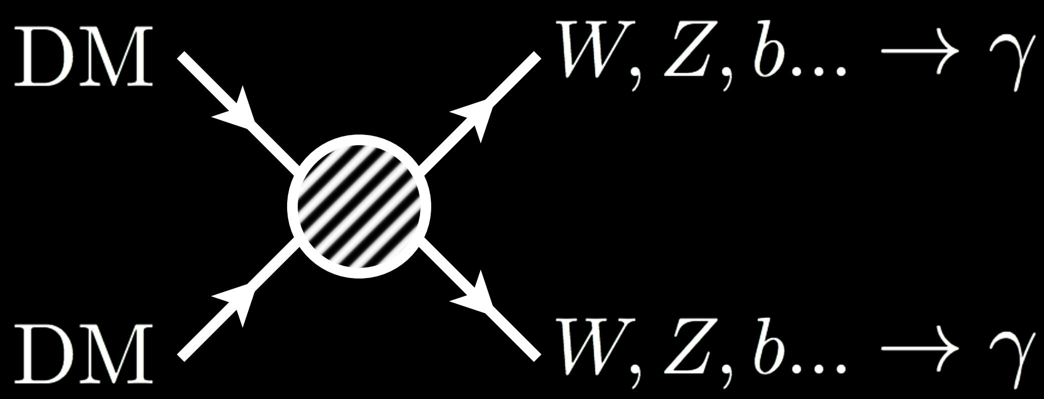
PRINCETON UNIVERSITY
TeVPA 2018

WITH MARIANGELA LISANTI, SIDDHARTH MISHRA-SHARMA [1804.04132]

THERMAL WIMP DARK MATTER



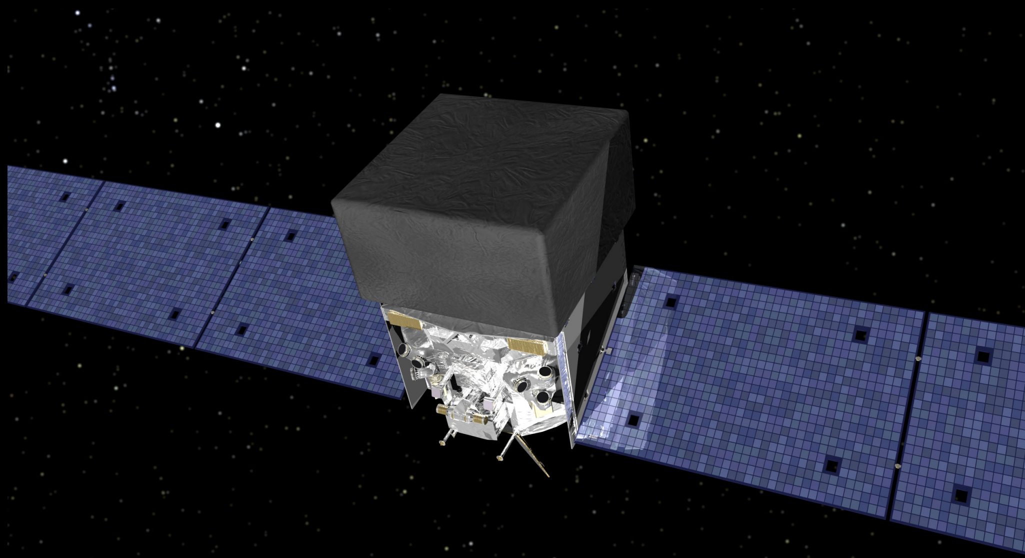
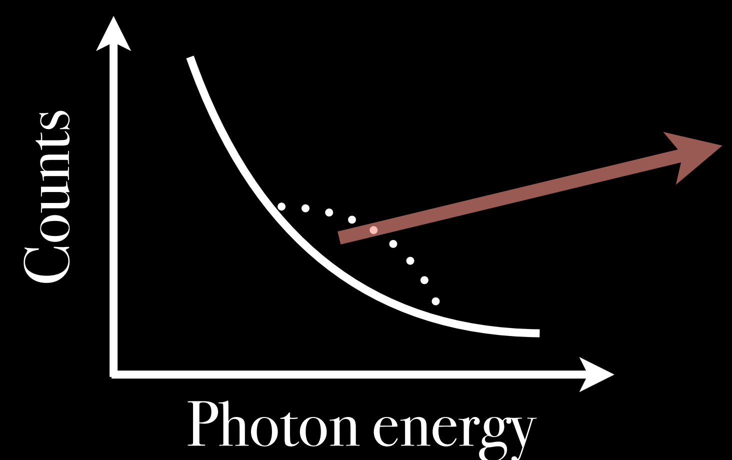


Image source: *Fermi* collaboration



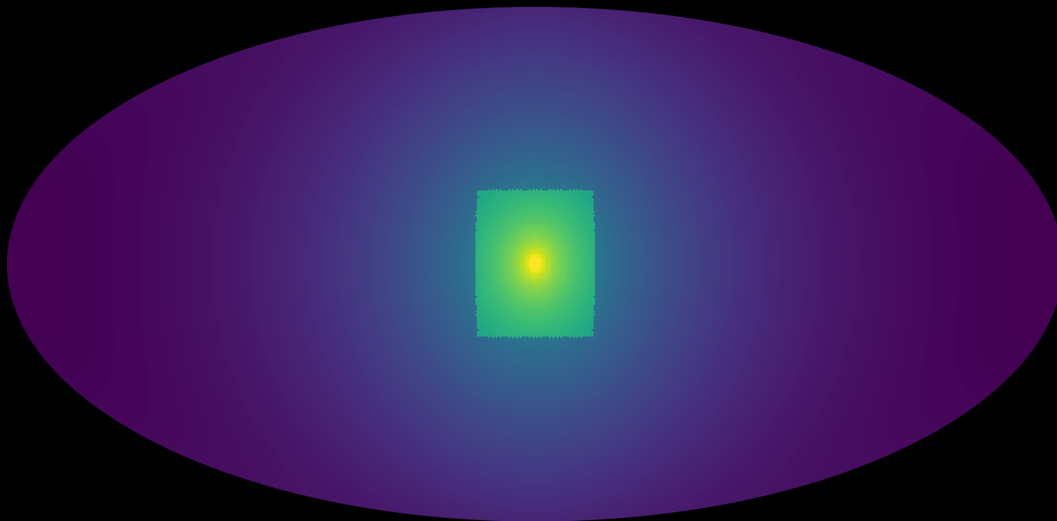
enhanced emission from dark matter-rich regions

Weakly **I**nteracting **M**assive **P**article**s** → gamma rays

$$\Phi_\gamma(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\int_{E_{\rm min}}^{E_{\rm max}}\frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}{\rm d}E_\gamma}_{\text{particle physics}} \times \underbrace{\int_{\Delta\Omega}\int_{\rm l.o.s.}\rho_{\rm DM}^2(\mathbf{r}){\rm d}l{\rm d}\Omega'}_{\text{astrophysics (J-factor)}}$$

HOW BRIGHT IS THE MILKY WAY HALO?

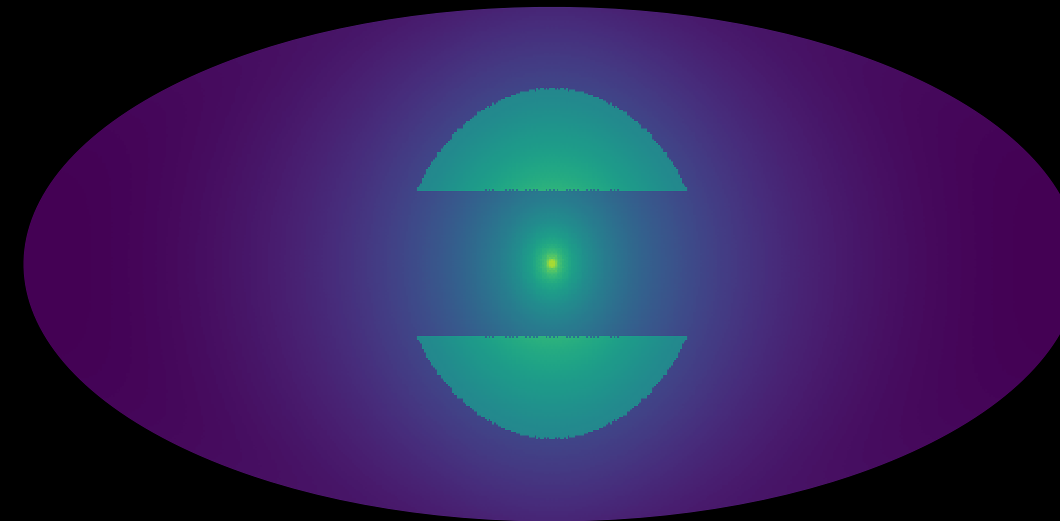
Milky Way halo, inner Galaxy



$|b| < 20^\circ, |l| < 20^\circ$

$J \sim 7.6 \times 10^{22}\,\mathrm{GeV}^2\mathrm{cm}^{-5}$

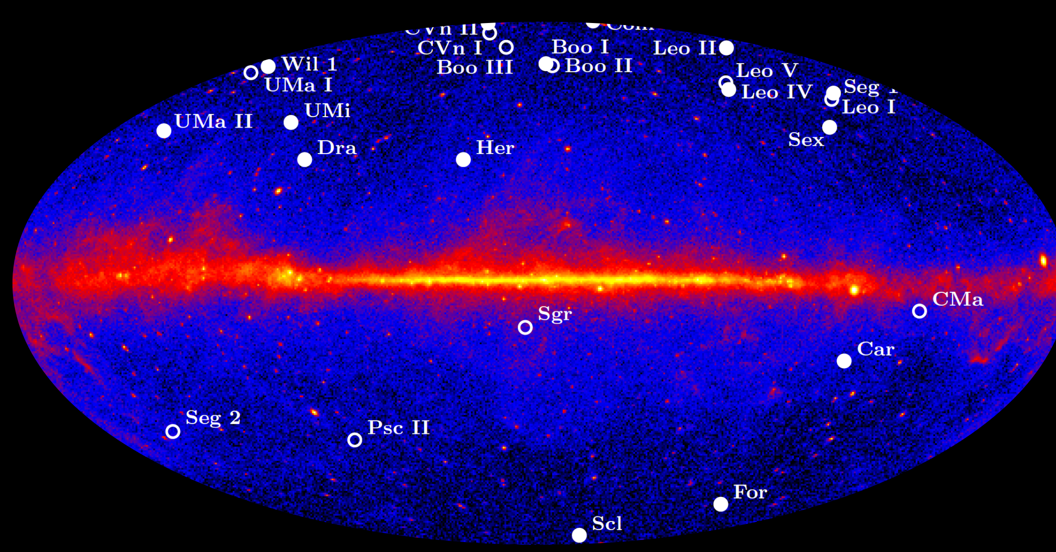
Milky Way halo, high latitude



$|b| > 20^\circ, r < 50^\circ$

$J \sim 2.2 \times 10^{22}\,\mathrm{GeV}^2\mathrm{cm}^{-5}$

Milky Way dwarf galaxies

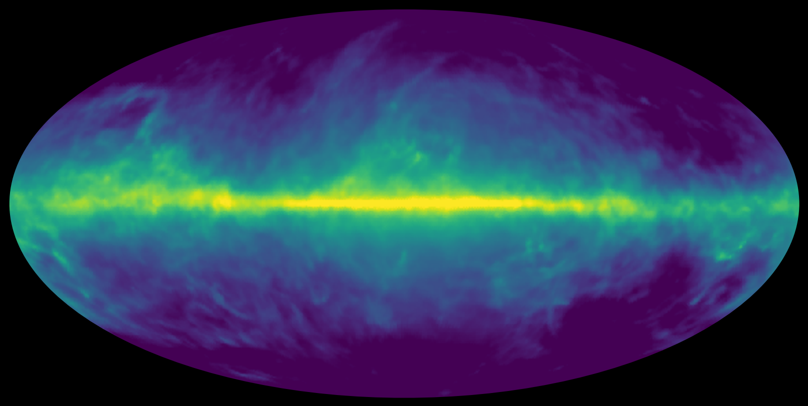


Fermi-LAT collaboration [1310.0828]

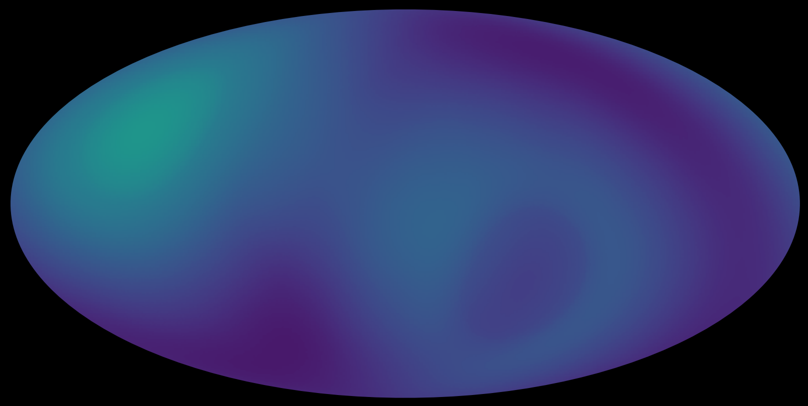
$J \sim 10^{17}\text{–}10^{19}\,\mathrm{GeV}^2\mathrm{cm}^{-5}$

HOW BRIGHT ARE THE BACKGROUNDS?

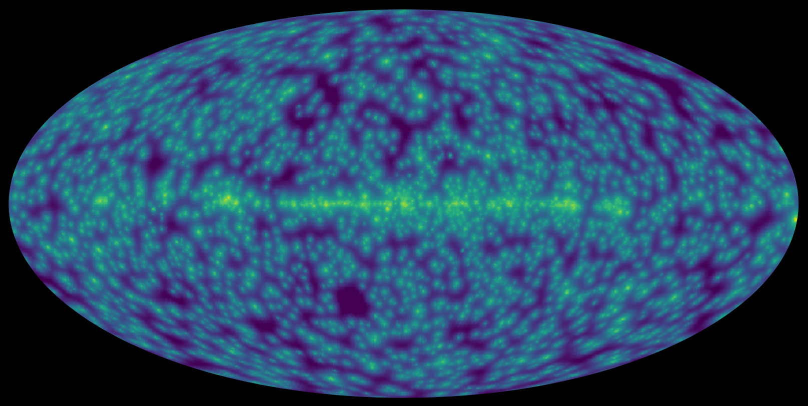
Diffuse foreground emission



Isotropic emission



Resolved point sources



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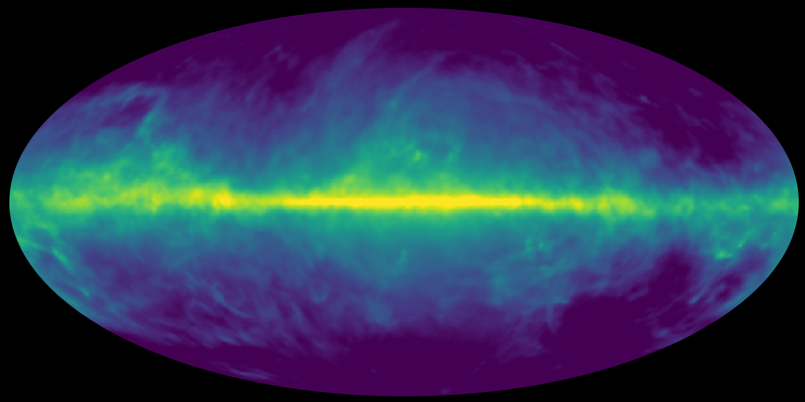
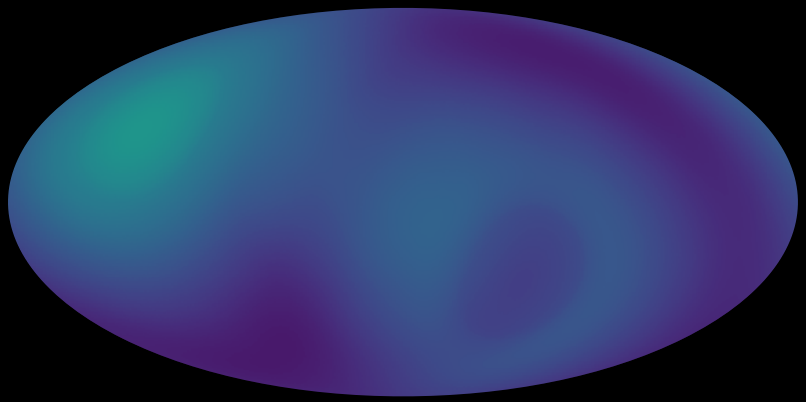


Isotropic emission



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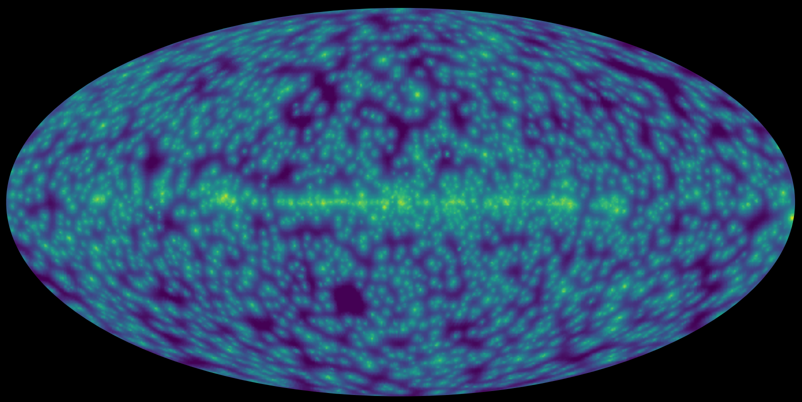

Dominant, difficult to model

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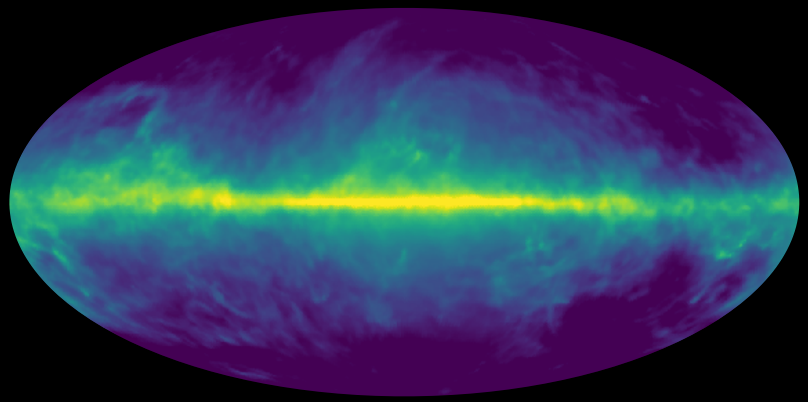

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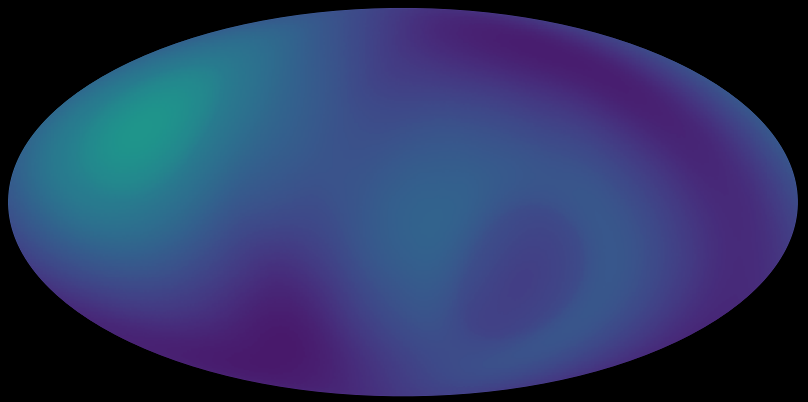
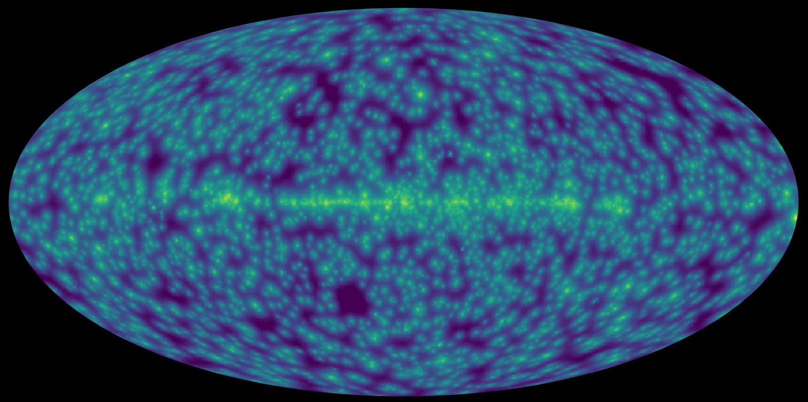


Resolved point sources

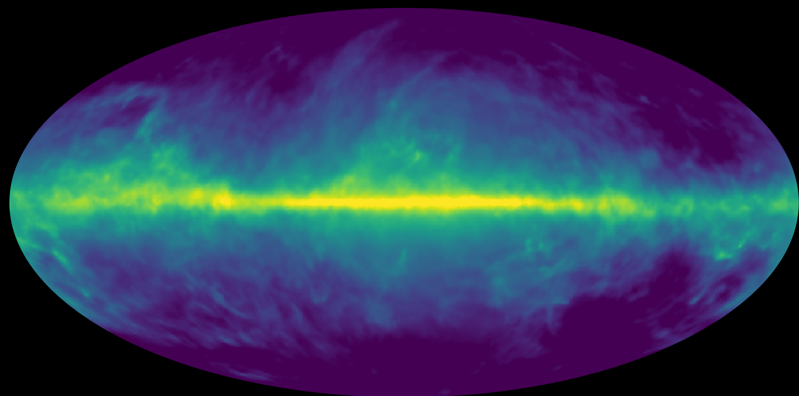


Dominant, difficult to model

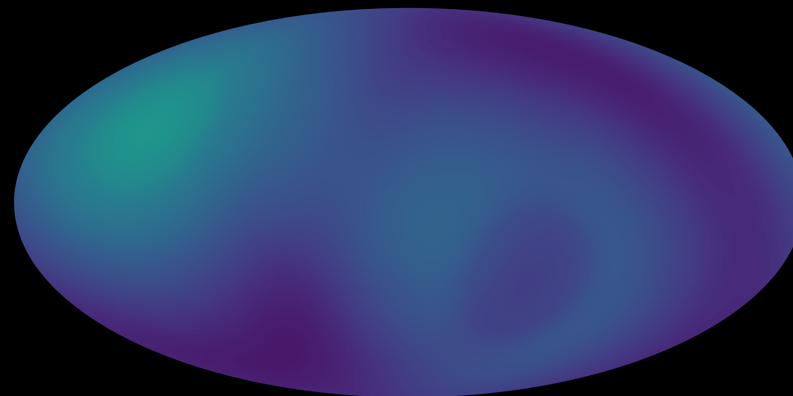
p6v11, 0.2–2000 GeV:

HOW BRIGHT ARE THE BACKGROUNDS?

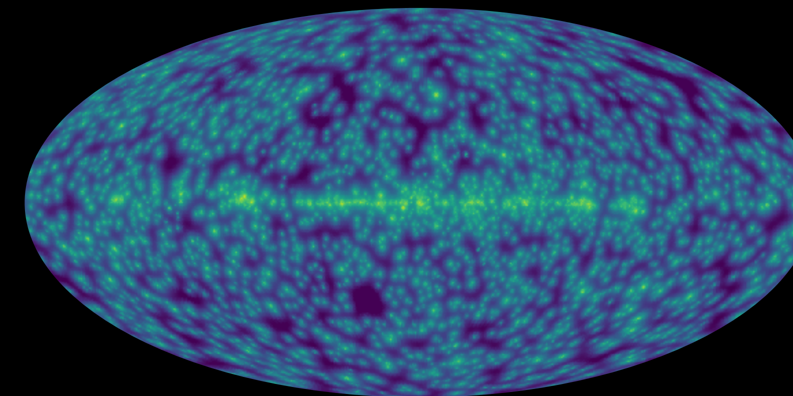
Diffuse foreground emission



Isotropic emission



Resolved point sources



Dominant, difficult to model

p6v11, 0.2–2000 GeV:

$\approx 1.36 \times 10^6$ counts/3538 deg^2

≈ 384 counts/deg^2

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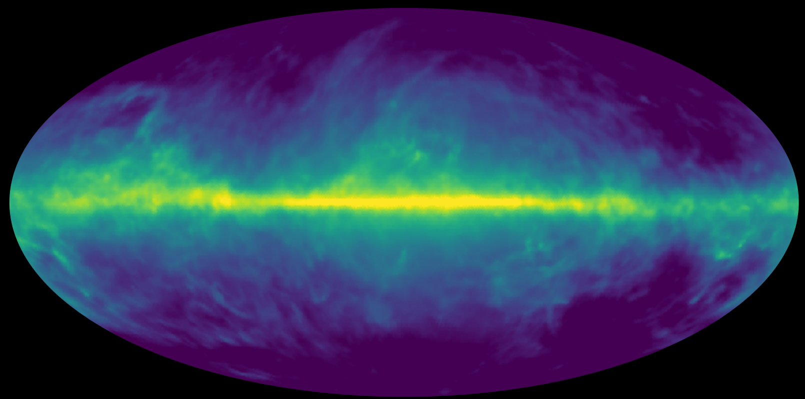
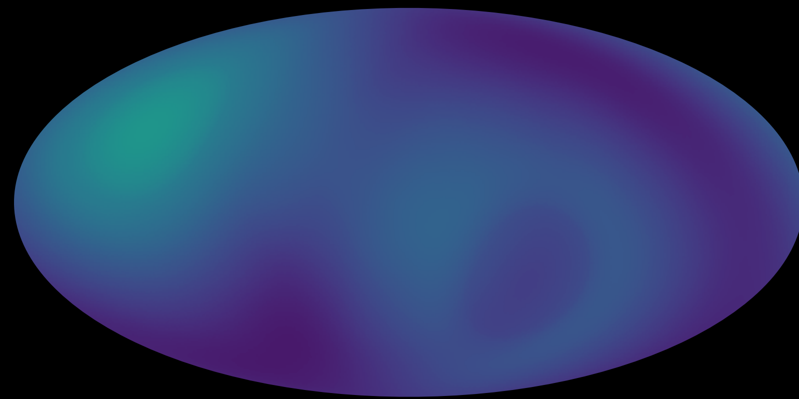
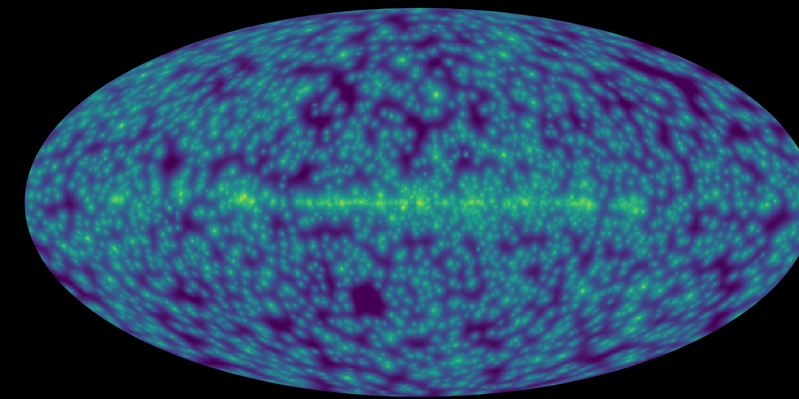
Diffuse foreground emission



Isotropic emission



Resolved point sources



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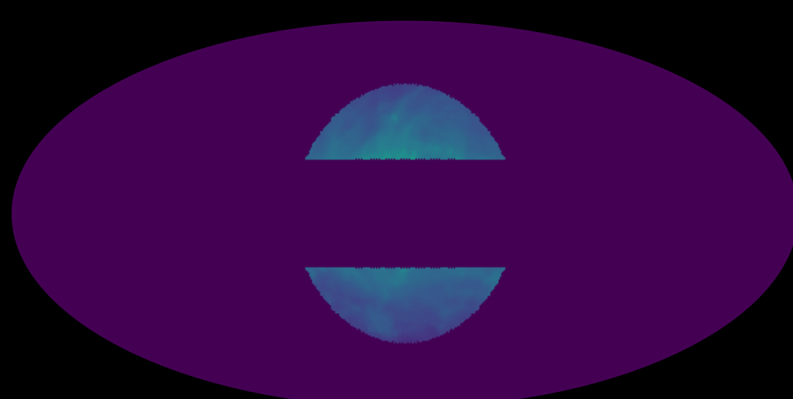

$\approx 1.36 \times 10^6$ counts/3538 deg^2

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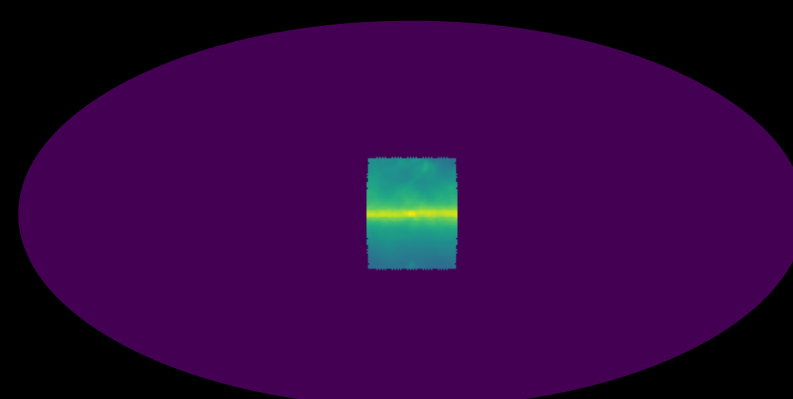
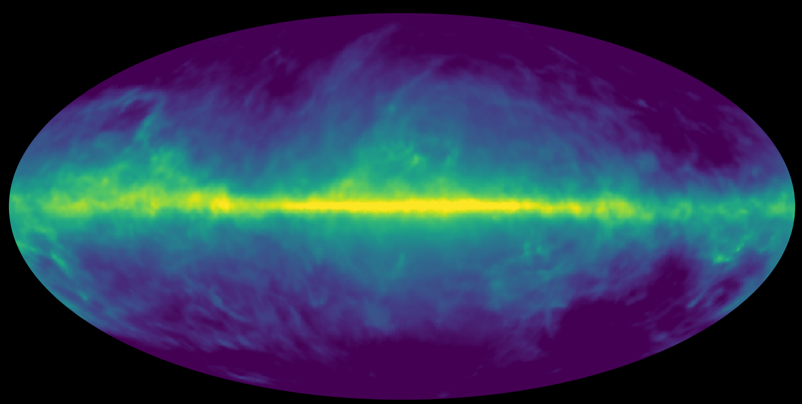


$\approx 3.06 \times 10^6$ counts/1553 deg^2

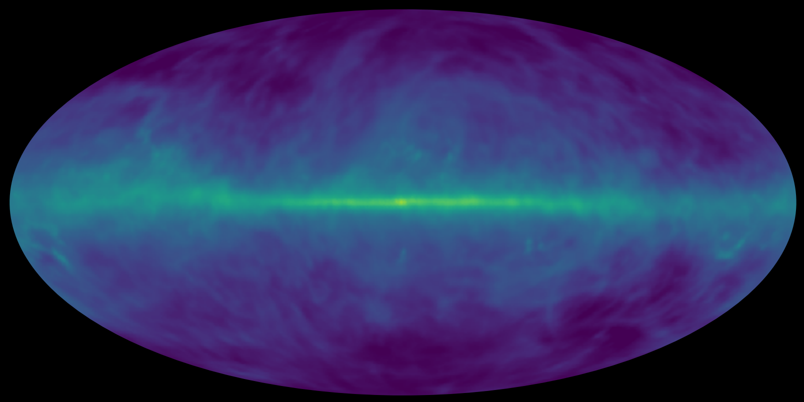
≈ 1972 counts/deg^2

DIFFUSE FOREGROUND COMPONENTS

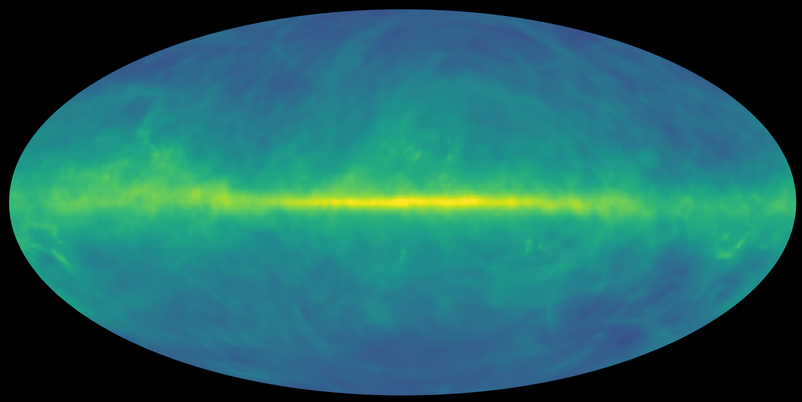


Trace gas/dust distribution

Bremsstrahlung

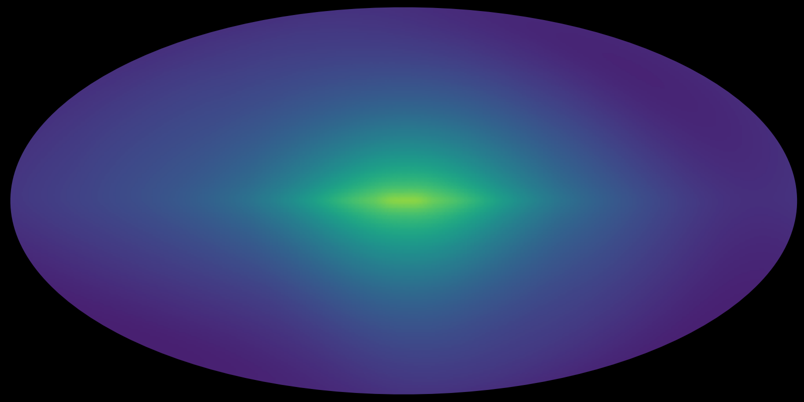


Neutral pion decay



Traces electron populations

Inverse Compton scattering (ICS)



CHALLENGES: DM ANALYSES IN THE INNER GALAXY

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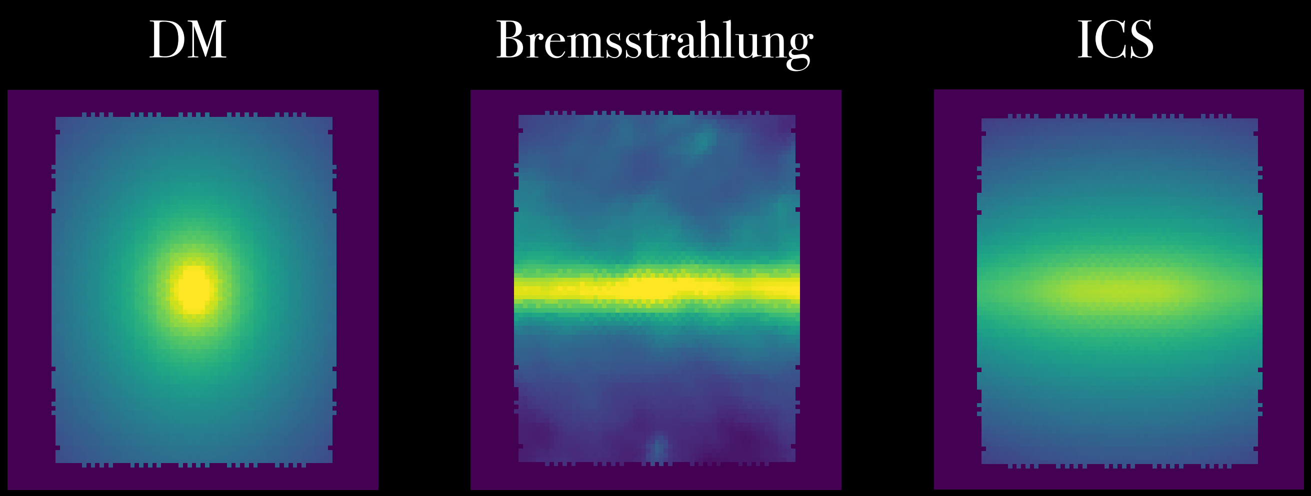
Bright diffuse foregrounds



(Normalized for ease of comparing morphologies)

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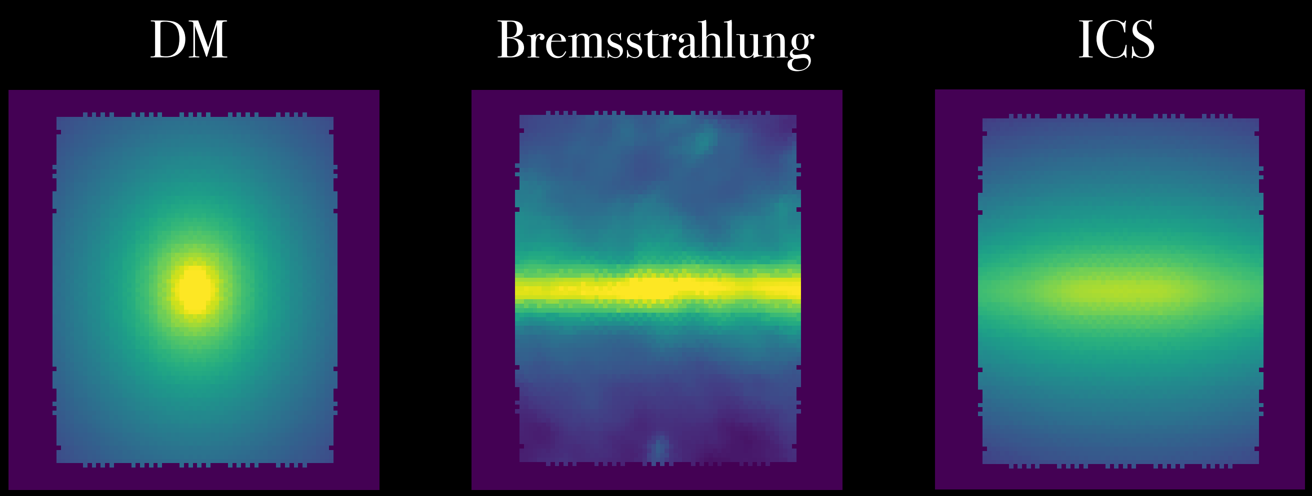

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Need accurate diffuse models!

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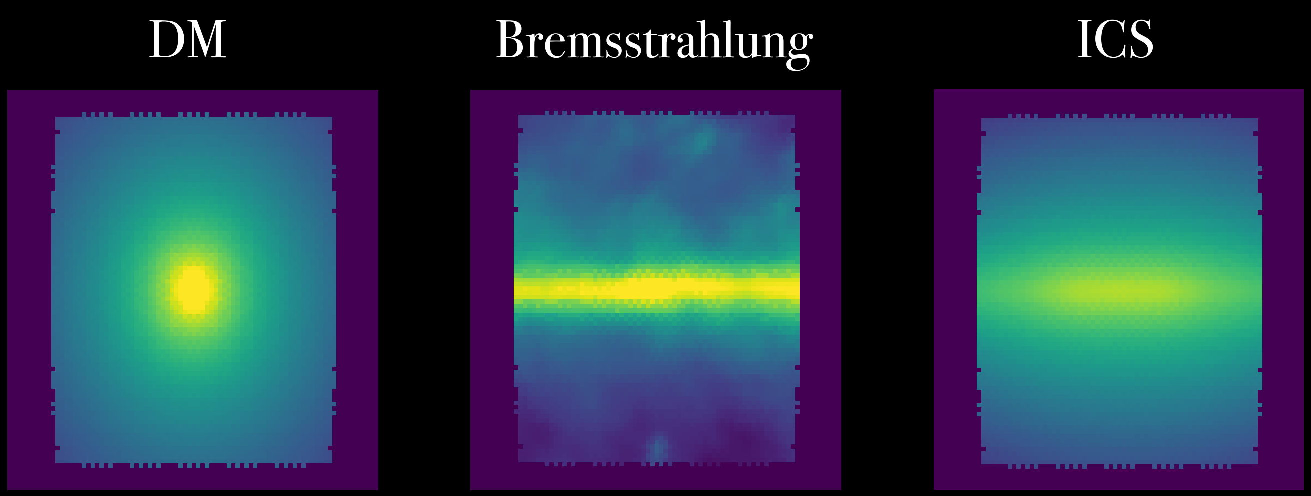

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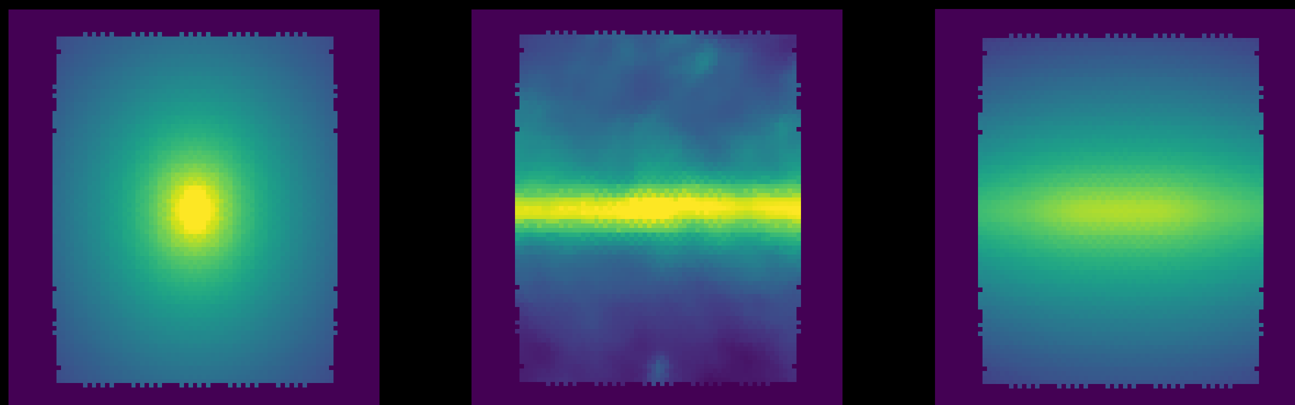
Potential degeneracies with the signal

CHALLENGES: DM ANALYSES IN THE INNER GALAXY

Bright diffuse foregrounds

DM Bremsstrahlung ICS



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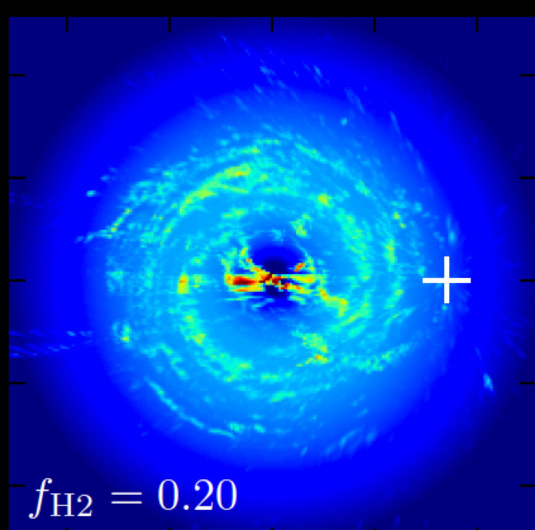
Cosmic ray sources



E. Carlson et al. [1603.06584]

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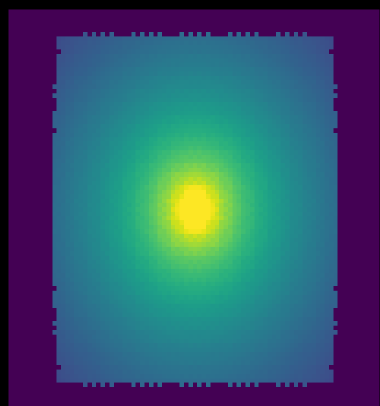
Bright diffuse foregrounds

DM



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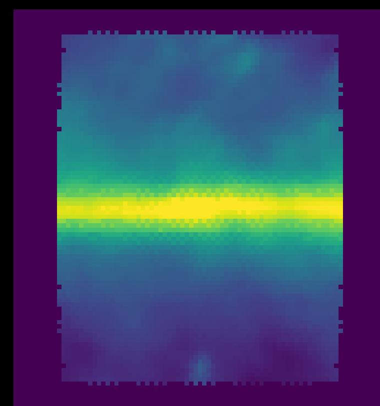
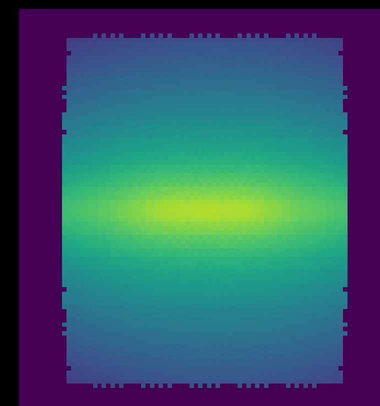


ICS



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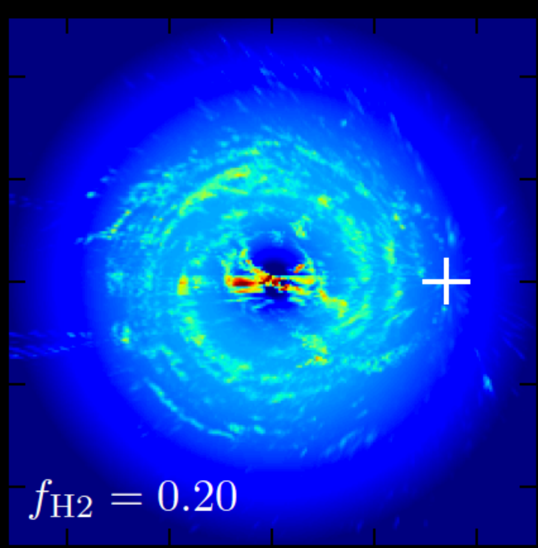

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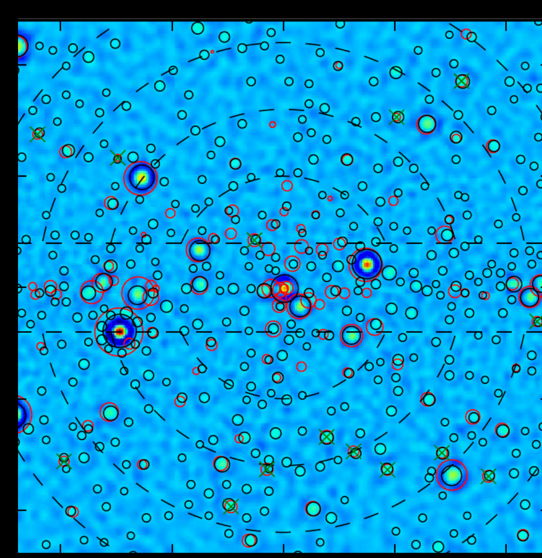

R. Bartels et al. [1506.05104]
S. Lee et al. [1506.05124]

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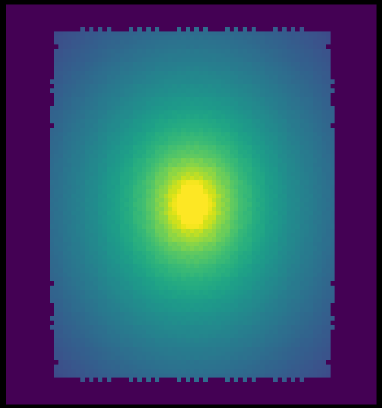
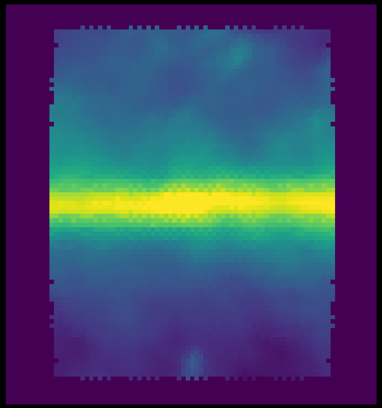
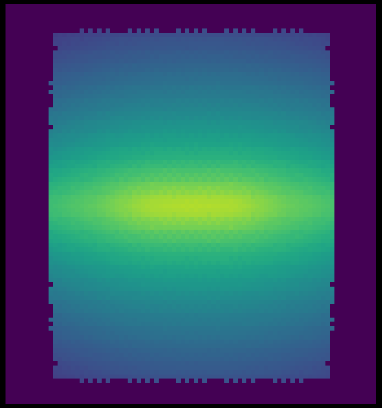


Bremsstrahlung



ICS



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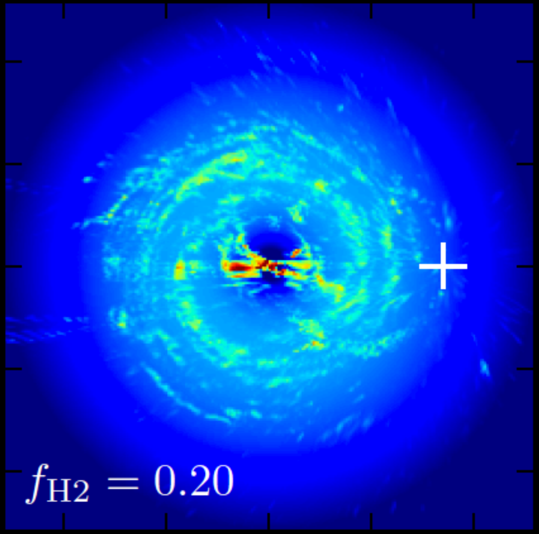

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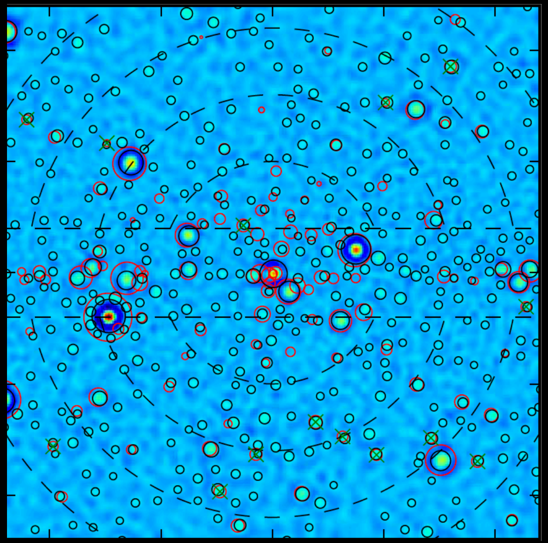

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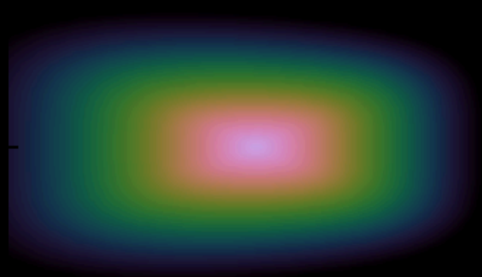
Stellar bulge



Boxy bulge

R. Bartels et al. [1711.04778]

CHALLENGES: DM ANALYSES AT HIGH LATITUDES

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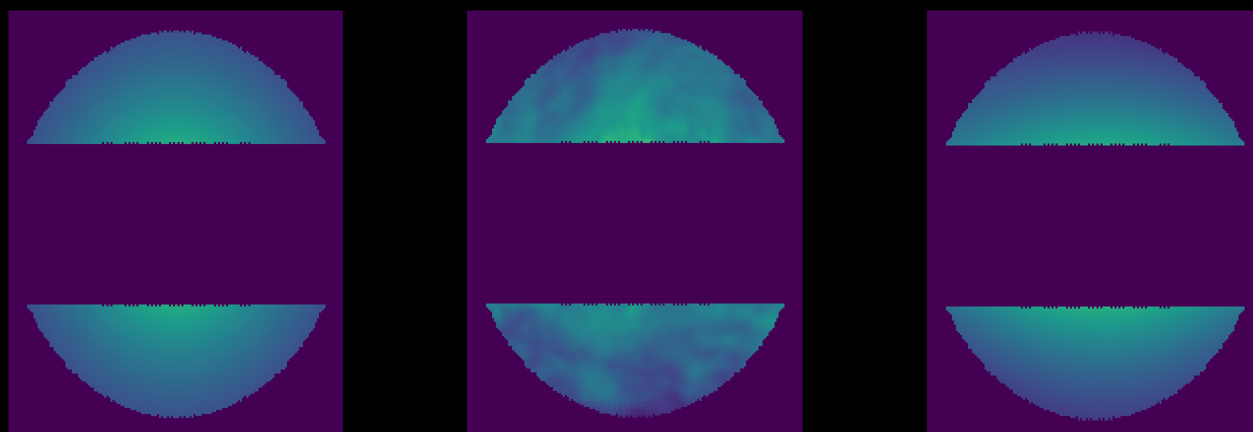
Morphological degeneracy with diffuse foreground

DM Bremsstrahlung ICS



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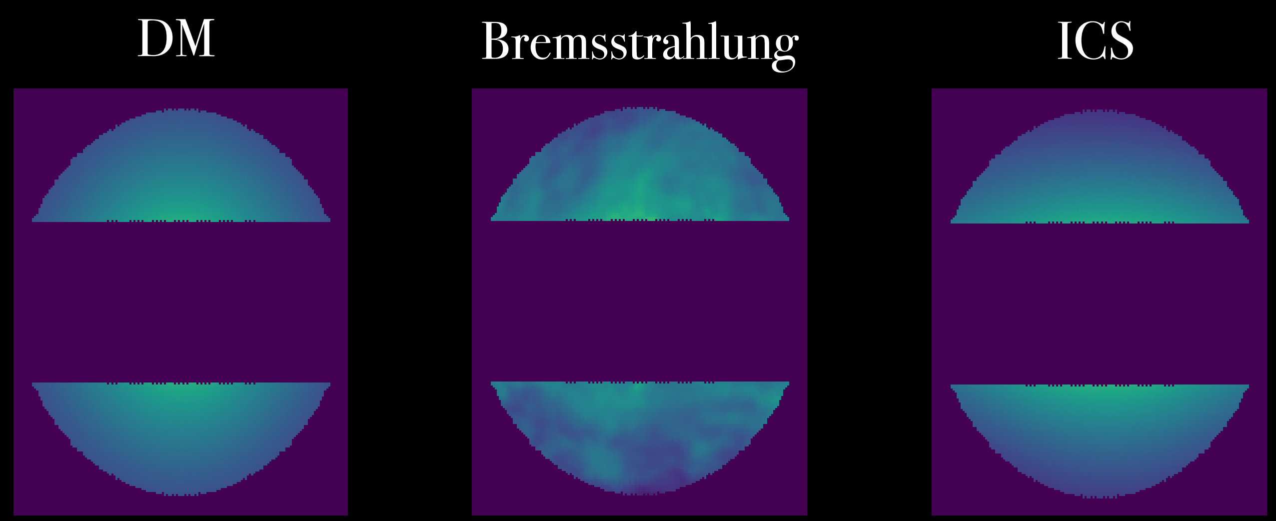

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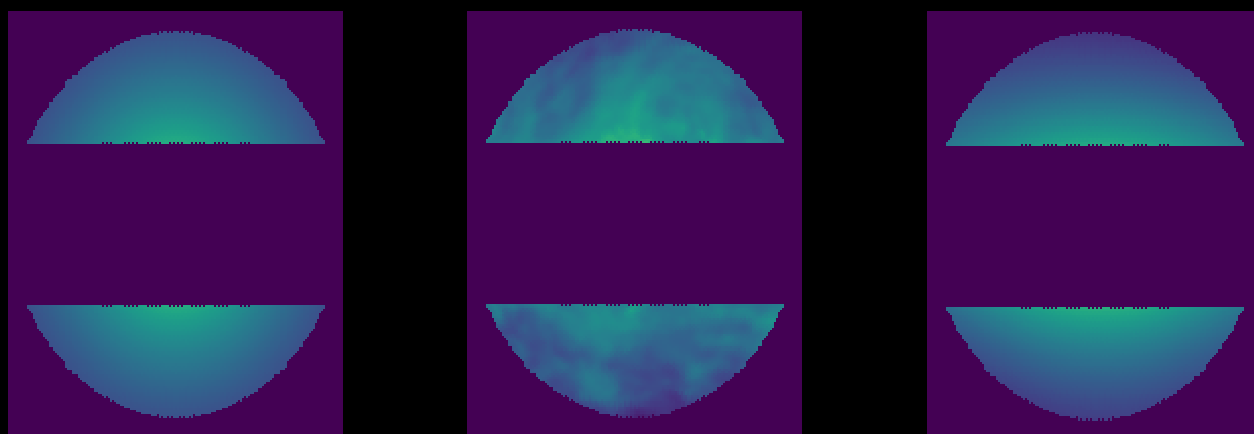
DM | Bremsstrahlung | ICS



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Fermi bubbles: potential degeneracy

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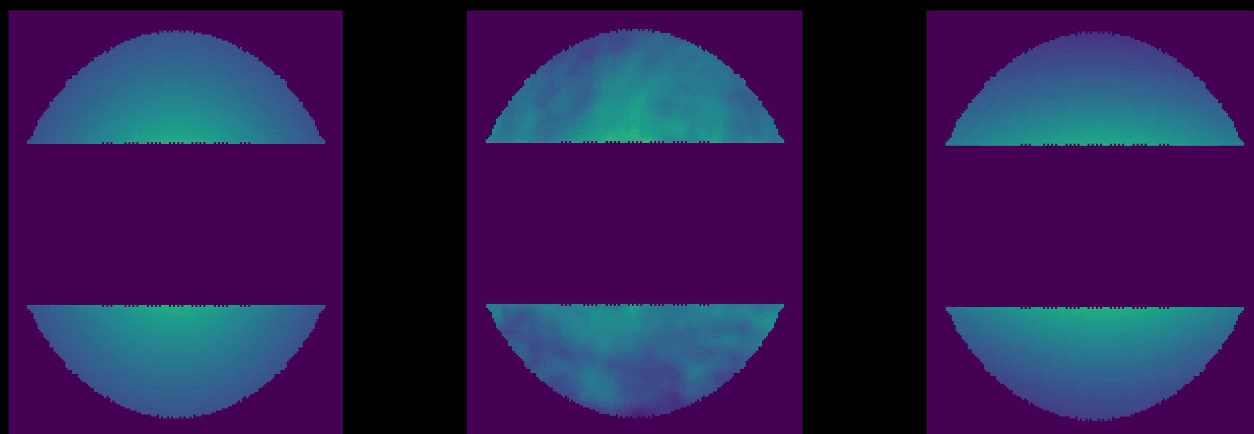

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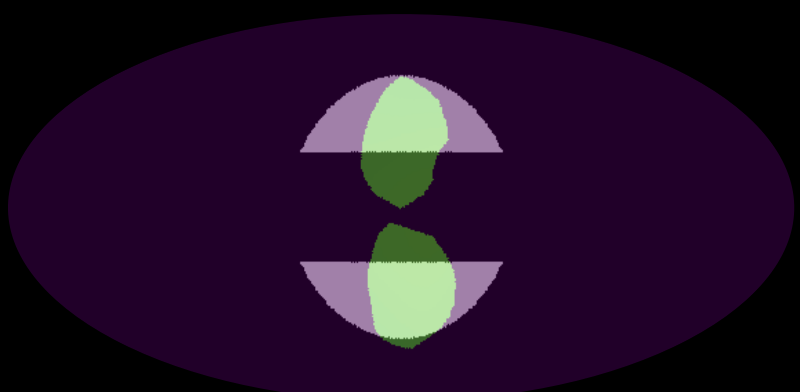
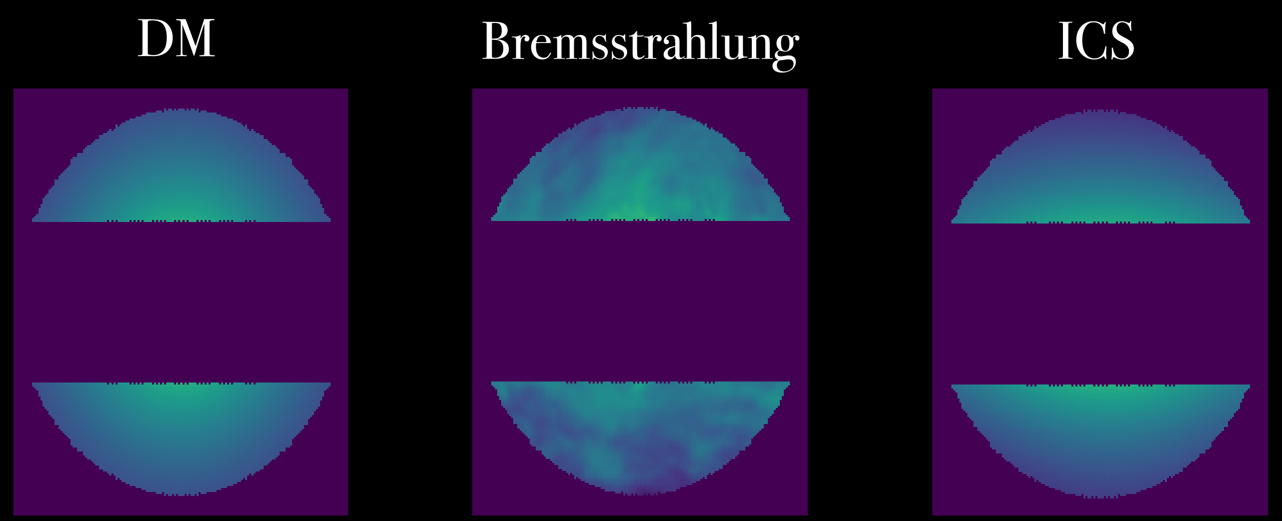


We include a template for the *Fermi* bubbles in our analysis

CHALLENGES: DM ANALYSES AT HIGH LATITUDES

Morphological degeneracy with diffuse foreground



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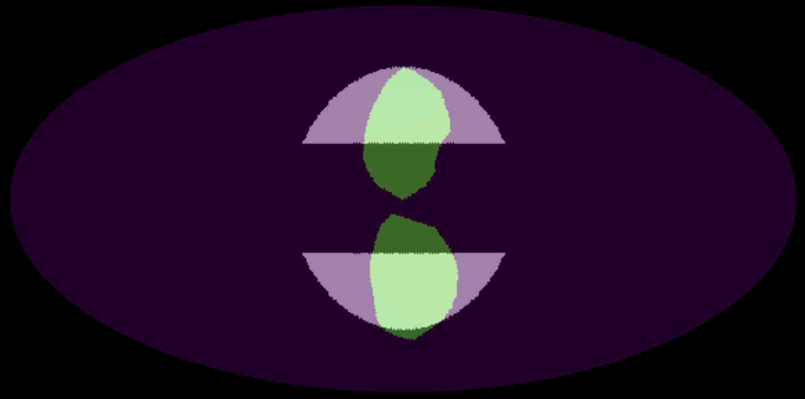
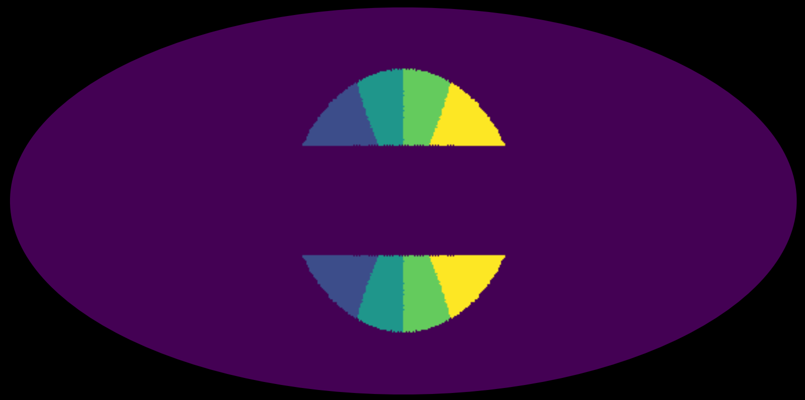


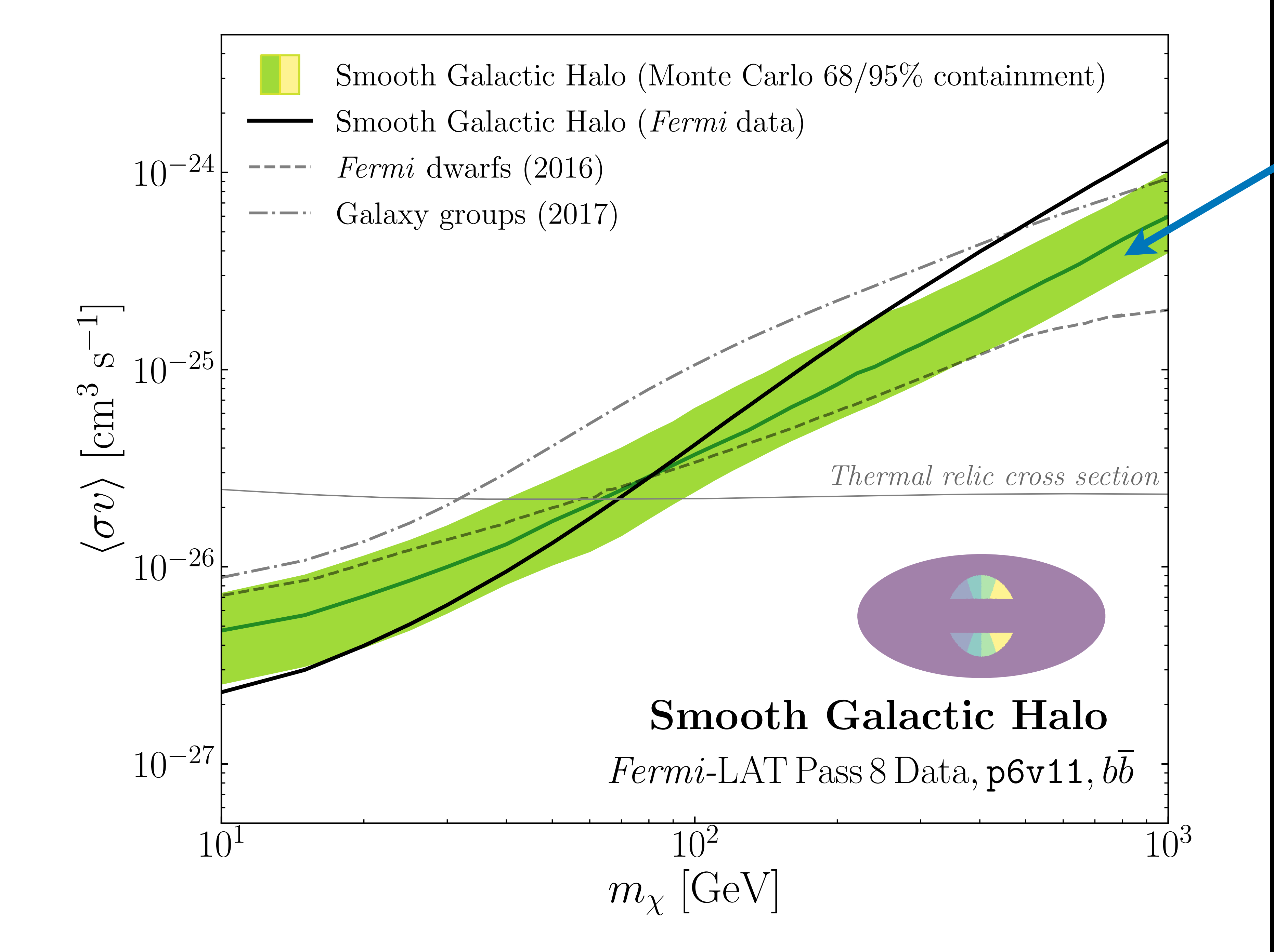
We include a template for the *Fermi* bubbles in our analysis

Fitting imperfect background models over large regions of the sky



We allow the diffuse template more freedom in our ROI

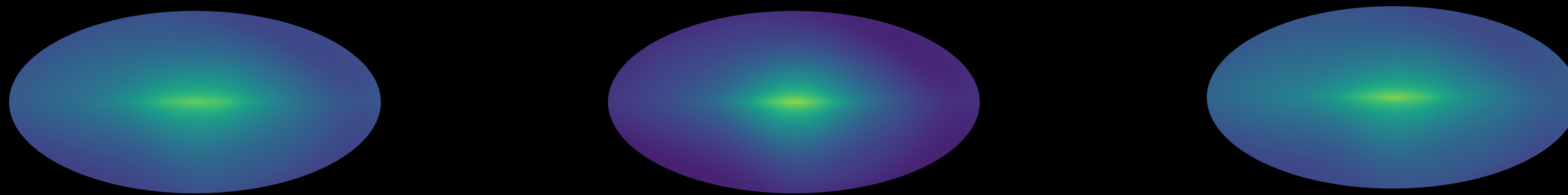
ANALYSIS RESULTS

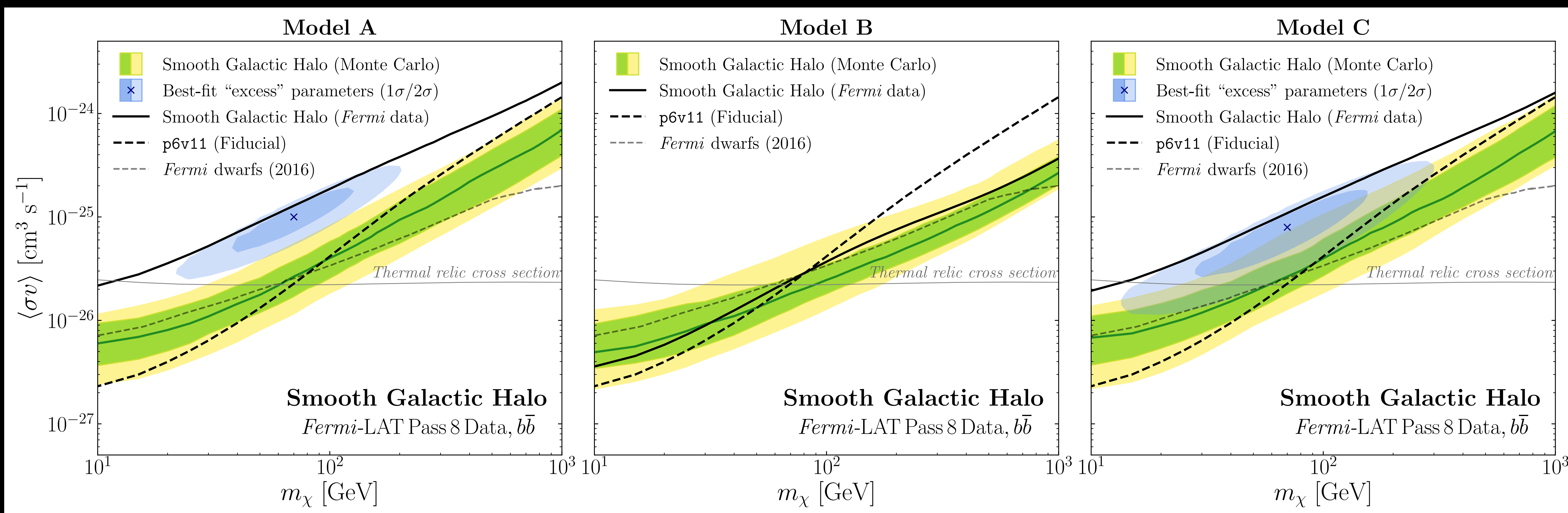


100 Poisson realizations of sum of best-fit backgrounds

VARYING OVER DIFFUSE MODELS

ICS, Model A | ICS, Model B | ICS, Model C

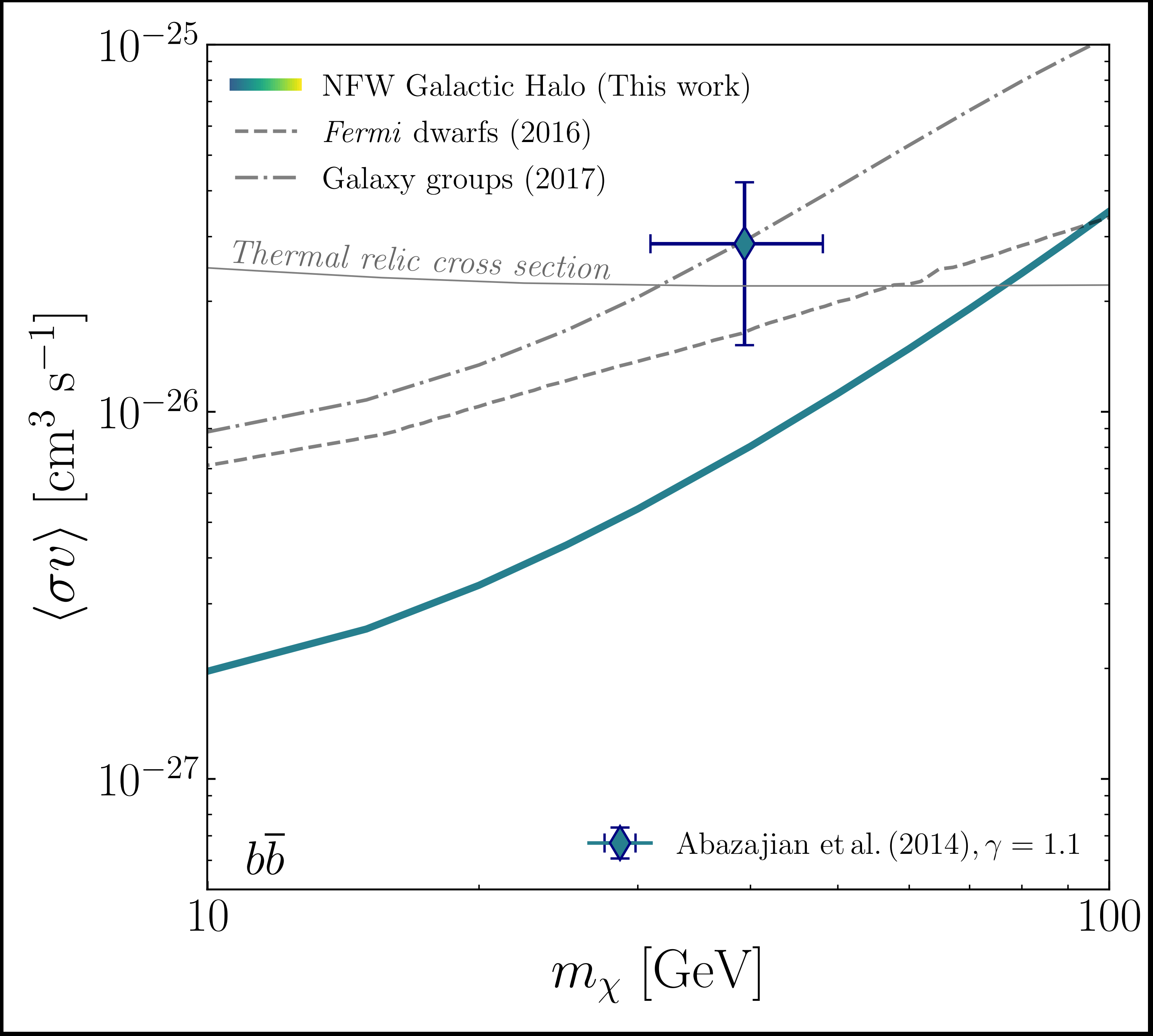




Models A, B, C developed by the *Fermi*-LAT collaboration for their study of the isotropic gamma-ray background at higher latitudes *Fermi*-LAT collaboration [1410.3696]

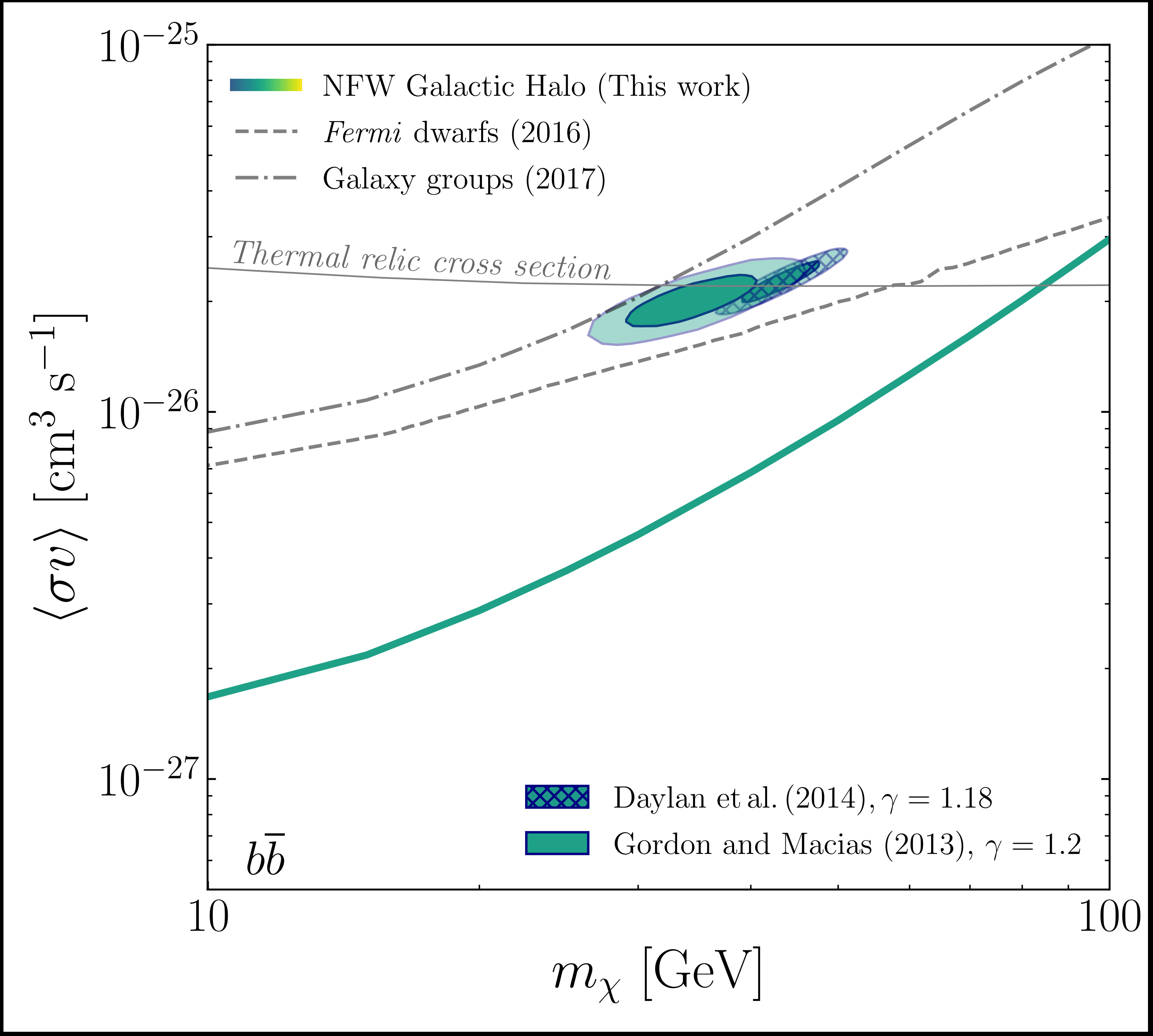
COMPARING TO THE GALACTIC CENTER EXCESS

$$\gamma_{\mathrm{NFW}} = 1.1$$



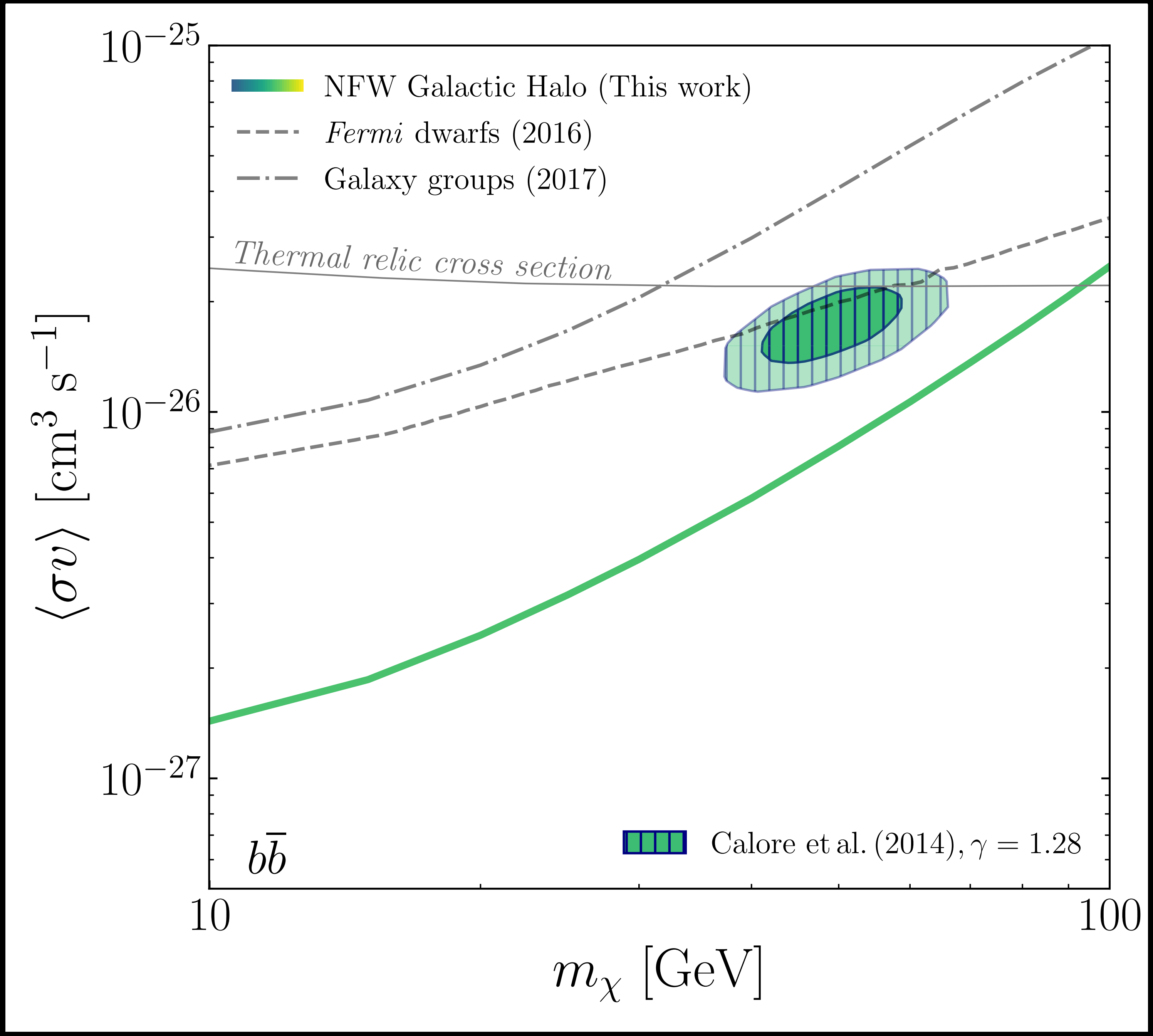
COMPARING TO THE GALACTIC CENTER EXCESS

$\gamma_{\mathrm{NFW}} = 1.2$

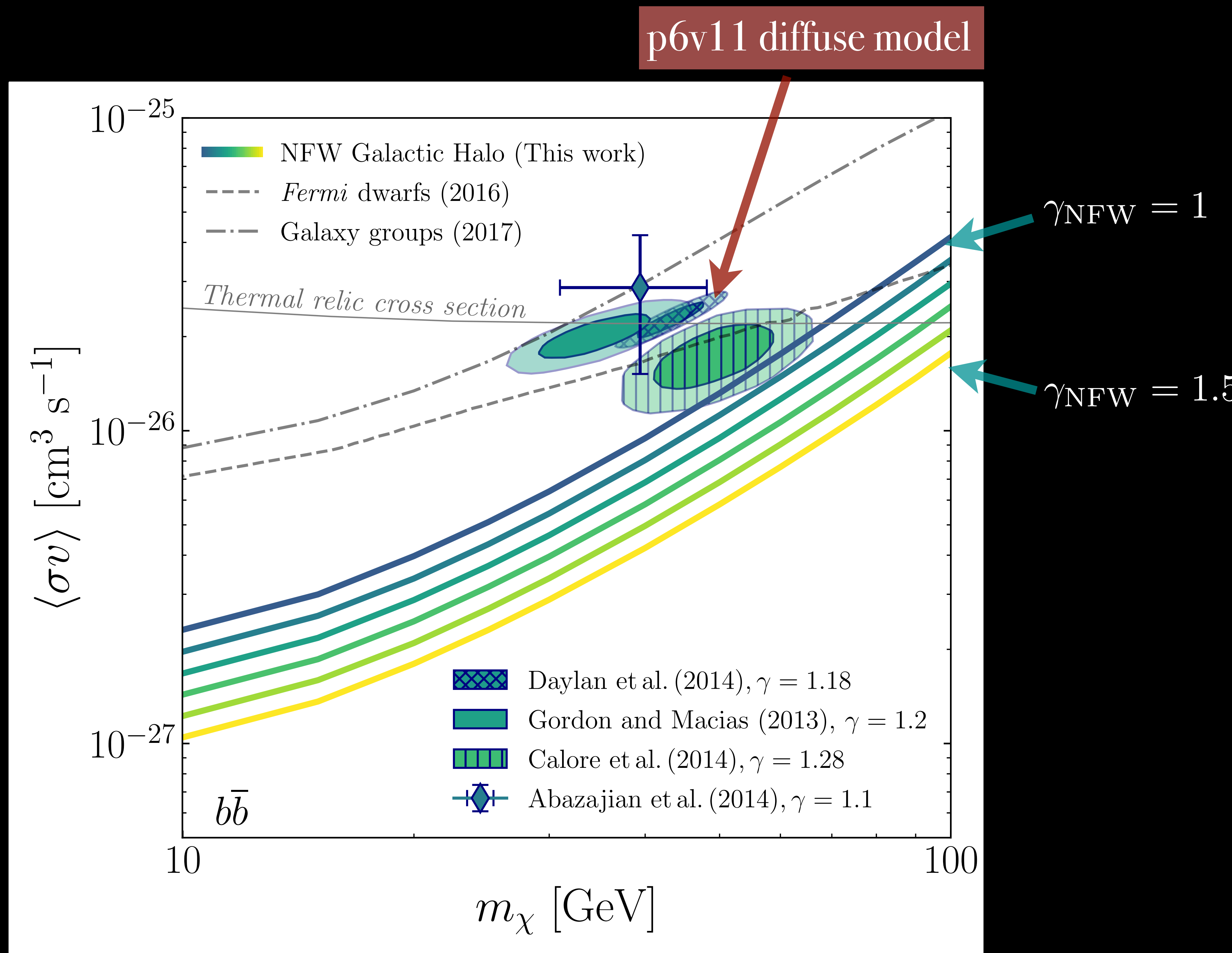


COMPARING TO THE GALACTIC CENTER EXCESS

$\gamma_{\mathrm{NFW}} = 1.3$



COMPARING TO THE GALACTIC CENTER EXCESS



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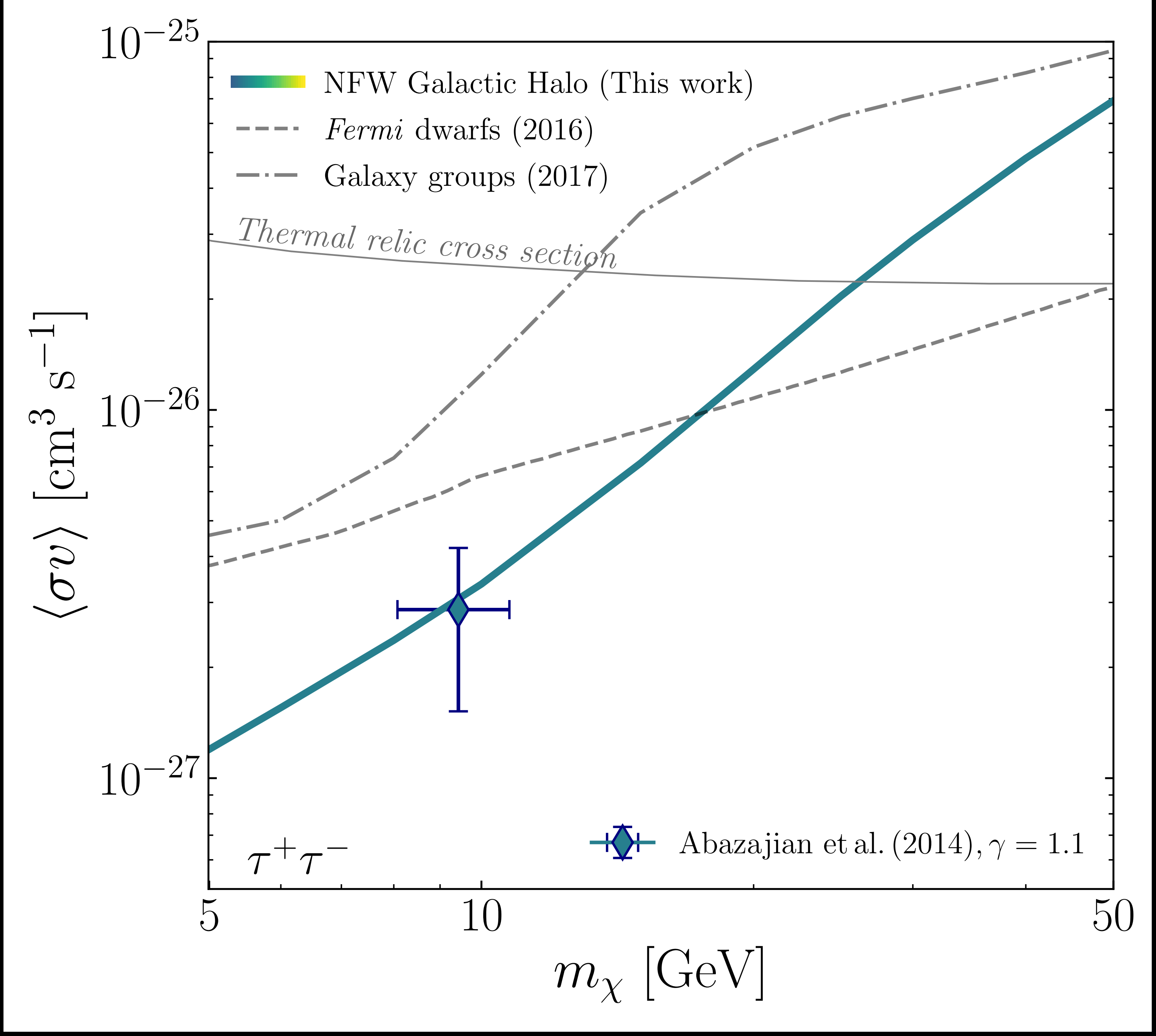
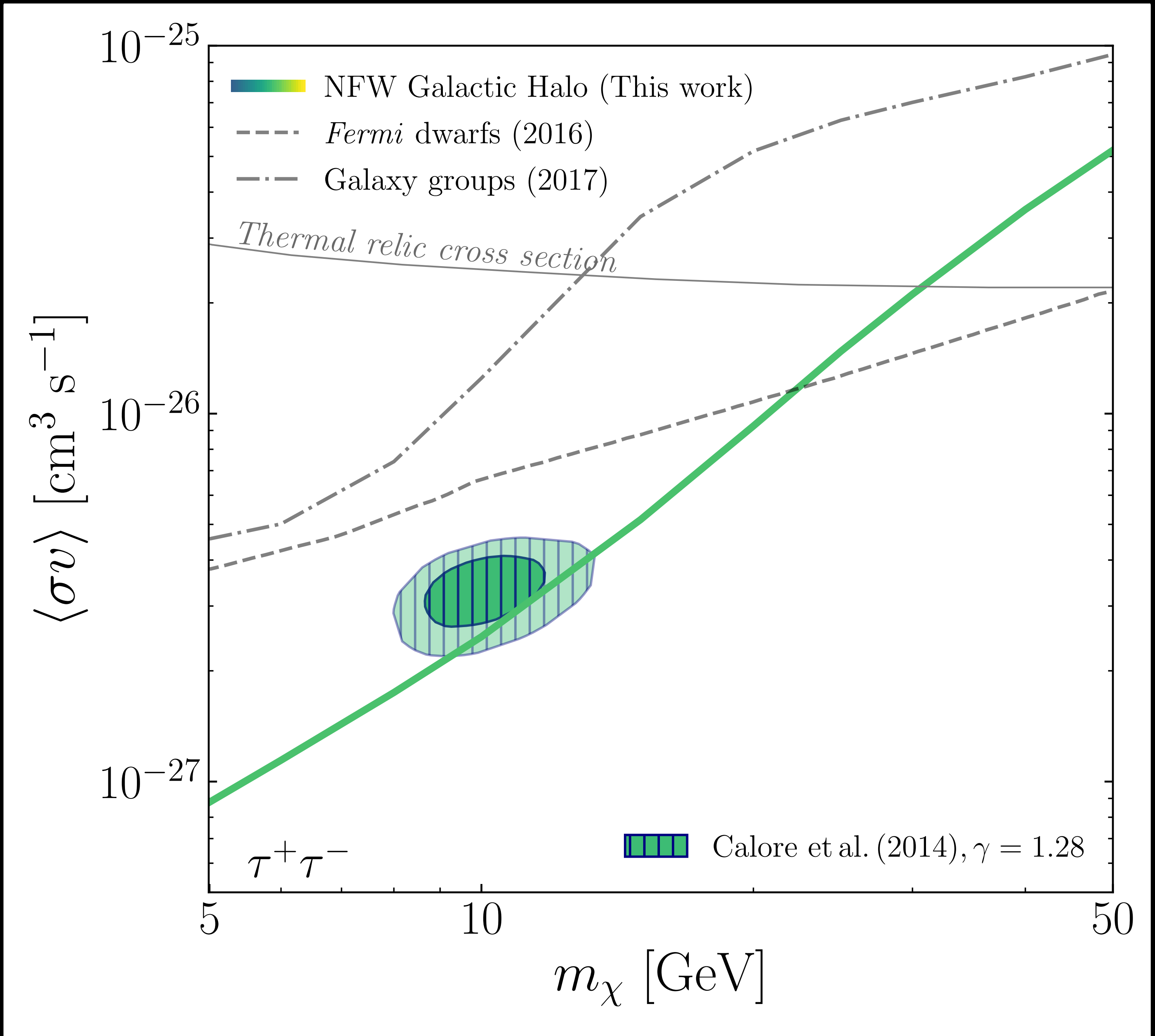
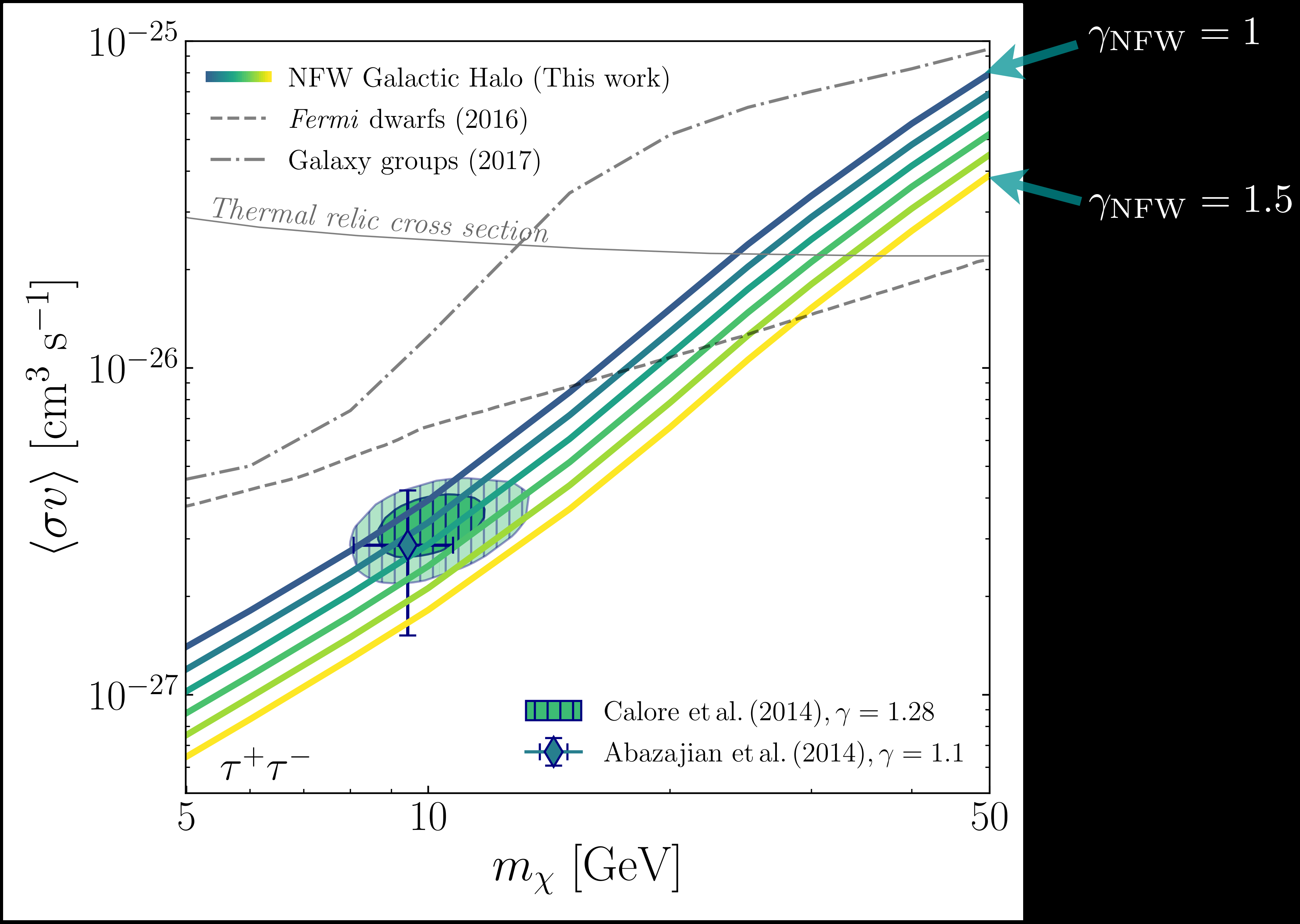


COMPARING TO THE GALACTIC CENTER EXCESS

$$\gamma_{\mathrm{NFW}} = 1.3$$

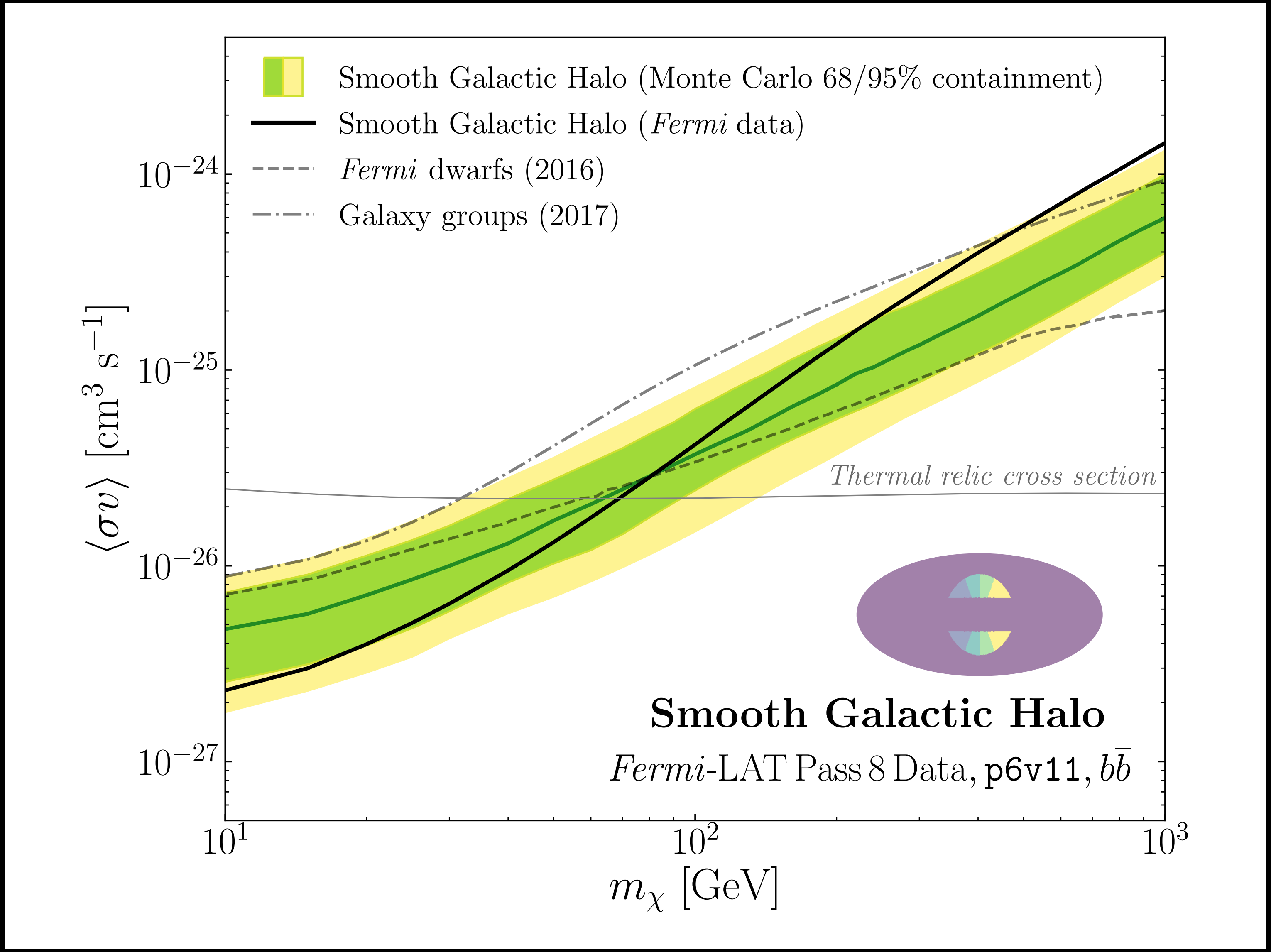


COMPARING TO THE GALACTIC CENTER EXCESS



CONCLUSIONS

- Milky Way halo can provide strong constraints on DM annihilation
- For robust analysis, must mitigate effect of background modeling uncertainties
  - independently fit diffuse background over 8 radial slices
  - perform consistency checks with Monte Carlo



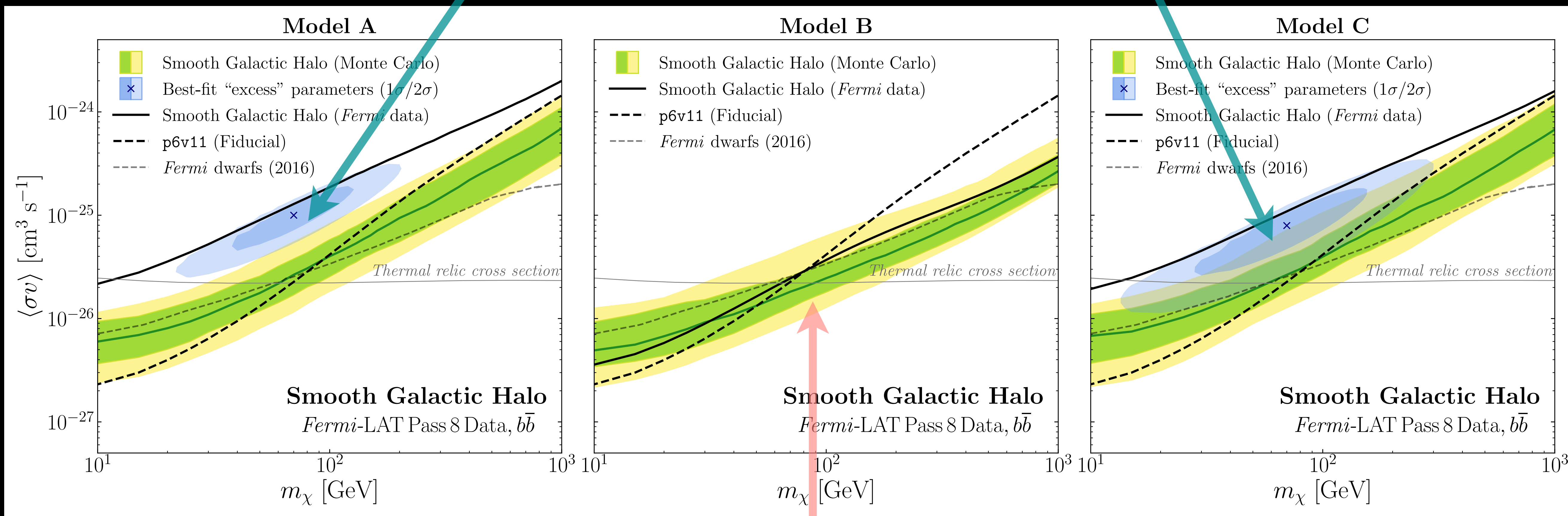
PAUL & DAISY SOROS FELLOWSHIPS FOR NEW AMERICANS

NSF

BACKUP SLIDES

VARYING OVER DIFFUSE MODELS

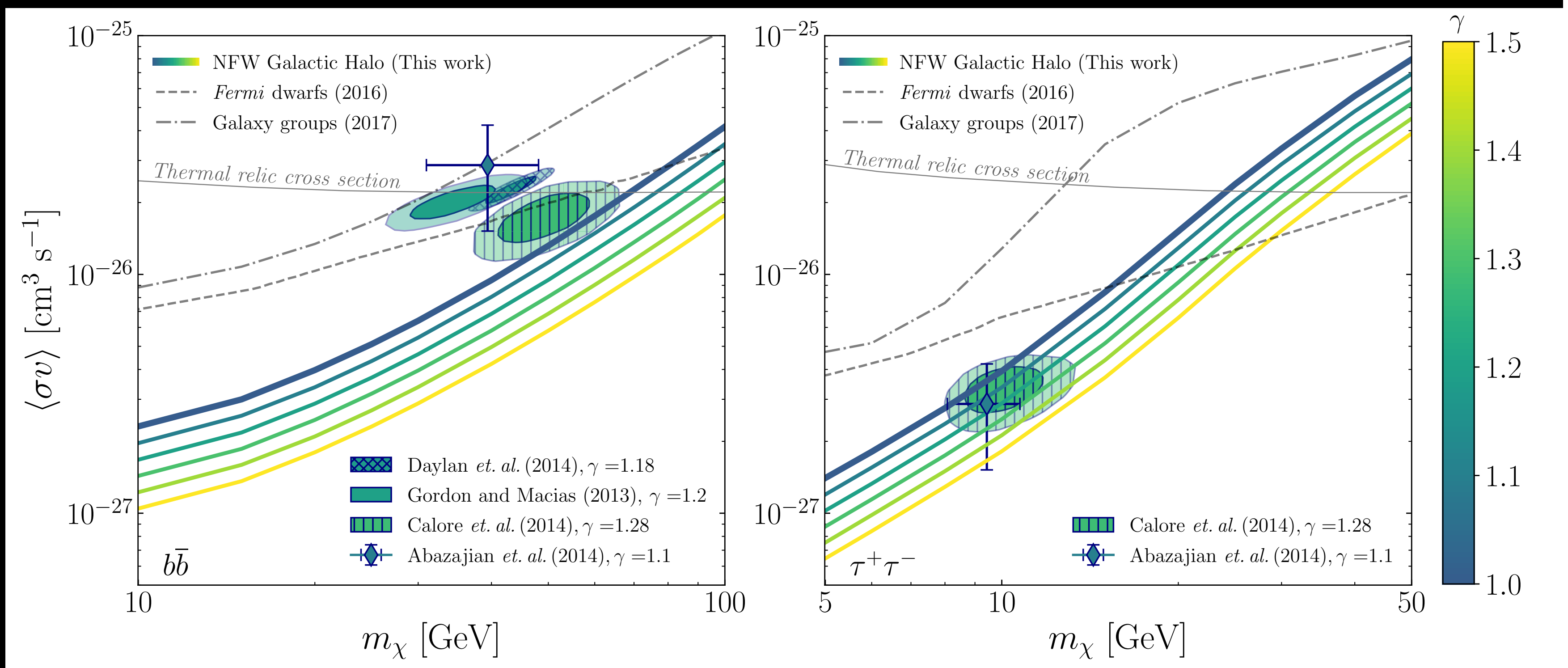
Models A, C: “excesses” robustly excluded by dwarf searches



Model B: additional source population of electrons near the Galactic center, IC spectrum in better agreement with the data

Models A, B, C developed by the *Fermi*-LAT collaboration for their study of the isotropic gamma-ray background at higher latitudes *Fermi*-LAT collaboration [1410.3696]

MORE INFO ON GCE



GCE studies specifics

GORDON AND MACIAS

- event class: SOURCE
- energy range: 0.2–100GeV
- diffuse model: p7v6_v0

ABAZAJIAN ET AL.

- 2 seperate analyses
    - 0.2–300GeV: SOURCE
    - 0.7–7GeV: ULTRACLEAN
- diffuse model: p7v6_v0 + 20 cm radio map (to account for bremsstrahlung off molecular gas)

DAYLAN ET AL.

- event class: ULTRACLEAN, Q2
- 0.316–10GeV
- diffuse model:
    - p6v11 for "inner Galaxy" analysis (40x40 deg)
    - p7v6_v0 + 20 cm map for "Galactic center" analysis (5x5 deg)

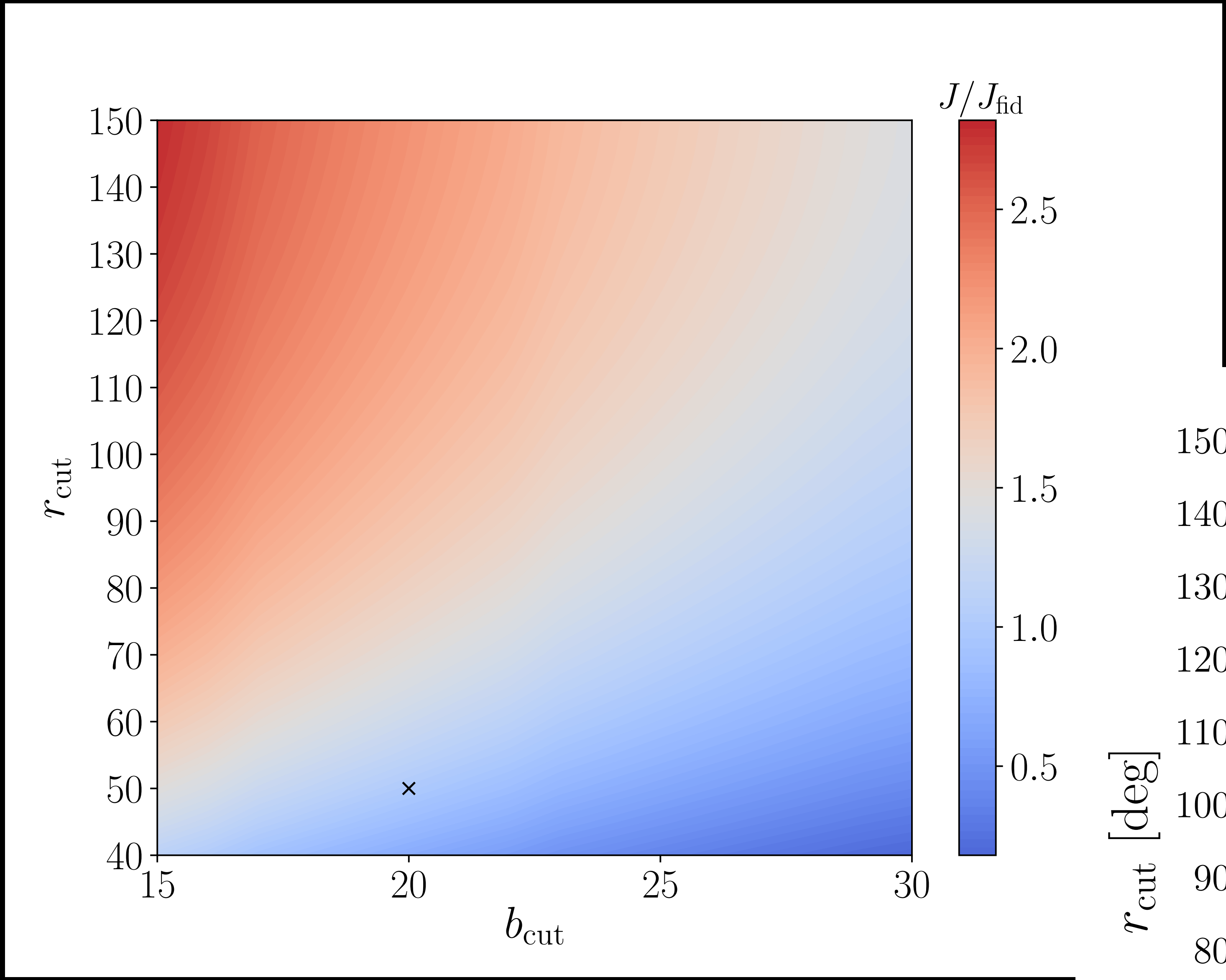
CALORE ET AL. (1409.0042)

- event class: CLEAN
- 0.3–500GeV
- diffuse model: "Model F" (Galprop best-fit to data in ROI)

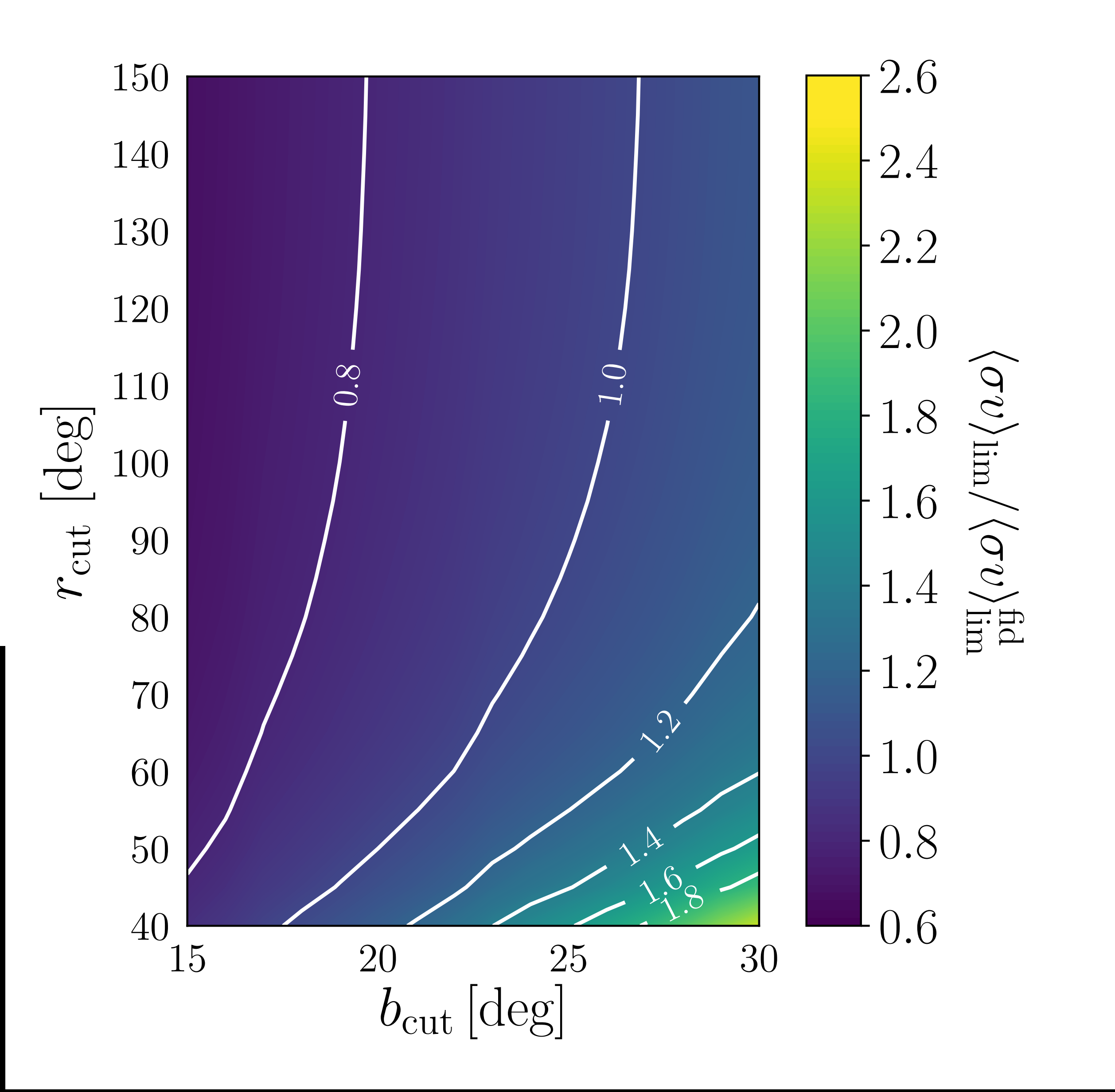
CALORE ET AL. (1411.4647)

Should be the same as in 1409.0042

PROJECTED SENSITIVITIES (ASIMOV TESTS)

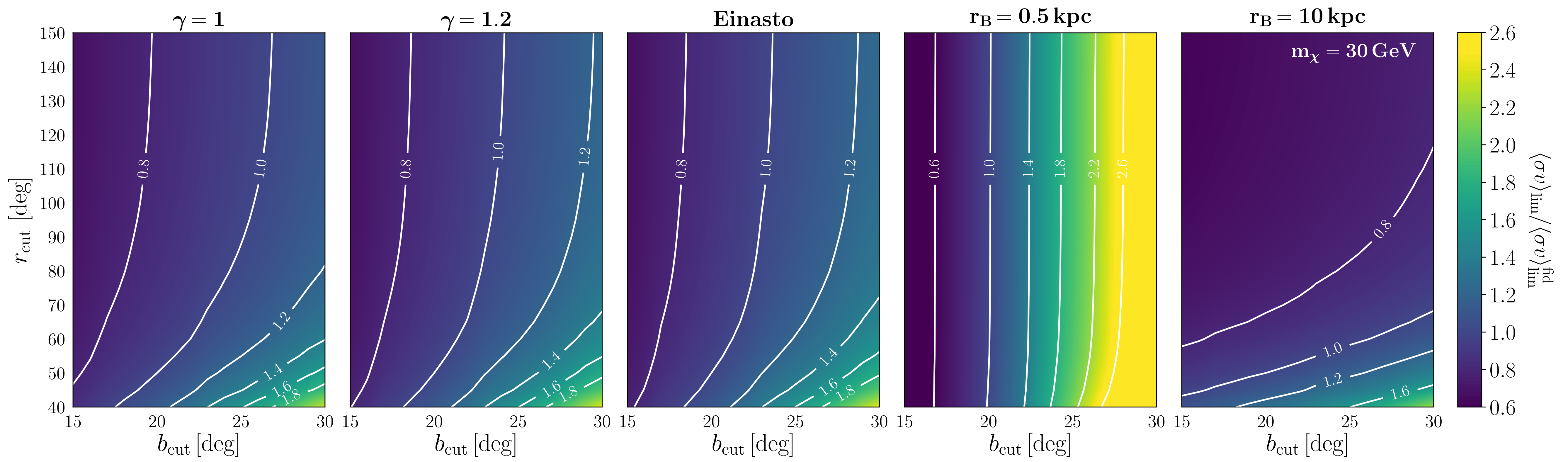


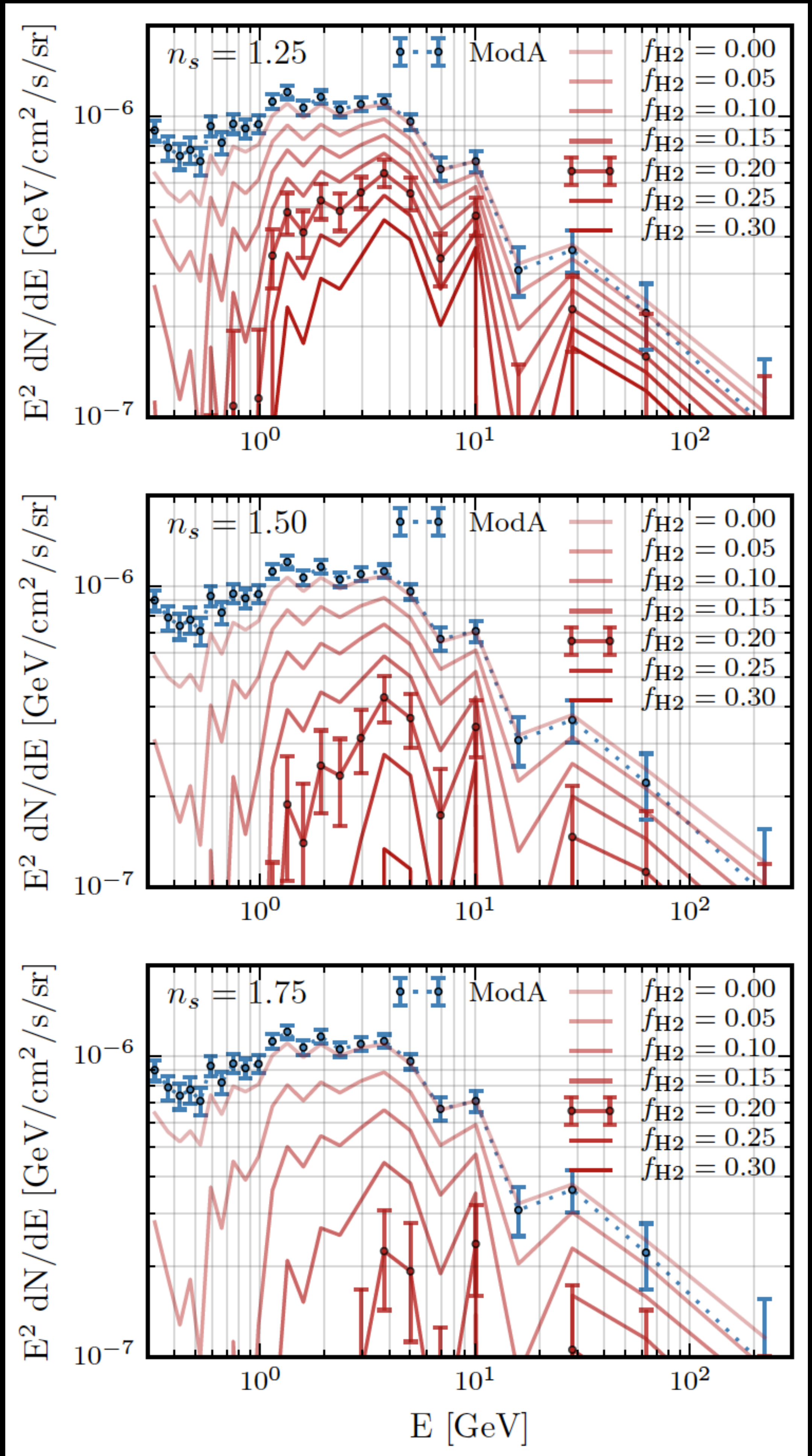
Larger areas of the sky leads to factor of 3 increase in J-factor…



…**but** the corresponding improvement in projected sensitivity to annihilation cross-section is only a factor of 1.6

PROJECTED SENSITIVITIES (ASIMOV TESTS)

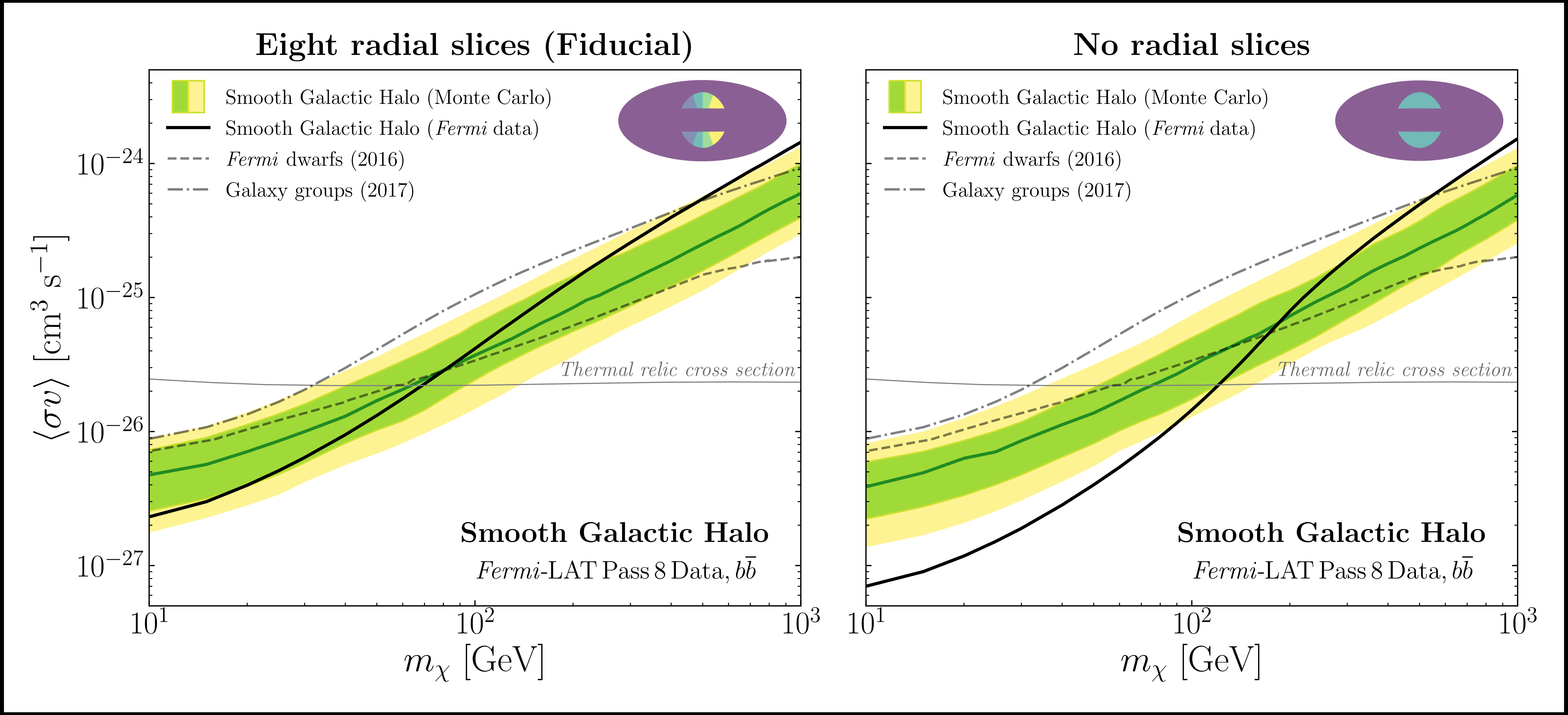




E. Carlson, et al. [1603.06584]

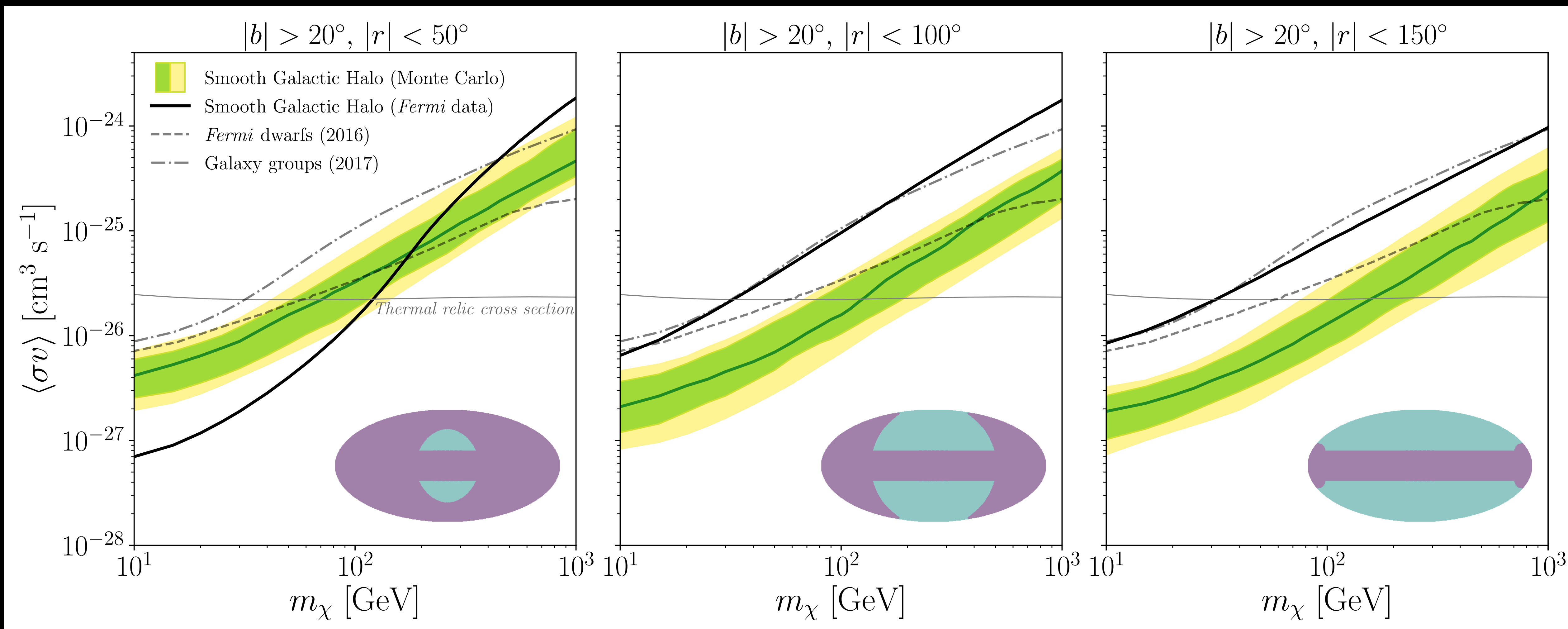
DIFFUSE MISMODELING: OVERSUBTRACTION & EXCESSES

p6v11 diffuse model



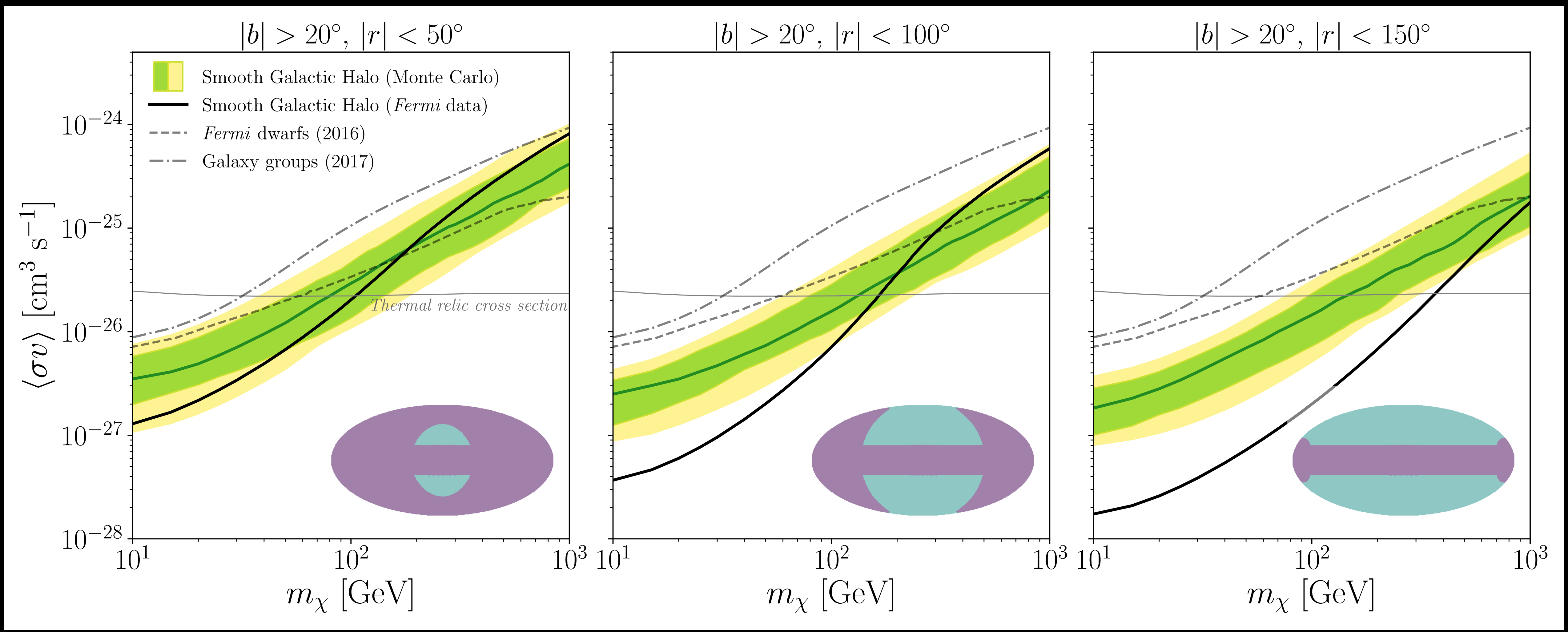
DIFFUSE MISMODELING: OVERSUBTRACTION & EXCESSES

p6v11 diffuse model, no radial slices

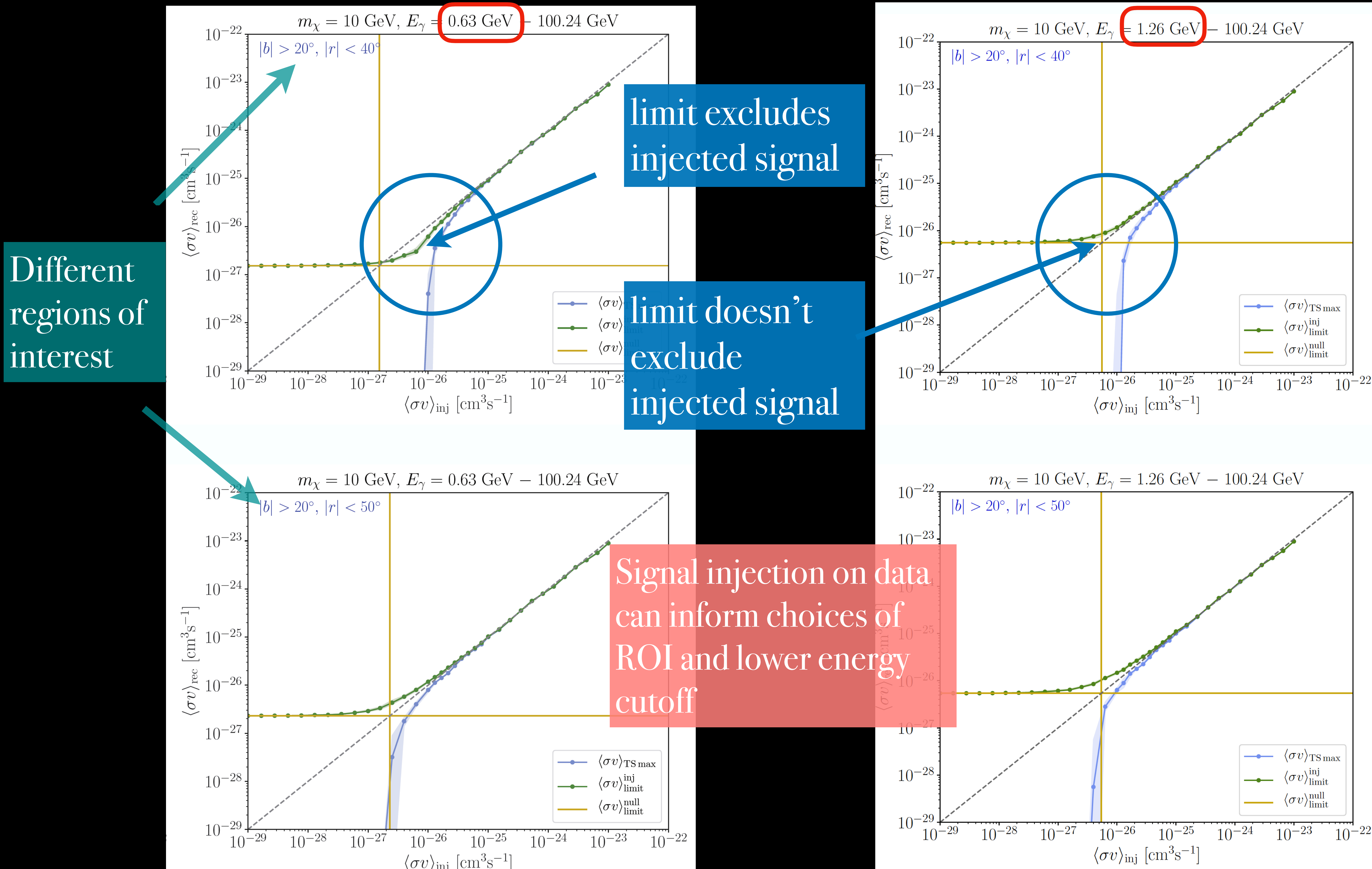


DIFFUSE MISMODELING: OVERSUBTRACTION & EXCESSES

p8R2 diffuse model, no radial slices

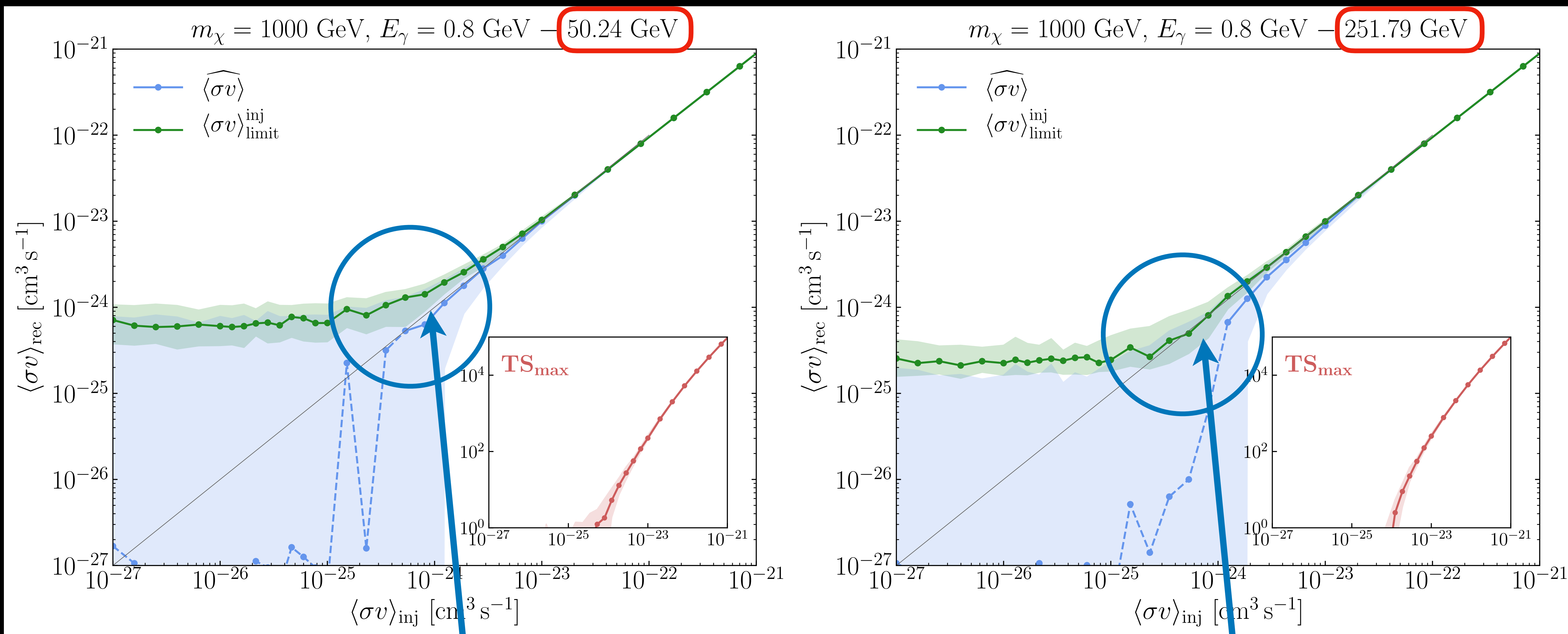


SIGNAL INJECTION ON DATA



SIGNAL INJECTION: MONTE CARLO

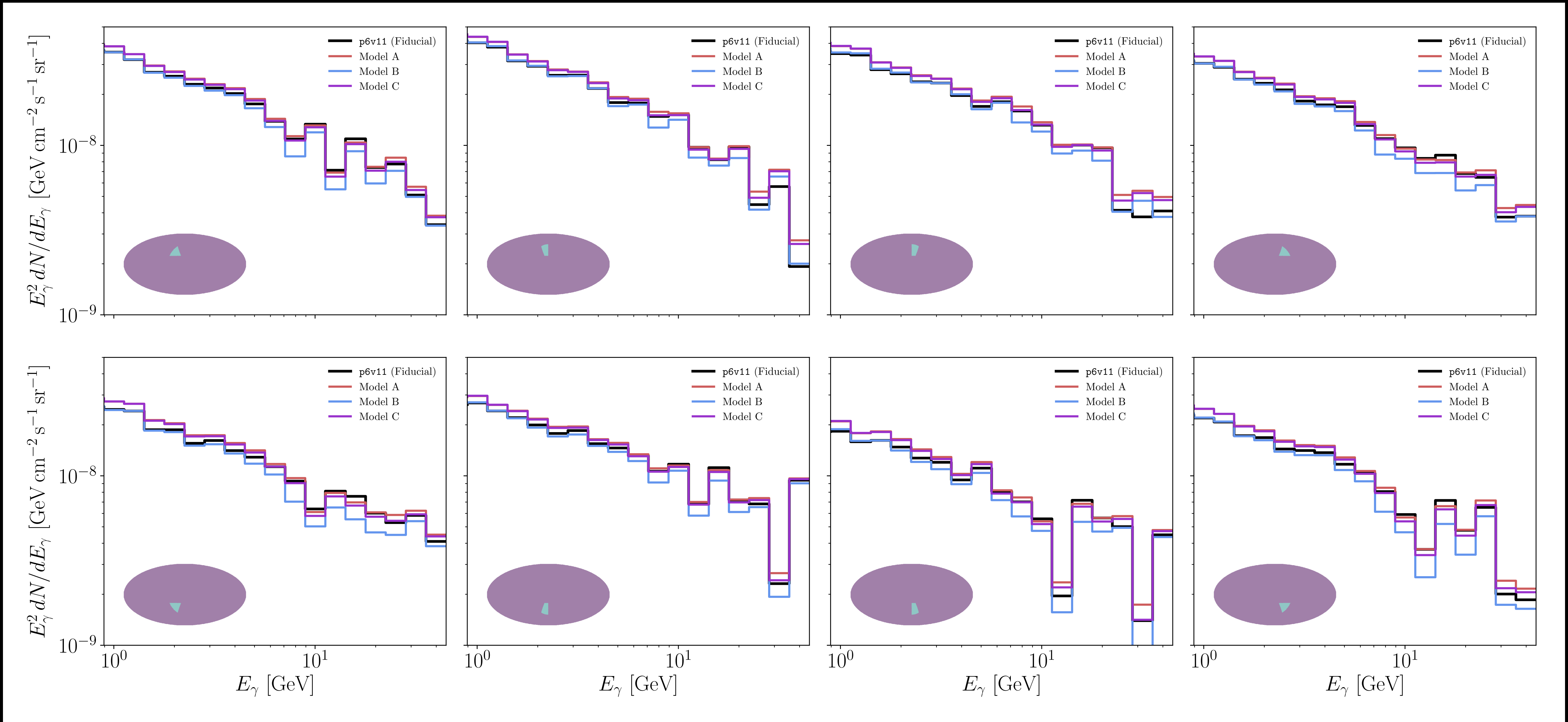
Signal injection on MCs can inform choice of upper energy cutoff



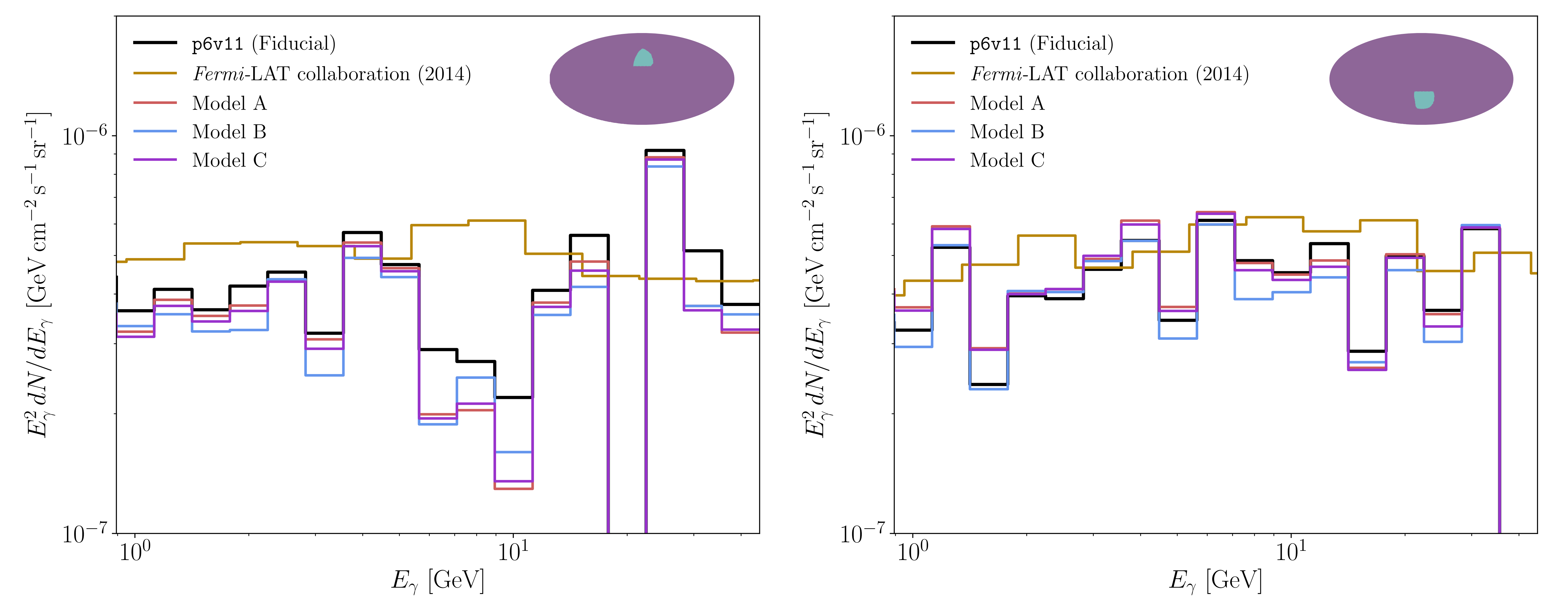
limit doesn't exclude injected signal

limit excludes injected signal

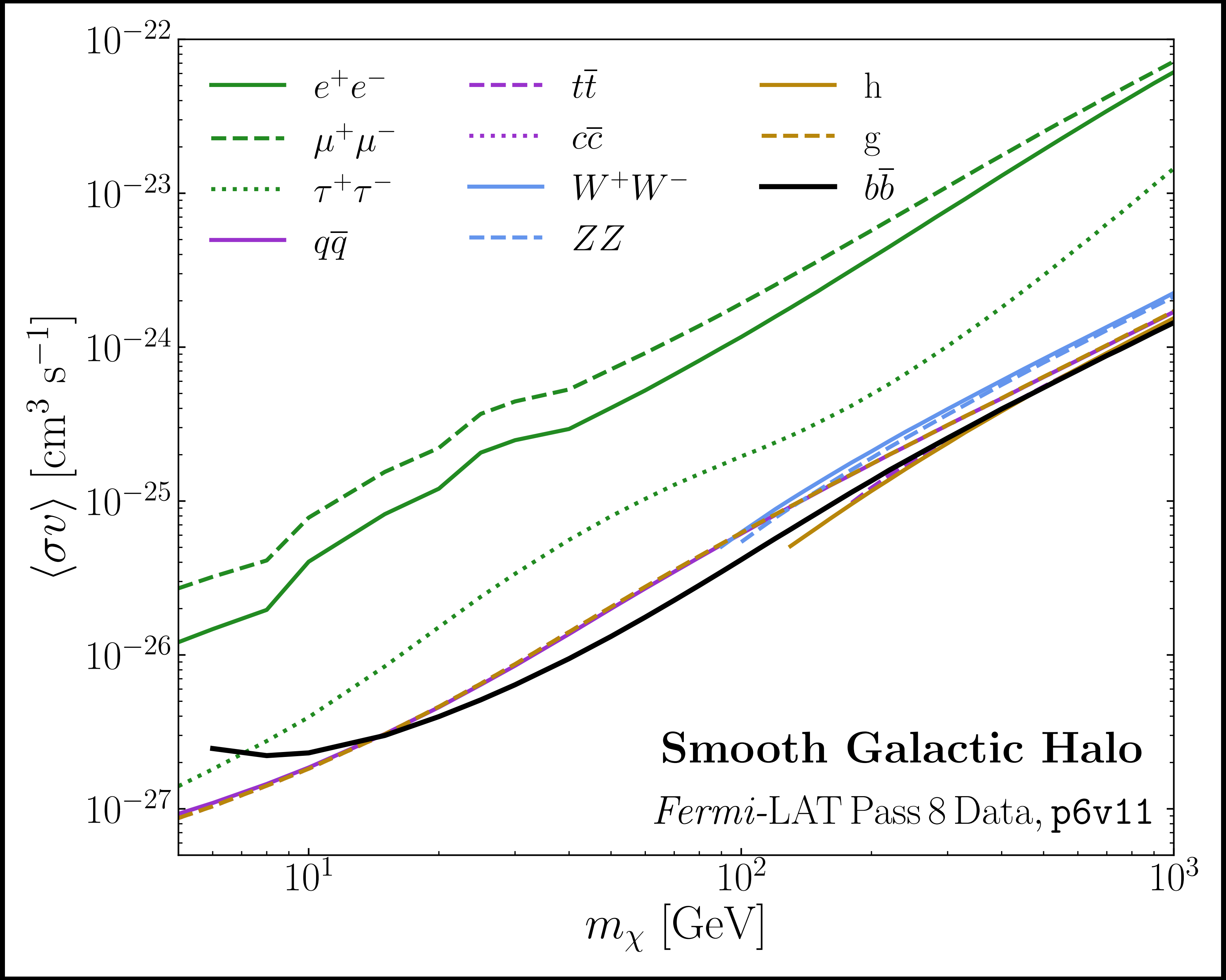
DIFFUSE SPECTRA



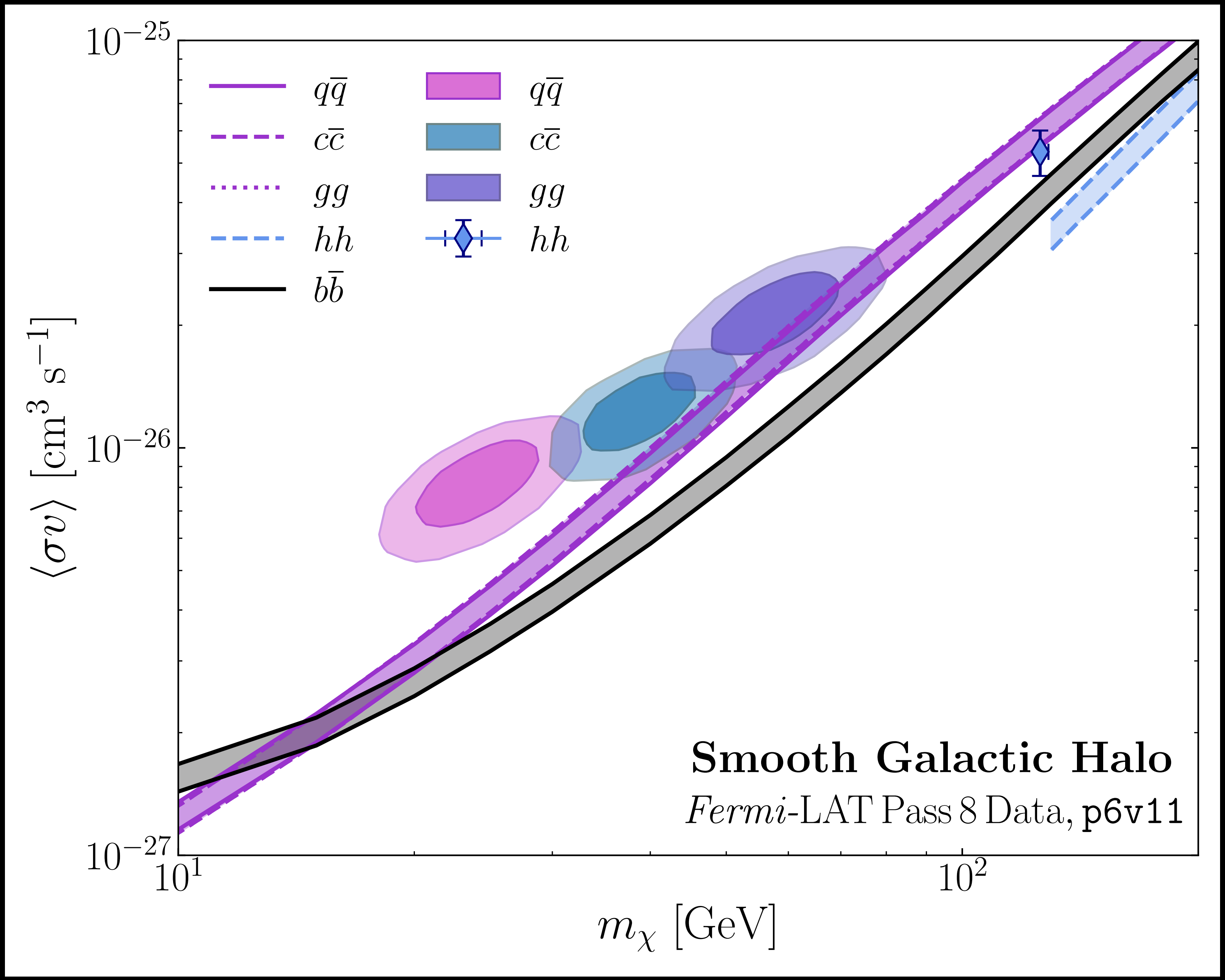
FERMI BUBBLES SPECTRA



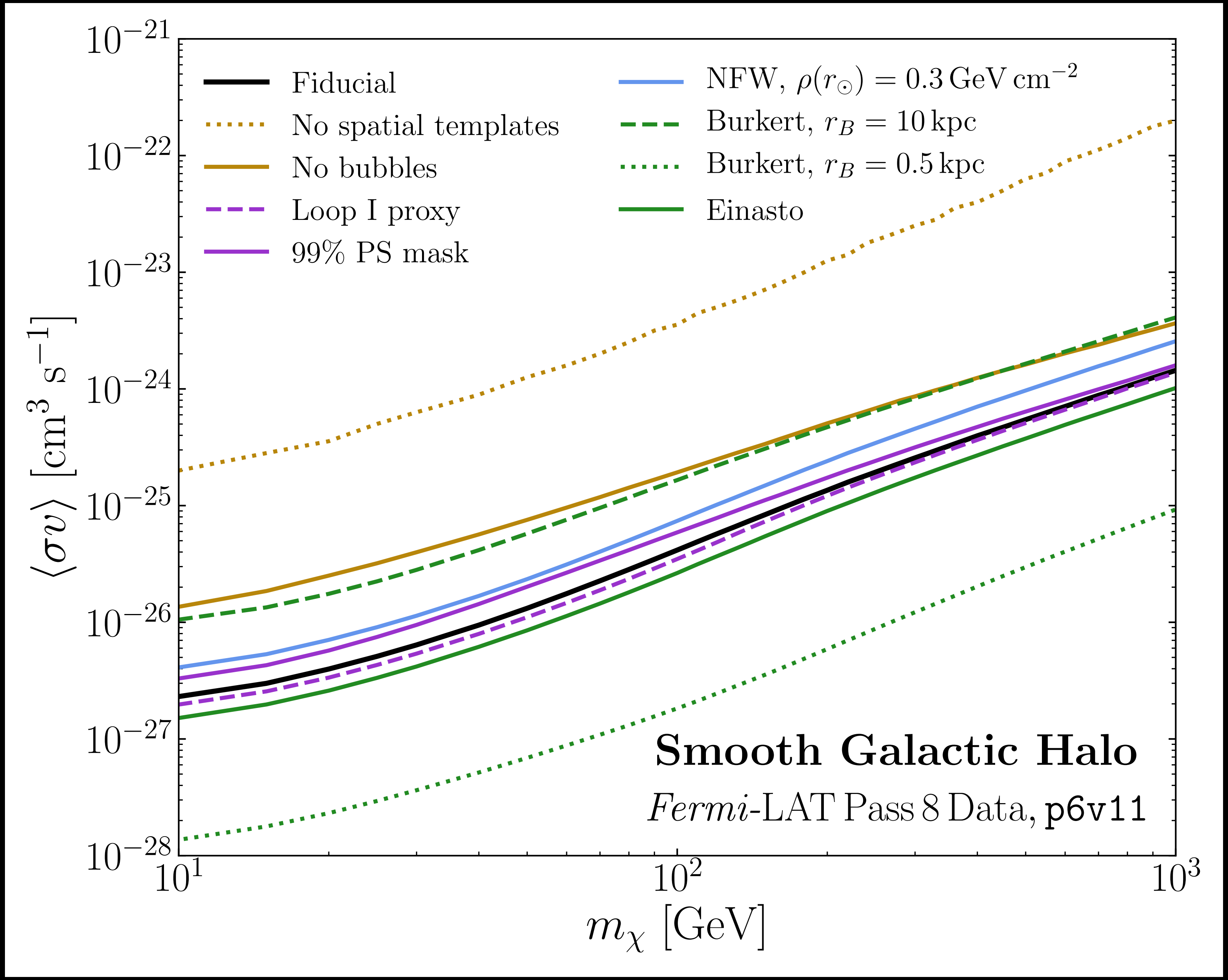
ANNIHILATION CHANNELS



ANNIHILATION CHANNELS, GCE



ADDITIONAL SYSTEMATICS



LIKELIHOOD PROFILES