Reticulum II: Evidence for gamma-ray emission, its dark matter content and implications for dark matter physics

Savvas M. Koushiappas

BROWN

Based on 1503.02320 and 1504.03309

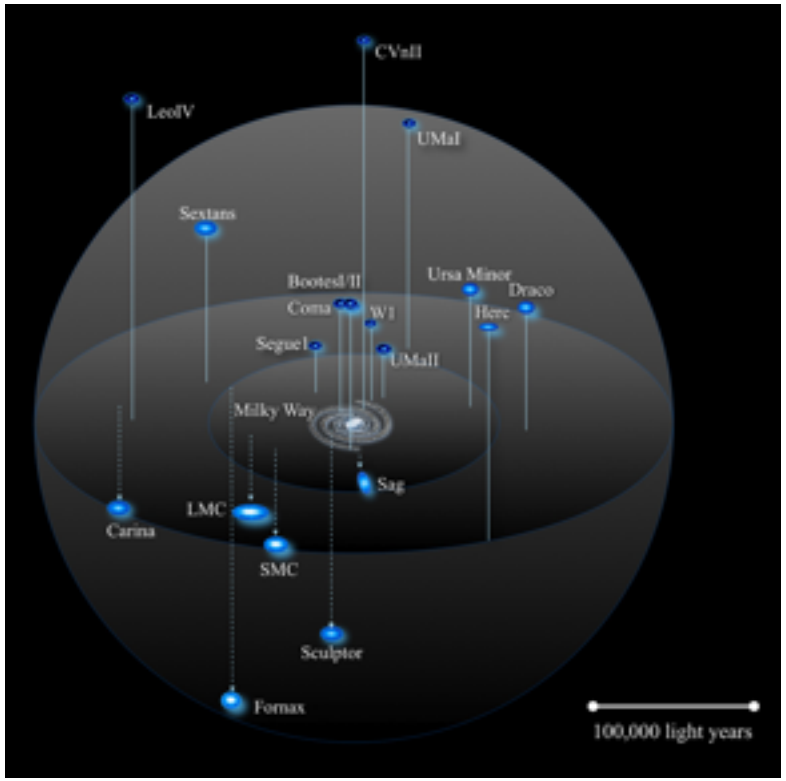
With: Alex Geringer-Sameth & Matthew Walker (Carnegie-Mellon U.),
Sergey Koposov, Vasily Belokurov, Gabriel Torrealba & Wyn Evans (Cambridge U.)
Vincent Bonnivard, Celine Combet, David Maurin (U. Grenoble-Alpes),
Mario Mateo, John Bailey (U. Michigan), Eduard Olszewski (U. Arizona)

NSF

NASA

Dwarf galaxies: The ideal targets in indirect detection

$$\chi\chi \xrightarrow{\langle\sigma_A v\rangle} q's,\ \ell's,\ etc. \qquad \Gamma \propto \int n_\chi^2 d^3r$$



Dwarf galaxies: The ideal targets in indirect detection

PHYSICAL REVIEW D **75,** 083526 (2007)

Precise constraints on the dark matter content of Milky Way dwarf galaxies for gamma-ray experiments

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THE MOST DARK-MATTER–DOMINATED GALAXIES: PREDICTED GAMMA-RAY SIGNALS FROM THE FAINTEST MILKY WAY DWARFS

Louis E. Strigari,[1] Savvas M. Koushiappas,[2] James S. Bullock,[1] Manoj Kaplinghat,[1]
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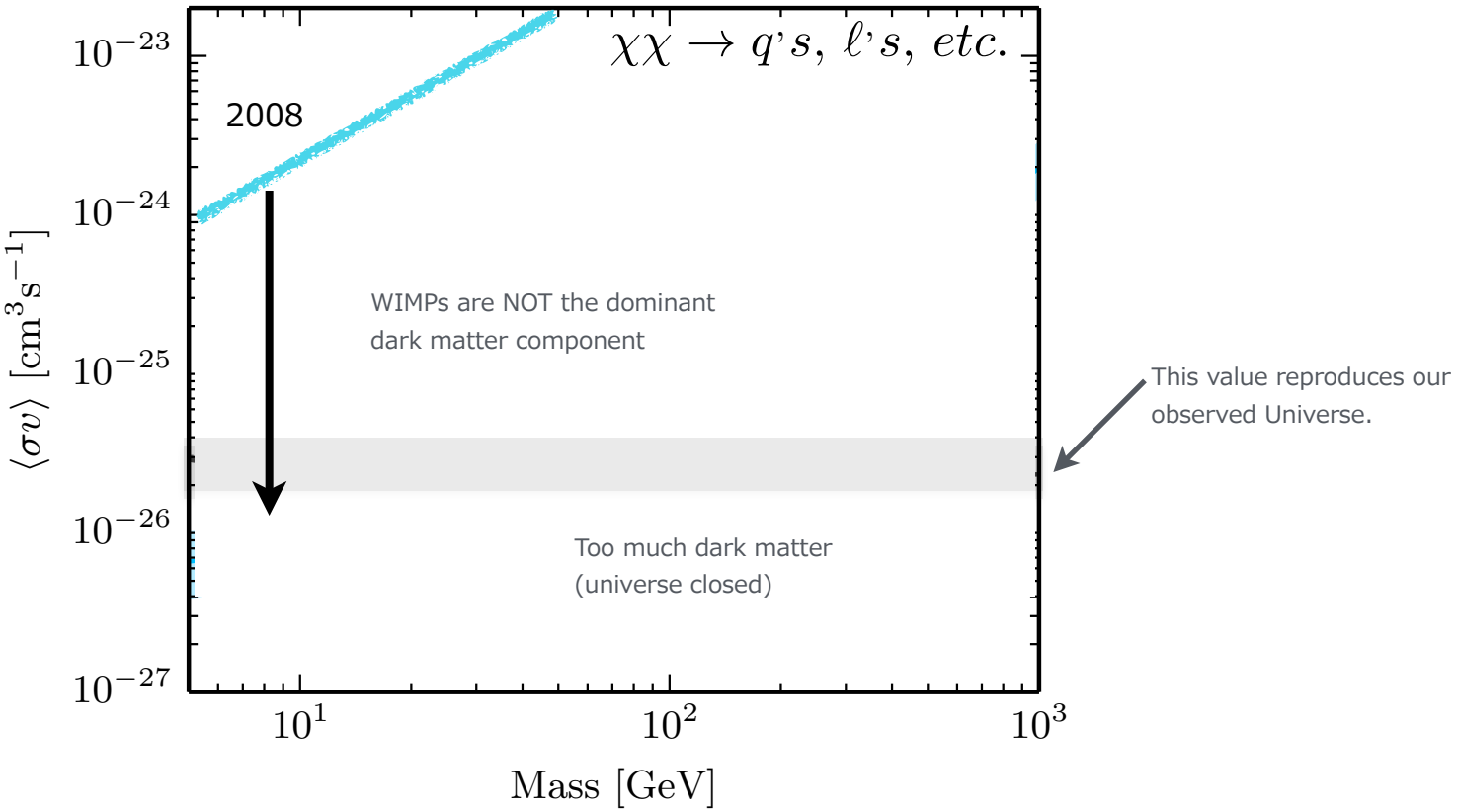
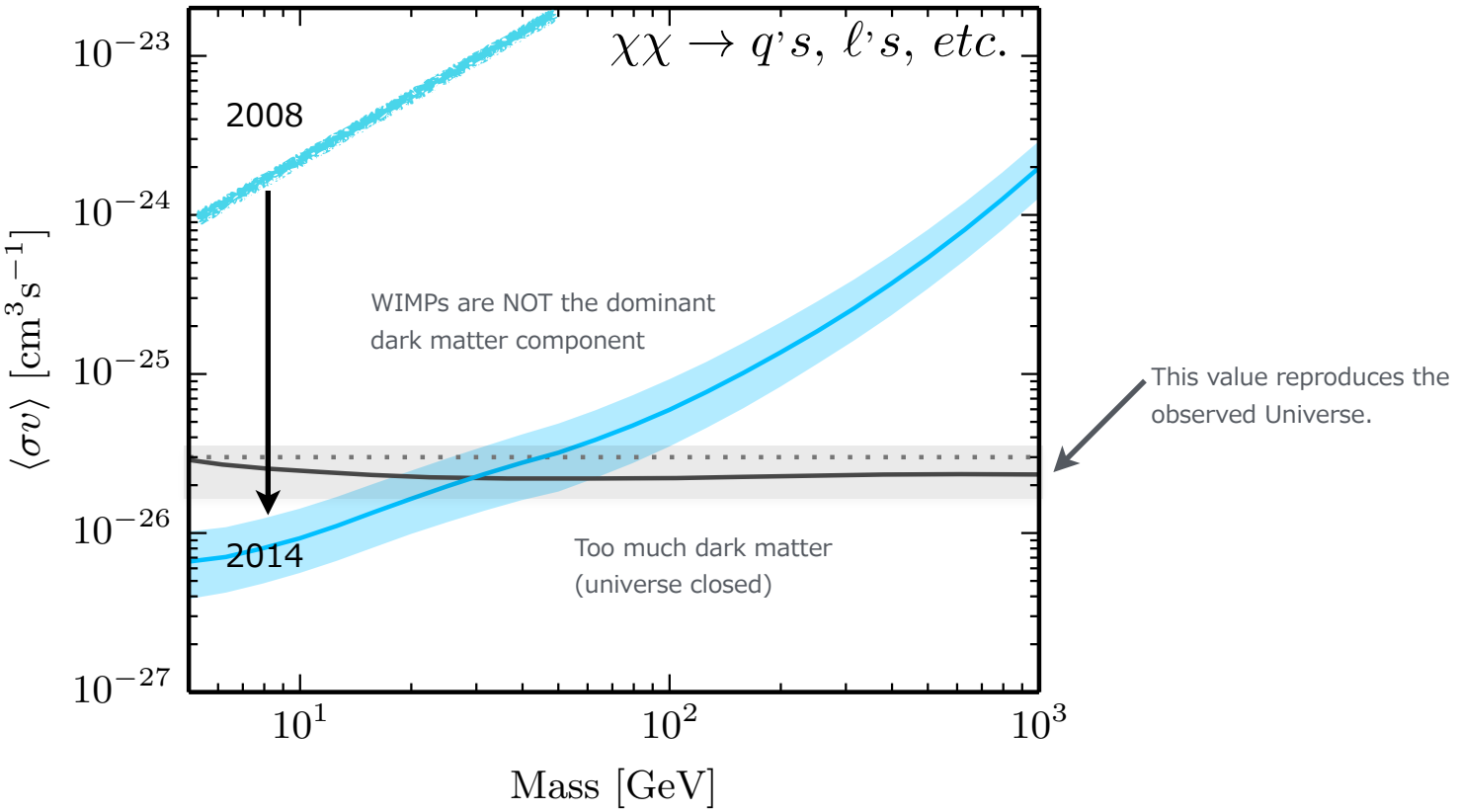
Dwarf galaxies — state of constraints on $\langle \sigma v \rangle$



Geringer-Sameth, Koushiappas & Walker, PRD 91, 083535 (2015), see also Ackermann et al., PRD 89, 042001 (2014) & 1503.02641

Dwarf galaxies — state of constraints on $\langle \sigma v \rangle$



Geringer-Sameth, Koushiappas & Walker, PRD 91, 083535 (2015), see also Ackermann et al., PRD 89, 042001 (2014) & 1503.02641

On March 8, 2015

arXiv:1503.02079 [pdf, ps, other]
Beasts of the Southern Wild. Discovery of a large number of Ultra Faint satellites in the vicinity of the Magellanic Clouds
Sergey E. Koposov, Vasily Belokurov, Gabriel Torrealba, N. Wyn Evans

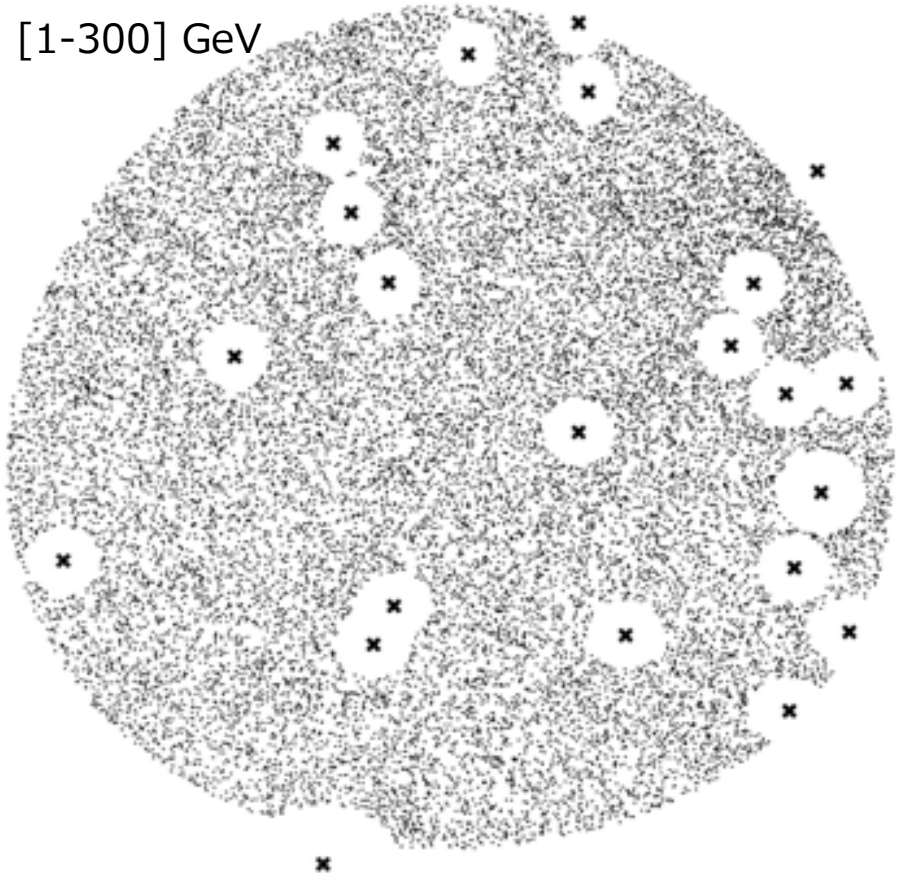
arXiv:1503.02584 [pdf, other]
Eight New Milky Way Companions Discovered in First-Year Dark Energy Survey Data
The DES Collaboration, K. Bechtol, A. Drlica-Wagner, E. Balbinot, A. Pieres, J. D. Simon, B. Yanny, B. Santiago, R. H. Wechsler, J. Frieman, A. R. Walker, P. Williams, E. Rozo, E. S. Rykoff, A. Queiroz, E. Luque, A. Benoit-Levy, R. A. Bernstein, D. Tucker, I. Sevilla, R. A. Gruendl, L. N. da Costa, A. Fausti Neto, M. A. G. Maia, T. Abbott, S. Allam, R. Armstrong, A. H. Bauer, G. M. Bernstein, E. Bertin, D. Brooks, E. Buckley-Geer, D. L. Burke, A. Carnero Rosell, F. J. Castander, C. B. D'Andrea, D. L. DePoy, S. Desai, H. T. Diehl, T. F. Eifler, J. Estrada, A. E. Evrard, E. Fernandez, D. A. Finley, B. Flaugher, E. Gaztanaga, D. Gerdes, L. Girardi, M. Gladders, D. Gruen, G. Gutierrez, J. Hao, K. Honscheid, B. Jain, D. James, S. Kent, R. Kron, K. Kuehn, N. Kuropatkin, O. Lahav, T. S. Li, et al. (32 additional authors not shown)

Name	α [deg]	δ [deg]	Signif	m−M [mag]	$\mathrm{Dist}_\odot$ [kpc]
Reticulum 2	53.9256	−54.0492	48.5	17.4	30
Eridanus 2	[illegible]	[illegible]	[illegible]	22.9	380
Horologium 1	43.8820	−54.1188	28.4	19.5	79
Pictoris 1	70.9475	−50.2830	17.3	20.3	114
Phoenix 2	354.9975	−54.4060	13.9	19.6	83
Indus 1	317.2044	−51.1656	13.7	20.0	100
Grus 1[a]	344.1765	−50.1633	10.1	20.4	120
Eridanus 3	35.6897	−52.2837	10.1	19.7	87
Tucana 2	342.9664	−58.5683	8.3	19.2	69

Reticulum II in gamma-rays

Based on 1503.02320 and 1504.03309

Reticulum II in gamma-rays



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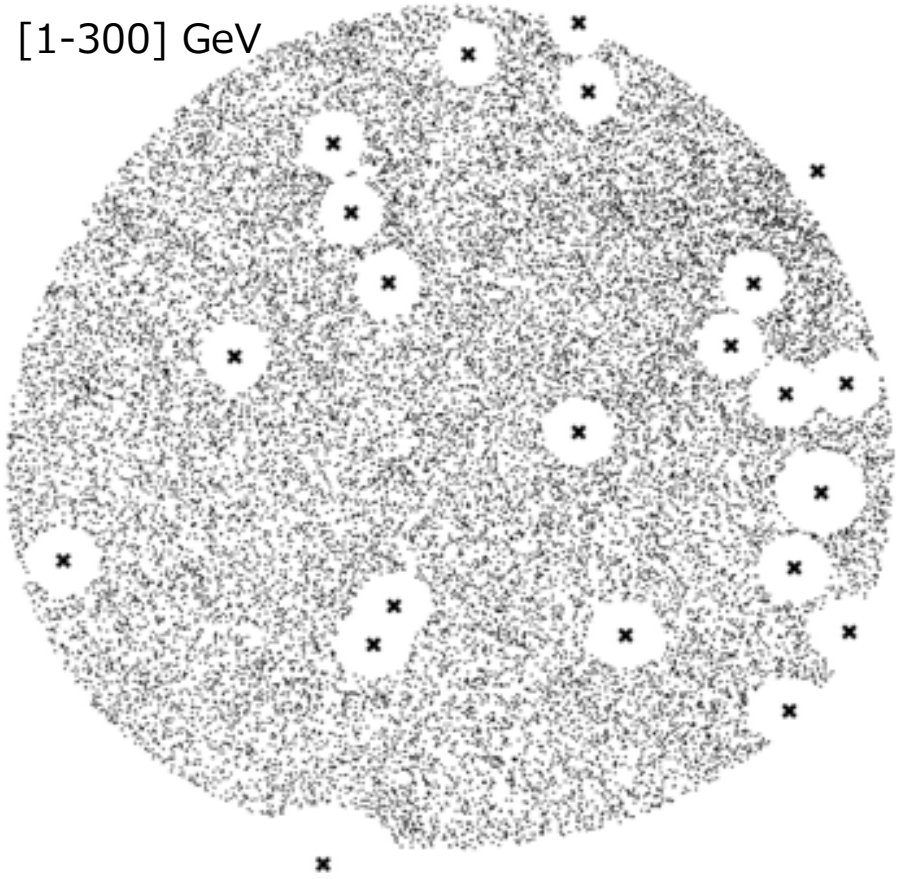
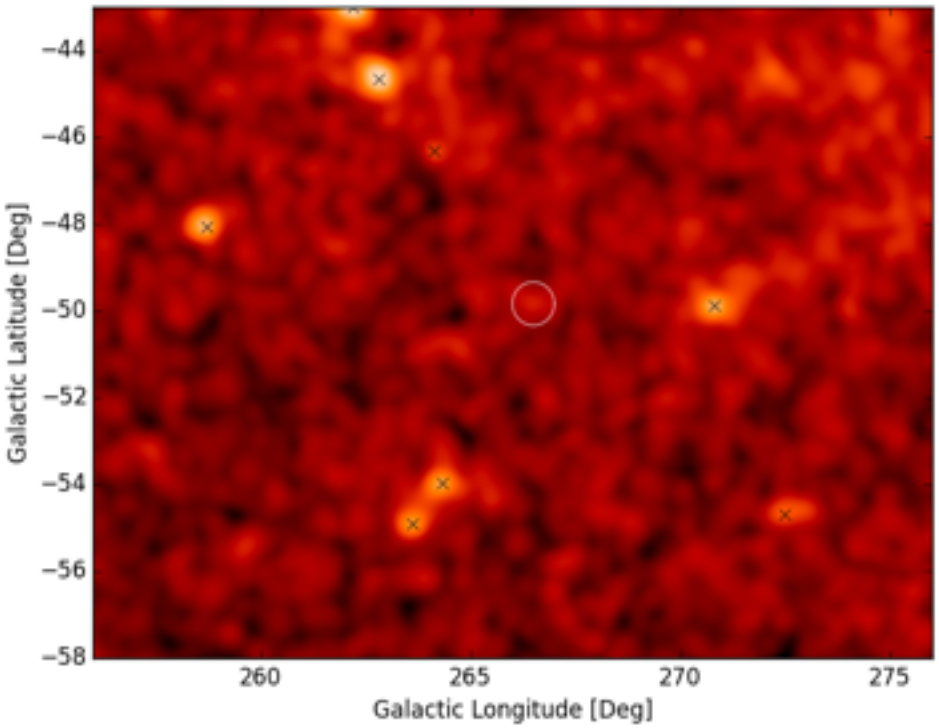
Reticulum II in gamma-rays

[1-300] GeV





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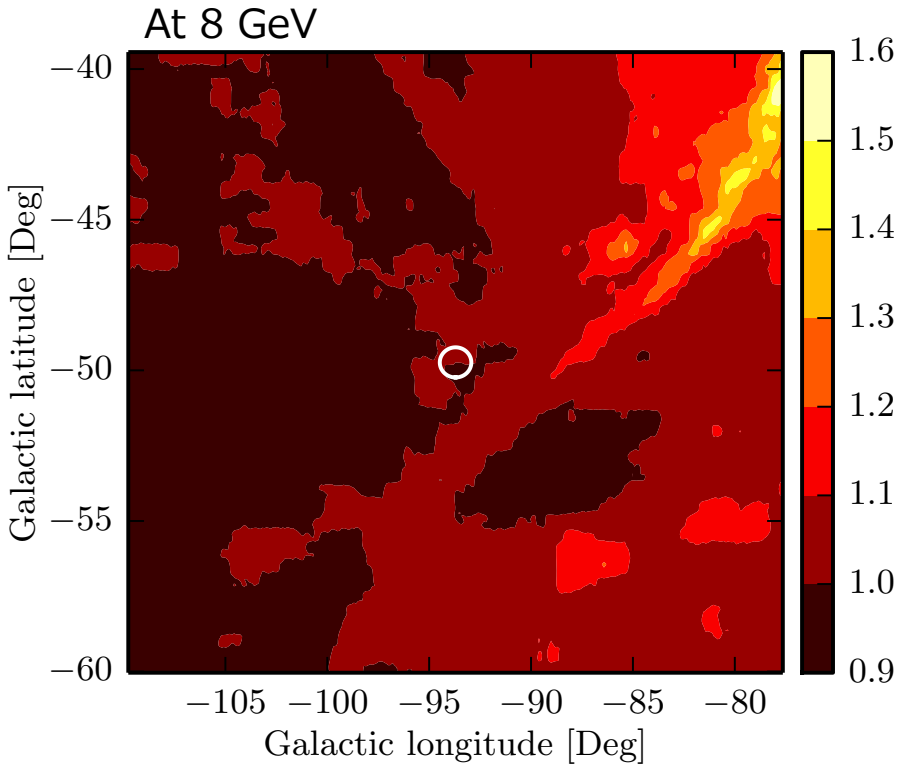
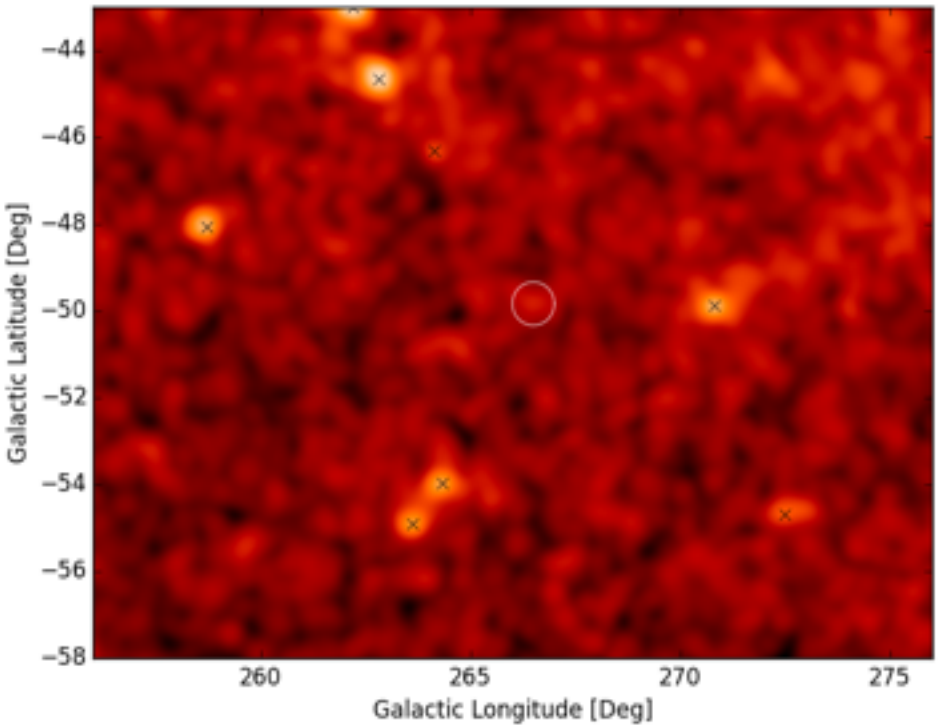
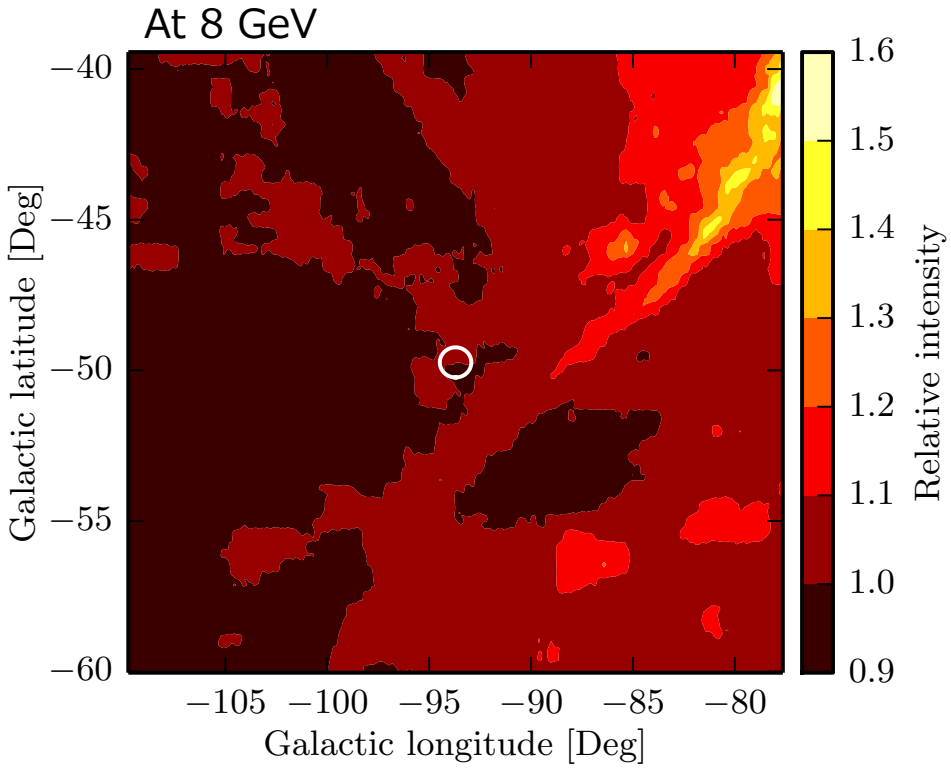
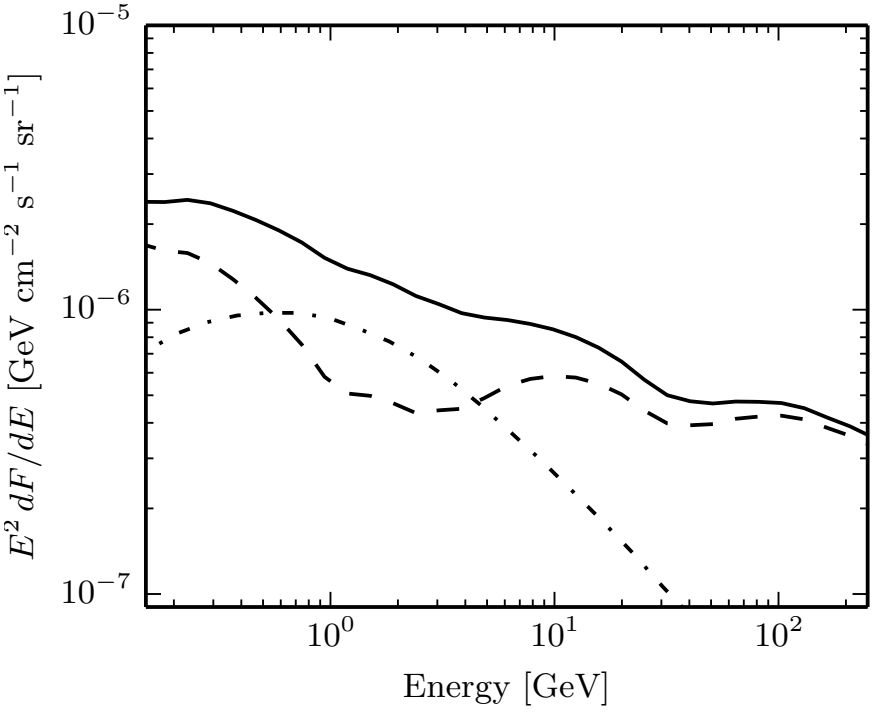




Based on 1503.02320 and 1504.03309

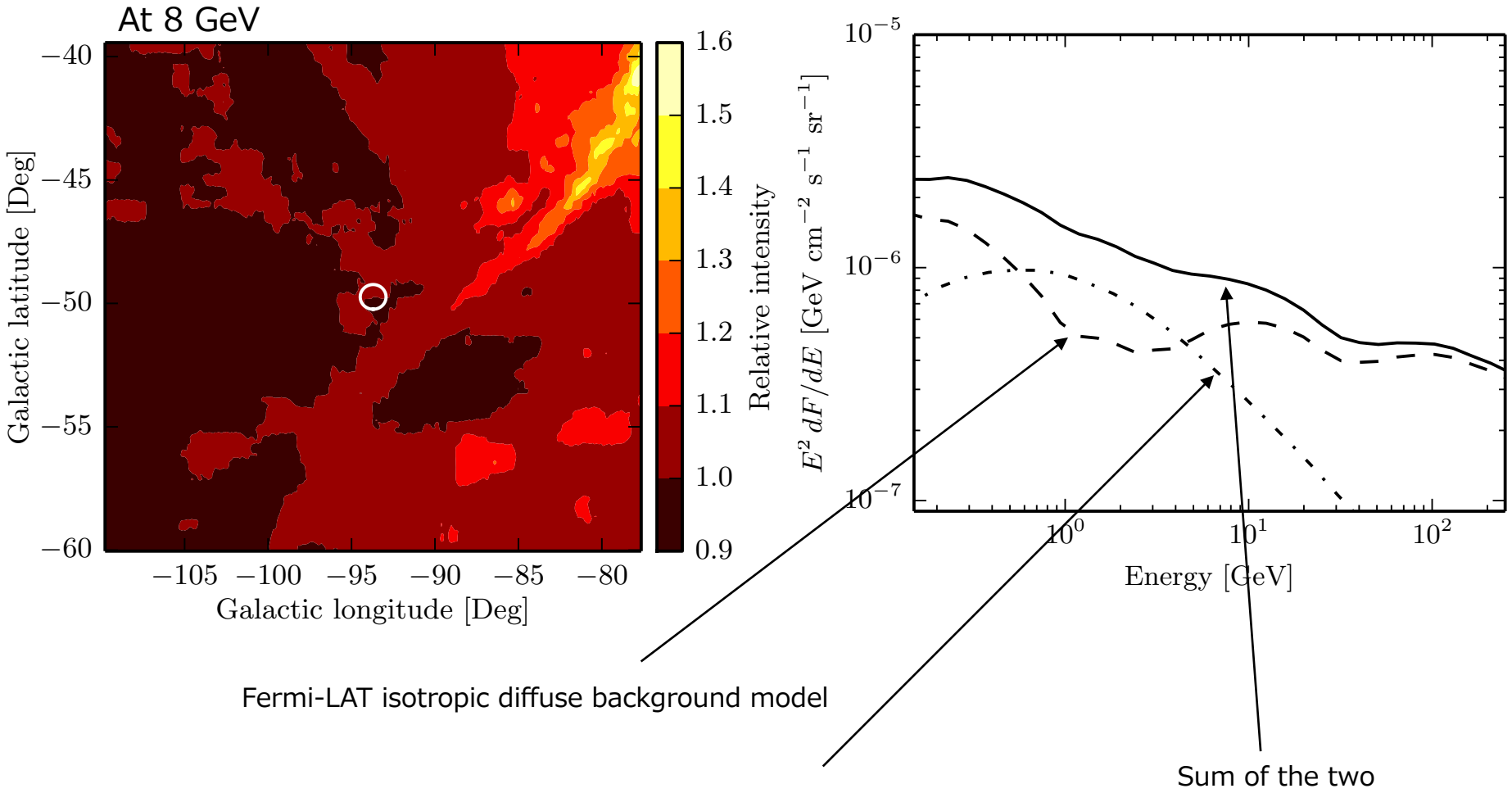
Reticulum II in gamma-rays





Based on 1503.02320 and 1504.03309

Reticulum II in gamma-rays



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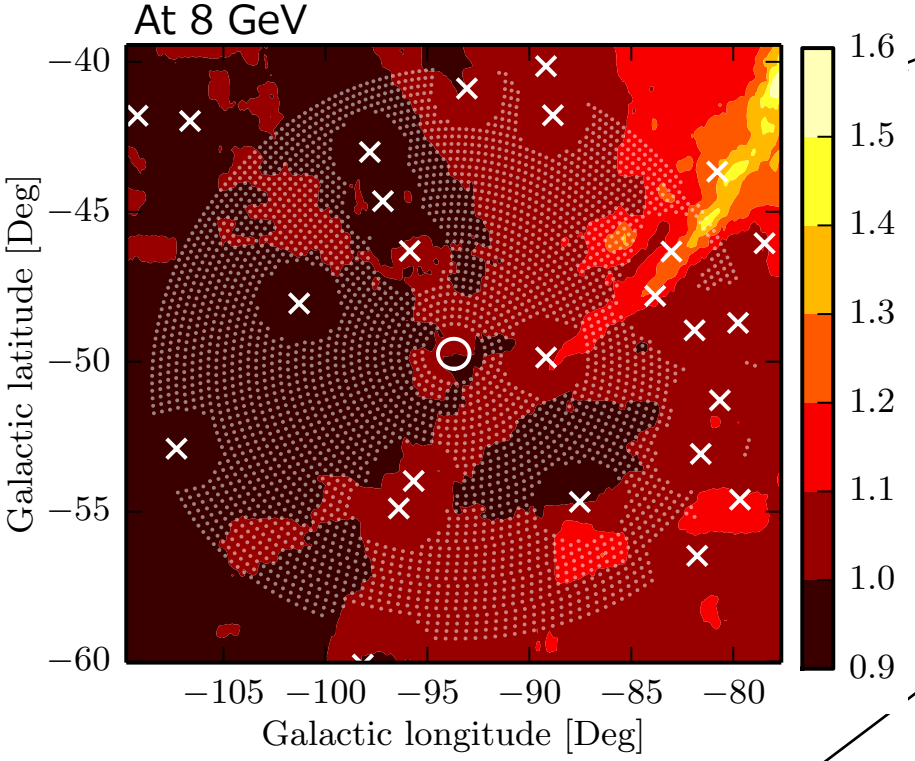
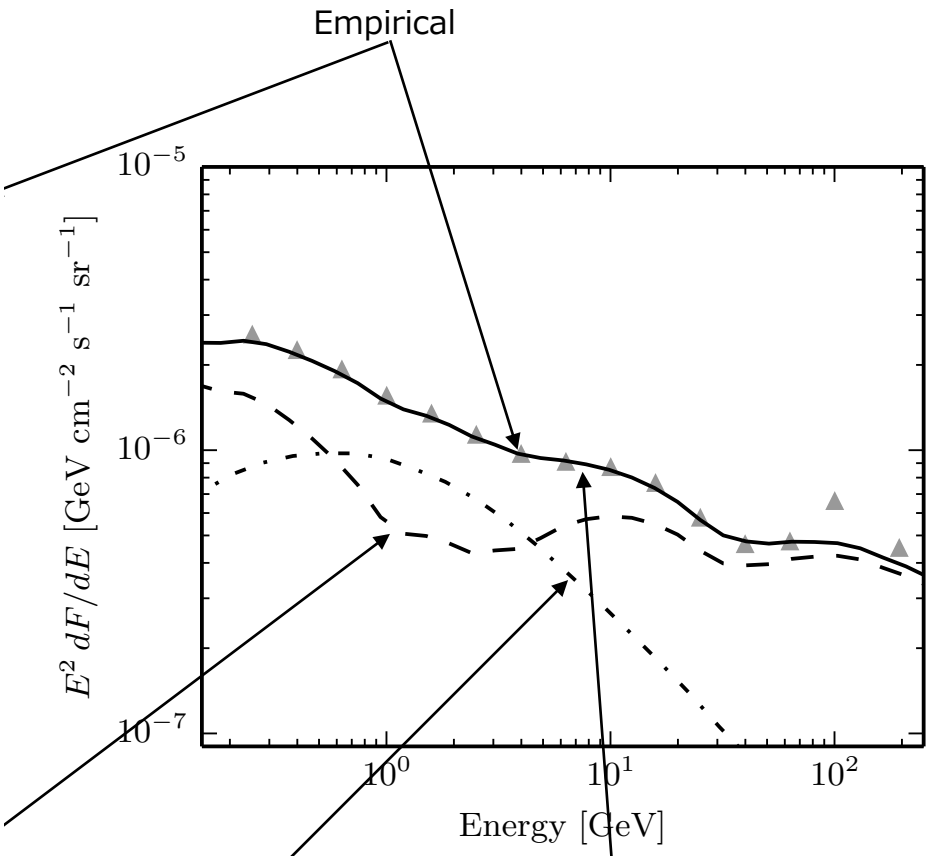
Reticulum II in gamma-rays



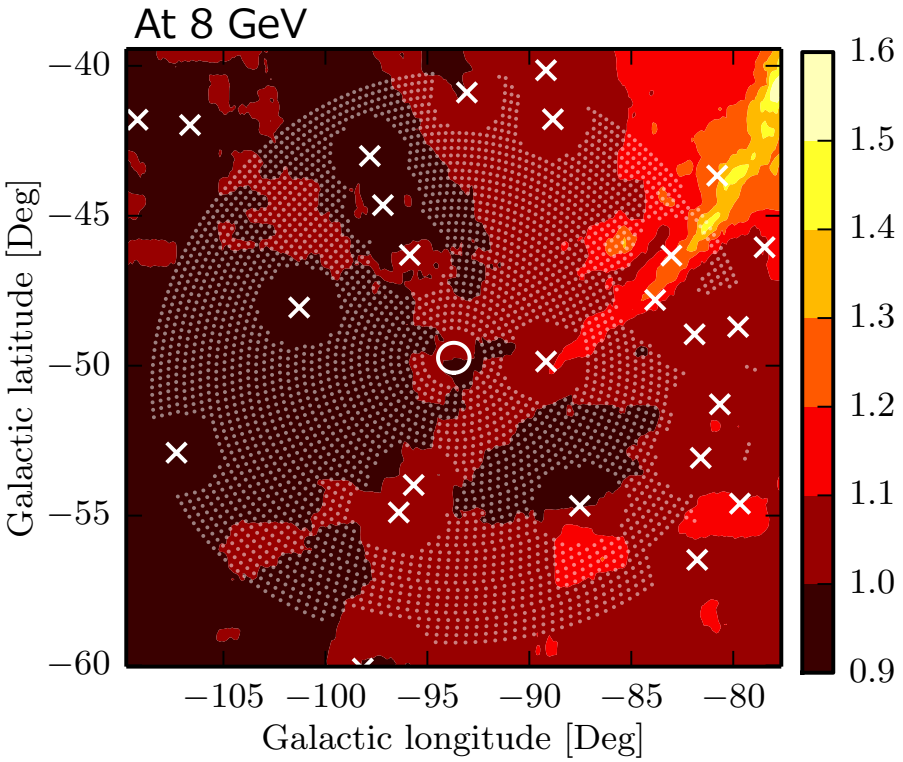
Fermi-LAT isotropic diffuse background model

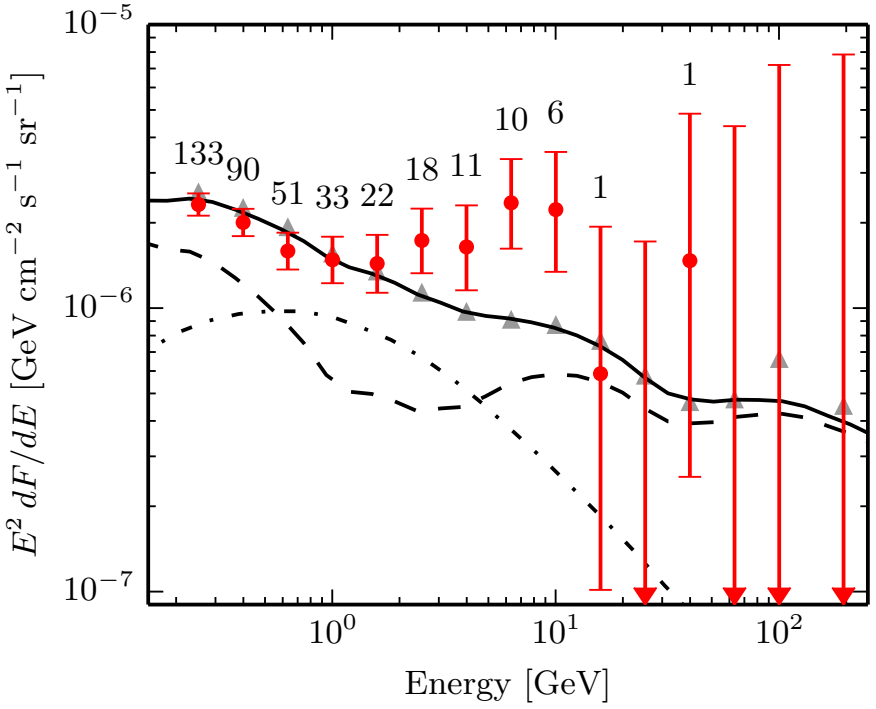


Fermi-LAT Galactic diffuse background model

Based on 1503.02320 and 1504.03309

Reticulum II in gamma-rays





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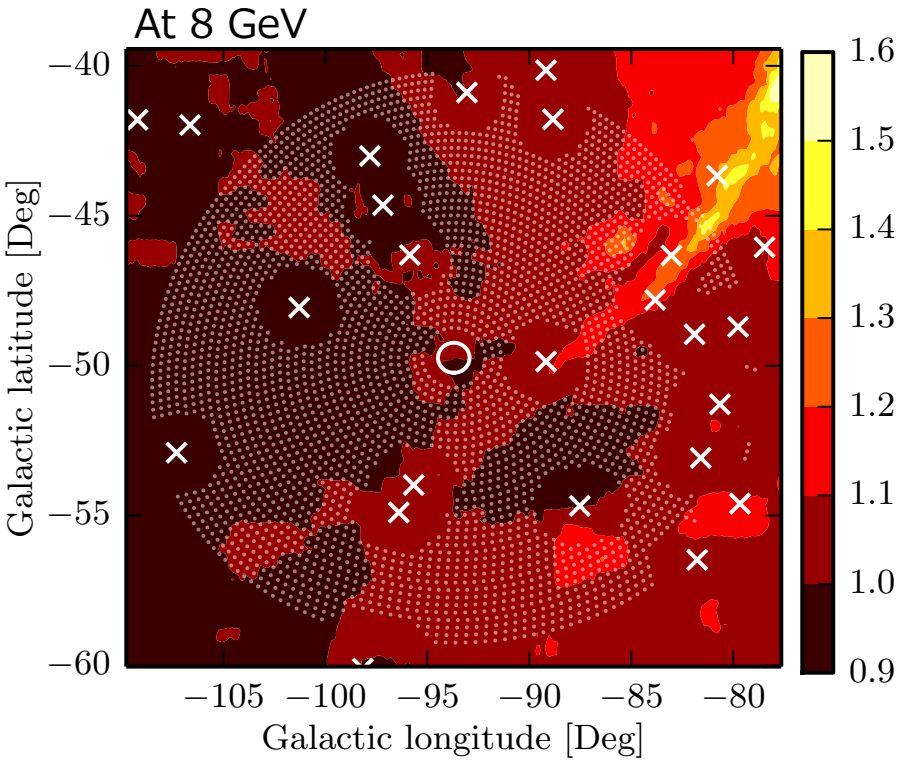
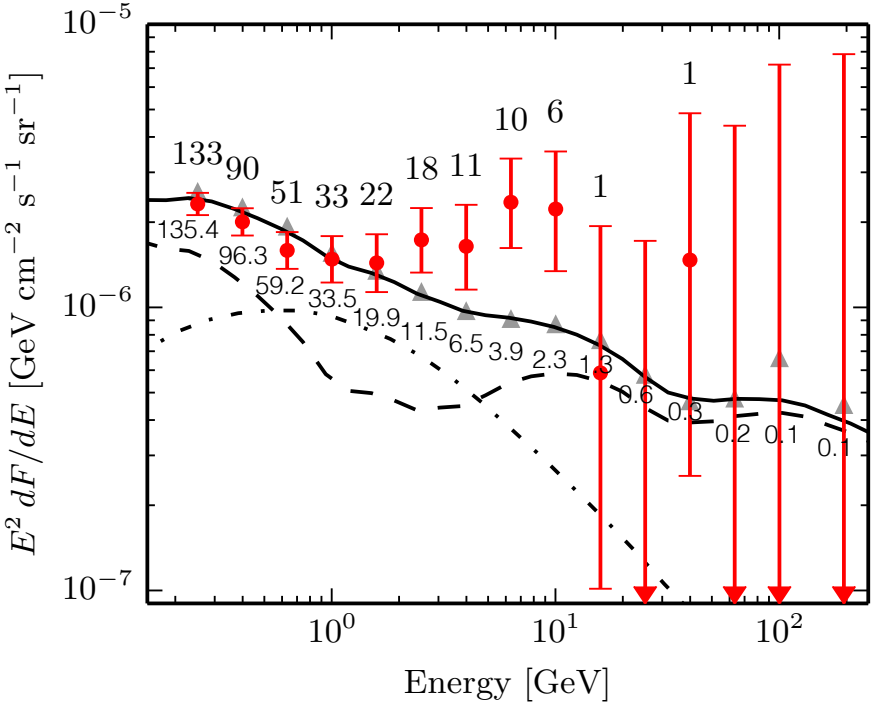




Based on 1503.02320 and 1504.03309

Photon weighting and statistical significance of a dark matter interpretation

See Geringer-Sameth, Koushiappas & Walker, PRD 91, 083535 (2015) for details

Photon weighting and statistical significance of a dark matter interpretation

$$T = \sum_{i=1}^{N} w(Q_i) \qquad Q = \{E, \theta\}$$

$$w(Q) = \log\left(1 + \frac{s_Q}{b_Q}\right)$$

$$s_Q = \frac{dN(E,\theta)}{dE d\Omega} = \frac{\langle \sigma v \rangle}{8\pi M^2} \frac{dN_\gamma(E)}{dE} [(J * \mathrm{PSF})(E,\theta)] \epsilon(E)$$

b_Q represents a description of the background

See Geringer-Sameth, Koushiappas & Walker, PRD 91, 083535 (2015) for details

Photon weighting and statistical significance of a dark matter interpretation

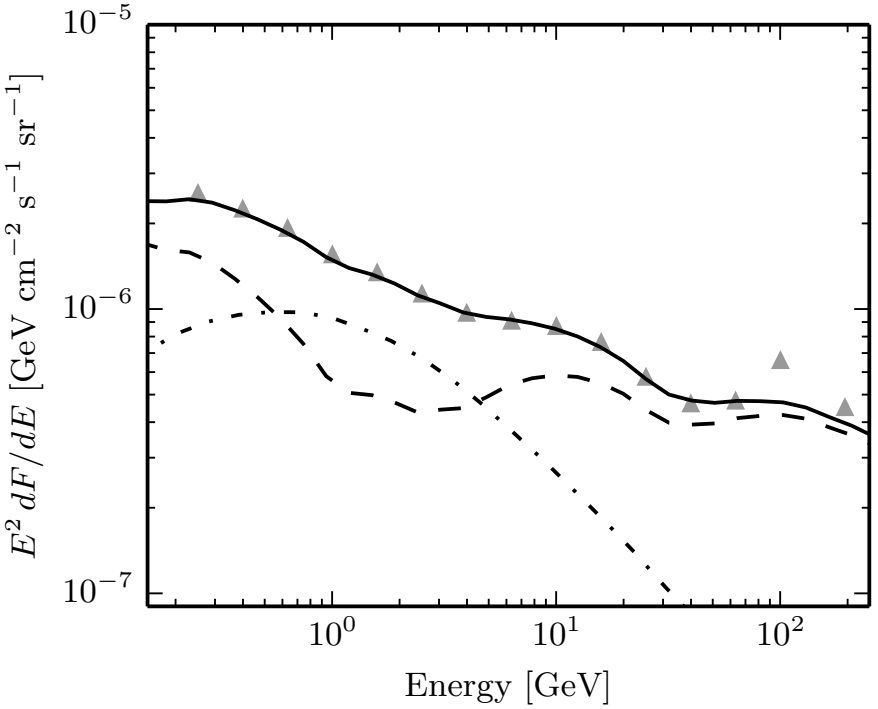
Background modeling

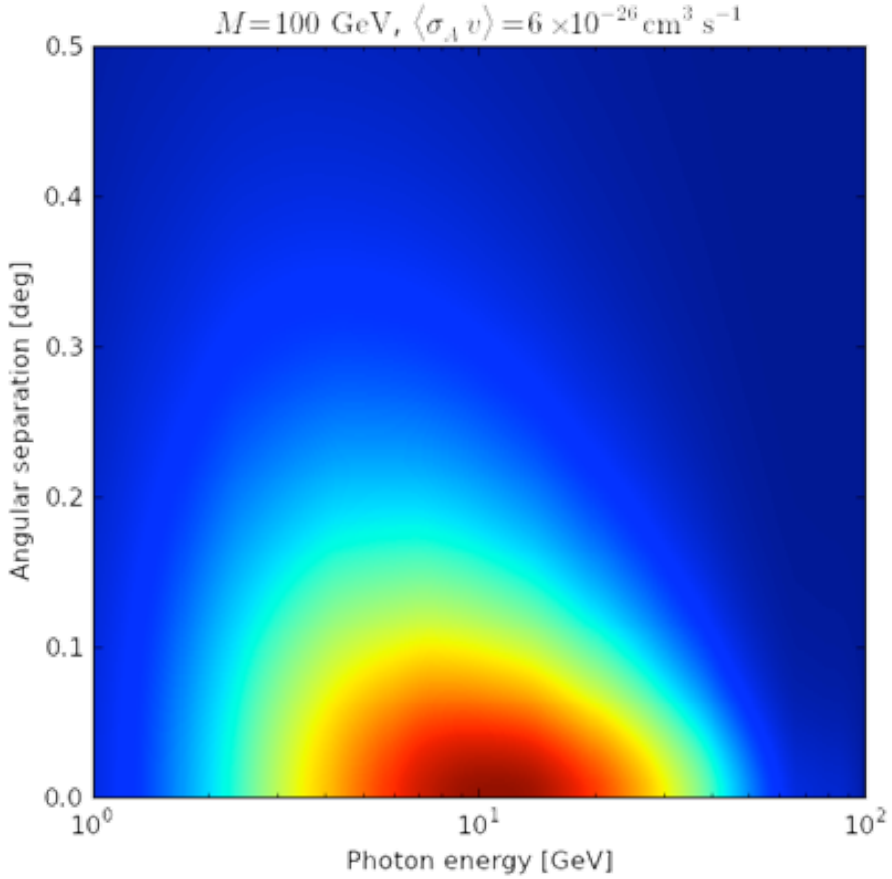
- Background in the central 0.5 degree ROI is a Poisson random variable
- Background is isotropic
- Energies are drawn from a given spectrum

Test statistic is a compound Poisson variate whose PDF can be obtained for any weight function and any adopted background spectrum (no asymptotic assumptions).

See Geringer-Sameth, Koushiappas & Walker, PRD 91, 083535 (2015) for details

Photon weighting and statistical significance of a dark matter interpretation





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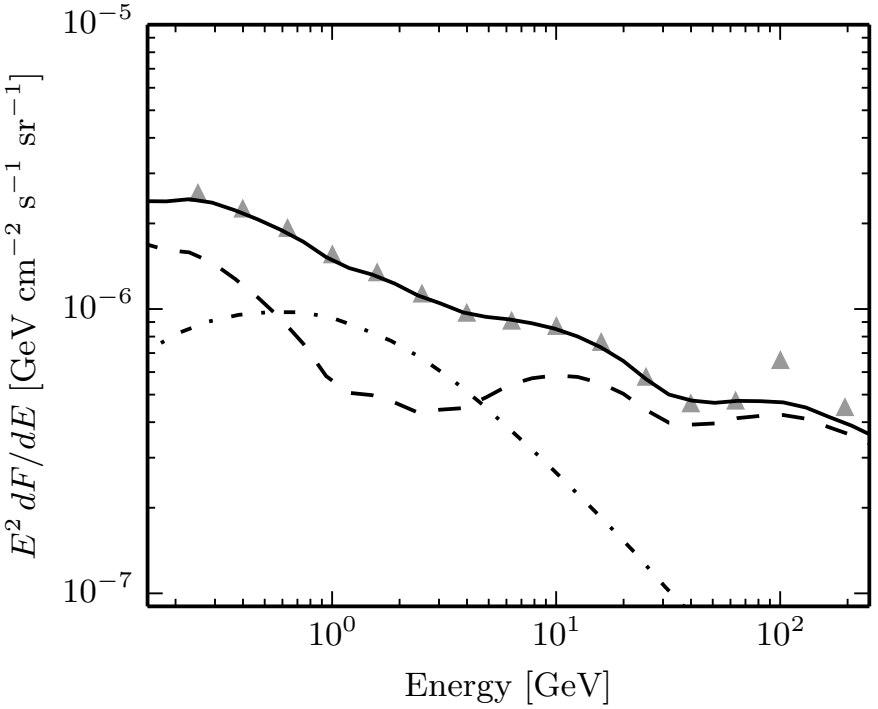
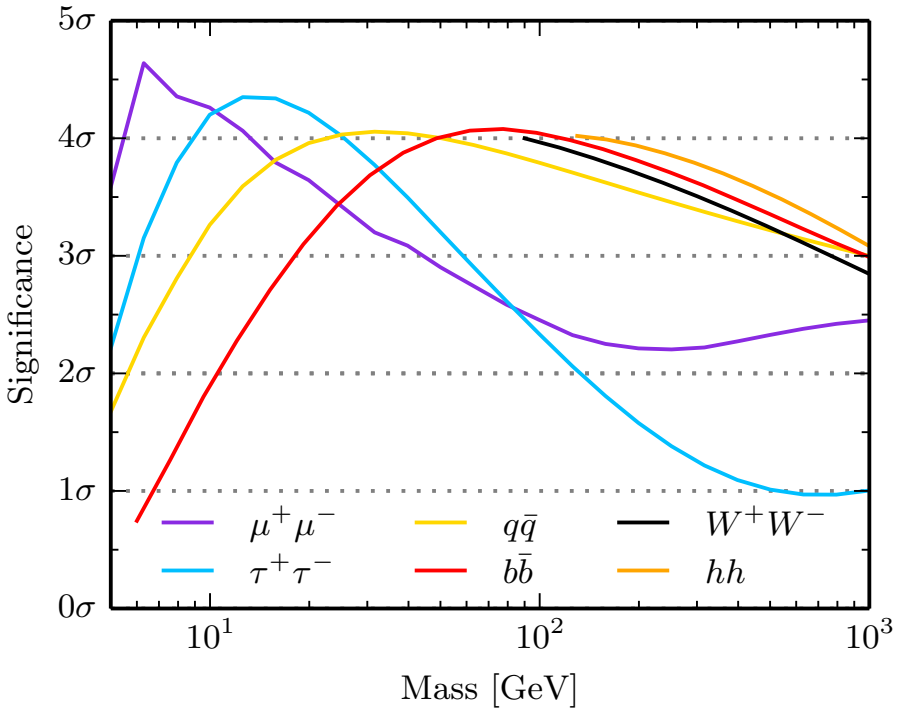
Photon weighting and statistical significance of a dark matter interpretation

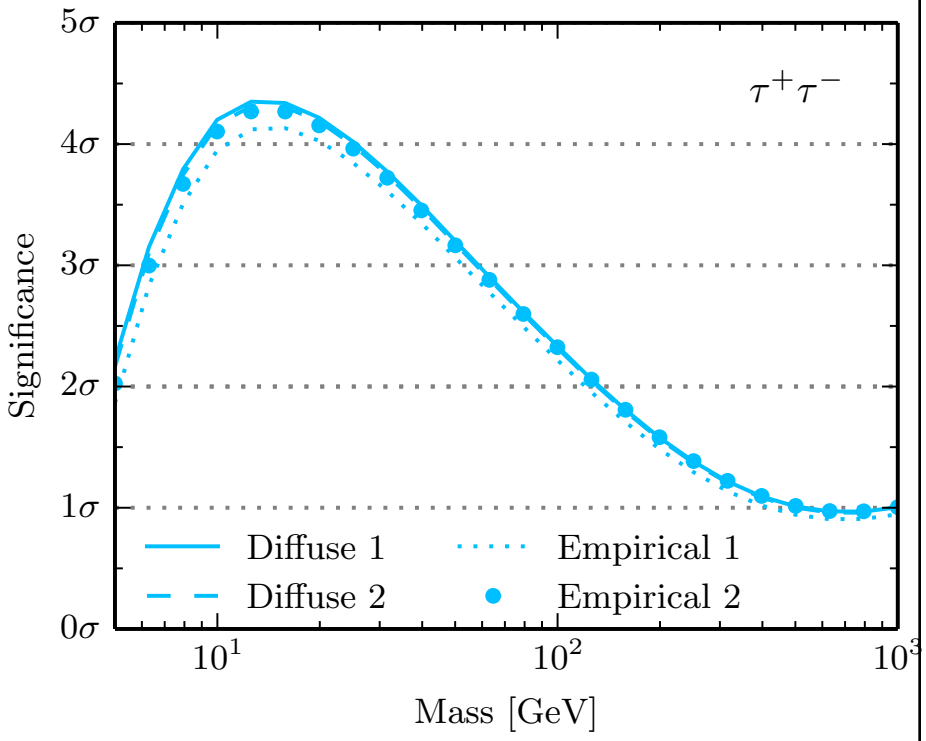


Background modeling

- ***Diffuse 1***: Fermi-LAT background averaged over 1 degree.
- ***Diffuse 2***: Fermi-LAT background averaged over 2 degrees.
- ***Empirical 1***: Events in an [1-5] degree annulus from central ROI with 20% gaussian width on energy.
- ***Empirical 2***: Bin *Empirical 1* events in energy.

Photon weighting and statistical significance of a dark matter interpretation





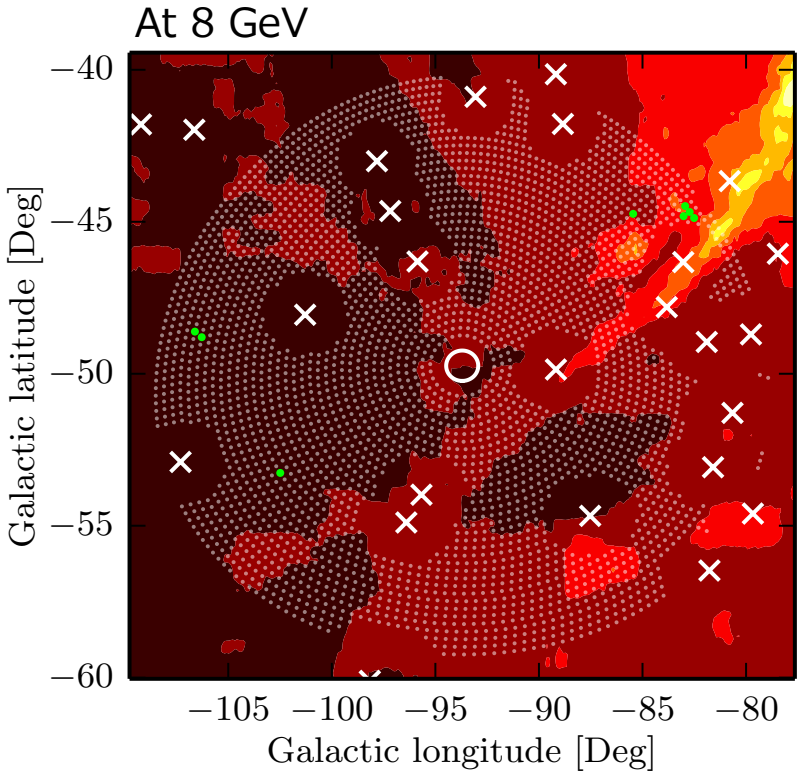
Local p-value $< 3 \times 10^{-5}$

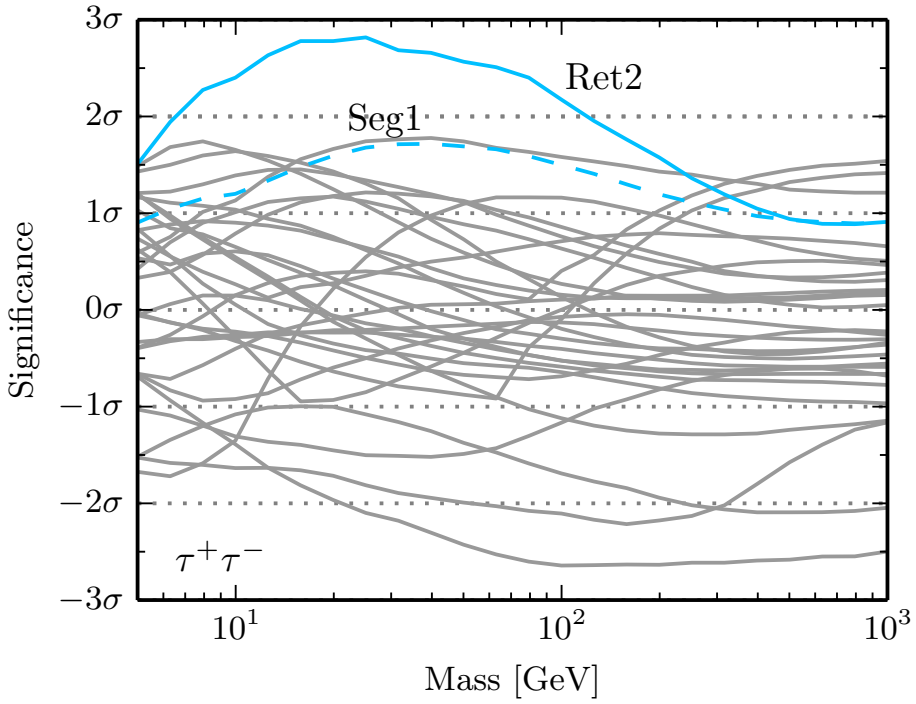
Global p-value $< 9.8 \times 10^{-5}$ Obtained from simulations

Based on 1503.02320 and 1504.03309

See also Drlica-Wagner et al. 1503.02632
Hooper & Linden 1503.06209

Photon weighting and statistical significance of a dark matter interpretation





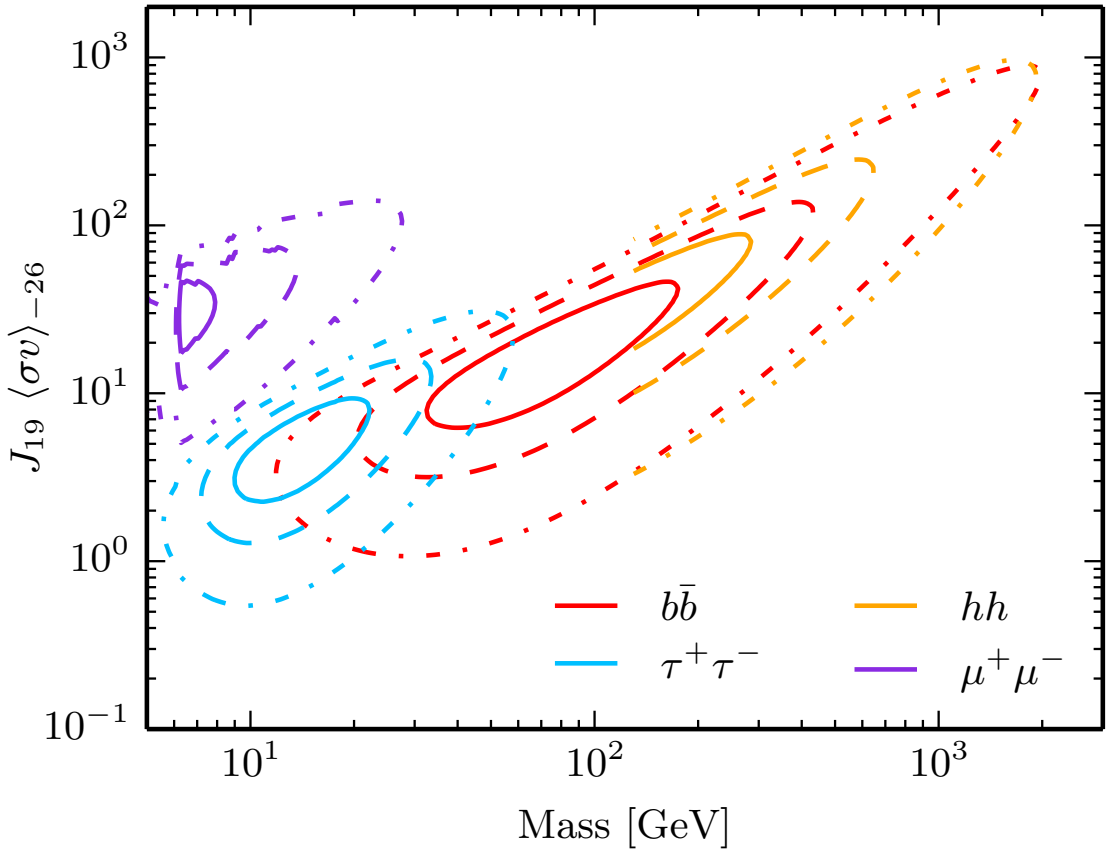
Local p-value = 0.0024 (8/3306)

Global p-value = 0.0097

Based on 1503.02320 and 1504.03309

See John Paul Chou's talk earlier today

Photon weighting and statistical significance of a dark matter interpretation



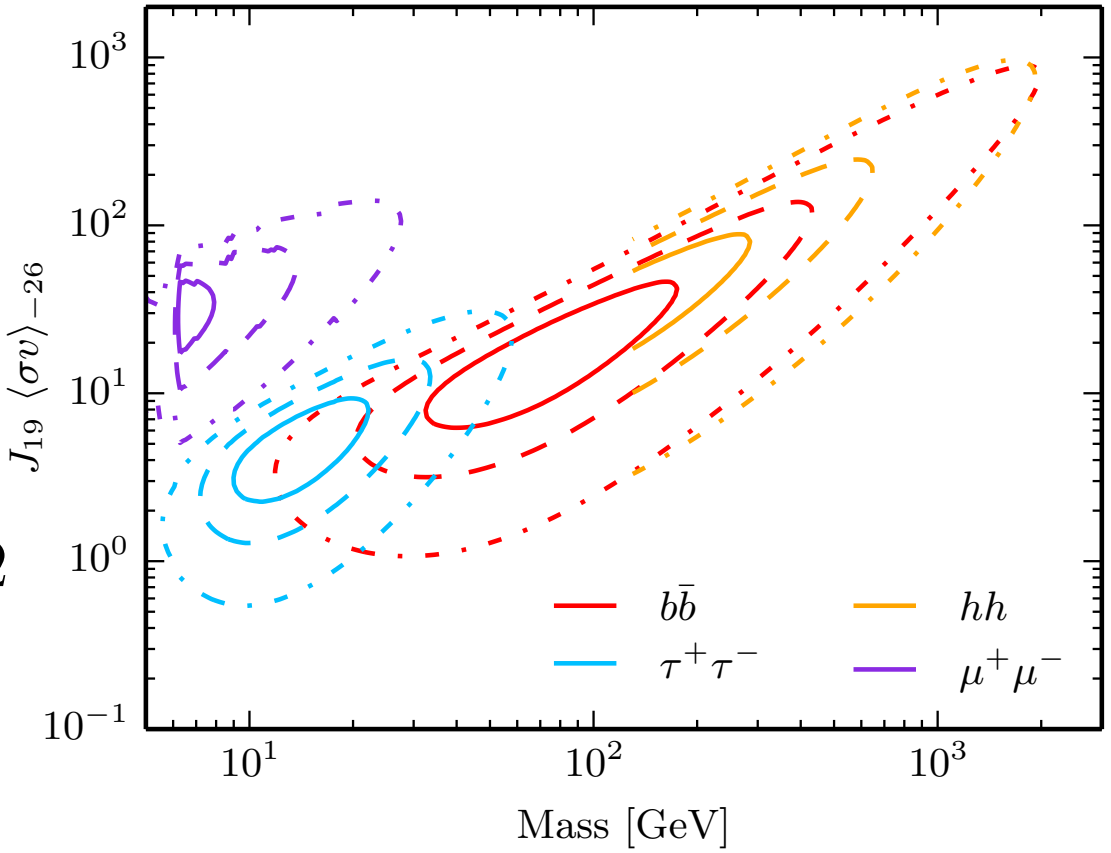
Does the data prefer one explanation (channel) over something else? What can the LHC tell us? (see Fan, Koushiappas & Landsberg, in preparation)

Based on 1503.02320 and 1504.03309

Photon weighting and statistical significance of a dark matter interpretation

We need this

$$J = \iint \rho^2_{\mathrm{DM}}(l, \Omega)\, dl d\Omega$$



Does the data prefer one explanation (channel) over something else? What can the LHC tell us? (see Fan, Koushiappas & Landsberg, in preparation)

Based on 1503.02320 and 1504.03309

The dark matter content of Reticulum II

Bonnivard et al. 1504.03309

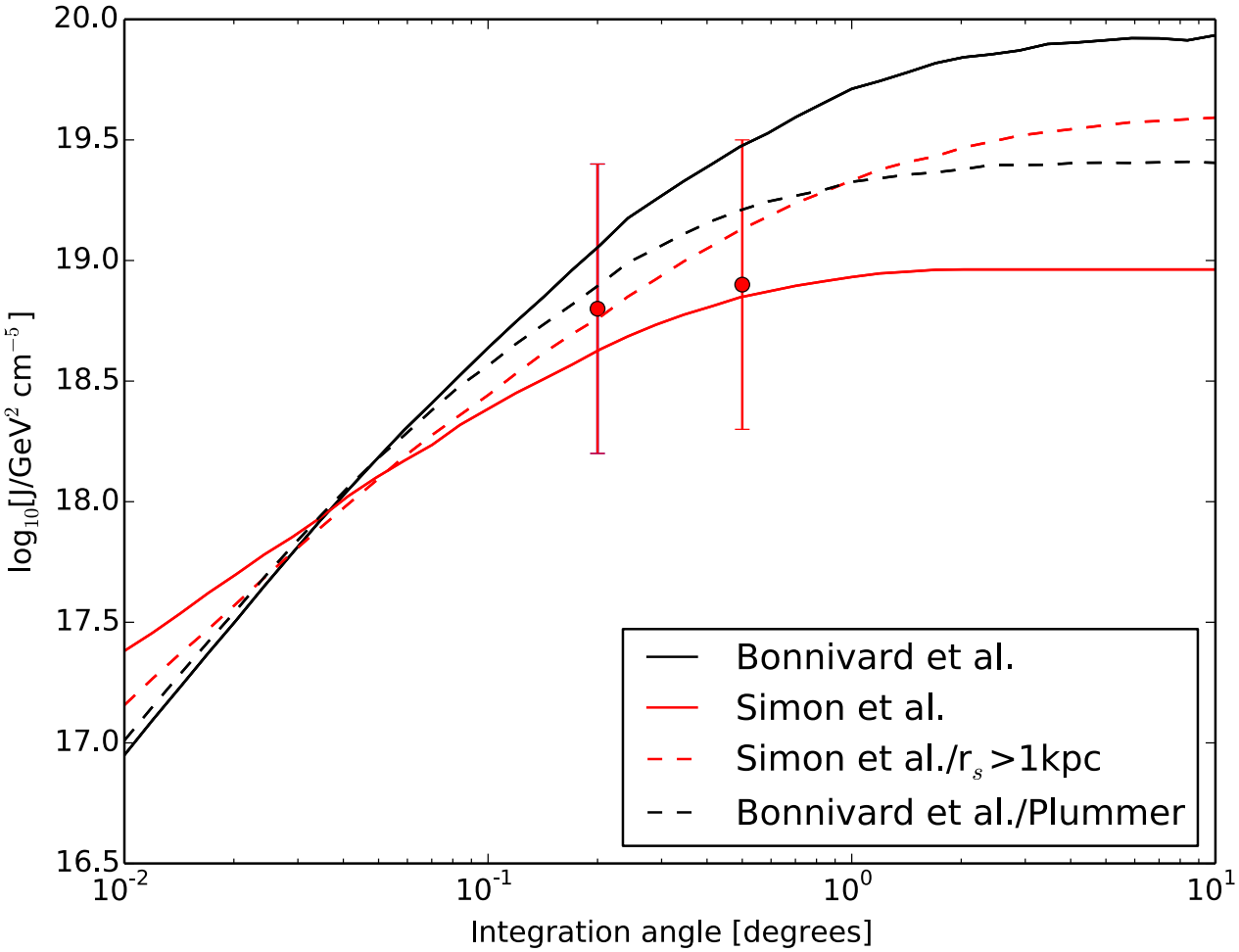
$\alpha_{\rm int}$ [deg]	$\log_{10}(J(\alpha_{\rm int}))$ $[J/{\rm GeV}^2\,{\rm cm}^{-5}]^{\rm a}$
0.01	$16.9^{+0.5(+1.1)}_{-0.4(-0.8)}$
0.05	$18.2^{+0.5(+1.0)}_{-0.4(-0.7)}$
0.1	$18.6^{+0.6(+1.1)}_{-0.4(-0.8)}$
0.5	$19.5^{+1.0(+1.6)}_{-0.6(-1.3)}$
1	$19.7^{+1.2(+2.0)}_{-0.9(-1.5)}$

Simon et al. 1504.02889

18.8 ± 0.6

18.9 ± 0.6

The dark matter content of Reticulum II



Where do we go from here

1. Is what we see consistent with background?

2. Is it consistent with any other possible source (pulsars, AGNs, ?)

3. Is it consistent with dark matter annihilation?

4. Is it something else? (e.g., instrumental/data set systematics?)

Given that this is the very first time of a detection of gamma-rays along the line of sight to a dwarf galaxy it is important we understand Reticulum II as much as the data allows.