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

Savvas M. Koushiappas

BROWN

Based on

PRL 115, 081101 (2015) 1503.02320

ApJL 808 L36 (2015) 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)

On March 8, 2015

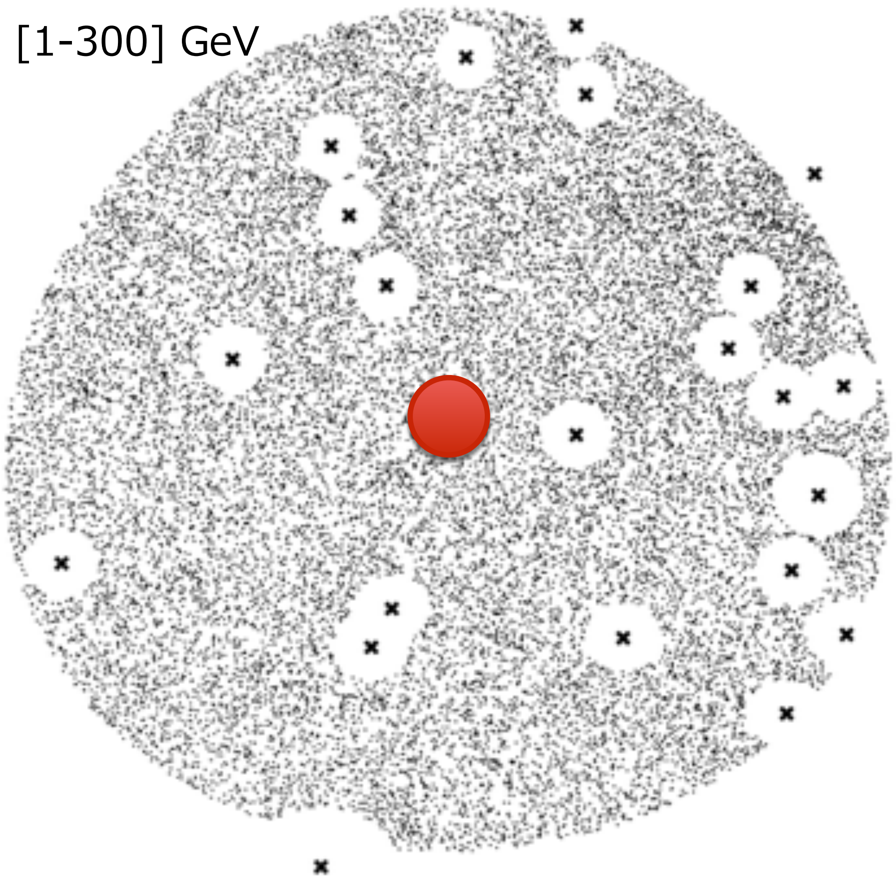
arXiv:1503.02079 [pdf, ps, other]
Beasts of the Southern Wild. Discovery of a large number of Ultra Faint satellites in the vicinity of the Magellanic Clouds
Sergey E. Koposov, Vasily Belokurov, Gabriel Torrealba, N. Wyn Evans

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	56.0878	−43.5332	31.5	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

[1-300] GeV



Based on PRL 115, 081101 & ApJL 808 L36 (2015)

Reticulum II in gamma-rays

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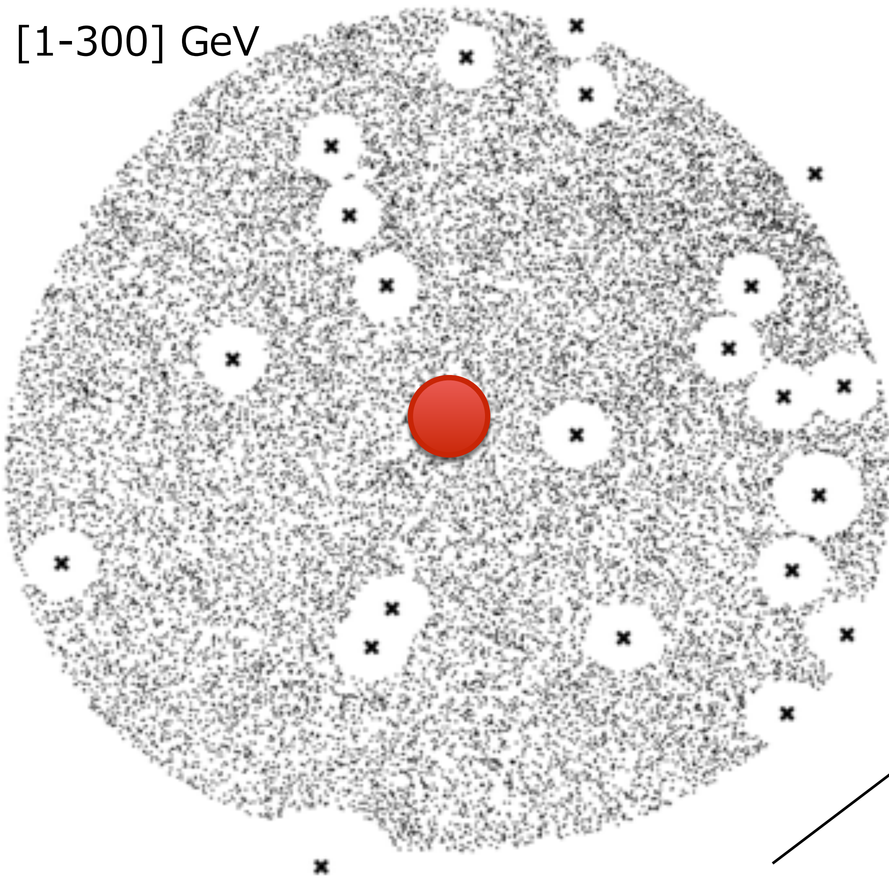
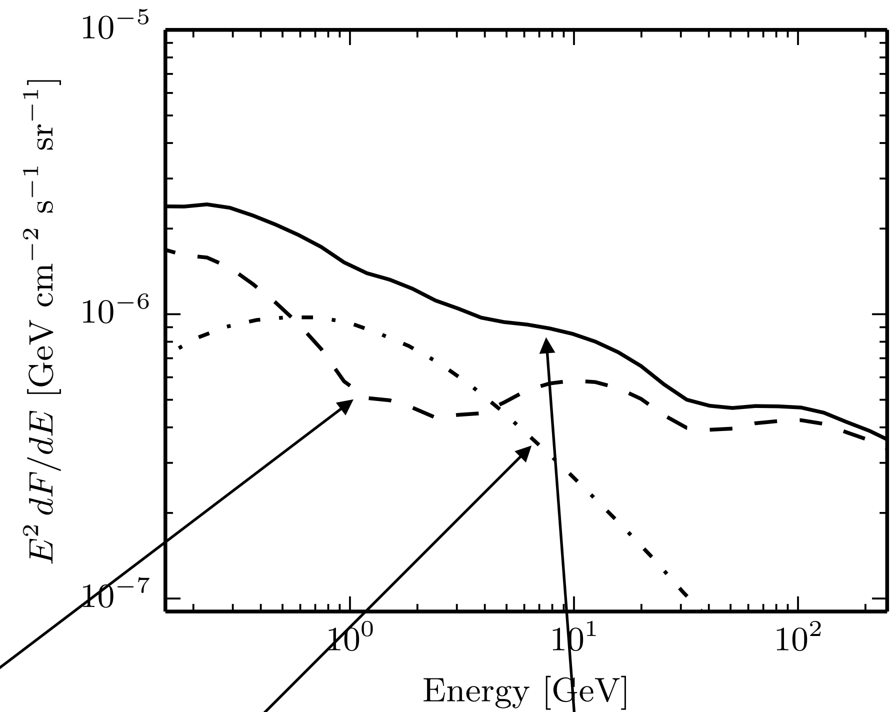




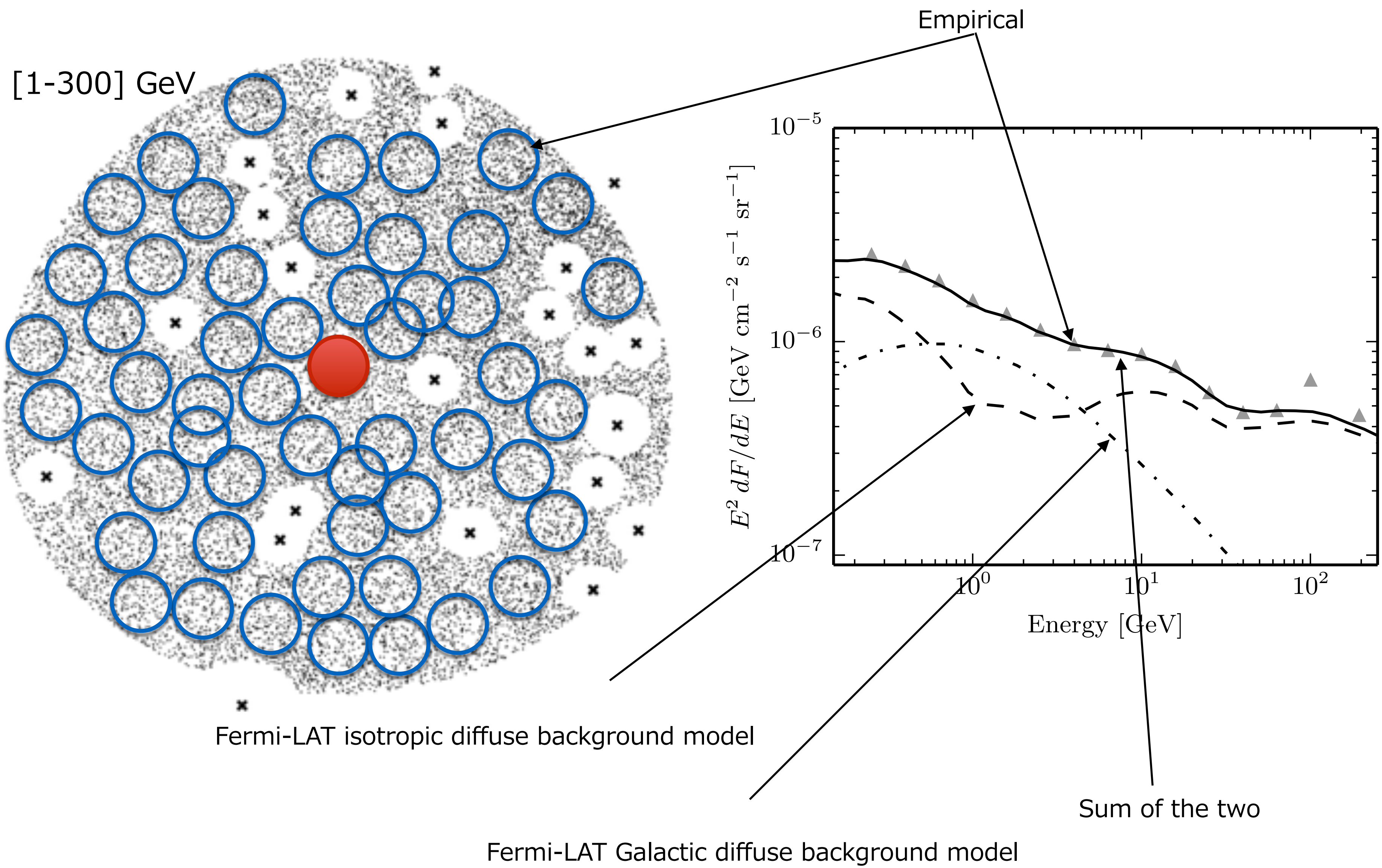
Fermi-LAT isotropic diffuse background model

Sum of the two

Fermi-LAT Galactic diffuse background model

Based on PRL 115, 081101 & ApJL 808 L36 (2015)

Reticulum II in gamma-rays



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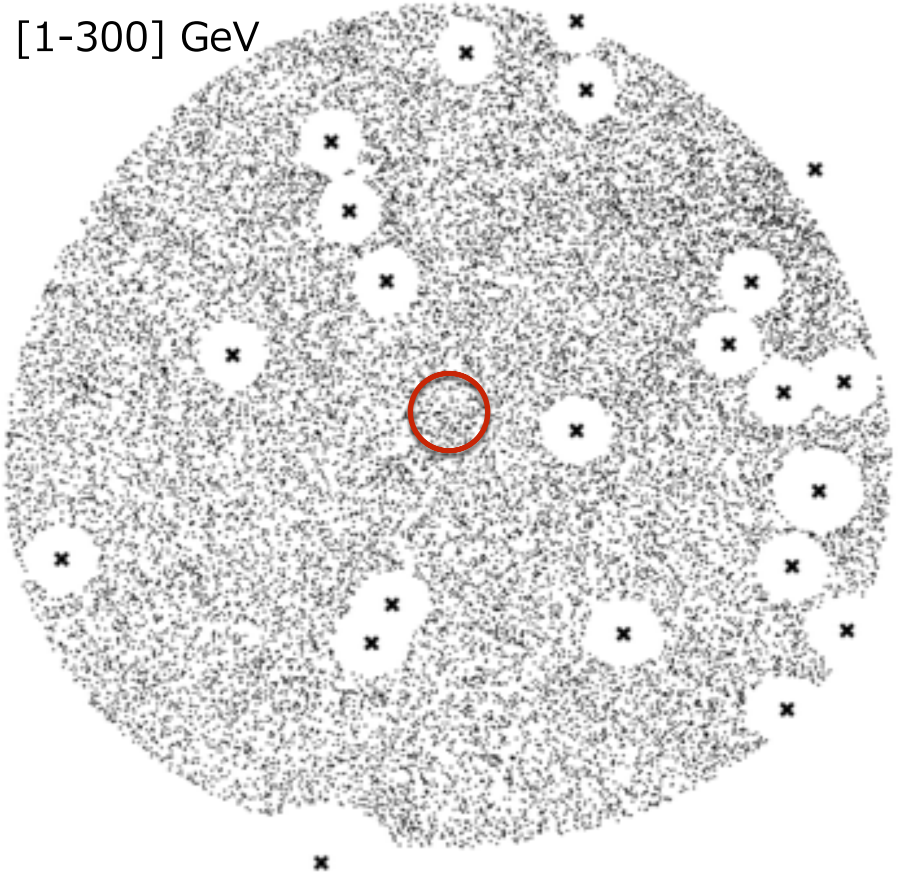
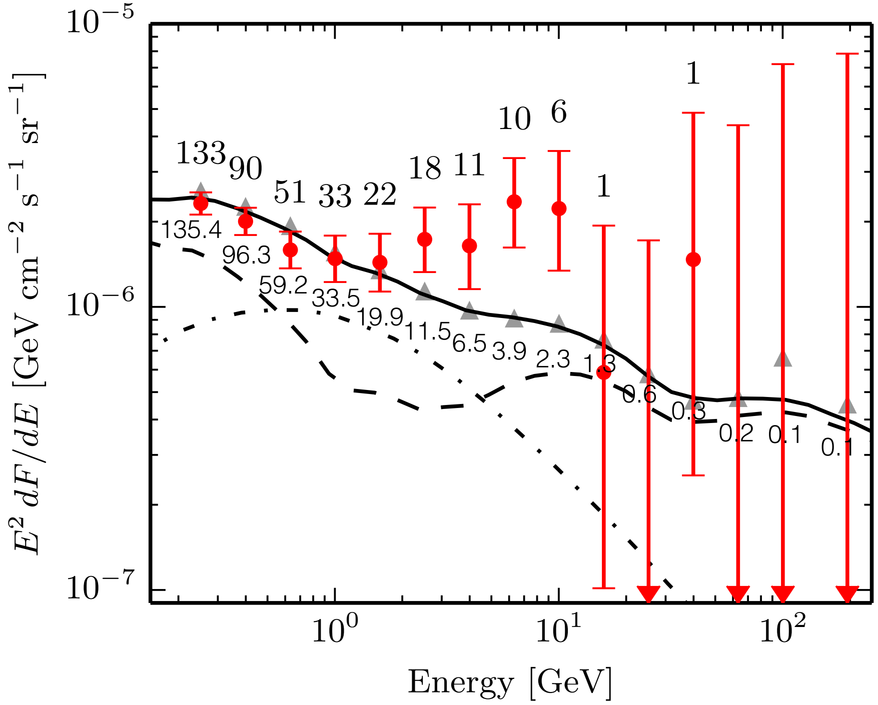
Reticulum II in gamma-rays





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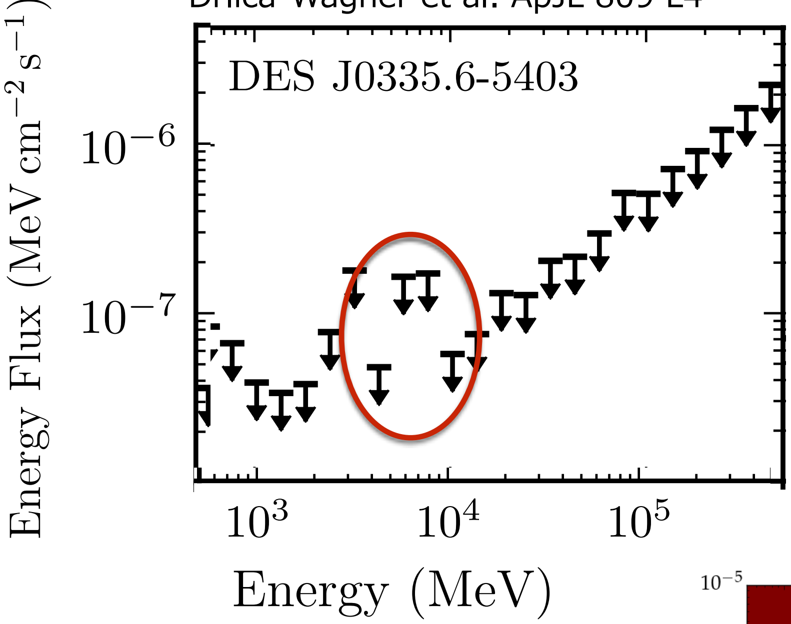
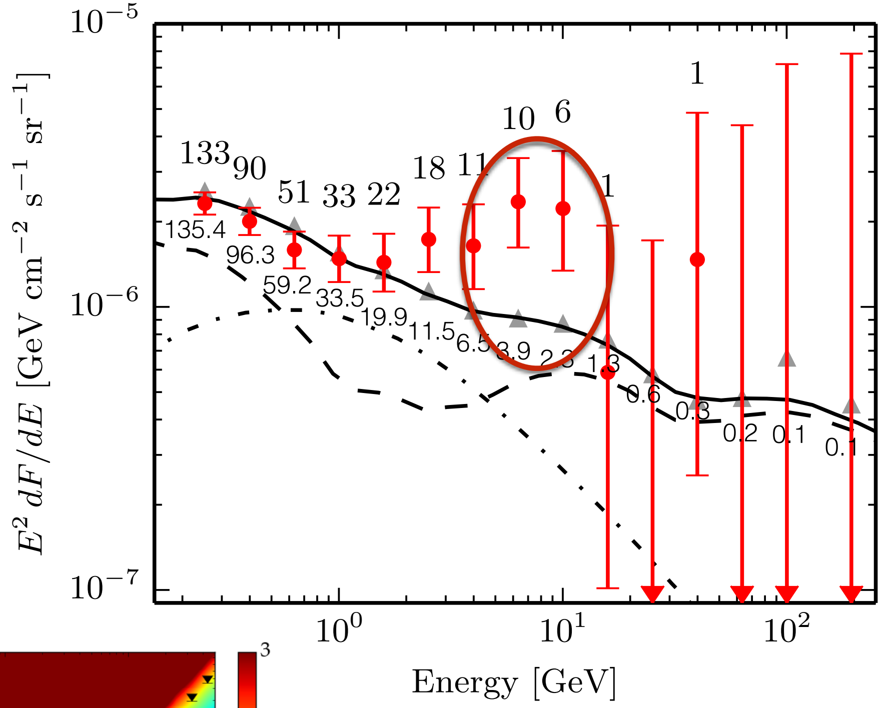
Reticulum II in gamma-rays

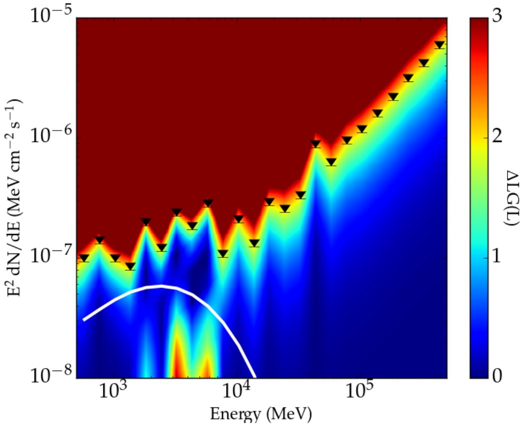
Pass8 Fermi-LAT
w/hybrid Pass8/7 background
Drlica-Wagner et al. ApJL 809 L4



Pass7R



See also Hooper & Linden 1503.06209

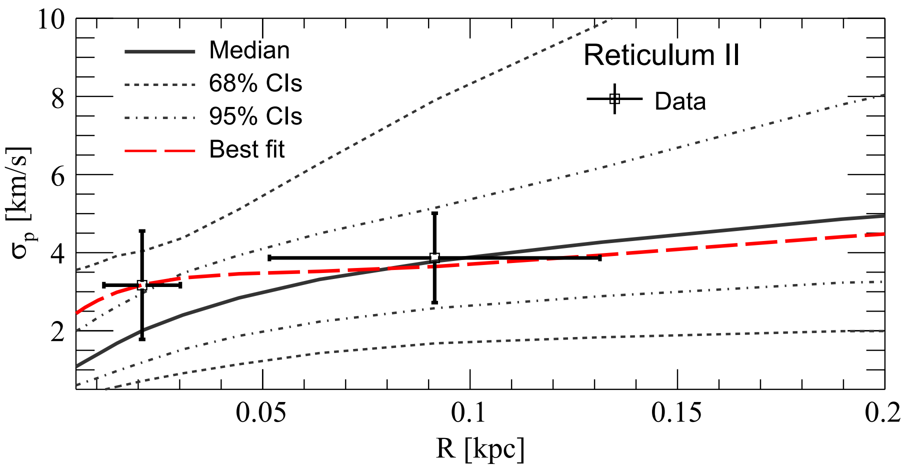


The dark matter content of Reticulum II

Use stellar kinematics to obtain $$J = \iint \rho^2_{\rm DM}(l,\Omega)\, dl d\Omega$$

Bonnivard et al. ApJL 808 L36 (2015)

Simon et al. ApJ 808, 95 (2015)



$$\sigma_p^2(R) = \frac{2}{\Sigma(R)} \int_R^\infty \left(1 - \beta_{\rm ani}(r)\frac{R^2}{r^2}\right) \frac{\nu(r)\bar{v_r^2}(r)\,r}{\sqrt{r^2 - R^2}} dr,$$

$$\mathcal{L} = \prod_{i=1}^{N_{\rm stars}} \frac{(2\pi)^{-1/2}}{\sqrt{\sigma_p^2(R_i) + \Delta^2_{v_i}}} \exp\left[-\frac{1}{2}\left(\frac{(v_{\rm i} - \bar{v})^2}{\sigma_p^2(R_i) + \Delta^2_{v_i}}\right)\right],$$

The dark matter content of Reticulum II

Bonnivard et al. ApJL 808 L36 (2015)

$\alpha_{\rm int}$ [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. ApJ 808, 95 (2015)

$\alpha_{\rm int}$ [deg]	$\log_{10}(J(\alpha_{\rm int}))$ $[J/{\rm GeV}^2\,{\rm cm}^{-5}]^{\rm a}$
0.2	18.8 ± 0.6
0.5	18.9 ± 0.6

The dark matter content of Reticulum II

Bonnivard et al. ApJL 808 L36 (2015)

$\alpha_{\rm int}$ [deg]	$\log_{10}(J(\alpha_{\rm int}))$ $[J/{\rm GeV}^2\,{\rm cm}^{-5}]$[a]
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Simon et al. ApJ 808, 95 (2015)

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Bonnivard et al. ApJL 808 L36 (2015)

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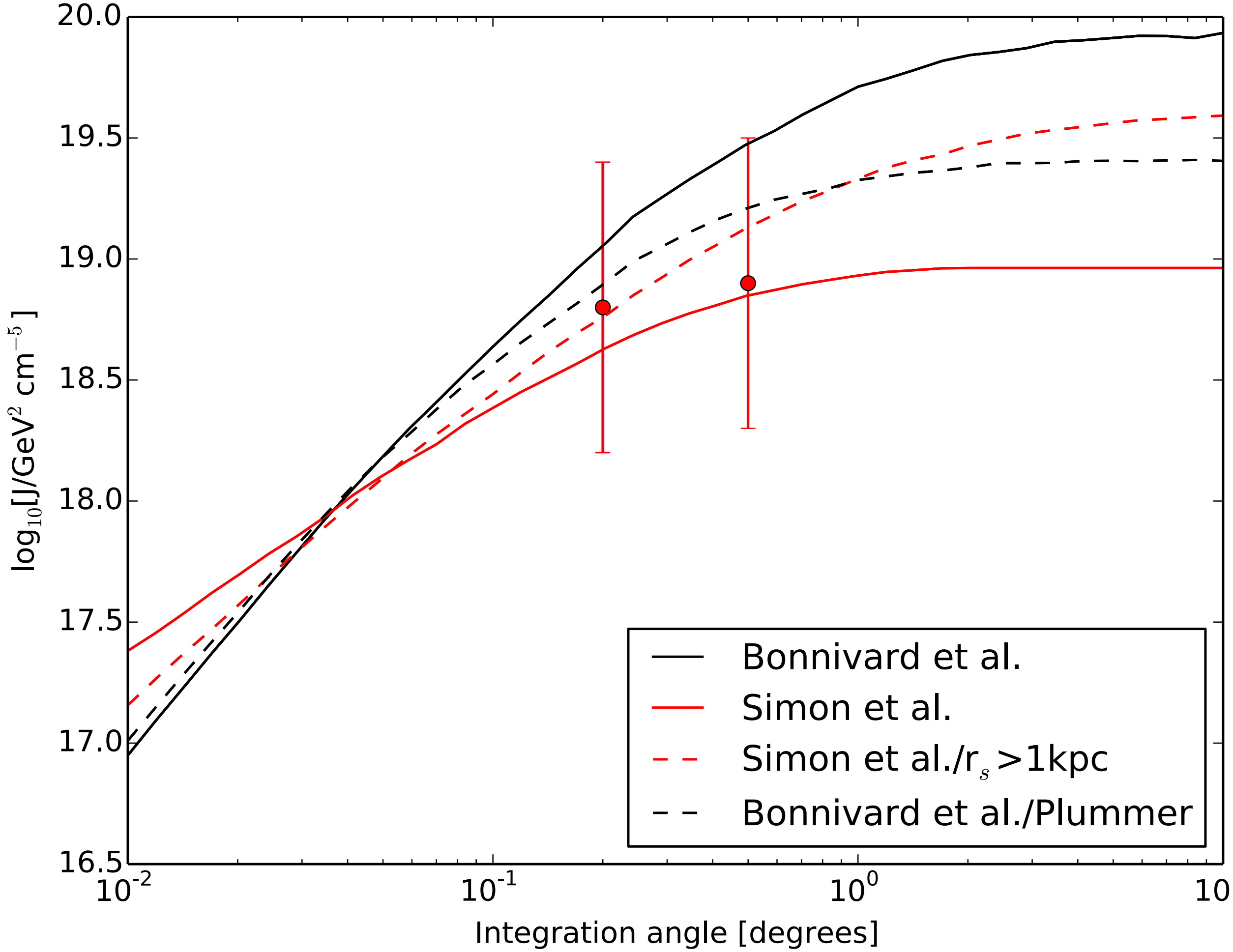
Flexible profile
No artificial truncation
No assumption on the distribution
J is the peak of the distribution
Error is percentiles

Simon et al. ApJ 808, 95 (2015)

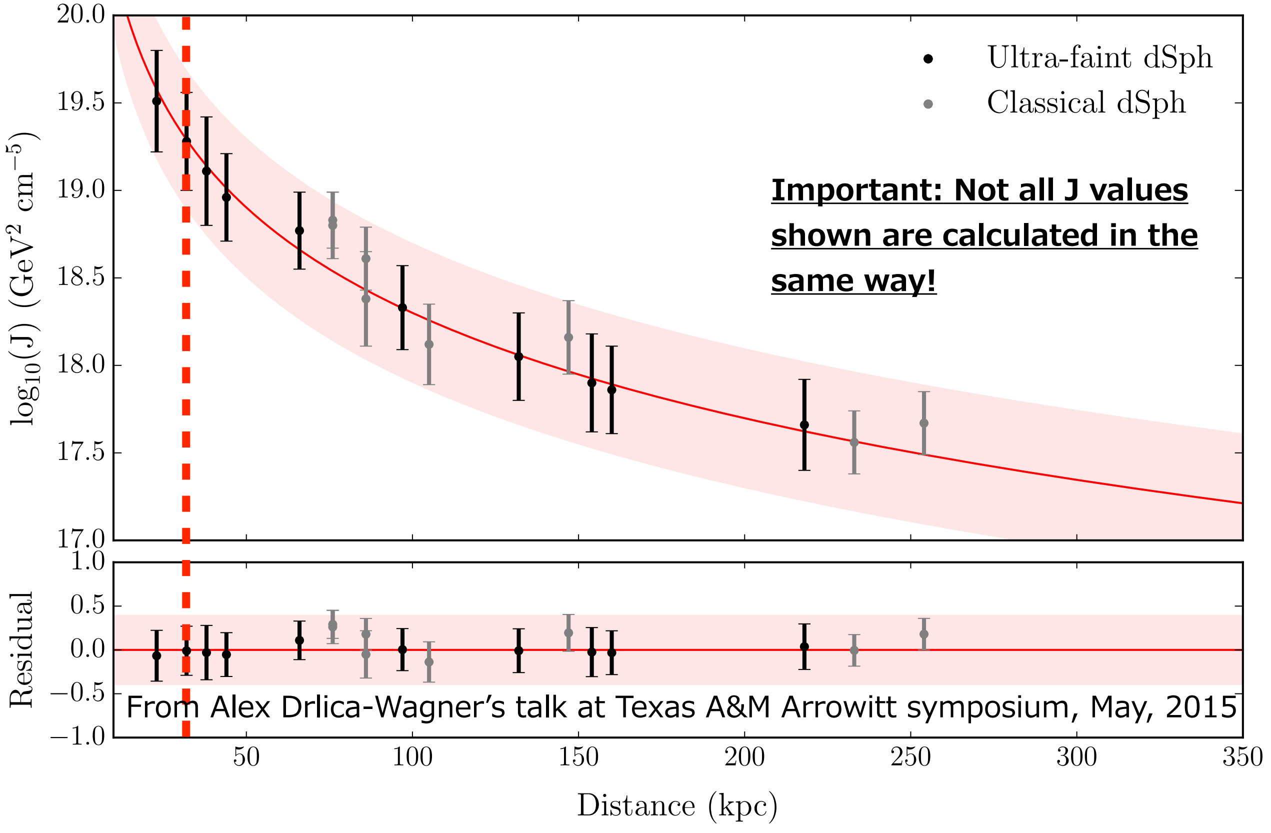
$\alpha_{\rm int}$ [deg]	$\log_{10}(J(\alpha_{\rm int}))$ $[J/{\rm GeV}^2\,{\rm cm}^{-5}]^{\rm a}$
0.2	18.8 ± 0.6
0.5	18.9 ± 0.6

Plummer profile
Truncation at 1 kpc
Gaussian approximation
J is the peak of the Gaussian
Error is standard deviation

The dark matter content of Reticulum II

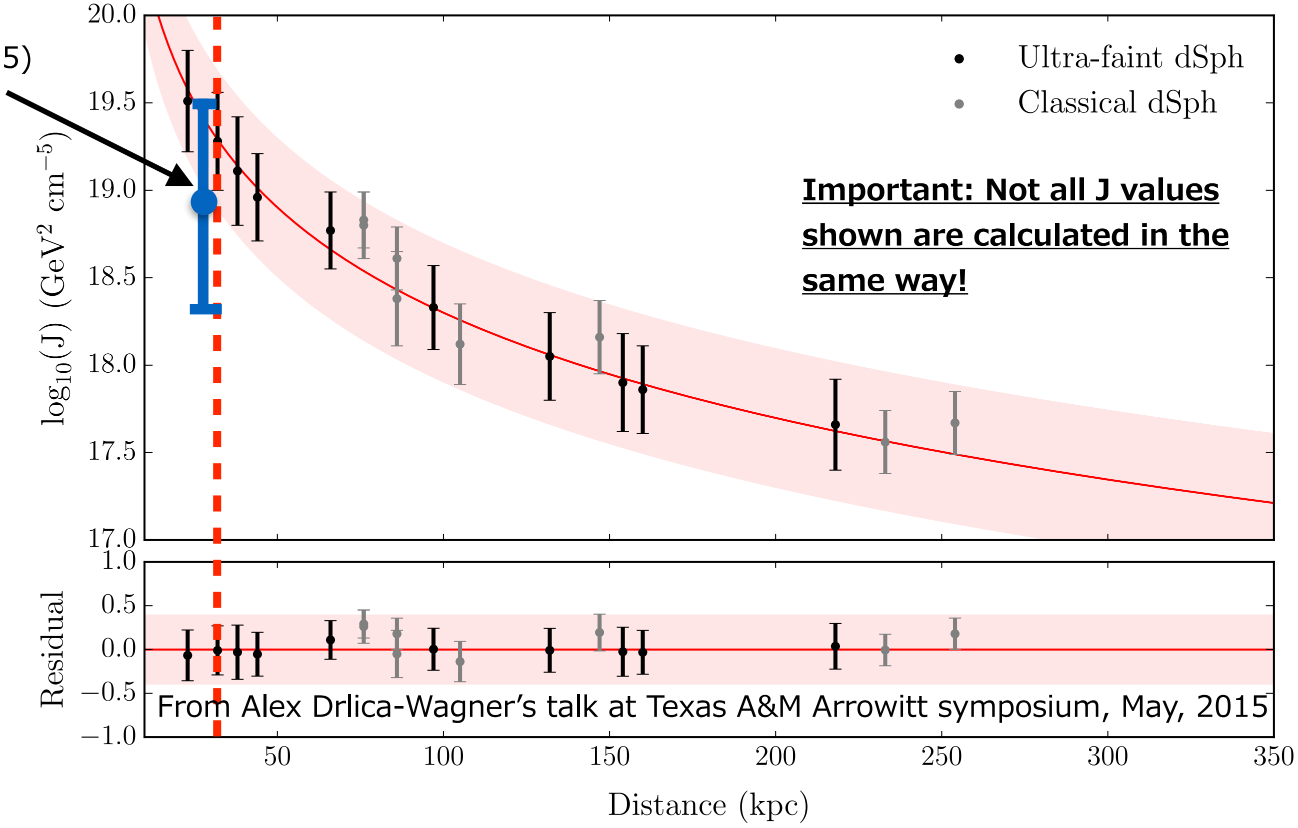


The dark matter content of Reticulum II

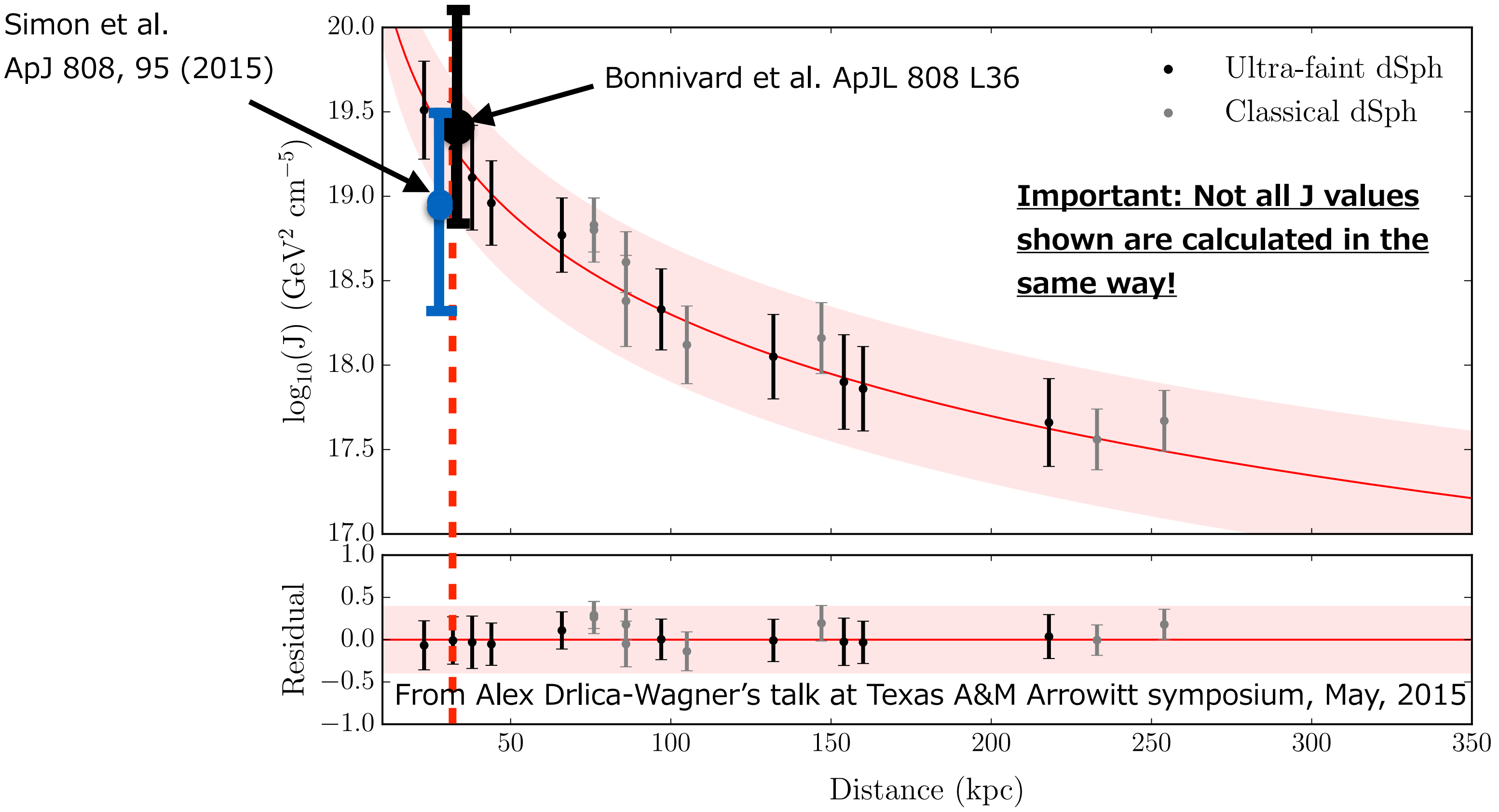


The dark matter content of Reticulum II

Simon et al.
ApJ 808, 95 (2015)



The dark matter content of Reticulum II



Where do we go from here

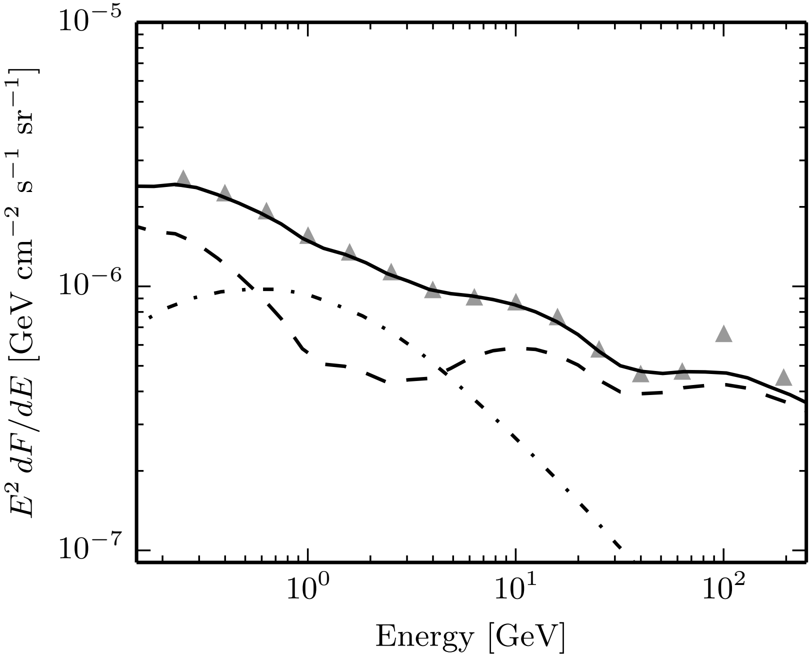
1. Is it consistent with background?

2. Is it consistent with dark matter annihilation?

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

4. Is it something else? (e.g., instrumental/data set systematics?) (P7R vs P8)

Statistical significance of a dark matter interpretation



Background modeling

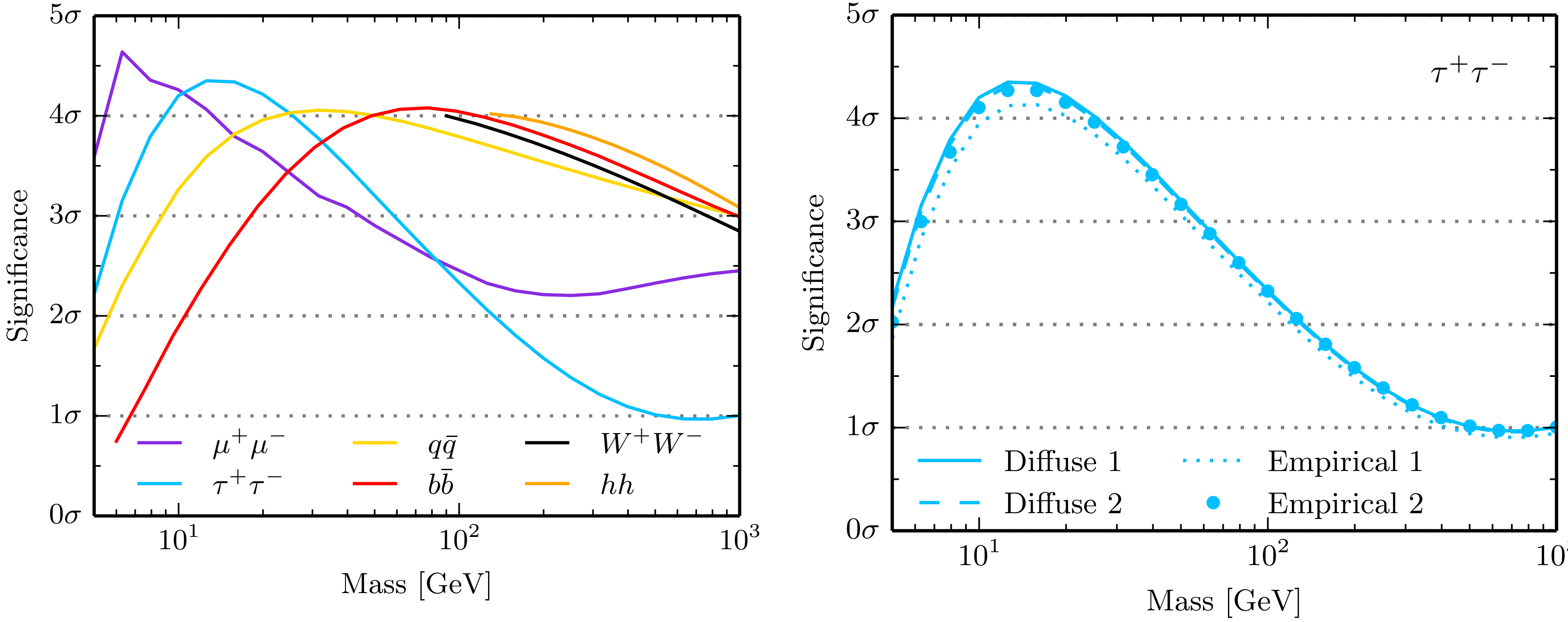
- ***Diffuse 1***: Fermi-LAT background averaged over 1 degree.
- ***Diffuse 2***: Fermi-LAT background averaged over 2 degrees.
- ***Empirical 1***: Events in an [1-5] degree annulus from central ROI with 20% gaussian width on energy.
- ***Empirical 2***: Bin *Empirical 1* events in energy.

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

Based on PRL 115, 081101 & ApJL 808 L36 (2015)

Statistical significance of a dark matter interpretation

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



Based on PRL 115, 081101 & ApJL 808 L36 (2015)

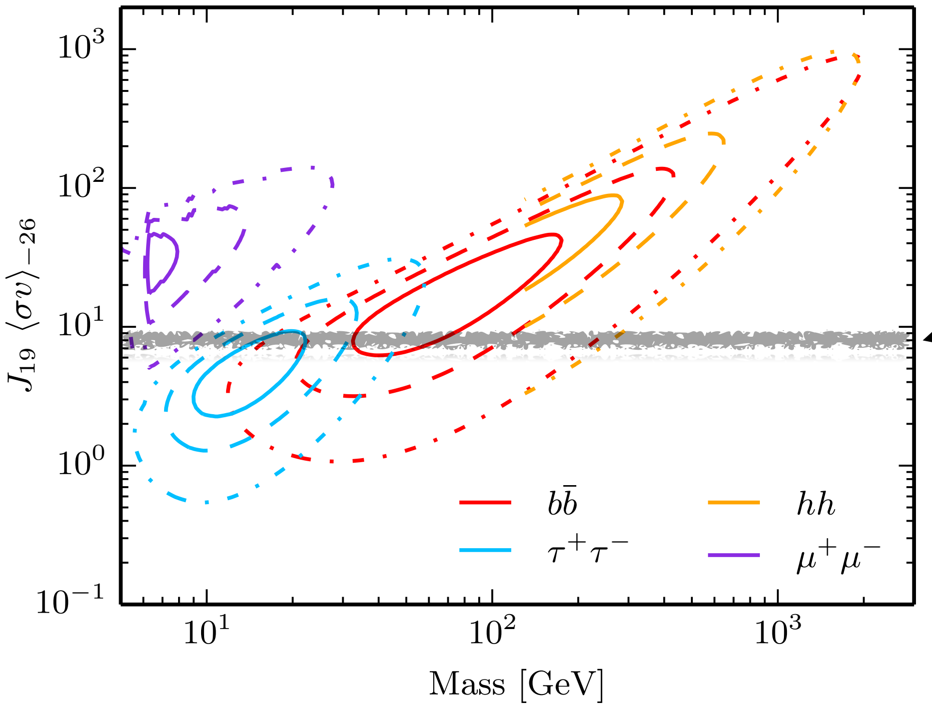
Statistical significance of a dark matter interpretation

	Pass7	**Pass8**
Empirical background		
	Local p-value = 0.0024 (2.8 sigma)	Local p-value = 0.0203 (2 sigma)
	Global p-value = 0.0097 (**2.3 sigma**)	Global p-value = 0.0553 (**1.6 sigma**)
Poisson background		
	Local p-value = 0.0000068 (4.4 sigma)	Local p-value = 0.0073 (2.4 sigma)
	Global p-value = 0.000042 (**3.7 sigma**)	Global p-value = 0.022 (**2 sigma**)

Based on PRL 115, 081101 & ApJL 808 L36 (2015)

Statistical significance of a dark matter interpretation

Based on PRL 115, 081101 & ApJL 808 L36 (2015)



Assuming a J value as in Bonnivard et al. ApJL 808 L36 (2015)

What about consistency checks with the Galactic center and other dwarfs?
(see e.g., Abazajian & Keeley 1510.06424)

Does the data prefer one explanation (channel) over something else? What can the LHC tell us?
(see e.g., Fan, Koushiappas & Landsberg, 1507.06993)

Where do we go from here

1. Is it consistent with background?
2. Is it consistent with dark matter annihilation?
3. Is it consistent with any other possible source (pulsars, AGNs, ?)
4. Is it something else? (e.g., instrumental/data set systematics?) (P7R vs P8)

In conclusion

Given that this is the very first time we have a hint 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 as it is a massive nearby dwarf galaxy — a prime target in the search for a non-gravitational signature of dark matter.