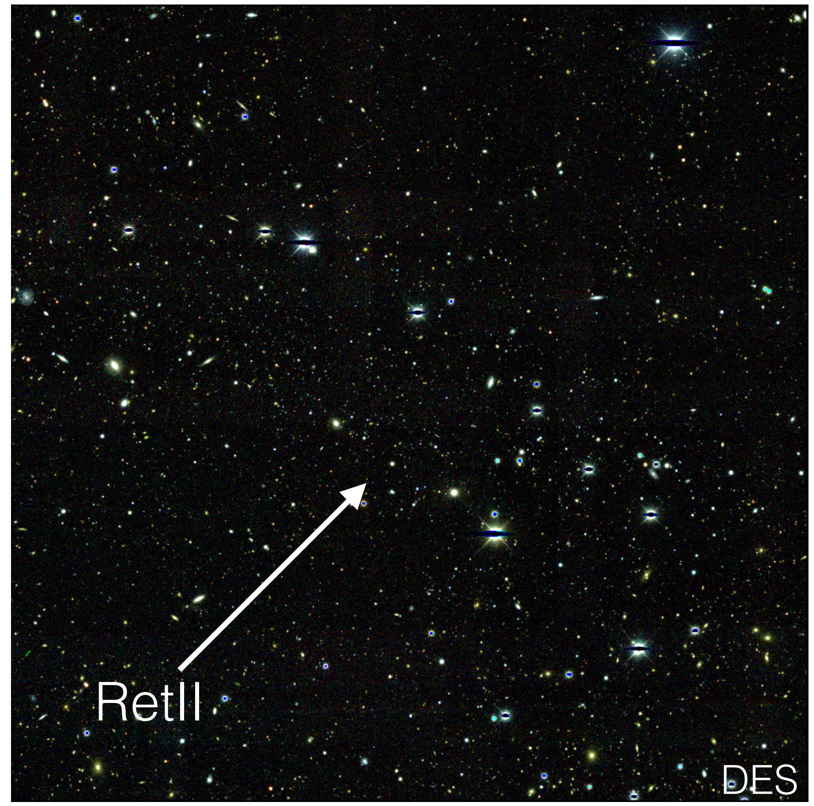
A Search for Dark Matter Annihilation in Newly Discovered Dwarf Galaxies



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Vincent Bonnivard, Celine Combet, David Maurin (**LPSC Grenoble**)

arXiv:1503.02320 (PRL), arXiv:1410.2242 (PRD), arXiv:1504.03309 (ApJL)

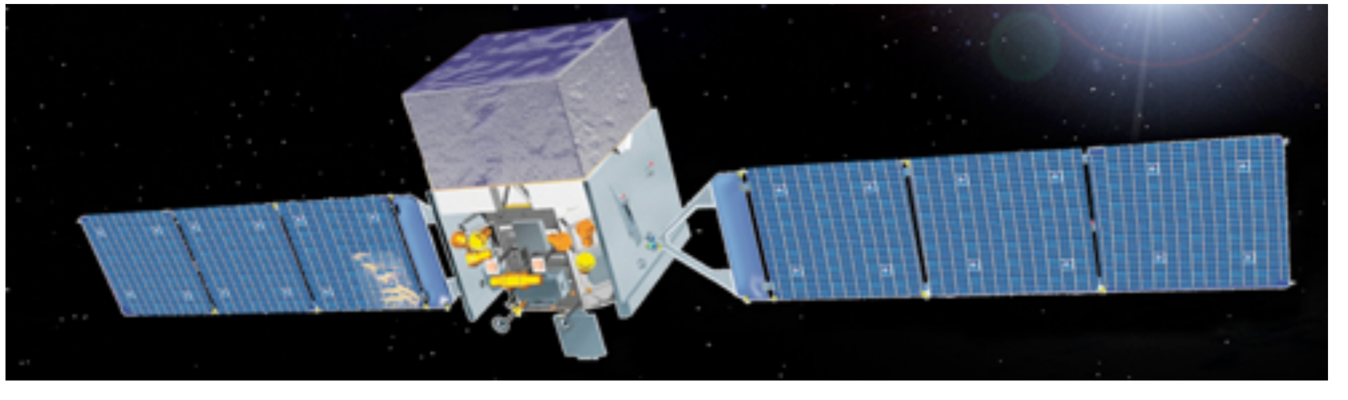
Dark matter

Large scales — gravity

Microscopic physics — what *is* it?

Look for its *particle interactions*

Gamma-rays — Fermi satellite



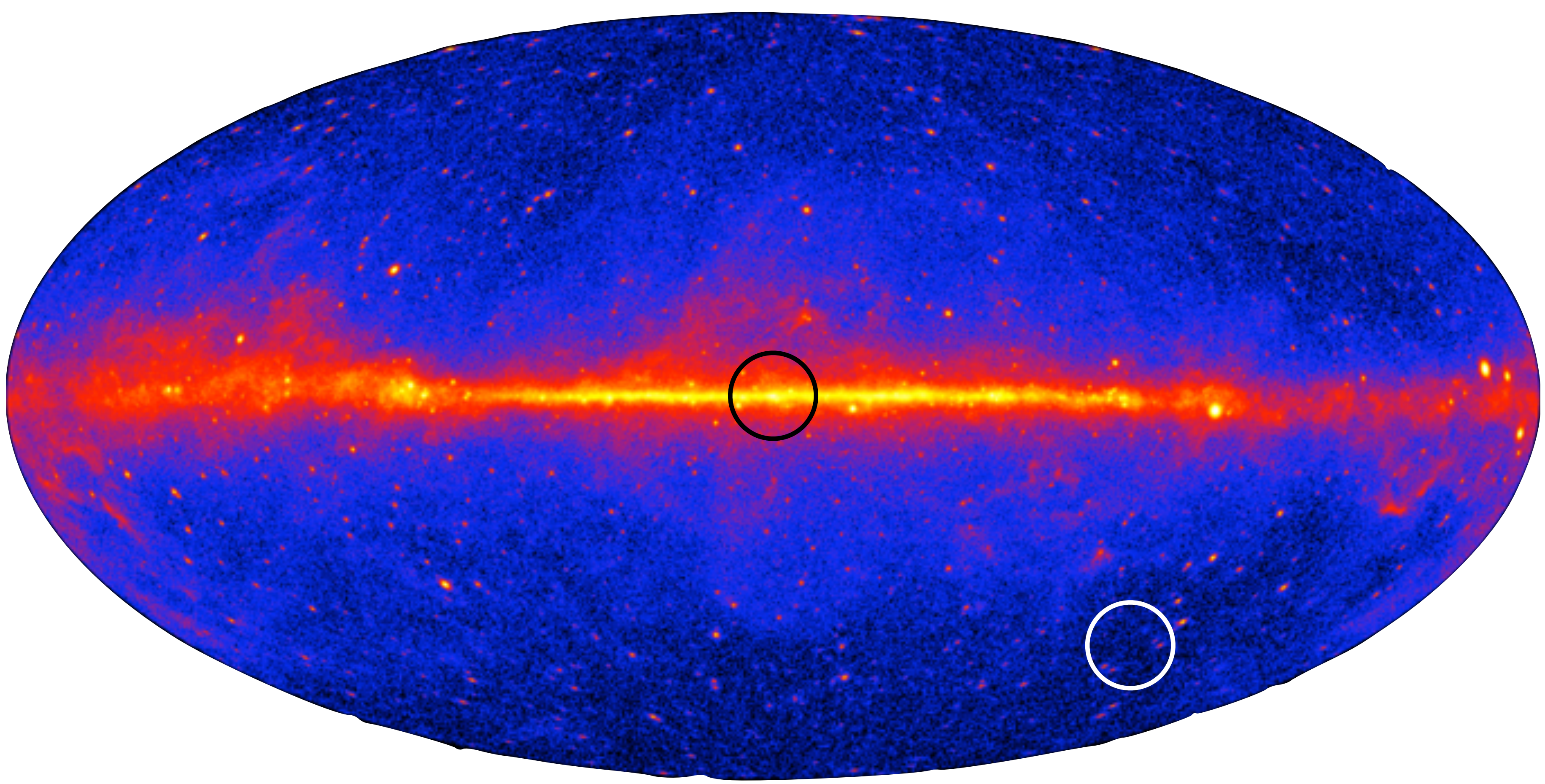
Milky Way dwarf galaxies

Nearby

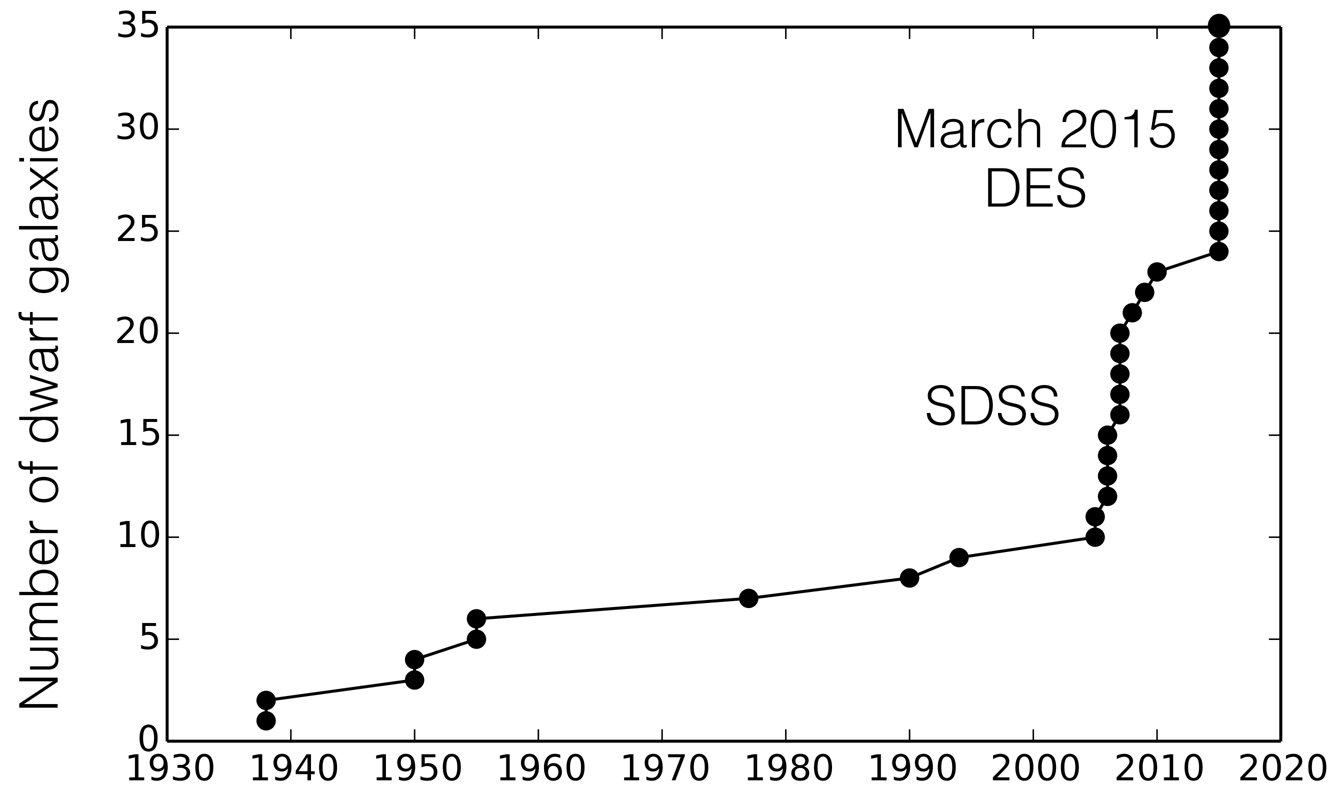
Lots of dark matter

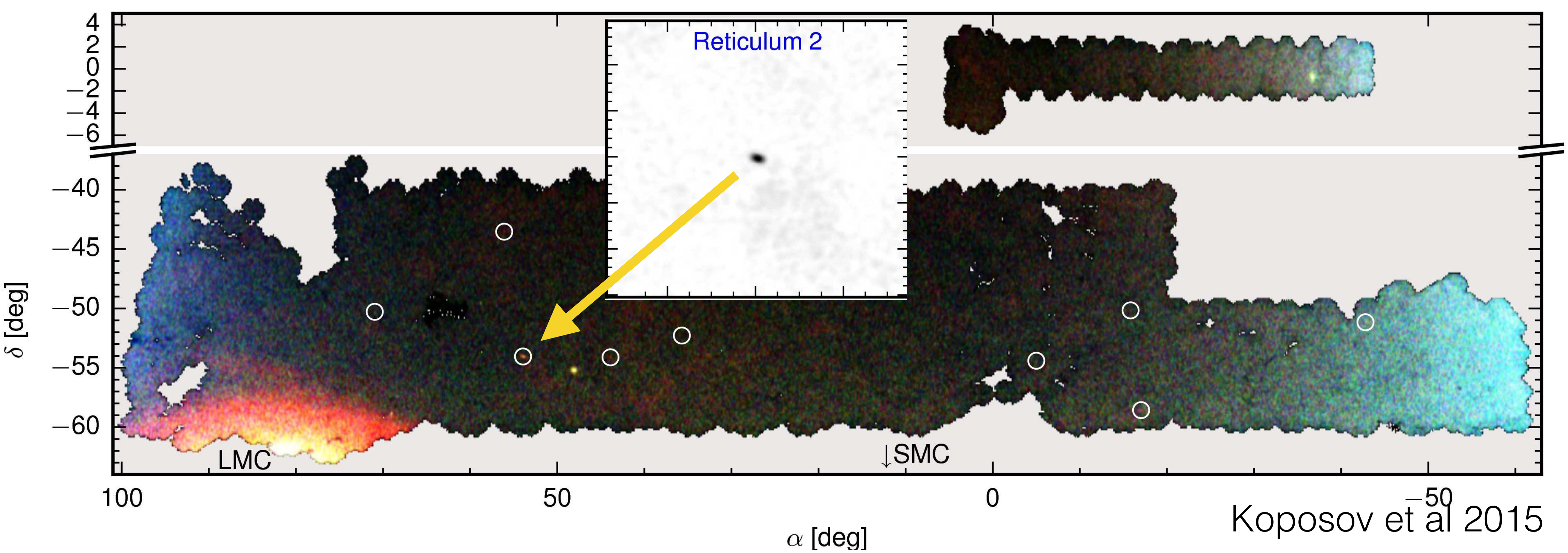
Not much else: no astrophysical background

Very important! e.g. Galactic center



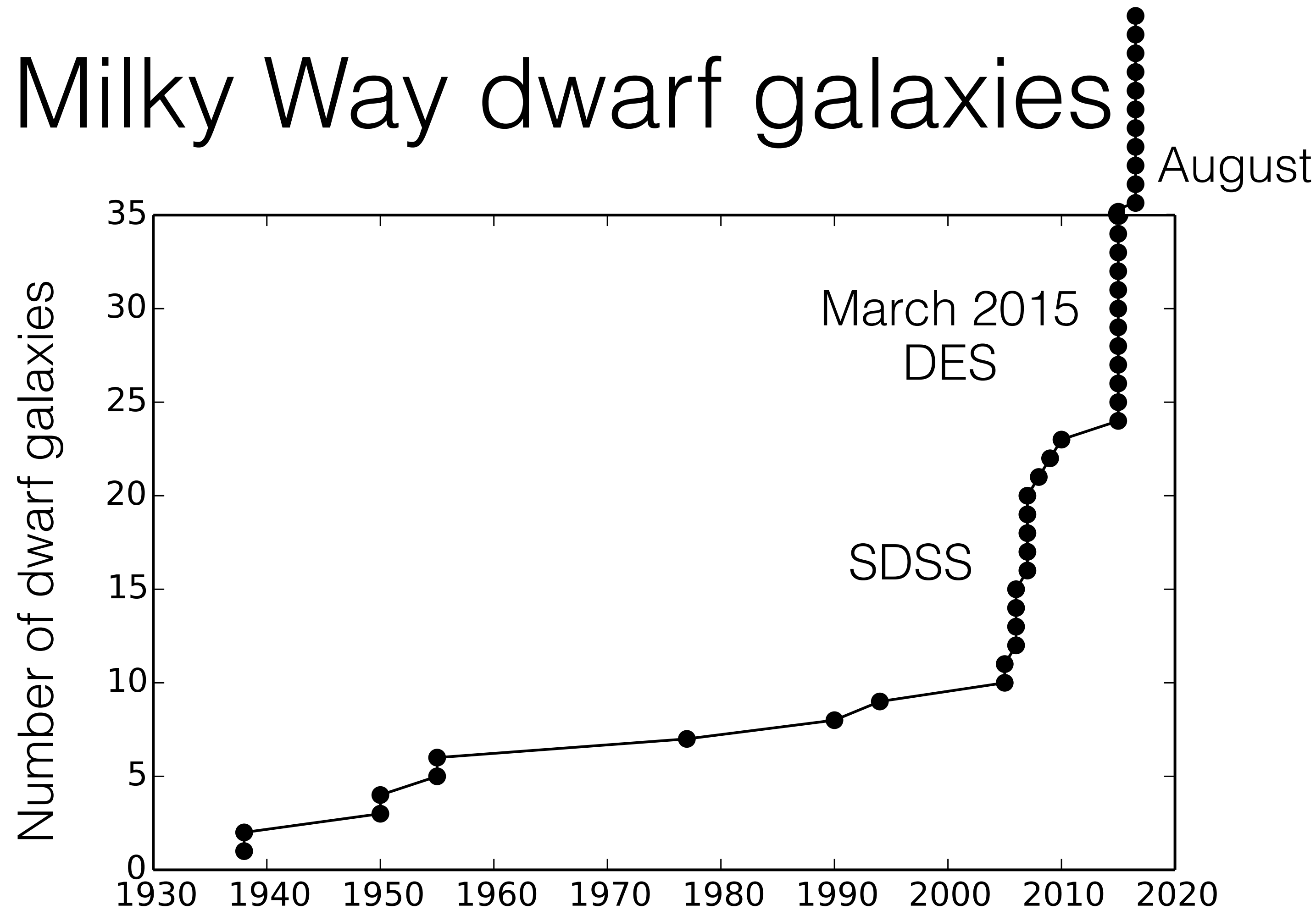
Milky Way dwarf galaxies

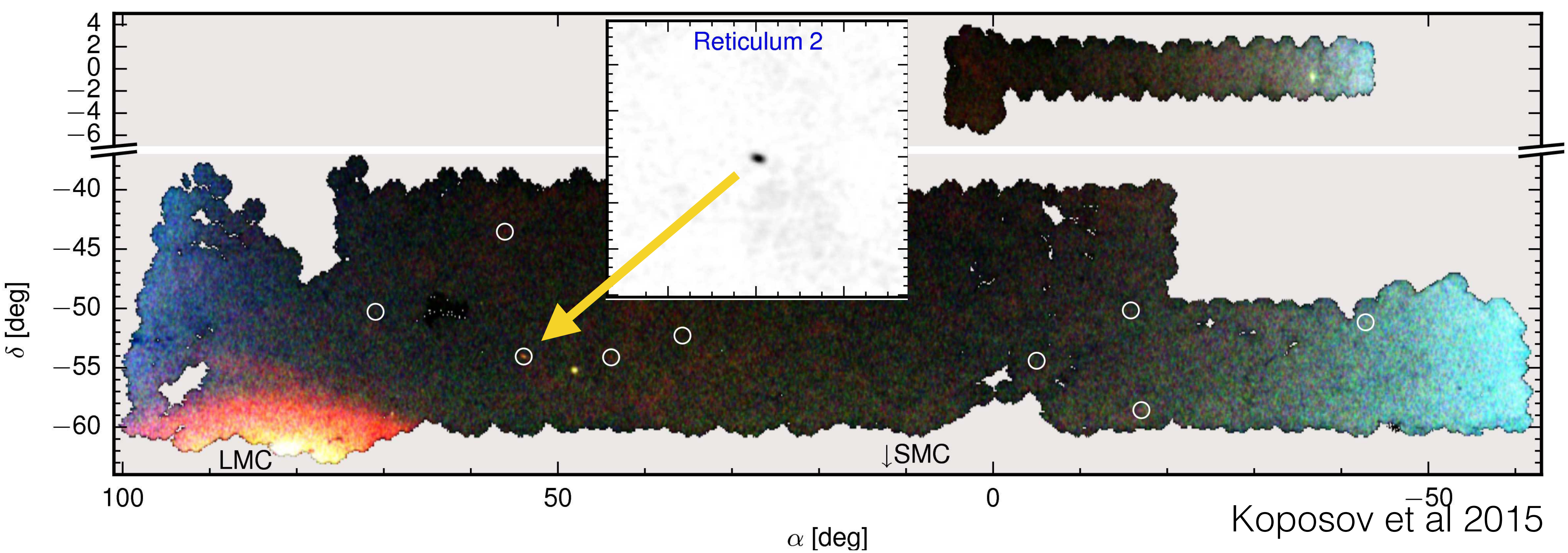




Koposov et al 2015

Milky Way dwarf galaxies



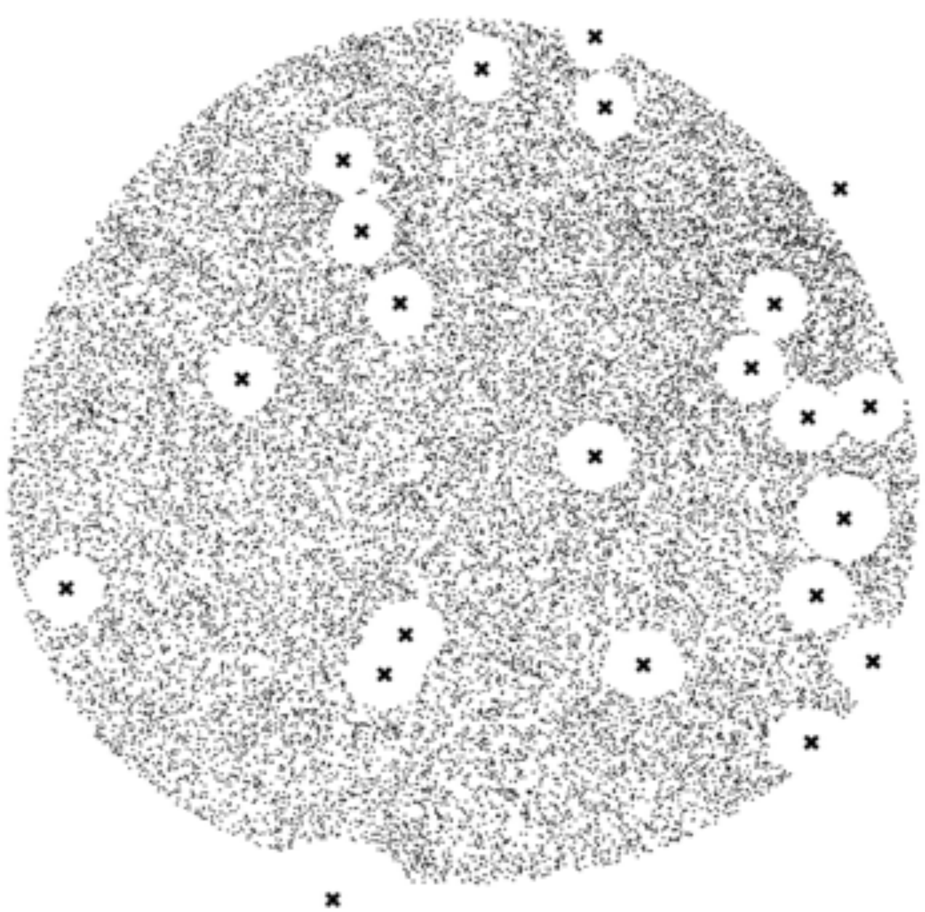


Koposov et al 2015

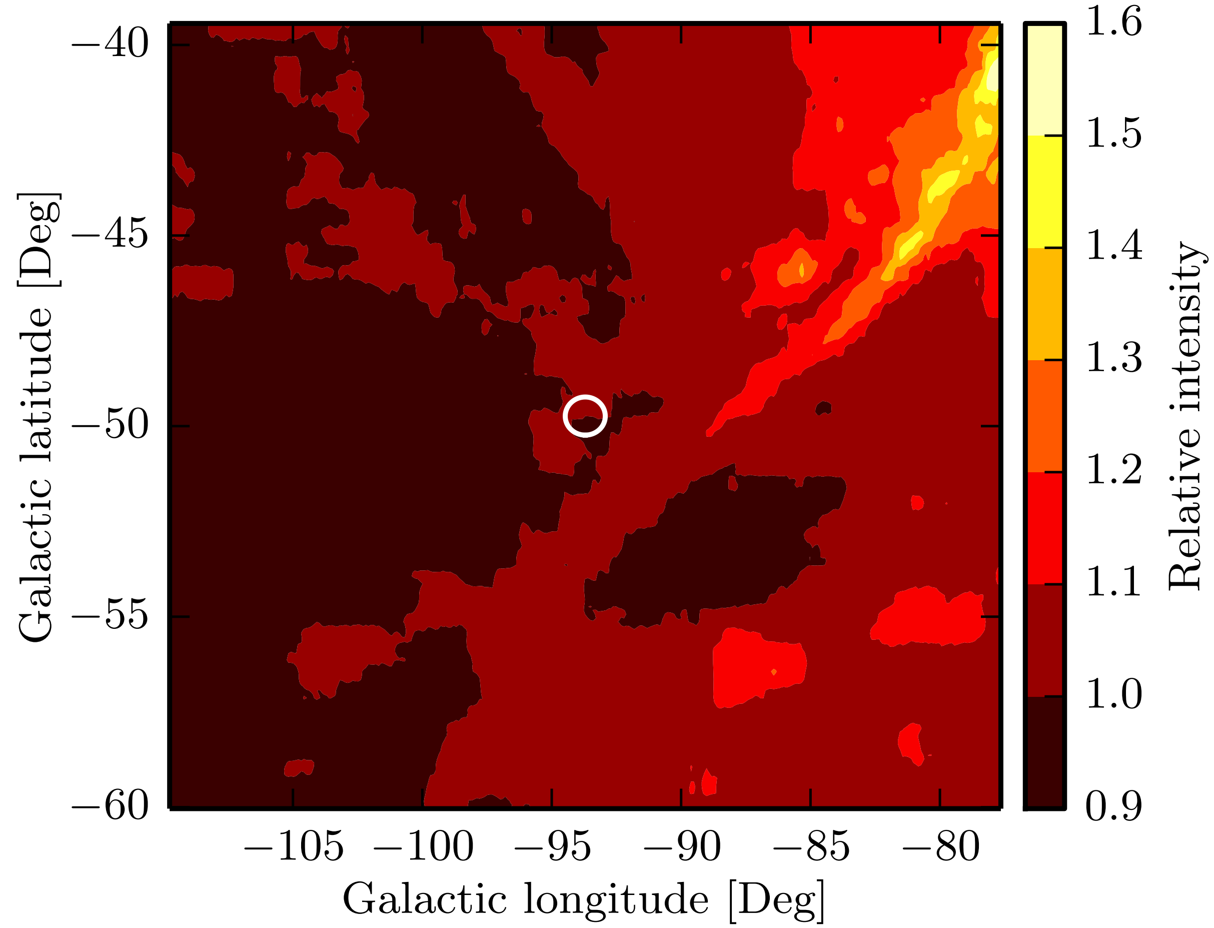
Reticulum II

nearest of the new DES dwarfs (30 kpc)
(Koposov+ 2015, Bechtol+ 2015)

Gamma-rays 1-300 GeV



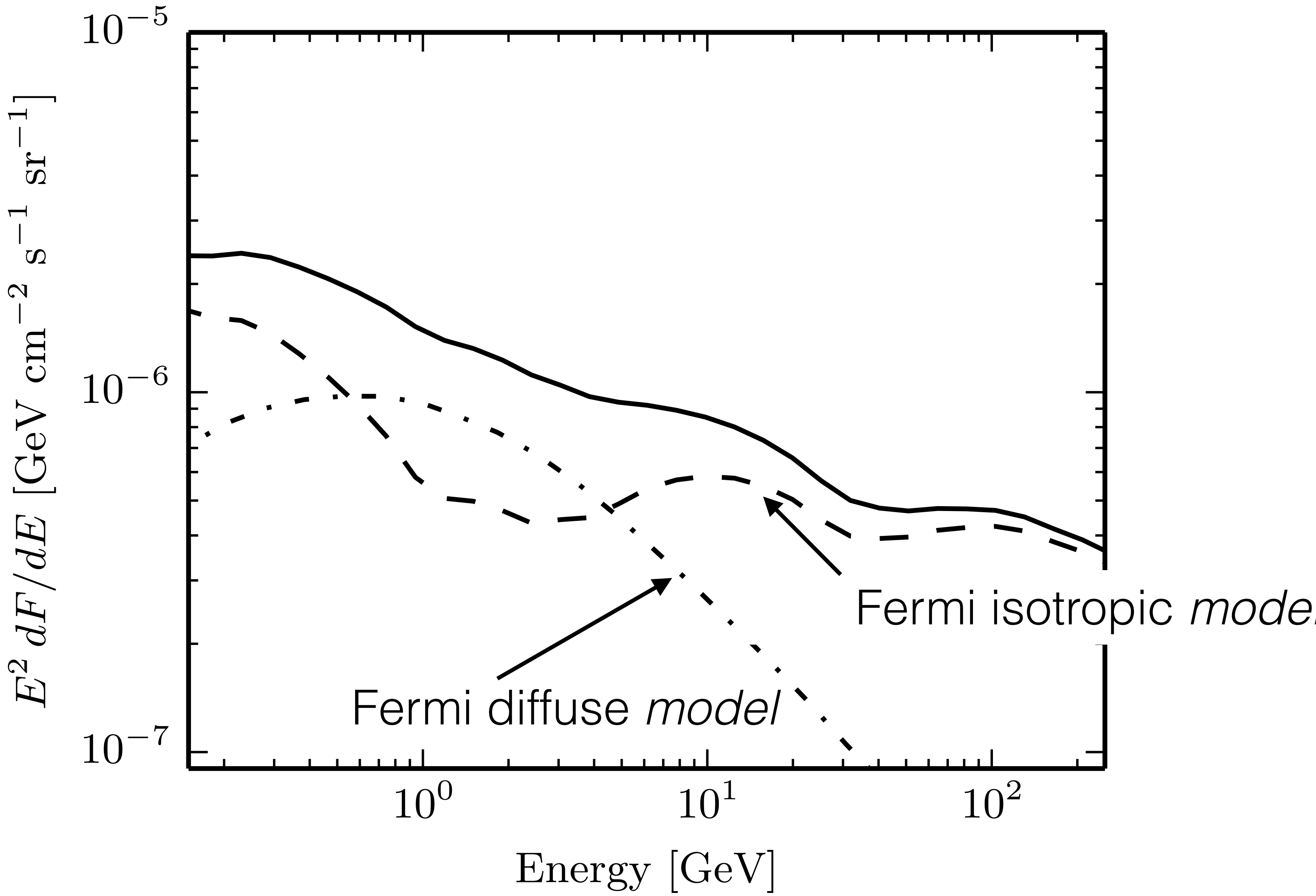
Gamma-ray background model at 8 GeV



Far away from known sources

Uniform background

A first look at the gamma-ray signal



AGS et. al. arXiv:1503.02320 (PRL)

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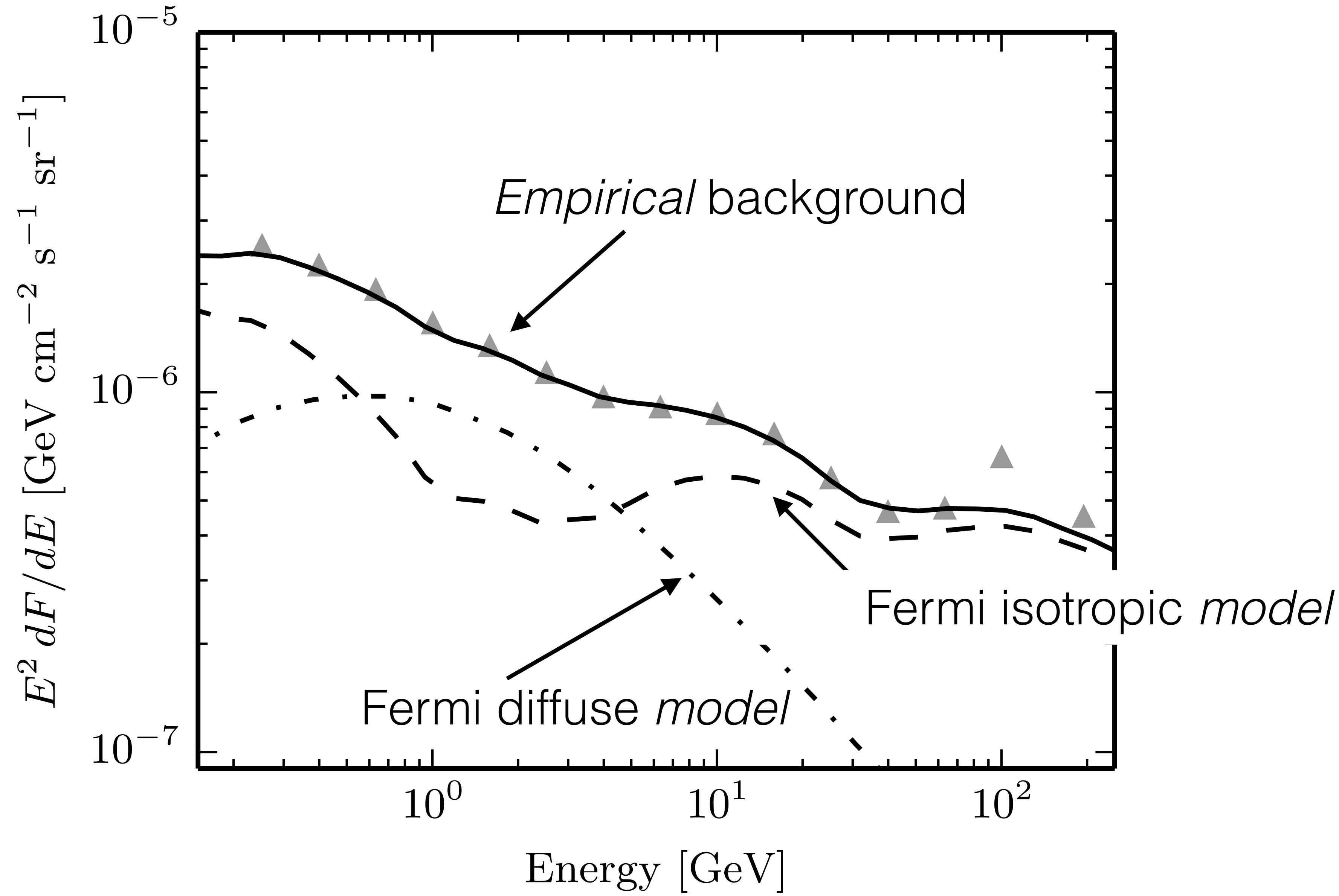

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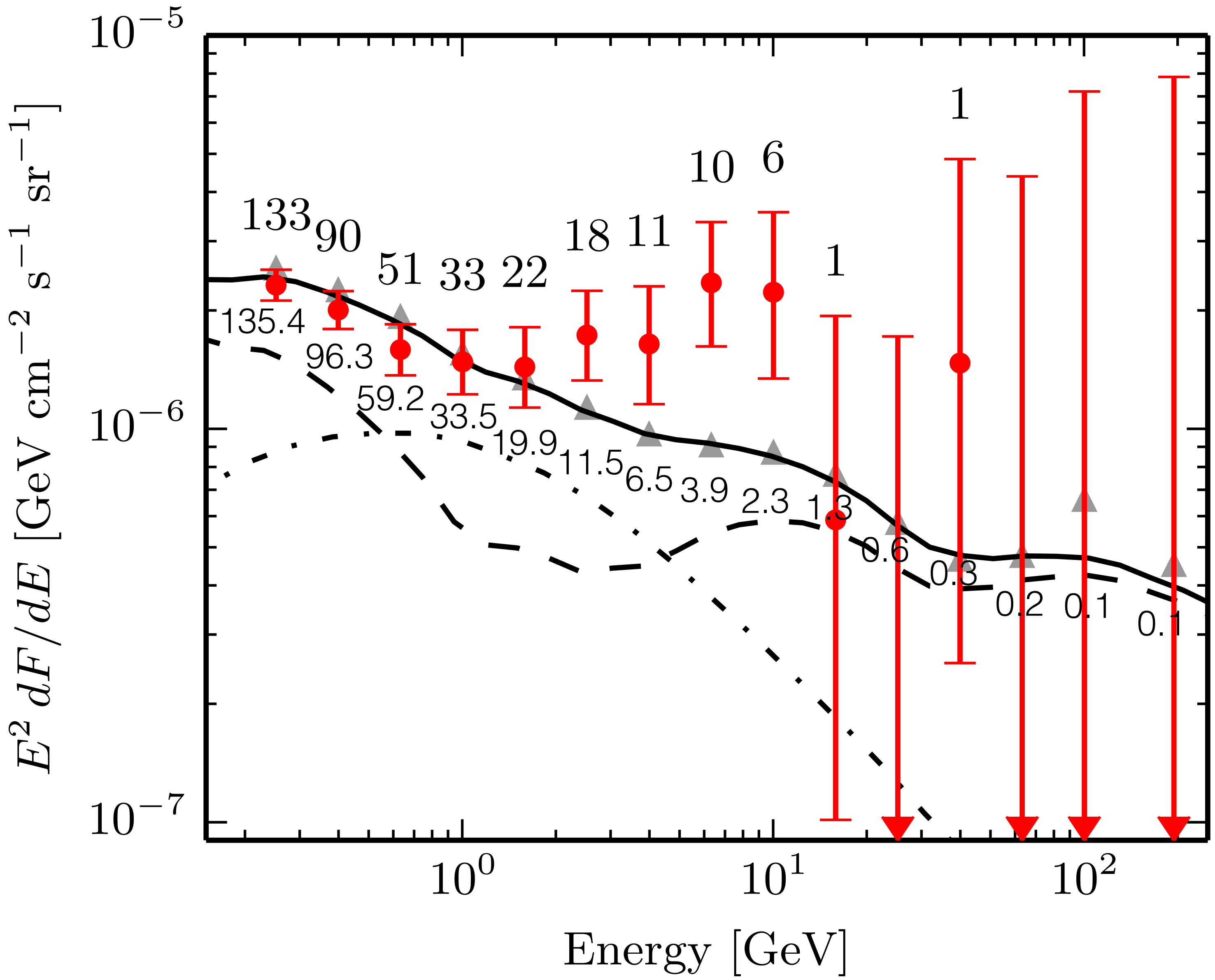


Events within 0.5° of RetII

AGS et. al. arXiv:1503.02320 (PRL)

Statistical procedure

Need to quantify the significance of the signal (e.g. *p*-value)

Each photon gets a weight

$$T = \sum_{i \in \text{photons}} w(Q_i)$$

sum over all observed events

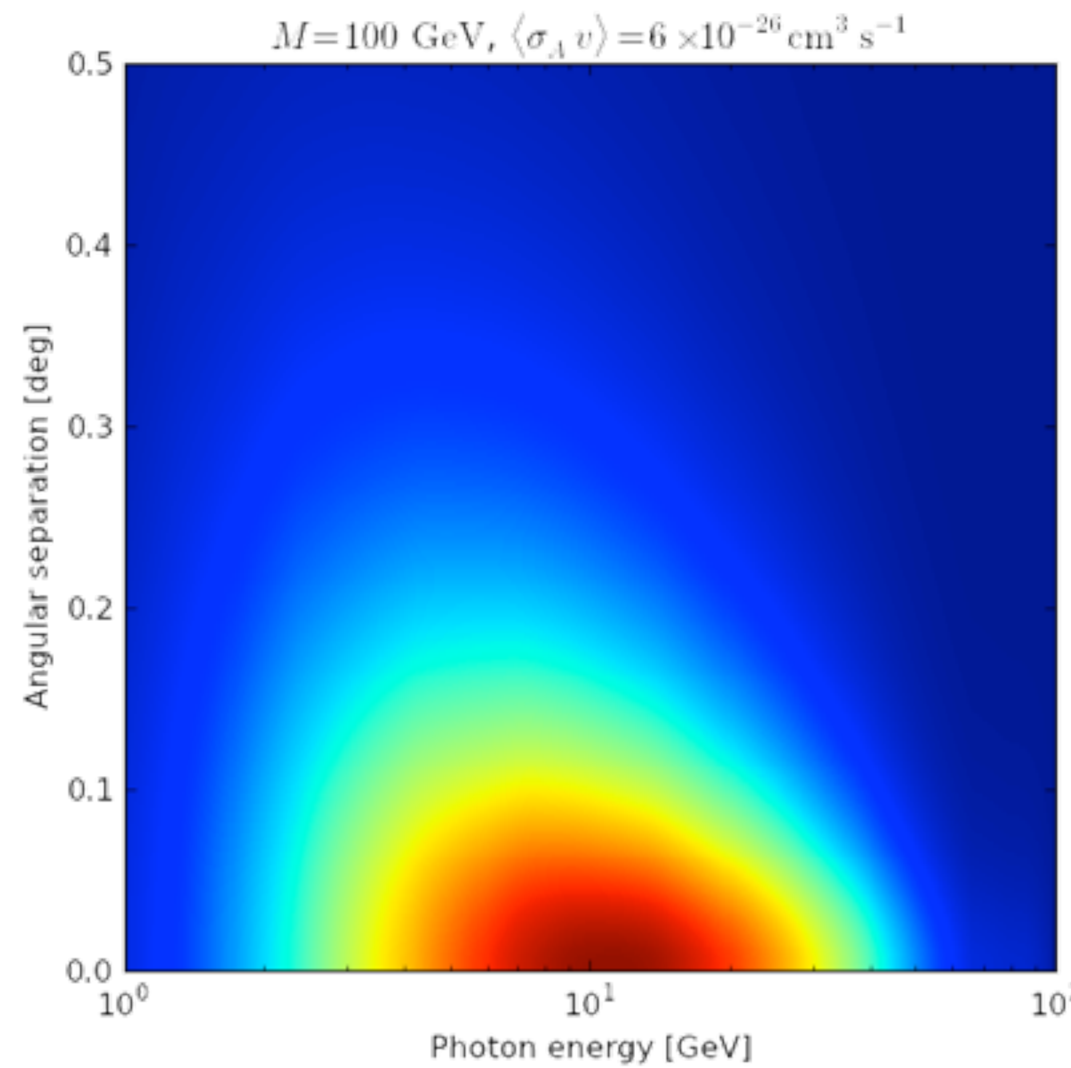
Weight of photon is based on:

$$\left.\begin{array}{l}\bullet\ \text{Energy} \\ \bullet\ \text{Angular separation from} \\ \quad \text{location of dwarf}\end{array}\right\} Q_i$$

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

signal

background

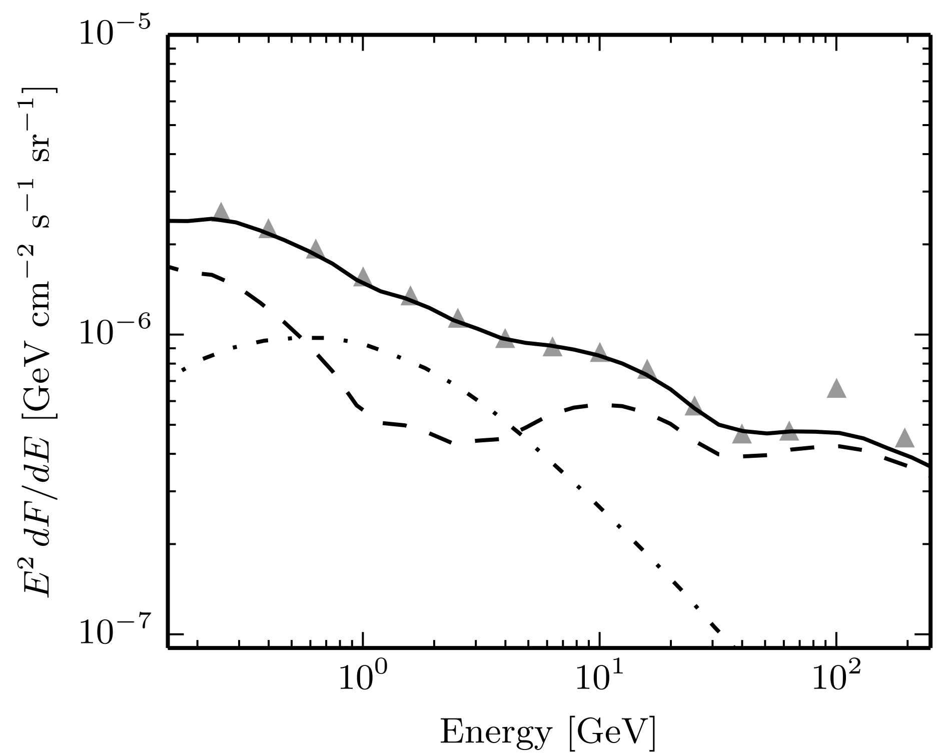


AGS, Koushiappas, Walker arXiv:1410.2242 (PRD)

Background modeling

Poisson process background:

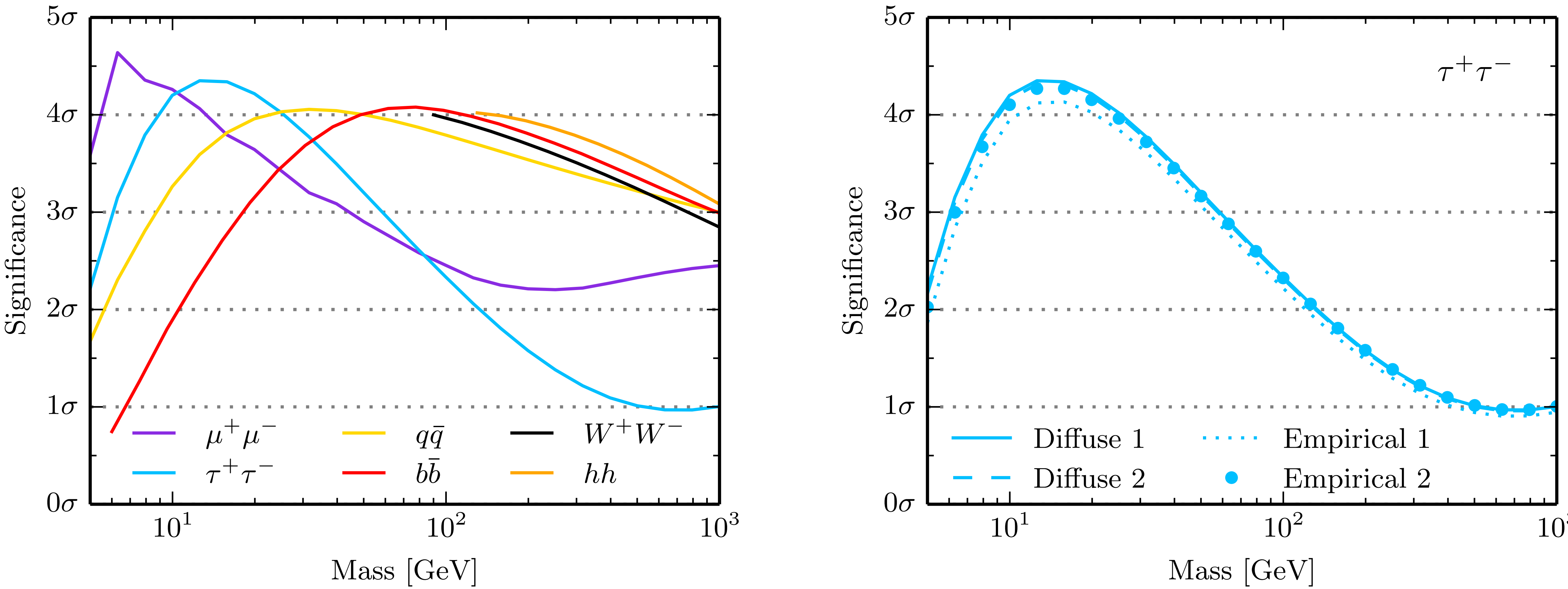
- Number of events is a Poisson variable
- Isotropic within 0.5° of RetII
- Event energies are independent draws from some energy spectrum



$$T = \sum_{i \in \mathrm{photons}} w(Q_i)$$ follows a compound Poisson distribution which we can compute exactly

AGS, Koushiappas, Walker arXiv:1410.2242 (PRD)

Results



Local *p*-value < 3×10^{-5} (4σ) in every channel

Robust to different background spectra

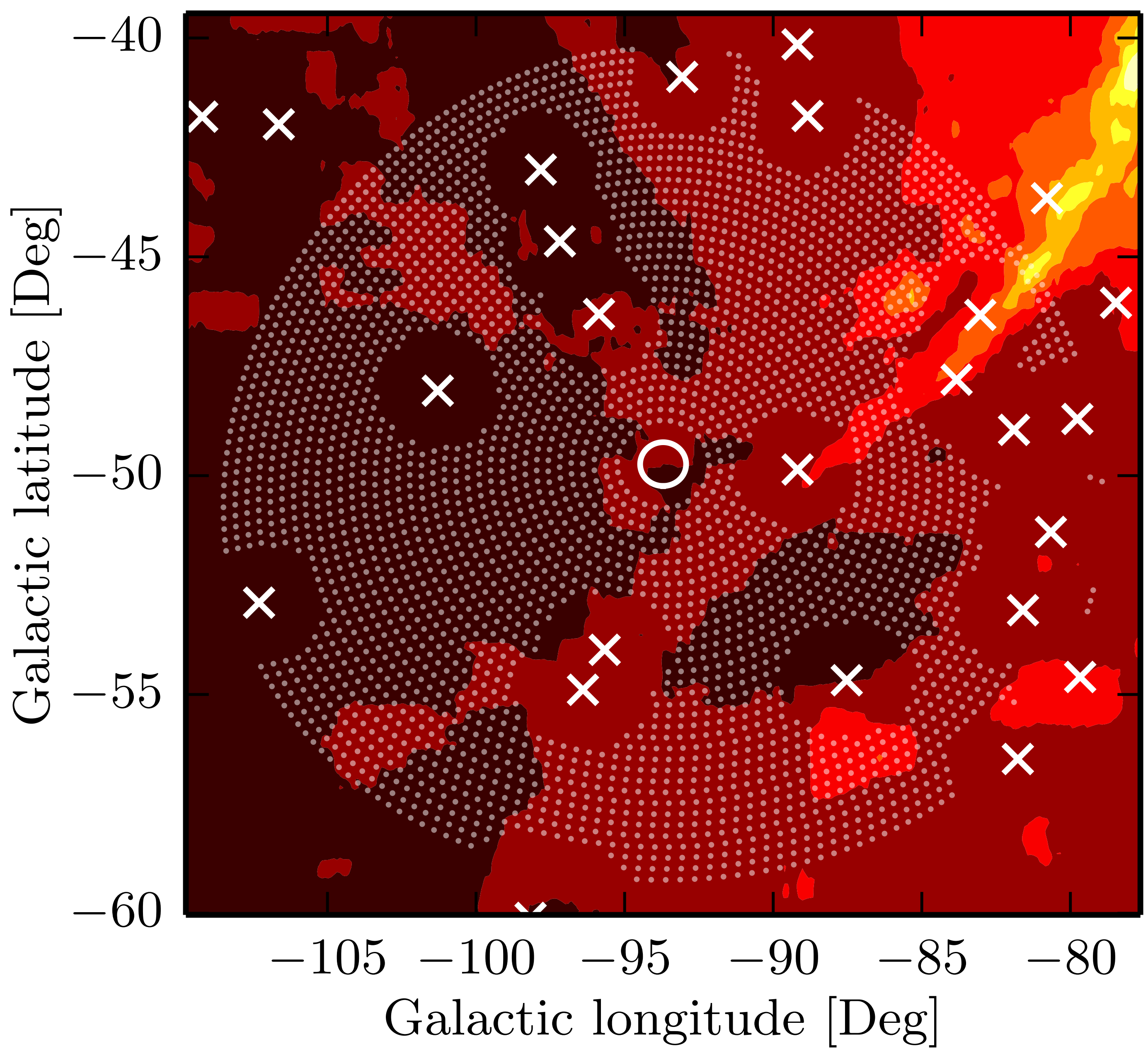
Searching over dark matter masses = multiple hypothesis tests

$p_{global} < 9.8 \times 10^{-5}$

Empirical background sampling

No assumptions about background

How many background ROIs have *T* larger than RetII?



Empirical background sampling

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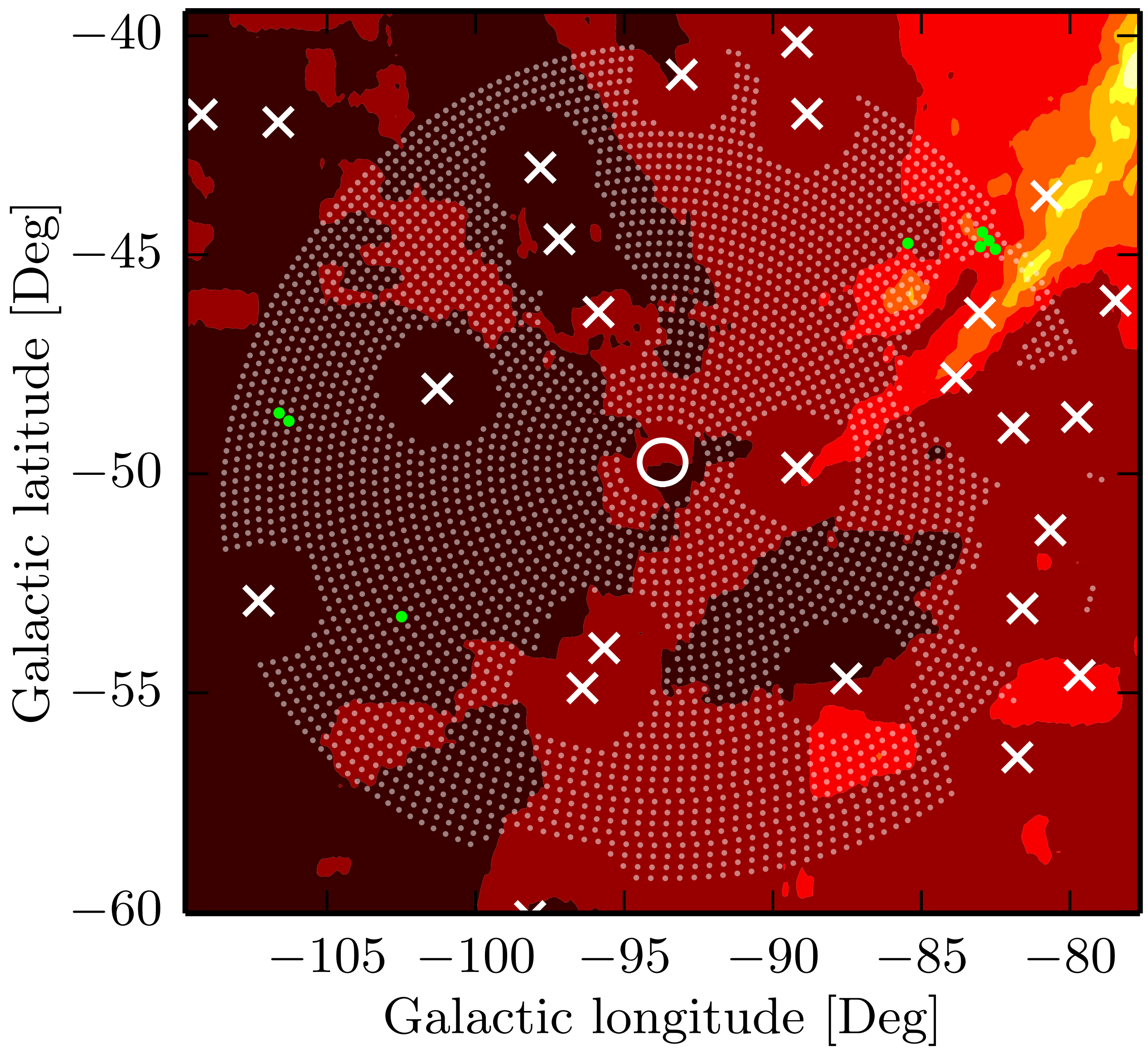
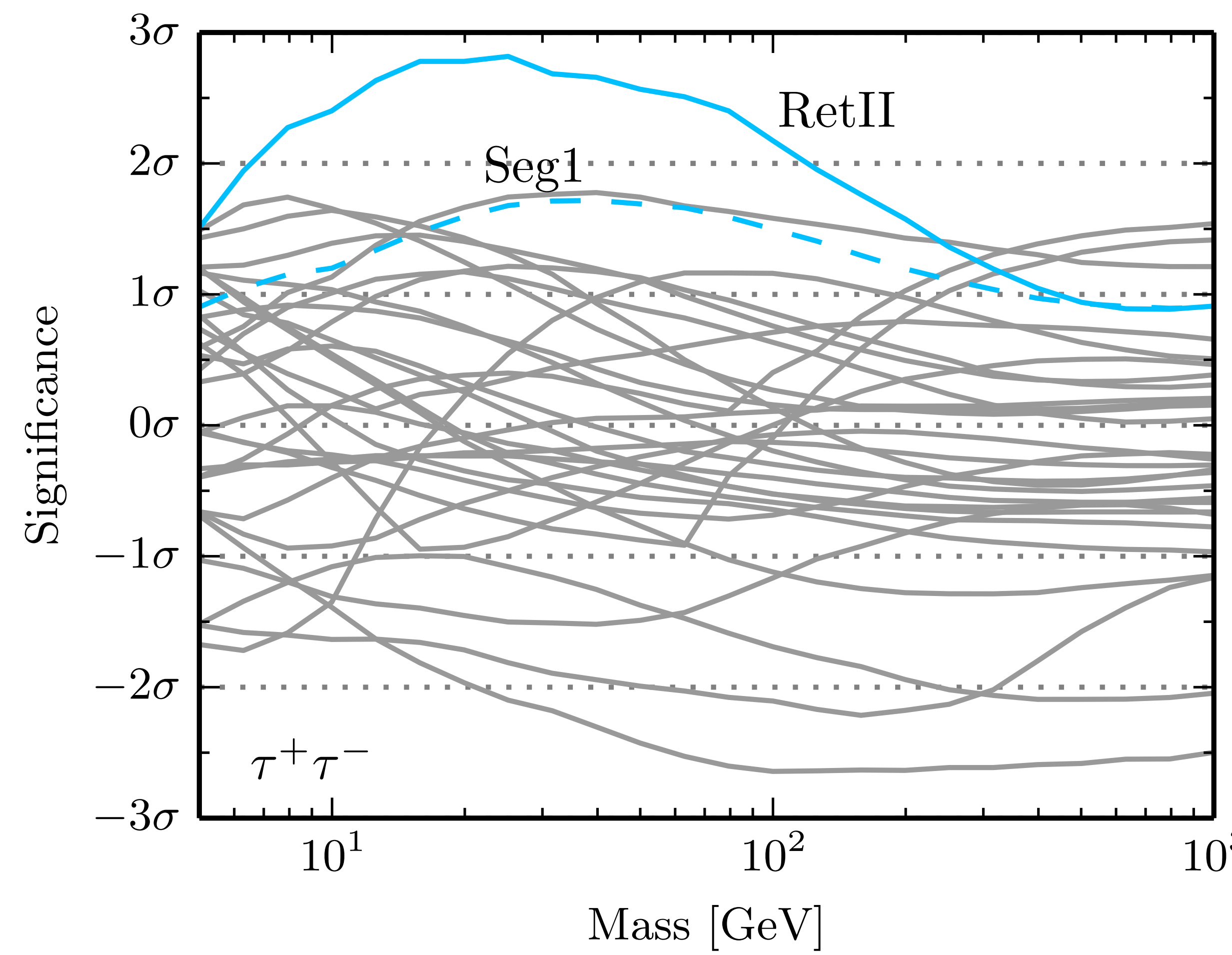


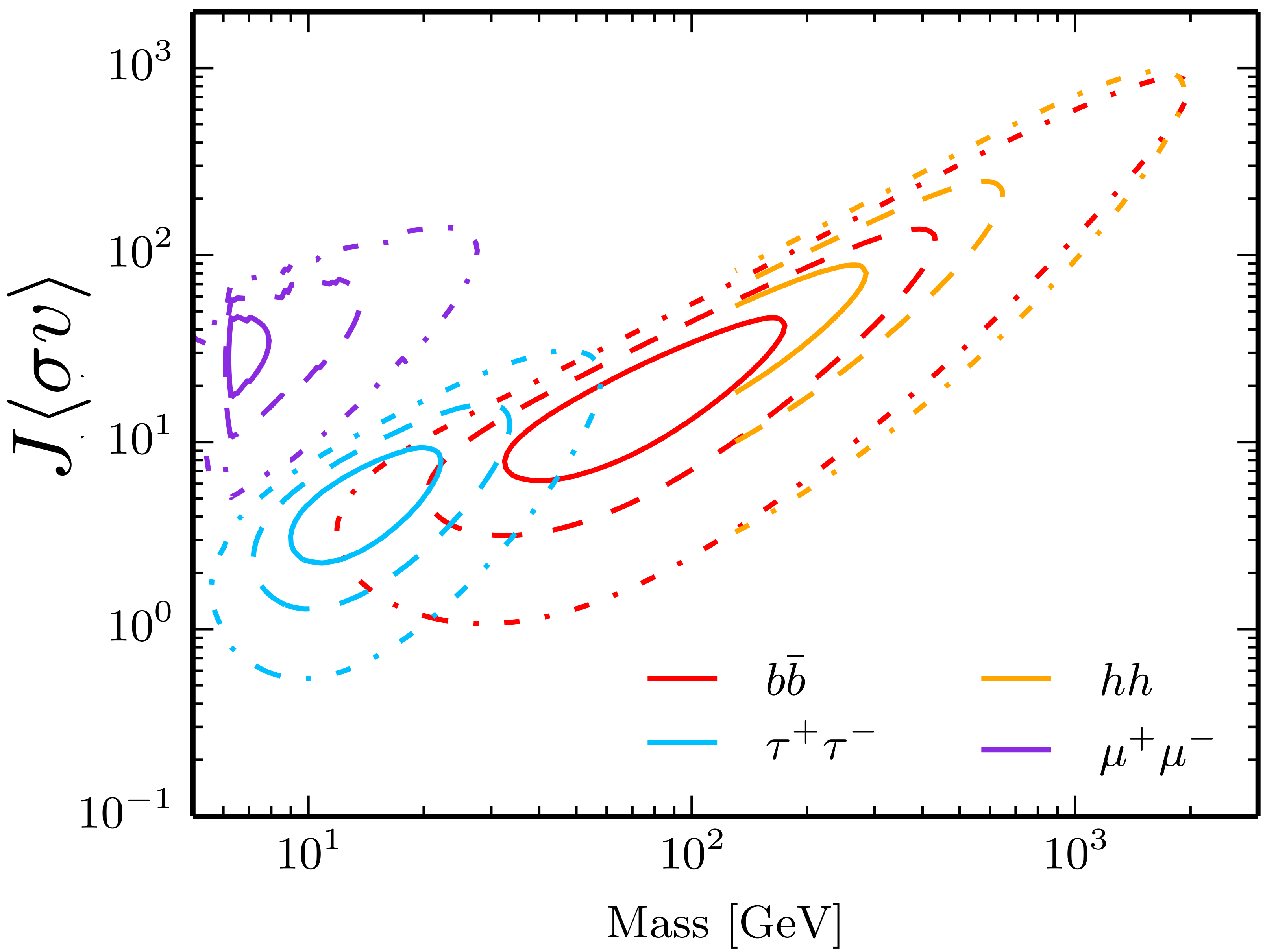


Local *p*-value of 8/3306 = 0.0024 (2.8σ)

Global *p*-value of 32/3306 = 0.0097 (2.3σ)

Fundamental limitation: strong signal = very few samples in tail

If signal is due to dark matter annihilation what can we say about the dark matter particle?

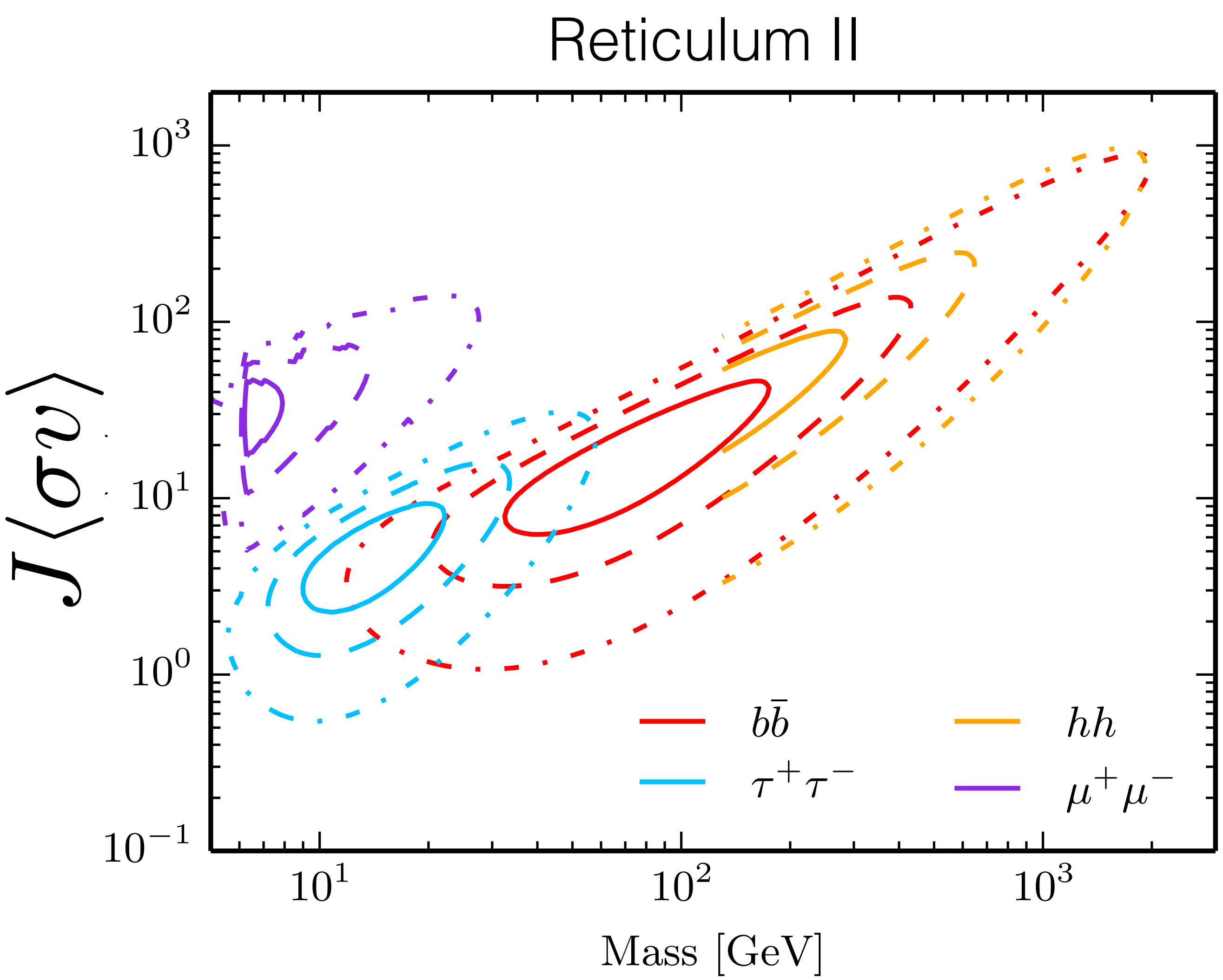


Gamma-rays can only constrain product $J\langle\sigma v\rangle$

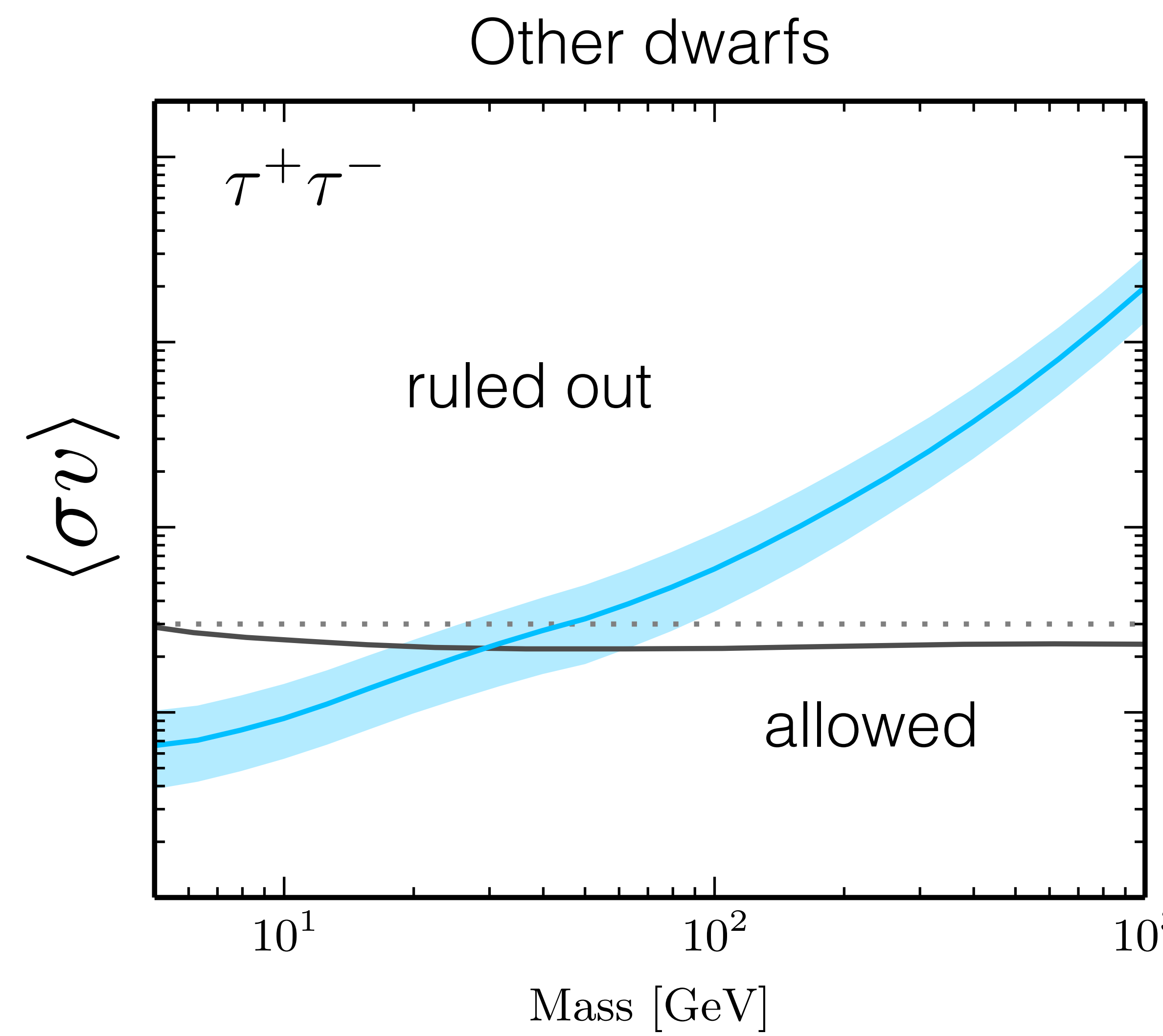
$\langle\sigma v\rangle$ = Strength of interaction (particle physics)

J = Dark matter content of RetII (astrophysics)

<*σv*> upper limits from other dwarfs gives a *prediction* for RetII's *J* value



AGS et. al. arXiv:1503.02320 (PRL)



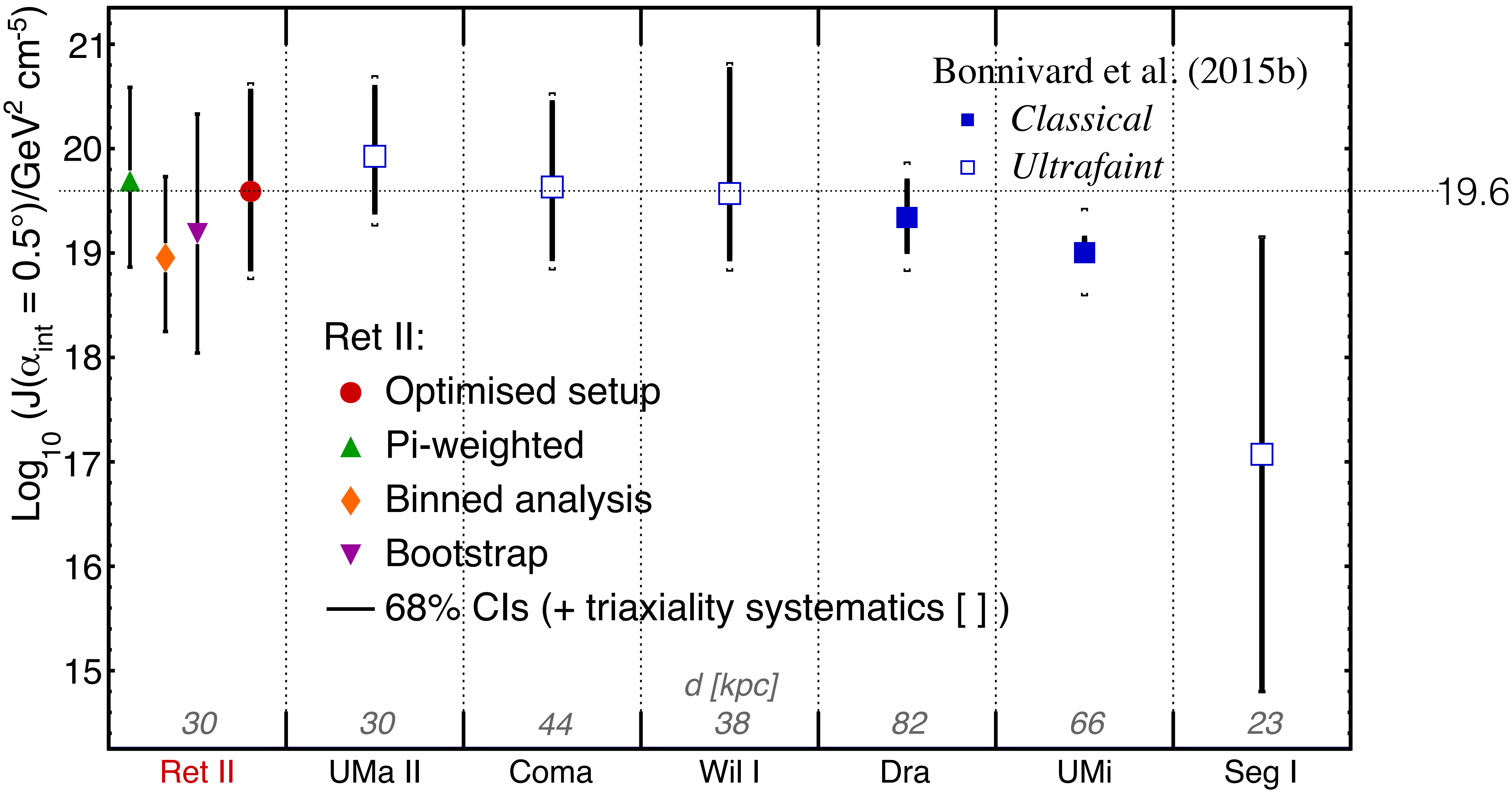
AGS, Koushiappas, Walker arXiv:1410.2242 (PRD)

$$\log_{10} J \gtrsim 19.6 \pm 0.3$$

Measured J values

Use line of sight velocities + Jeans equation to infer dark matter density profile

Bonnivard et. al. arXiv:1504.03309 (ApJL)



see also Simon et. al. arXiv:1504.02889 (ApJ)

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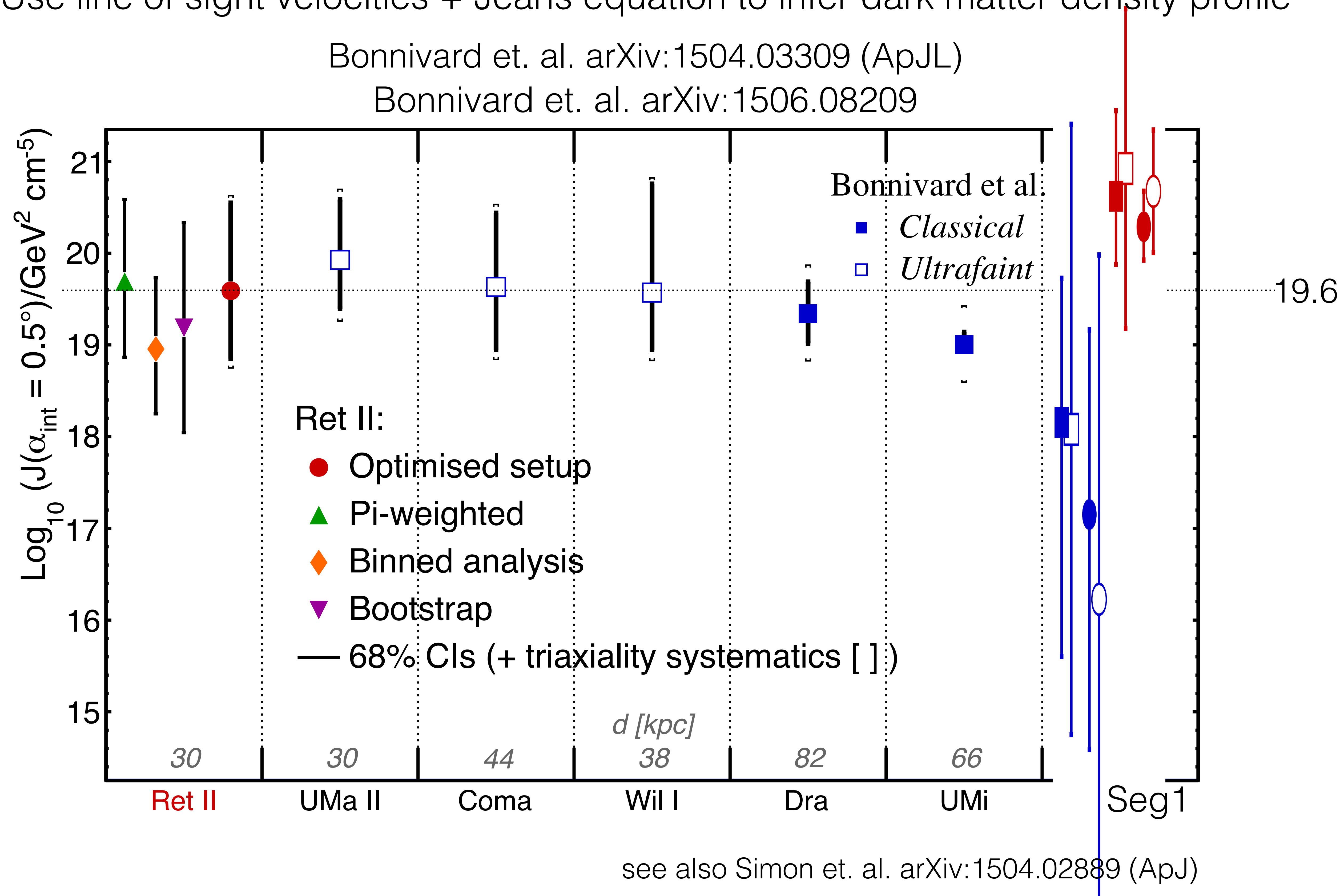
Bonnivard et. al. arXiv:1506.08209



see also Simon et. al. arXiv:1504.02889 (ApJ)

Path forward…

1. Gamma-ray data is inconsistent with background ✓

2. Consistent with dark matter annihilation

3. Inconsistent with any other possible source

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    Dark matter halo of RetII ✓ also Simon+ (DES) 1504.02889

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    Other indirect, direct, and collider searches

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   Population of sources inside RetII (pulsars?) ✓

   Distant source coincidentally in same direction **??** — related to (1)

   Instrument/data, Pass 8 **??** Drlica-Wagner+ (Fermi,DES) 1503.02632 (ApJL)
   Hooper & Linden 1503.06209