Gamma-ray signals from WIMP dark matter in Milky Way dwarf galaxies

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Barolo Astroparticle Meeting

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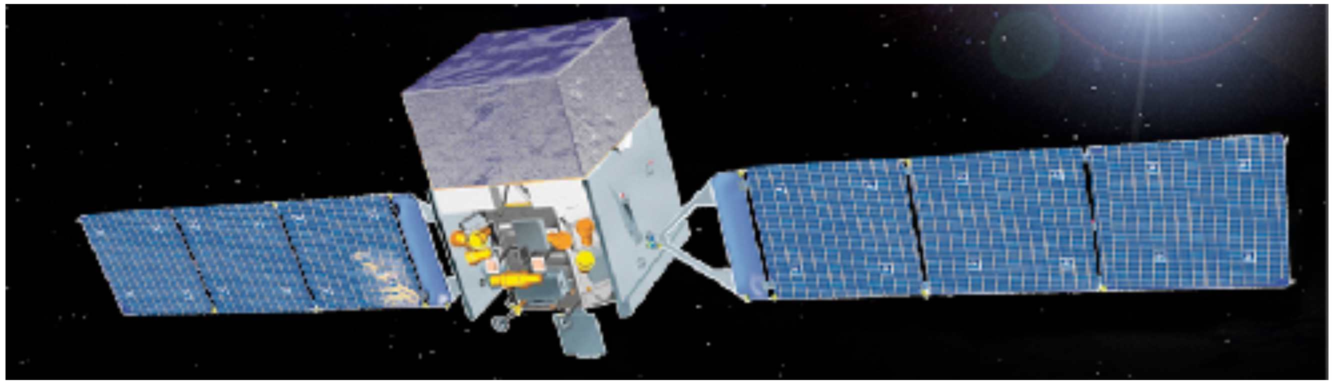
Dark matter

Particle interactions with Standard Model

GeV scale

Gamma-rays — Fermi satellite



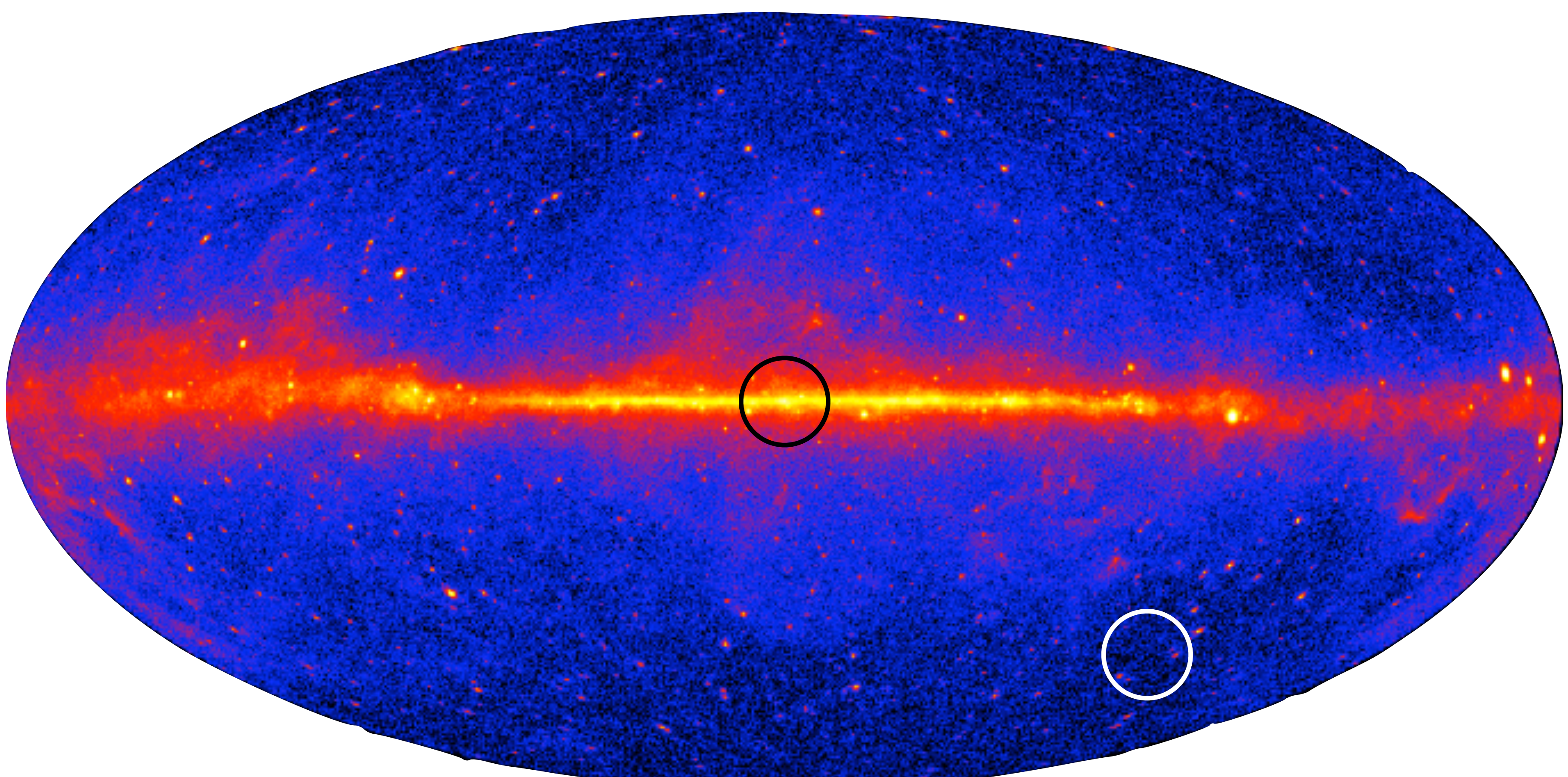
Milky Way dwarf galaxies

Nearby

Lots of dark matter

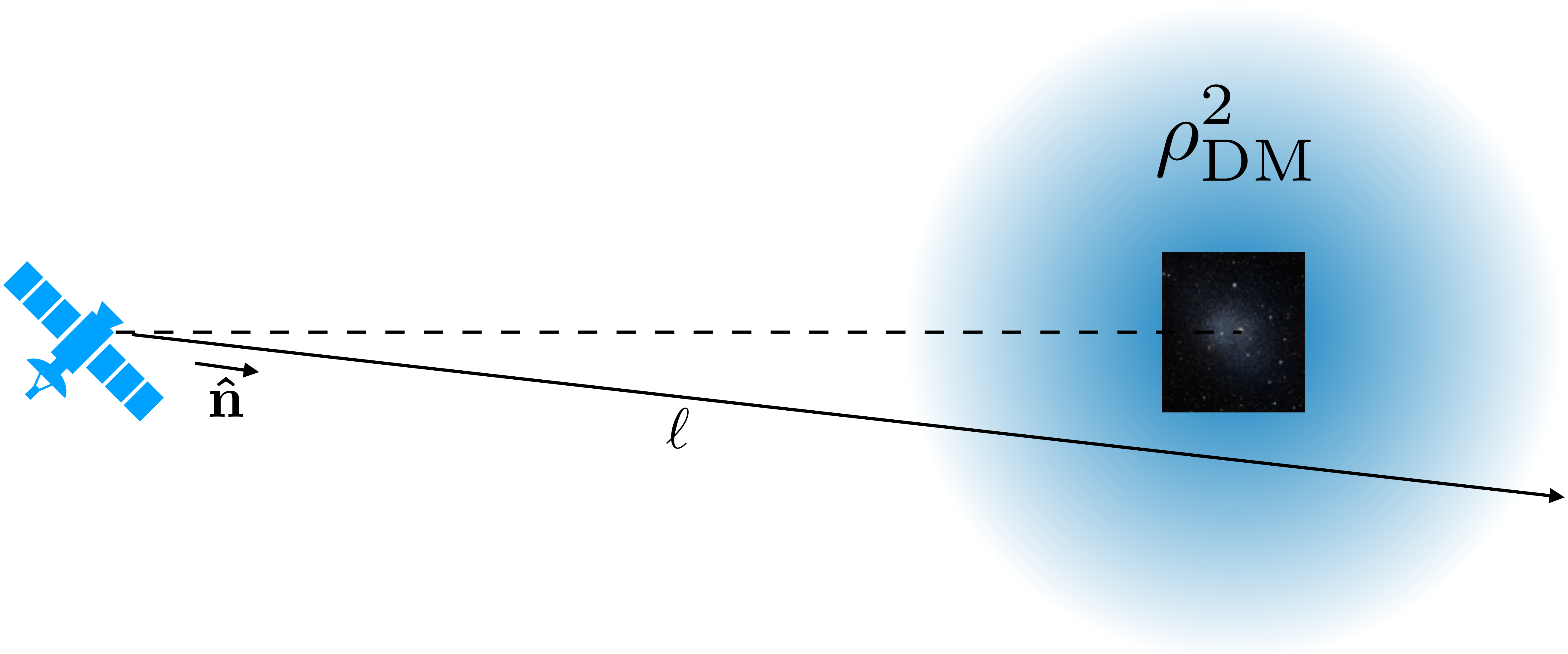
Not much else: no astrophysical background*

(compare with galactic center)



"gamma-ray flux = particle physics x astrophysics"

$$\frac{dJ(\hat{\mathbf{n}})}{d\Omega} = \int d\ell \, \left[\rho_{\mathrm{DM}}(\ell\hat{\mathbf{n}})\right]^2$$

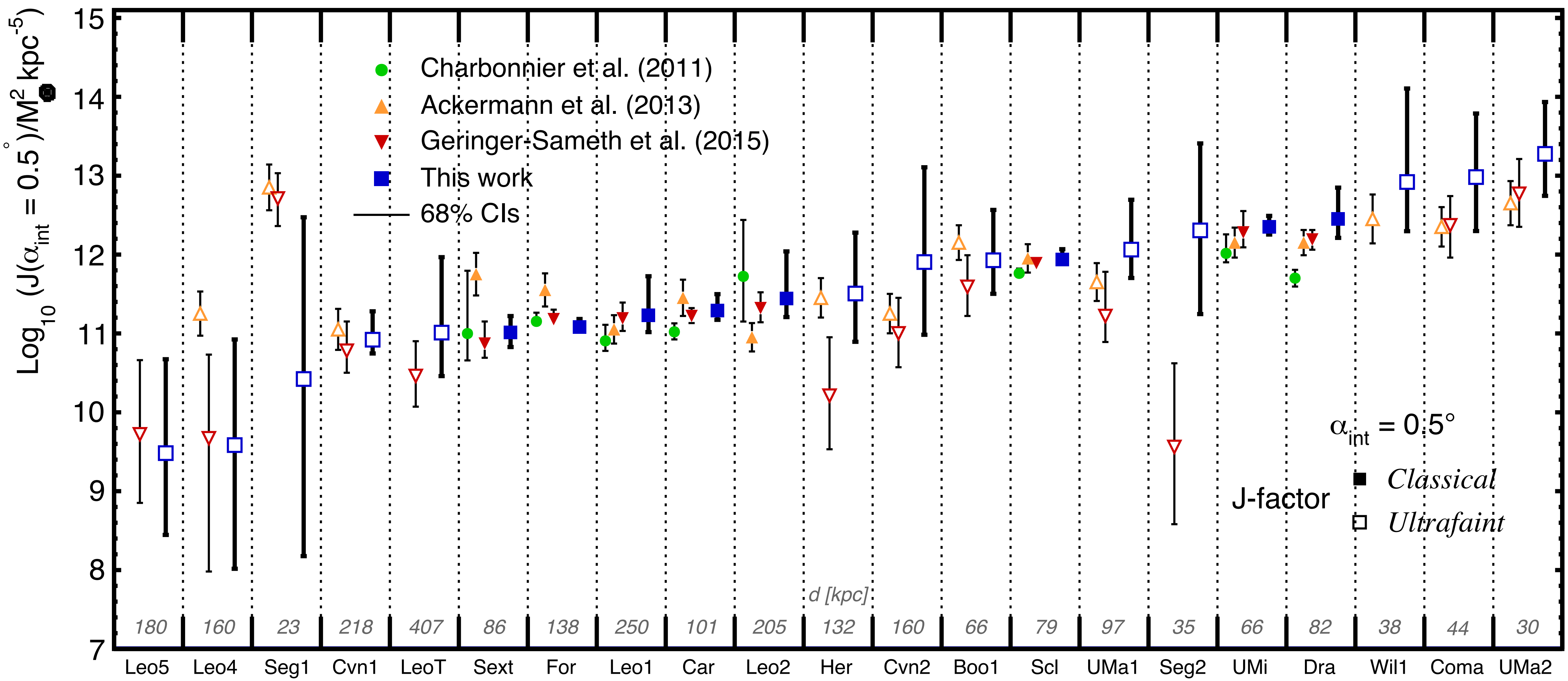


Jeans equation: gravitational potential → stellar kinematics

spectroscopic line of sight velocities → velocity dispersion profile

Bayesian exploration of possible dark matter density profiles

Velocity anisotropy, light profile, truncation, priors



Bonnivard+ 1504.02048 (MNRAS)

see also Charbonnier+ 1104.0412 (MNRAS), Martinez 1309.2641 (MNRAS), Geringer-Sameth+1408.0002 (ApJ), Hayashi+ 1603.08046 (MNRAS), Ullio & Valli 1603.07721 (JCAP), and others

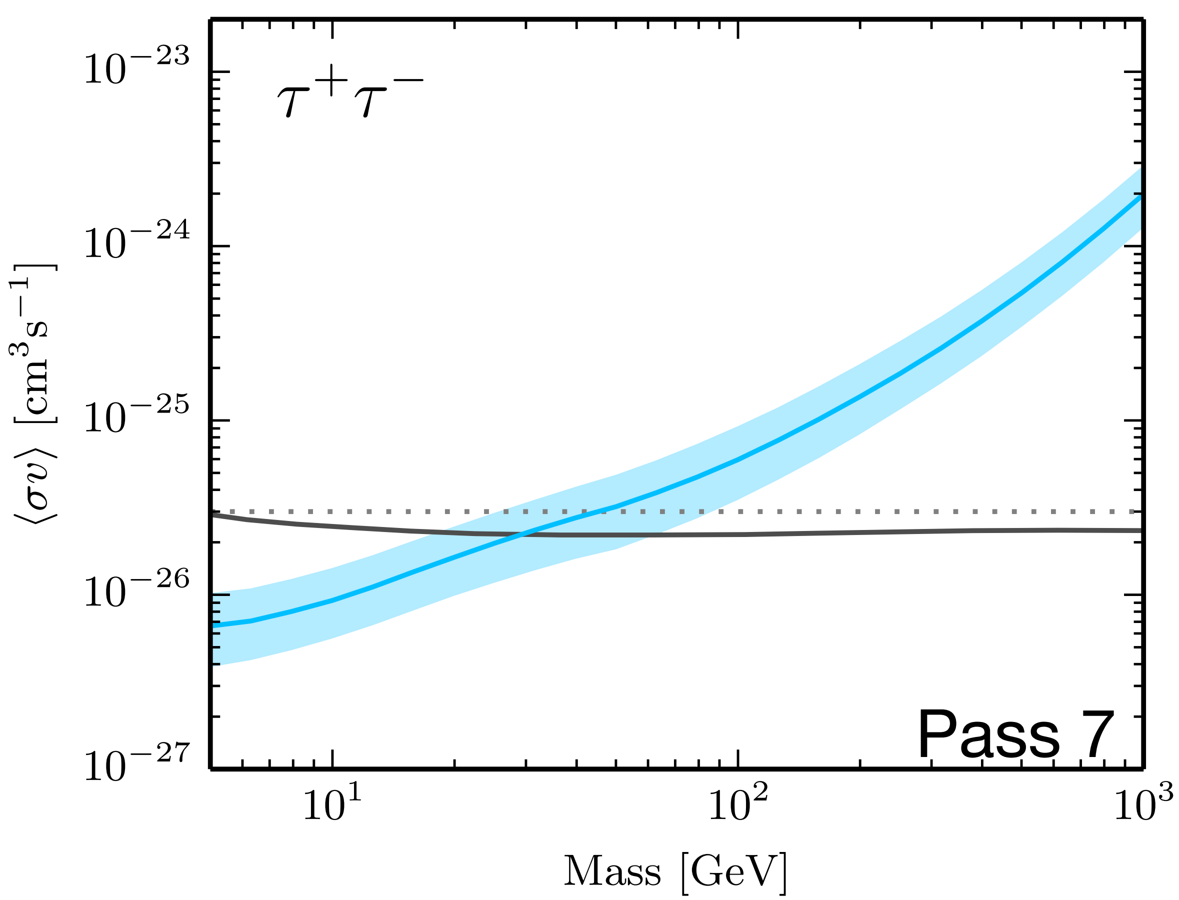
(BAM2017: Celine Combet and Mauro Valli)

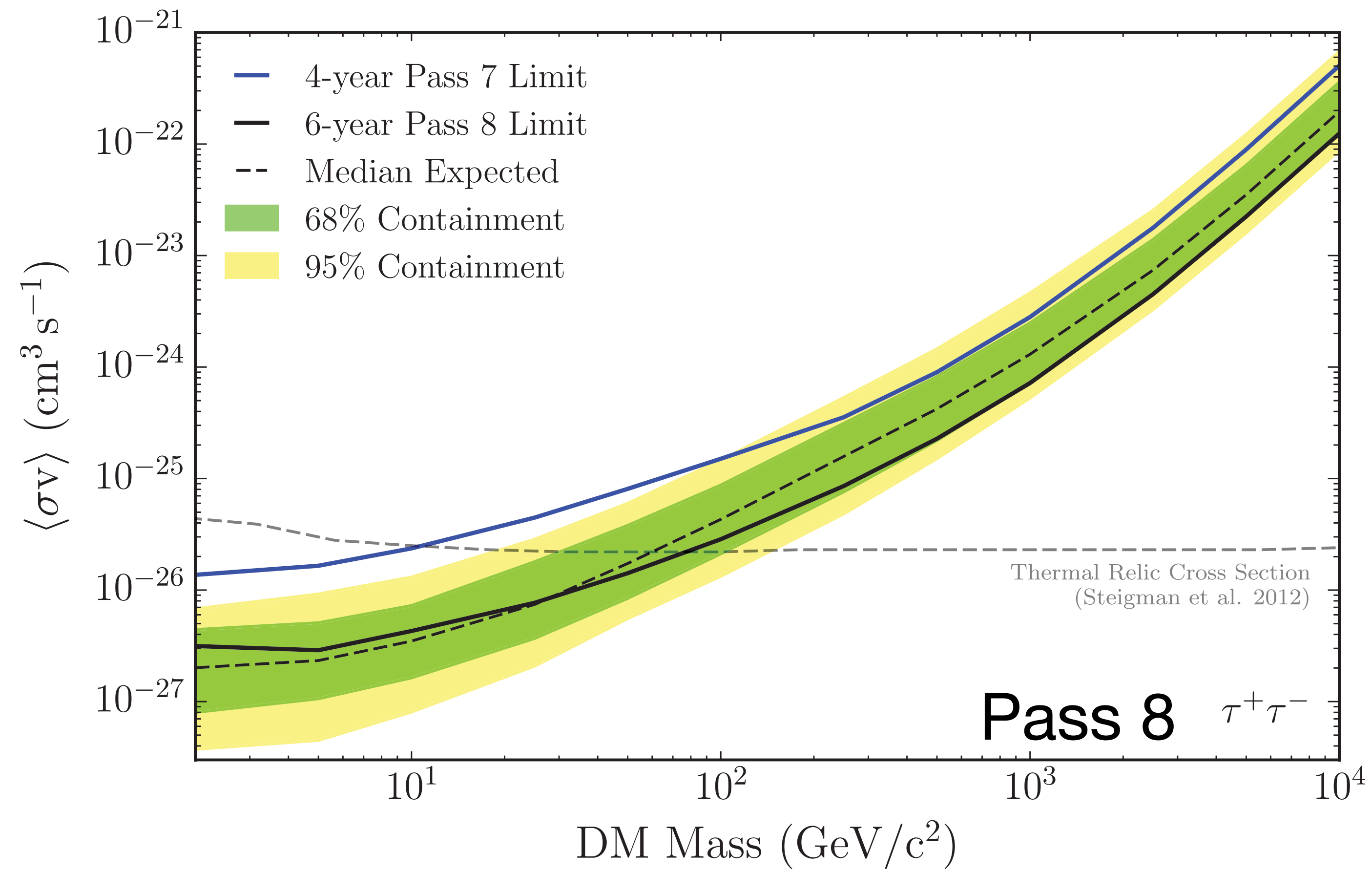
Joint analysis of multiple dwarfs ("stacking")

$$\text{flux} \propto \langle \sigma v \rangle J$$

Cross section upper limits

6 years of Fermi data





Geringer-Sameth, Koushiappas, Walker 1410.2242 (PRD)

J's from Geringer-Sameth+1408.0002 (ApJ)

Fermi collab 1503.02641 (PRL)

J's from Martinez 1309.2641 (MNRAS)

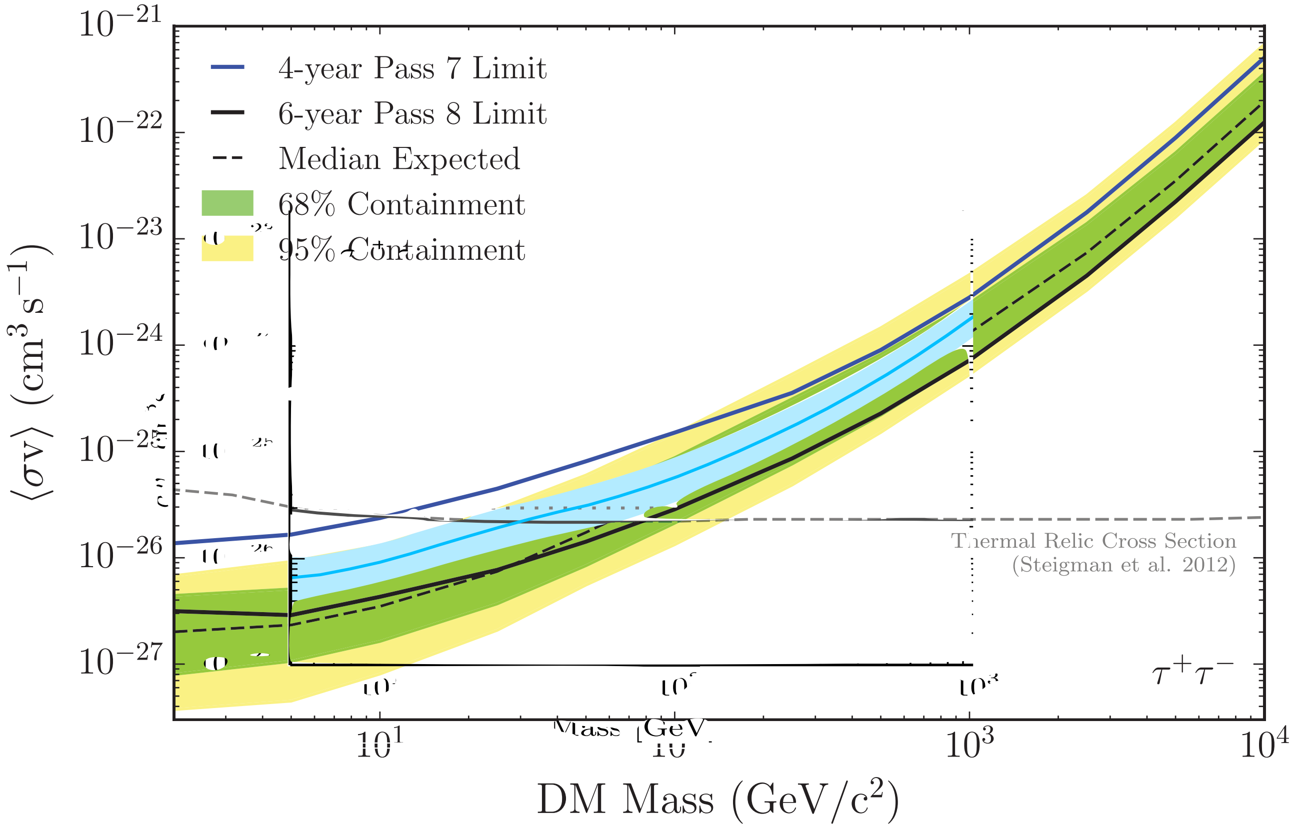
Joint analysis of multiple dwarfs ("stacking")

flux $\propto \langle \sigma v \rangle J$

Cross section upper limits

6 years of Fermi data

"Pass 7 vs Pass 8"

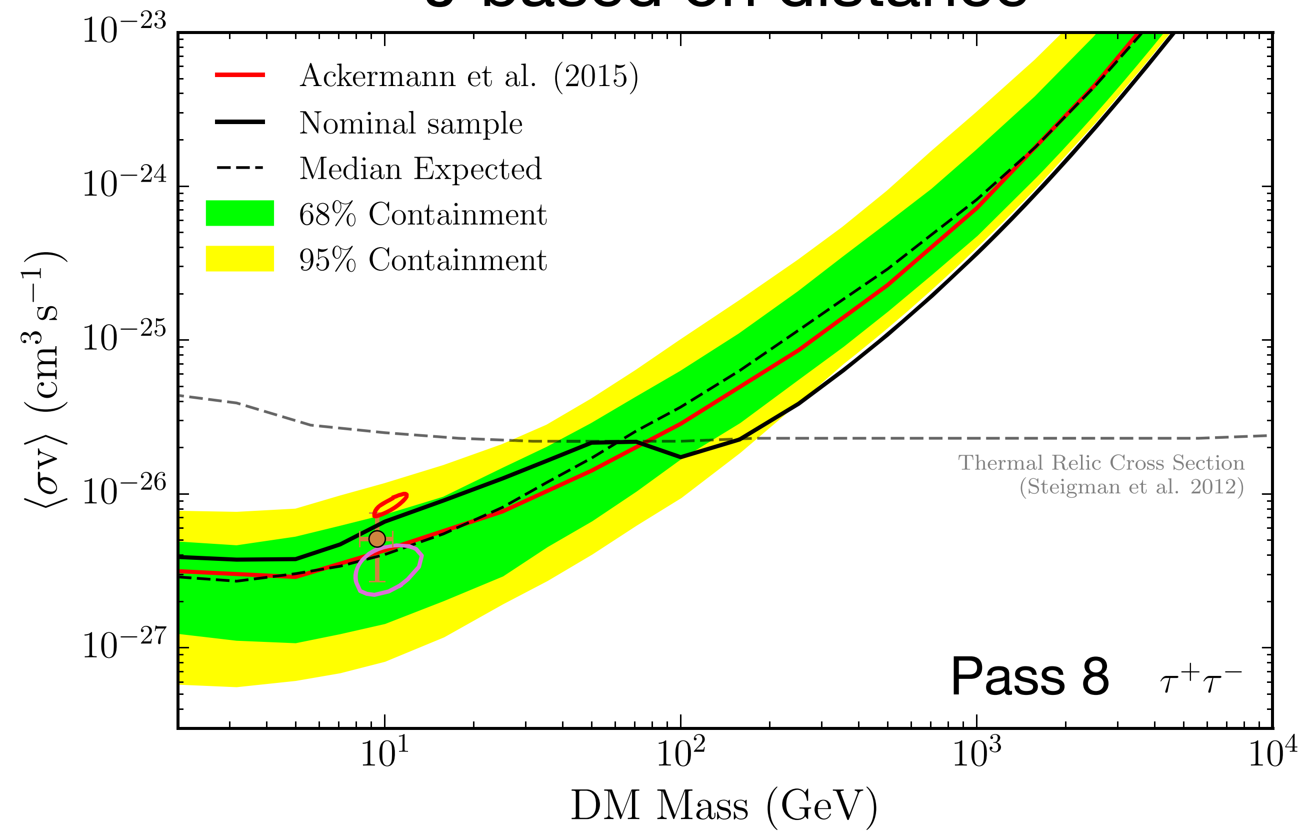


Fermi collab 1503.02641 (PRL)

Geringer-Sameth, Koushiappas, Walker 1410.2242 (PRD)

Including new ultrafaint discoveries

J based on distance

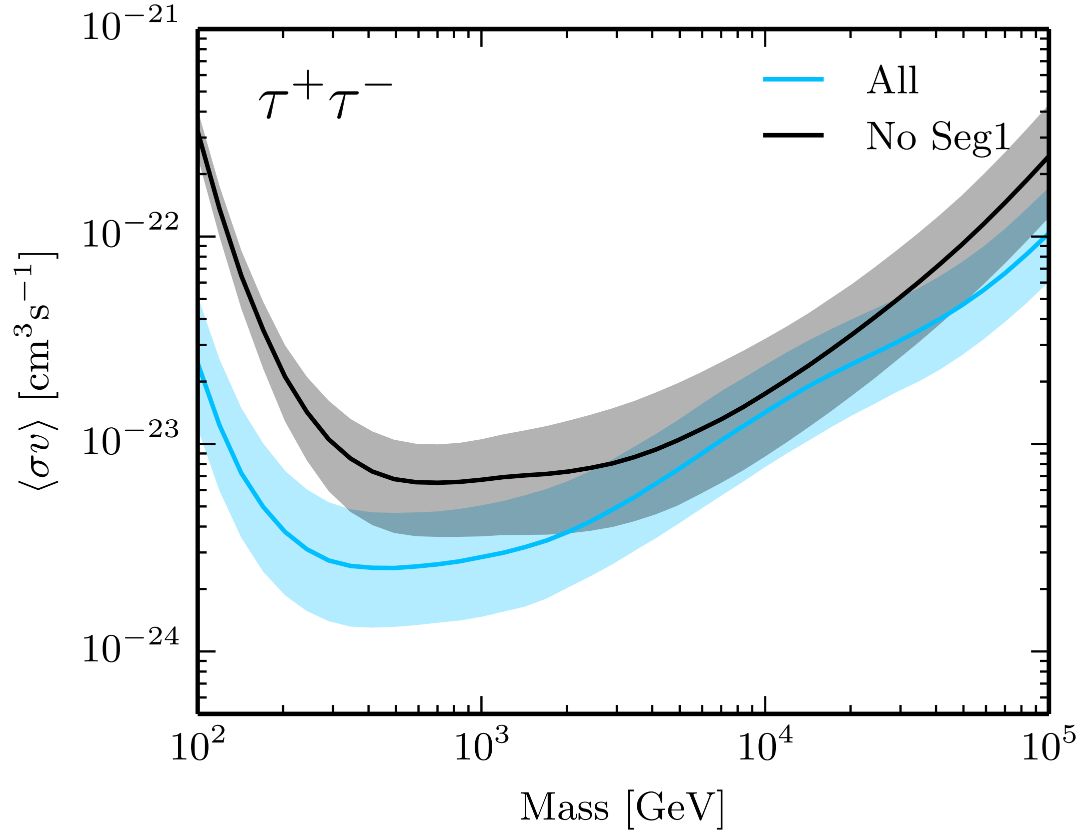


Fermi+DES 1611.03184 (ApJ)

At higher DM masses use atmospheric Cherenkov telescopes

(talk tomorrow by Michele Doro)

Draco, Bootes I, Ursa Minor, Segue 1, (Willman 1)



VERITAS collaboration 1703.04937 (PRD)

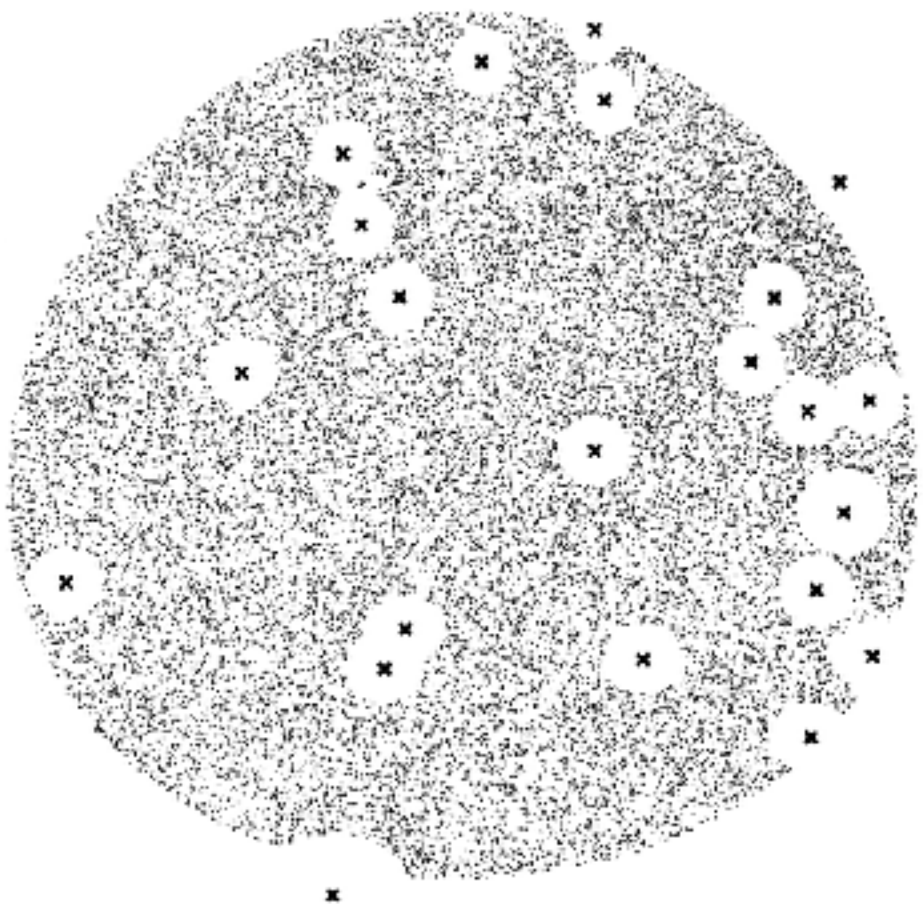
see also H.E.S.S. collab 1410.2589 (PRD),
MAGIC collab 1312.1535 (JCAP), Ahnen+ 1601.06590 (JCAP)

Reticulum II

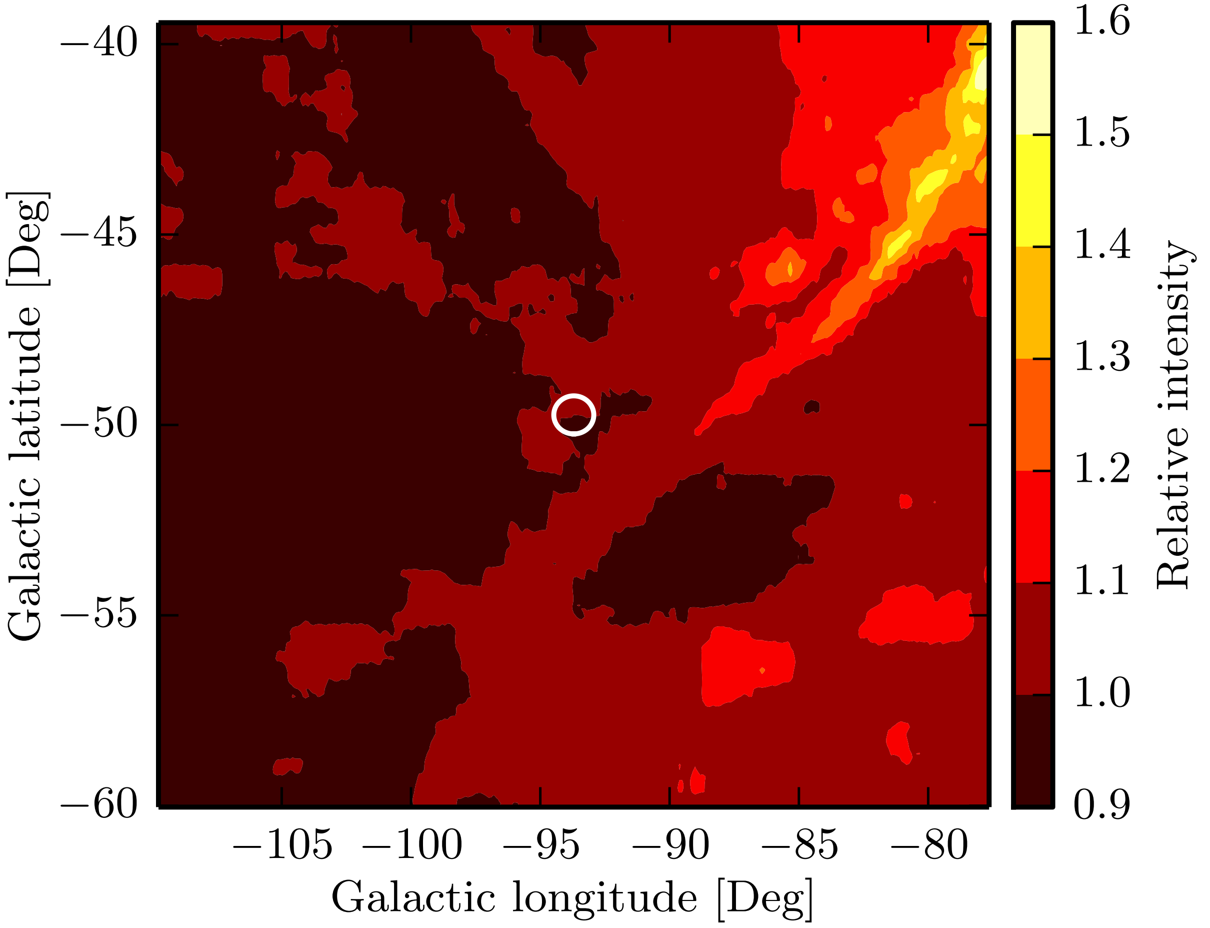
very close (30 kpc)

(Koposov+ 1503.02079 (ApJ), Bechtol+ 1503.02584 (ApJ))

Gamma-rays 1-300 GeV

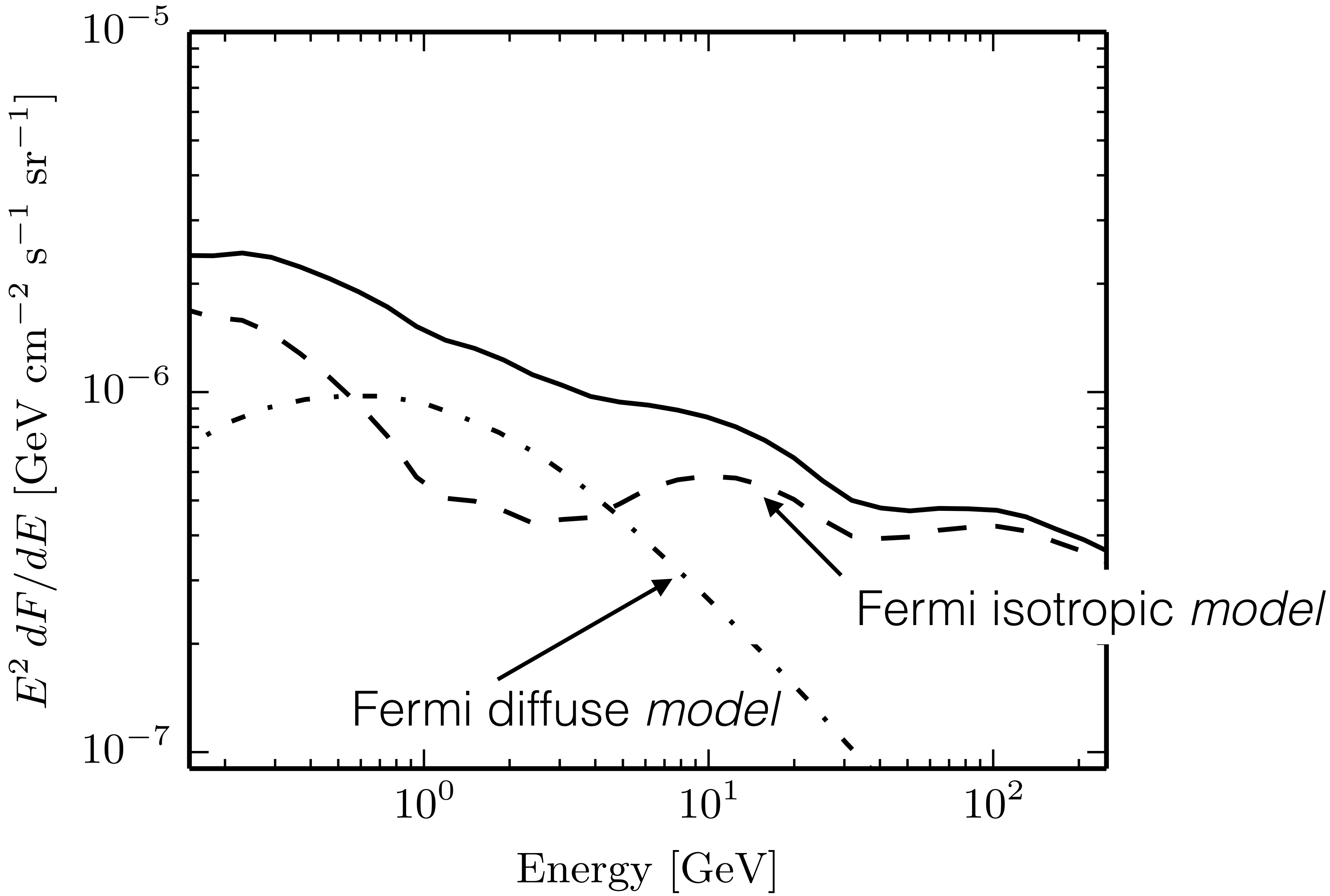


Gamma-ray background model at 8 GeV

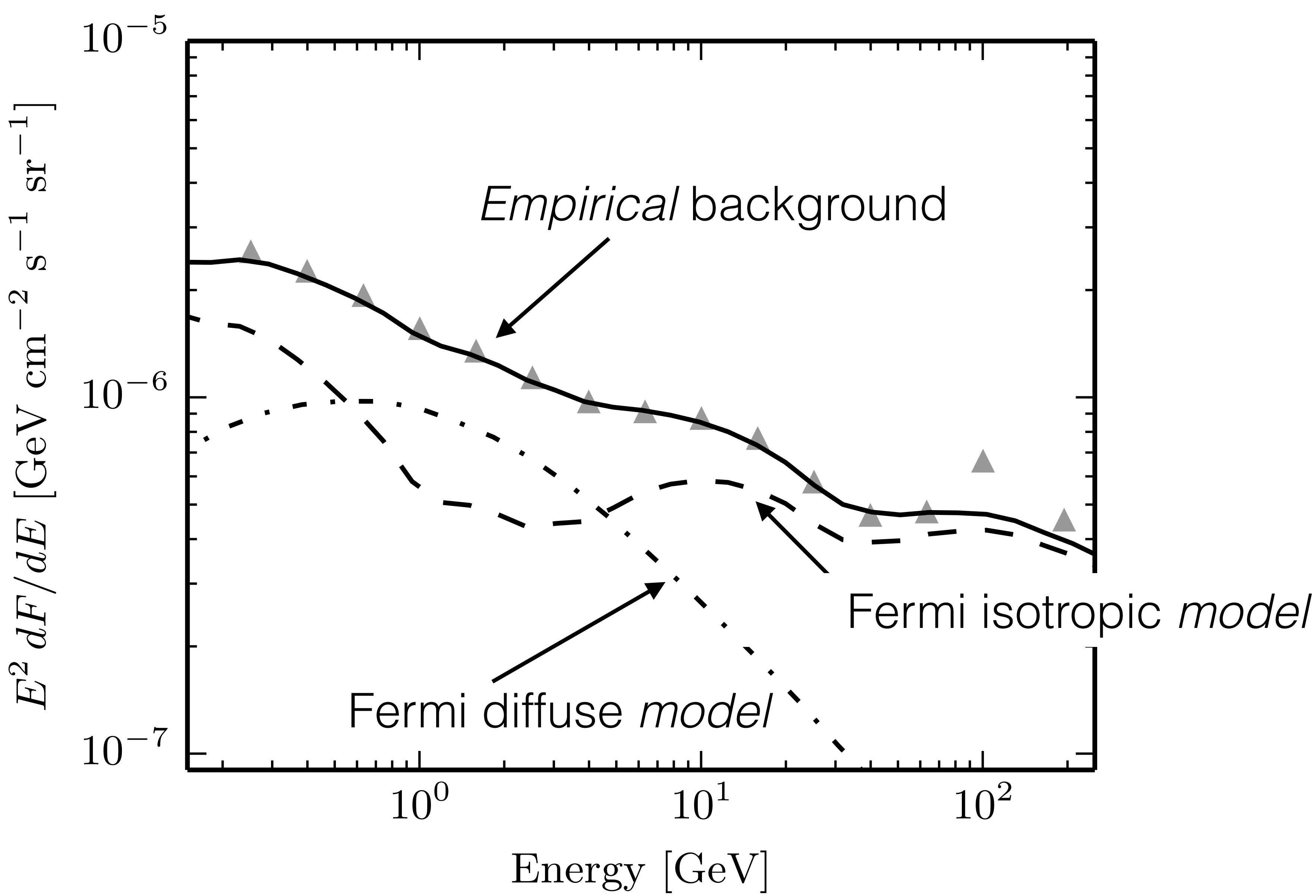


Far away from known sources

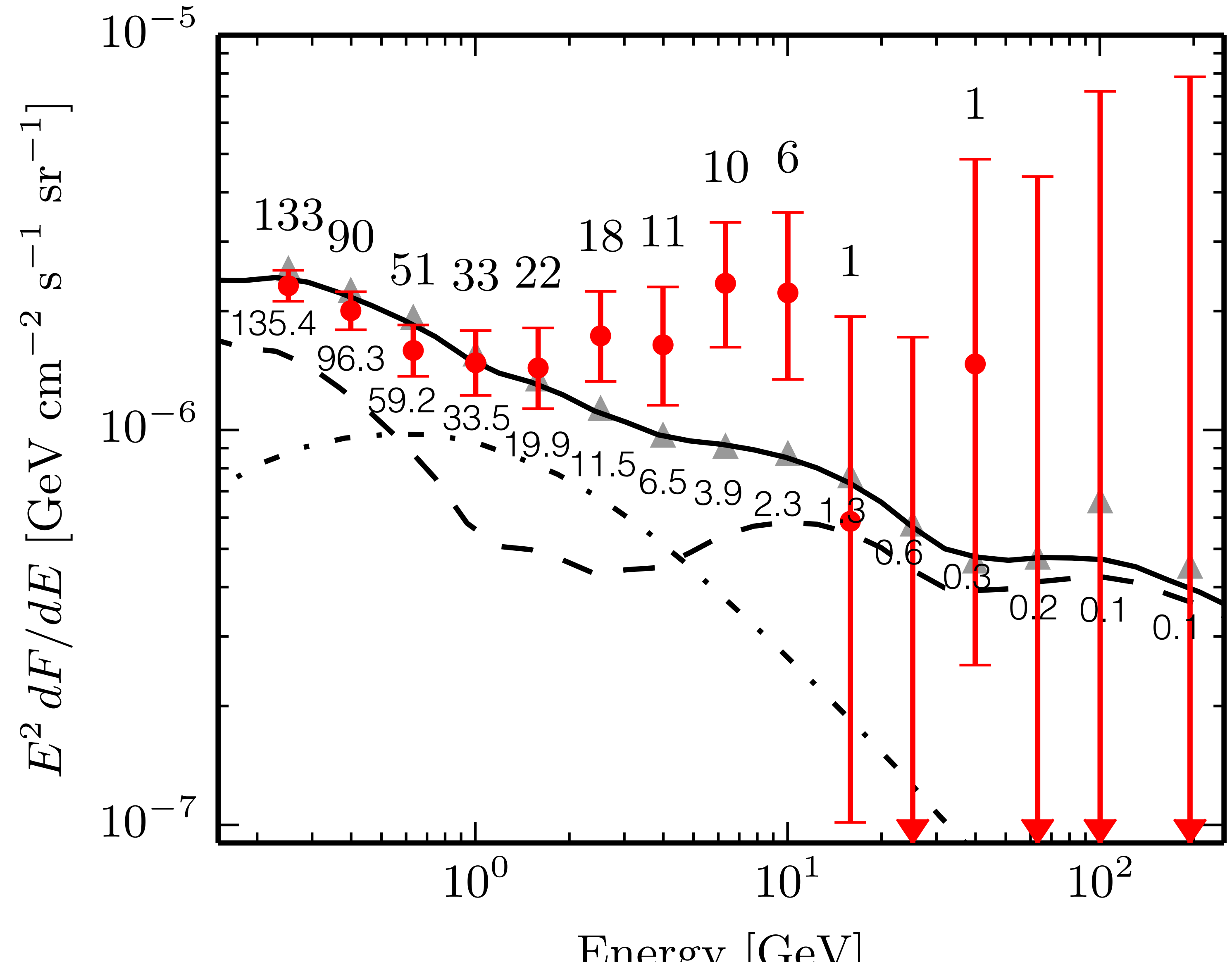
Uniform background



AGS et. al. arXiv:1503.02320 (PRL)



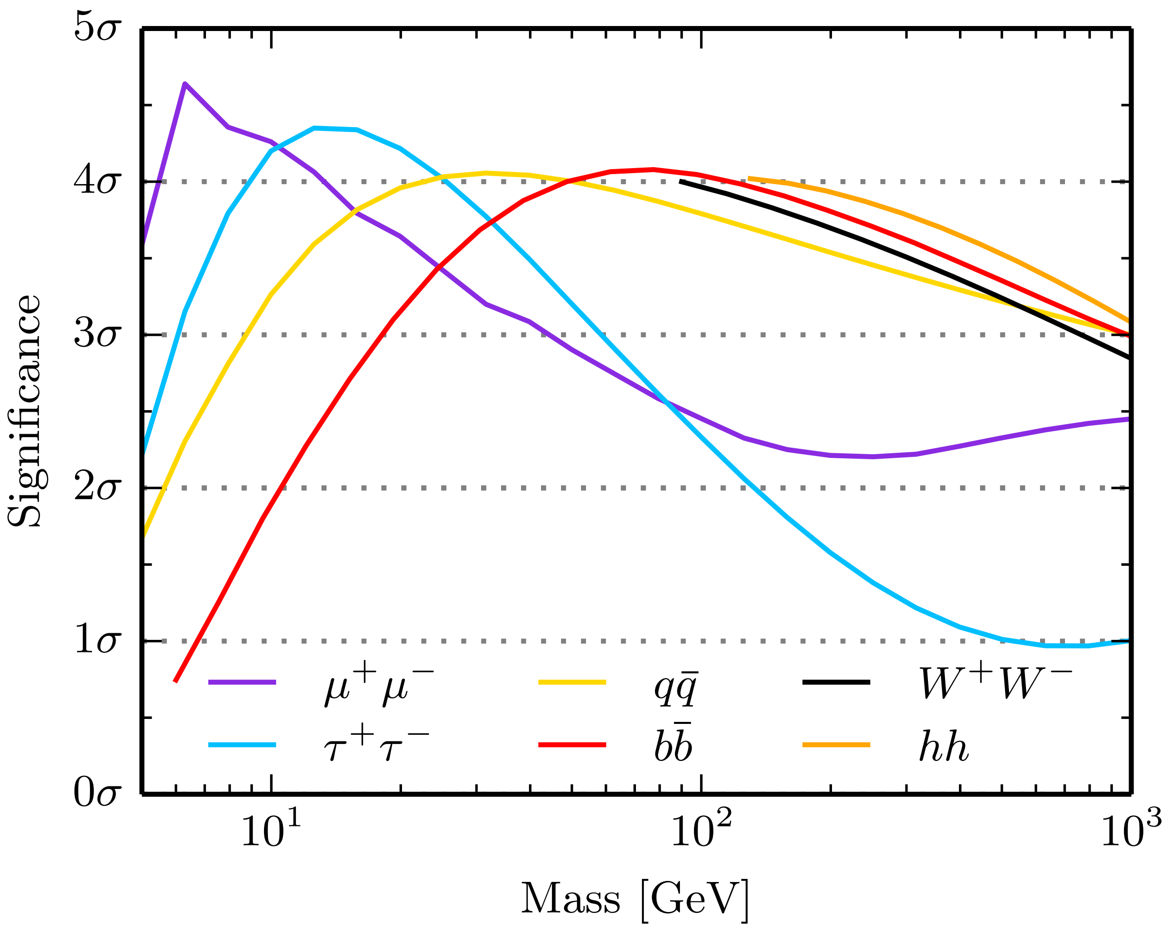
AGS et. al. arXiv:1503.02320 (PRL)

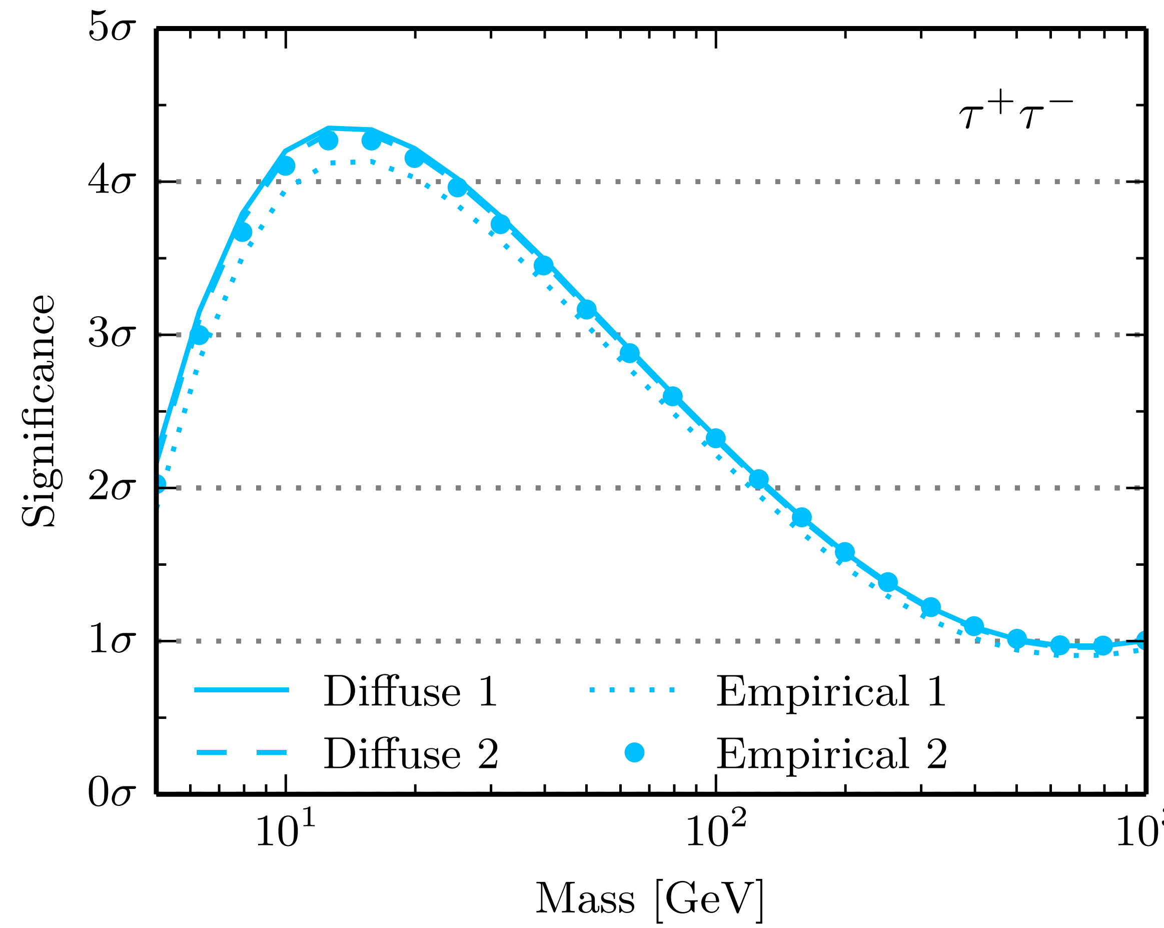


Events within 0.5° of RetII

AGS et. al. arXiv:1503.02320 (PRL)

Results





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

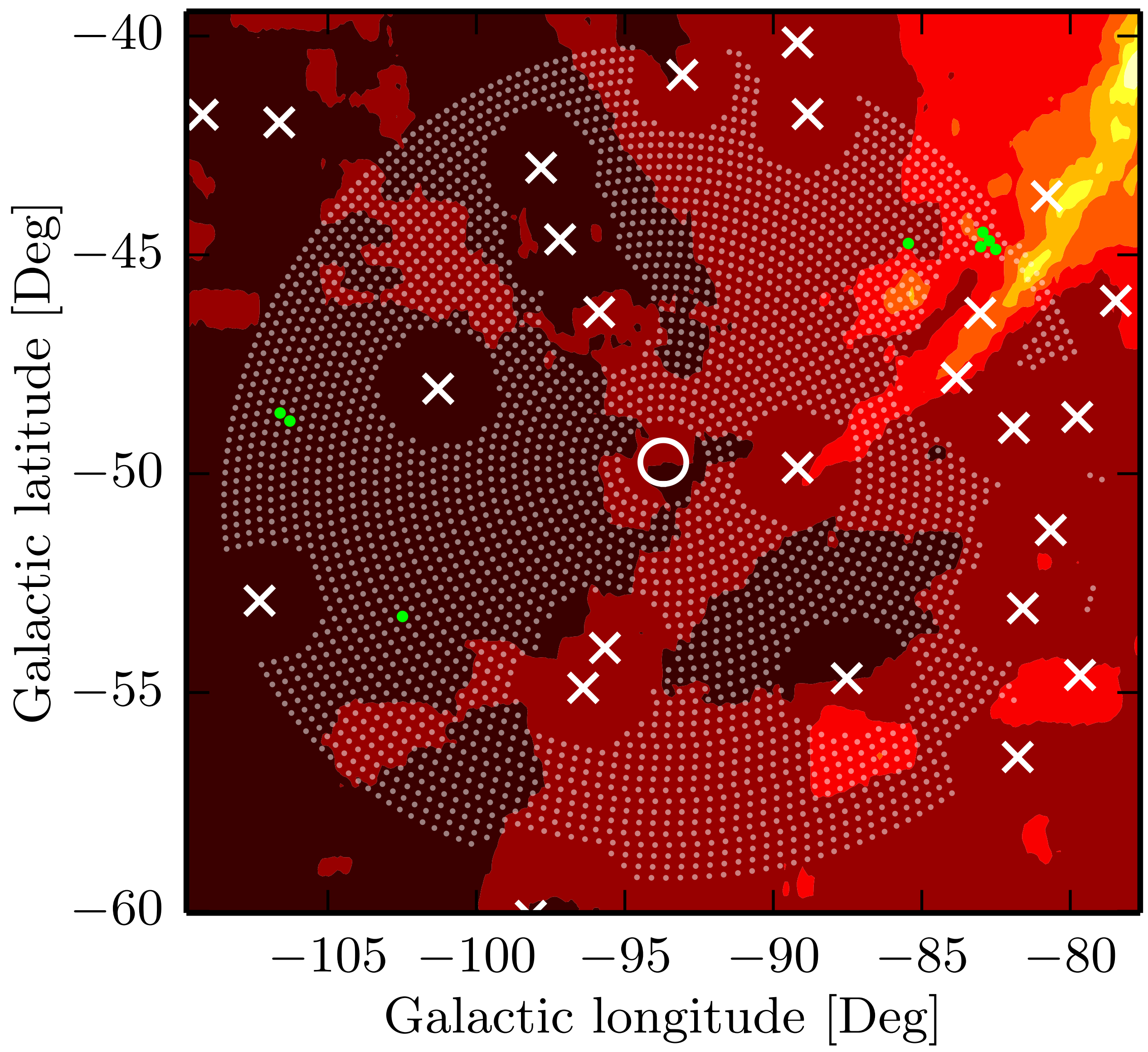
Robust to different background spectra

Searching over dark matter masses = multiple hypothesis tests

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

Empirical background sampling

Results



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

Dark matter?

1. Gamma-ray data is inconsistent with background

    see also Drlica-Wagner+ (Fermi,DES) 1503.02632 (ApJL) — (Pass 8 analysis)
    Hooper & Linden 1503.06209 (Pass 7)

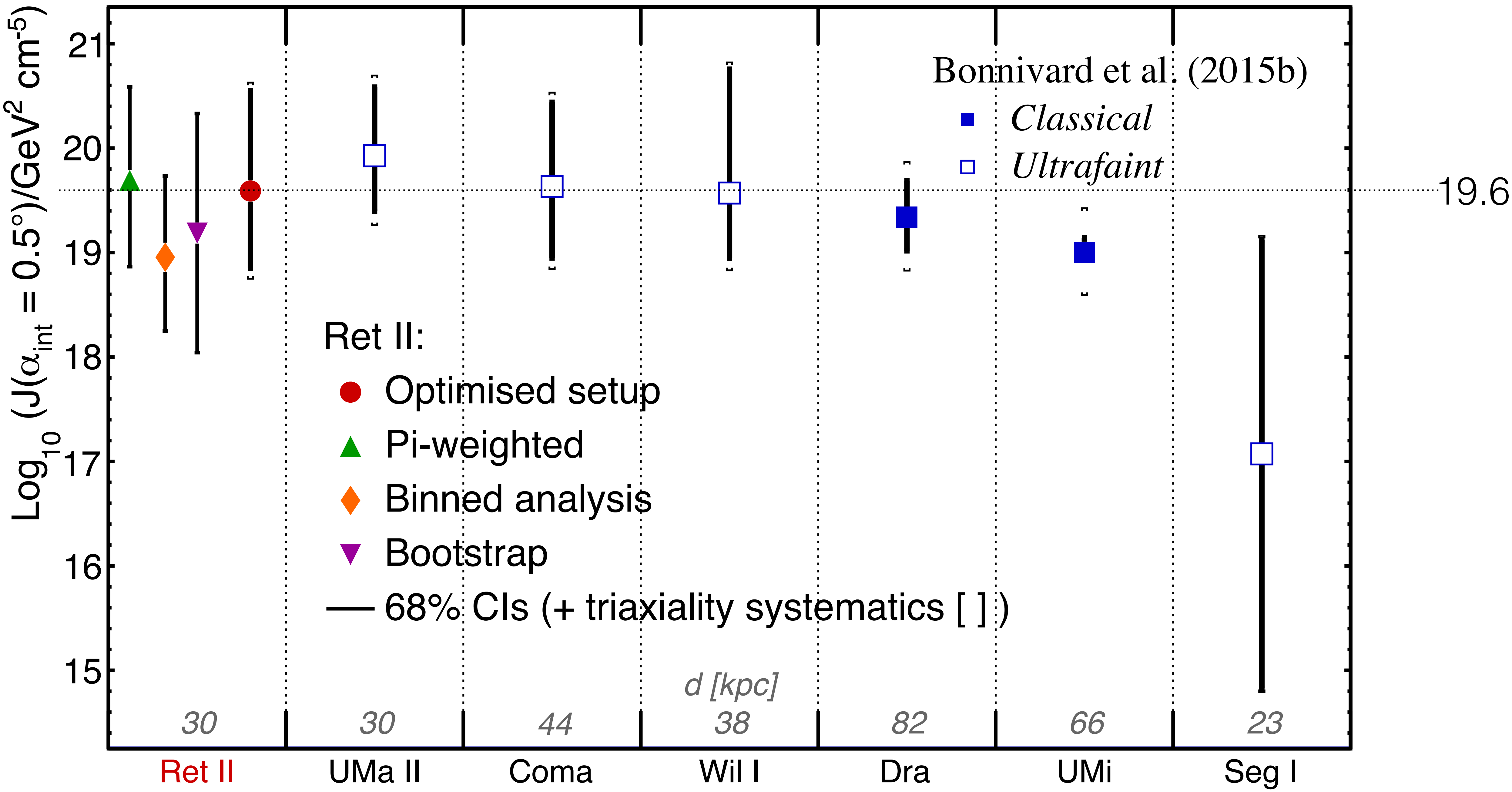
2. Consistent with dark matter annihilation

3. Inconsistent with any other possible source

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)

Measured J values

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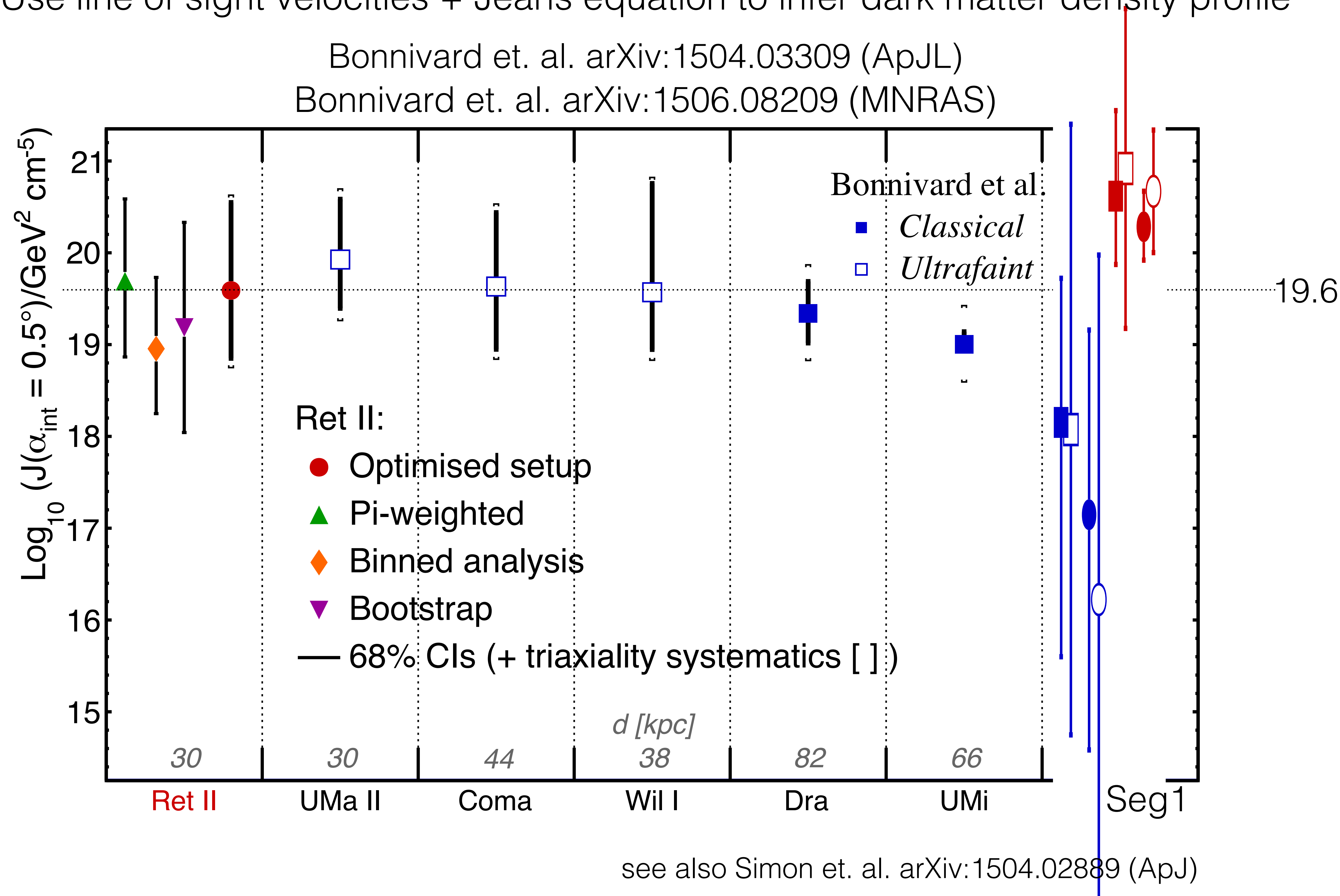
Bonnivard et. al. arXiv:1504.03309 (ApJL)
Bonnivard et. al. arXiv:1506.08209 (MNRAS)



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

Other large J contenders

Reticulum II	30 kpc	$\sigma = 3.6\,\mathrm{km/s}$ Walker et. al. 1504.03060 (ApJ) $\sigma = 3.2\,\mathrm{km/s}$ Koposov et. al. 1504.07916 (ApJ)
Tucana III	25 kpc	$\sigma < 1.5\,\mathrm{km/s}$ Simon et. al. 1610.05301 (ApJ)
Triangulum II	30 kpc	$\sigma = 5.1\,\mathrm{km/s}$ Kirby et. al. 1510.03856 (ApJ) revised to $\sigma < 3.4\,\mathrm{km/s}$ Kirby et. al. 1703.02978 (ApJ) star cluster or tidally stripped dwarf
Cetus II	30 kpc	no follow-up yet (too small, extremely low luminosity)

Segue 1	23 kpc	MW contamination -> giant error bar on J
Ursa Major II	32 kpc	tidal disturbance? e.g. Munoz et. al. 0910.3946 (AJ)
Coma Berenices	44 kpc	
Willman 1	38 kpc	irregular kinematics
Draco and Ursa Minor	76 kpc	classical dwarfs — good handle on J

Effect of contamination on J not studied except for Ret2 and Seg1

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   J values *must* work out

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(next talks by Sergio Colafreancesco and Marco Regis)

Diffuse background model

$p = 0.01\%$

Empirical background

$p = 1\%$

Why?

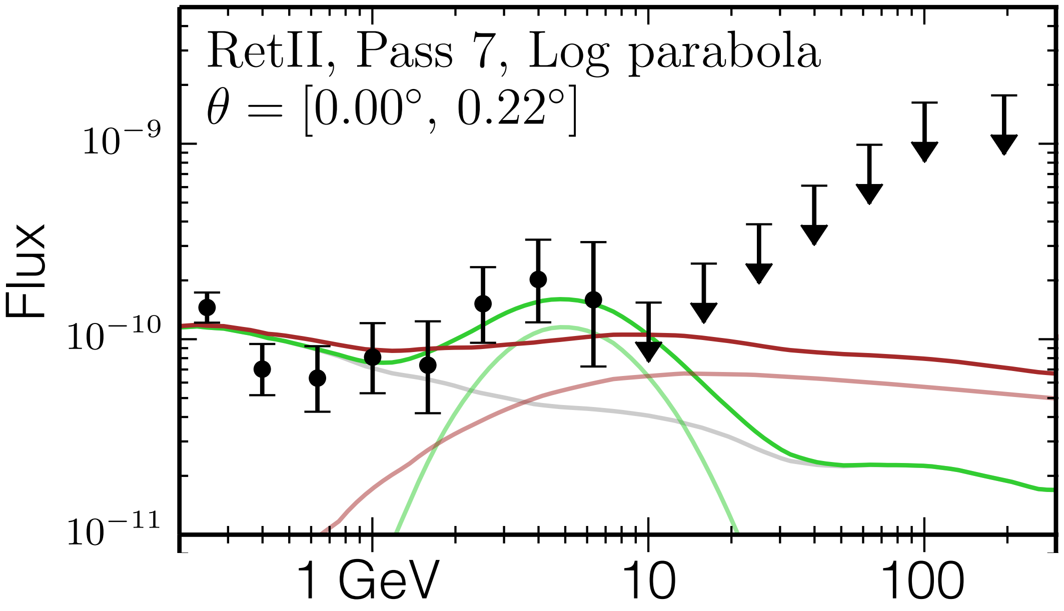
- Fit spectrum with a flexible function
- Compare with known gamma-ray emitters

(2523 Fermi catalog sources)

$$\frac{dF(E)}{dE} = F_0 \left(\frac{E}{E_0}\right)^{-\alpha-\beta\log(E/E_0)}$$

α = slope at E_0

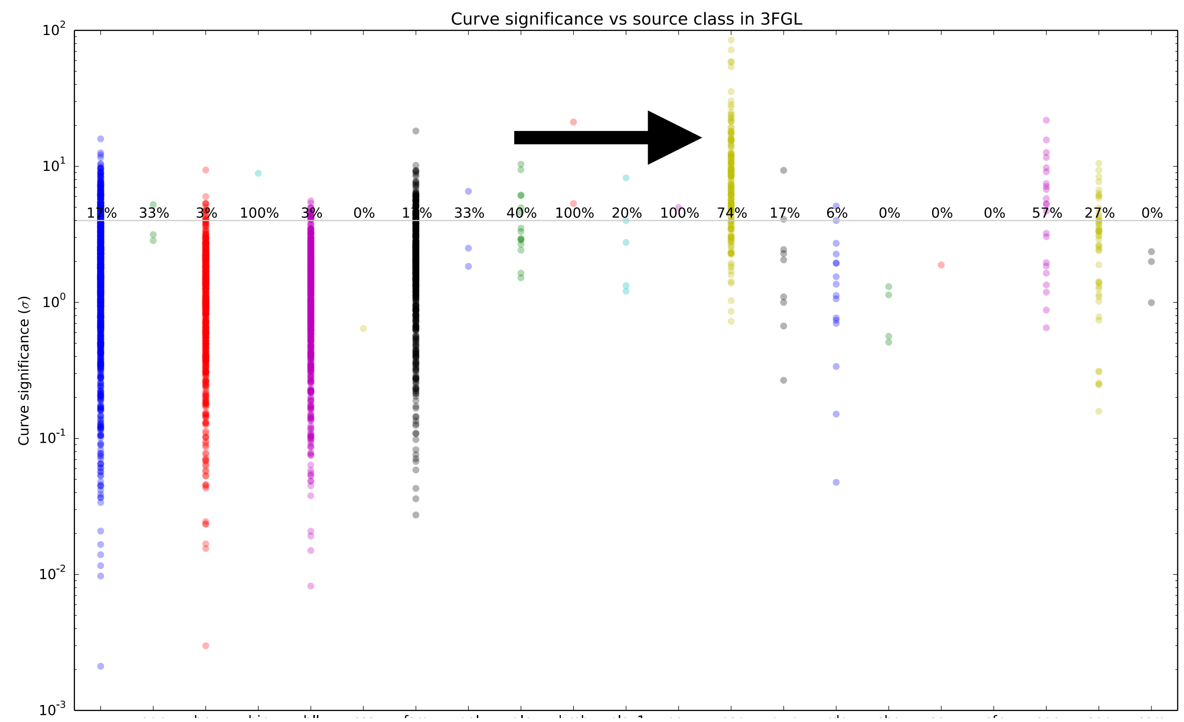
β = curvature



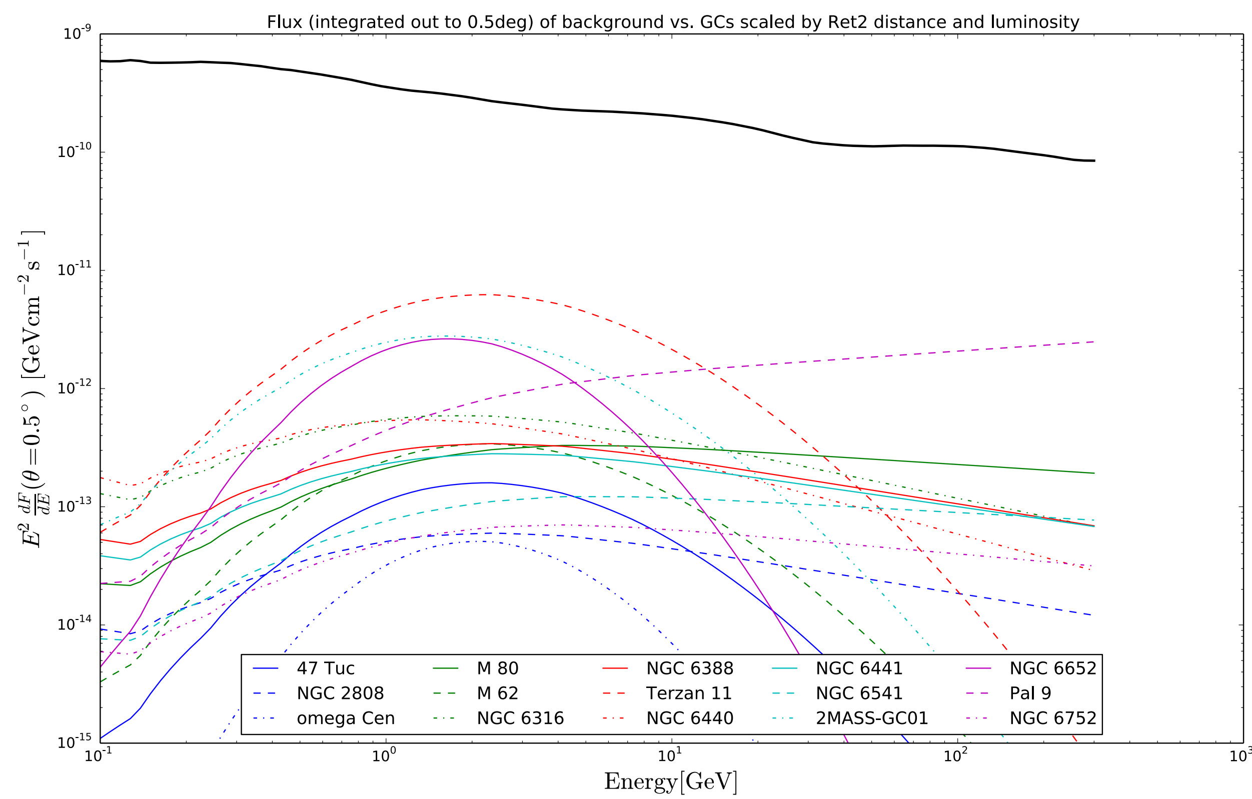
AGS et. al. in prep

Sources *within* RetII? (talk yesterday by Eline Tolstoy)

Pulsars have curved spectra



Globular clusters as analogs



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   Understand all objects along line of sight