Dynamical Models of Dwarf Galaxies and Dark Matter Particle Searches

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Exploring the Dark Universe — Quy Nhon, July 25, 2017

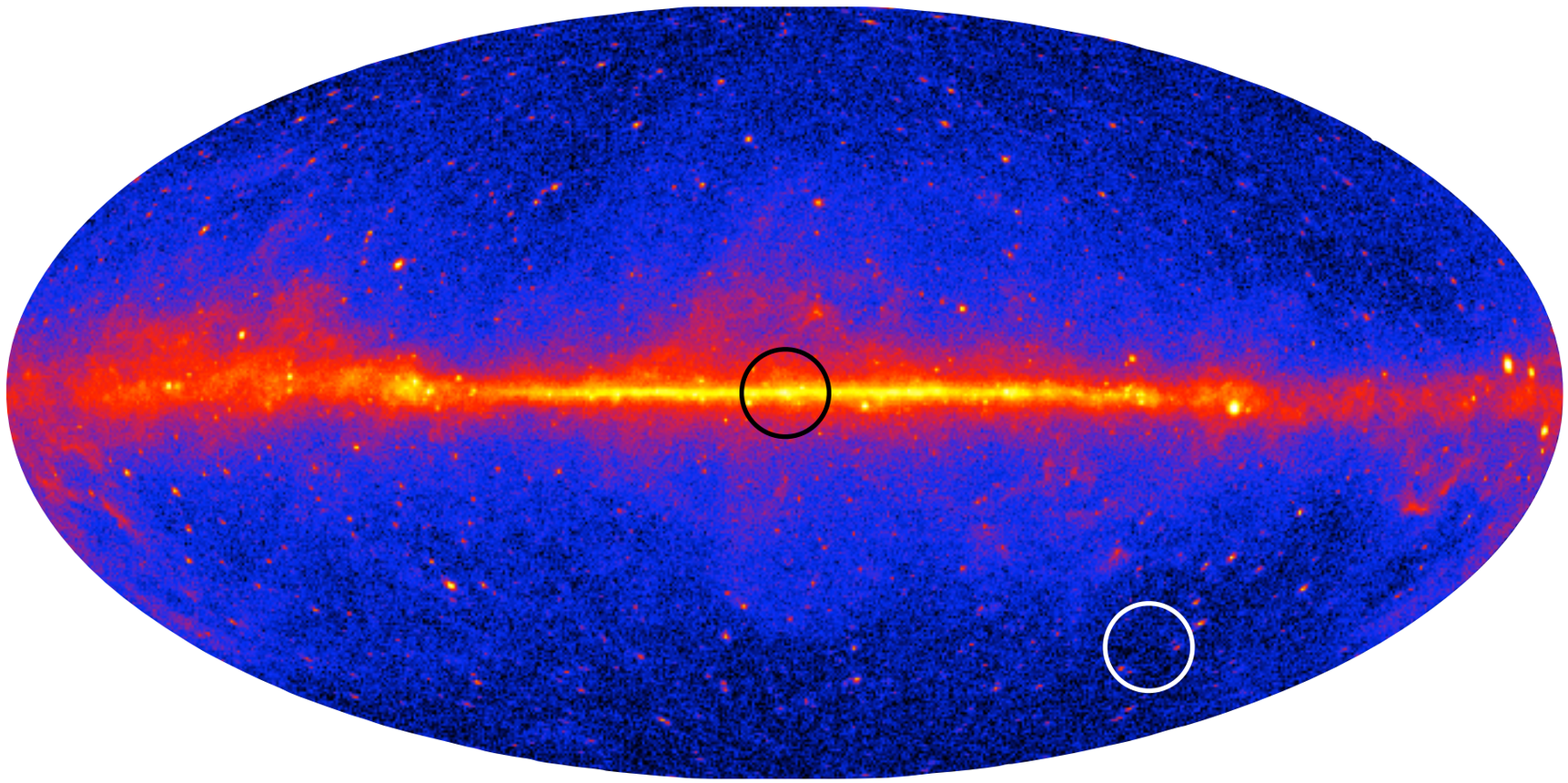
Milky Way dwarf galaxies

Nearby

Lots of dark matter

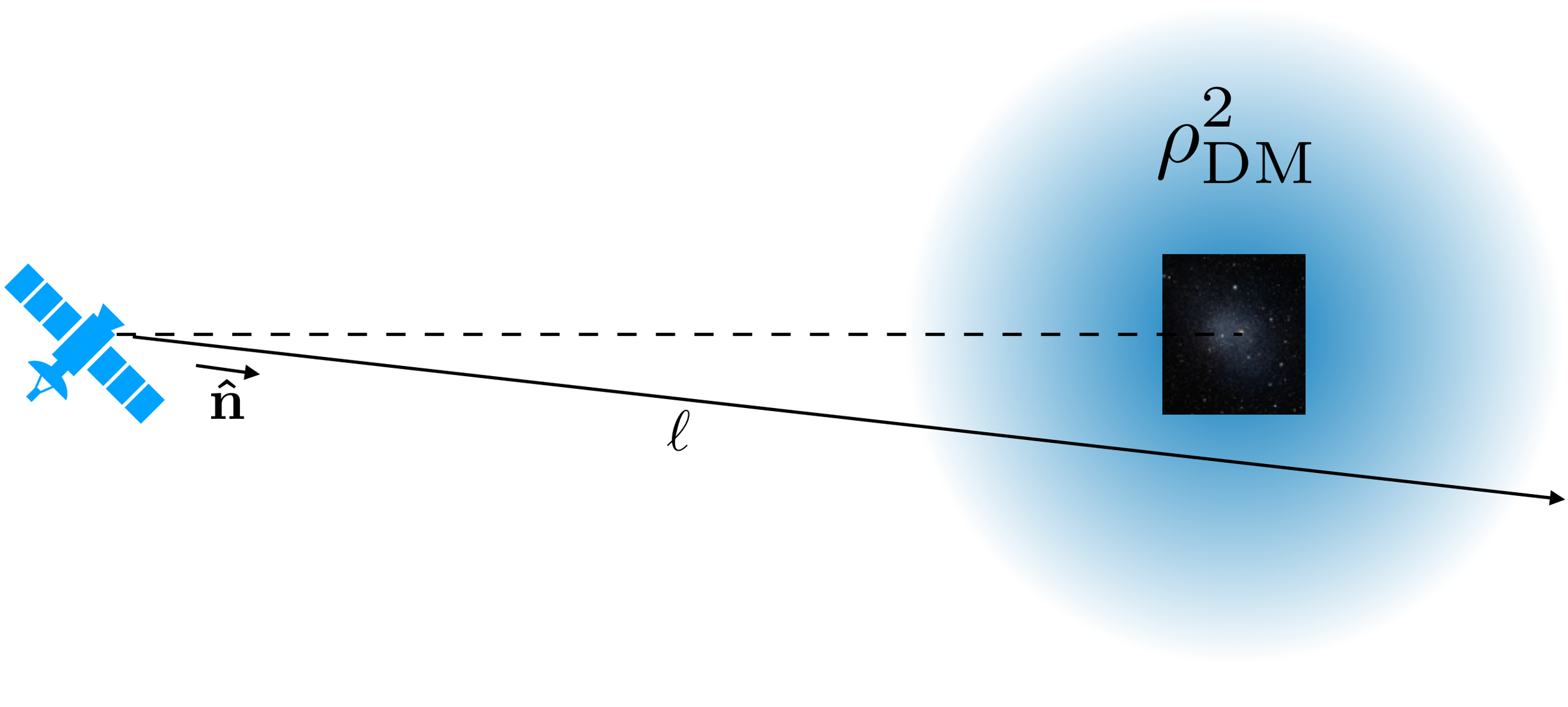
Not much else: no astrophysical background*

(compare with Galactic center)



"gamma-ray flux = particle physics x astrophysics"

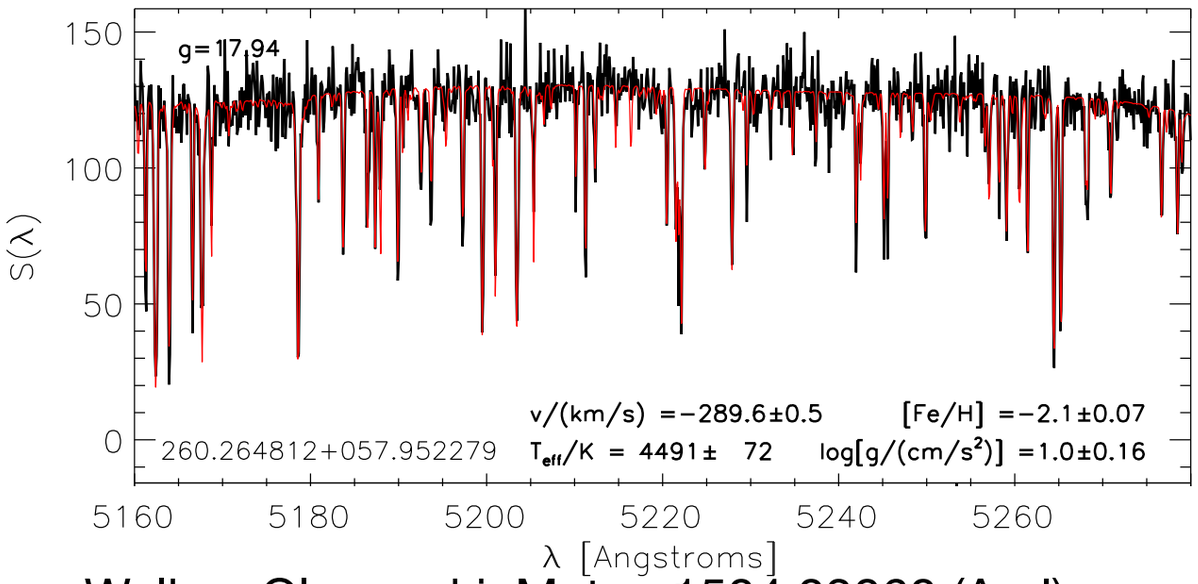
$$\frac{dJ(\hat{\mathbf{n}})}{d\Omega} = \int d\ell \; [\rho_{\rm DM}(\ell\hat{\mathbf{n}})]^2$$



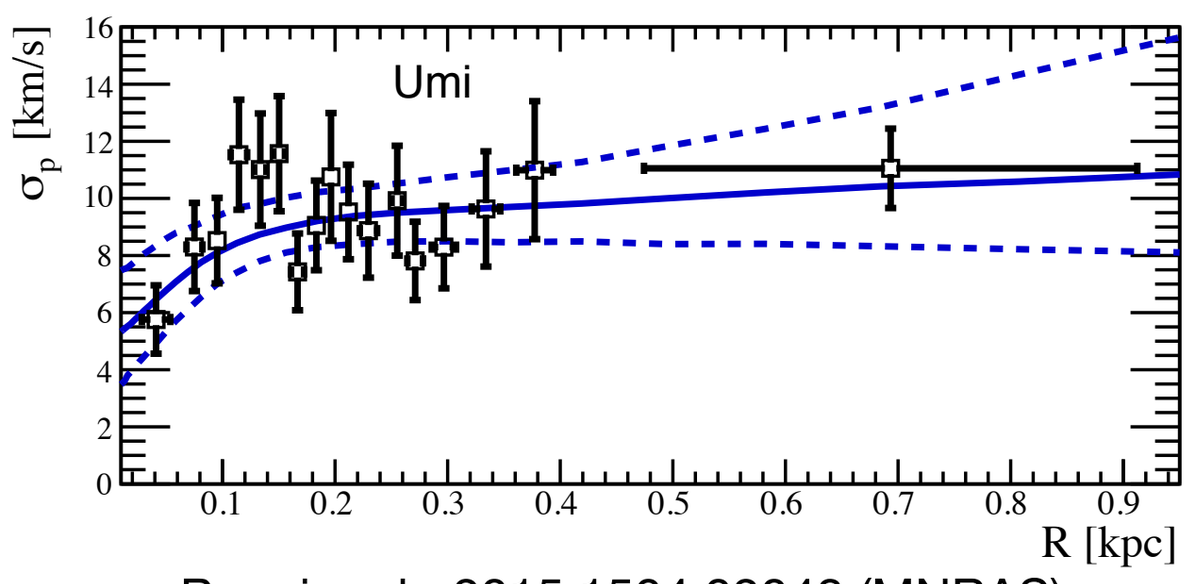
Observation: stars orbiting inside the dwarf

Jeans equation: gravitational potential ⟶ stellar kinematics

spectroscopic line of sight velocities ⟶ velocity dispersion profile



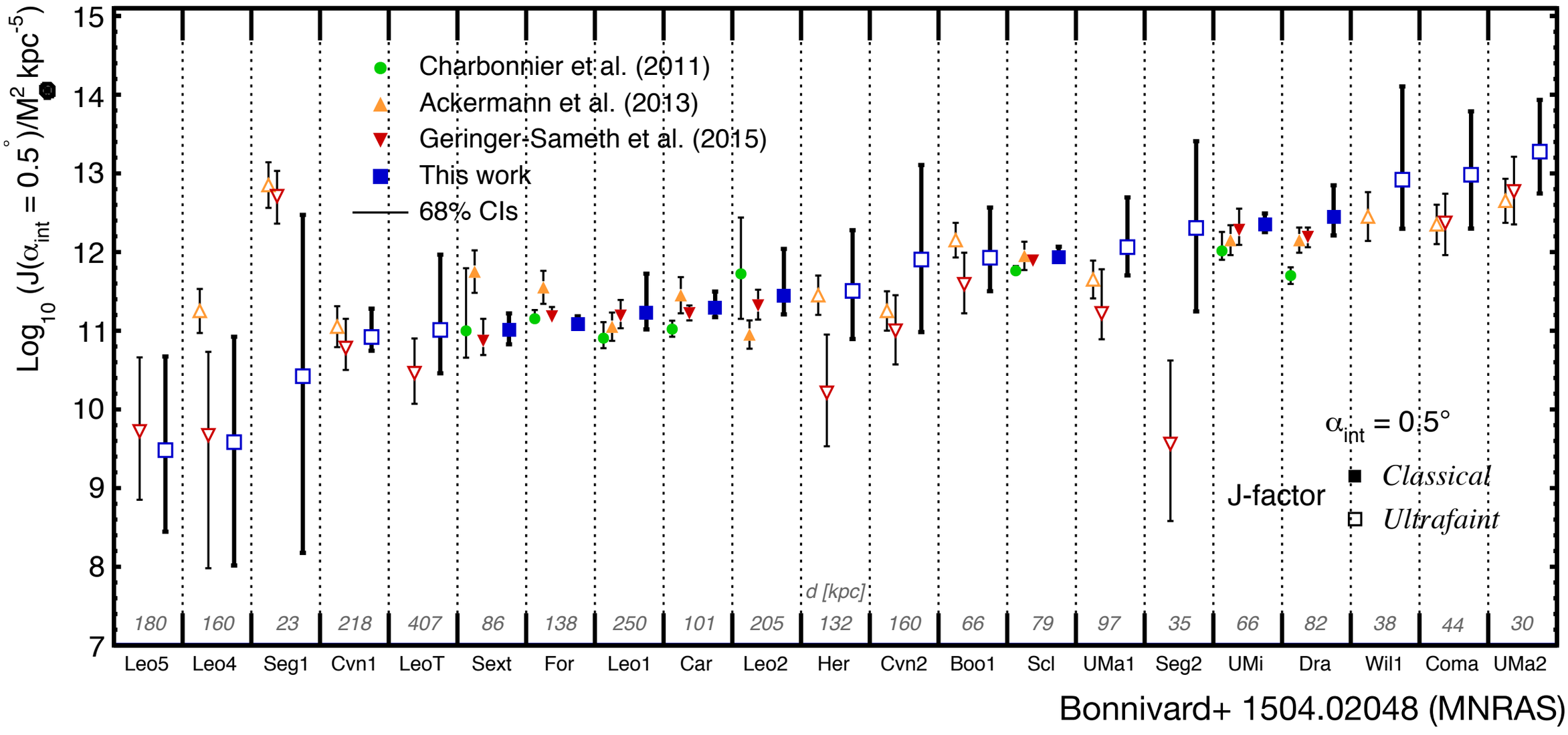
Walker, Olszewski, Mateo 1504.03060 (ApJ)



Bonnivard+ 2015 1504.02048 (MNRAS)

Bayesian exploration of possible dark matter density profiles

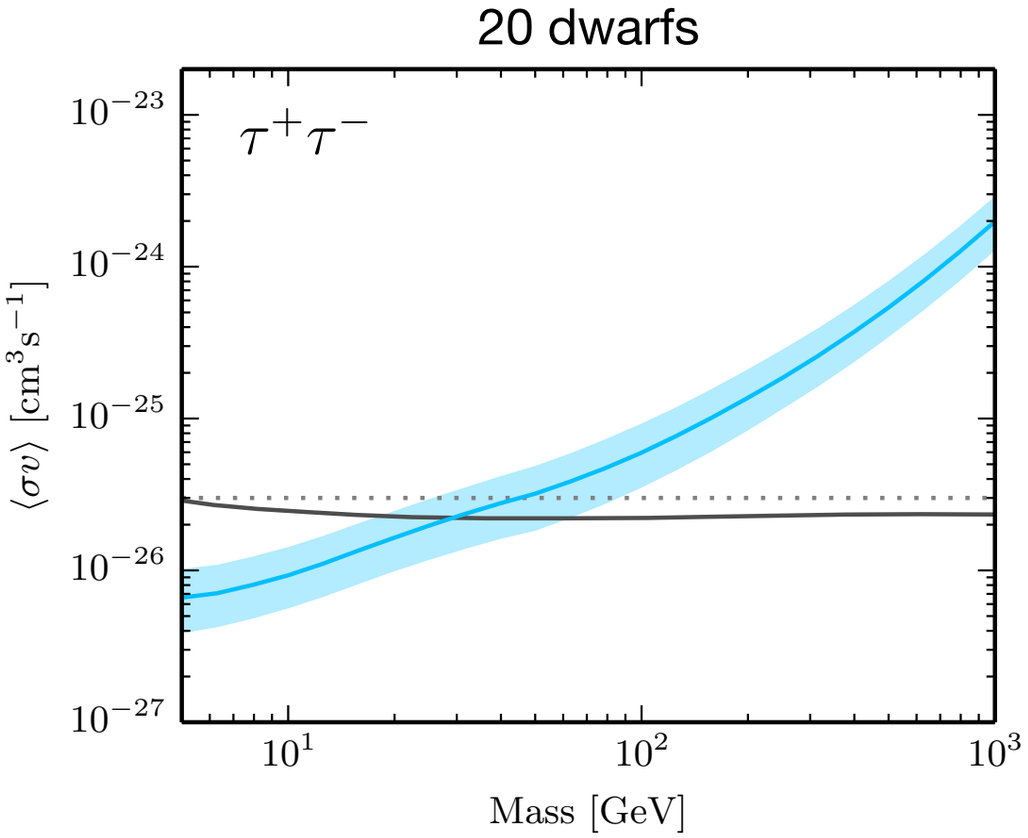
Velocity anisotropy, light profile, truncation, priors



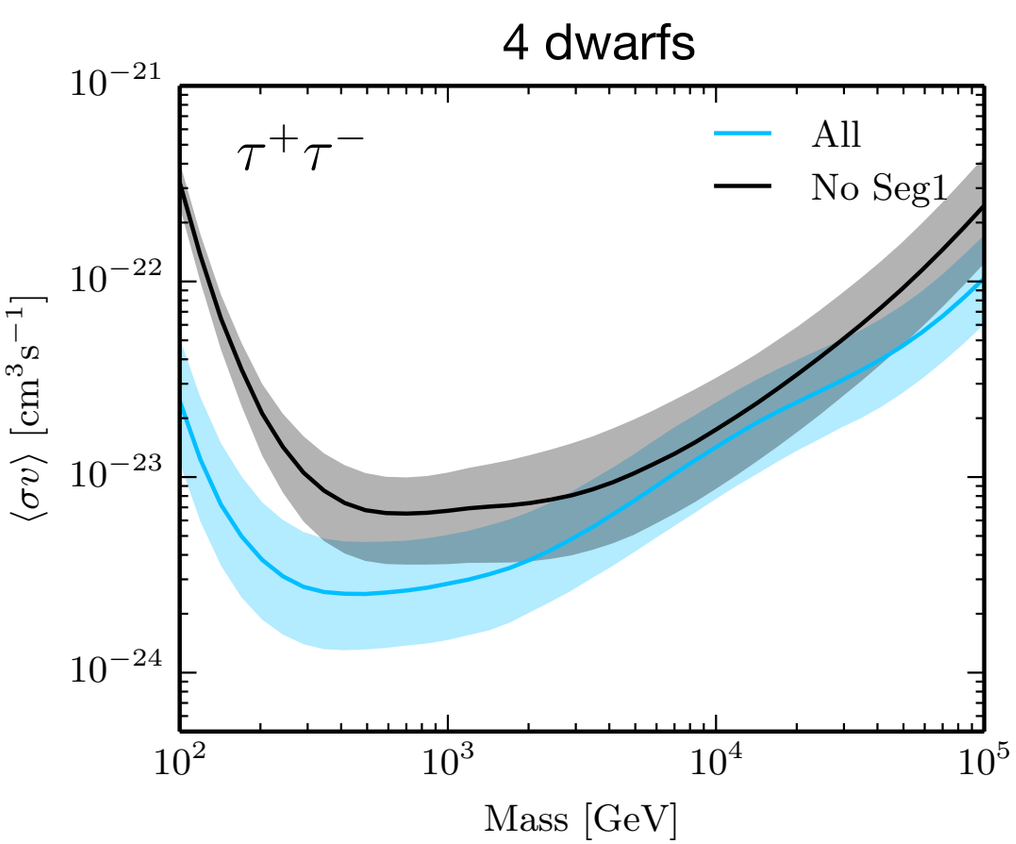
see also Charbonnier+ 1104.0412 (MNRAS), Martinez 1309.2641 (MNRAS),
Geringer-Sameth+1408.0002 (ApJ), Hayashi+ 1603.08046 (MNRAS)

Cross section upper limits

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



Geringer-Sameth, Koushiappas, Walker 1410.2242 (PRD)



VERITAS collaboration 1703.04937 (PRD)

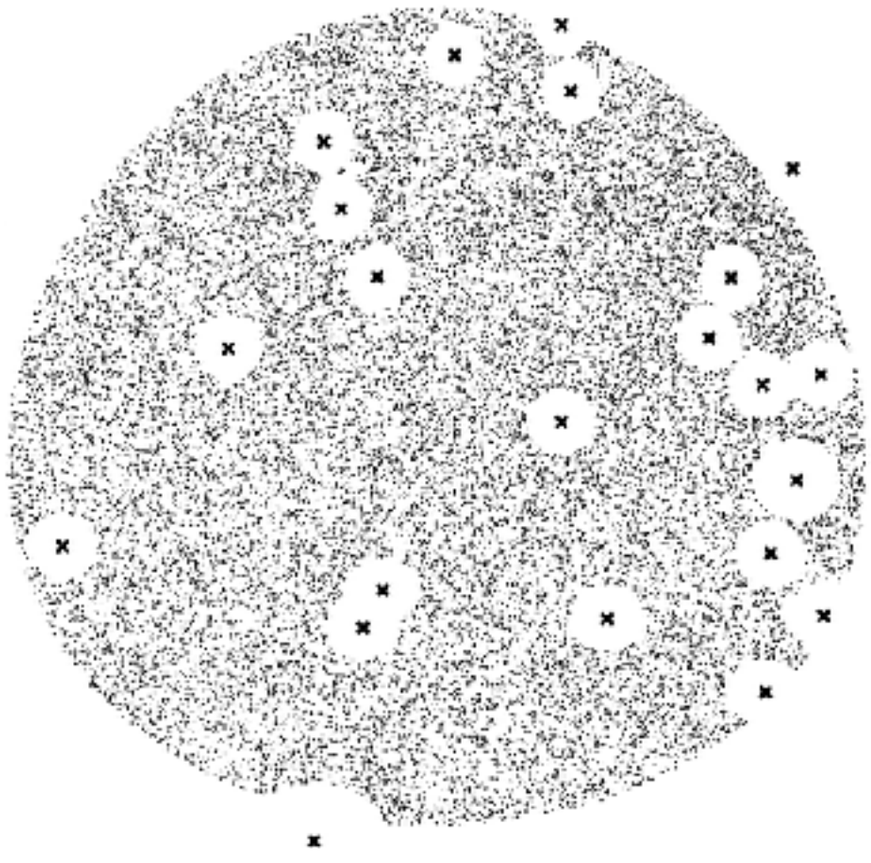
see also Fermi collab 1503.02641 (PRL), Fermi+DES 1611.03184 (ApJ),
H.E.S.S. collab 1410.2589 (PRD), MAGIC collab 1312.1535 (JCAP)

Reticulum II

very close (30 kpc)

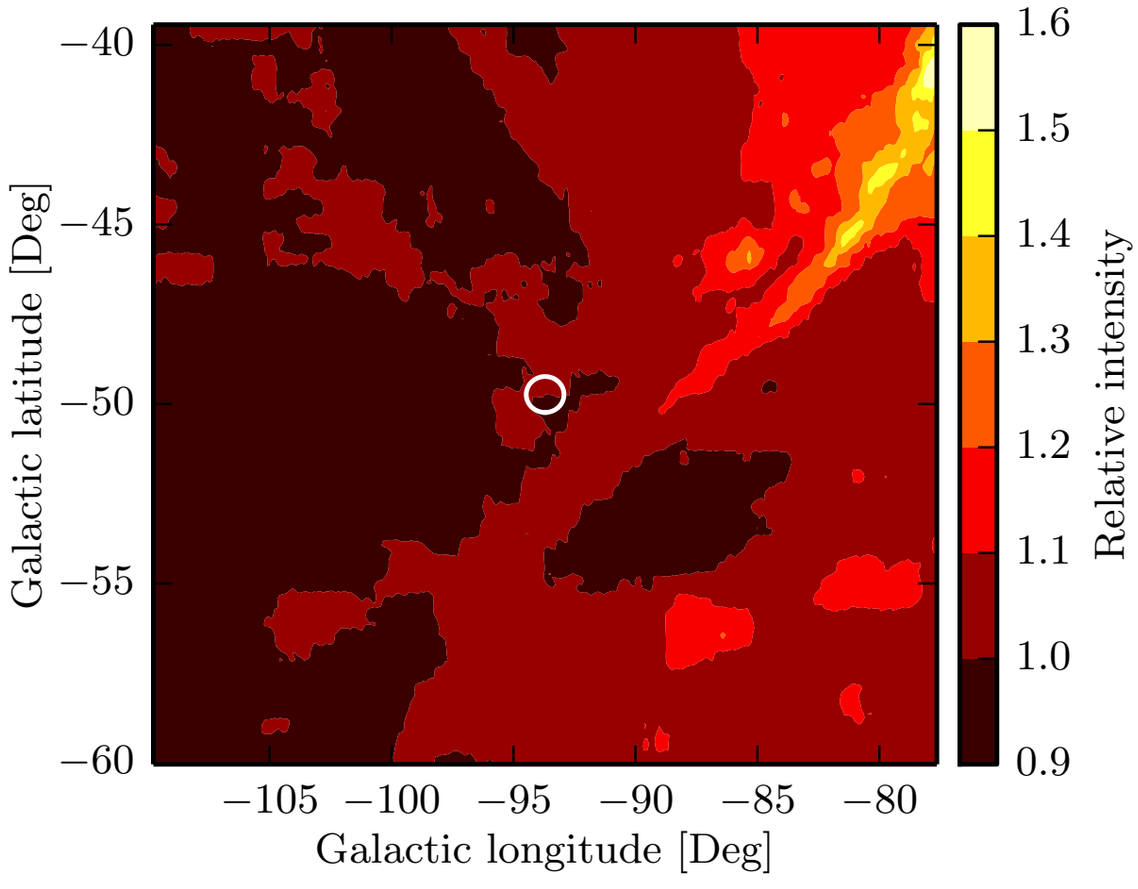
(Koposov+ 1503.02079 (ApJ), Bechtol+ 1503.02584 (ApJ))

Gamma-rays 1-300 GeV

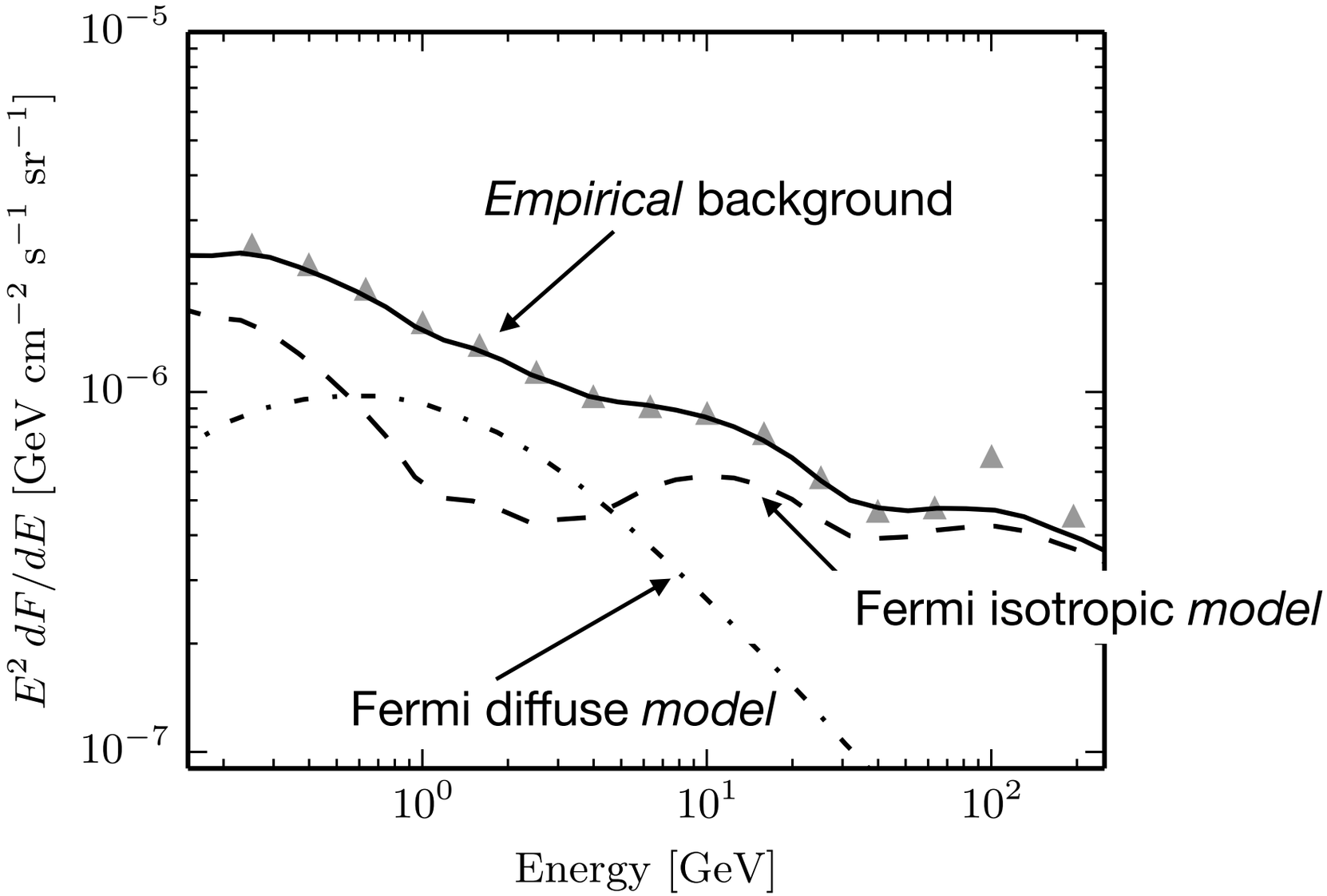


Far away from known sources

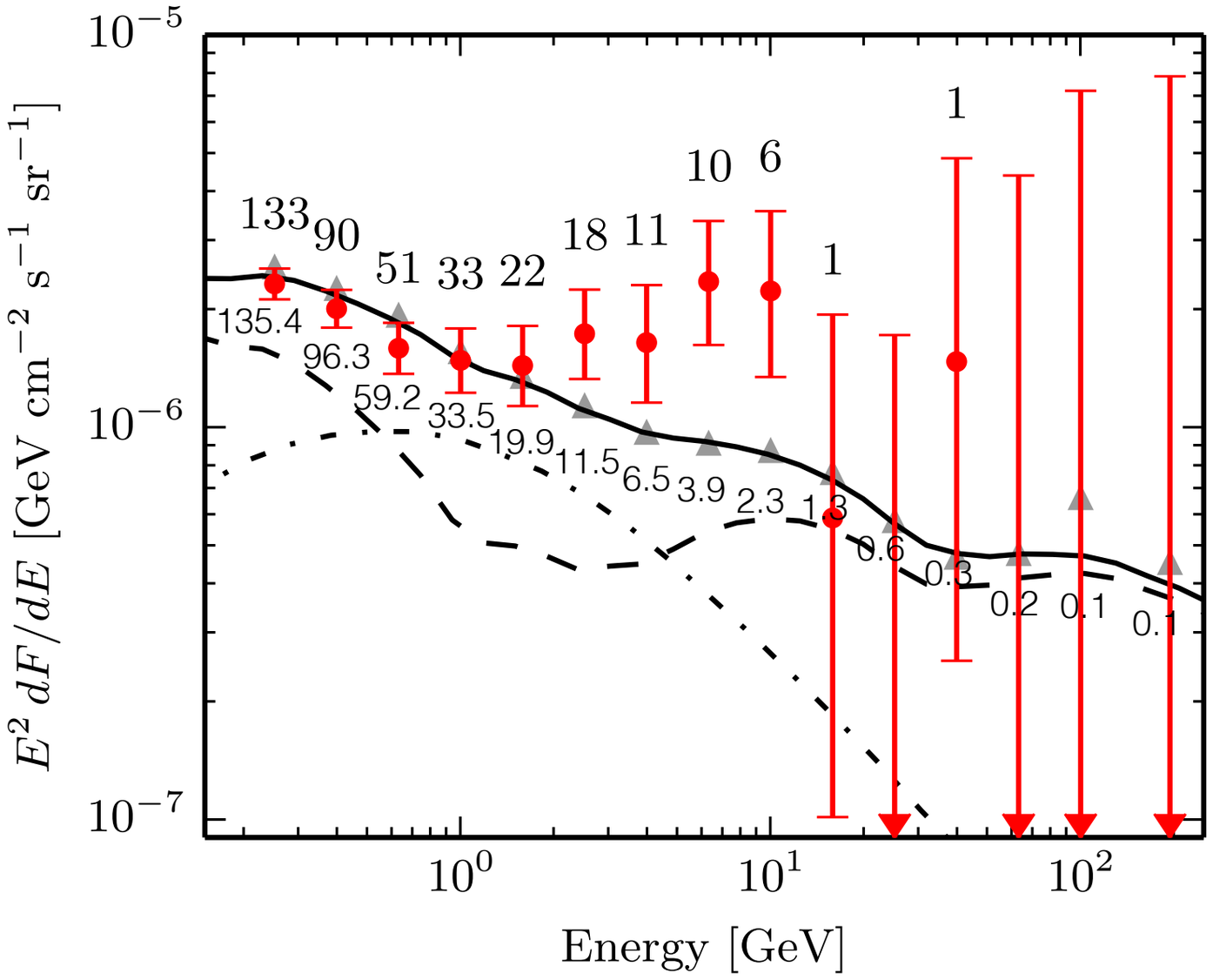
Gamma-ray background model at 8 GeV



Uniform background



Geringer-Sameth+ 1503.02320 (PRL)



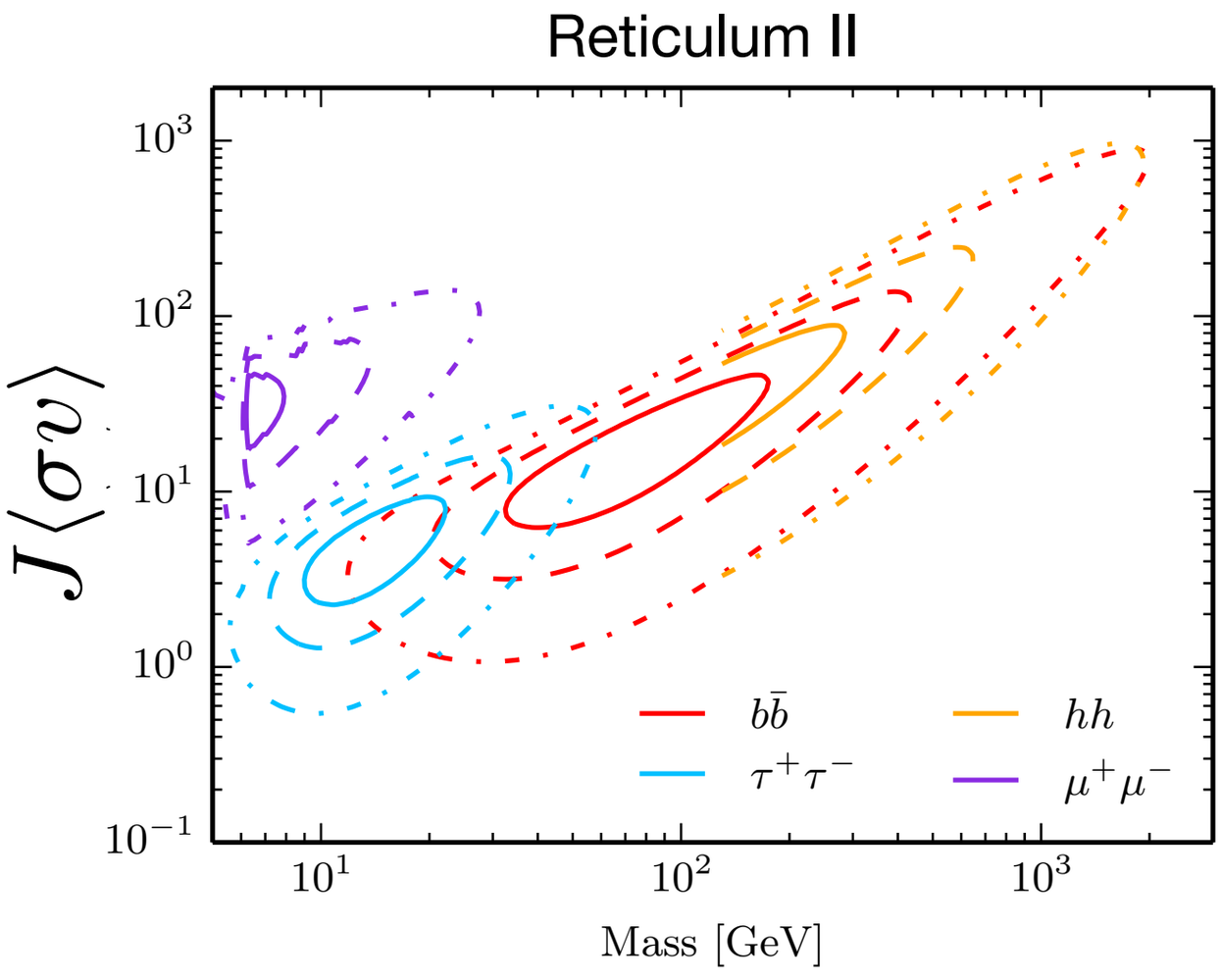
Events within 0.5° of RetII

detection significance (*p* value) of 0.01% to 1% depending on background modeling

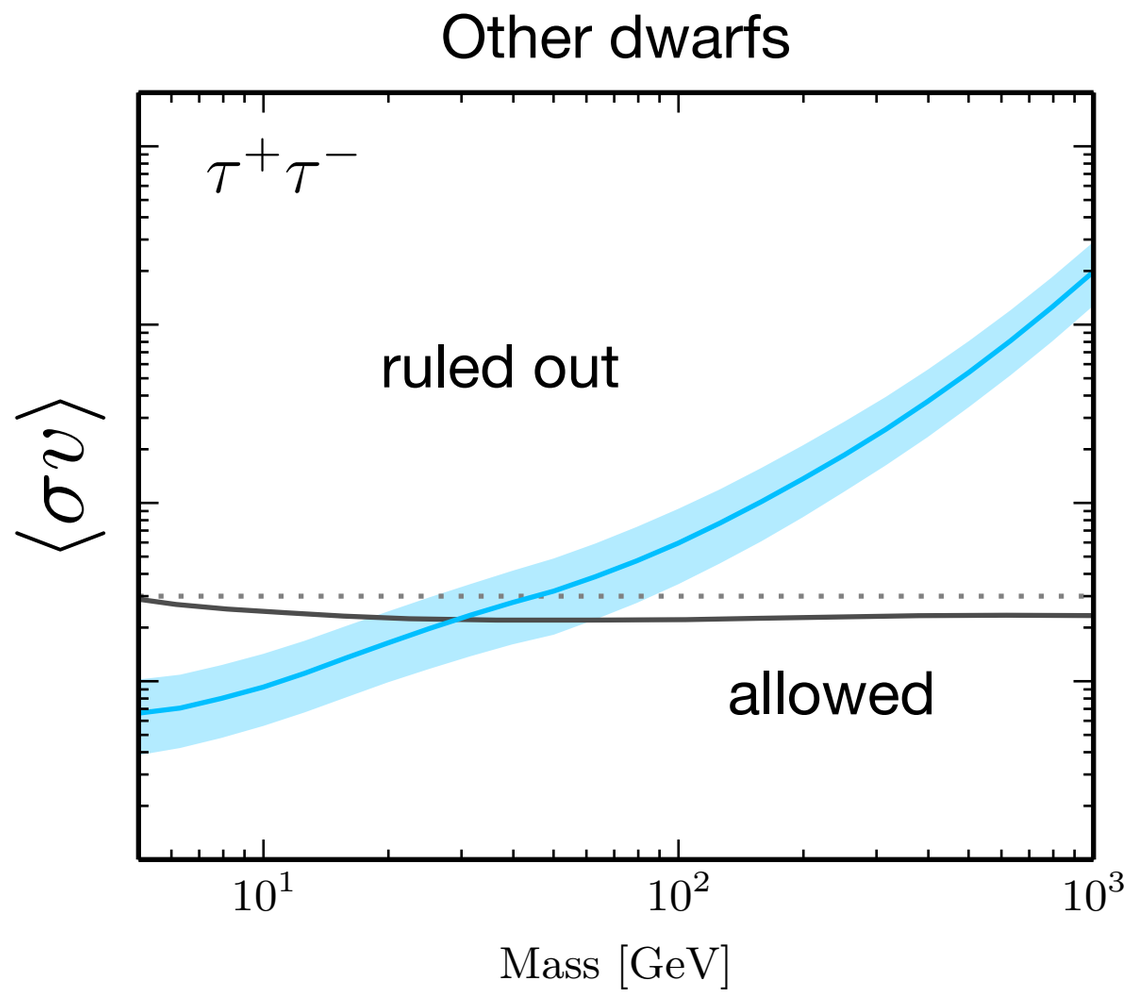
Geringer-Sameth+ 1503.02320 (PRL)

see also Fermi+DES 1503.02632 (ApJL), 1611.03184 (ApJ), Hooper, Linden 1503.06209 (JCAP), Baring+ 1510.00389 (PRD), Siegert+ 1608.00393 (A&A), Zhao+ 1702.05266, Regis, Richter, Colafrancesco 1703.09921

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



AGS et. al. 1503.02320 (PRL)



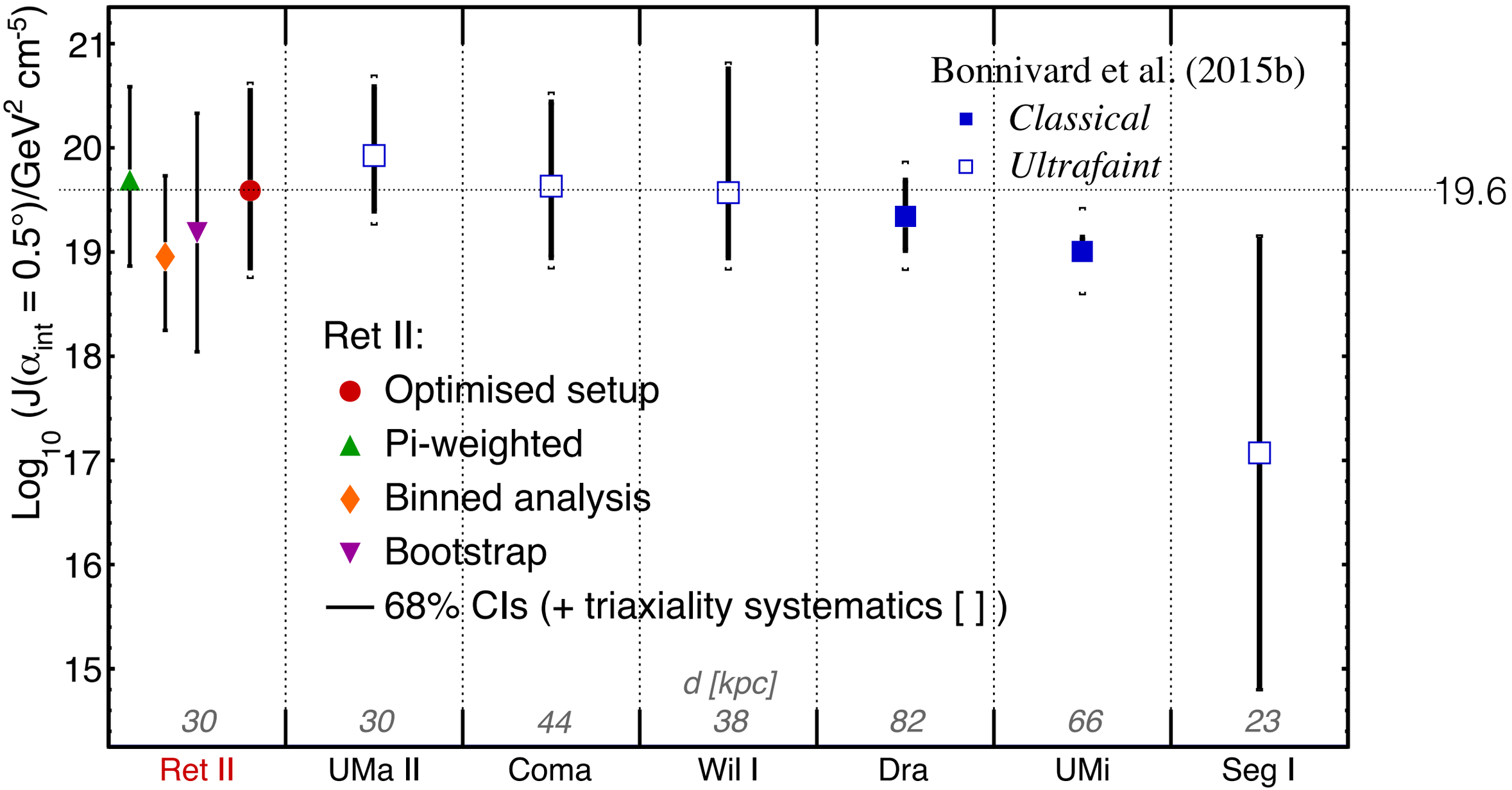
AGS, Koushiappas, Walker 1410.2242 (PRD)

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

Measured J values

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

Bonnivard+ 1504.03309 (ApJL)



Unmodeled systematics and statistics issues:

Ultrafaint dwarf galaxies: need to measure small σ^2 from 10s of stars

Tidal stripping, not in equilibrium

Contamination

(and many more!)
e.g. non-sphericity: Bonnivard+ 1407.7822 (MNRAS), Hayashi+ 1603.08046 (MNRAS)
binary stars: Minor+ 1001.1160 (ApJ)

Other large *J* contenders

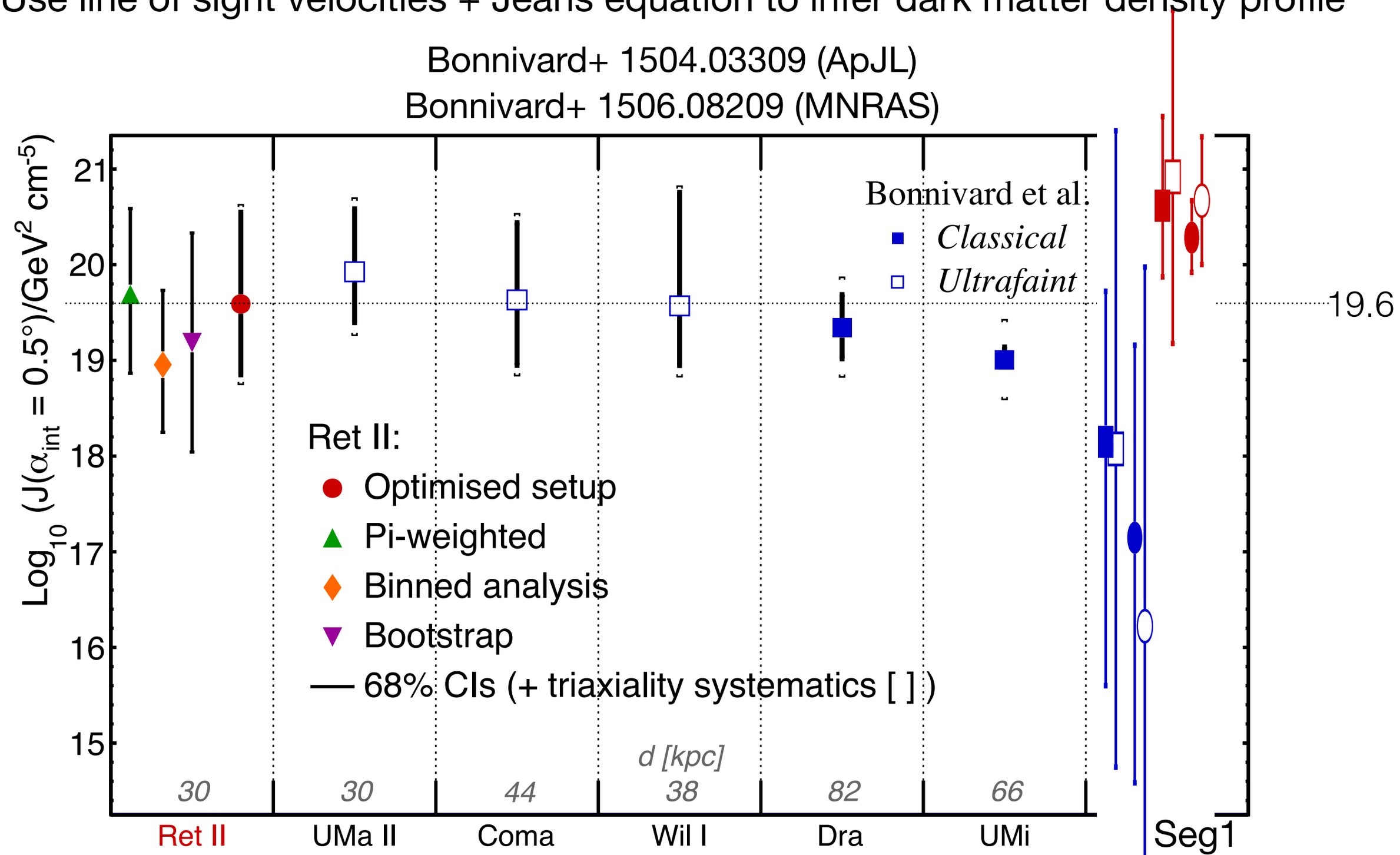
Reticulum II	30 kpc	$\sigma = 3.6\,\mathrm{km/s}$ Walker et. al. 1504.03060 (ApJ)
Tucana III	25 kpc	$\sigma < 1.5\,\mathrm{km/s}$ Simon et. al. 1610.05301 (ApJ)
Triangulum II	30 kpc	$\sigma = 5.1\,\mathrm{km/s}$ Kirby et. al. 1510.03856 (ApJ) revised to $\sigma < 3.4\,\mathrm{km/s}$ Kirby et. al. 1703.02978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

Segue 1	23 kpc	suffers 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

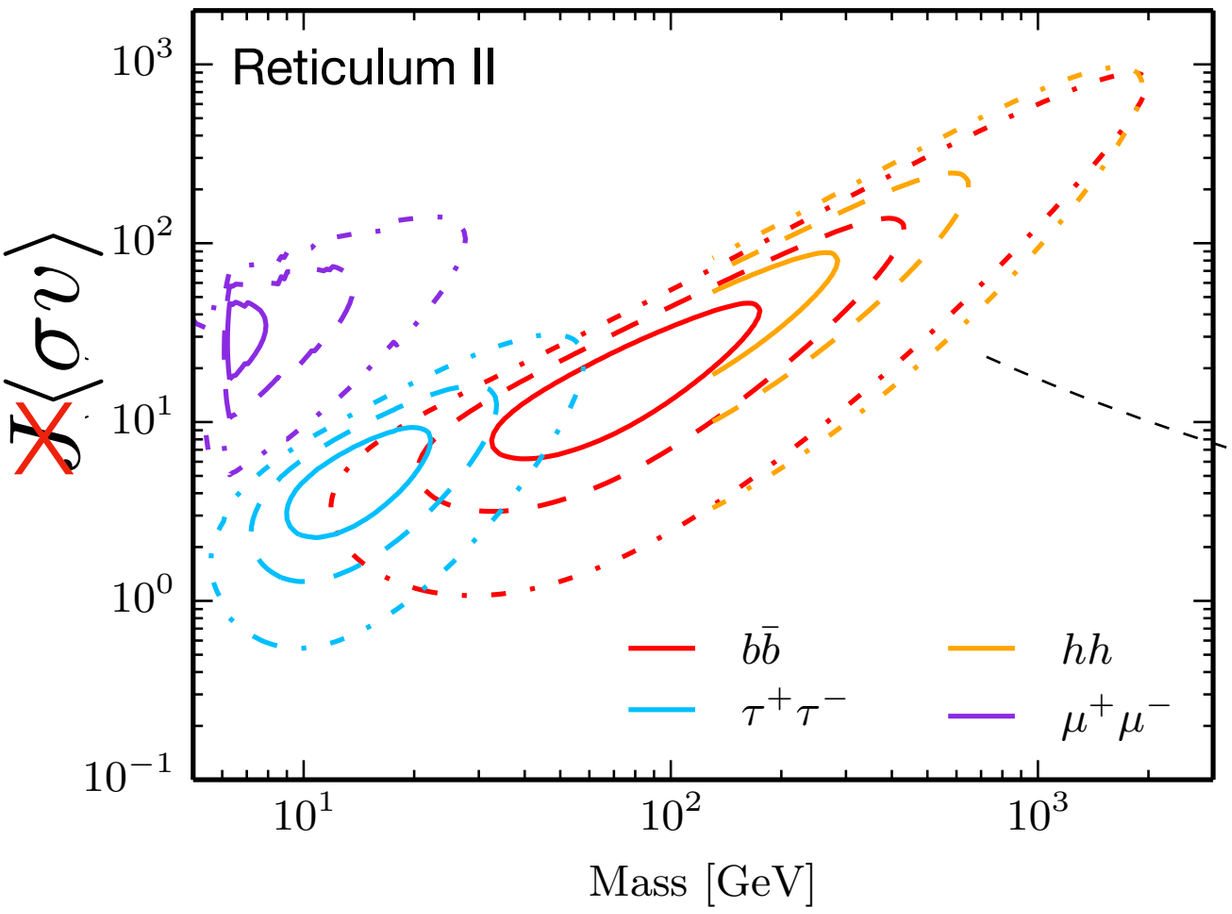
Contamination

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

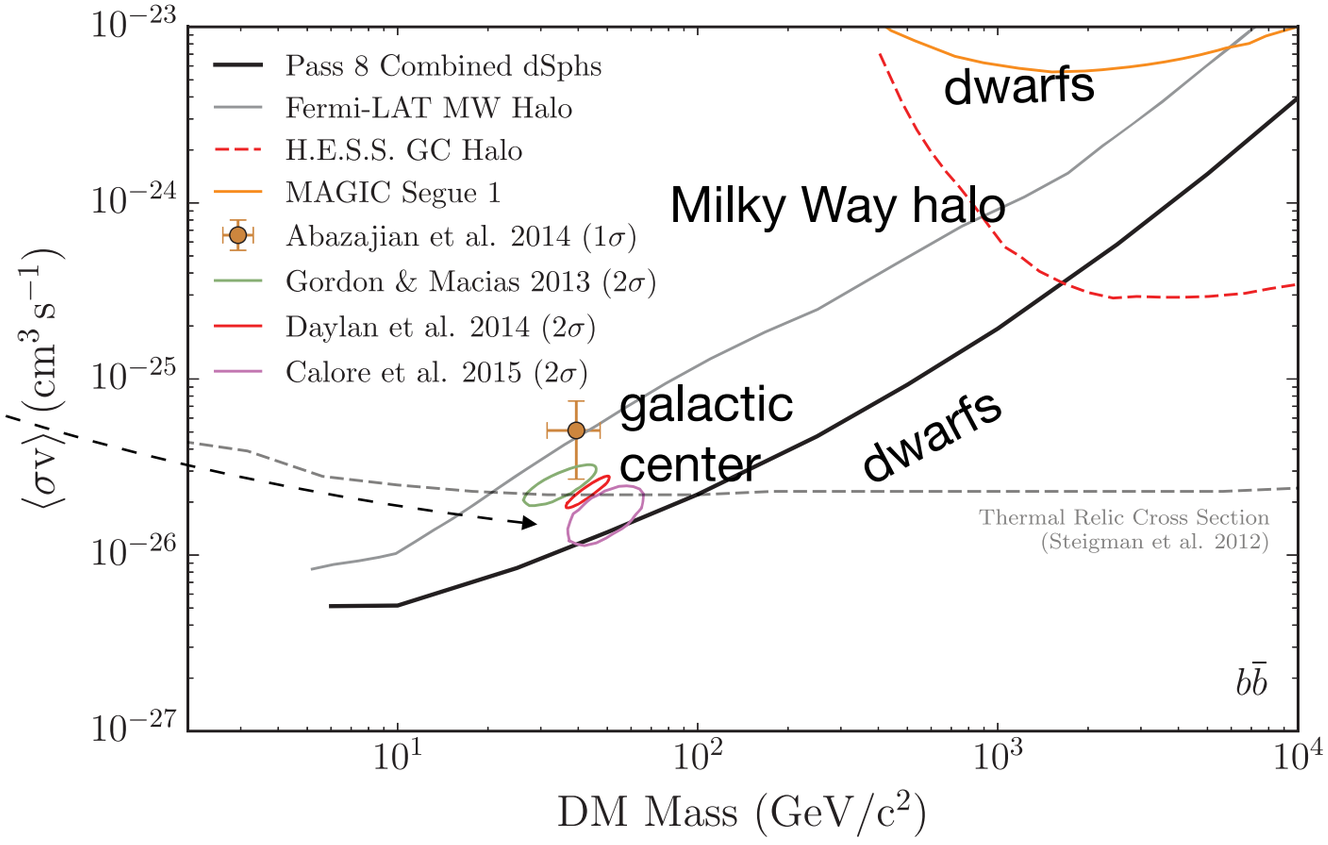


see also Simon+ 1504.02889 (ApJ), Ichikawa+ 1608.01749 (MNRAS), 1706.05481

Everything* in these plots requires a *J* value and dynamical modeling is always involved



AGS et. al. 1503.02320 (PRL)



Fermi collab 1503.02641 (PRL)