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Sommerfeld-Enhanced J-Factors for Dwarf Spheroidal Galaxies

Mei-Yu Wang
Texas A&M University

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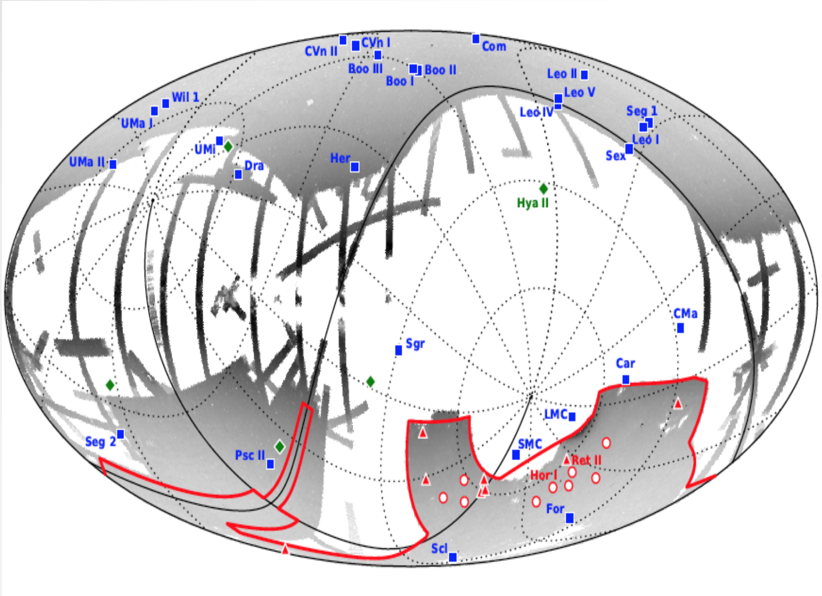
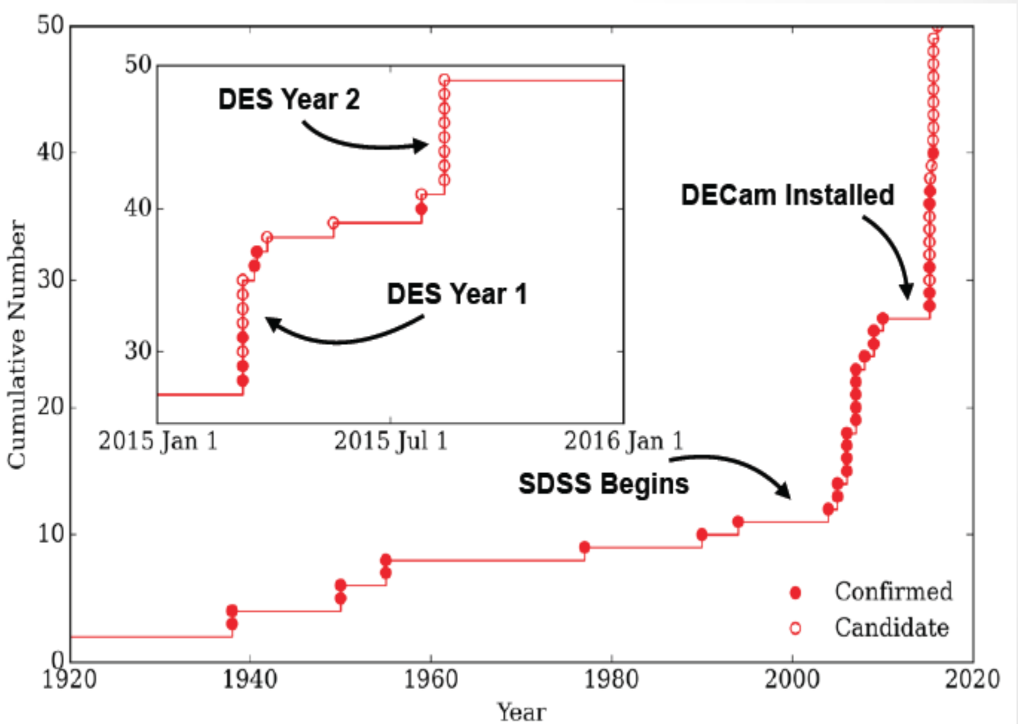
Authors: Kimberly Boddy, Jason Kumar, Louis Strigari, Mei-Yu Wang

Discoveries of Milky Way dwarf satellite galaxies



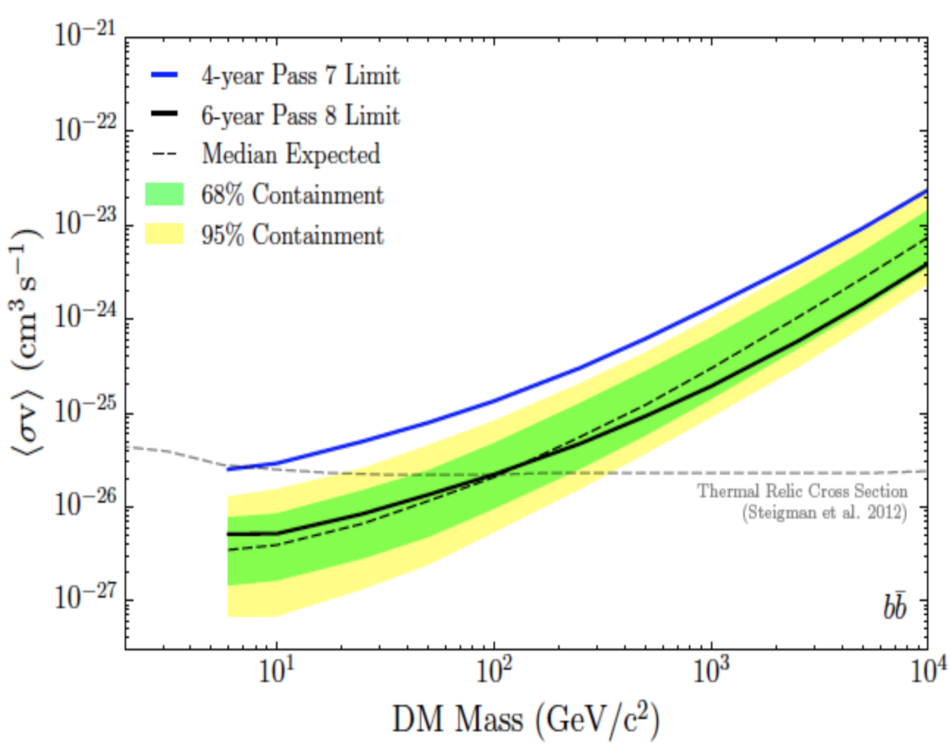
- Sloan Digital Sky Surveys (SDSS) : ~20
- Dark Energy Survey (DES) : >16 (~5 confirmed)
- Pan-STARRS : 3 (2 confirmed)
- Large Synoptic Survey Telescope (LSST) (starting 2019) ~ 100

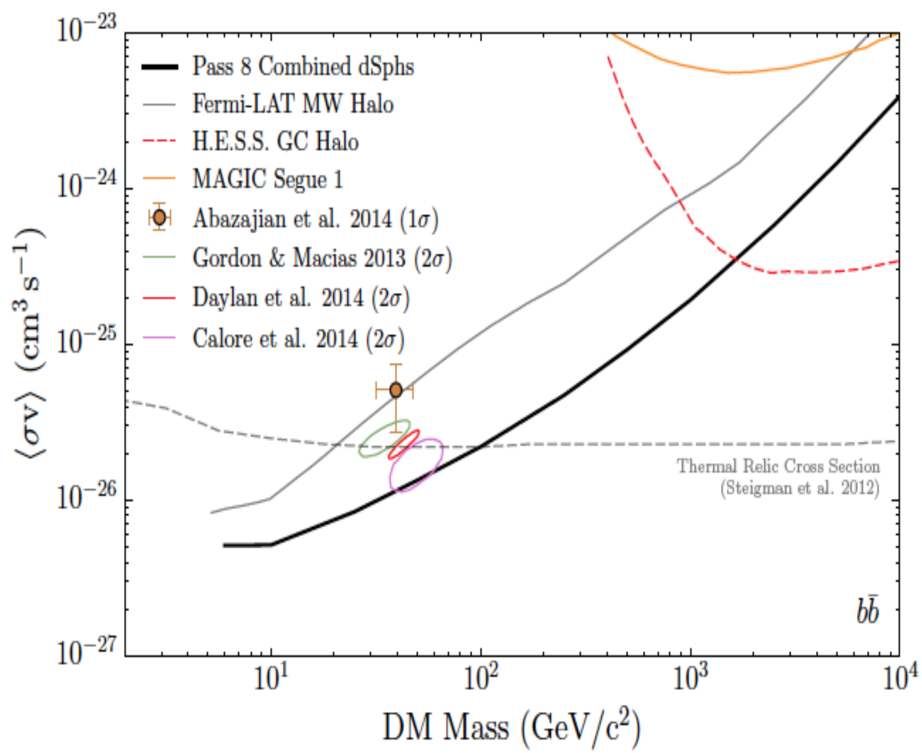
Drlica-Wagner et al., the DES collaboration (2015)



Plot credit: Keith Bechtol

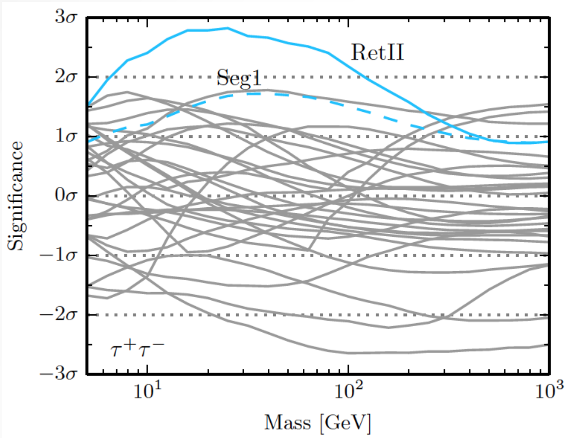
WIMP DM annihilation cross section constraints from Milky Way dwarf satellite galaxies



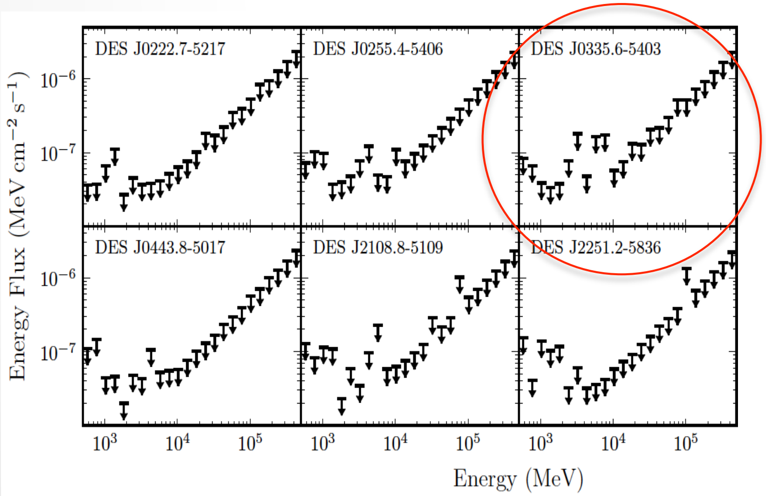


Ackermann et al., the Fermi-LAT collaboration (2015)

γ ray excess signal from Milky Way dwarf satellite galaxies

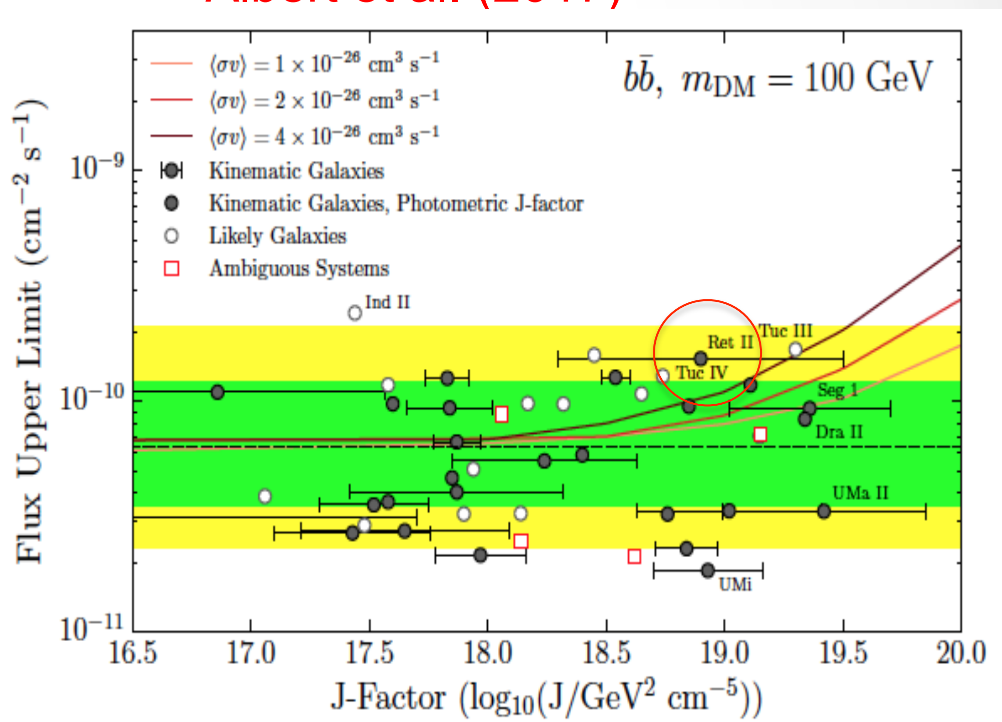


Geringer-Sameth et al. (2015)



Drlica-Wagner et al. (2015), Fermi PASS 8 data

Albert et al. (2017)

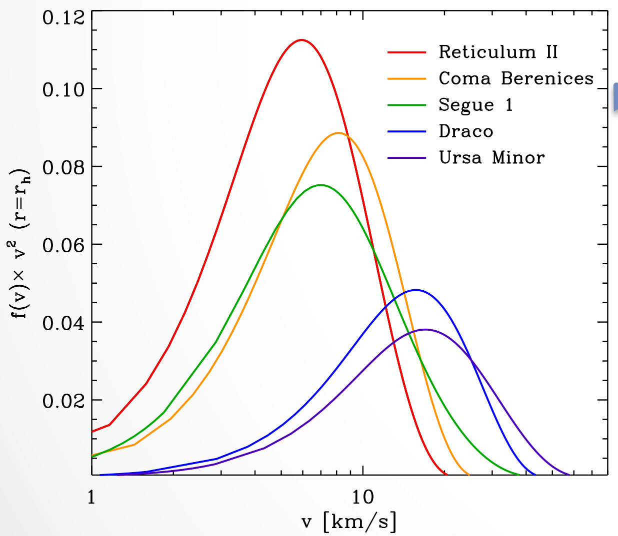


Sommerfeld-enhanced J-factor for Milky Way satellite galaxies

Velocity-dependent cross section

Boddy, Kumar, Strigari, M.W. (2017)

$$\frac{d\Phi}{dE_\gamma} = \frac{1}{4\pi}\frac{dN}{dE_\gamma}\int_{\Delta\Omega} d\Omega \int d\ell \int d^3v_1 \frac{f(r(\ell,\Omega),\vec{v}_1)}{m_X}\int d^3v_2 \frac{f(r(\ell,\Omega),\vec{v}_2)}{m_X}\frac{(\sigma_A|\vec{v}_1-\vec{v}_2|)}{2}$$



DM velocity distribution f(v)

Examples of previous Sommerfeld enhancement effects discussions for indirect detection:

Arkani-Hamed, Finkbeiner, Slatyer, Weiner, (2008)

Robertson & Zentner (2009)

Feng, Kaplinghat, Yu (2010)

Ferrer & Hunter (2013)

Sommerfeld-enhancement model

$$V(r) = -\frac{\alpha_X}{r} e^{-m_\phi r}$$

Assuming the interaction between dark matter particles is described by a Yukawa potential

Solving the 1D radial Schrodinger equation

$$S \simeq \frac{\pi}{\epsilon_v} \frac{\sinh\left(\frac{2\pi\epsilon_v}{\pi^2\epsilon_\phi/6}\right)}{\cosh\left(\frac{2\pi\epsilon_v}{\pi^2\epsilon_\phi/6}\right) - \cos\left(2\pi\sqrt{\frac{1}{\pi^2\epsilon_\phi/6} - \frac{\epsilon_v^2}{(\pi^2\epsilon_\phi/6)^2}}\right)}$$

Sommerfeld enhancement factor

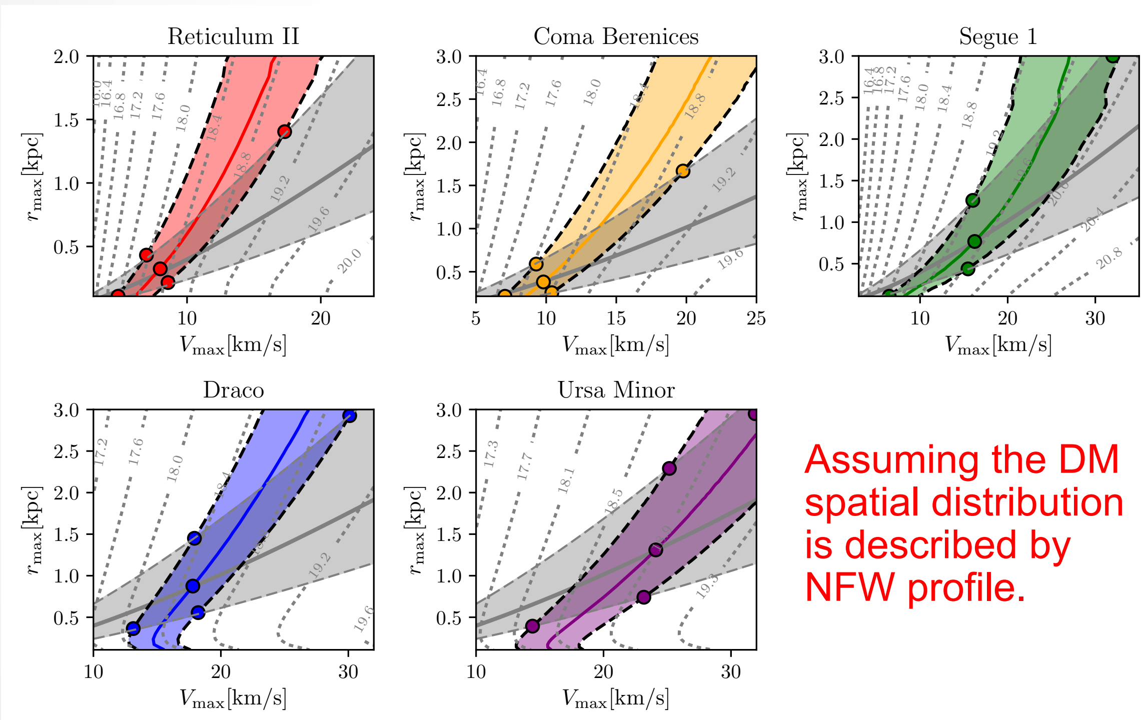
$$J_S(\Delta\Omega) \equiv \int_{\Delta\Omega} d\Omega \int d\ell \int d^3v_1 f(r(\ell,\Omega),\vec{v}_1) \int d^3v_2 f(r(\ell,\Omega),\vec{v}_2) S(|\vec{v}_1 - \vec{v}_2|/2)$$

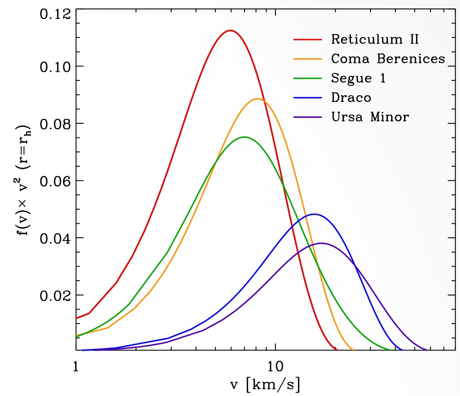
DM velocity distribution f(v)

When $S \rightarrow 1$, no enhancement $\quad J_S(\Delta\Omega) \rightarrow J(\Delta\Omega) = \int_{\Delta\Omega} d\Omega \int d\ell \, [\rho(r(\ell,\Omega))]^2$

Constructing DM/stellar velocity distribution with Eddington formula

$$f_{\rm DM}(\epsilon) = \frac{1}{\sqrt{8}\pi^2}\int_\epsilon^0 \frac{d^2\rho_{\rm DM}}{d\Psi^2}\frac{d\Psi}{\sqrt{\epsilon-\Psi}}$$





Assuming the DM spatial distribution is described by NFW profile.

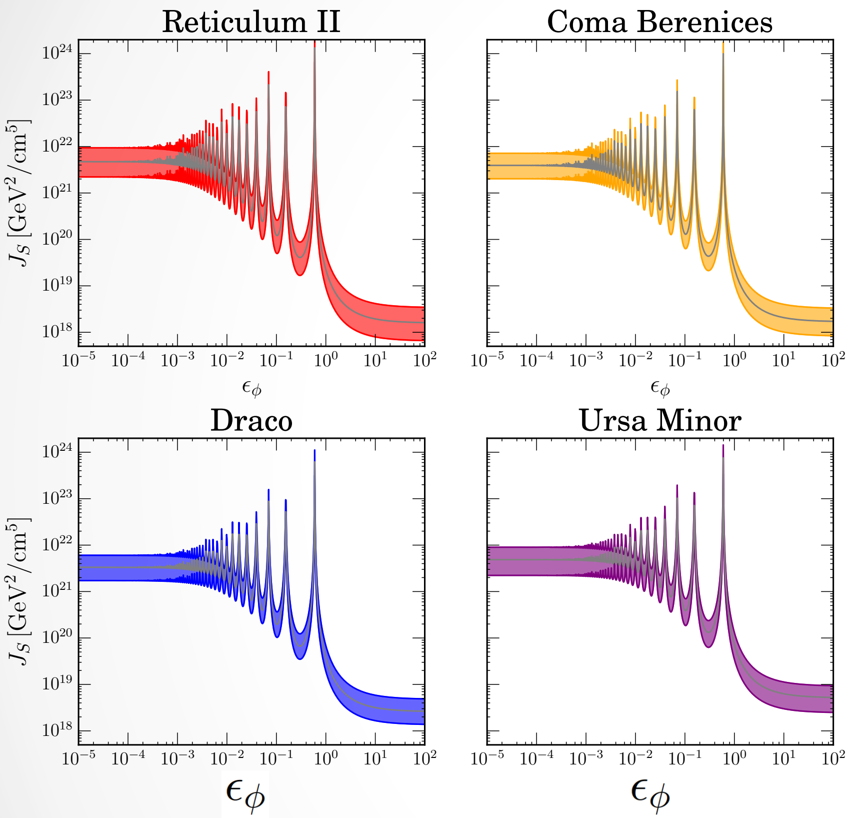
(1) Drawing NFW profile constraints from N-body simulations (grey bands)

(2) NFW profile constraints from measured stellar velocities (color bands)

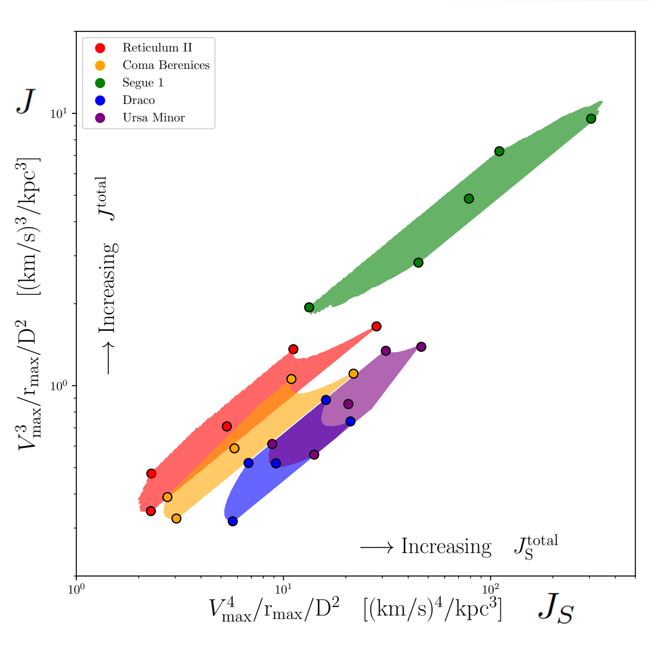
(3) Choose the regions where these two constraints are satisfied and derived the

$$f_*(\epsilon) = \frac{1}{\sqrt{8}\pi^2}\int_\epsilon^0 \frac{d^2\rho_*}{d\Psi^2}\frac{d\Psi}{\sqrt{\epsilon-\Psi}} \longrightarrow \langle\sigma_\star^2(r)\rangle = \frac{\int v_\star^4 f_\star(v_\star, r)\, dv_\star}{\int v_\star^2 f_\star(v_\star, r)\, dv_\star}$$

Sommerfeld-enhancement can change the ordering of J-factor among satellite galaxies



$$\epsilon_\phi \equiv \frac{m_\phi}{\alpha_X m_X}$$



$\epsilon_\phi \gg 1$ → Non-enhanced limit

$\epsilon_\phi \ll 1$ → Coulomb-like potential

Conclusion

- As new dwarf satellite galaxies continue to be discovered by Dark Energy Survey (DES) and in the near future, LSST, Milky Way dwarf satellite galaxies will continue to provide powerful constraints on the WIMP DM paradigm using indirect detection experiment data such as gamma-ray data from Fermi-LAT.

- We show that, in Sommerfeld-enhanced models, the ordering of the most promising systems may be different relative to the standard case of velocity-independent cross sections

- Our results can have important implications for derived upper limits on the annihilation cross section, or on possible signals, from Milky dwarf satellite galaxies.