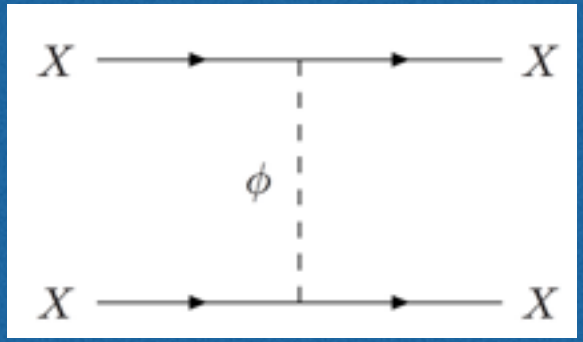
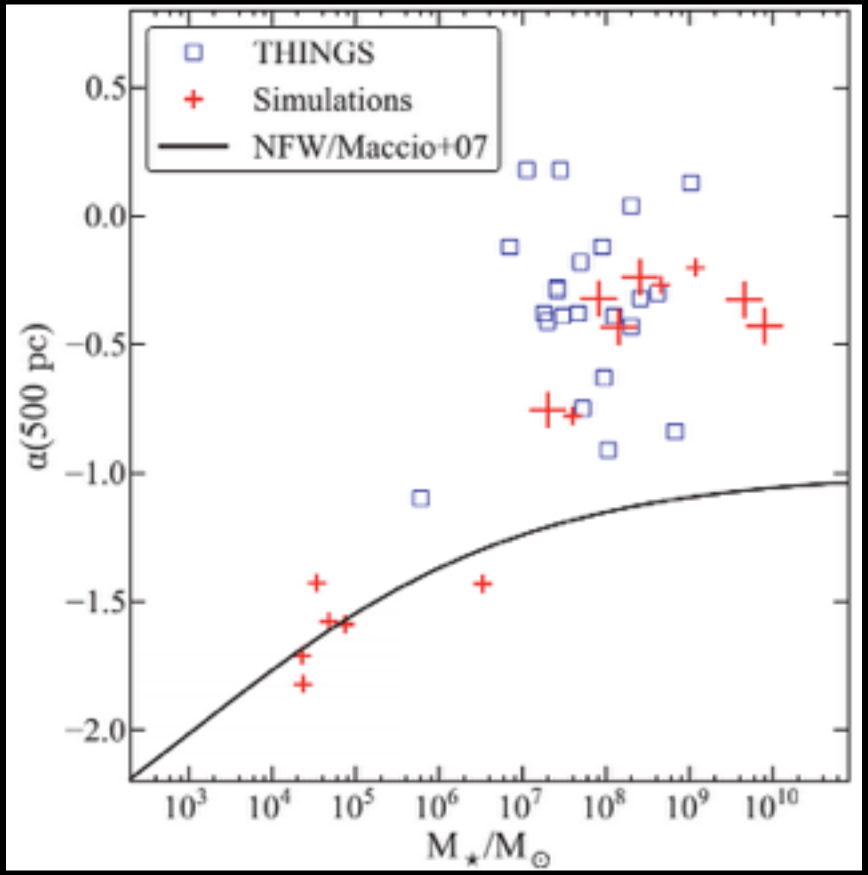
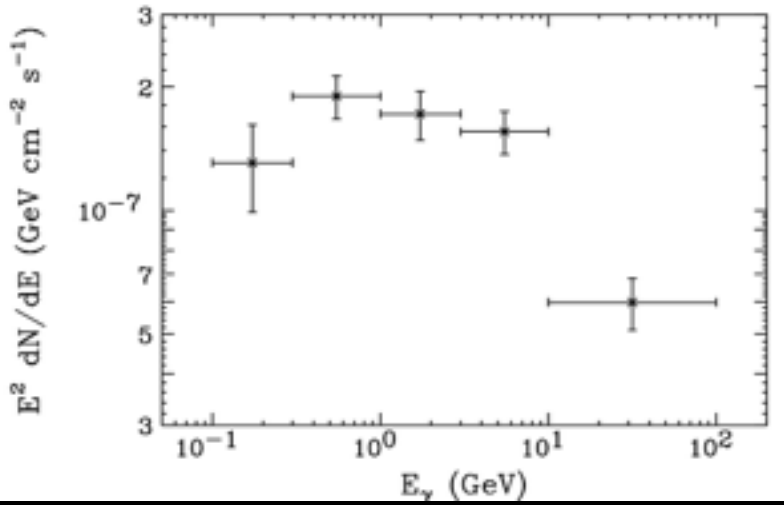
The Indirect Detection of Self-Interacting Dark Matter





Tim Linden

KICP Fellow

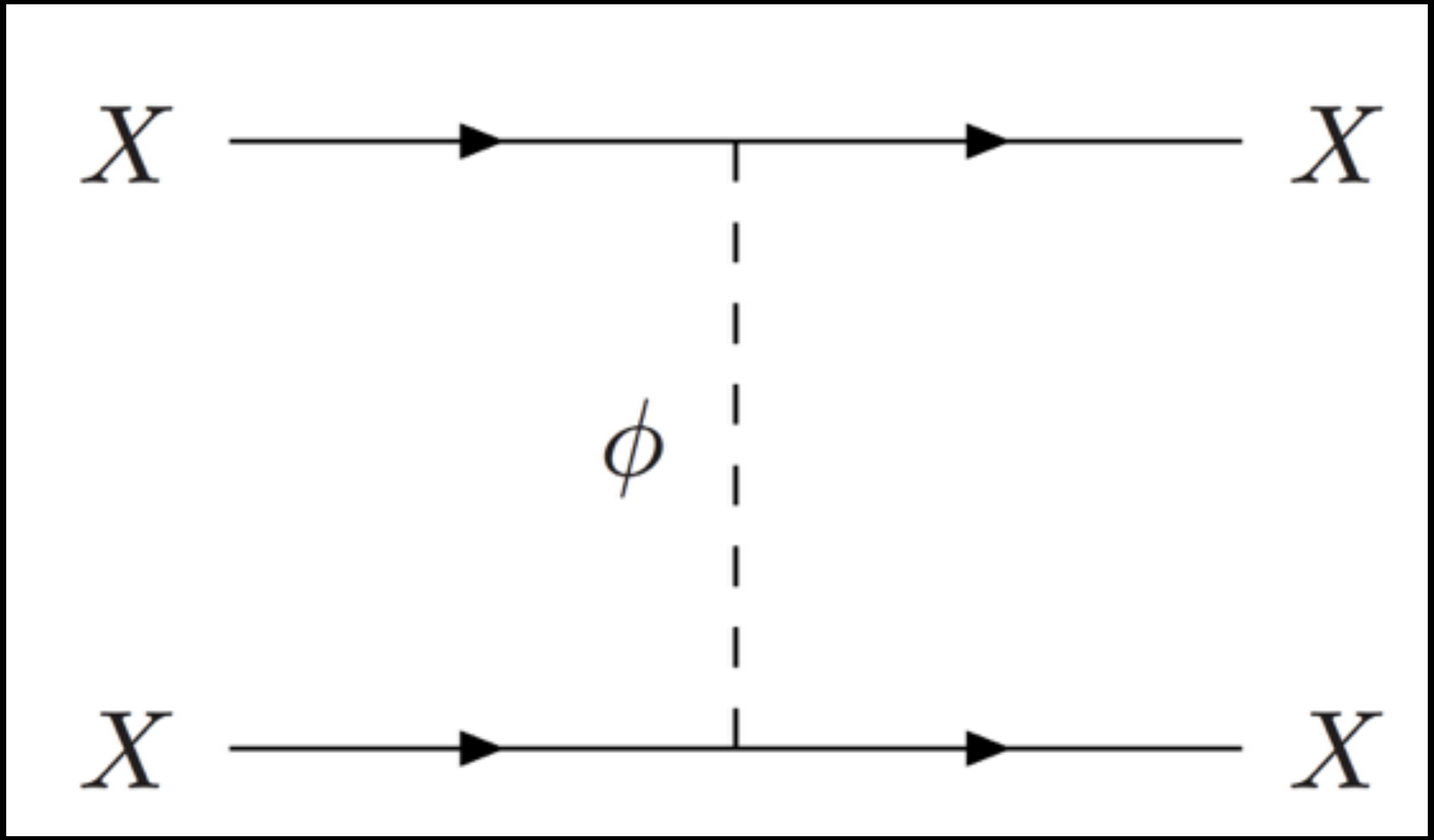


Based on Two Soon to be Submitted Papers:

"Density Profile of Self-Interacting Dark Matter in the Presence of Baryons"
Kaplinghat, Linden, Keeley, Yu (2013)

"Indirect Searches for Self-Interacting Dark Matter"
Kaplinghat, Linden, Yu (2013)

What are Self-Interactions?



Add a dark force carrier to the dark sector, which allows interactions between dark matter particles

In this case - a dark photon

Cluster Constraints?

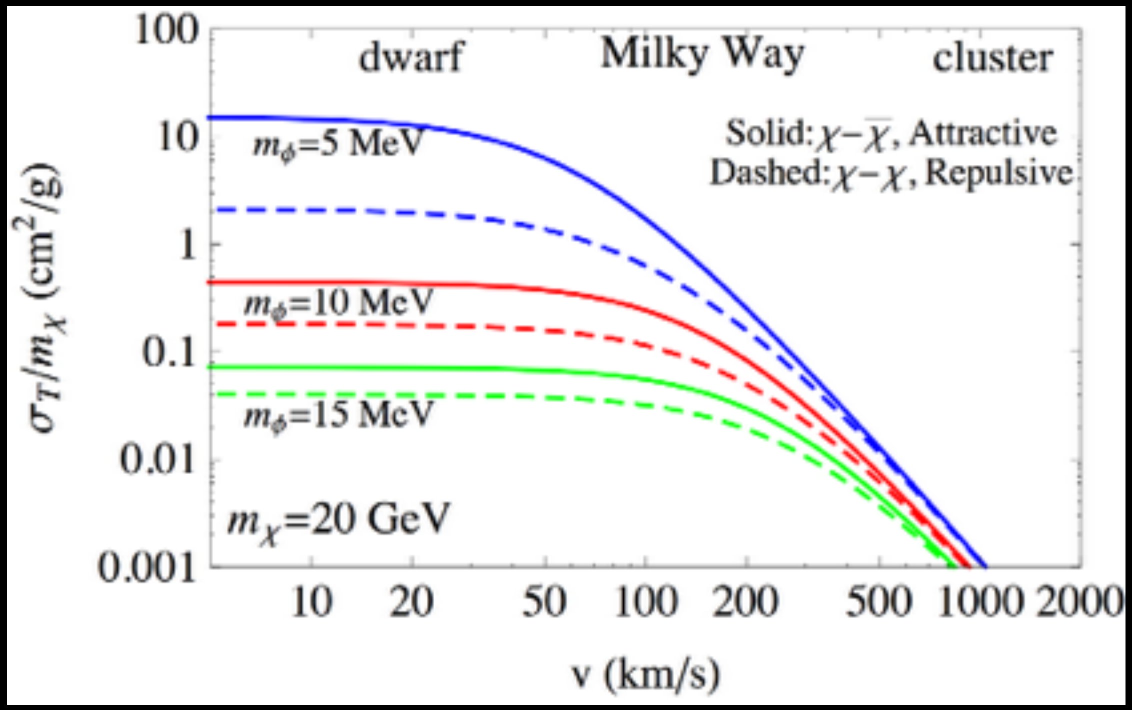
Bullet Cluster observations show that dark matter is collisionless — kind of?

Actual constraint is about 1 $cm^2/g \sim 2$ barn/GeV

This is about 10 orders of magnitude above the expected WIMP annihilation cross-section

(WIMP miracle implies $\sigma \sim 10^{-10}$ barn)

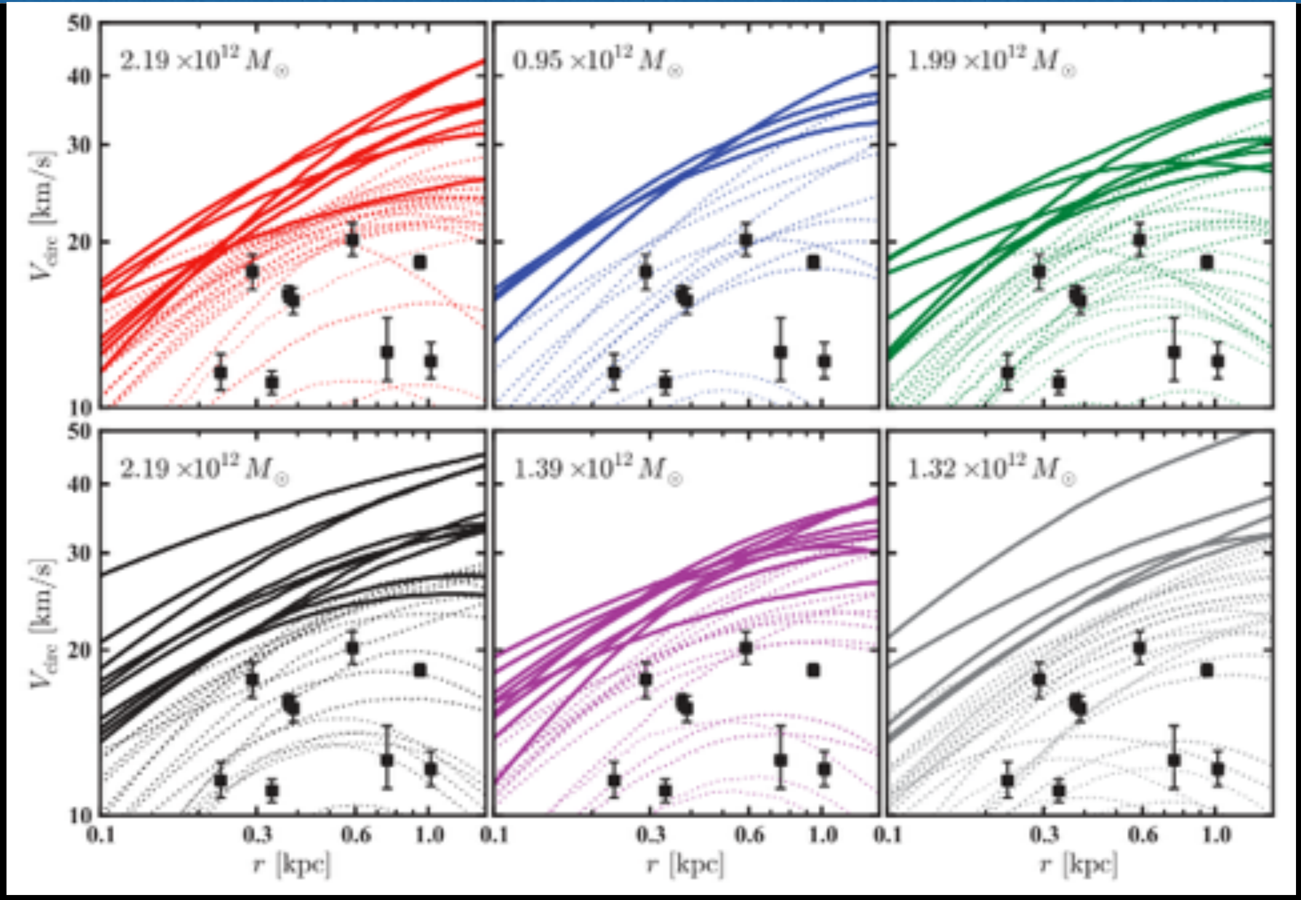
Moreover, the self-interaction cross-section may be velocity dependent



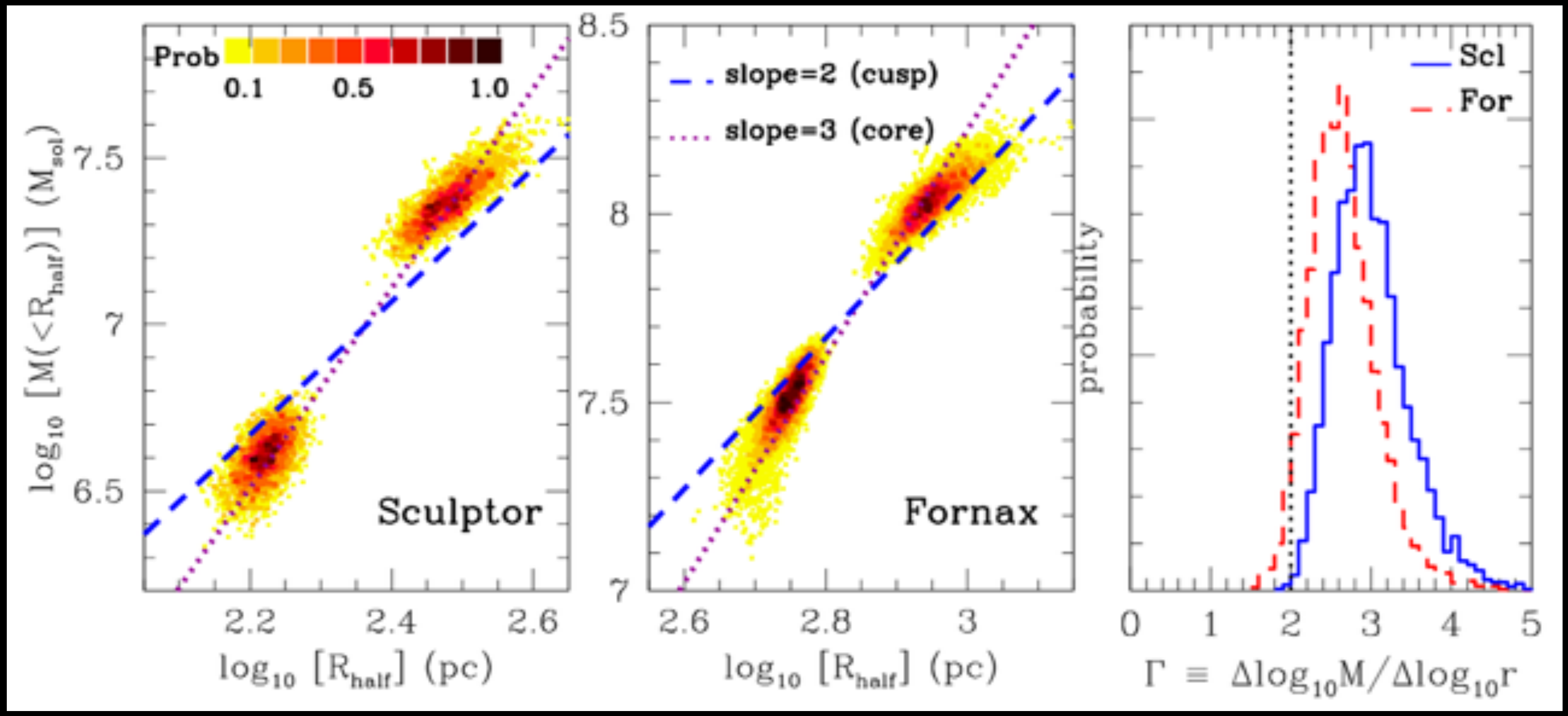
Why Self-Interactions?

Cusped profiles (e.g. NFW) may not fit the observed density profiles of dwarfs

Stellar feedback is unlikely to solve the problem, as these are dark matter dominated systems

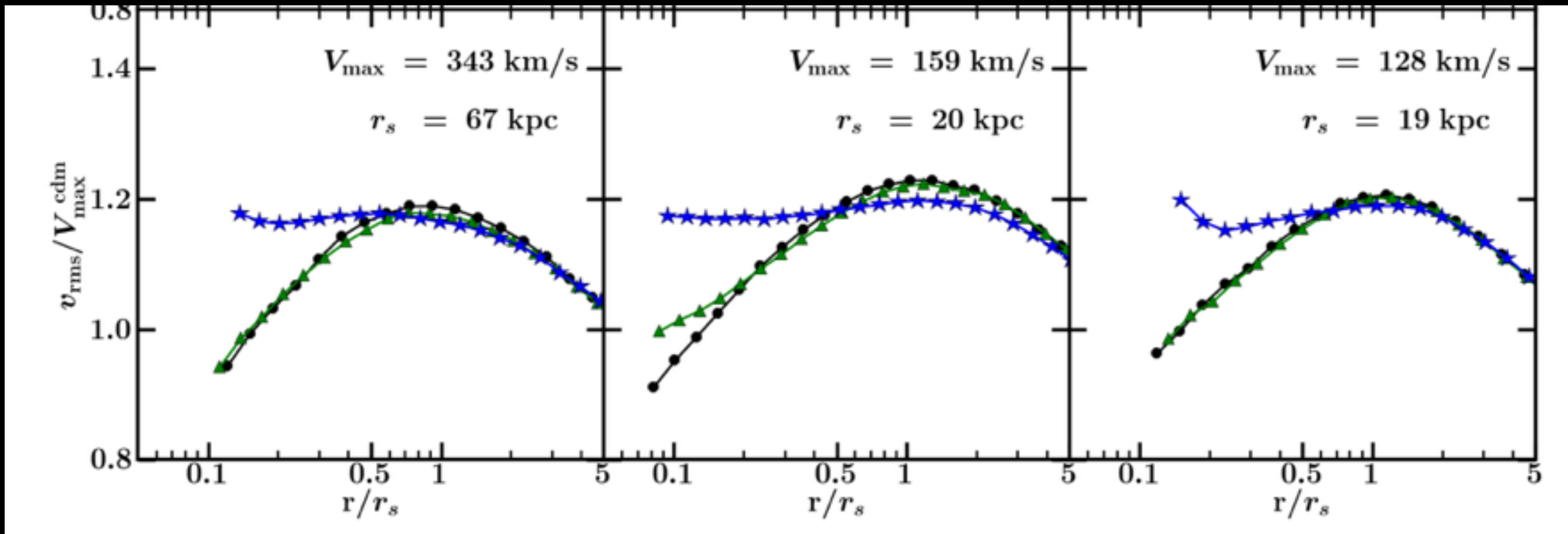


"Too Big to Fail" - Boylin-Kolchin et al. 2012



"Core-Cusp Problem"
Walker & Penarrubia (2012)

Why Self-Interactions?



Self-Interactions produce a DM core at approximately the point where one interaction is expected per Hubble time.

$$\sigma_{SIDM}\left(\frac{\rho(r)}{M_{DM}}\right)v_{rms} = \Gamma(r) > 1$$

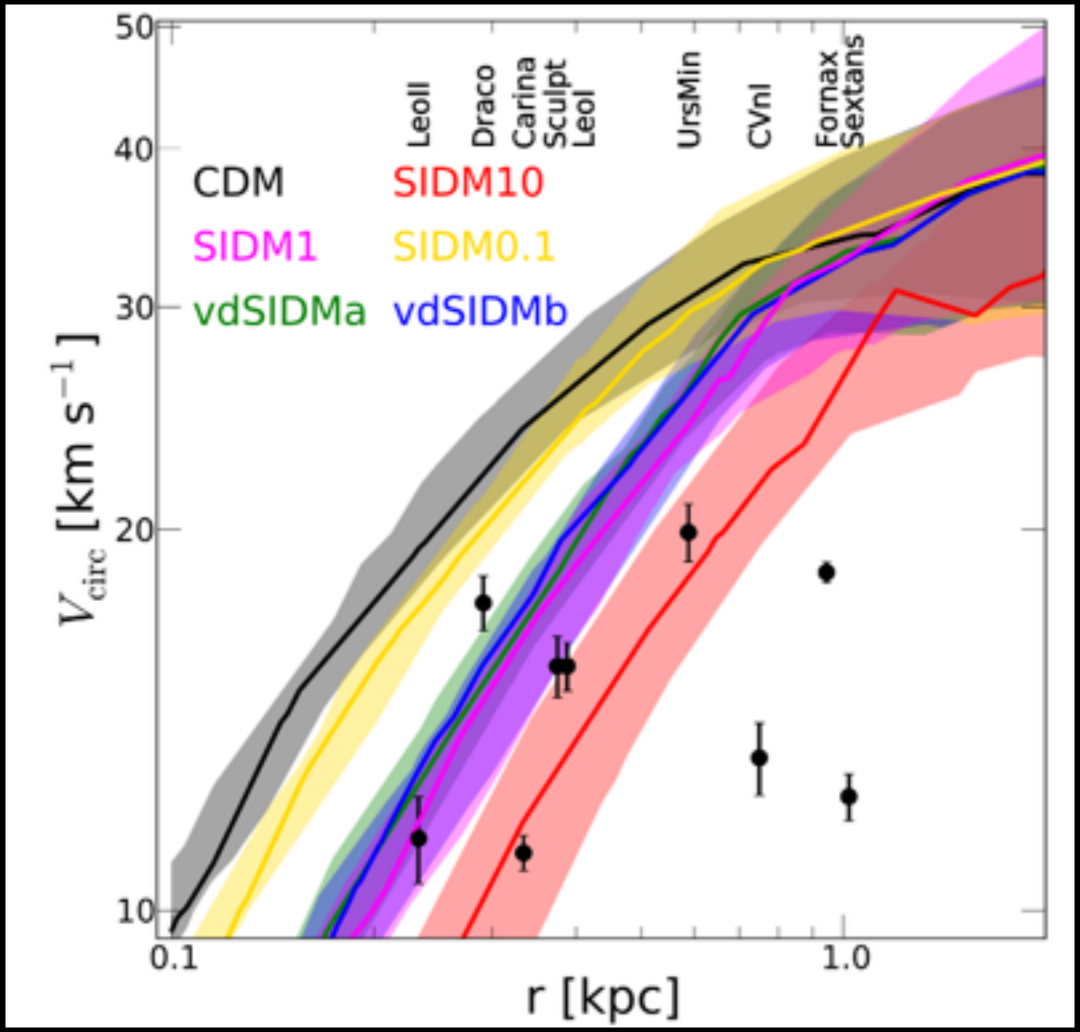
Inside this region, interactions move high temperature (high v_{rms}) DM into the center and move low temperature gas outside, creating a constant density, constant temperature core

Why Self-Interactions?

DM less peaked at GC -> higher mass clusters have smaller circular velocities inside the core

This solves too-big-to fail and the core-cusp problem

Requires a self-interaction in dwarf galaxies of ~10 cm^2/g



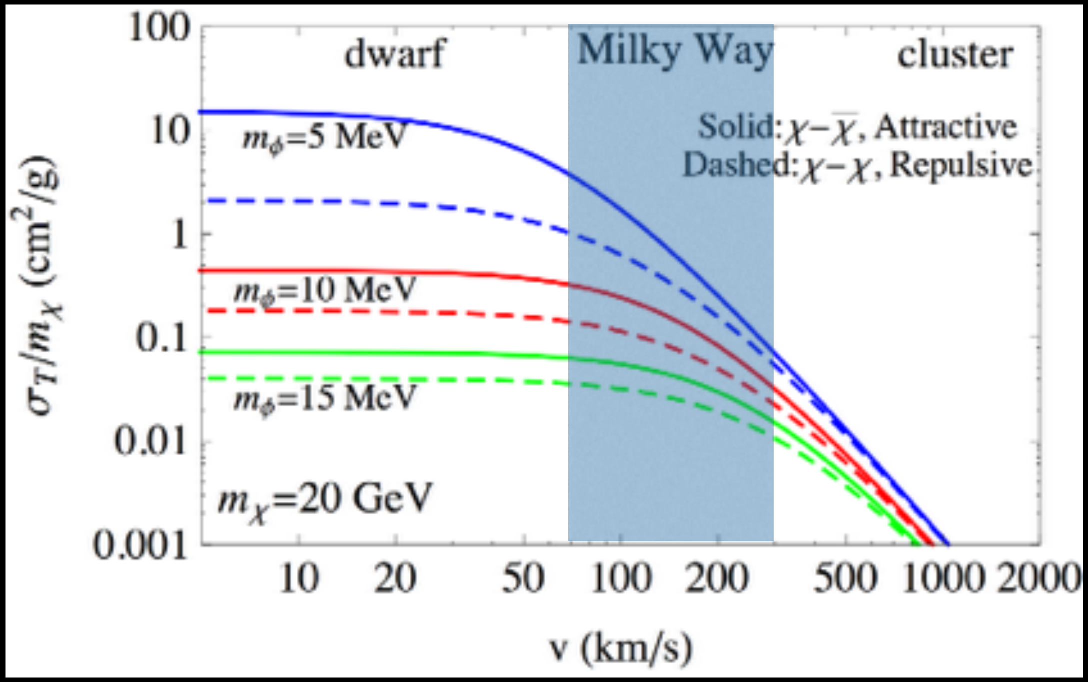
Zavala et al. (2013)

The Milky Way Density Profile

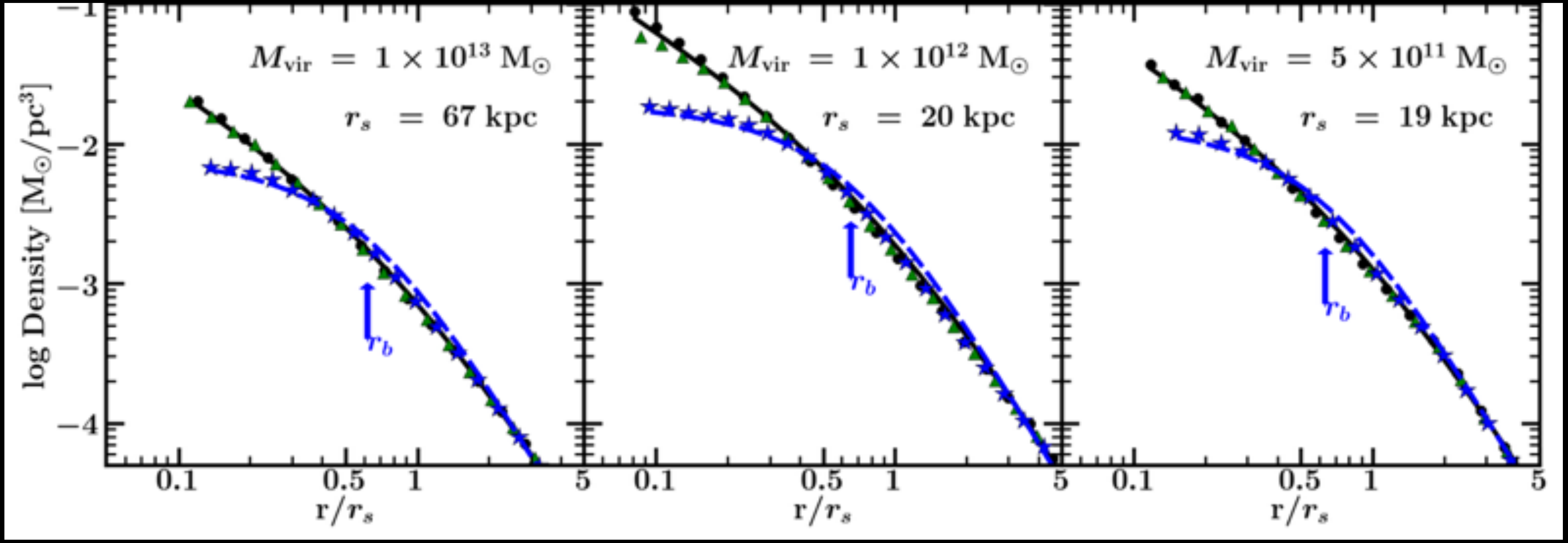
But what about the Milky Way Density Profile?

SIDM σ > 1 in dwarf galaxies predicts σ ~ 1 in the Milky Way

This produces a core with a radius ~ 10 kpc

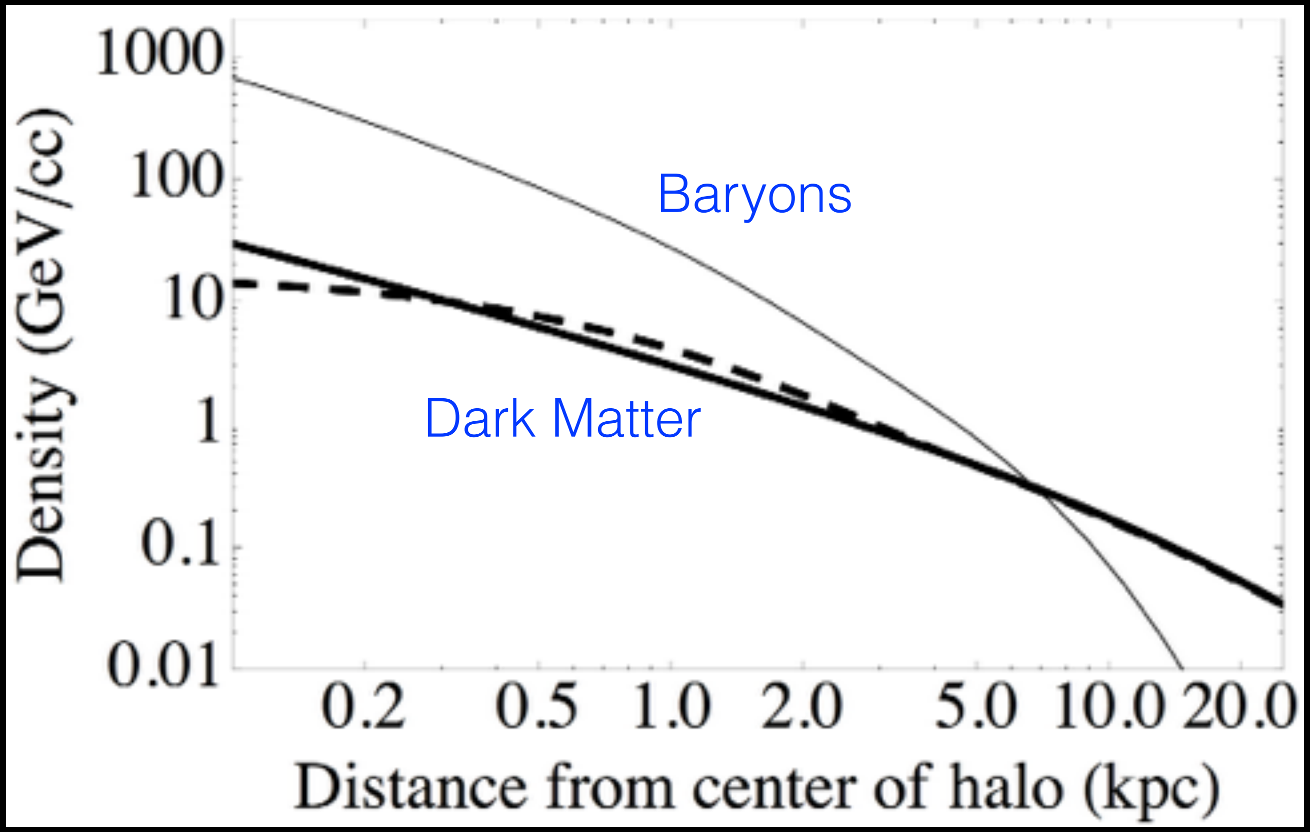


Rocha et al. (2012)

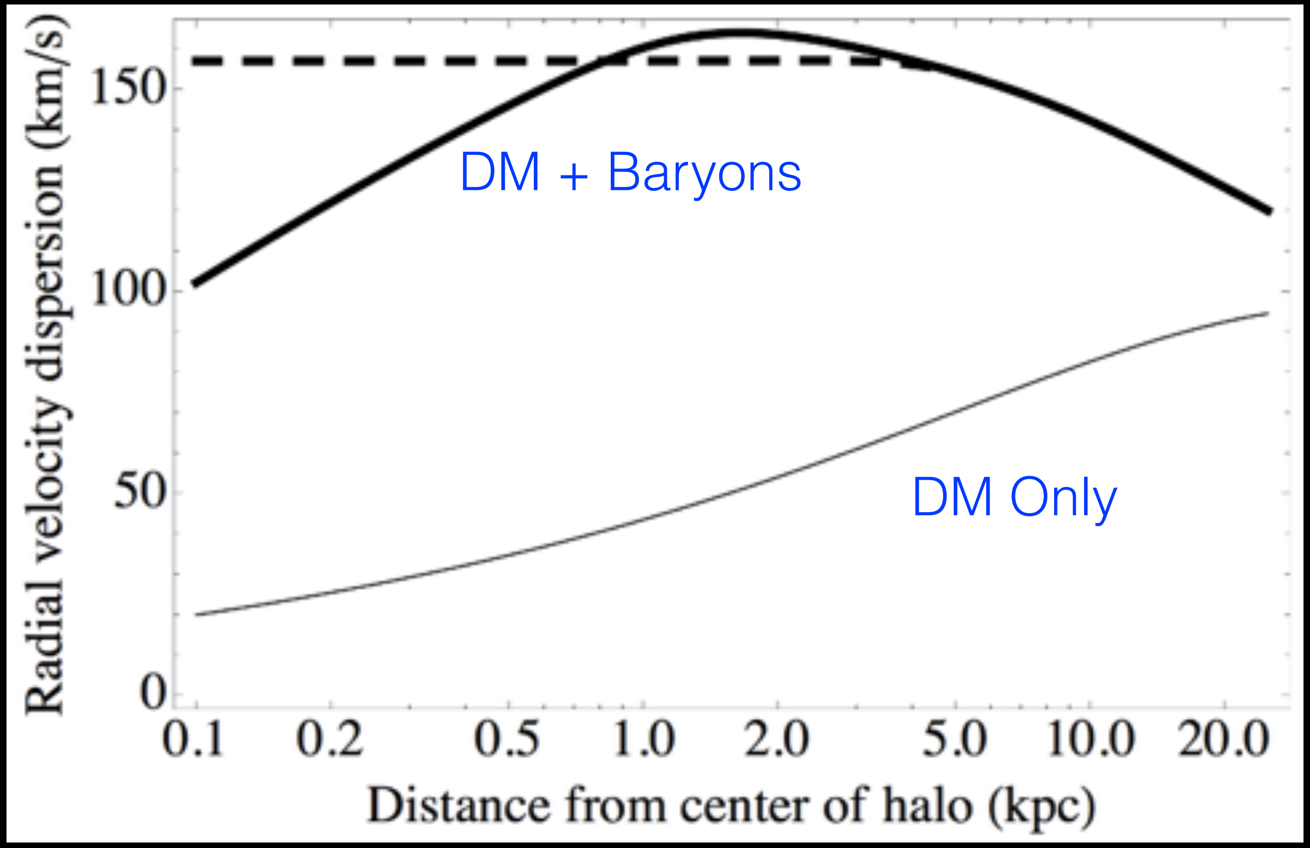


Add a Dash of Baryons

But baryons dominate the potential within 10 kpc of the Galactic Center, they must affect the DM density profile



This means that at the SIDM critical point (1 interaction) the temperature is falling, and not rising



Add a Dash of Baryons

$$\nabla_x^2 \left(h(\vec{x}) + \Phi_B(\vec{x})/\sigma_0^2\right) + \frac{4\pi G_N \rho_0 r_0^2}{\sigma_0^2} \exp\left(h(\vec{x})\right) = 0$$

Use these conditions to solve the Jeans equation for the potential, which is dominated by baryons

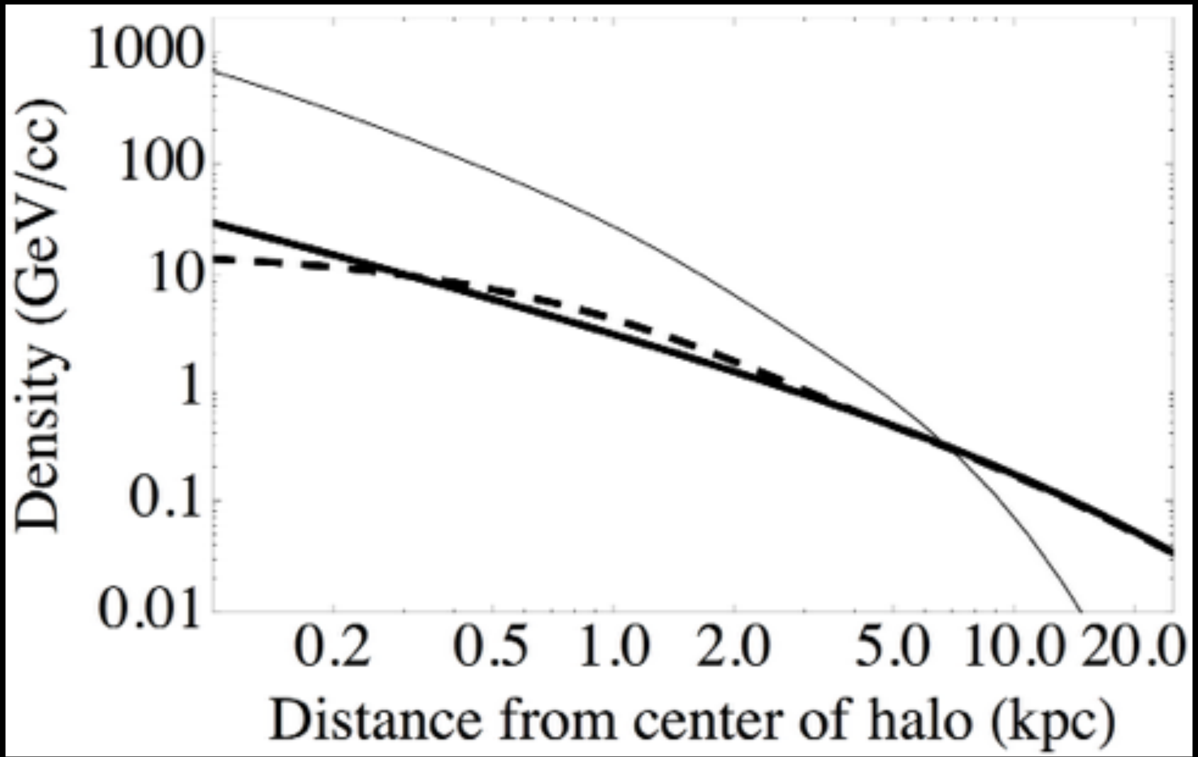
$$\frac{1}{y^2}\frac{d}{dy}\left[y^2 \frac{d}{dy} w(y)\right] + \frac{2a_1}{y} + \frac{a_0}{(1-y)^4} \exp\left[w(y)\right] = 0$$

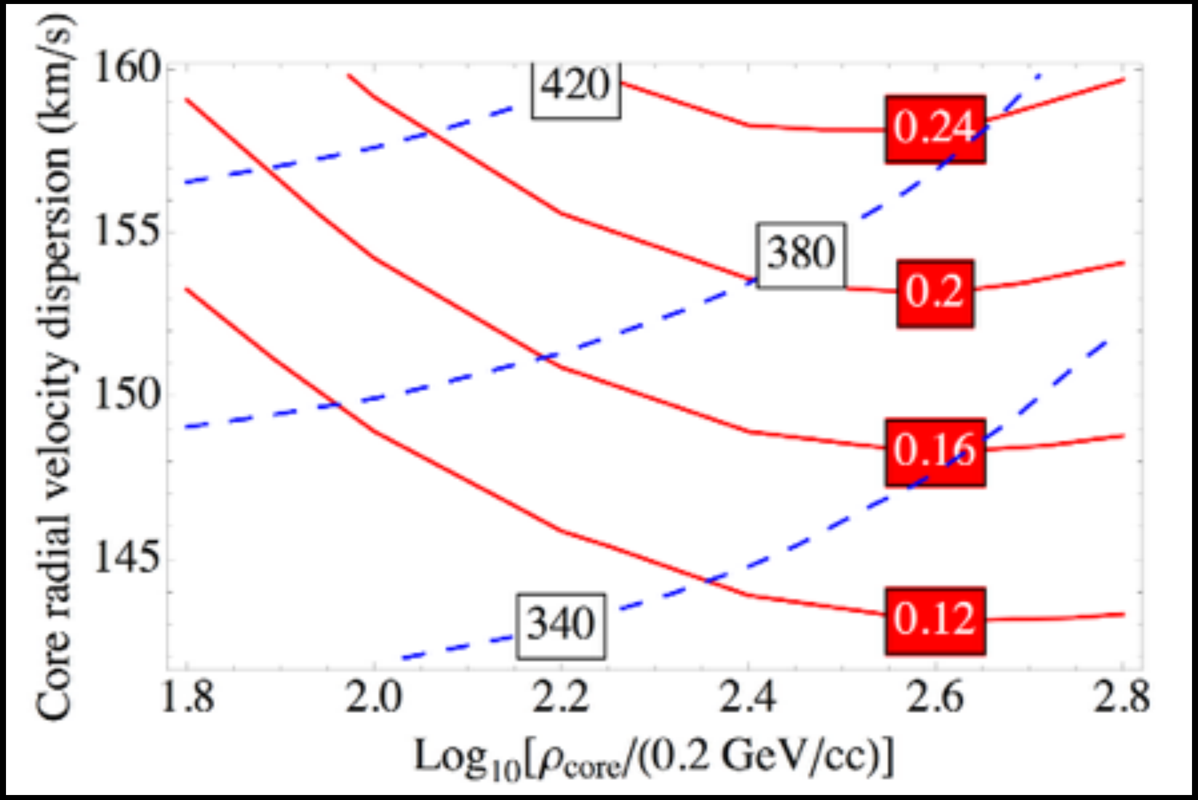
$$r_c \approx r_0 \frac{\sqrt{1 + (2/3)\ln(2) a_0/a_1^2} - 1}{1 + a_0/(3a_1) - \sqrt{1 + (2/3)\ln(2) a_0/a_1^2}}$$

Add a Dash of Baryons

Analytically solving the Jeans equation produces a dark matter density profile which increases until the inner few hundred pc

Density profile ends up being comparable to NFW - less steep within inner 200 pc, steeper from 200 - 4000 pc

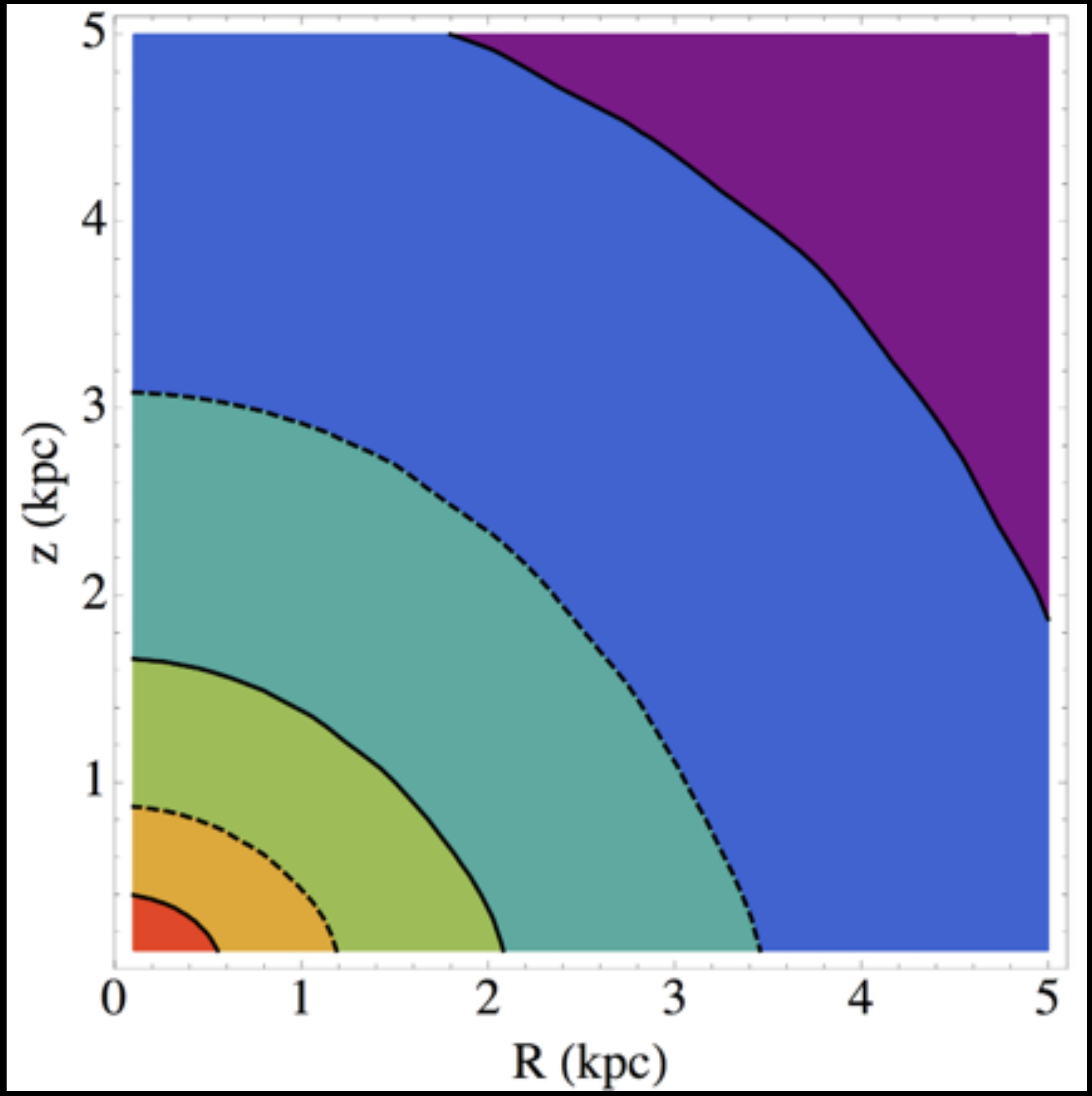


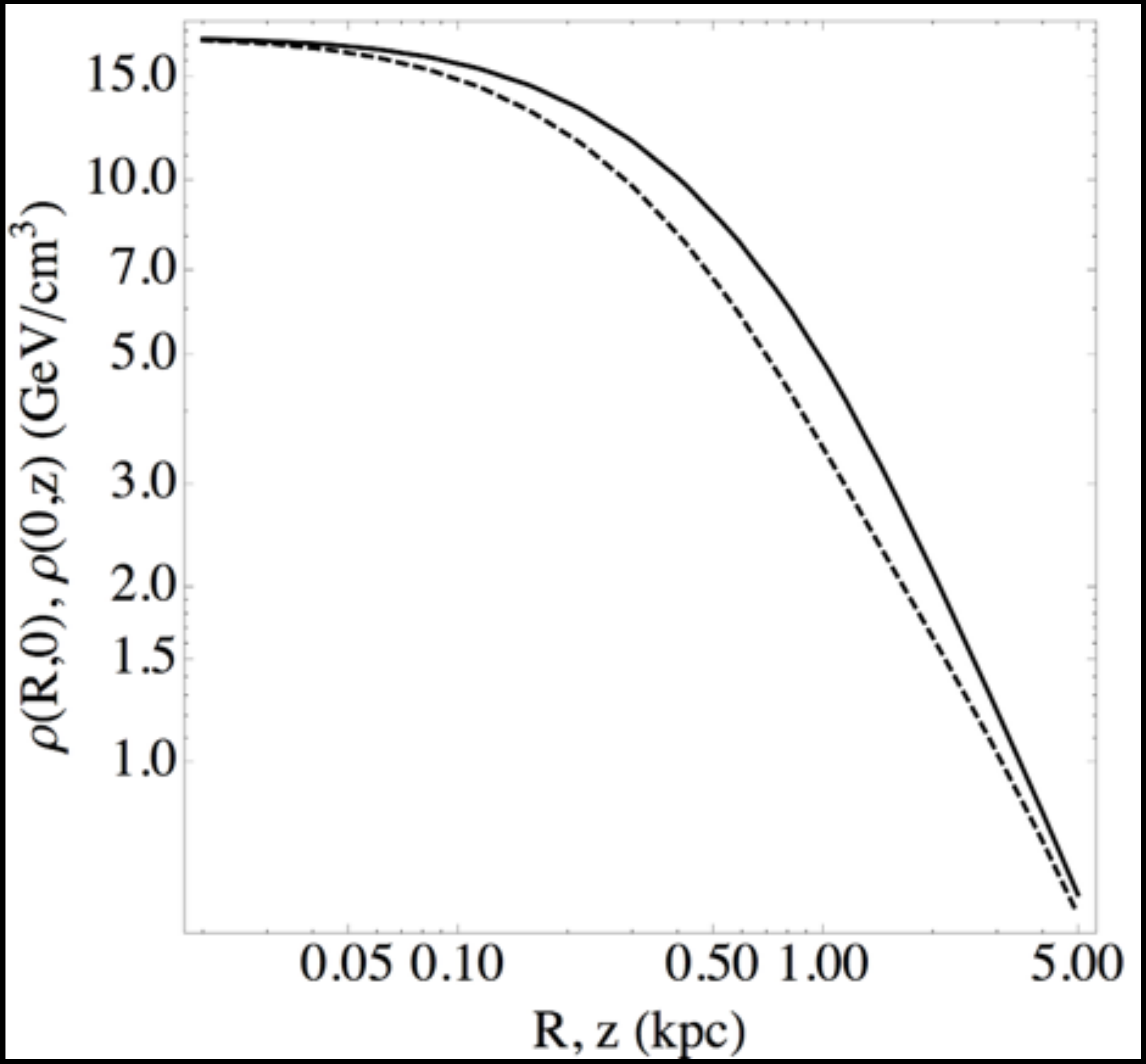


Add a Dash of Baryons

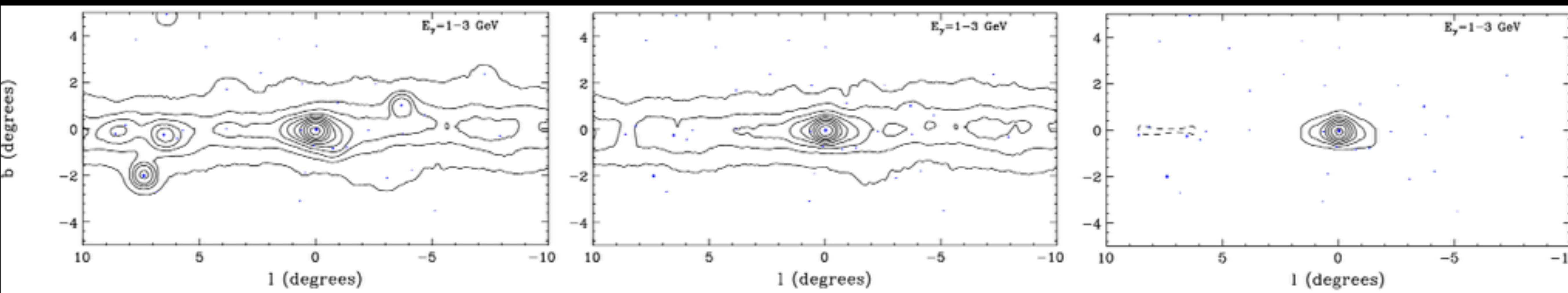
Can also solve in 2D!

$$\nabla_x^2 \left(h(\vec{x}) + \Phi_B(\vec{x})/\sigma_0^2\right) + \frac{4\pi G_N \rho_0 r_0^2}{\sigma_0^2} \exp\left(h(\vec{x})\right) = 0$$

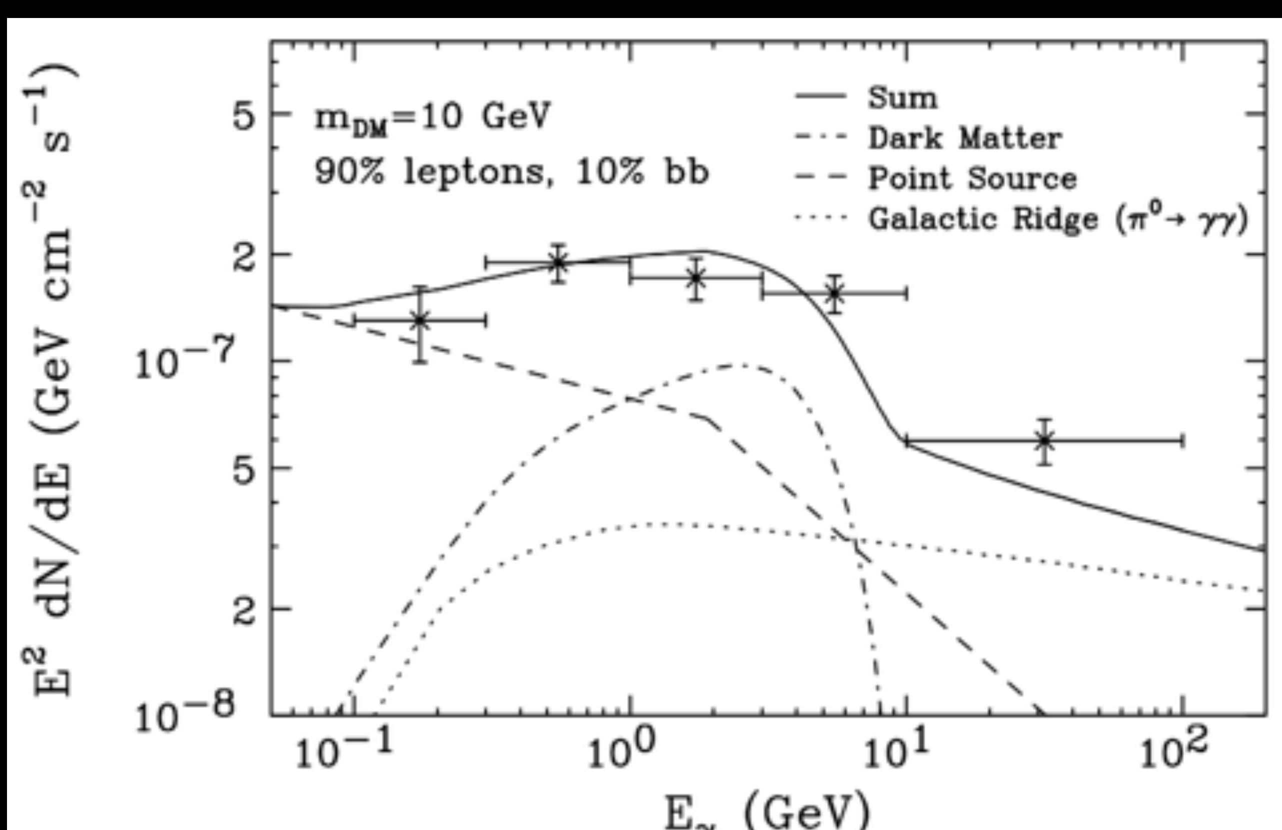


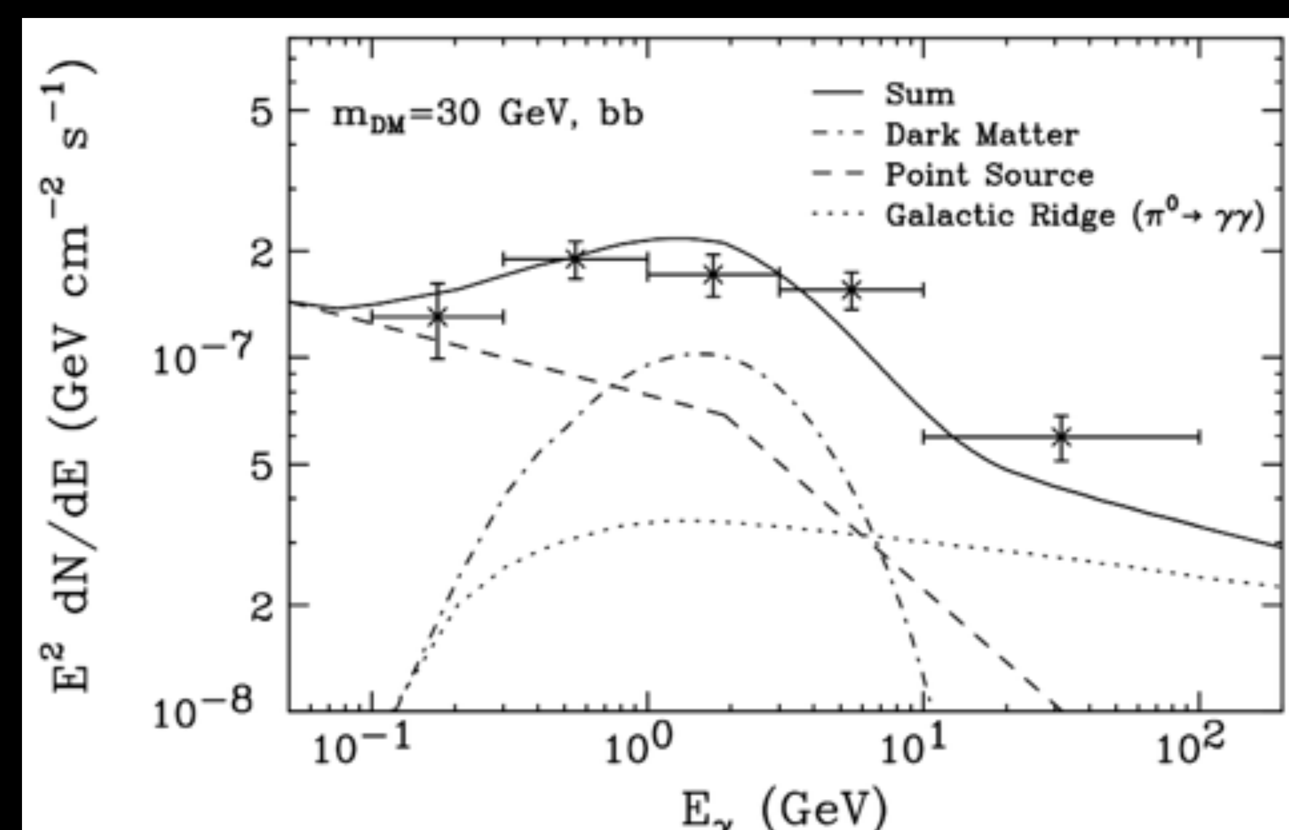


Gamma-Rays from The Galactic Center



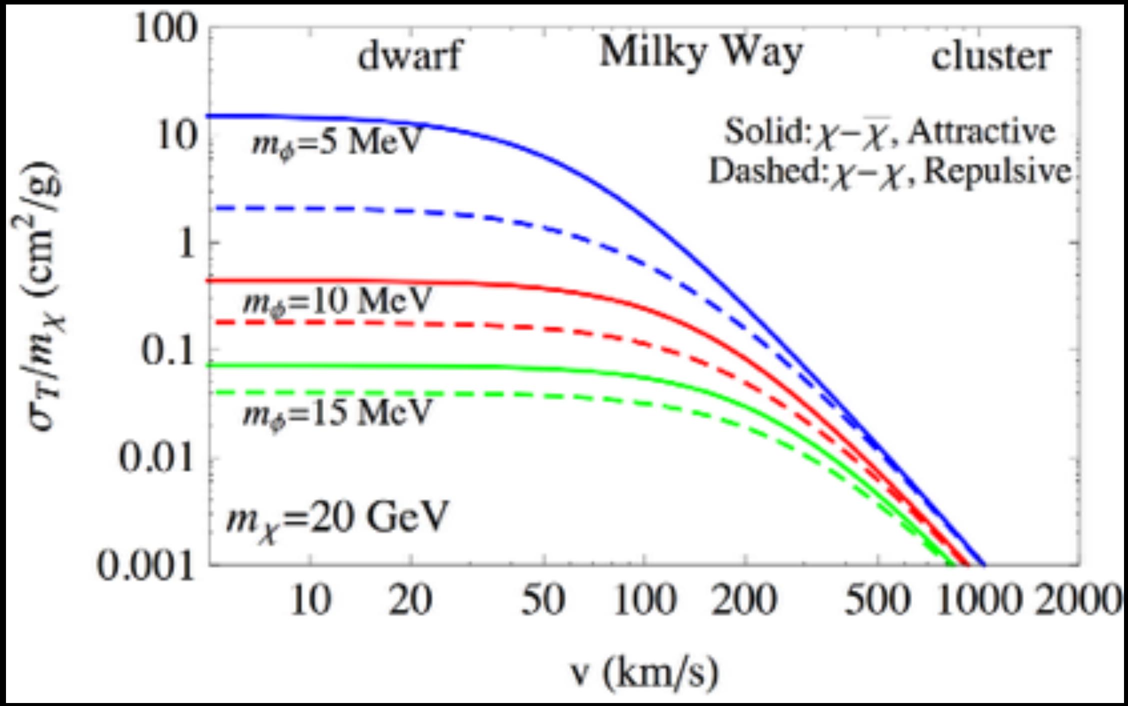
Hooper & Linden (2011)





Particle Physics Model

Remember SIDM mediator mass is < 20 MeV

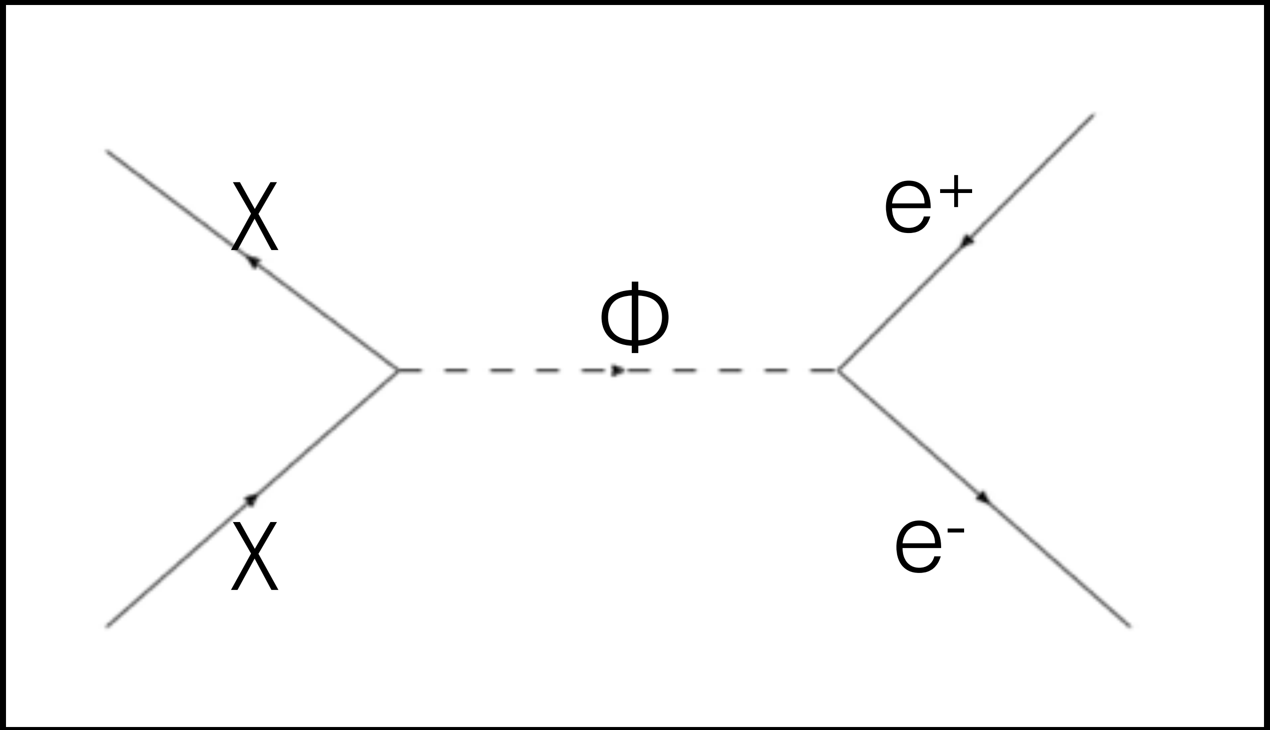


Annihilations through mediator can produce only e^+e^-

$$\mathcal{L}_{\rm int} = g_\chi \bar{\chi}\gamma^\mu \chi \phi_\mu + \frac{\epsilon_Y}{2}\phi^{\mu\nu}B_{\mu\nu}$$

$$\Omega_\chi h^2 \simeq 0.11\, \xi_f \left[\frac{4.4\times 10^{-26}\ {\rm cm^3/s}}{\langle \sigma v\rangle_{\rm ann}}\right]$$

$$\rho_{DM}(r) = \begin{cases} 0.2\ \frac{\rm GeV}{\rm cm^3}\left(\frac{r_\odot^2+r_c^2}{r^2+r_c^2}\right), & {\rm r} \le r_1 \simeq 15\ {\rm kpc}. \\ 0.065\ \frac{\rm GeV}{\rm cm^3}\left(\frac{r_1(r_1+r_s)^2}{r(r+r_s)^2}\right), & {\rm r} > r_1\ {\rm kpc}. \end{cases}$$



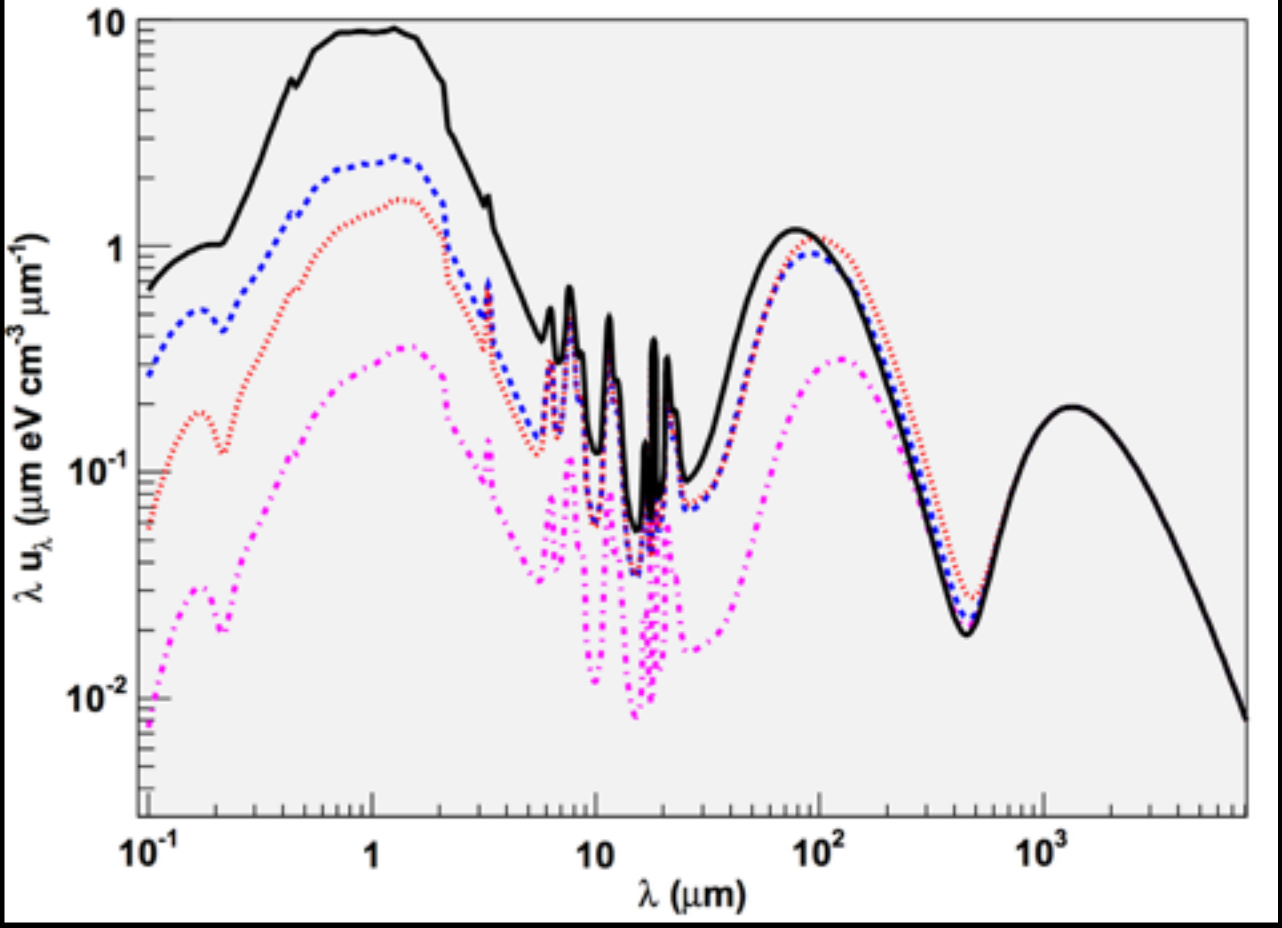
We choose M_{DM} = 20 GeV

Gamma-Rays from The Galactic Center

Now that SIDM has a large dark matter density around the GC, can you explain the GC excess with SIDM?

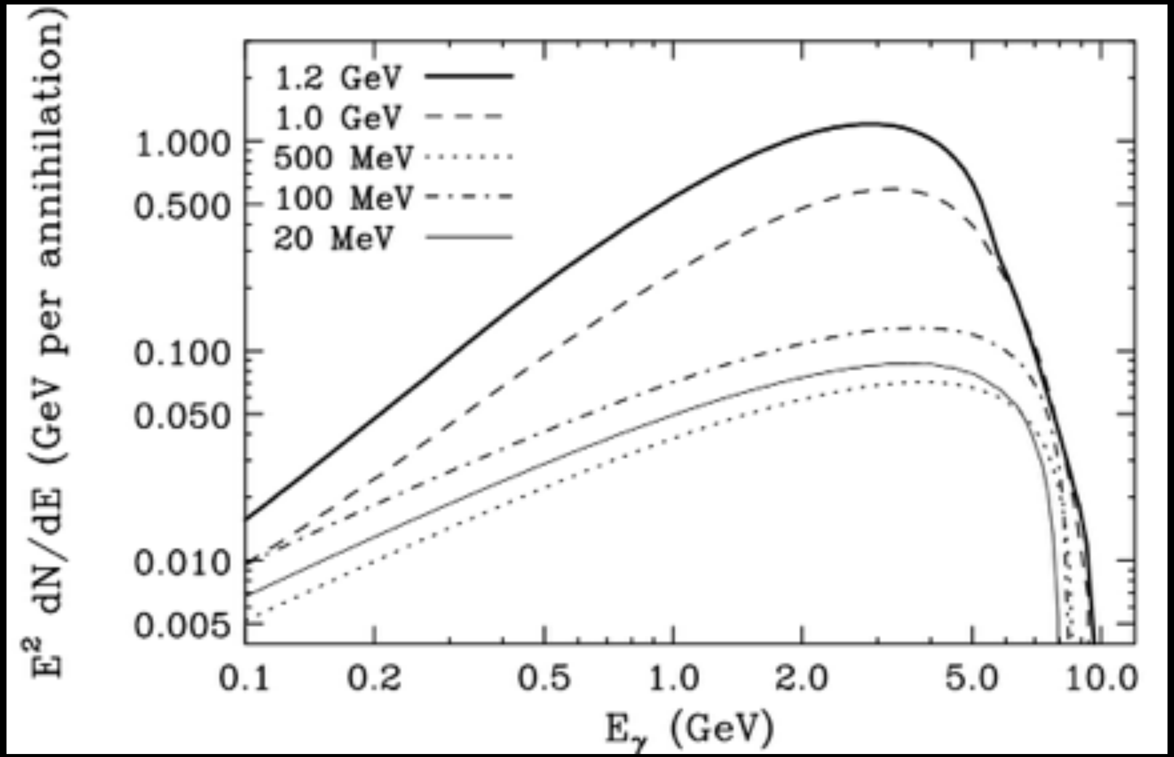
Annihilation to e^+e^- only

Need some mechanism to produce gamma-rays



Porter et al. (2006)

What about Inverse Compton Scattering?

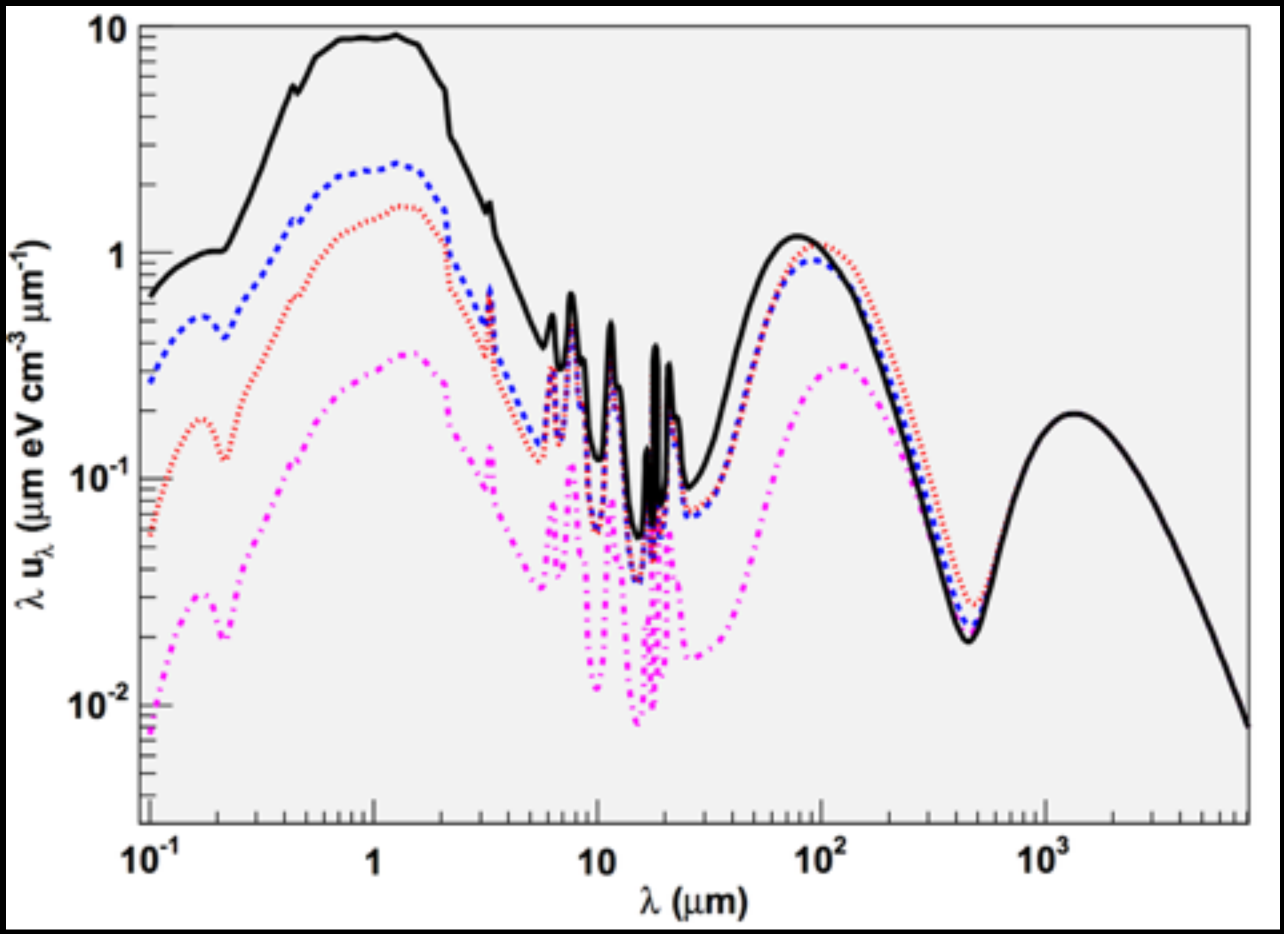


FSR intensity is small

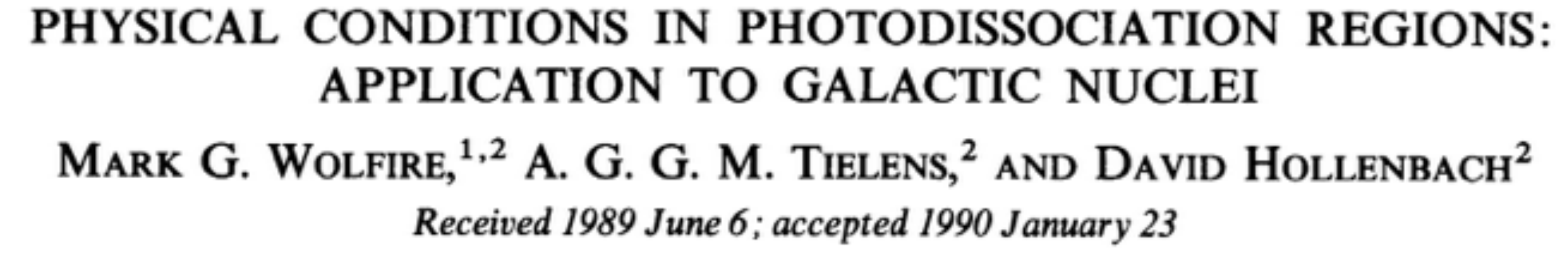
Hooper et al. (2012)

Gamma-Rays from The Galactic Center

In fact, the ISRF near the GC is much more intense than this, and dominates the magnetic field density within 10 pc of the GC



Porter et al. (2006)



PHYSICAL CONDITIONS IN PHOTODISSOCIATION REGIONS: APPLICATION TO GALACTIC NUCLEI

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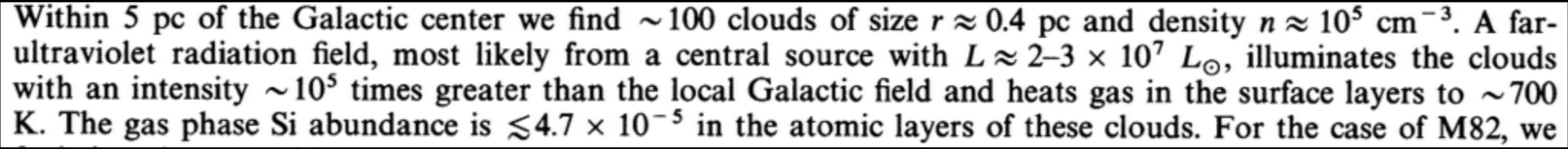


Within 5 pc of the Galactic center we find ~100 clouds of size $r \approx 0.4$ pc and density $n \approx 10^5$ cm^{-3}. A far-ultraviolet radiation field, most likely from a central source with $L \approx 2\text{–}3 \times 10^7$ $L_\odot$, illuminates the clouds with an intensity ~10^5 times greater than the local Galactic field and heats gas in the surface layers to ~700 K. The gas phase Si abundance is $\lesssim 4.7 \times 10^{-5}$ in the atomic layers of these clouds. For the case of M82, we

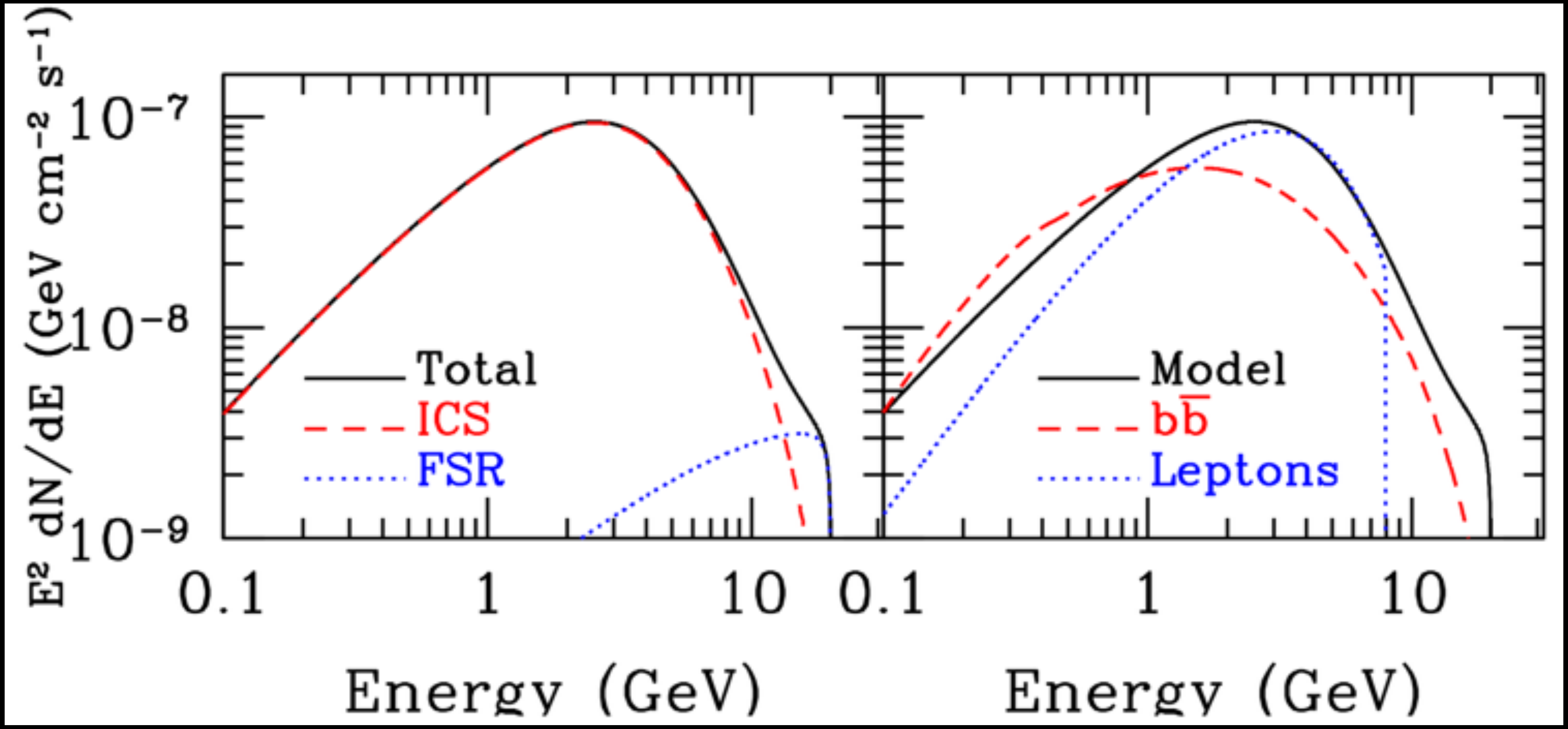
The Gamma-Ray Spectrum

Multiple Uncertainties:

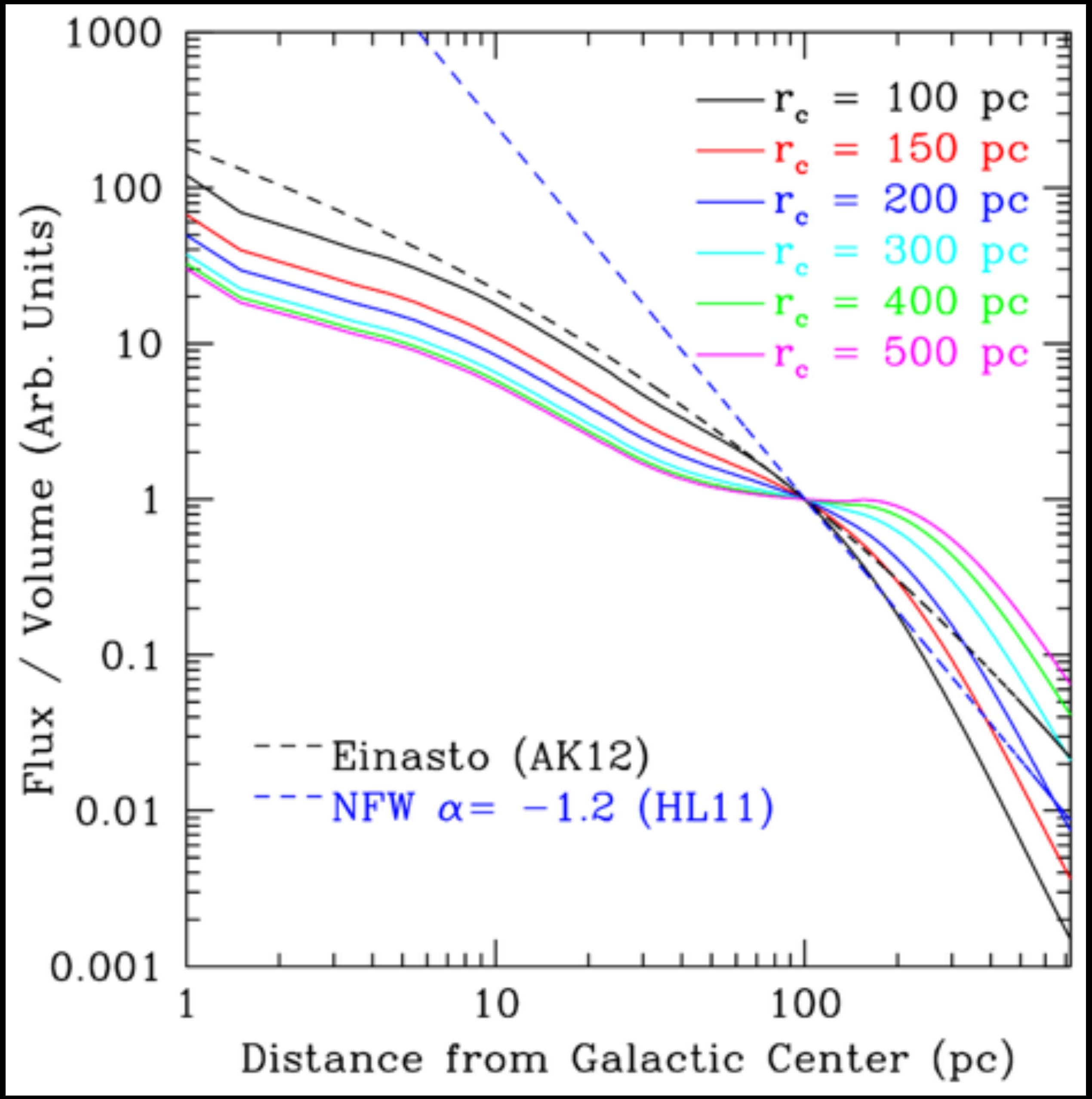
Electron Diffusion Length and Energy Loss

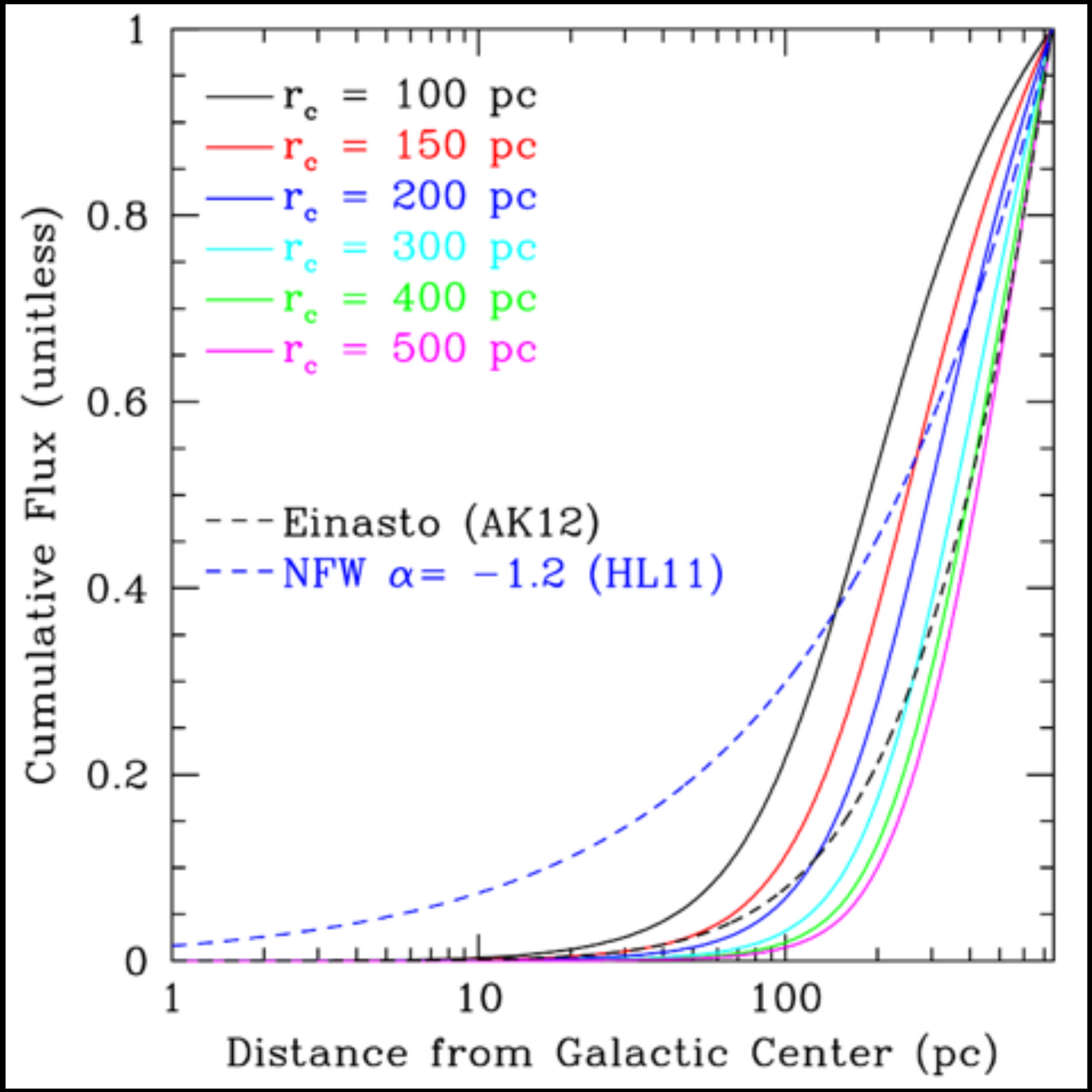
Magnetic Field Strength and ISRF Energy Density

Plus Normal Uncertainties (Cross-Section, DM Density, Mass etc.)



The Gamma-Ray Morphology





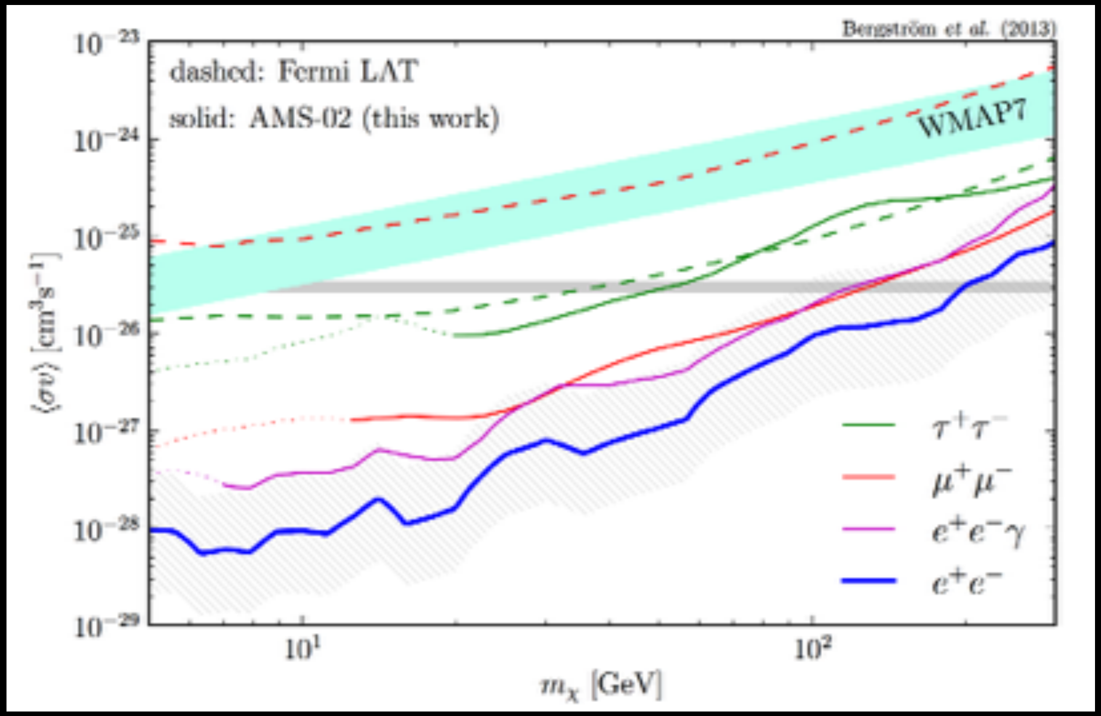
Local Positron Excess

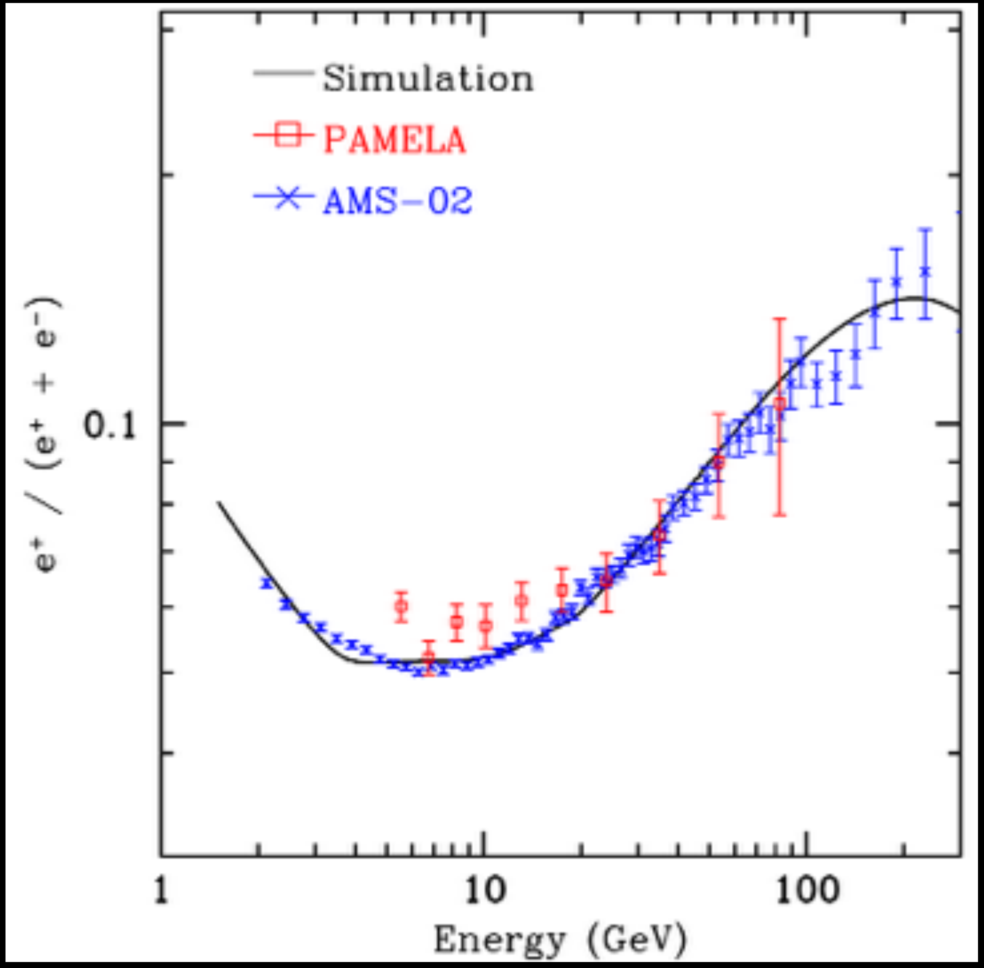
This SIDM model should also be highly detectable by AMS-02, as a bump in the positron excess

This is currently avoidable so long as:

- DM Annihilation is sub thermal ($< 6 \times 10^{-27}\ cm^3 s^{-1}$)
- The local density is slightly low ($\sim 0.2\ GeV\ cm^{-3}$)

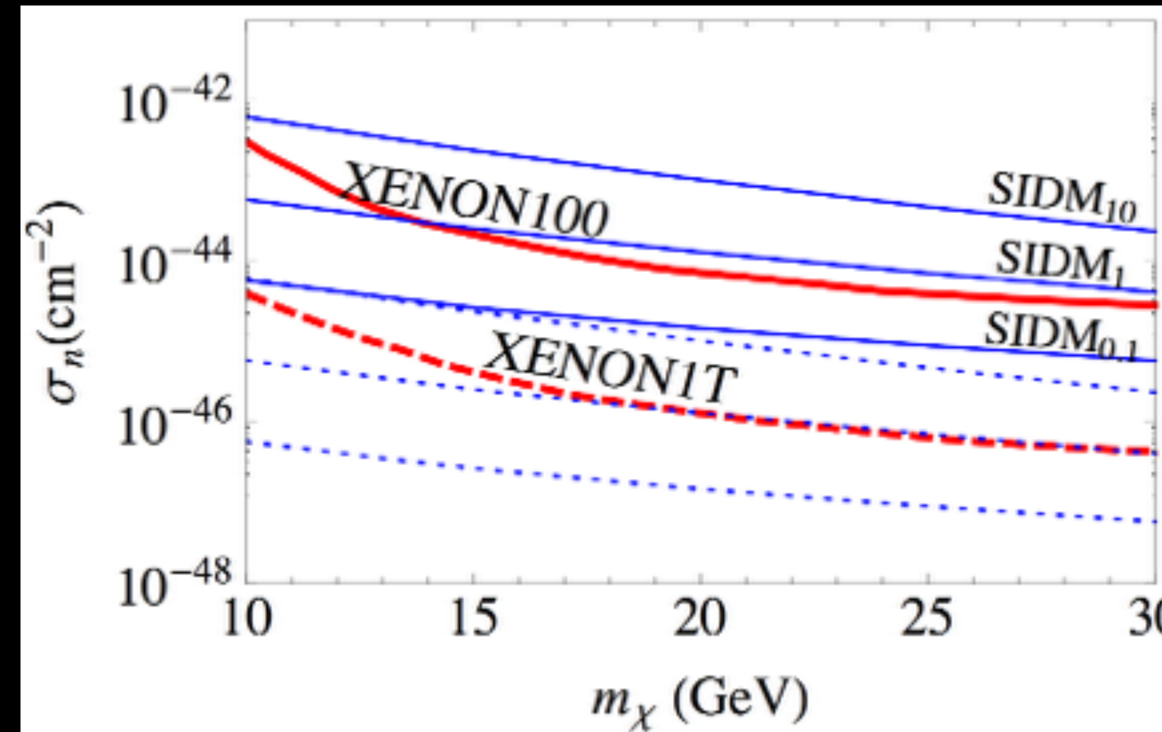
Should strongly test models in next few years

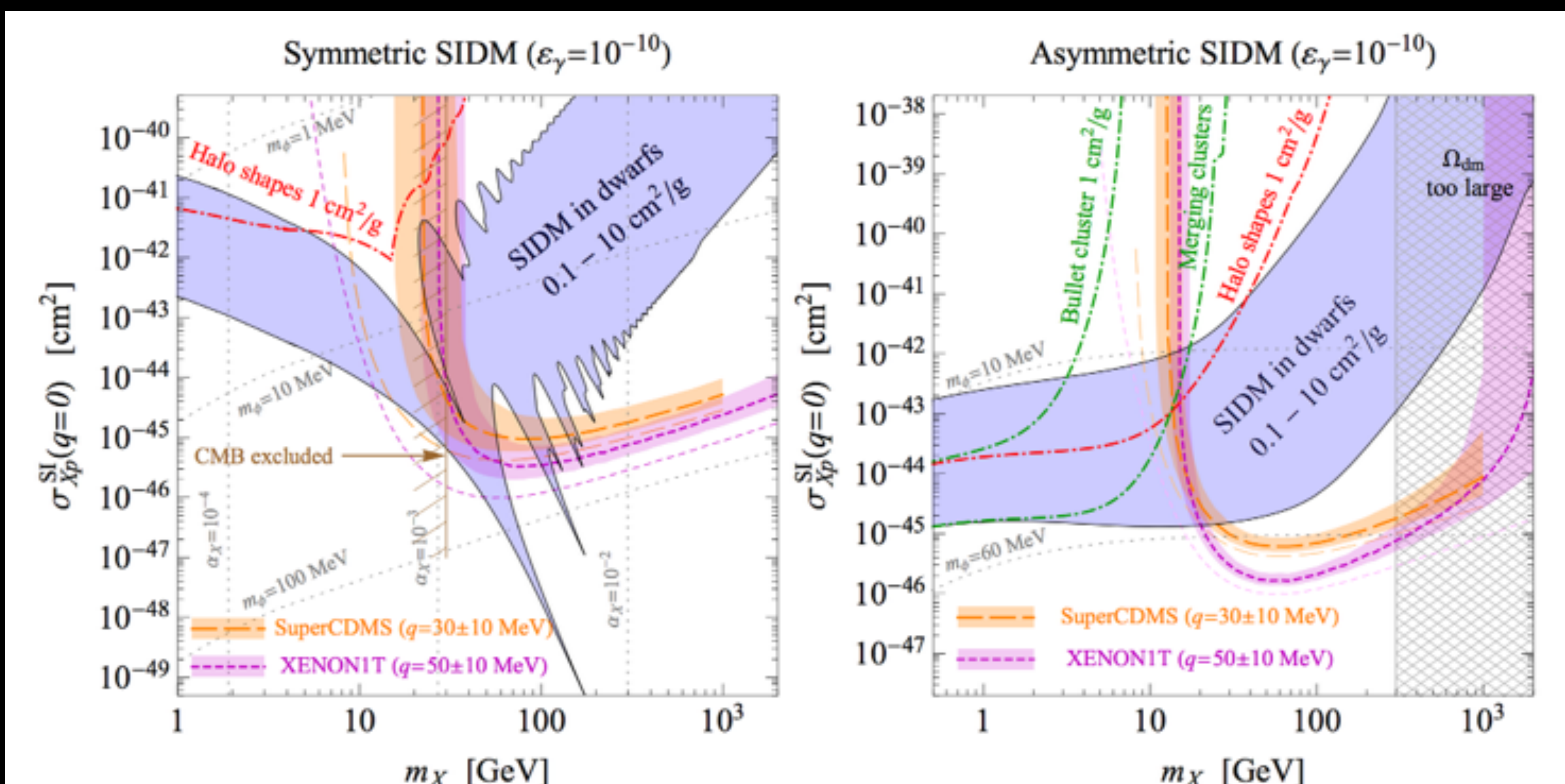




Dark Matter Direct Detection

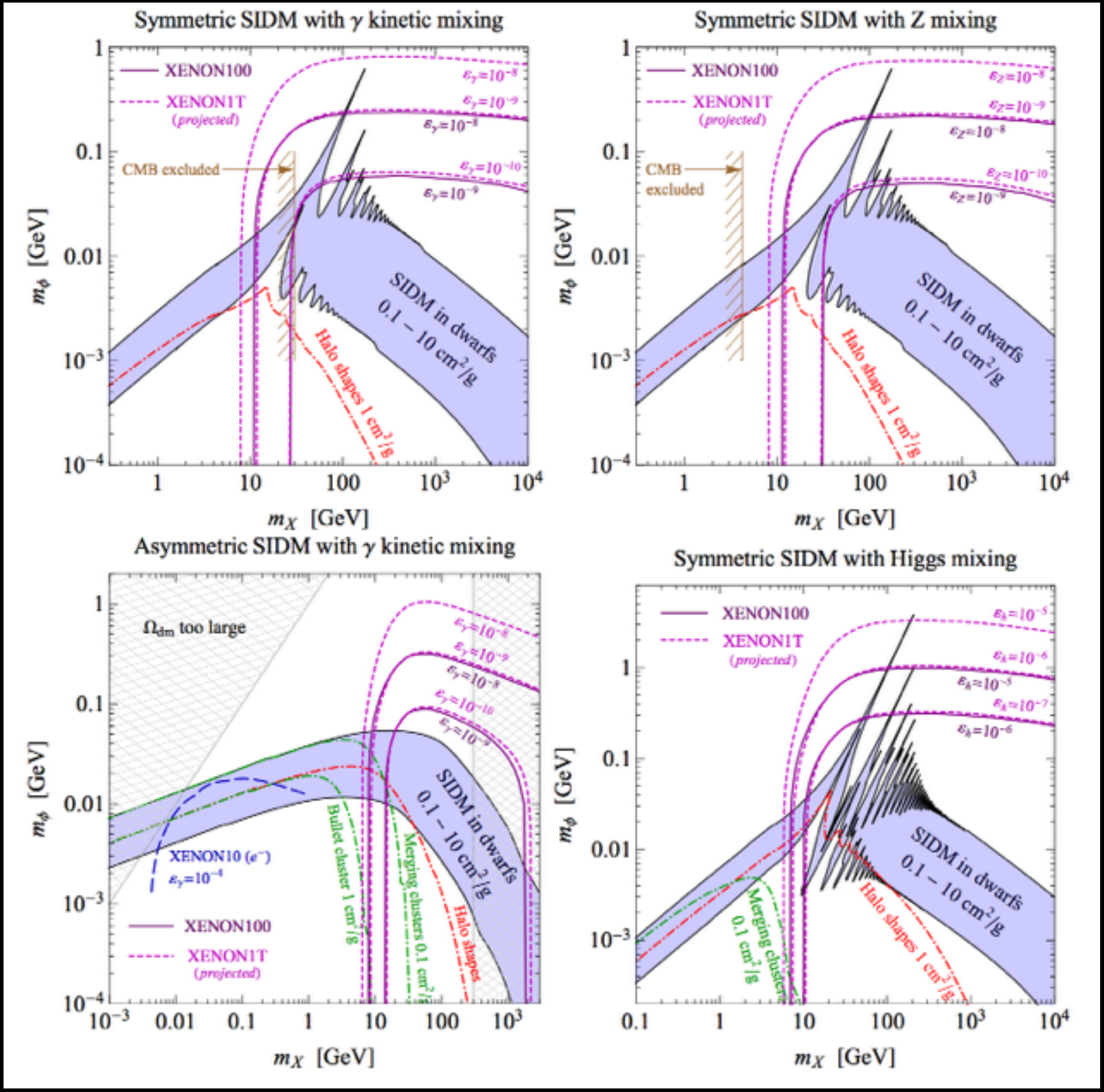
Future ton-scale direct detection experiments can also rule out much of the SIDM parameter space





Kaplinghat et al. (2013)

Dark Matter Direct Detection



Kaplinghat et al. (2013)

Conclusions

SIDM is an interesting empirical dark matter model, it solves many problems with small scale structure

Until recently, it was thought that the Indirect Detection of SIDM was difficult, since high densities would not be observed - but this is not true in systems dominated by a baryonic potential

Interestingly, SIDM produces very good fits to the observed GC excess