Signals of asymmetric dark matter from galactic center pulsar implosions

VIA Lecture

Joseph Bramante
Feb. 20, 2015

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Dark matter may soon be discovered in nuclear/electron recoils, nuclear/electron collisions, or electromagnetic oscillations.

But in order to fundamentally advance understanding of the universe's symmetries, we must determine what is stabilizing the dark matter abundance and how it was primordially produced.

The hardest task will be to identify and categorize the interactions dark matter may have with other dark particles.

There are many possible handles on this — the collision of galaxies in bullet clusters, the inferred velocity dispersion of dwarf, spiral, and elliptic halos, and acoustic oscillations in and the normalization of the primordial power spectrum.

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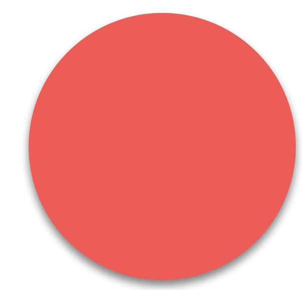
In a very futuristic setting, the interactions (C,CP violating) that lead to a dark asymmetry might be revealed through something like a pulsed collider + kamioka program.

This talk suggests that on a much shorter timescale, old pulsars in the galactic center imploding into black holes could be a signal of asymmetric dark matter. This signal relies on the fact that annihilating dark matter cannot copiously collect in pulsars to form black holes.

A neutron star is a ball of fermions formed from the supernova of a 10 solar mass progenitor star.

$$N_f = \frac{m_{pl}^3}{m_X^3}$$



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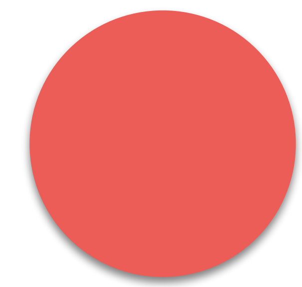

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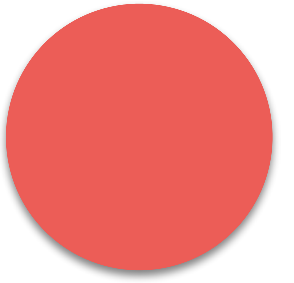

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Of course, these collapse bounds will apply to both visible and dark matter.

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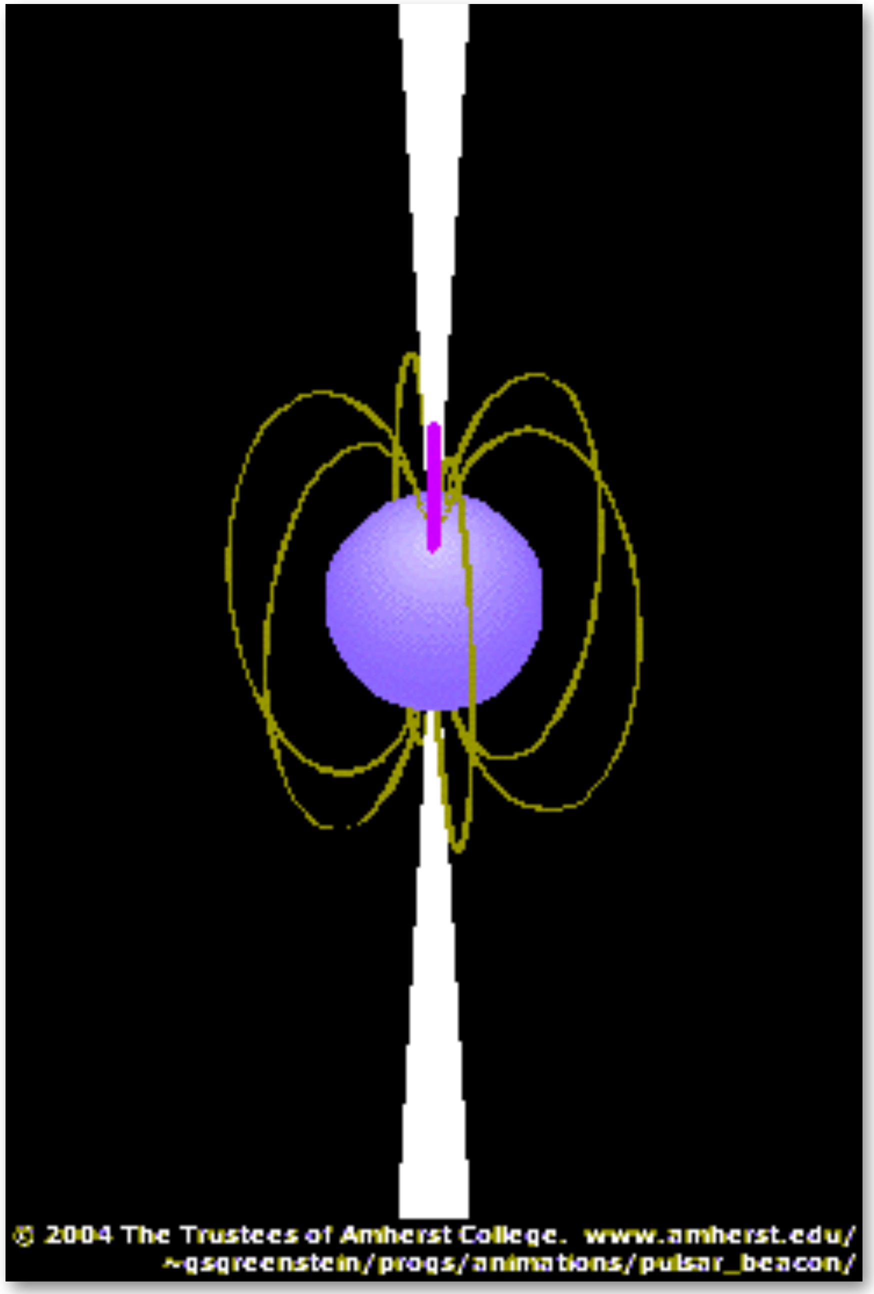

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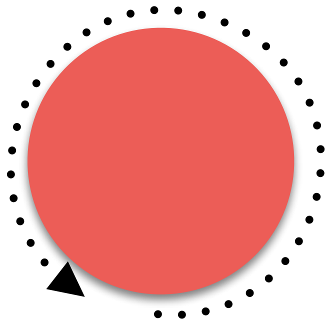

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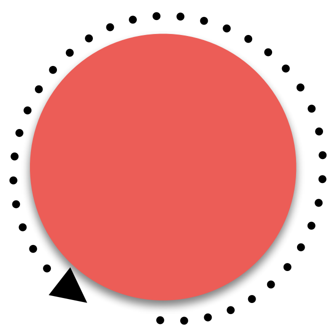

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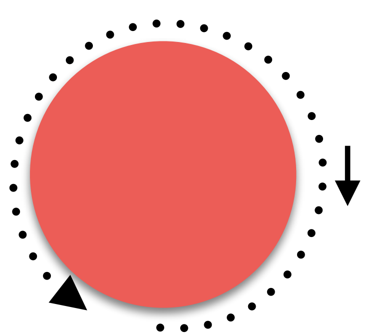

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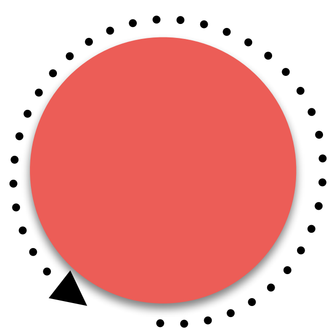

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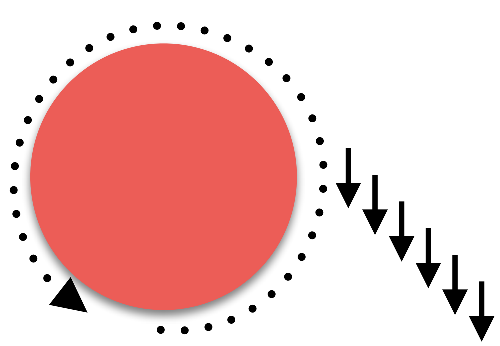

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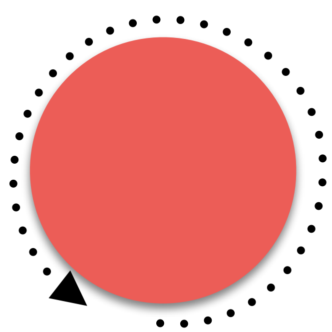

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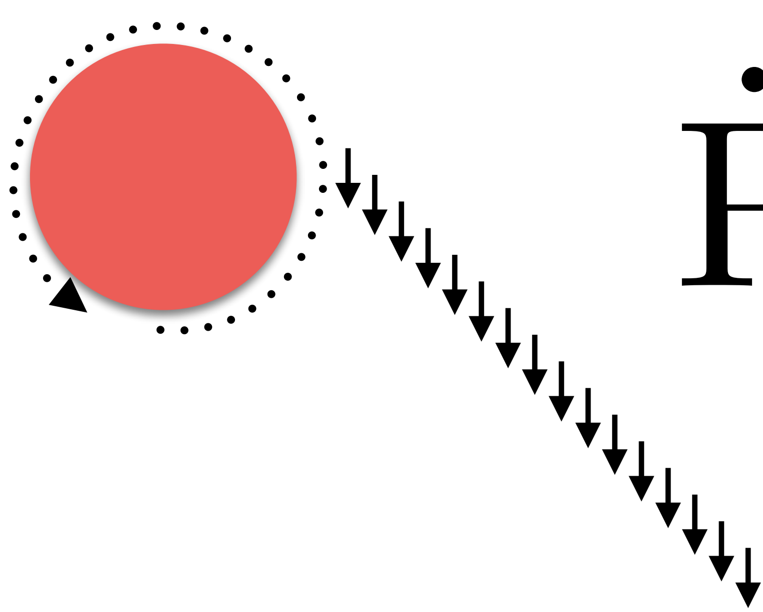

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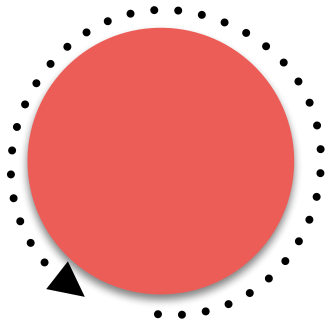

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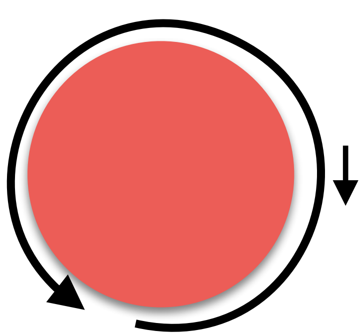

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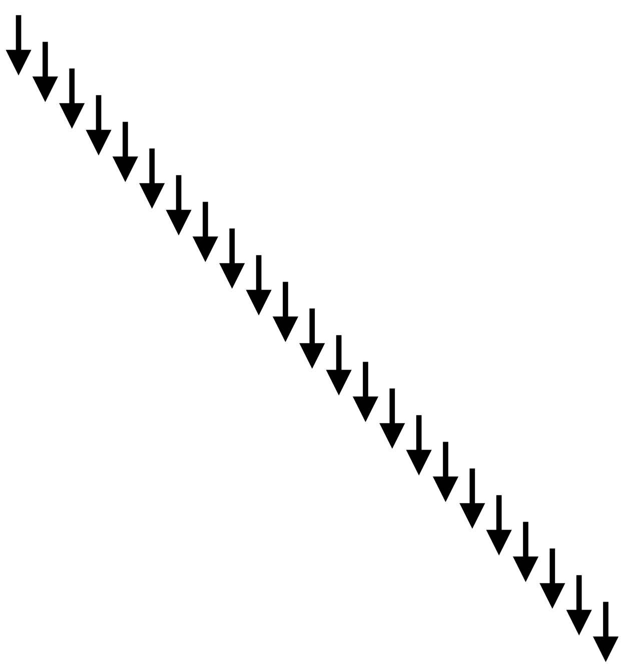

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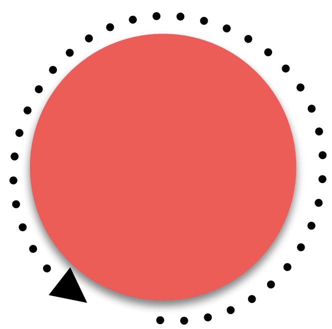

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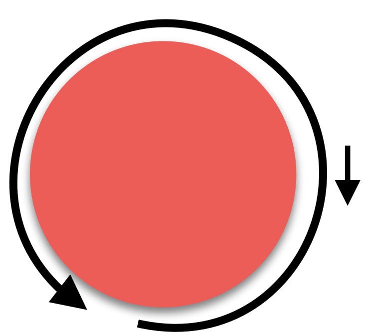

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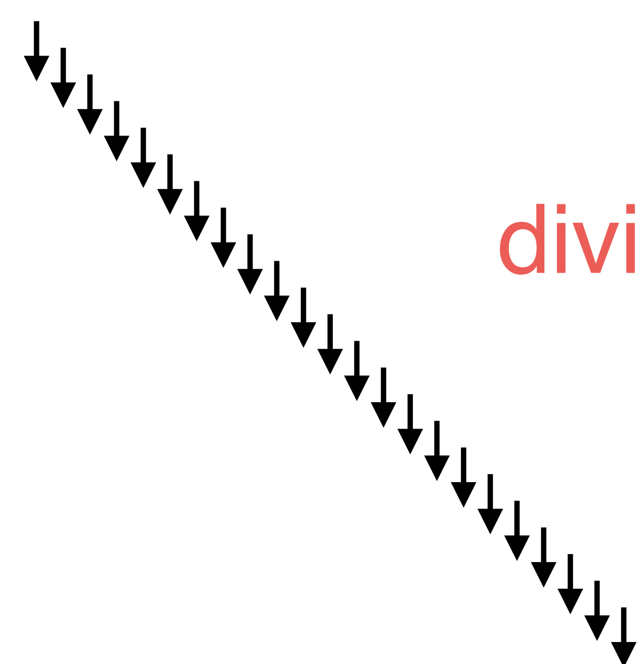

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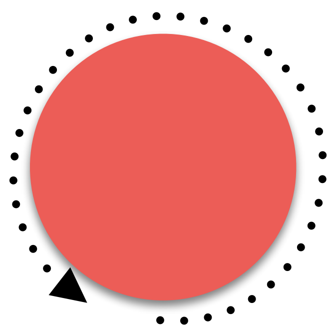

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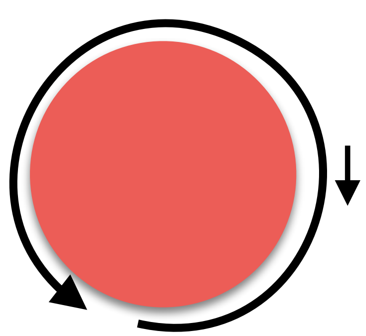

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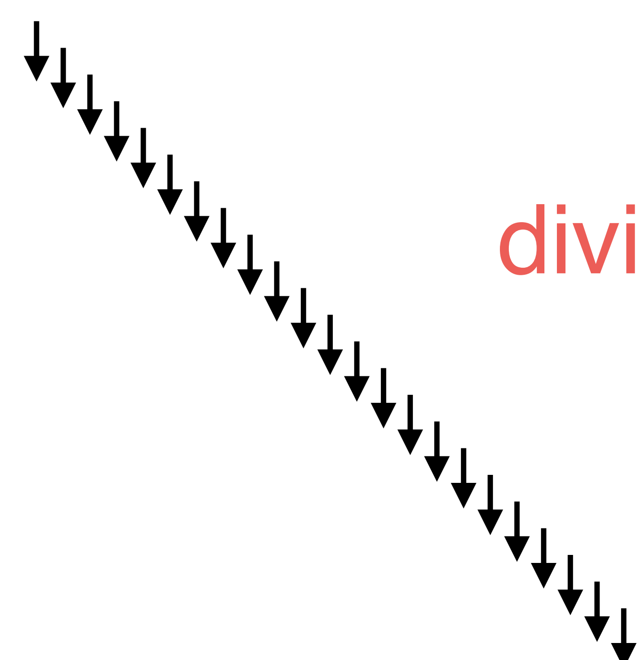

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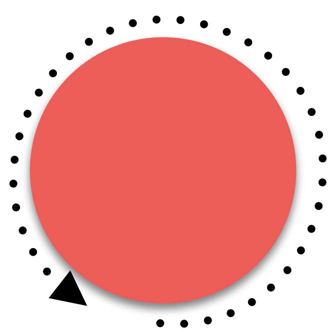
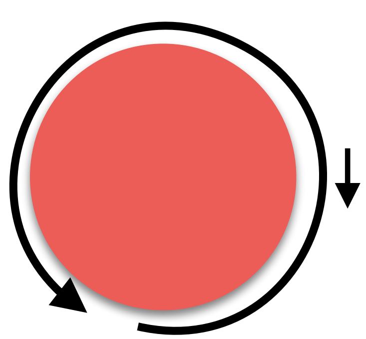


$$\mathrm{P}$$

$$t_{NS} = \frac{\mathrm{P}}{2\dot{\mathrm{P}}}$$



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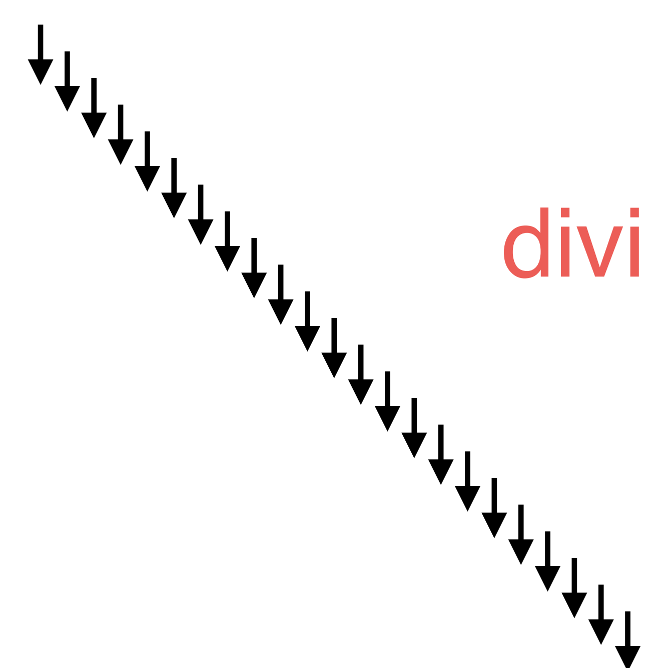
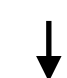


divided by 

Now we know how old pulsars are, and that either Heisenberg or Fermi pressure stabilizes compact matter.

We can now discuss pulsar-destroying black holes formed from dark matter collected in pulsars.

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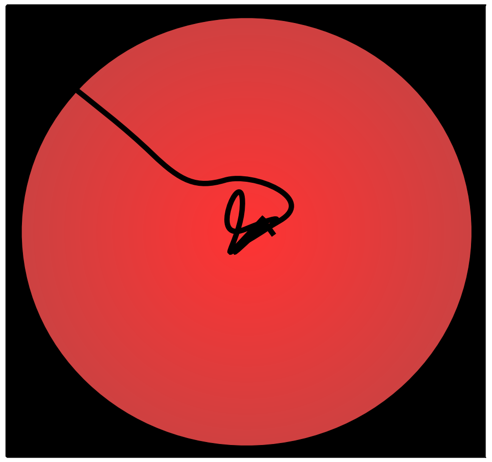

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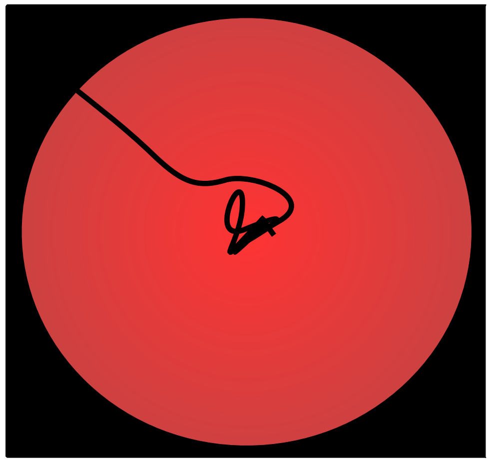

$$C_X \propto \frac{\rho_X}{\bar{v}} \sigma_{nX}$$

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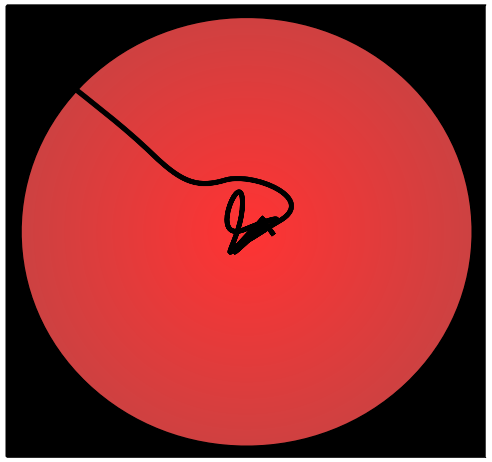

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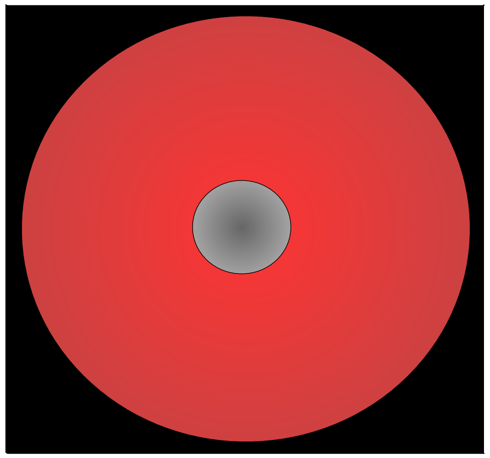

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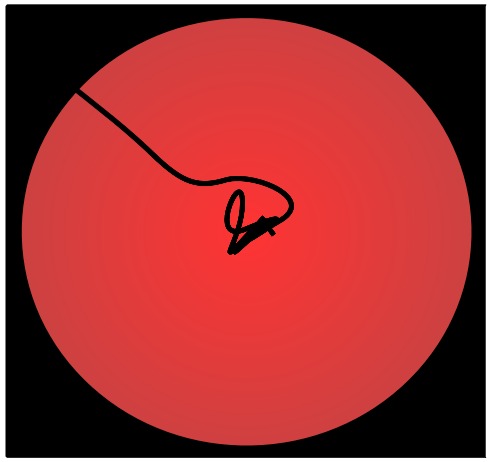

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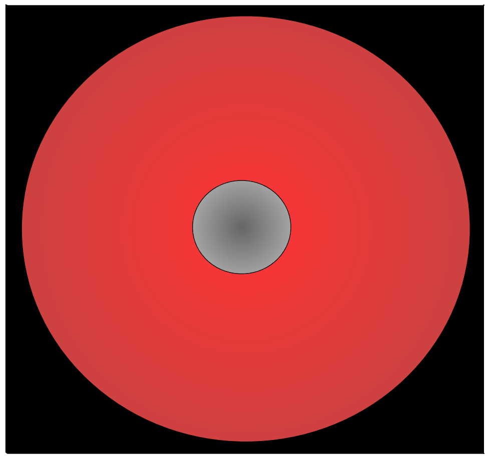

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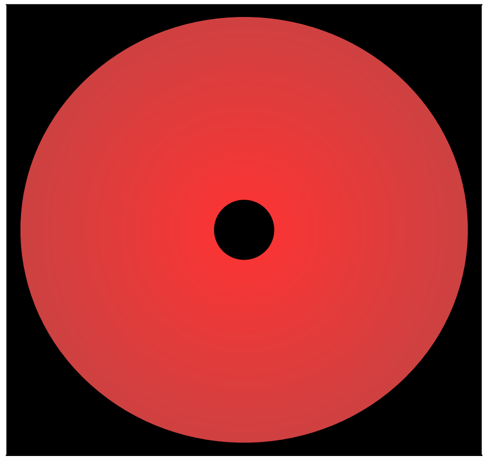

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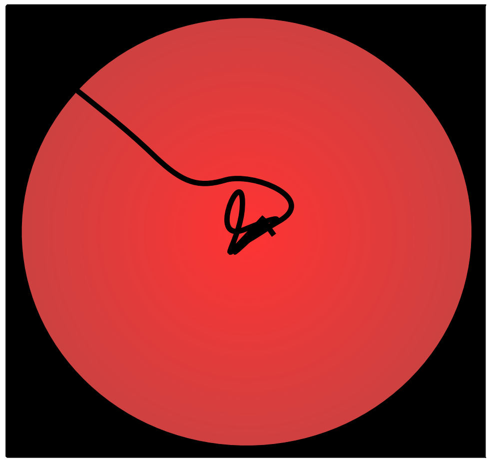

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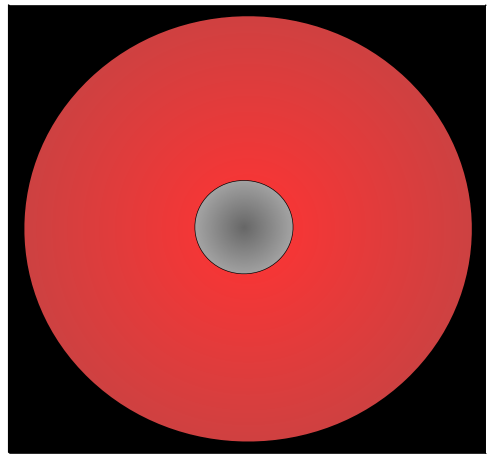

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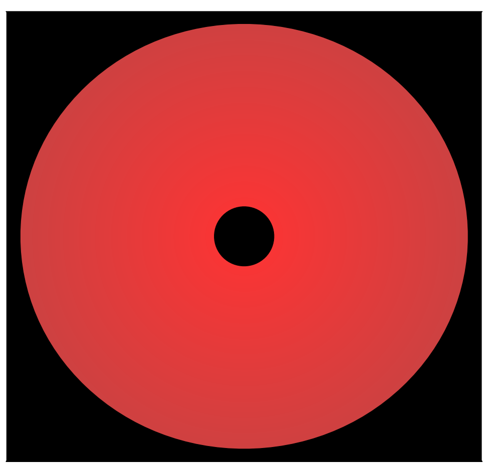

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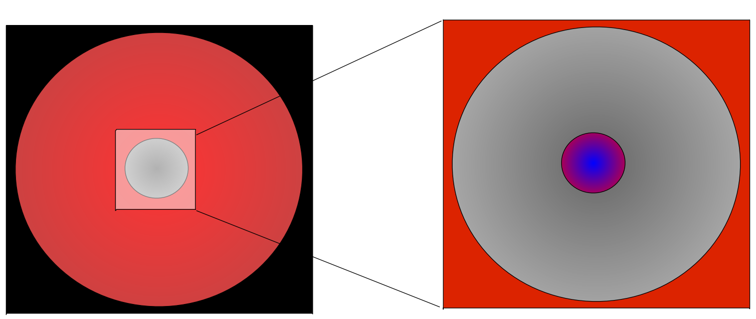

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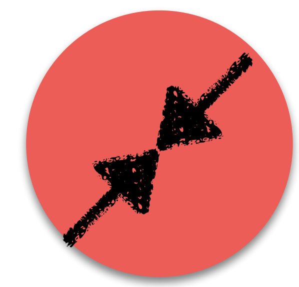

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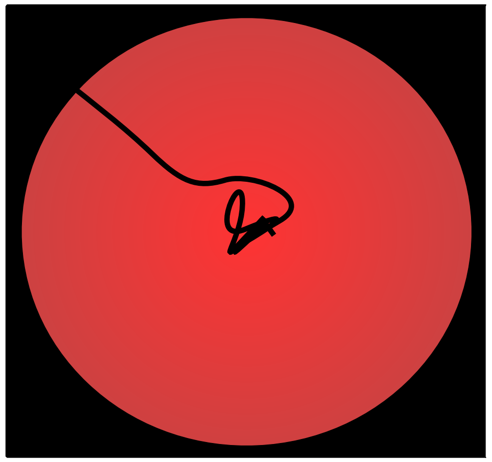

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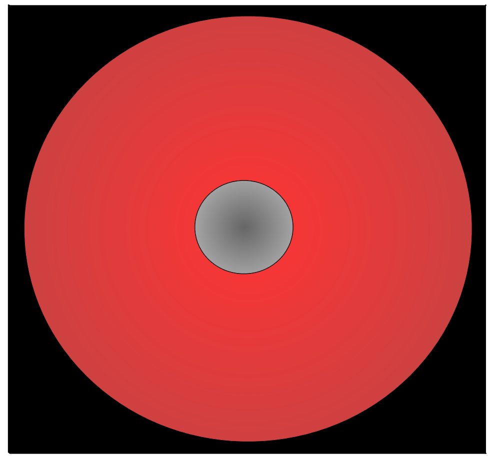

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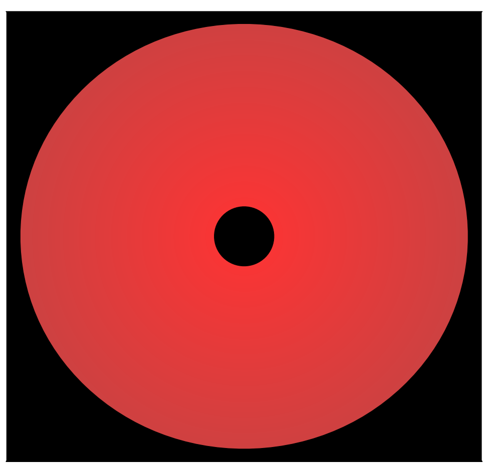

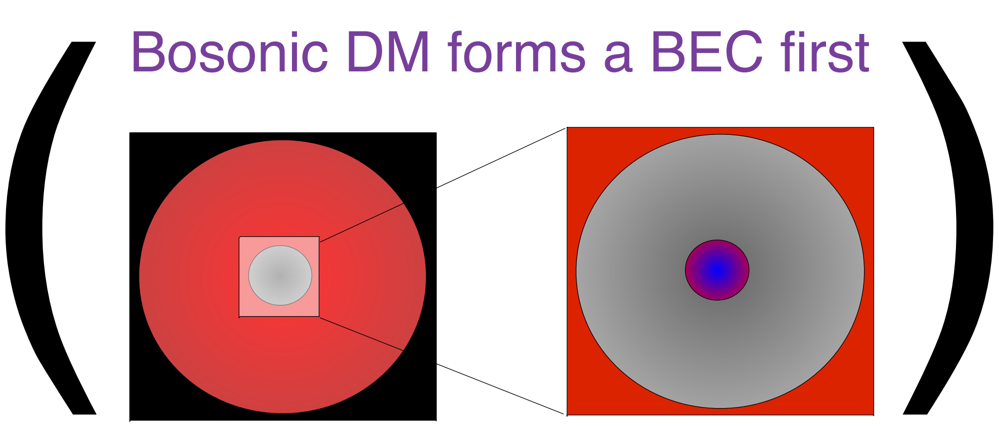

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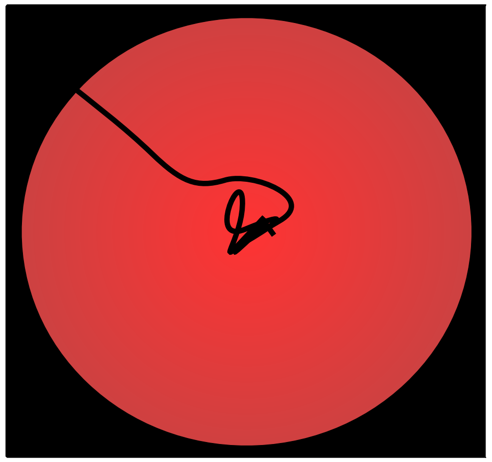

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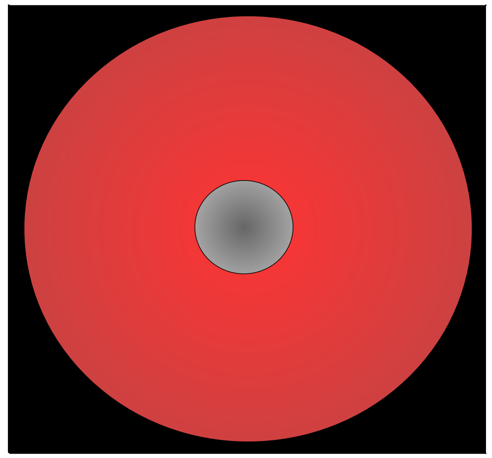

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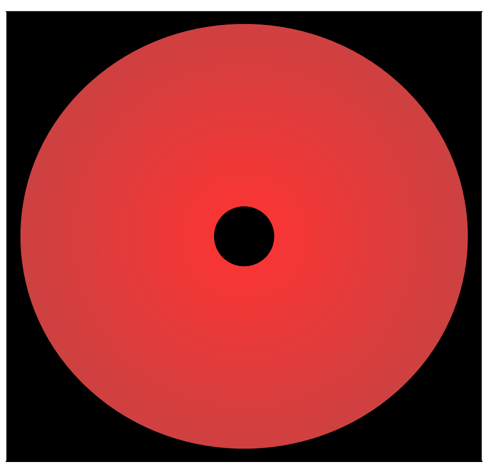

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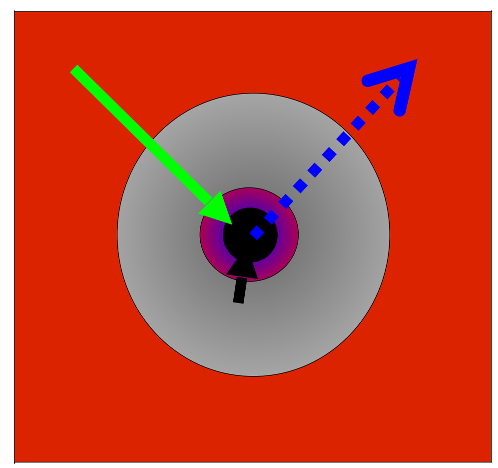
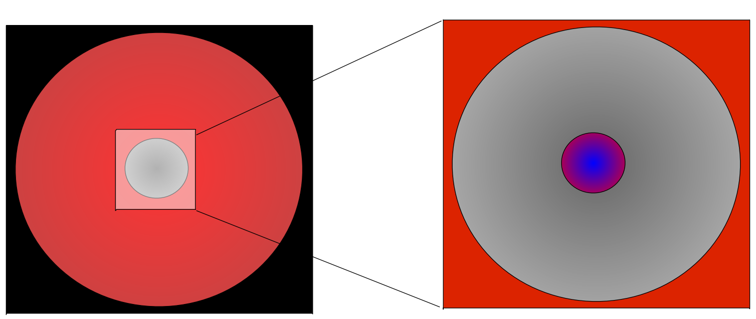


if it grows rapidly, then

(Bosonic DM forms a BEC first



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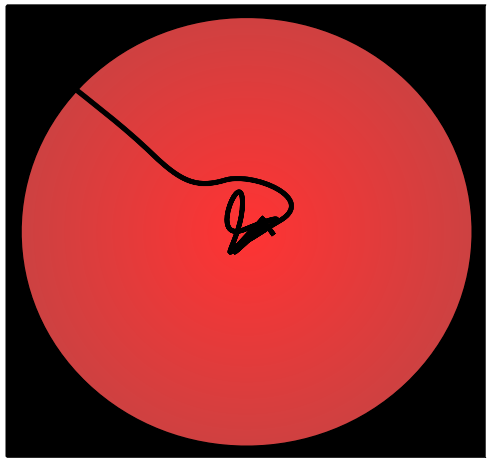

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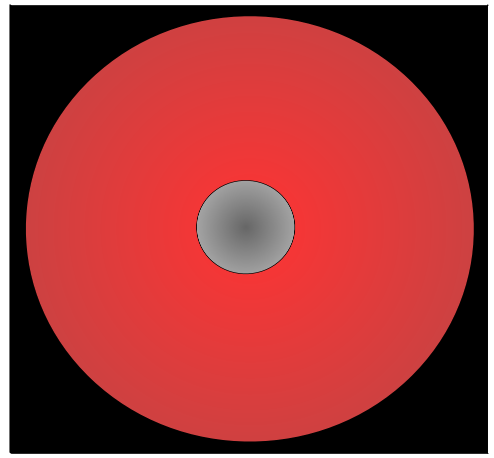

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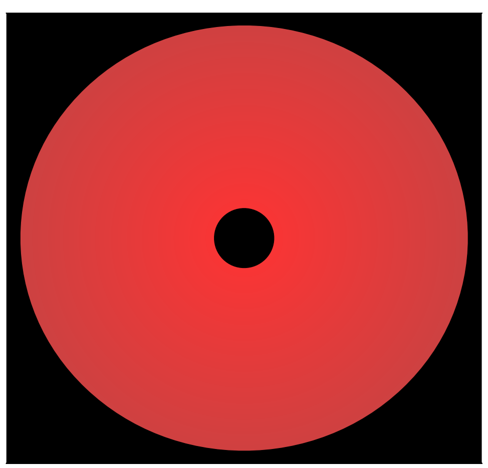

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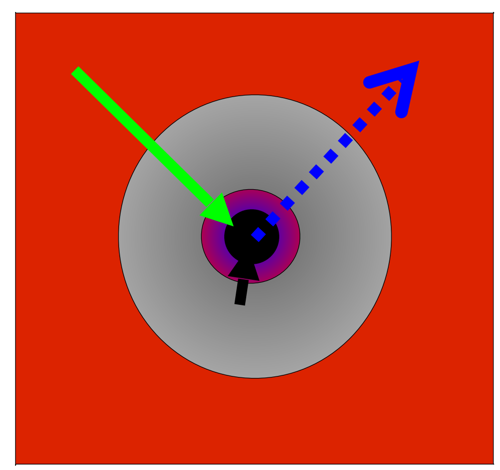

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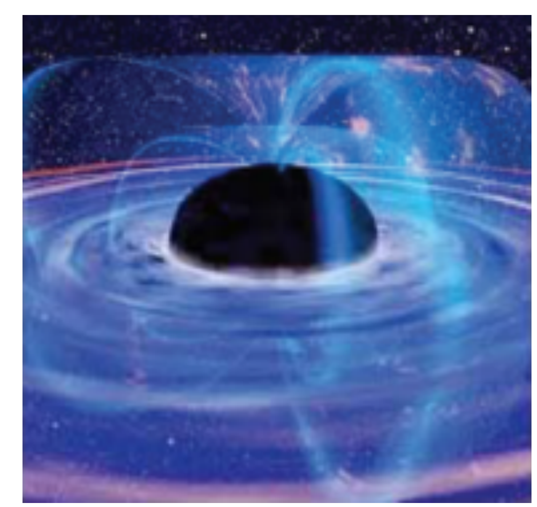

bound

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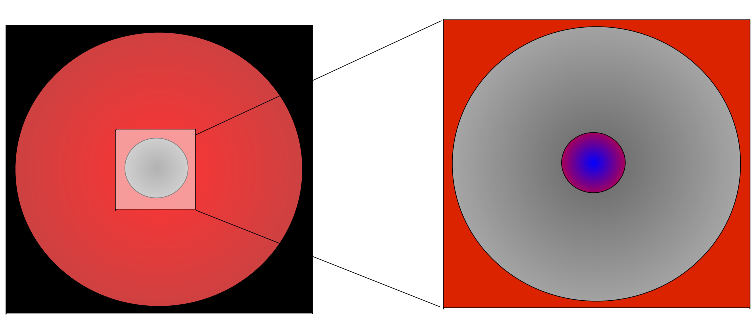

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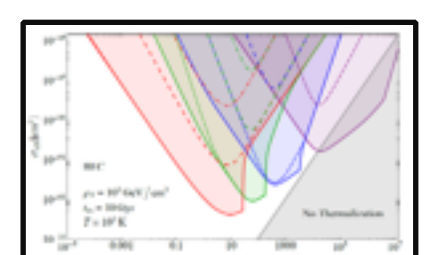

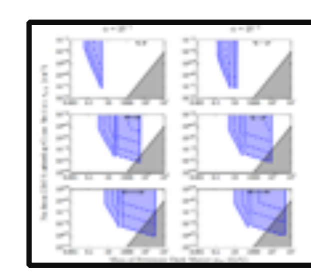

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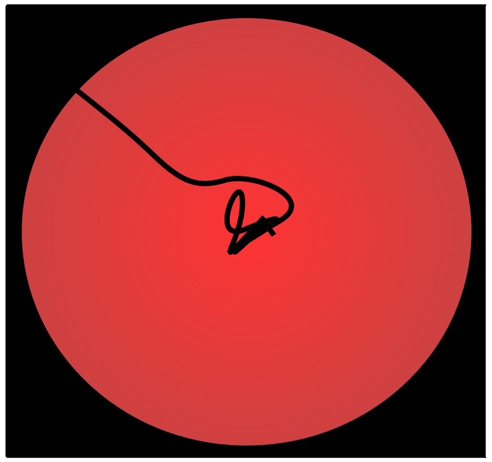

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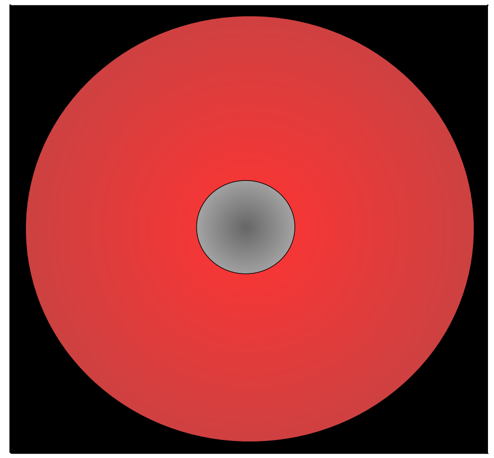
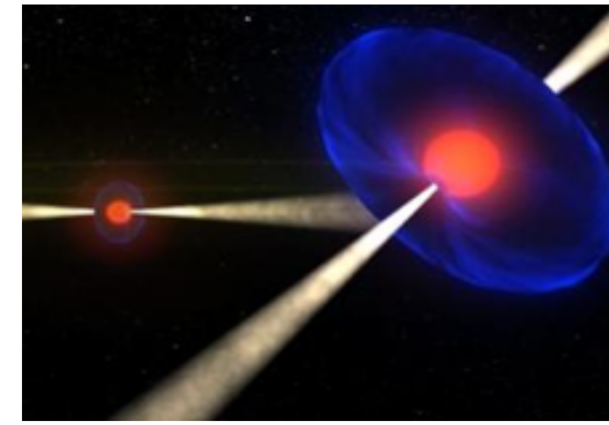


if it shrinks, (Hawking)



no bound

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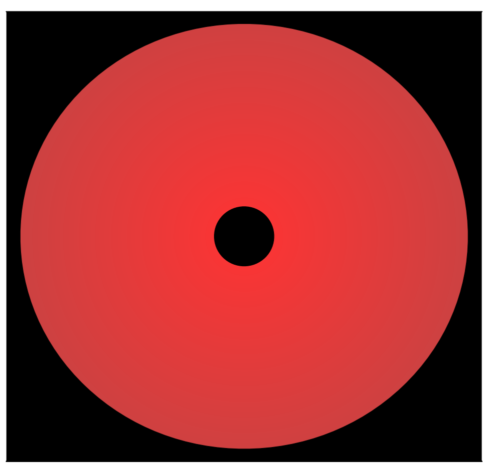

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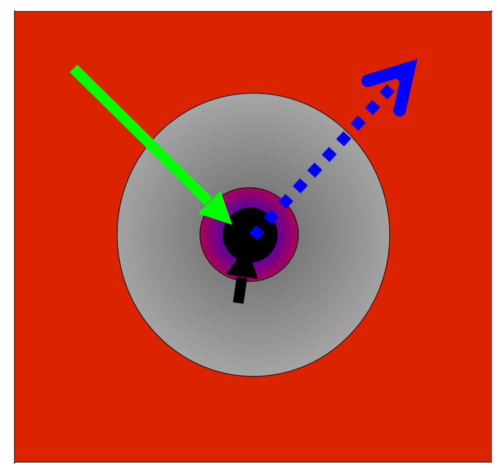

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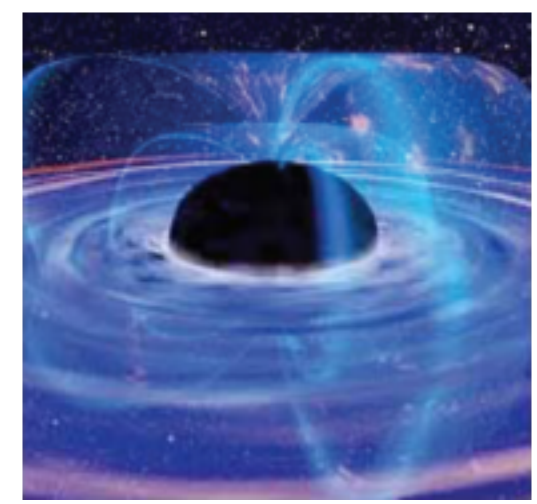
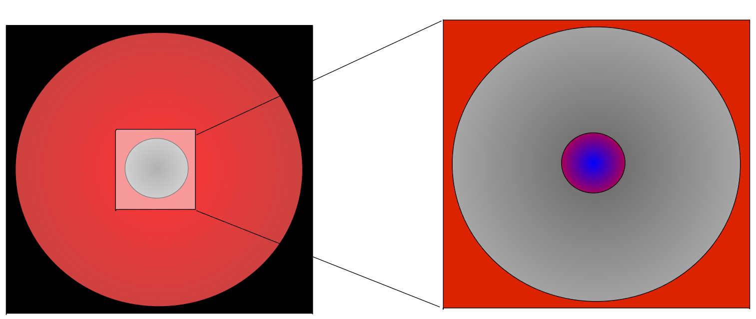
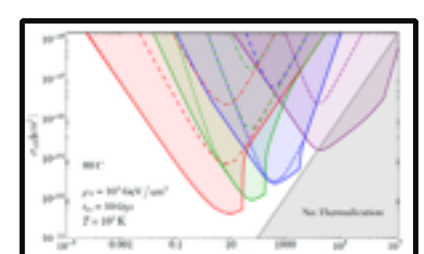


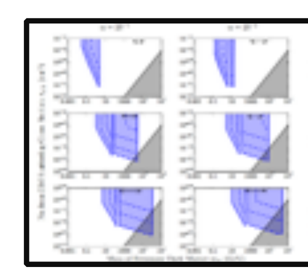
bound

(Bosonic DM forms a BEC first

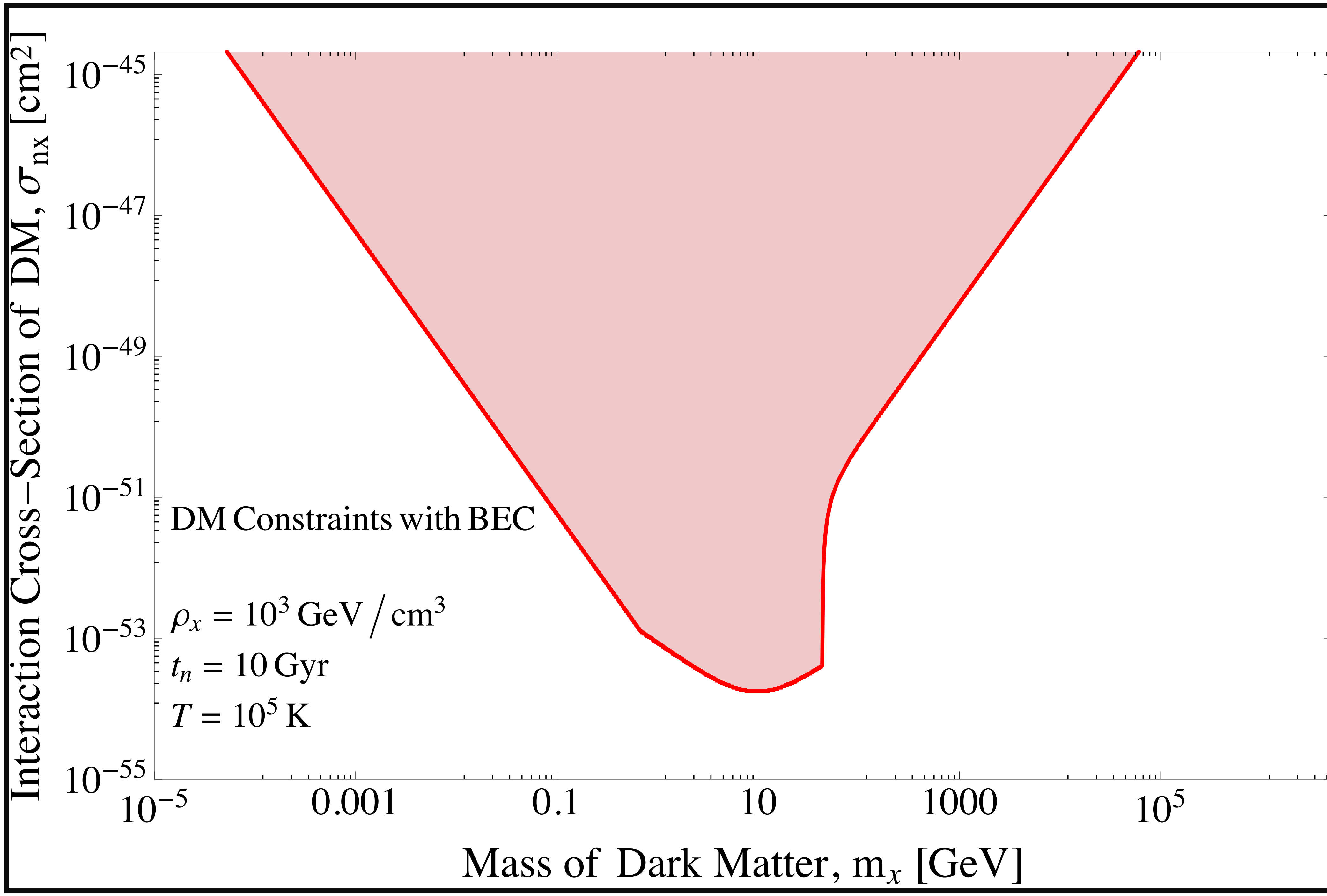


)





Asymmetric Boson DM Bounds



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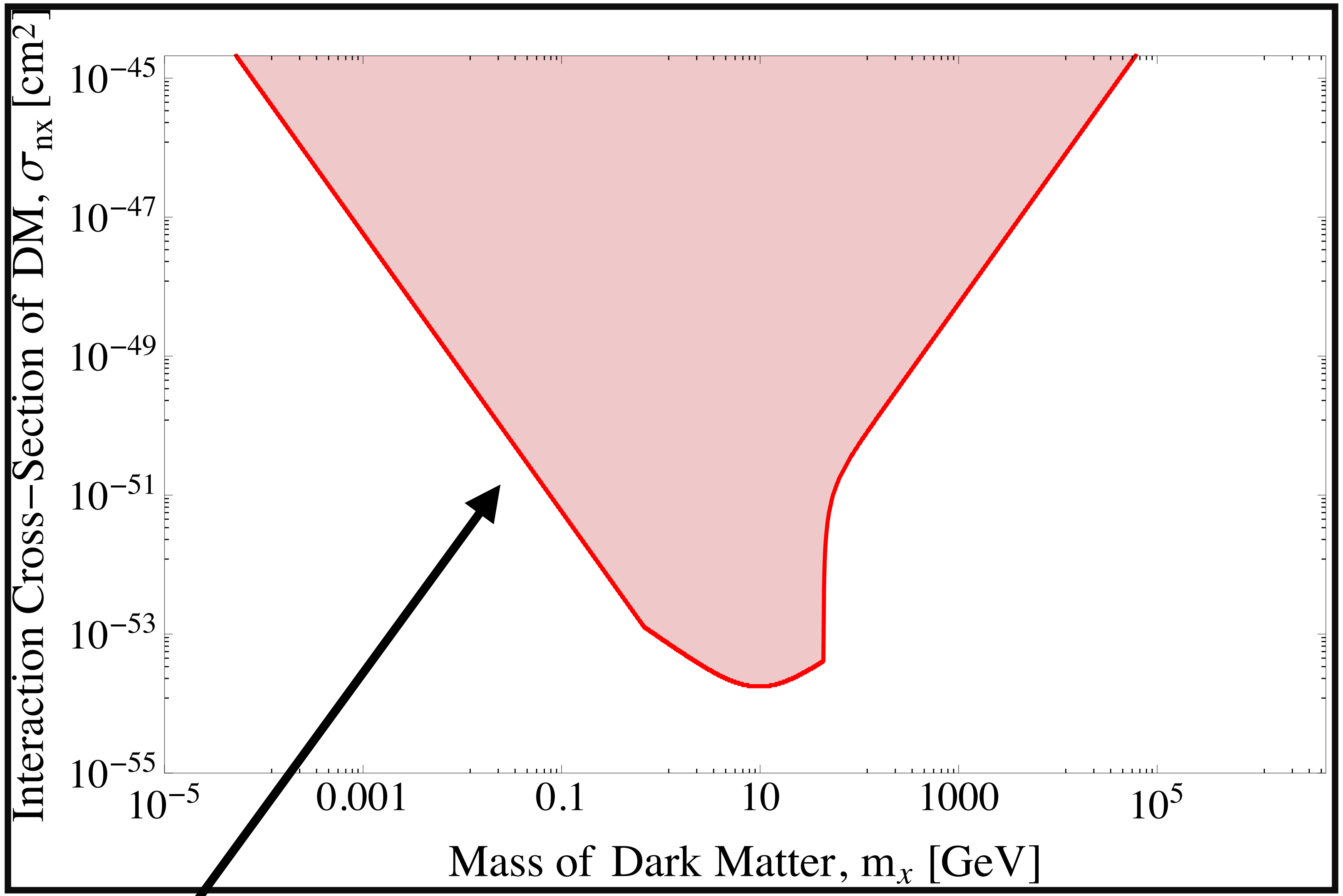

Pauli Blocking: $1/m_x$

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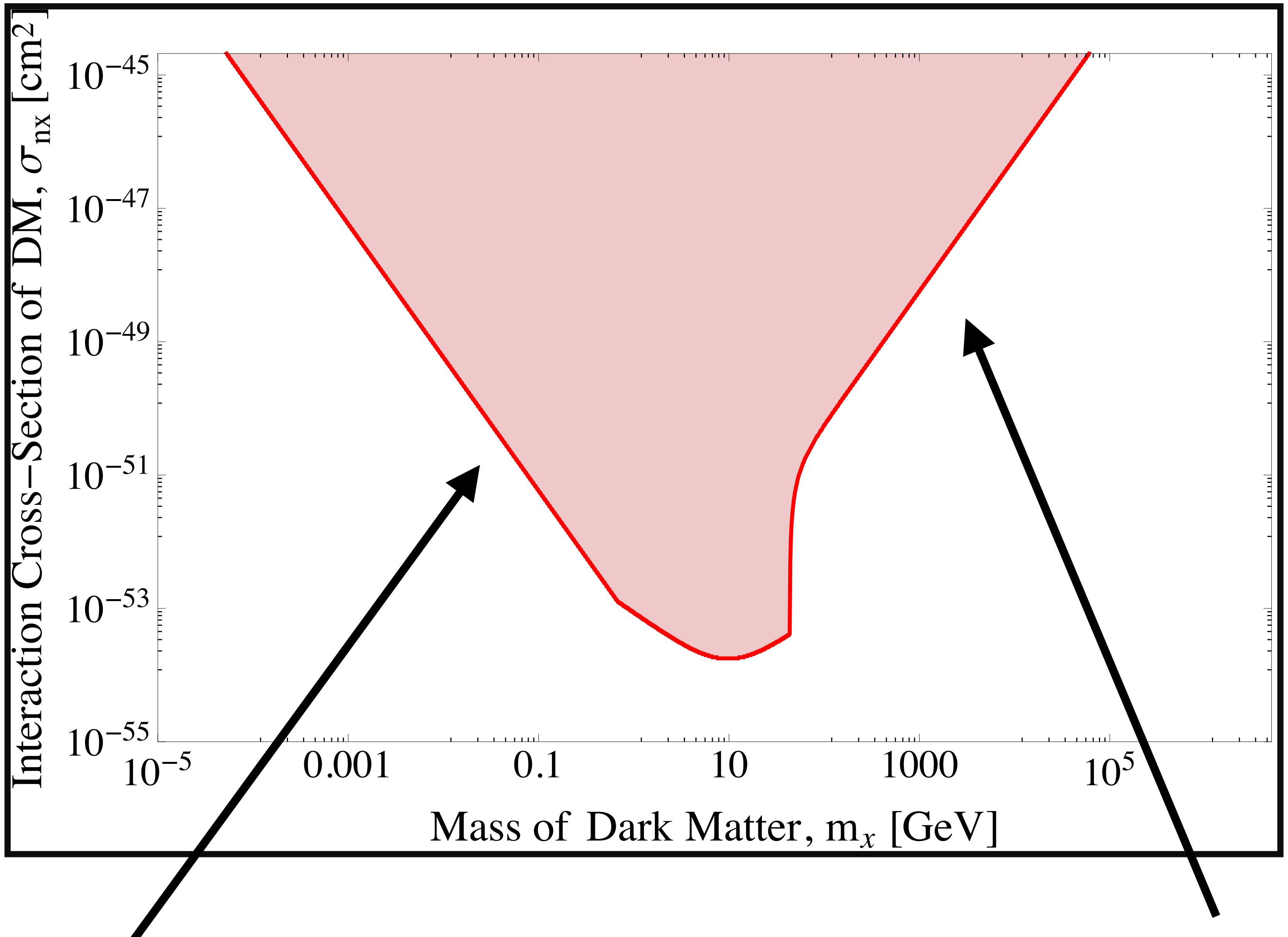

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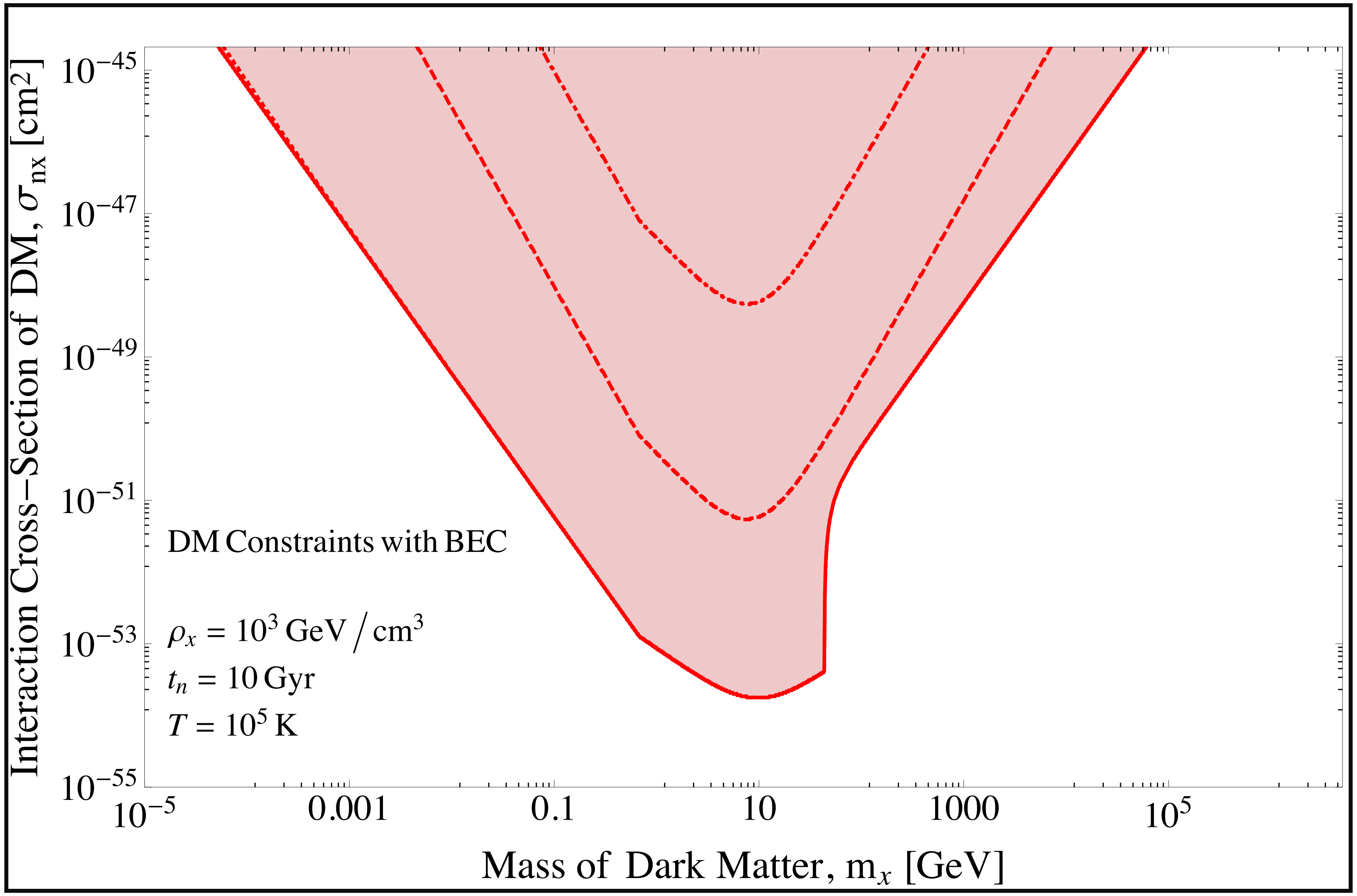
Hawking vs Accretion of black hole

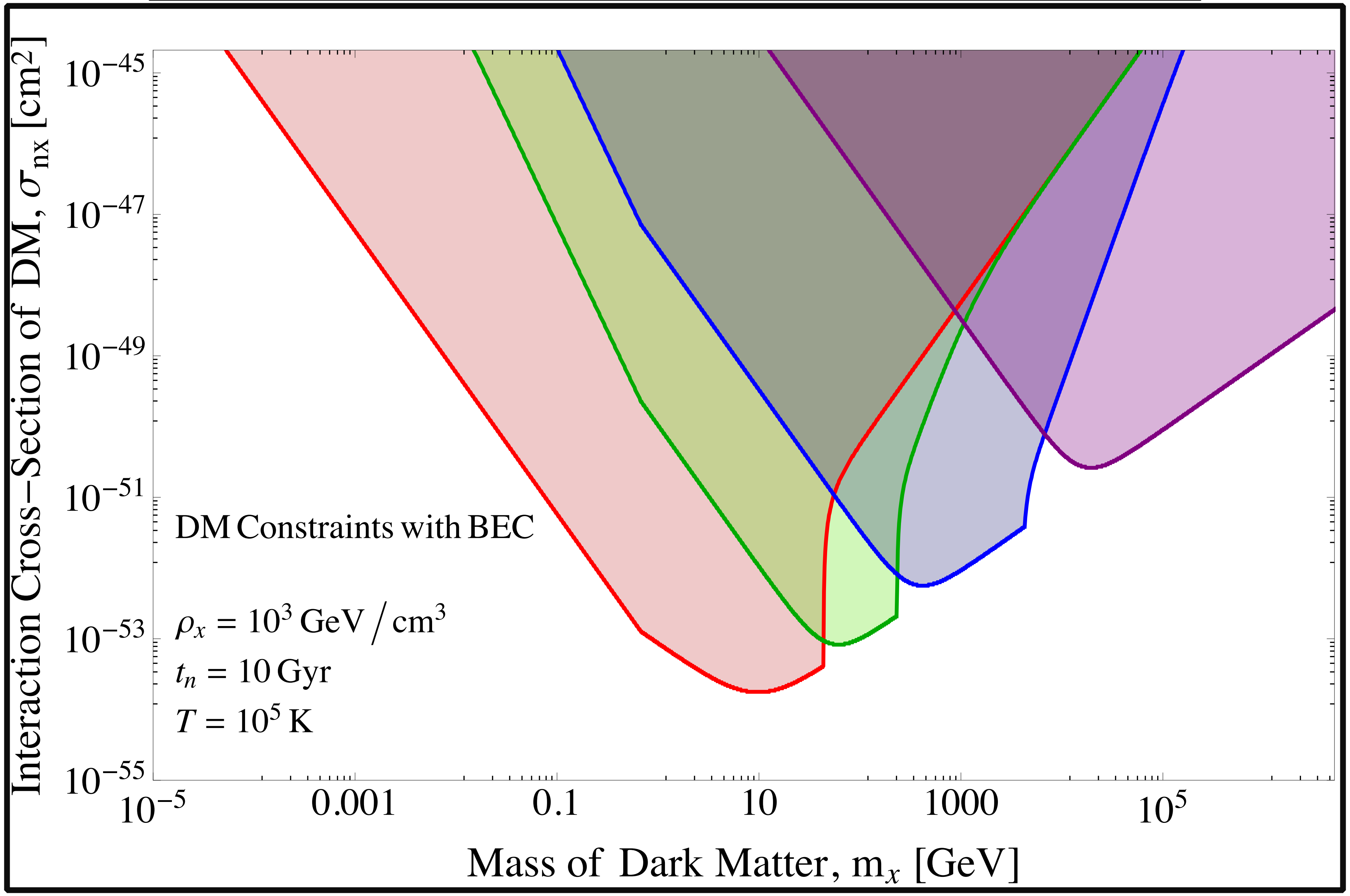
Asymmetric Boson DM Bounds



Extremely tiny self-annihilations remove the bound.

$$\langle \sigma_a v \rangle = 0 \quad 10^{-50} \quad 10^{-45} \quad 10^{-42} \ \mathrm{cm^3/s}$$

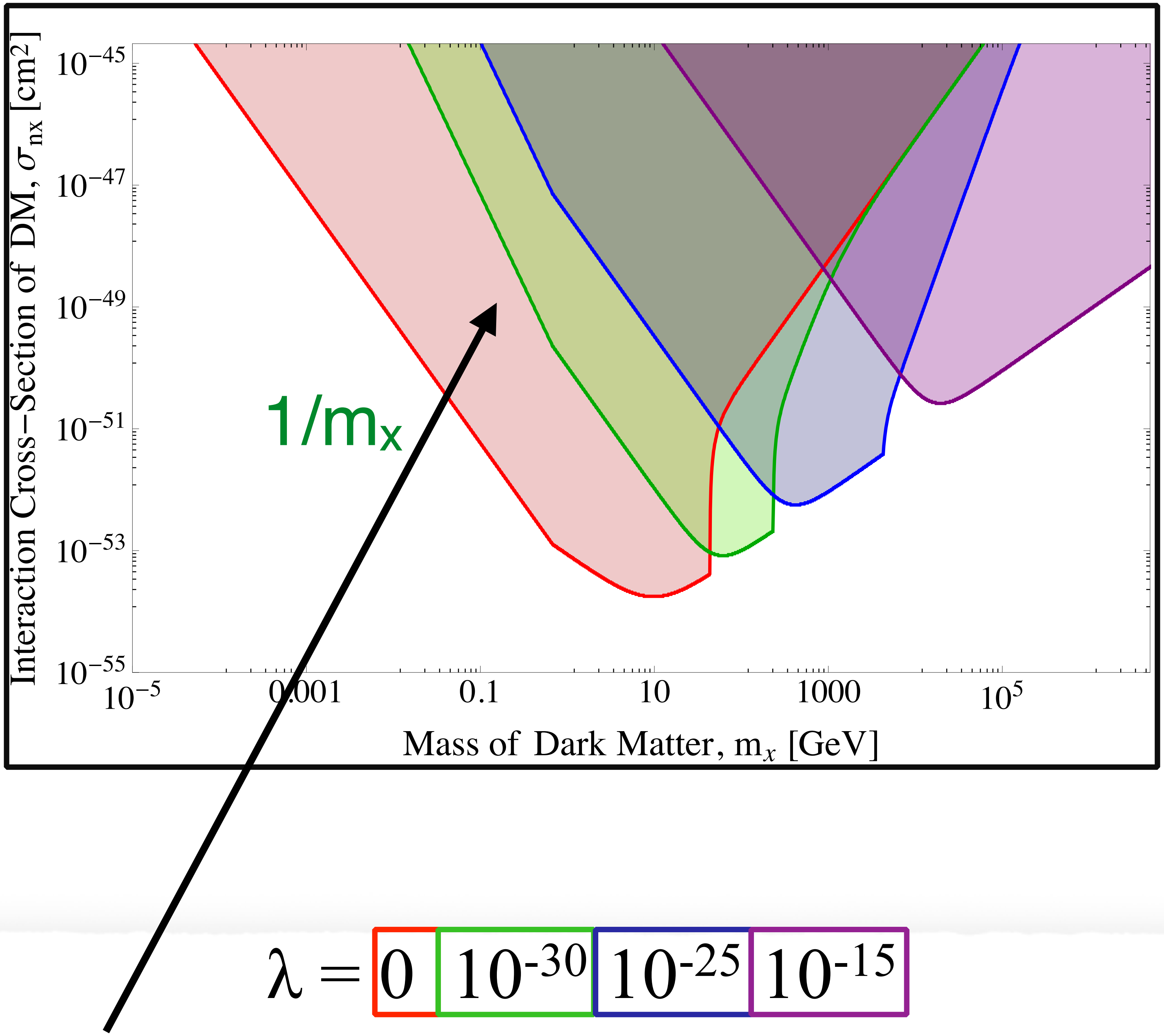
Asymmetric Boson DM Bounds



Repulsive self-interactions push the bounds to higher masses — lower mass DM can no longer collapse, higher mass DM collapses to a bigger black hole.

$$\lambda = 0 \quad 10^{-30} \quad 10^{-25} \quad 10^{-15}$$

Asymmetric Boson DM Bounds



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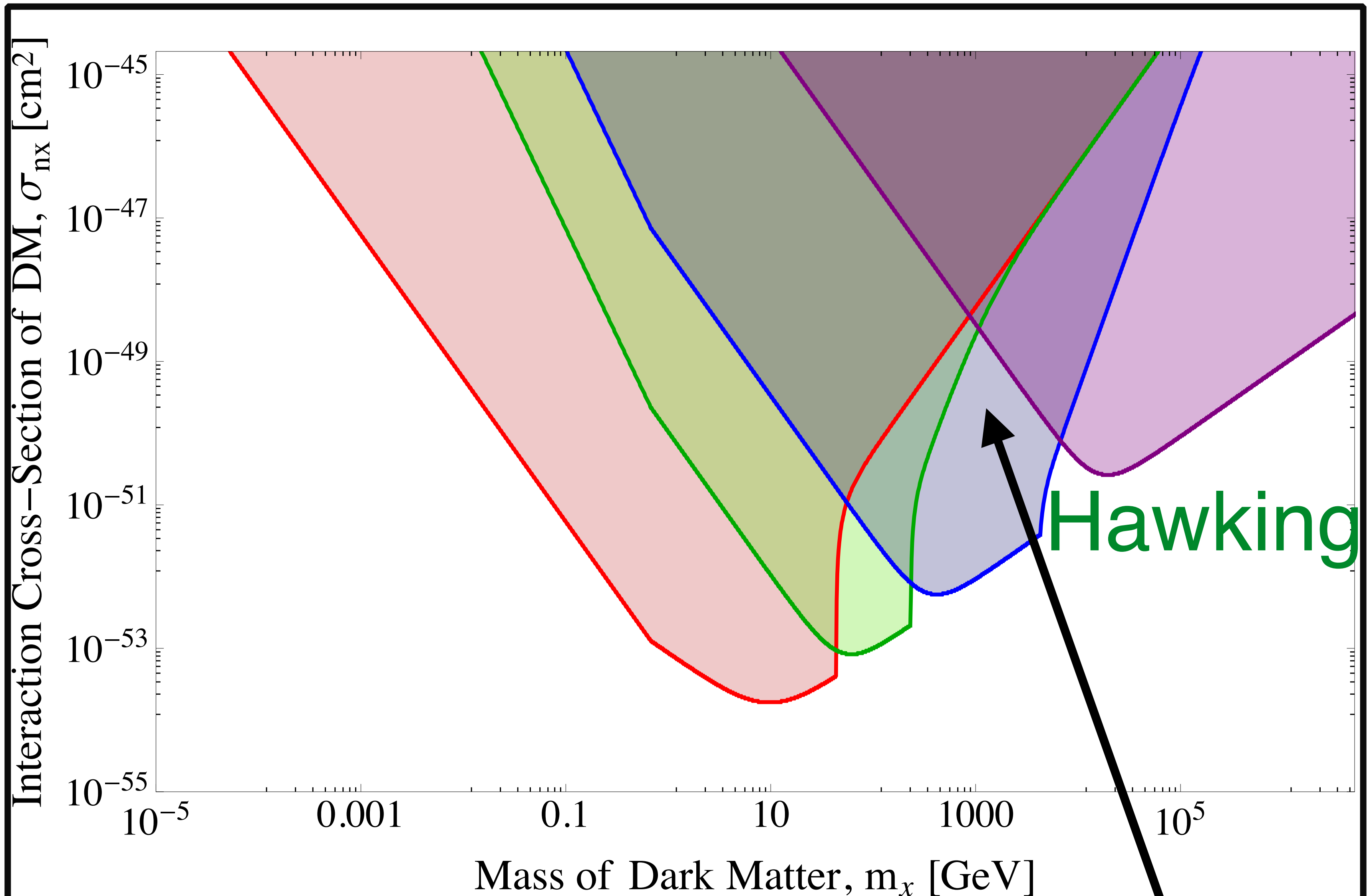
Need more massive ball of DM to collapse

Asymmetric Boson DM Bounds



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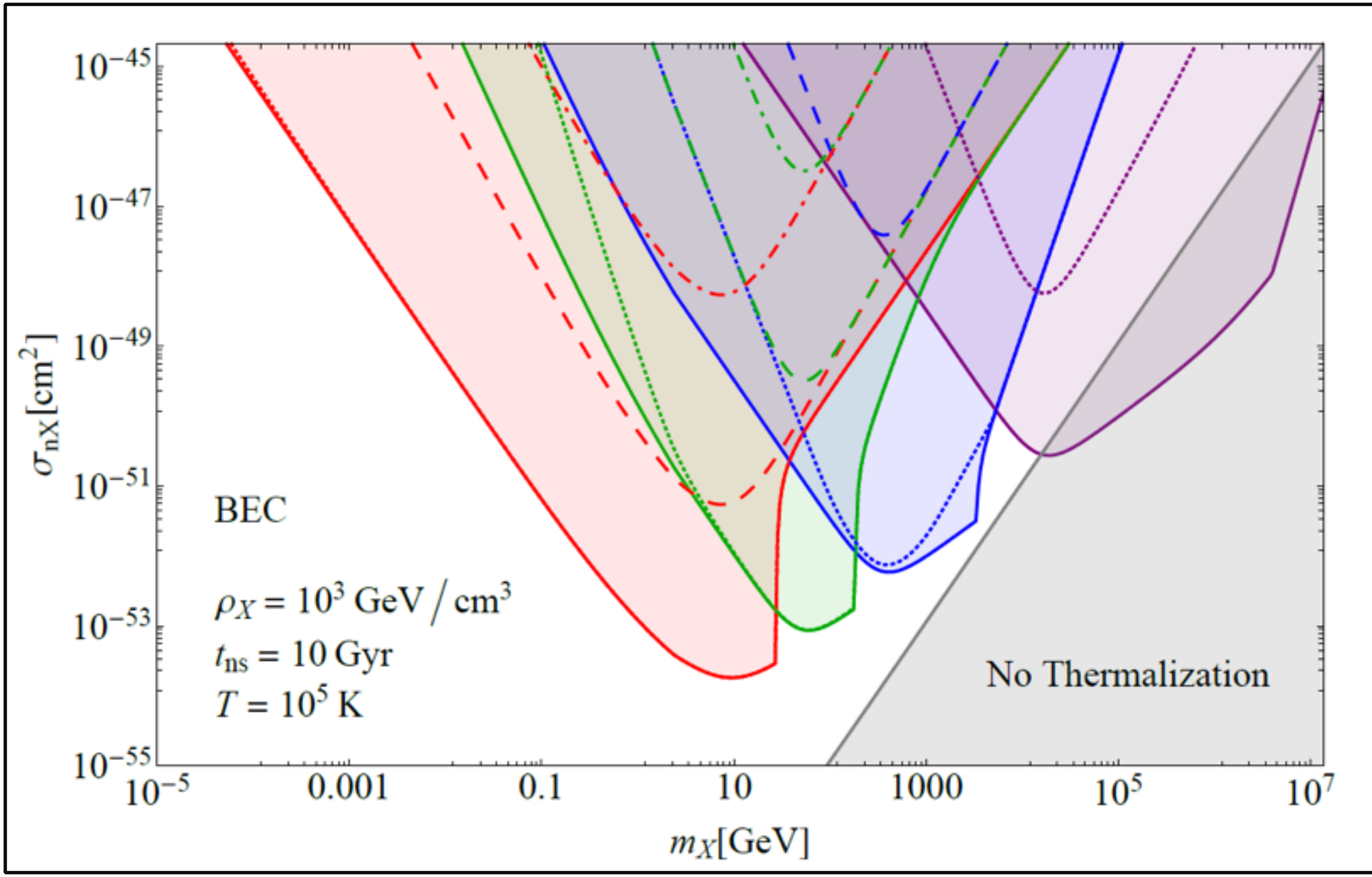


$\lambda = 0 \quad 10^{-30} \quad 10^{-25} \quad 10^{-15} \quad [\sigma_{xx} \sim 0,\ 10^{-118}, 10^{-98}, 10^{-58}\ \text{cm}^2]$

$<\sigma_a v> = 0 \quad 10^{-50} \quad 10^{-45} \quad 10^{-42}\ \text{cm}^3/\text{s}$

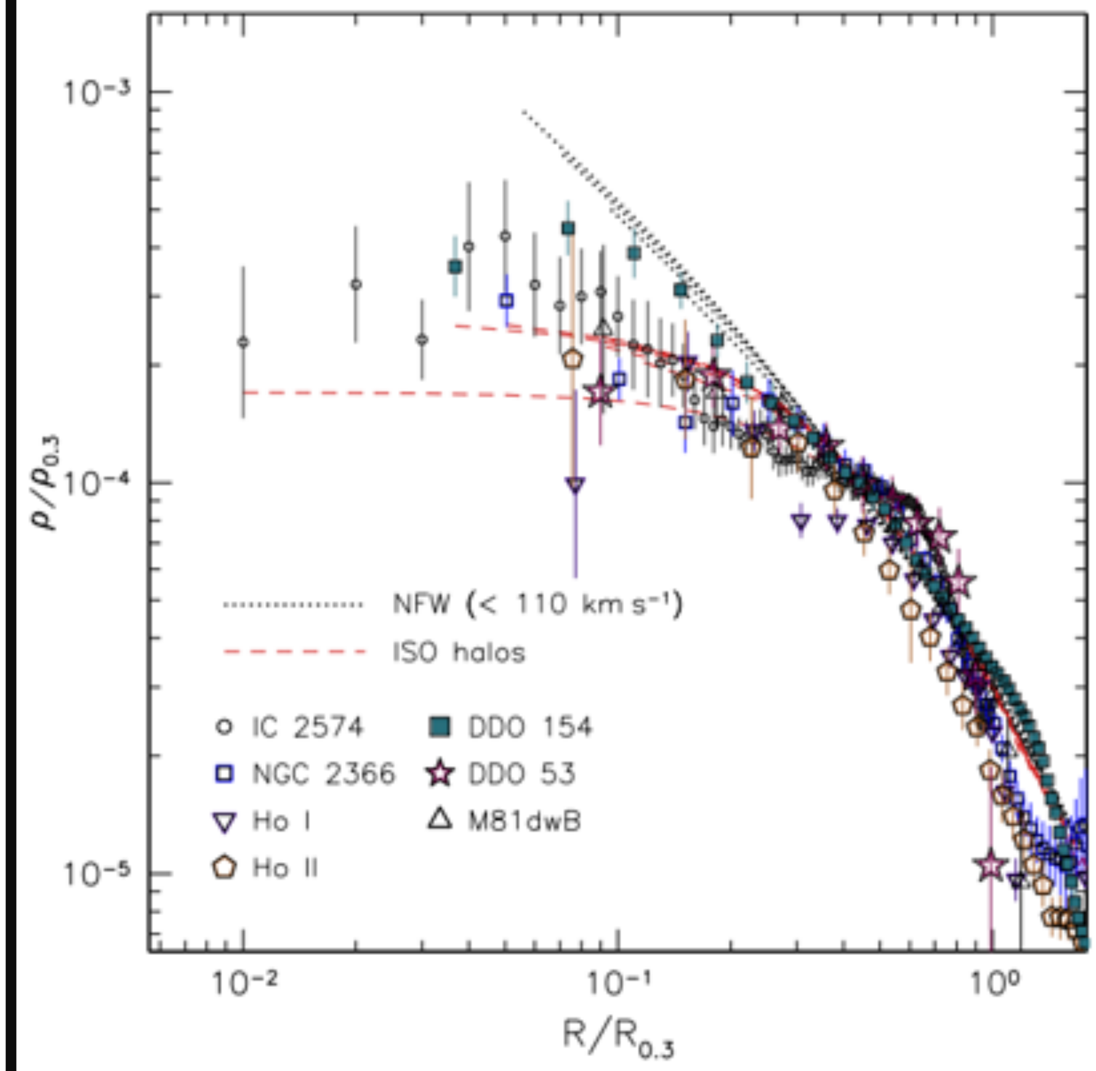
Fermionic asymmetric dark matter

Seven dwarves with mined out DM cores

7 dwarf galaxies measured by THINGS do not show a cold, collisionless NFW profile which would cusp in the center. They instead have a more cored out shape.

-Caveat: Baryonic outflow via SN

-Counter: less luminous galaxies should not experience outflow, but seem to.



Heon et al.
1011.0899

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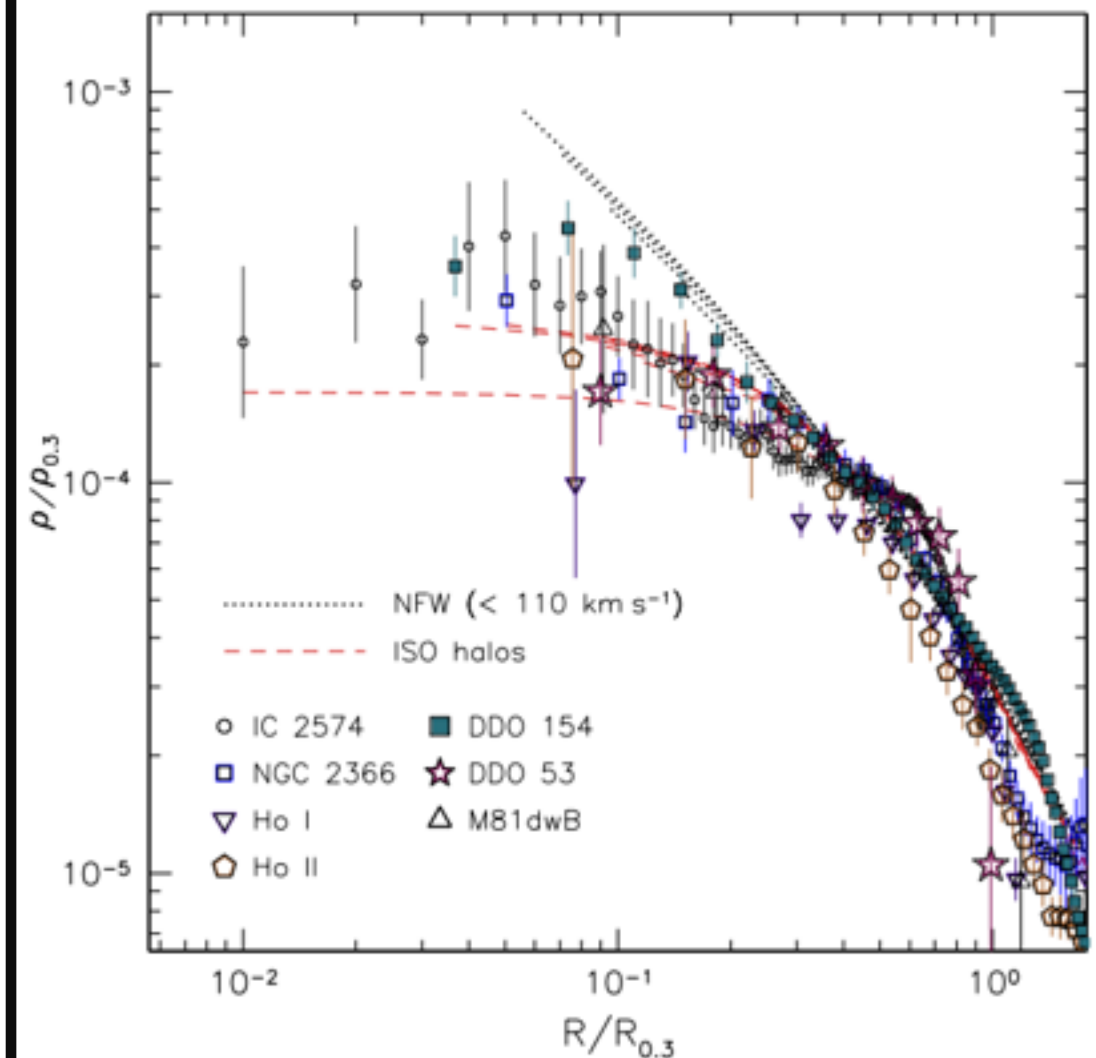
Also, many simulations suggest that we should have ~50 subhalos in the MW, we see only 12.

-Caveat: Different models of star formation, subhalos too dim?

-Counter: "Too big to fail to form star subhalos not seen in the Milky Way.



Heon et al.
1011.0899

Resonant Self-Interacting Fermionic DM

Bullet clusters (1000 km/s) and spiral galaxies (200 km/s) constrain the cross-section of dark matter with itself to

$\sigma/m < 1\ \mathrm{cm^2/g}$, $\sigma/m < 1\ \mathrm{cm^2/g}$

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Answer: velocity dependent cross-section provided by light mediator.

$$\text{if } \mathcal{L} \supset \alpha\phi\bar{\psi}\psi$$

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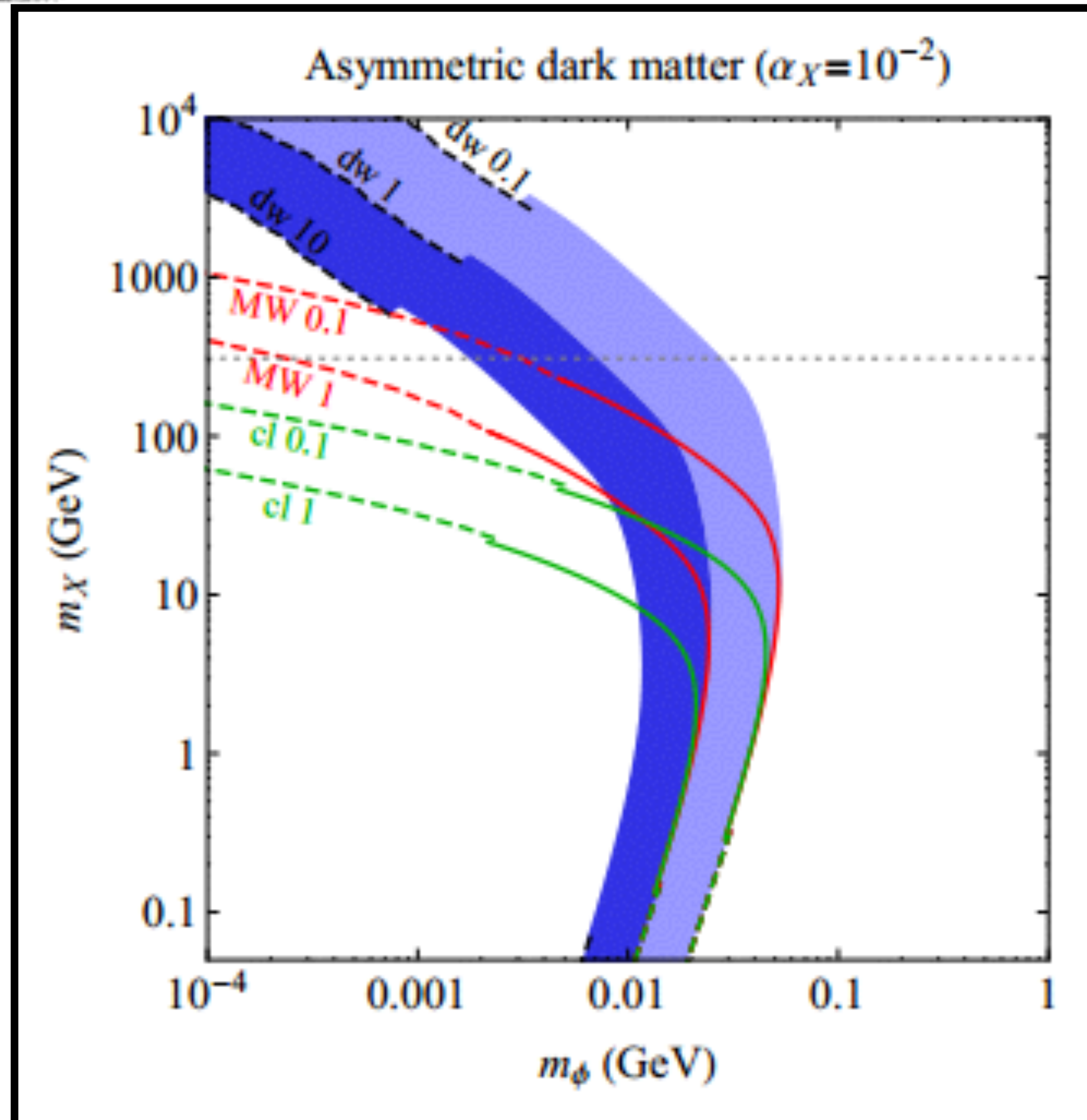
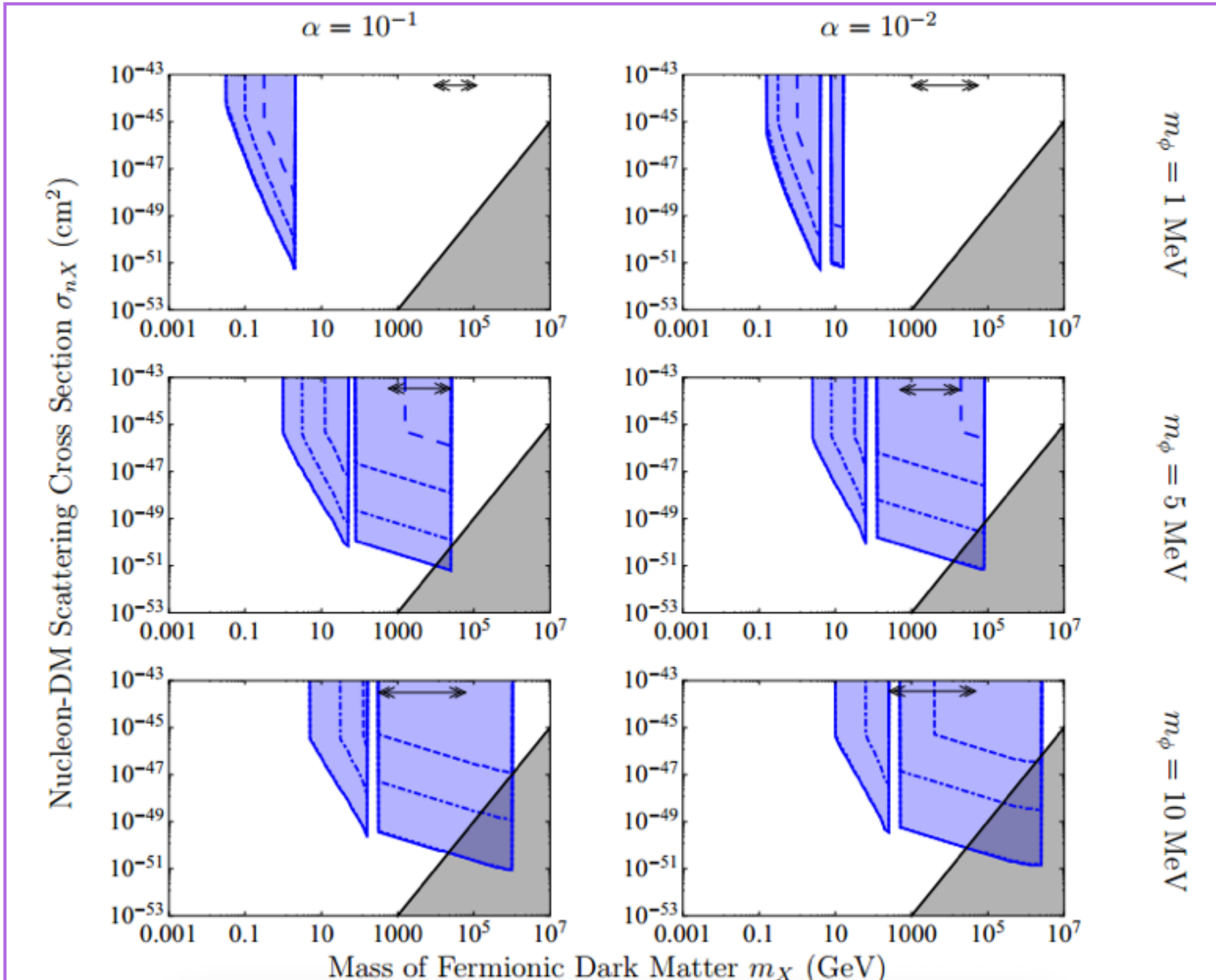


Tulin, Yu, Zurek
1210.0900

if $\mathcal{L} \supset \alpha\phi\bar{\psi}\psi$

Bounds on SIDM Fermions



$<\sigma_a v> =$ 0 10^{-47} 10^{-45} 10^{-43} cm^3/s

JB,Kumar,Fukushima, Stopnitzky (2013)

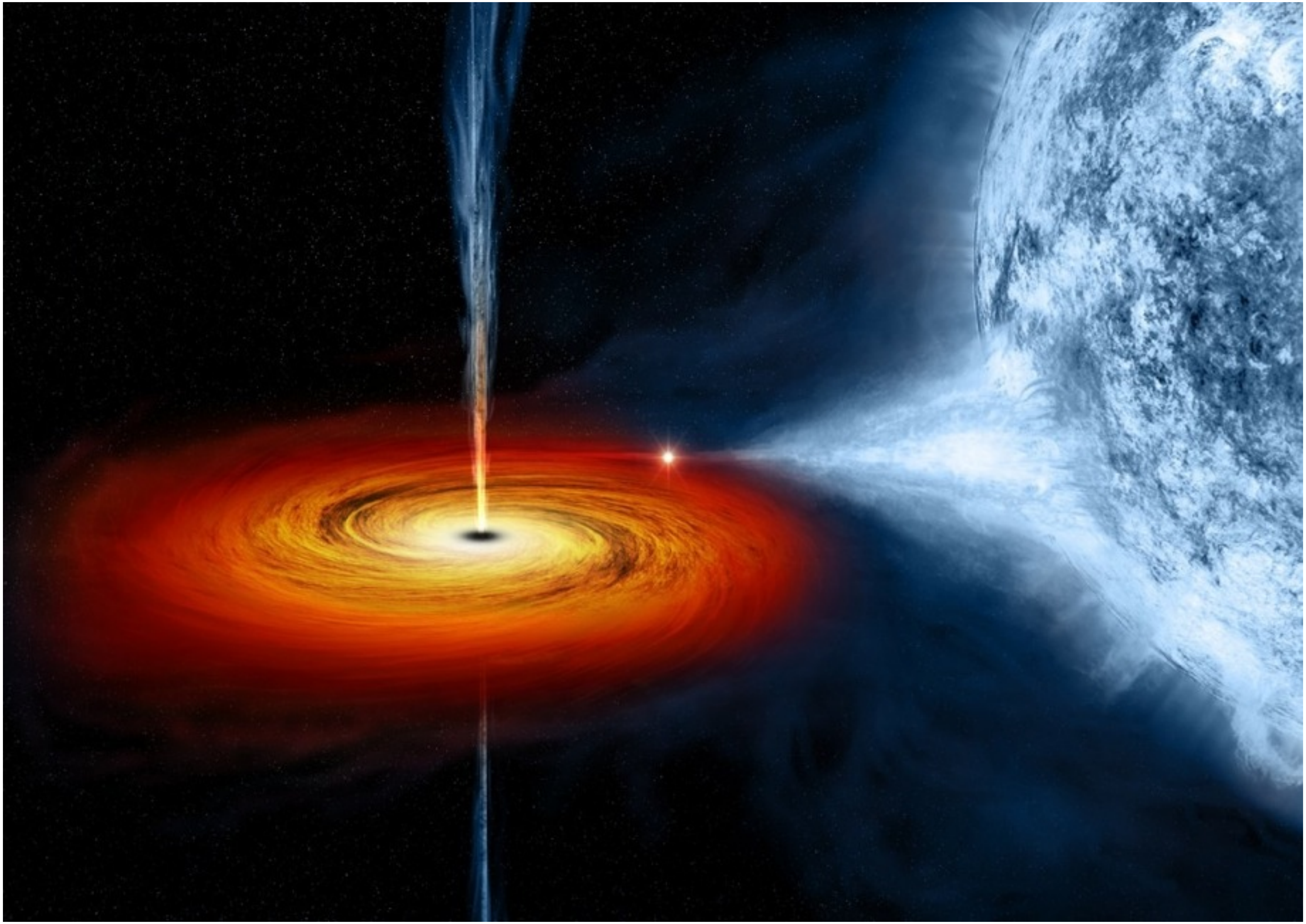
The missing pulsar problem

Prior to the detection of a very luminous magnetar one tenth of a parsec away from the (10^8 ☉ mass) black hole at the galactic center, it was assumed that pulsars had not been detected there, because a charged screen of material at the galactic center was broadening pulse signals. Pulsars are expected because of a large population of high mass progenitor stars and X-ray binary systems.

The missing pulsar problem

However, measurements of radio pulses from the newly discovered galactic center magnetar indicate a much cleaner path for radio pulses than was supposed. In addition, measurements of the radio pulses' angular broadening match those of SgA*. This is evidence that the scattering screen is homogeneous.

(Older) millisecond pulsars form from x-ray binaries



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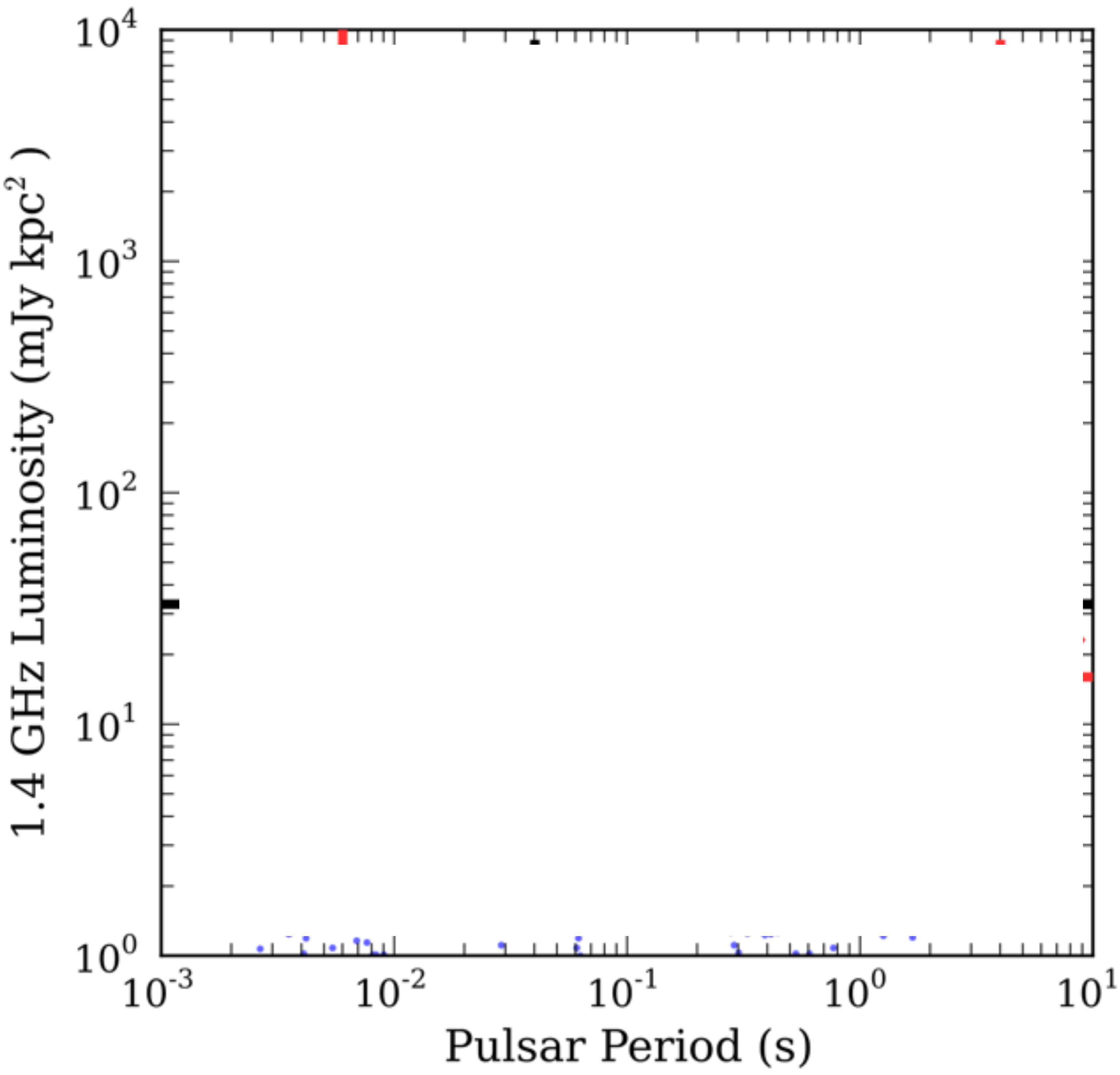
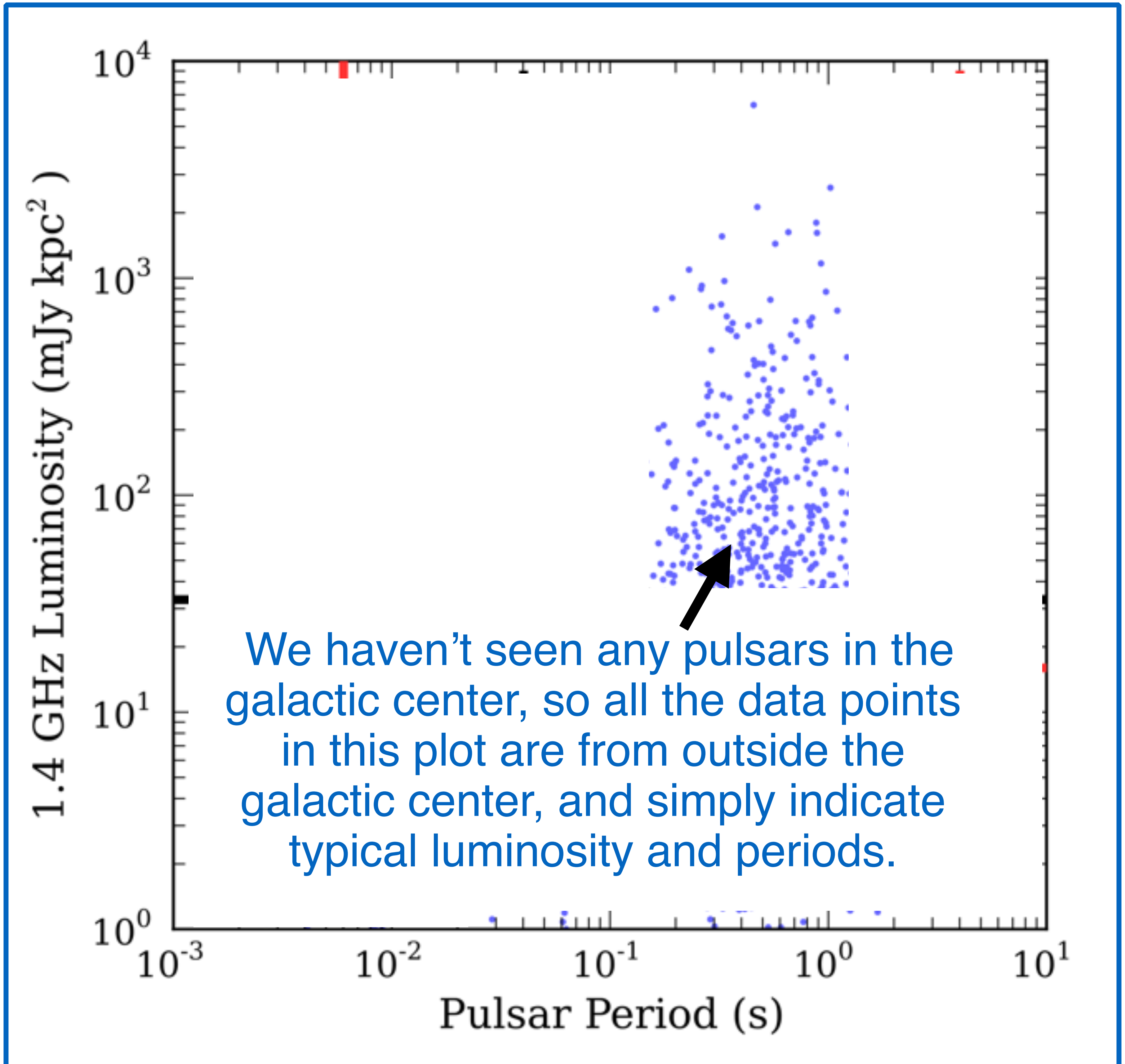
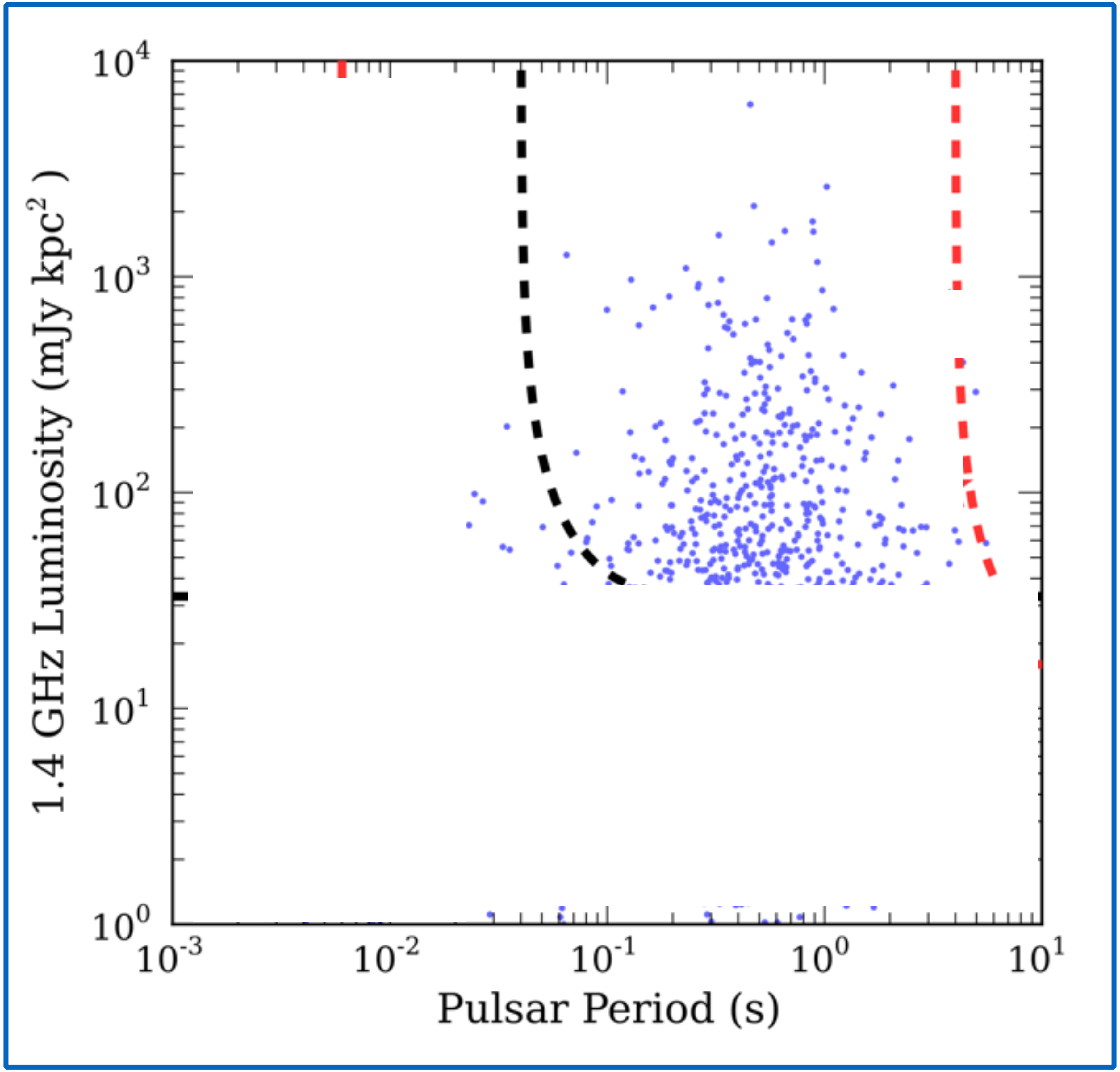
This creates two missing pulsar problems. Both young and old millisecond pulsars seem to be absent. There are 50-500 missing millisecond pulsars.

The missing pulsar problem



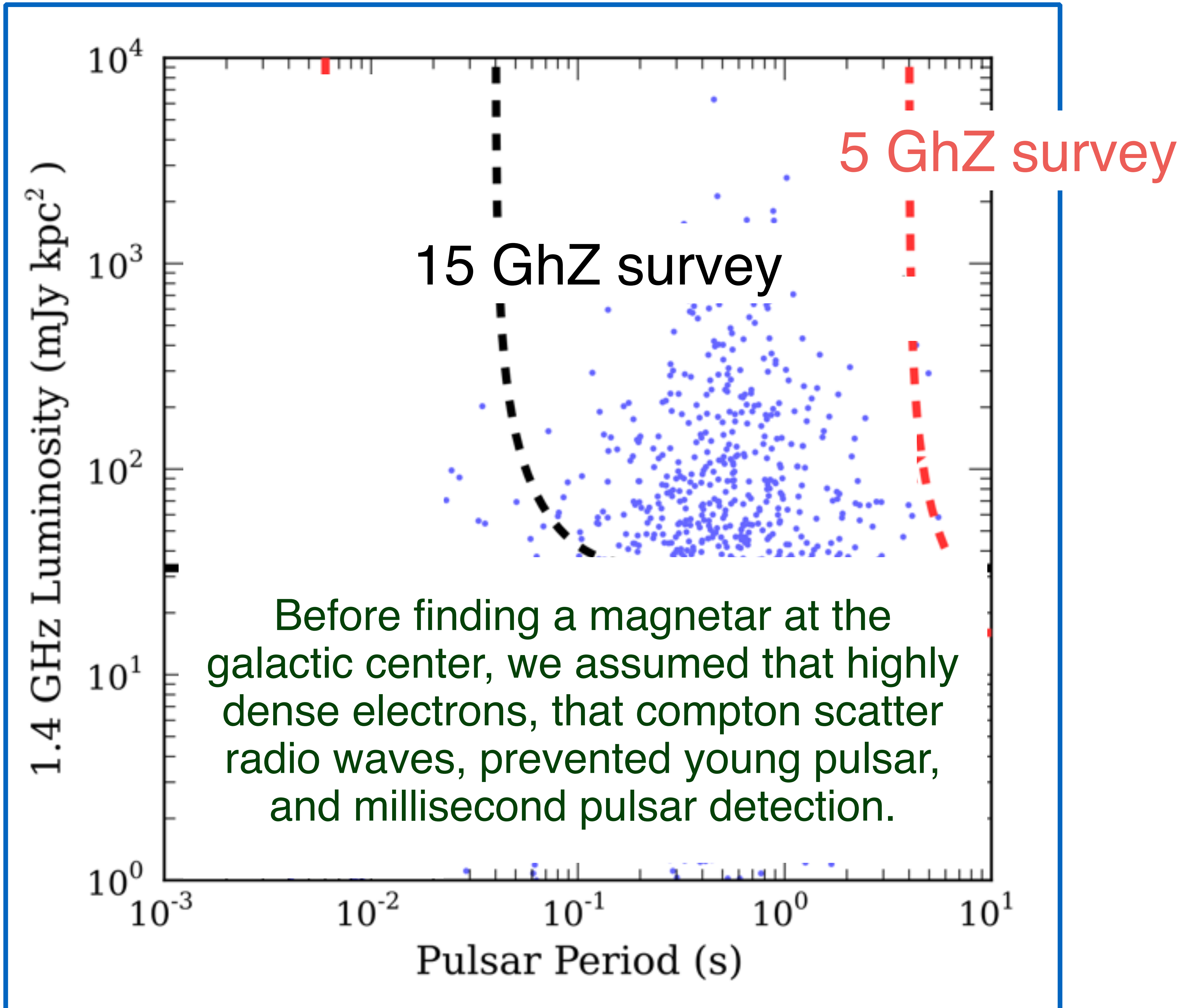
Dexter, O'Leary
1310.7022


1.4 GHz Luminosity (mJy kpc^2)
Pulsar Period (s)
We haven't seen any pulsars in the galactic center, so all the data points in this plot are from outside the galactic center, and simply indicate typical luminosity and periods.

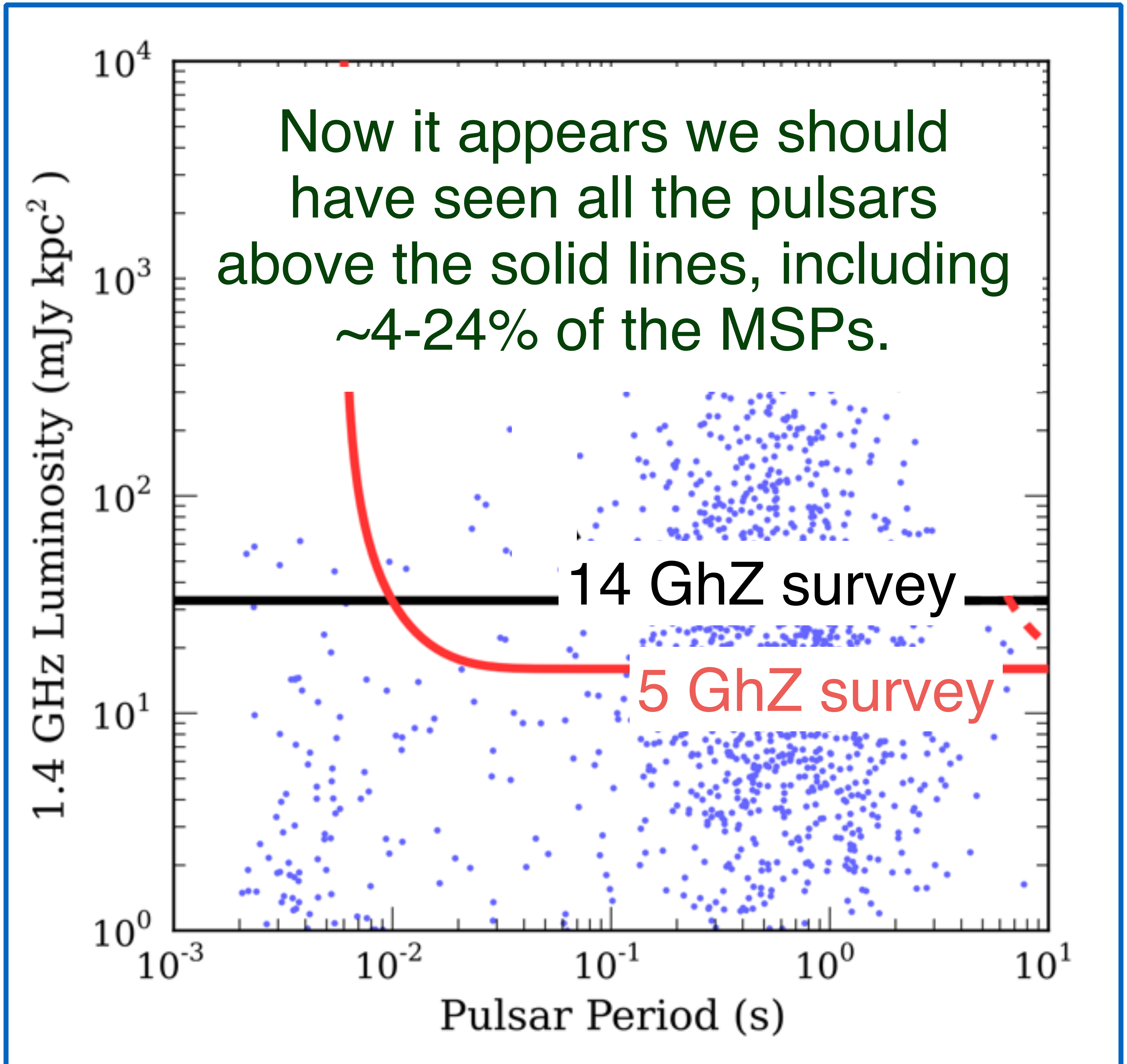


1.4 GHz Luminosity (mJy kpc^2)
10^4
10^3
10^2
10^1
10^0
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
Pulsar Period (s)

Survey sensitivity before magnetar

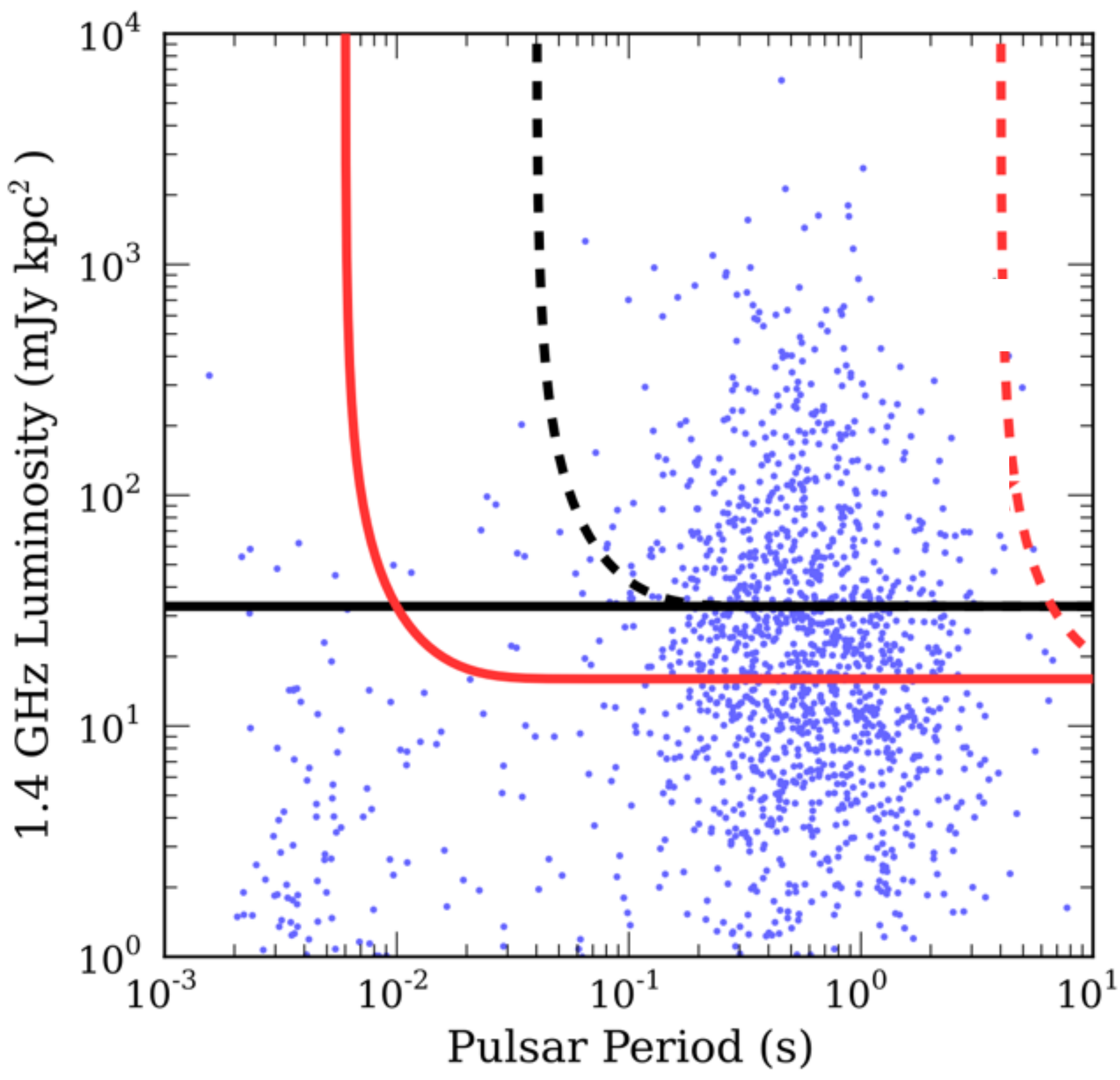


Before finding a magnetar at the galactic center, we assumed that highly dense electrons, that compton scatter radio waves, prevented young pulsar, and millisecond pulsar detection.



Now it appears we should have seen all the pulsars above the solid lines, including ~4-24% of the MSPs.
14 GhZ survey
5 GhZ survey
1.4 GHz Luminosity (mJy kpc²)
Pulsar Period (s)
10^4
10^3
10^2
10^1
10^0
10^-3
10^-2
10^-1
10^0
10^1

So where are the galactic center pulsars?



Dexter, O'Leary
1310.7022

Asymmetric Dark Matter Imploding Pulsars

The capture rate for dark matter on pulsars scales inversely with velocity dispersion and linearly with the local dark matter density.

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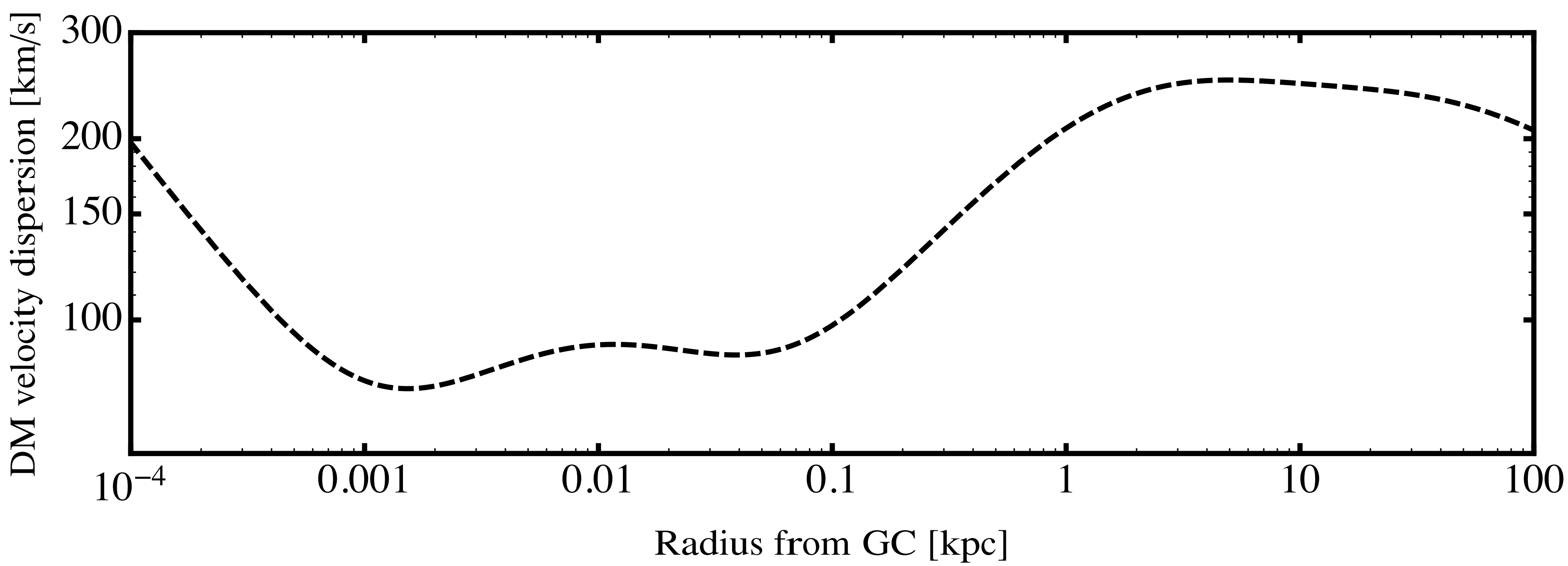
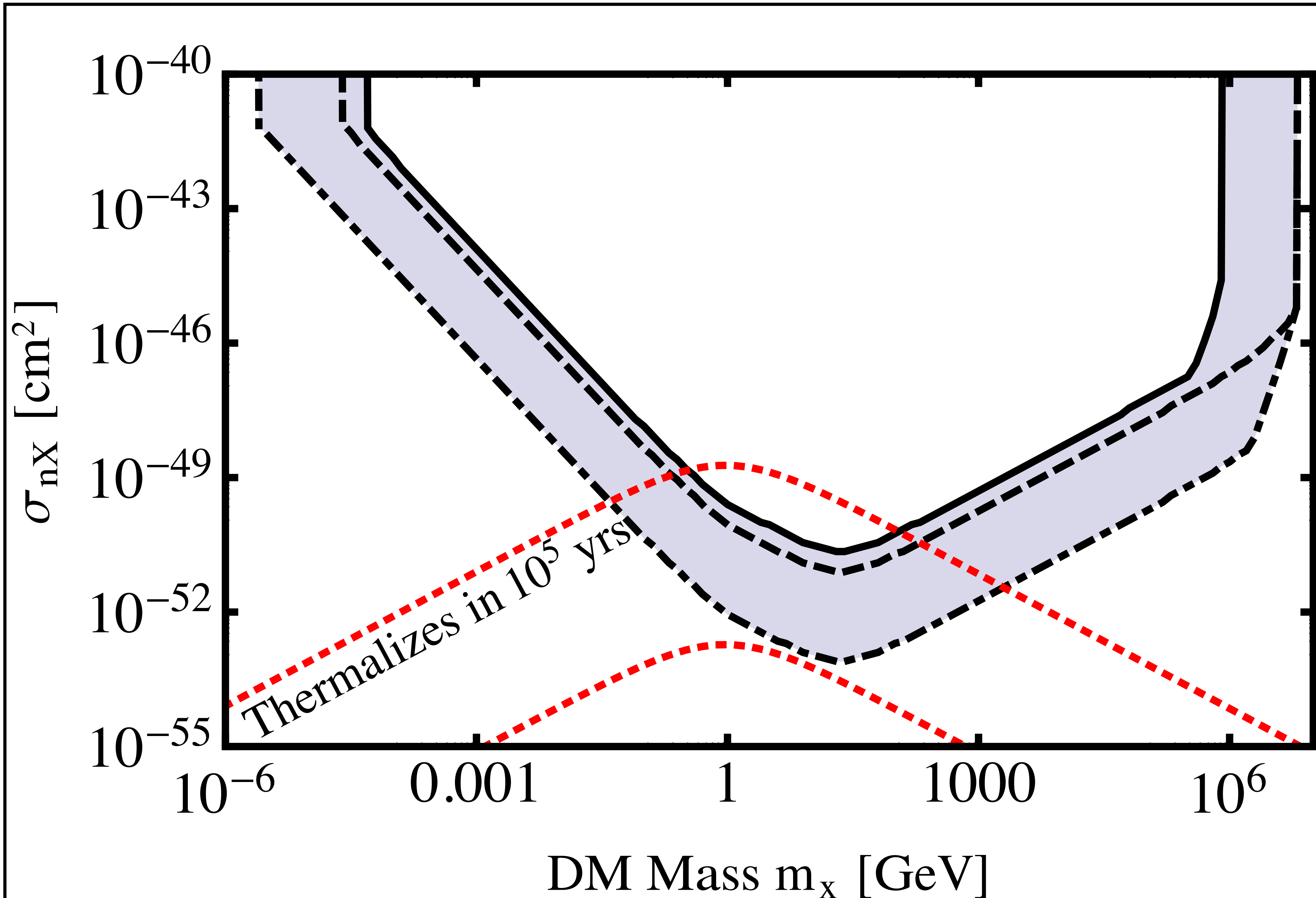
Model our galaxy's dark matter profile using disc and galactic center star velocity measurements (NFW).

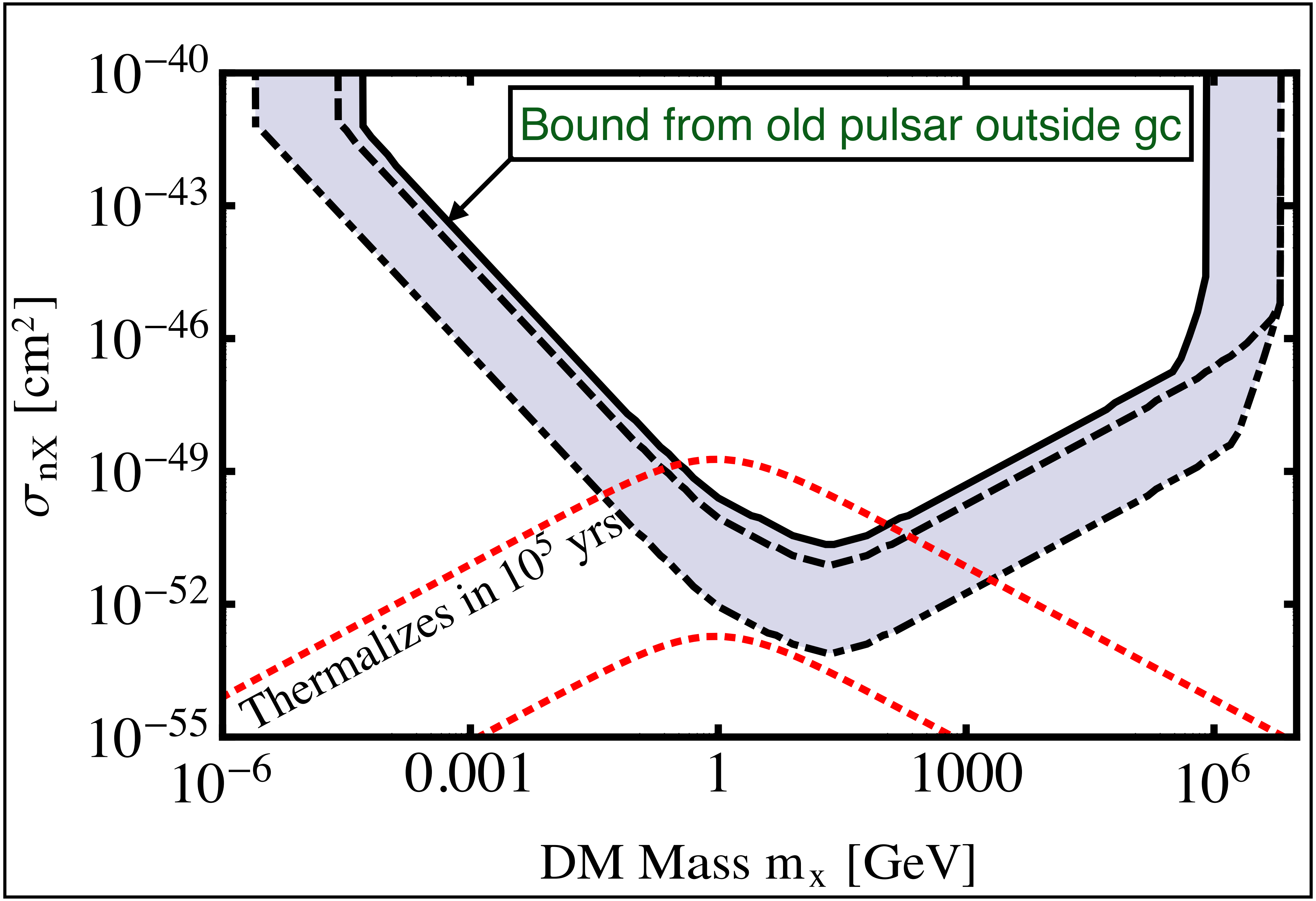


Bosons Imploding Pulsars



JB,Linden (2014)

Bosons Imploding Pulsars



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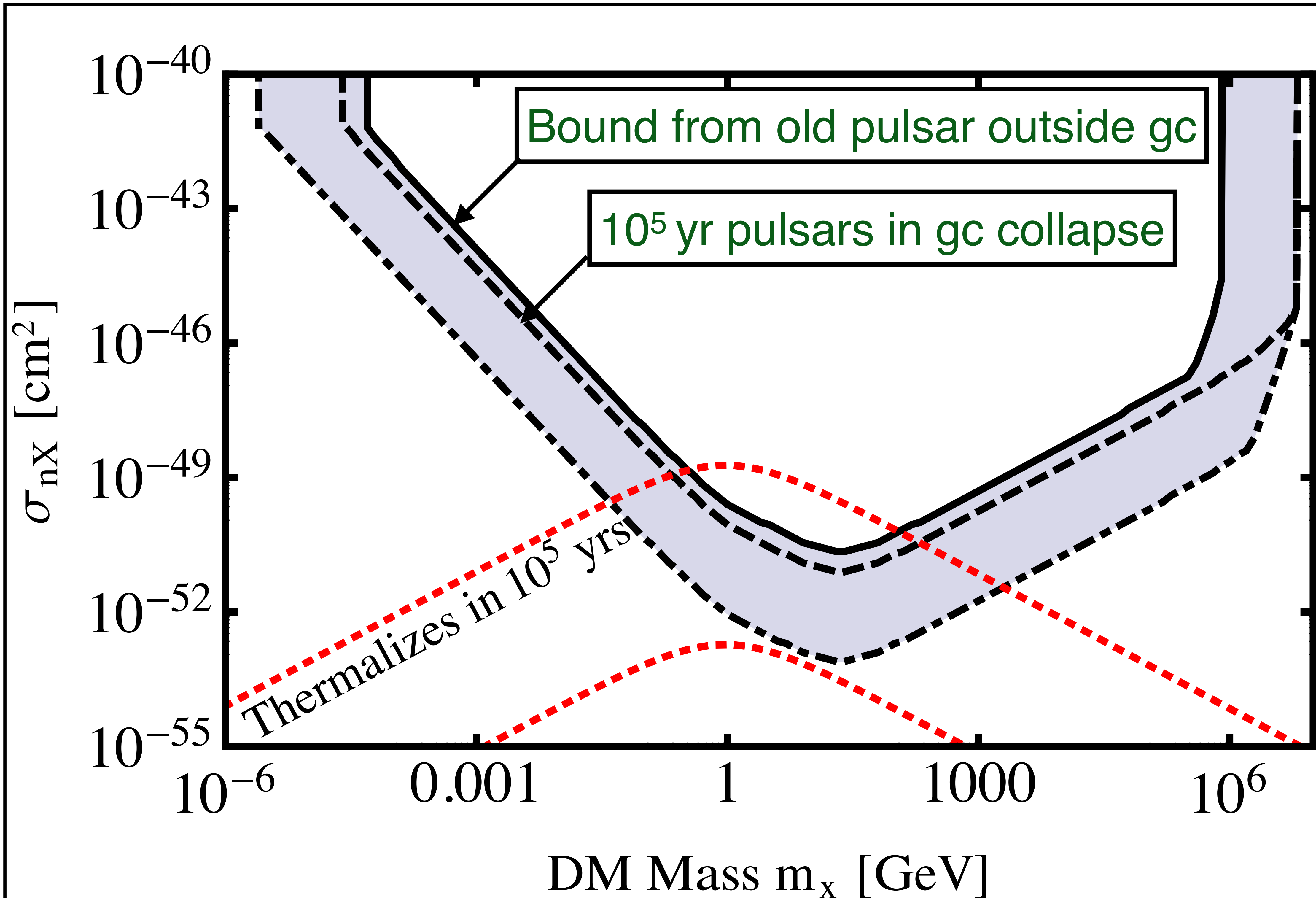

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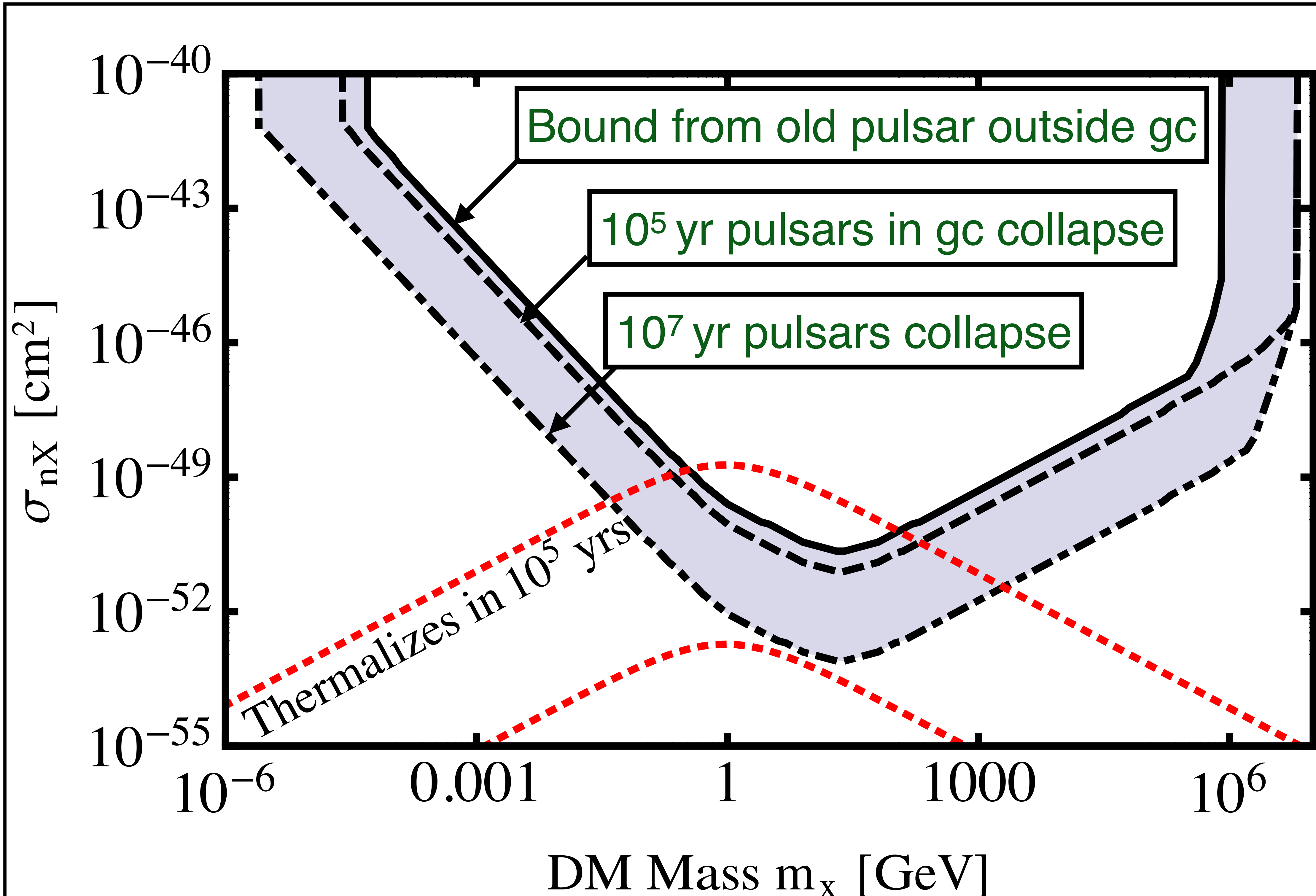

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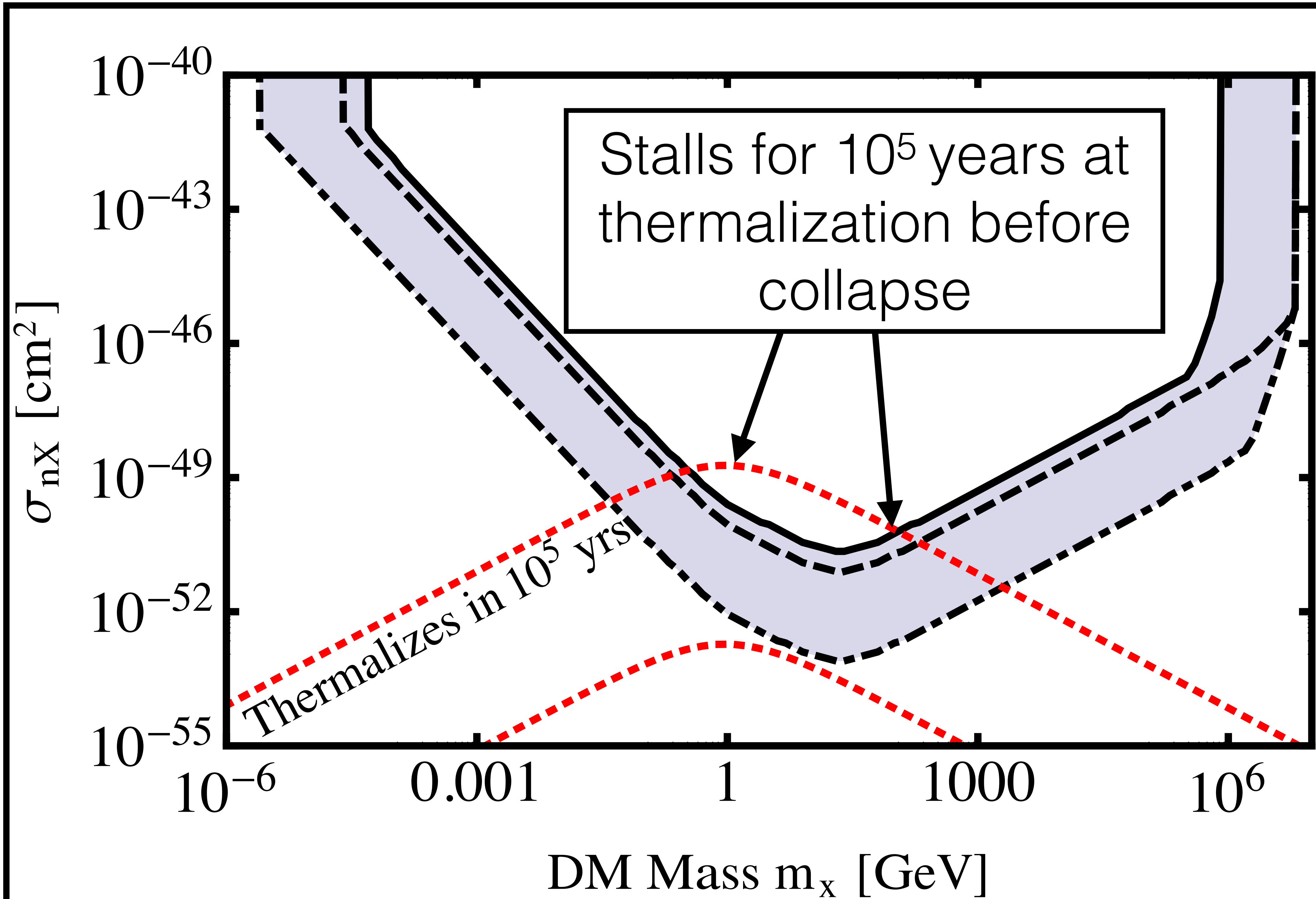

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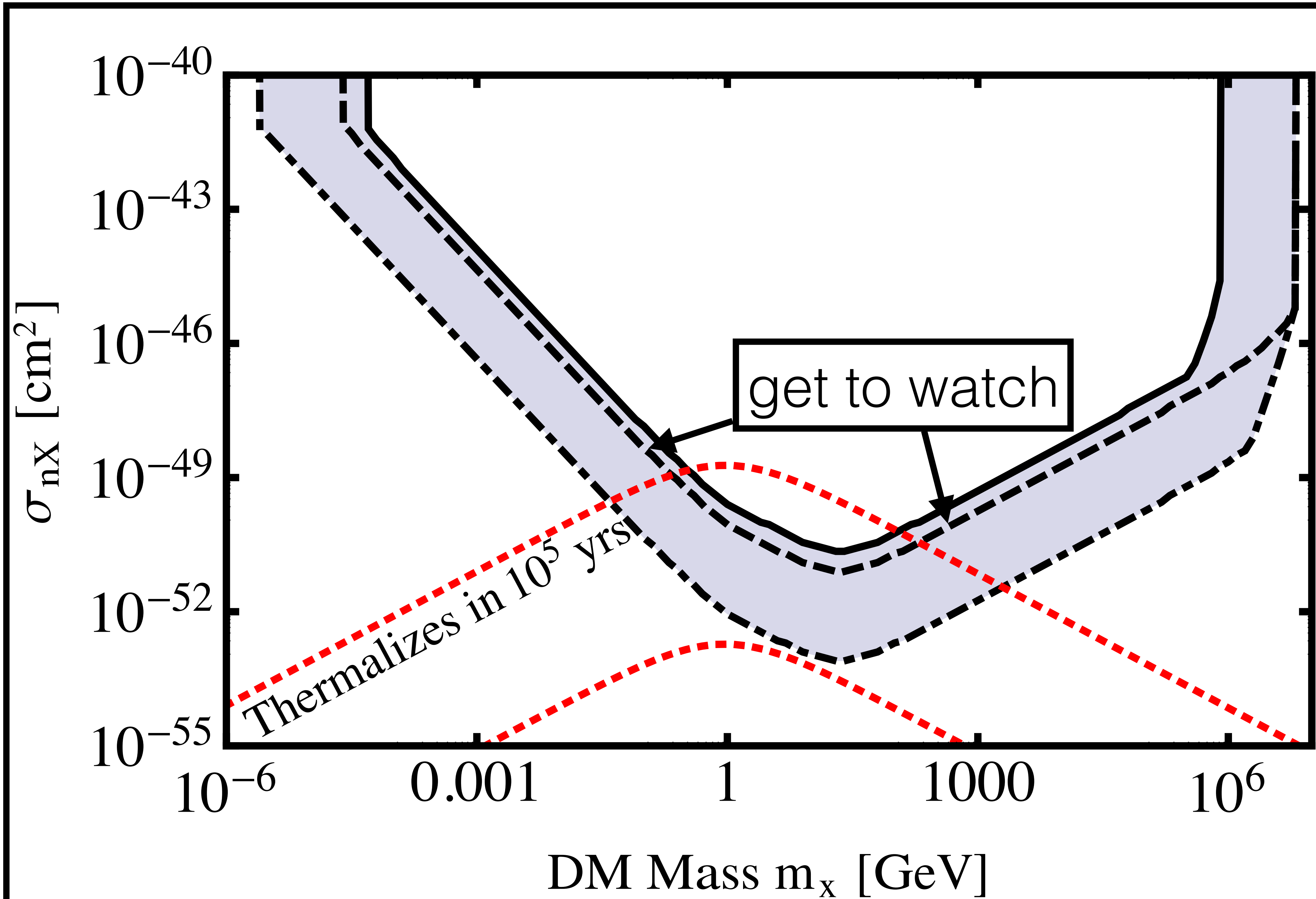
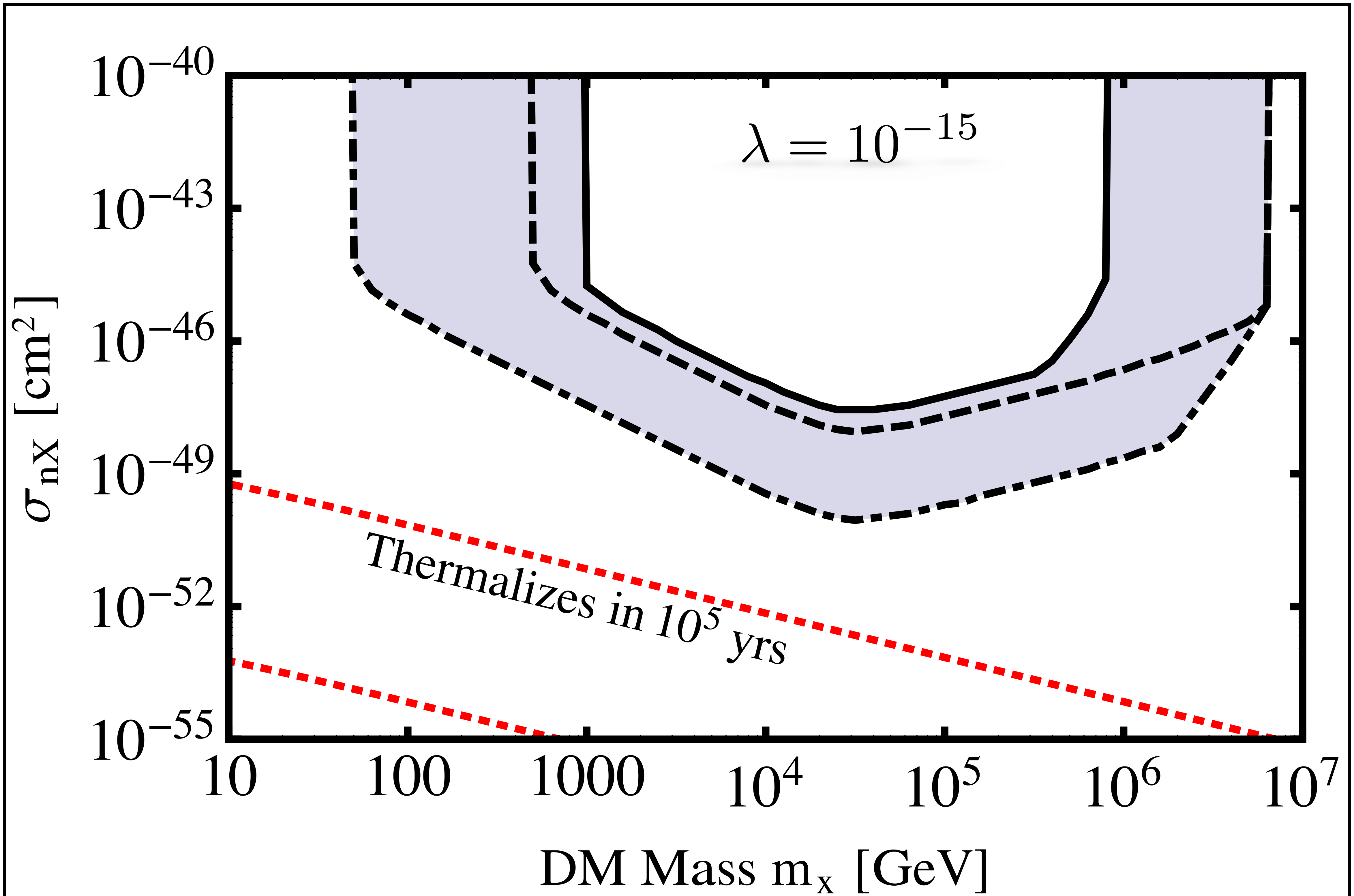
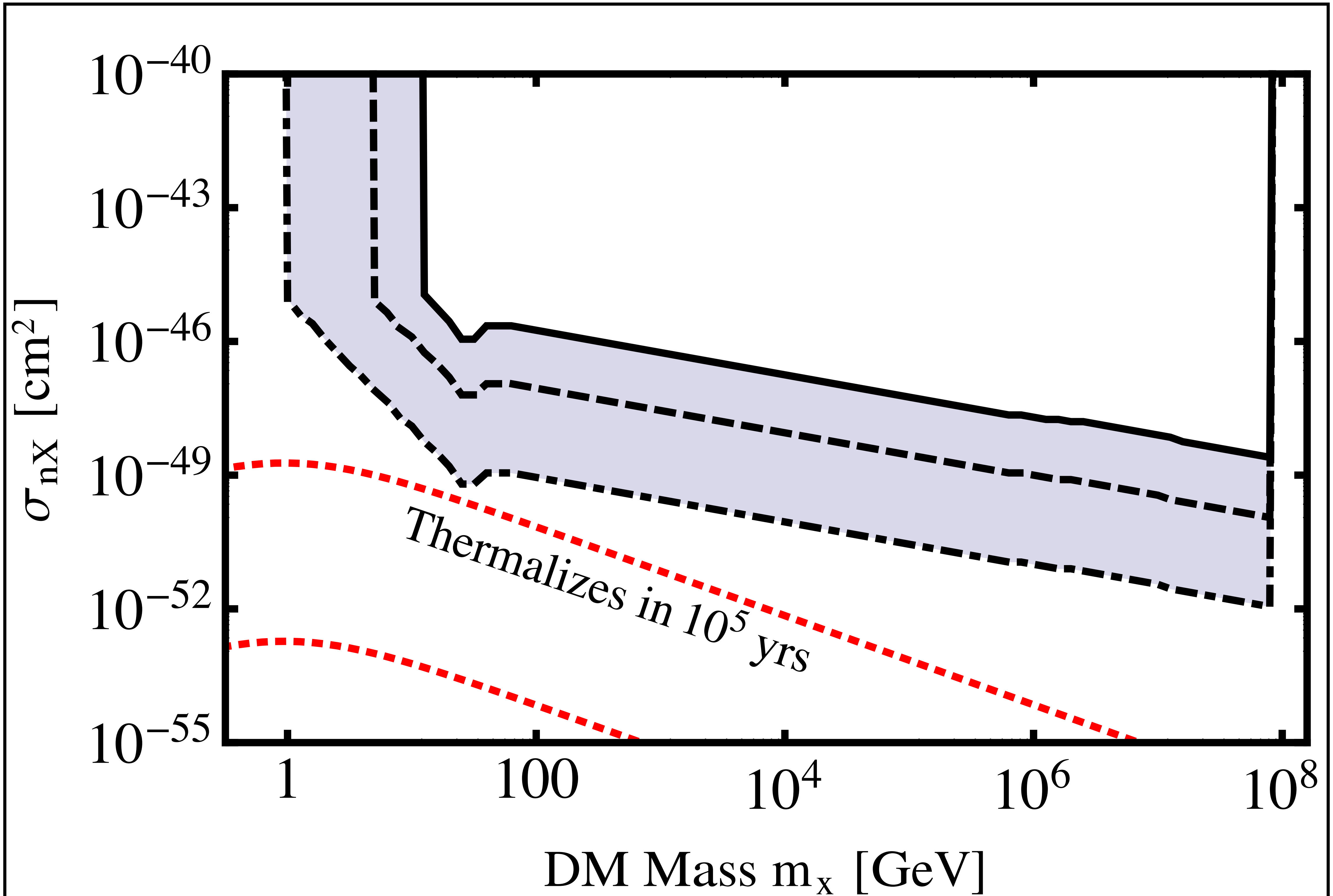


Bosons Imploding Pulsars

Highly Sensitive to Self-Interactions

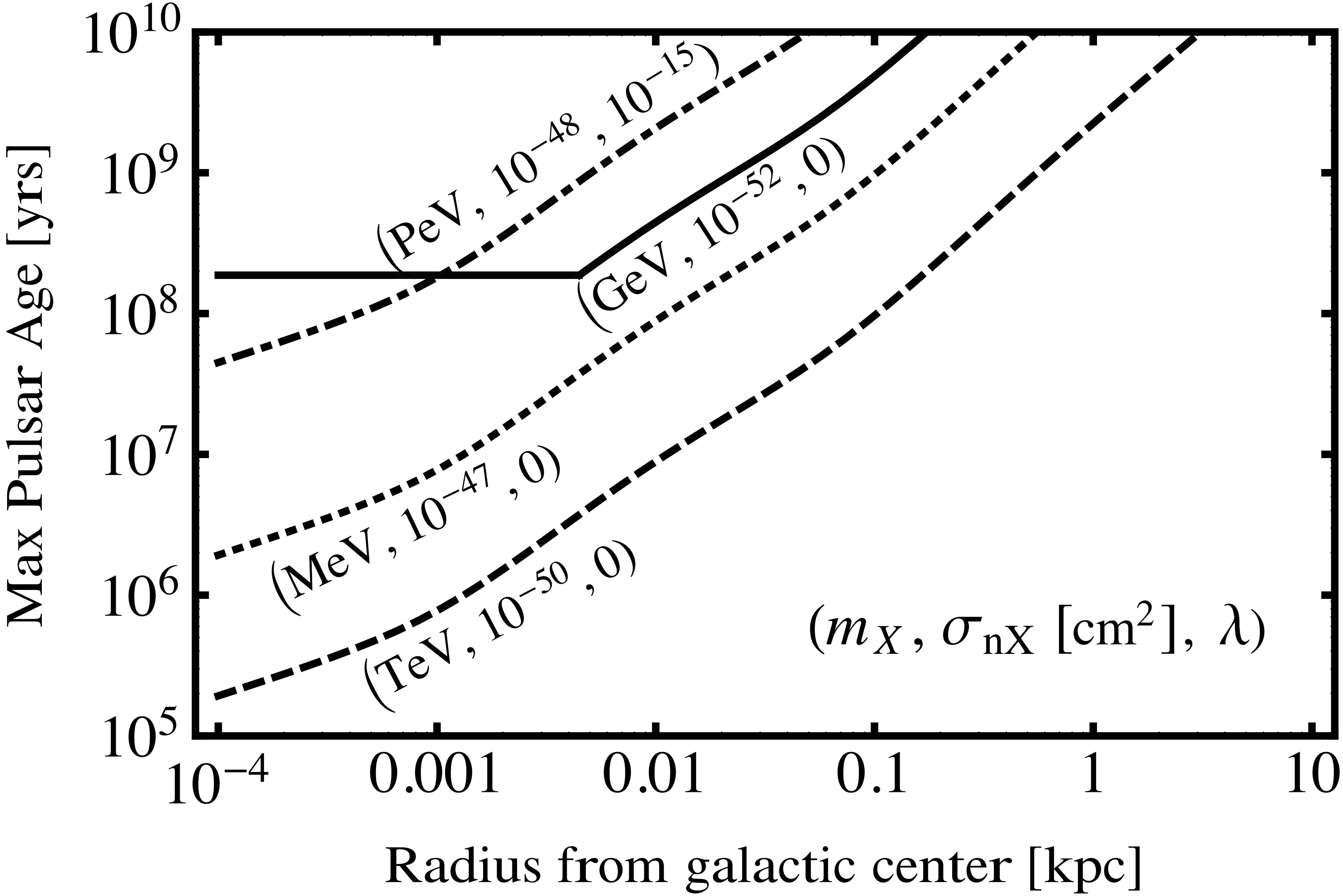


Fermions Imploding Pulsars



$m_\phi = 10$ MeV, $\alpha = 0.1$

Prediction of Pulsar Age Curves



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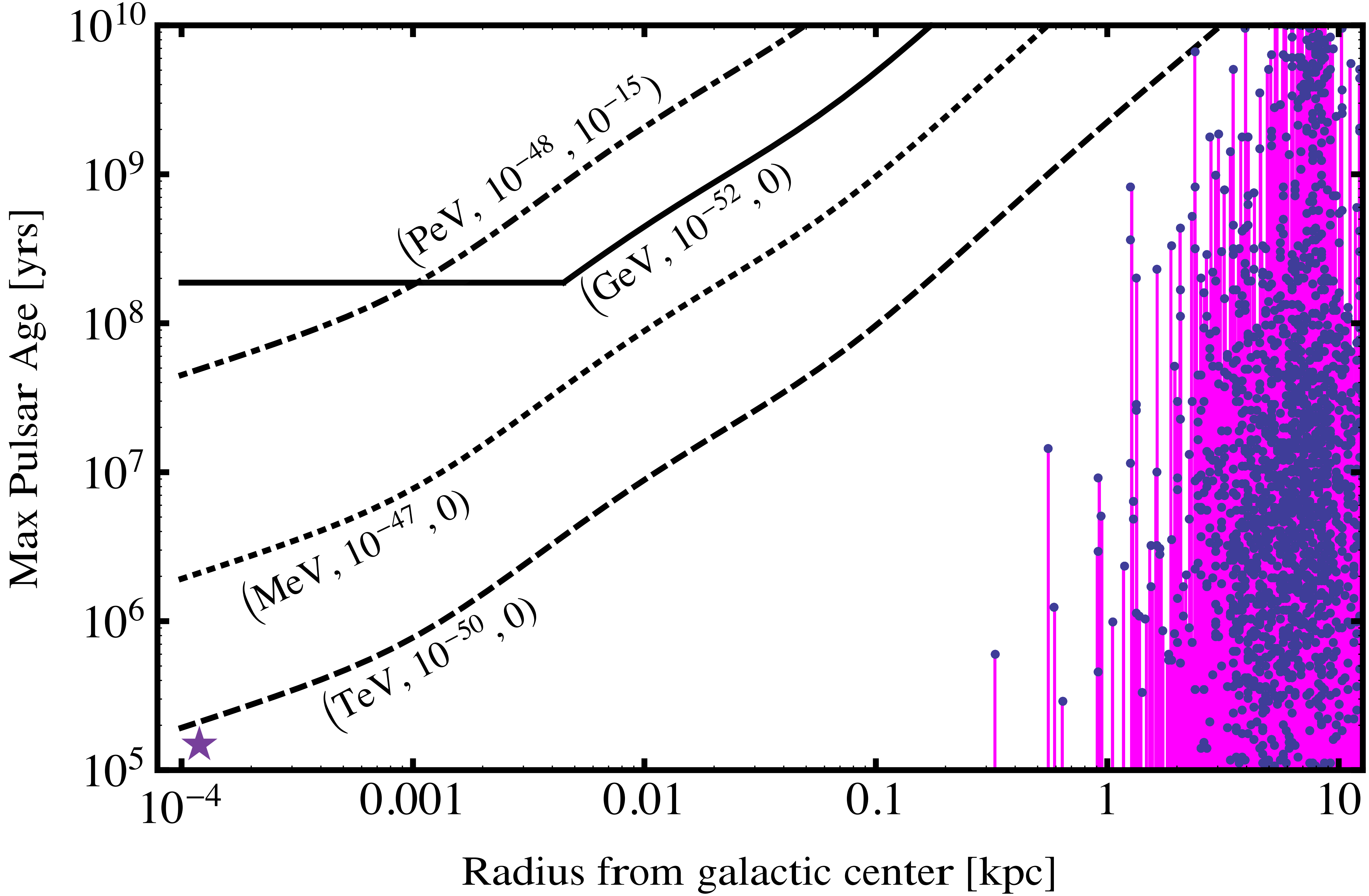
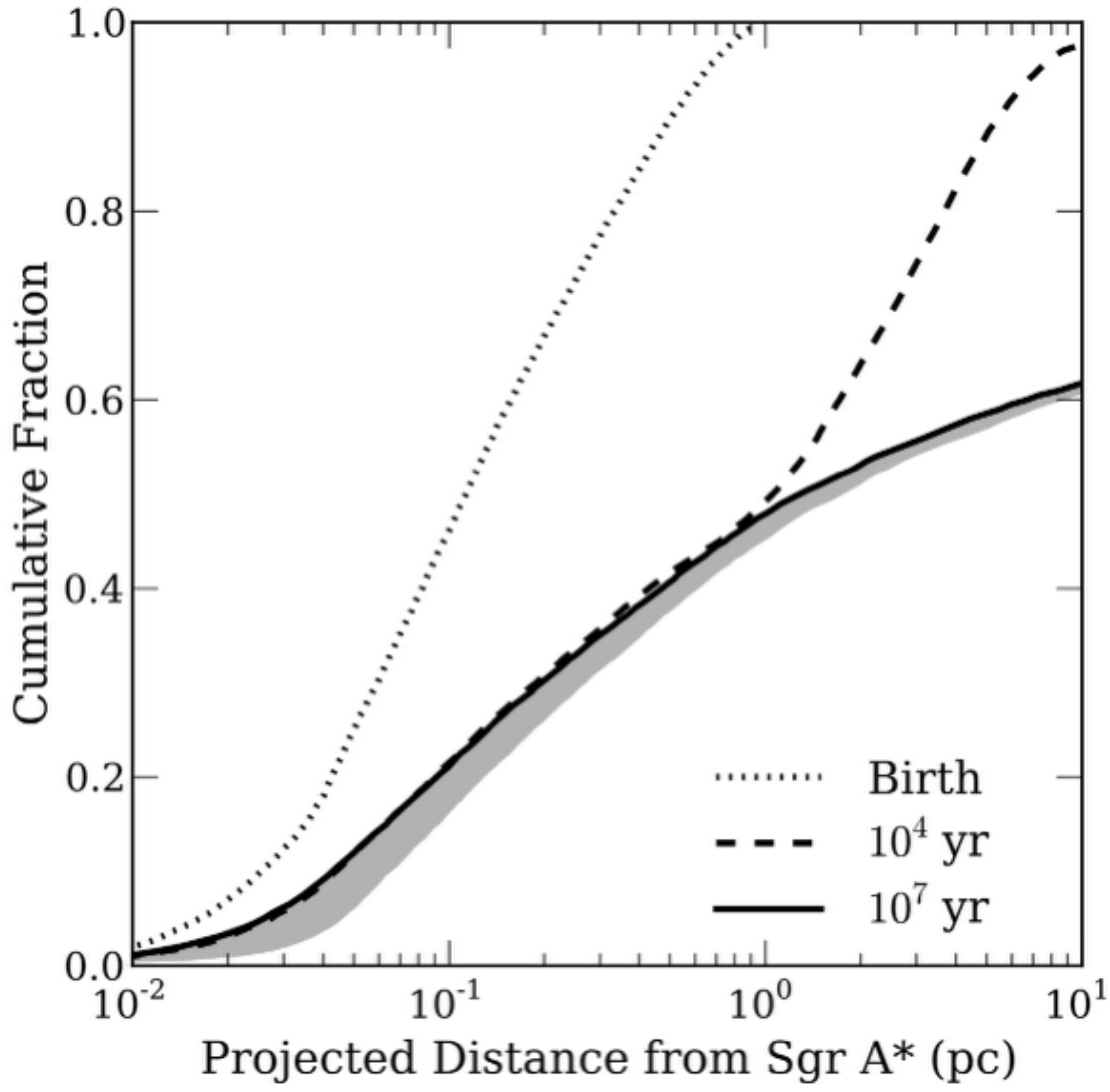


Conclusions

There is an exciting method to distinguish asymmetric from majorana or mixed dark matter. Pulsar age distributions could also be applied to bounds on and searches for multicomponent dark matter.

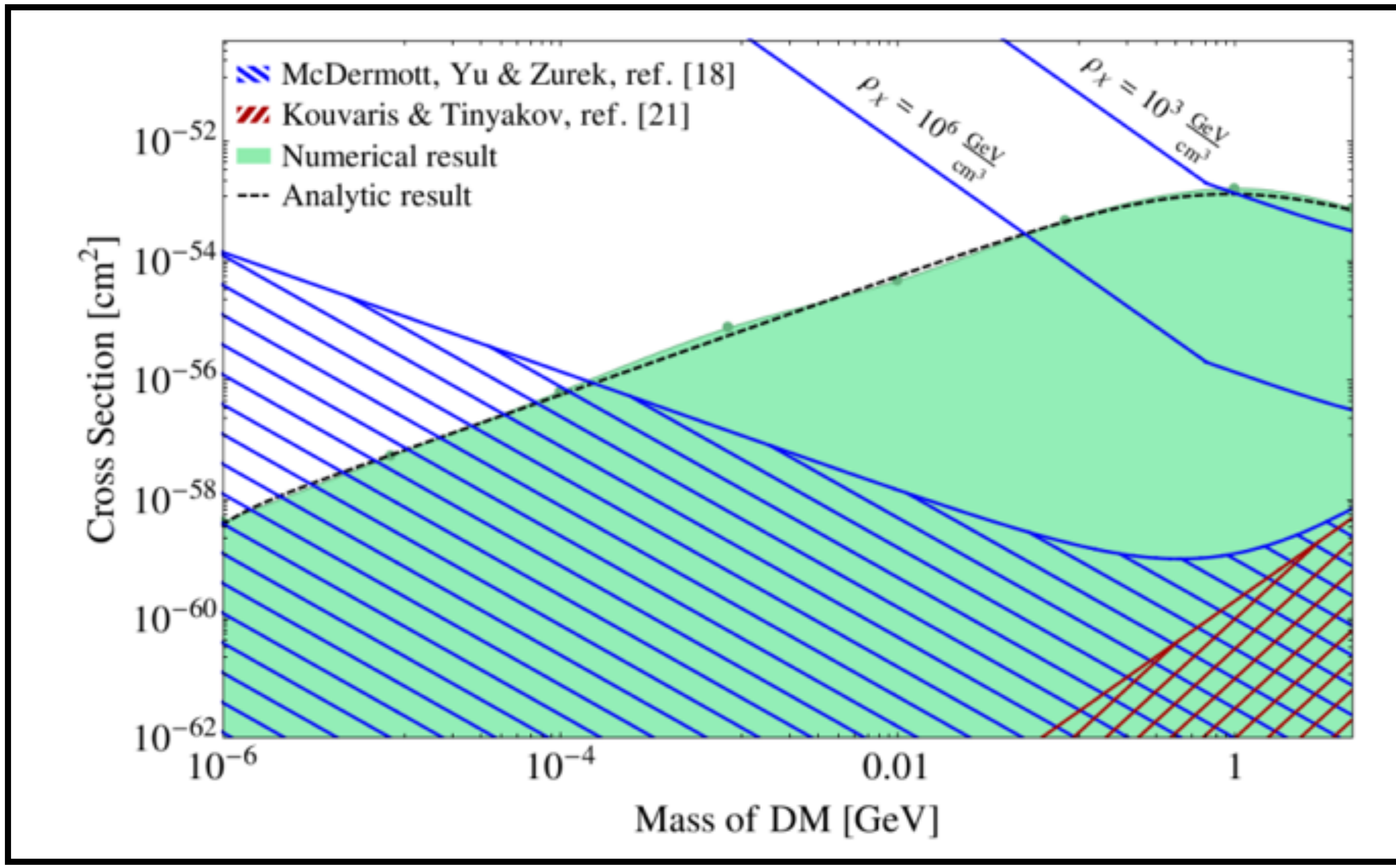
The missing pulsar problem



More Precise DM-Neutron Star Thermalization Times

Assumes a 100 GeV heavy mediator and axial/vector nucleon coupling to dark matter.

In a full treatment, thermalization time may be shorter for heavier DM.



Bertoni, Nelson, Reddy 1309.1721

Self-interactions, bullet clusters

- Bullet clusters provide an upper bound on dark matter self-interactions.
- Xray-emitting ionized IGM slowed by ram pressure as the subcluster slams through a megacluster.

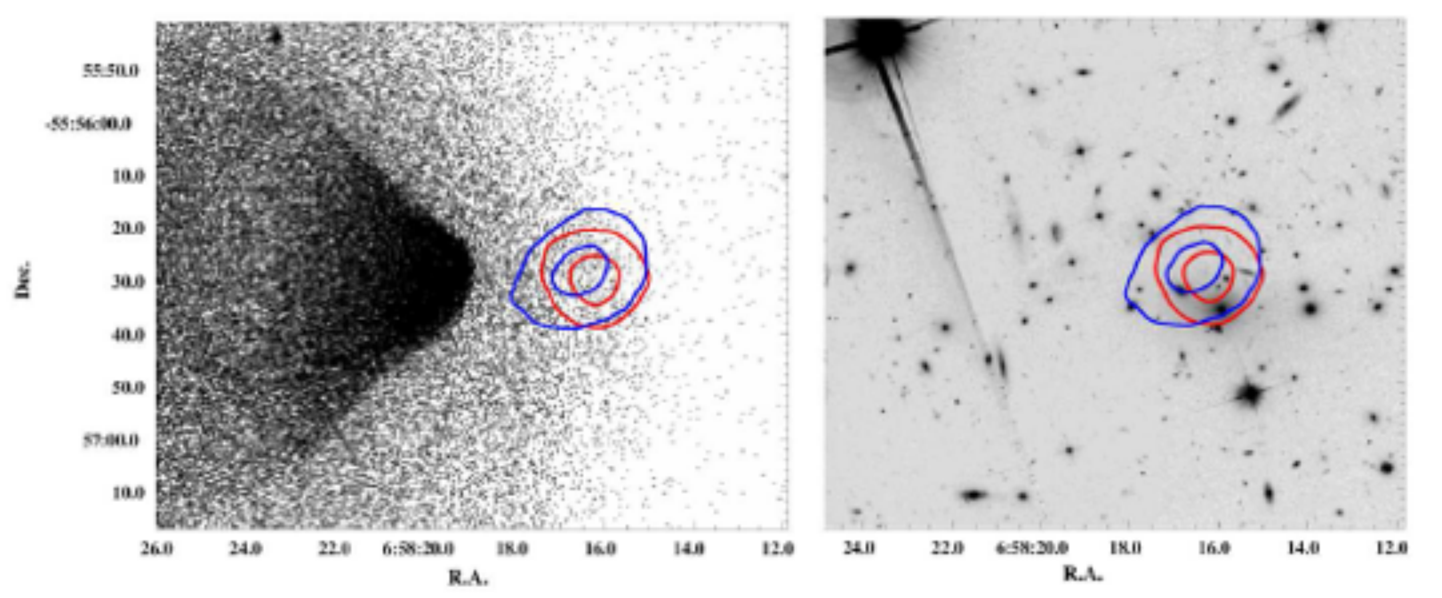


Fig. 2.— Close up of the subcluster bullet region, with the DM (blue) and galaxy (red) centroid error contours overlain. The contours show the 68.3% and 99.7% error regions. The left panel shows the X-ray *Chandra* image, while the right shows the optical *HST* image.

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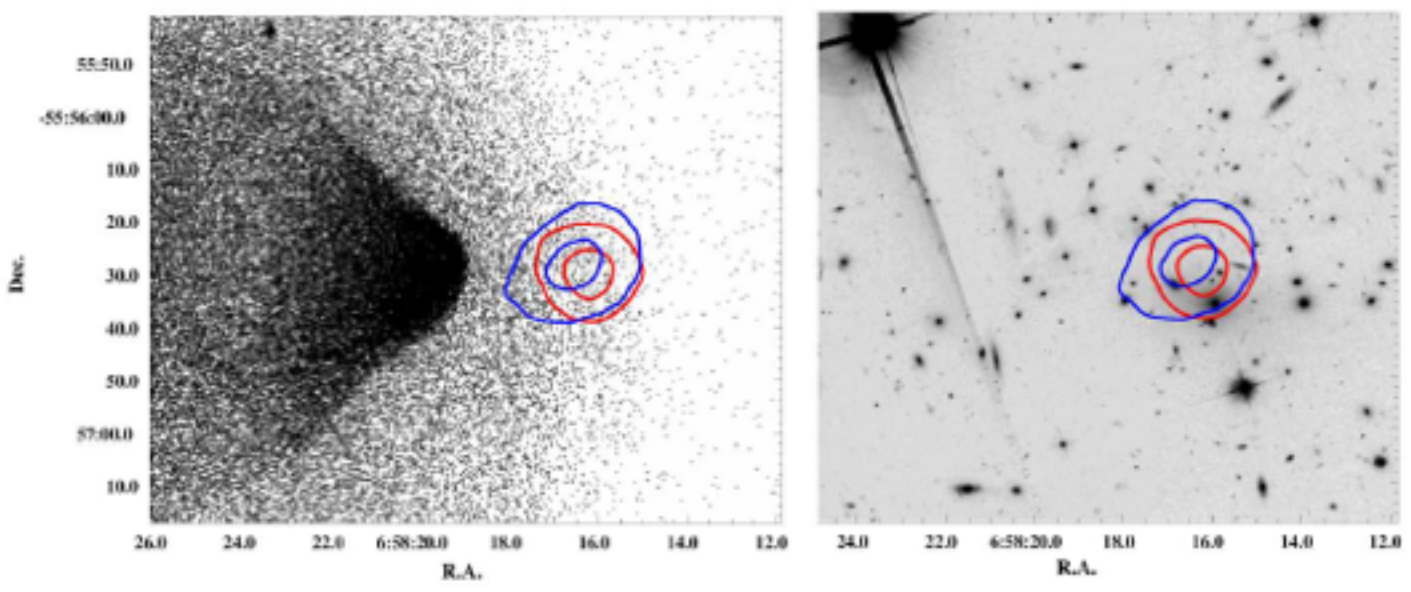

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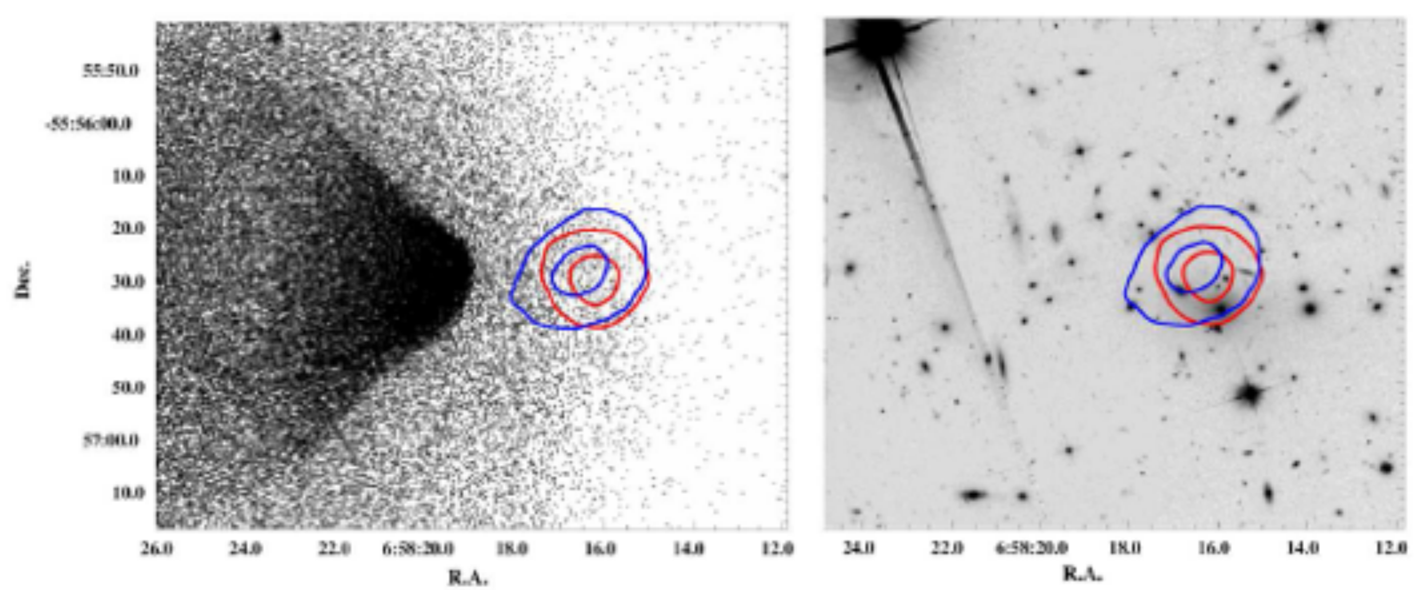

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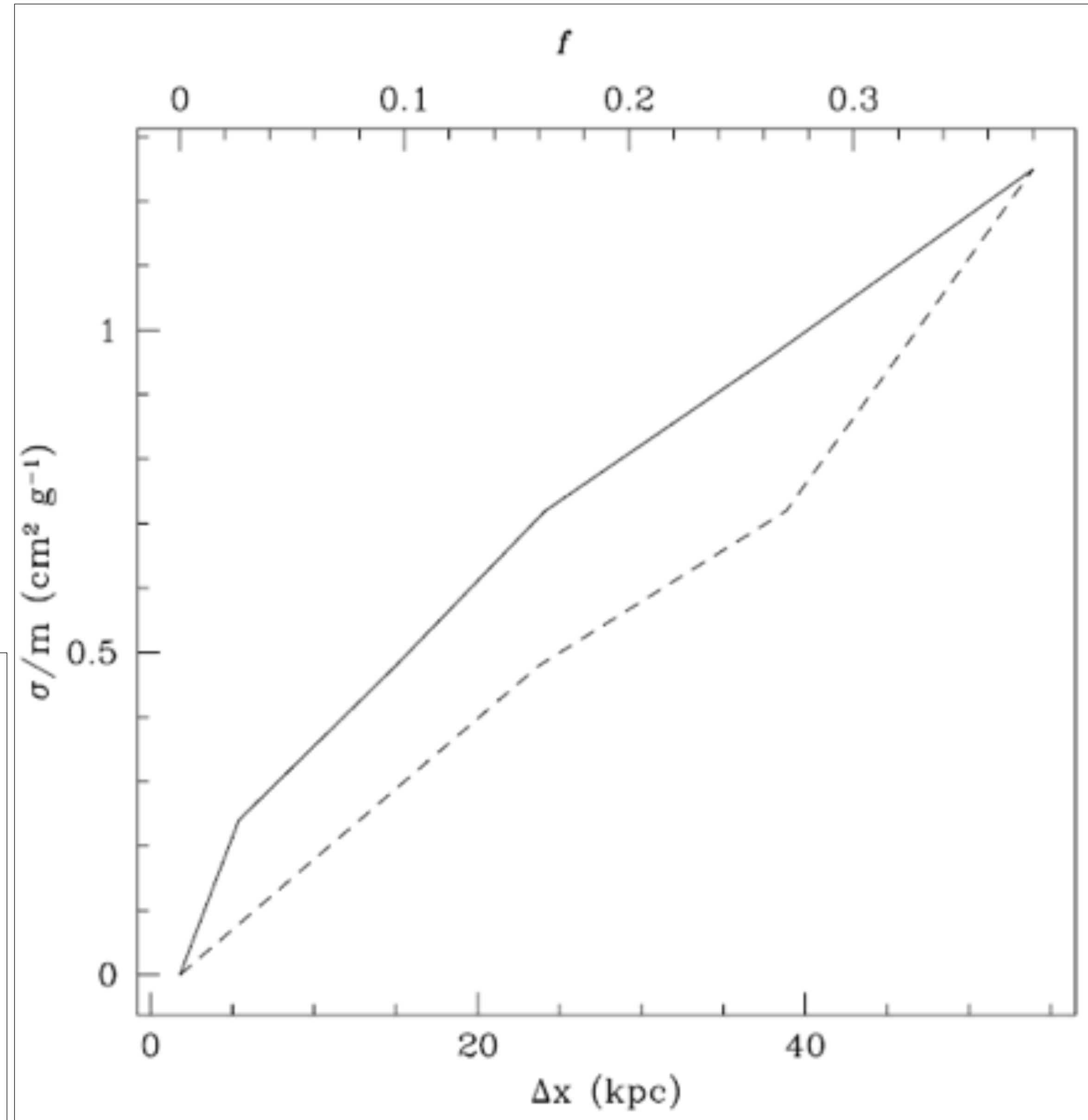

Fig. 5.— The dependence of the subcluster galaxy and total mass centroid offset (Δ x, solid line) and the fractional change in the subcluster M/L ratio (f, dashed line) on σ/m. Based on the values given in Table 2.

Randall et al.
0704.0261