Higgs portals to galactic center pulsar collapse

Pheno 2015

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work with Tim Linden and Fatemah Elahi

1405.1031 1504.04019

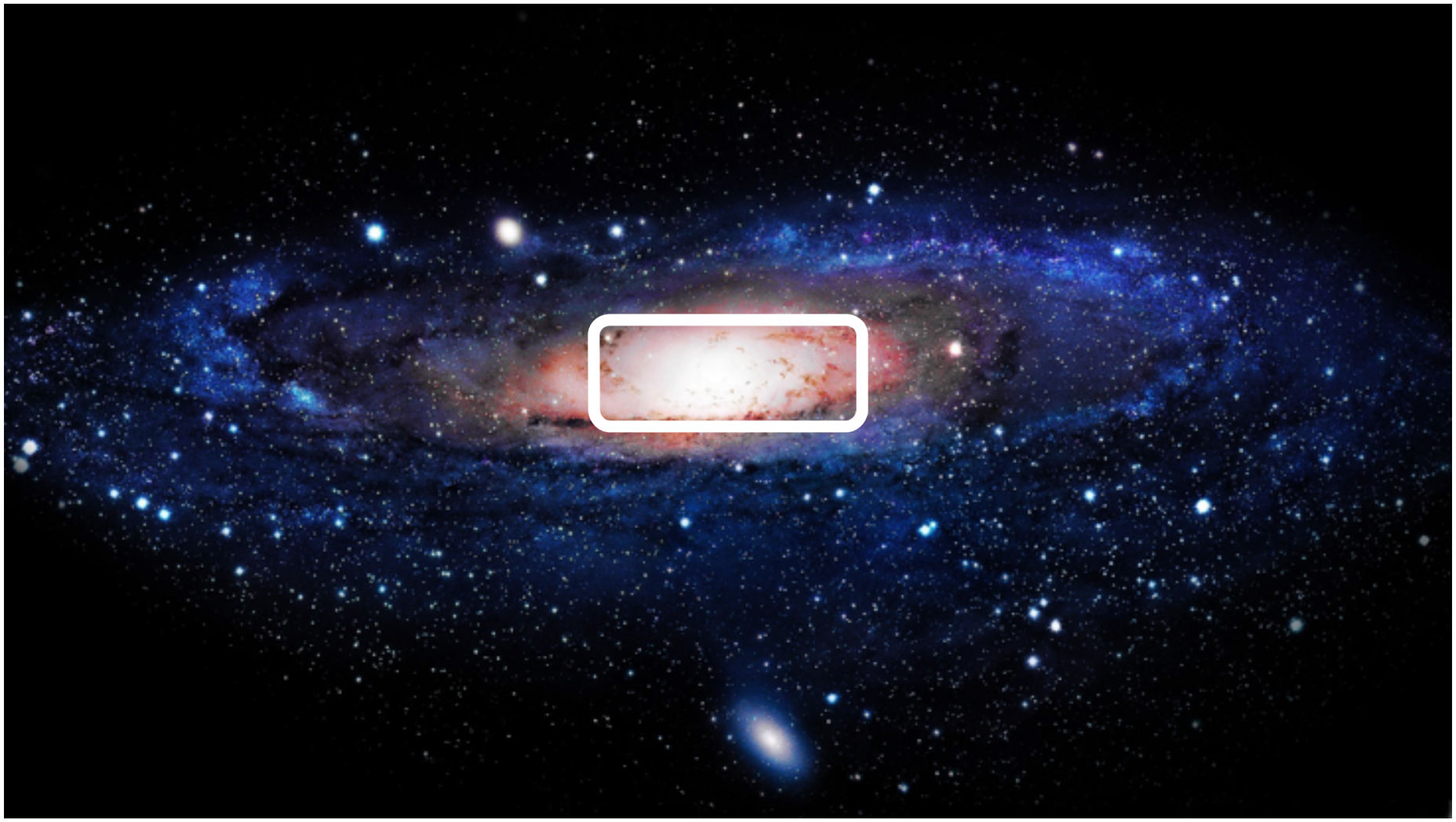
Asymmetric dark matter models suppose that dark matter in galactic halos, like ordinary matter in galactic halos, is composed of particles and not antiparticles of some symmetry.

$$\phi\phi^* \quad \text{or} \quad \psi\bar{\psi}$$

This dark asymmetry could arise in conjunction with the baryon/lepton asymmetries.

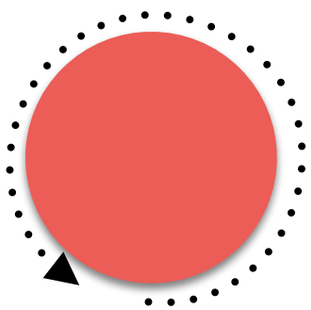
In a very futuristic setting, the interactions (C,CP violating) that lead to a dark asymmetry might be revealed through something like a pulsed collider + kamioka program…

…on a much shorter timescale, old pulsars in the Milky Way's center getting eaten by dark matter black holes could be a signal of asymmetric dark matter. This signal arises because asymmetric dark matter would collect in pulsars without annihilating to SM or relativistic dark particles.



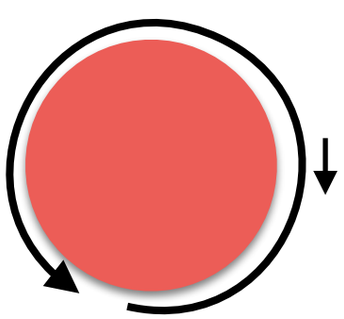
A pulsar is a spinning neutron star, observed as a regularly radiating revolving magnetic dipole. It is very near collapsing (escape velocity of 0.7 c).

We can tell about how old it is by looking at its pulses.

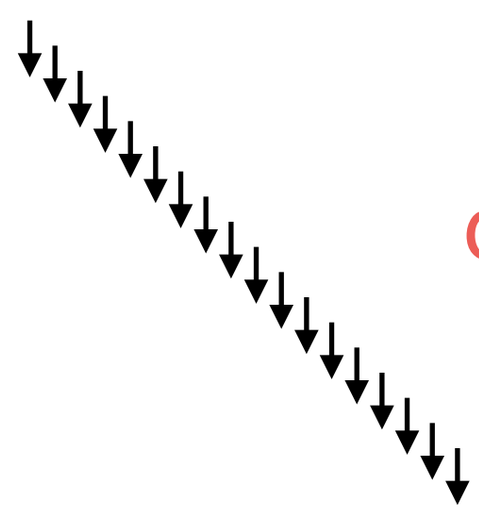


$$\mathrm{P}$$

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

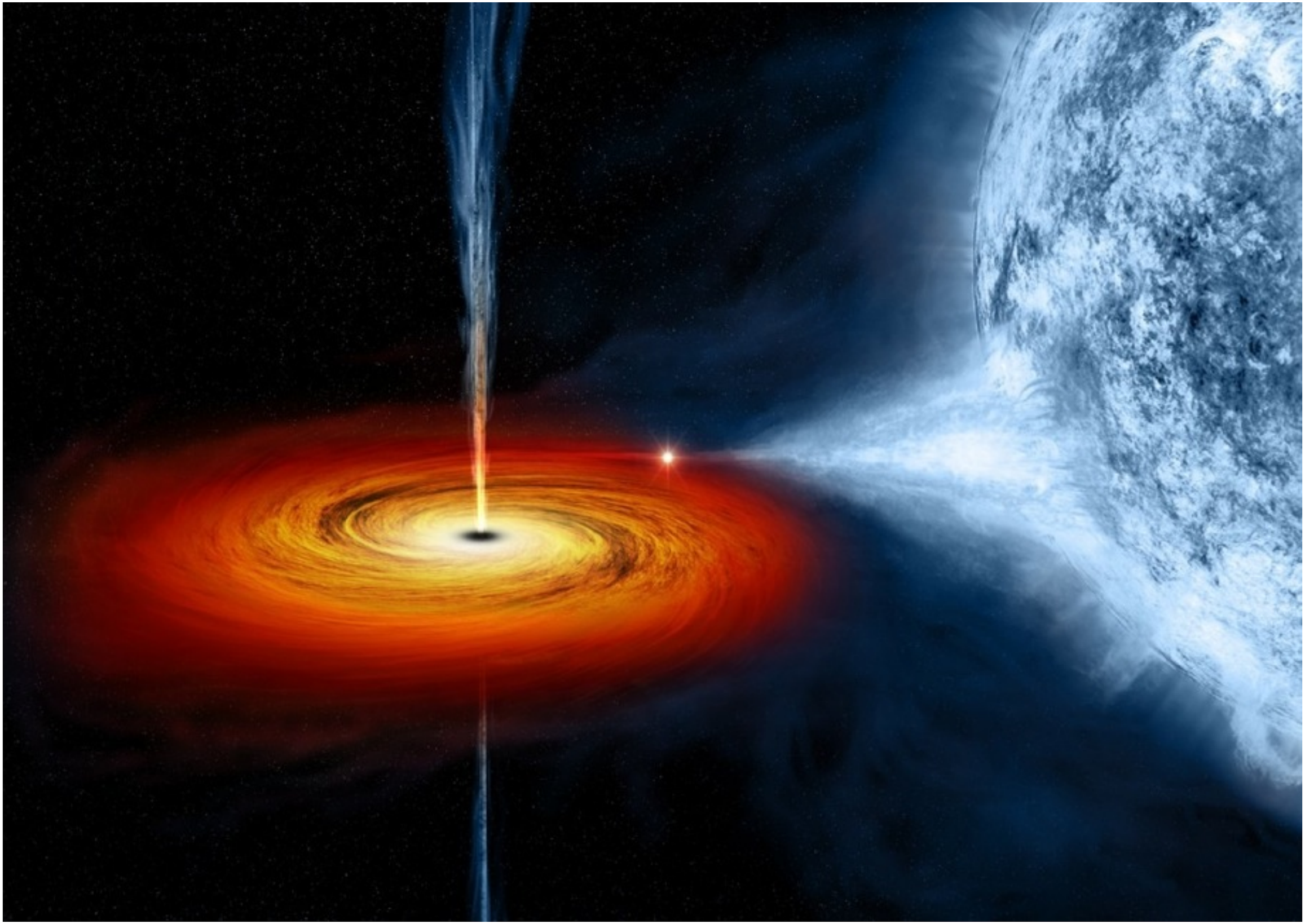


$$\dot{\mathrm{P}}$$



divided by

(Older) Millisecond pulsars form from x-ray binaries



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.

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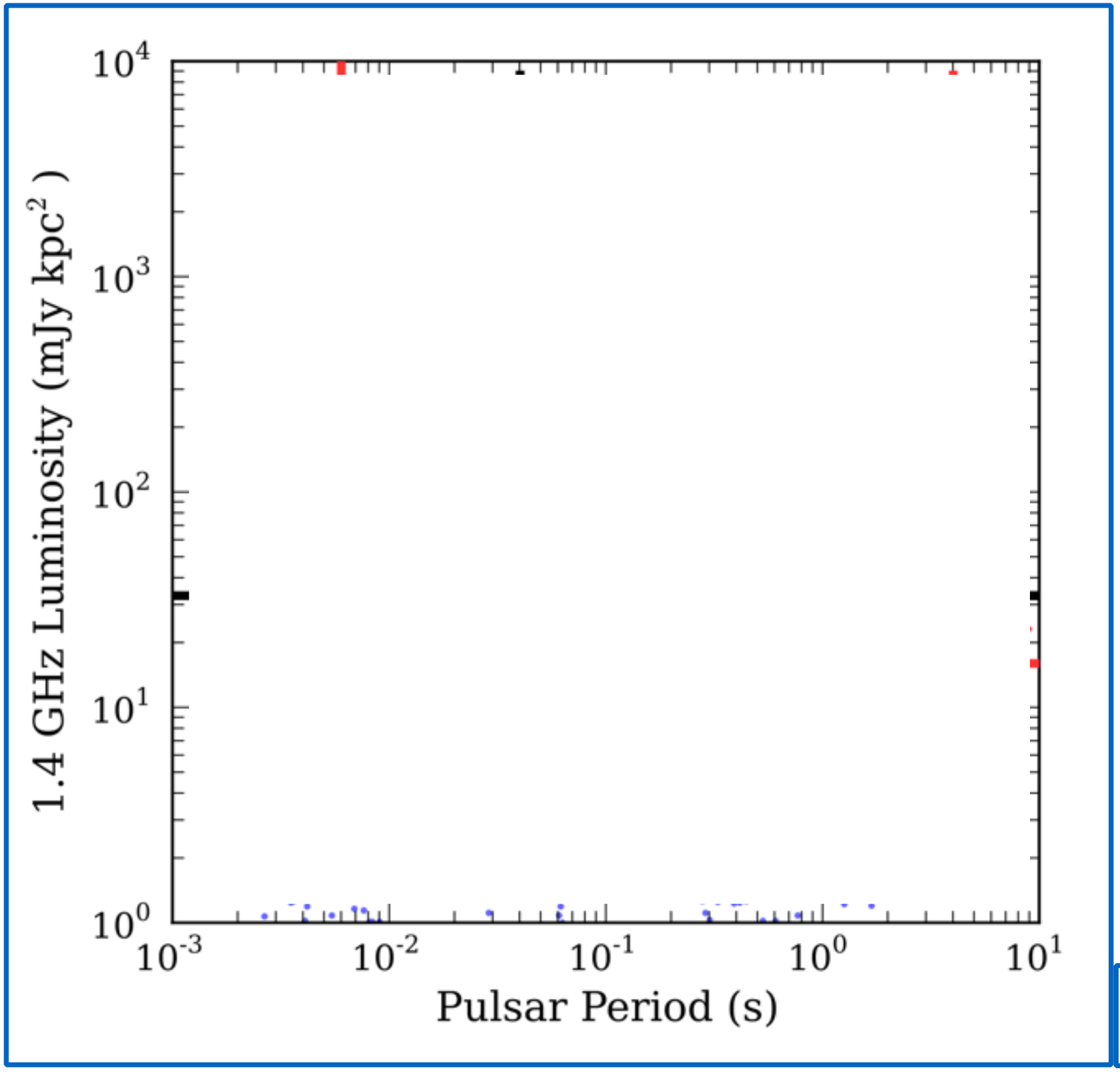
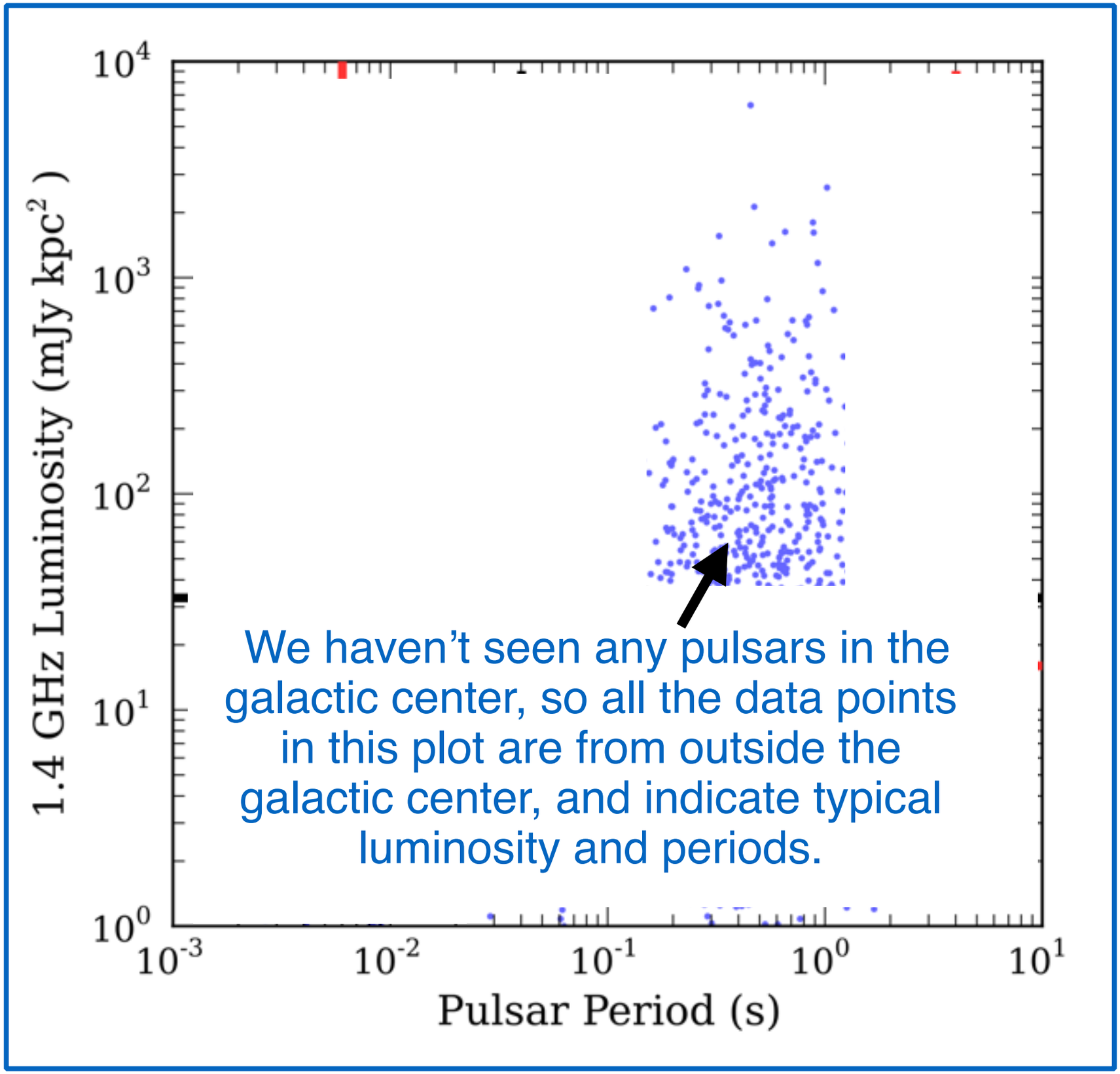
This creates two missing pulsar problems. Both young and old millisecond pulsars seem to be absent. There are 50-500 missing millisecond pulsars.

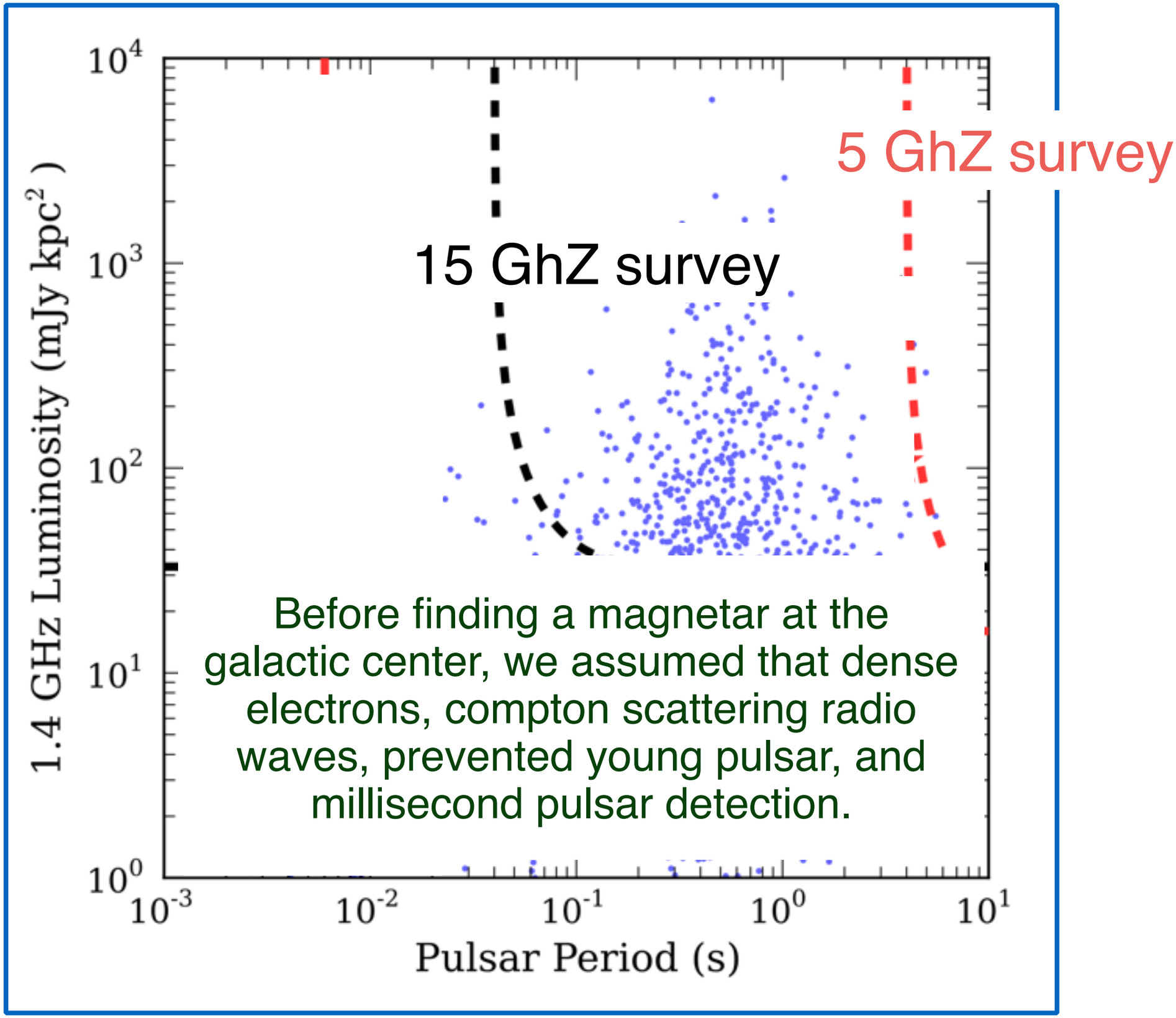
The missing pulsar problem



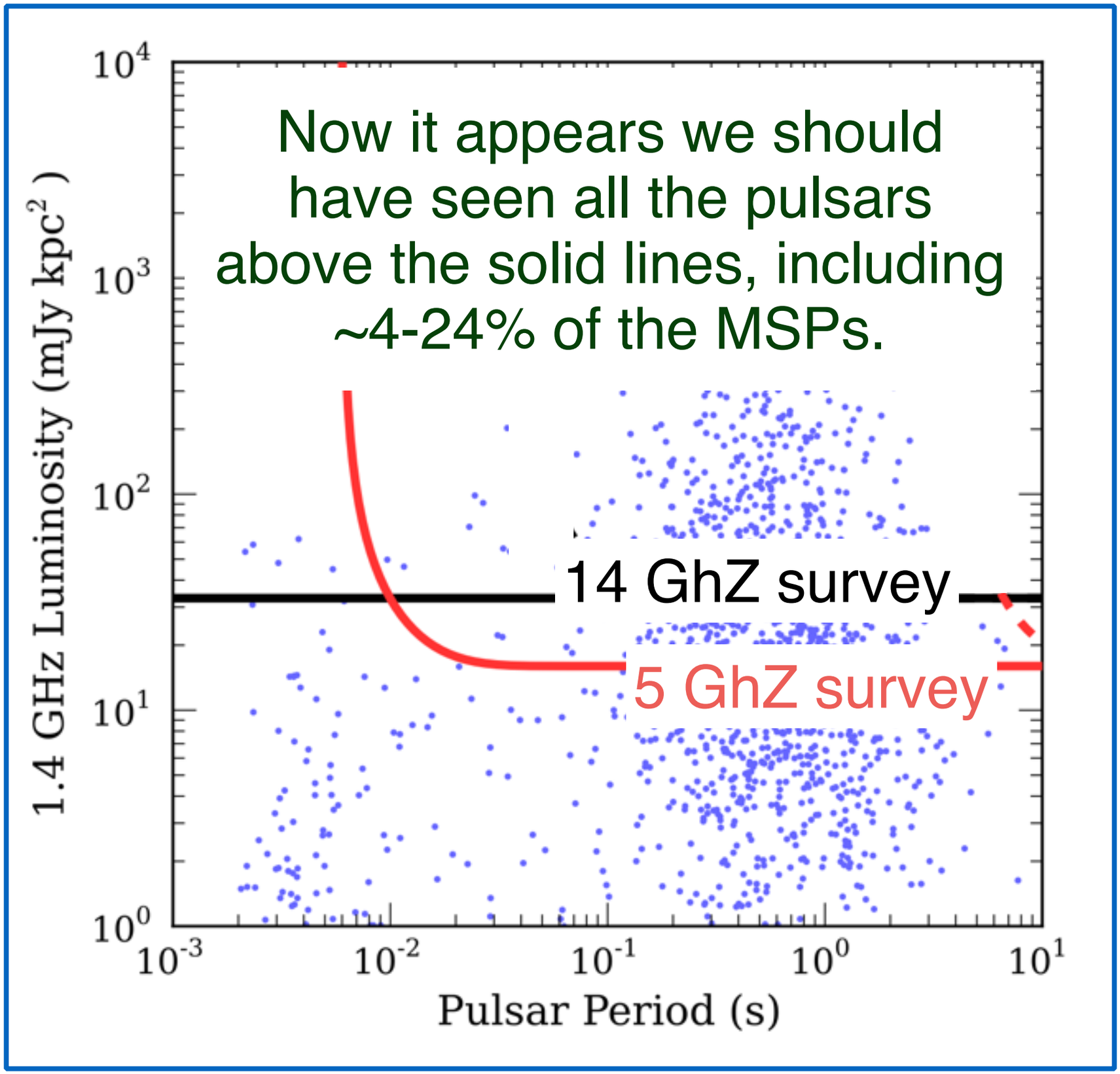
Dexter, O'Leary
1310.7022


1.4 GHz Luminosity (mJy kpc^2)
10^4
10^3
10^2
10^1
10^0
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
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 indicate typical luminosity and periods.

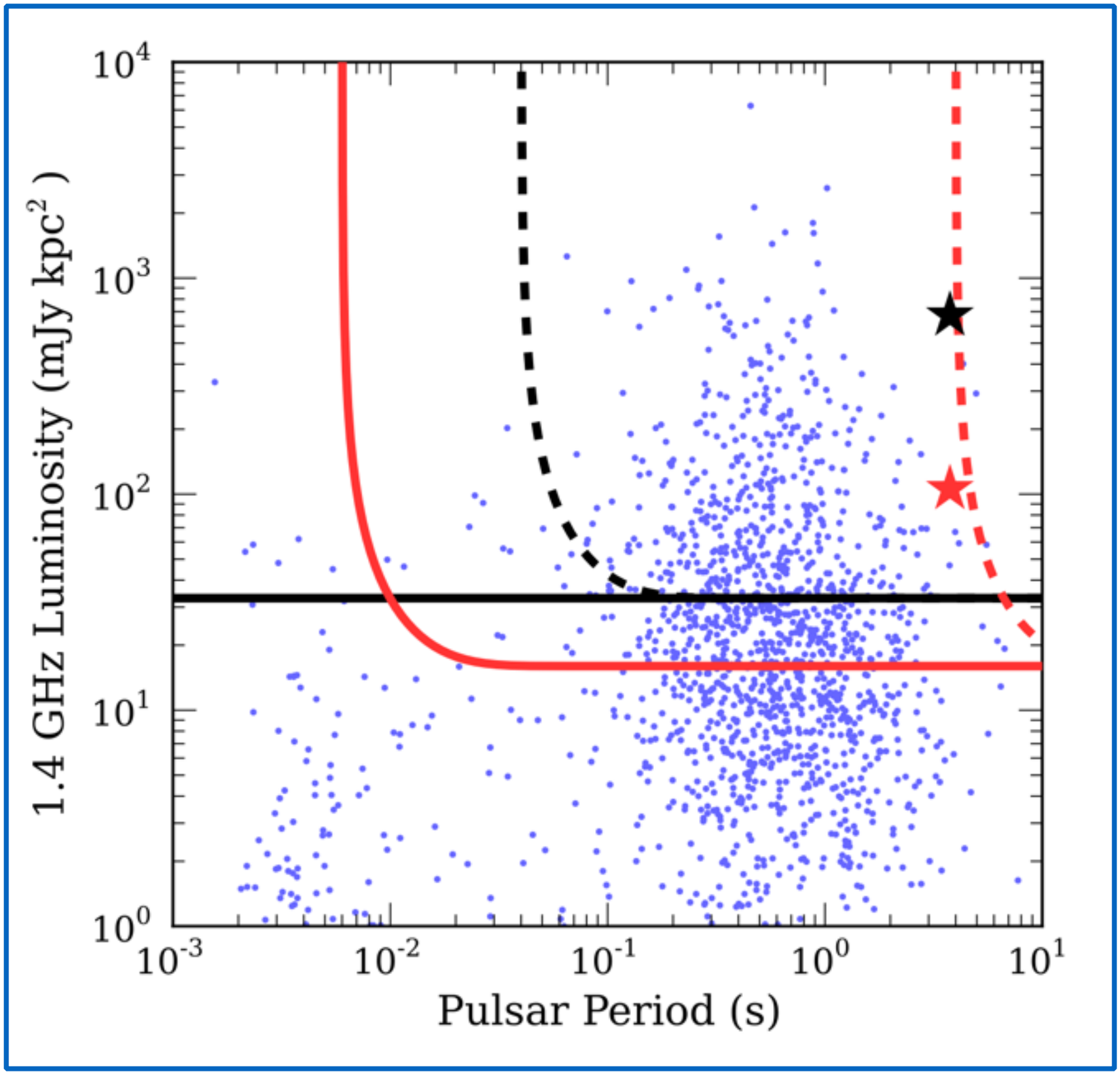
Survey sensitivity before magnetar



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

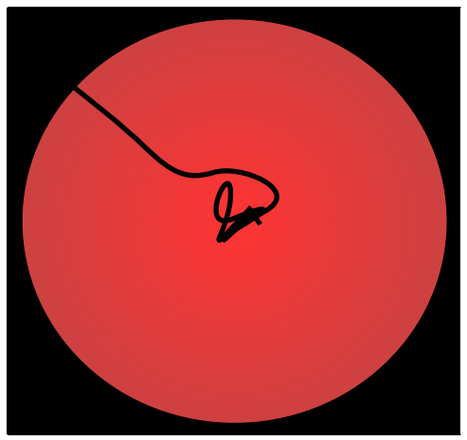

Now it appears we should have seen all the pulsars above the solid lines, including ~4-24% of the MSPs.
14 GhZ survey
5 GhZ survey
1.4 GHz Luminosity (mJy kpc^2)
Pulsar Period (s)
10^4
10^3
10^2
10^1
10^0
10^{-3}
10^{-2}
10^{-1}
10^0
10^1

Where are the galactic center pulsars?

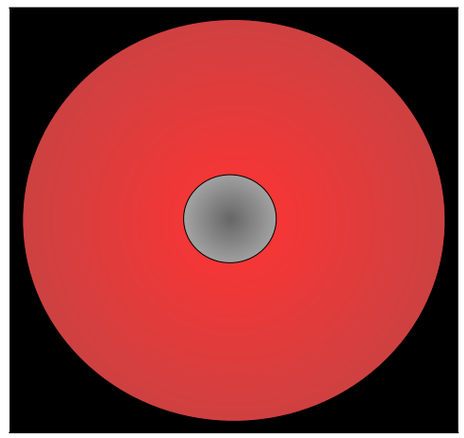


Asymmetric Dark Matter Imploding Pulsars

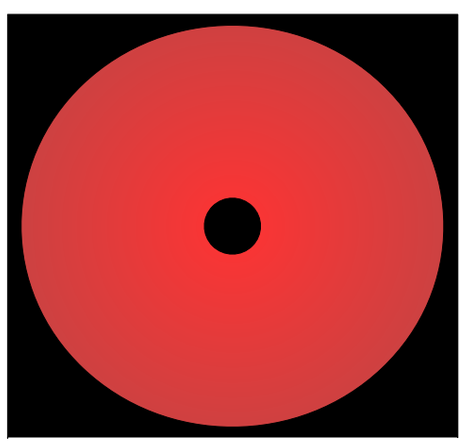
1] DM captured



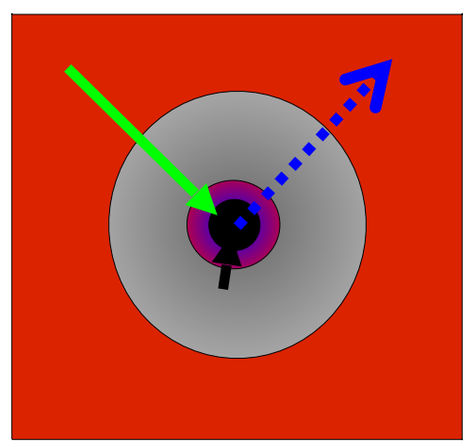
2] DM thermalizes



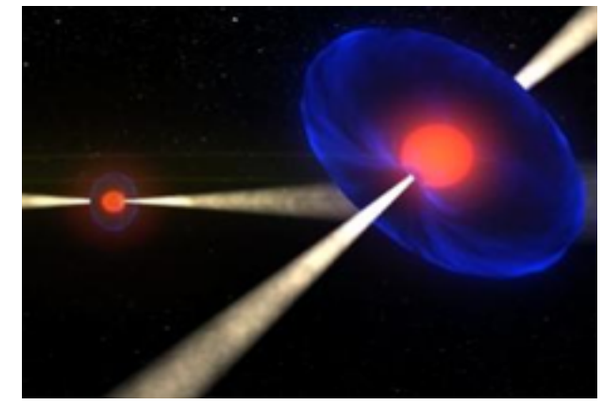
3] DM collapses



4] BH accretes, radiates

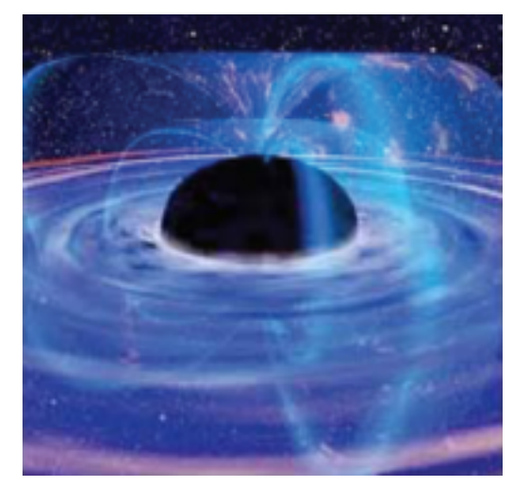


5a] if it shrinks, (Hawking)



no collapse

5b] if it grows rapidly,



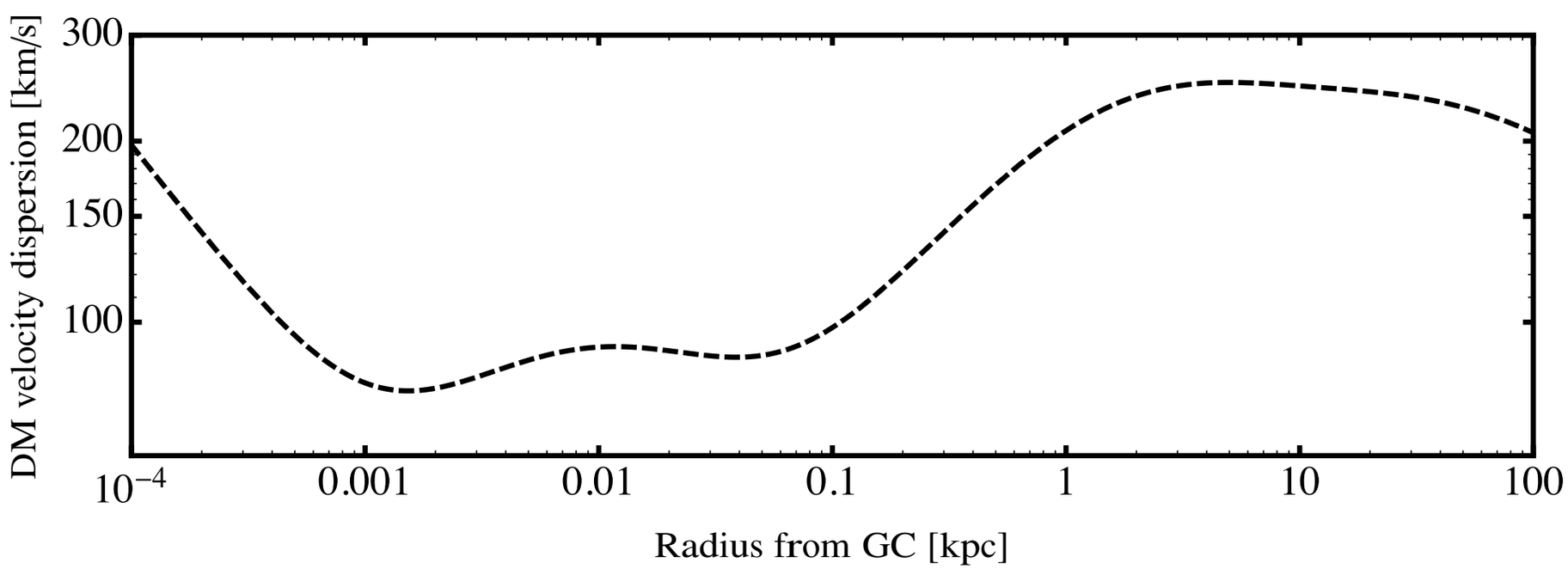
collapse

Asymmetric Dark Matter Imploding Pulsars

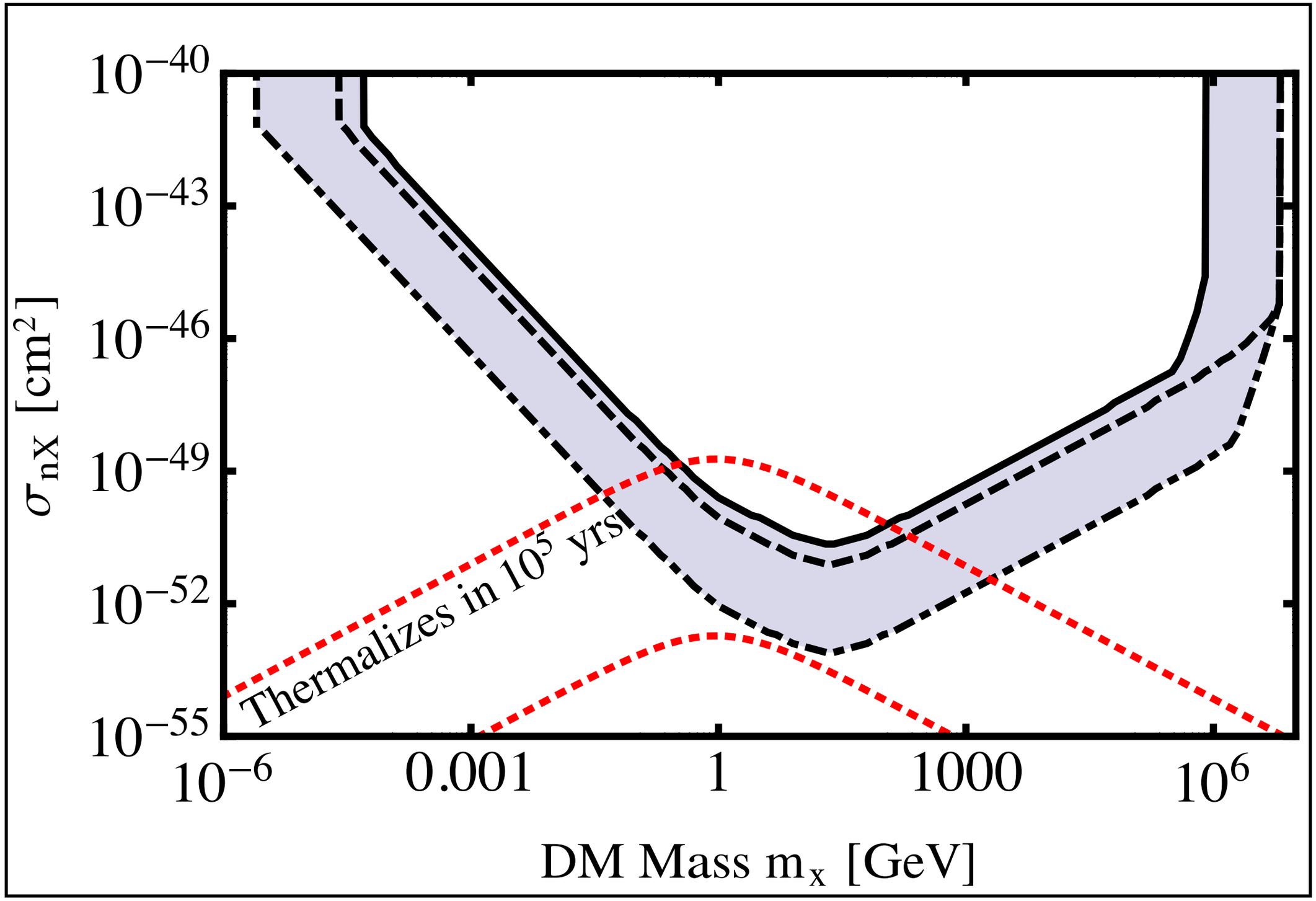
The capture rate for dark matter on pulsars scales inversely with velocity dispersion and linearly with the local dark matter density.

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

For bosonic DM, we model our galaxy's profile using disc and galactic center star velocity measurements (NFW).

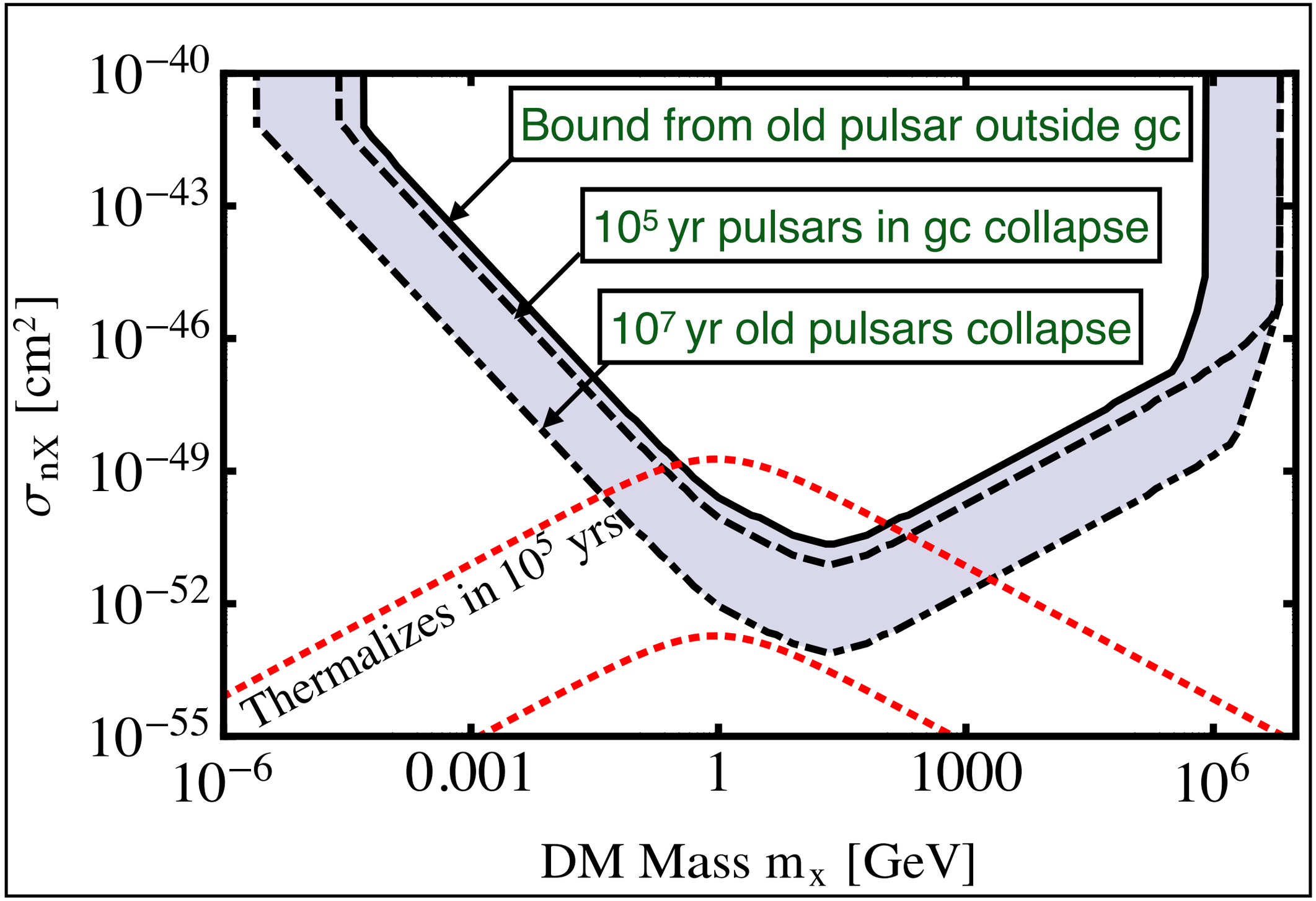


ADM Bosons Imploding Pulsars

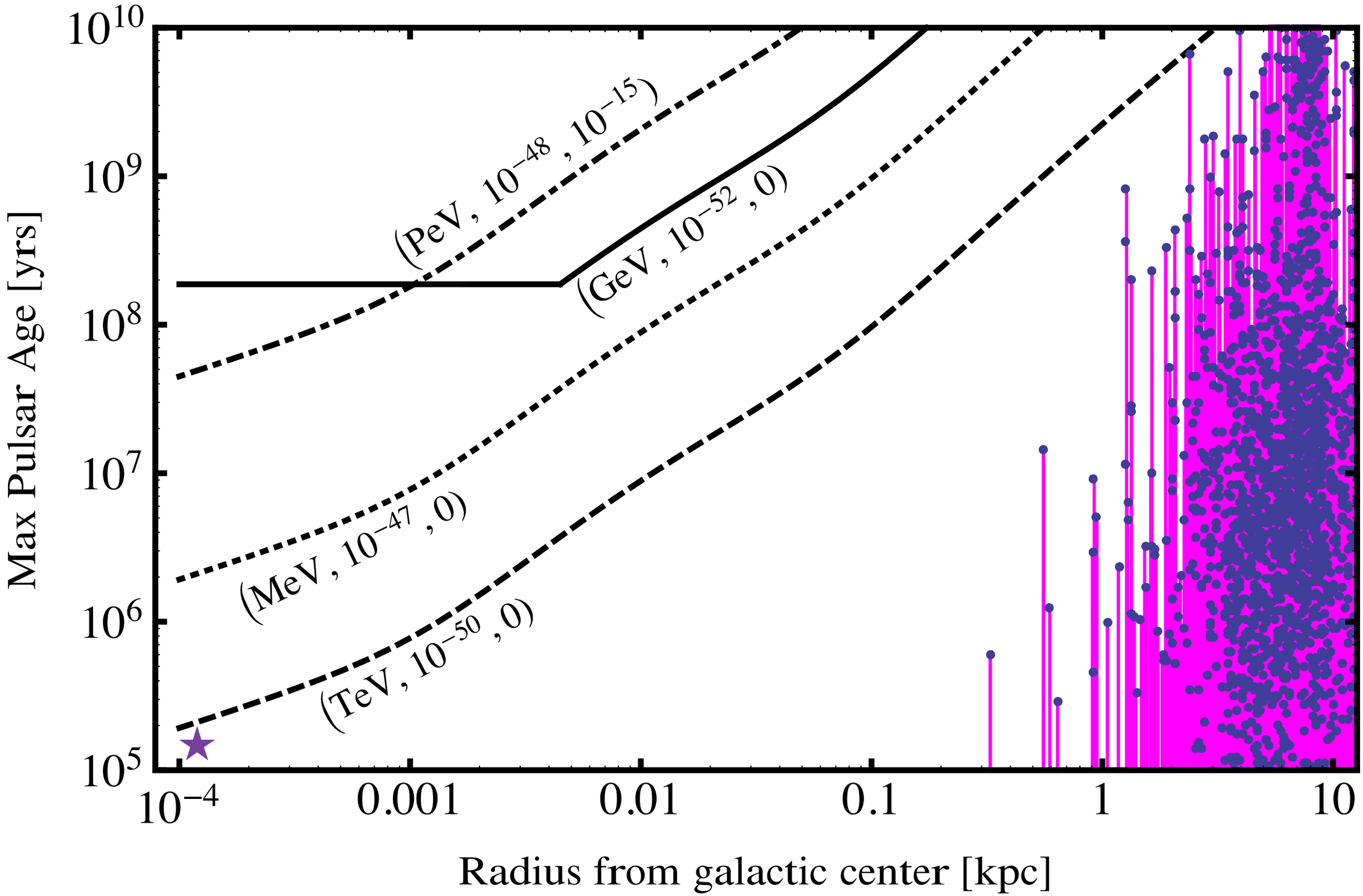


JB,Linden (2014)

ADM Bosons Imploding Pulsars



ADM Bosons Imploding Pulsars



A ball of fermions has fermi degeneracy pressure which provides a minimum pressure that sets the Chandrasekhar limit, but attractive self-interactions decrease this number.

The standard Chandrasekhar bound is $N_f \sim \frac{m_{pl}^3}{m_X^3}$

But... if $\mathcal{L} \supset \alpha_D \phi X \bar{X}$ $N_f < \frac{m_{pl}^3}{m_X^3}$

Higgs portals to pulsar collapse

$$\mathcal{L}_{\rm SM} + i\bar{X}\partial\!\!\!/ X + \frac{1}{2}(\partial\phi)^2 - a\phi(|H|^2 - v^2/2)$$

$$-b\phi^2(|H|^2 - v^2/2) - g_D\phi\bar{X}X - m_\phi^2\phi^2 - m_X\bar{X}X$$

asymmetric $\bar{X}X$

light mediator $m_\phi \sim \mathrm{MeV}$

Higgs portals to pulsar collapse

1. Direct detection in next decade

2. Resolves core/cusp problem

3. Signature in pulsar age vs. distance curves

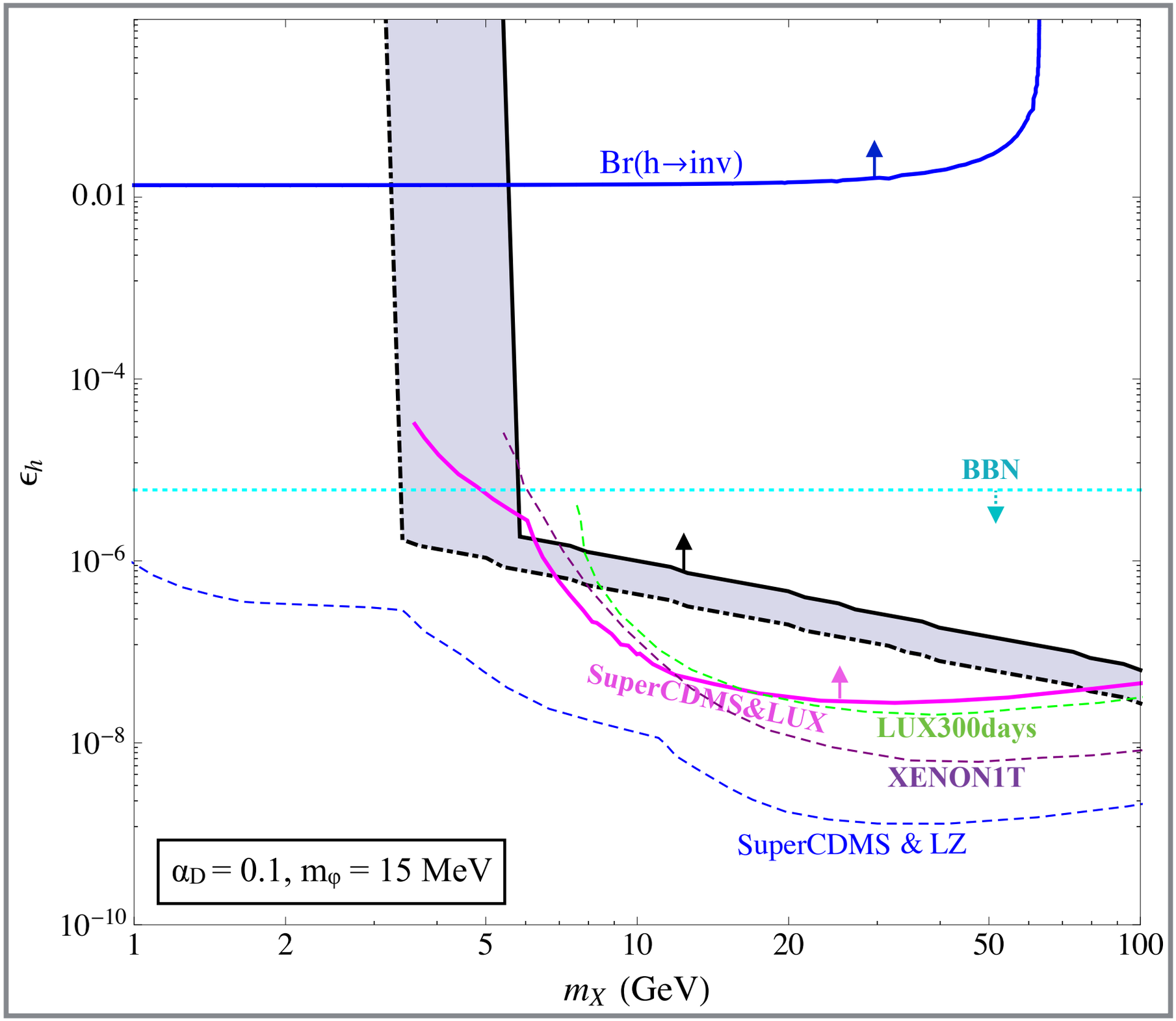
ρ_X = 80 or 0.2 GeV/cm^3, τ_{NS} = 0.01 or 1 Gyr, v = 150 or 200 km/s,

$T_{NS} = 10^4$ K, $M_{NS} = 1.4\ M_\odot$, R_{NS} = 10 km

1. Direct detection

$$\mathcal{L} \supset a\phi(|H|^2 - v^2/2)$$

$$\epsilon_h \equiv \frac{\sqrt{2}av}{m_h^2}$$



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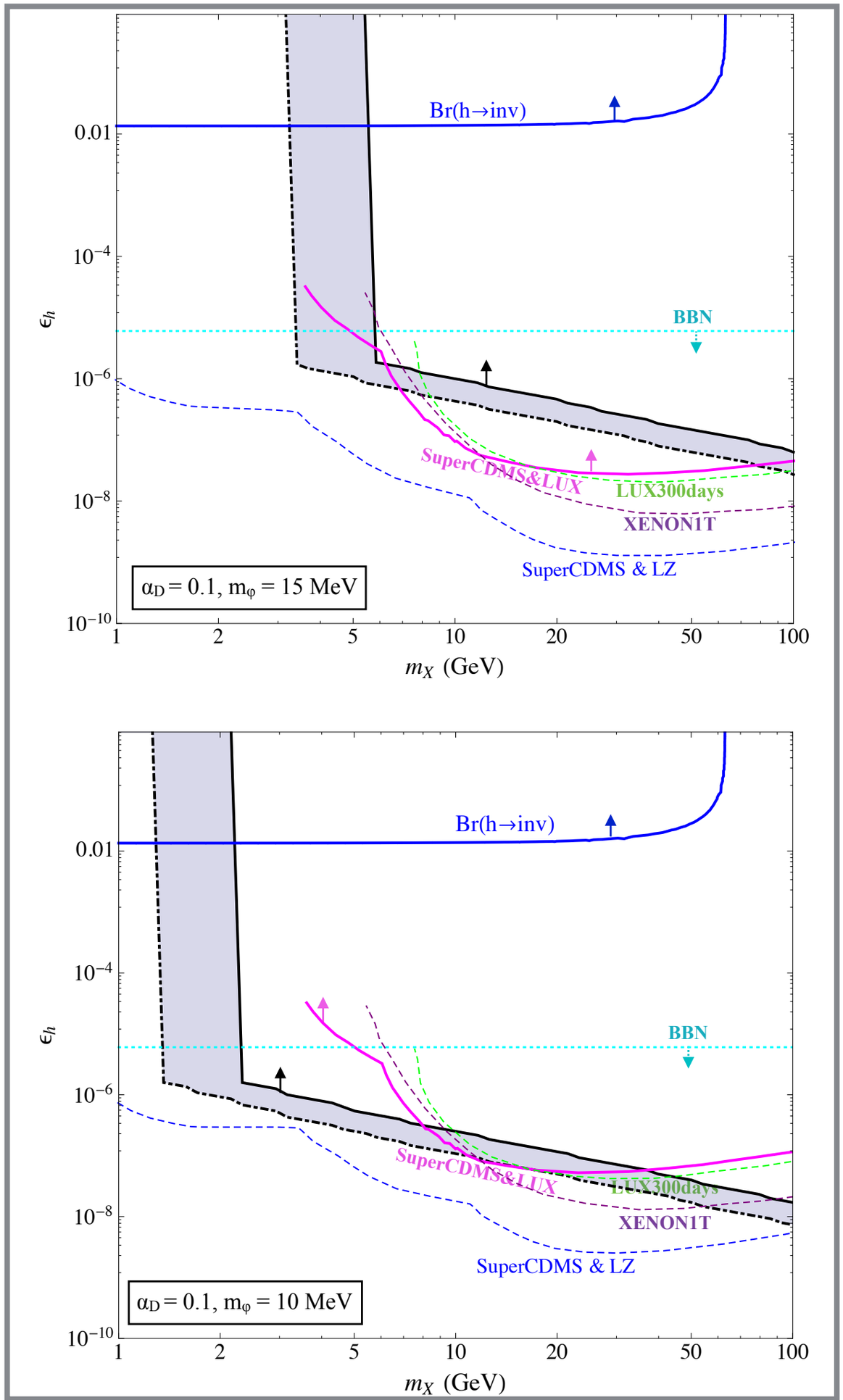
Note dependence on mass of mediator

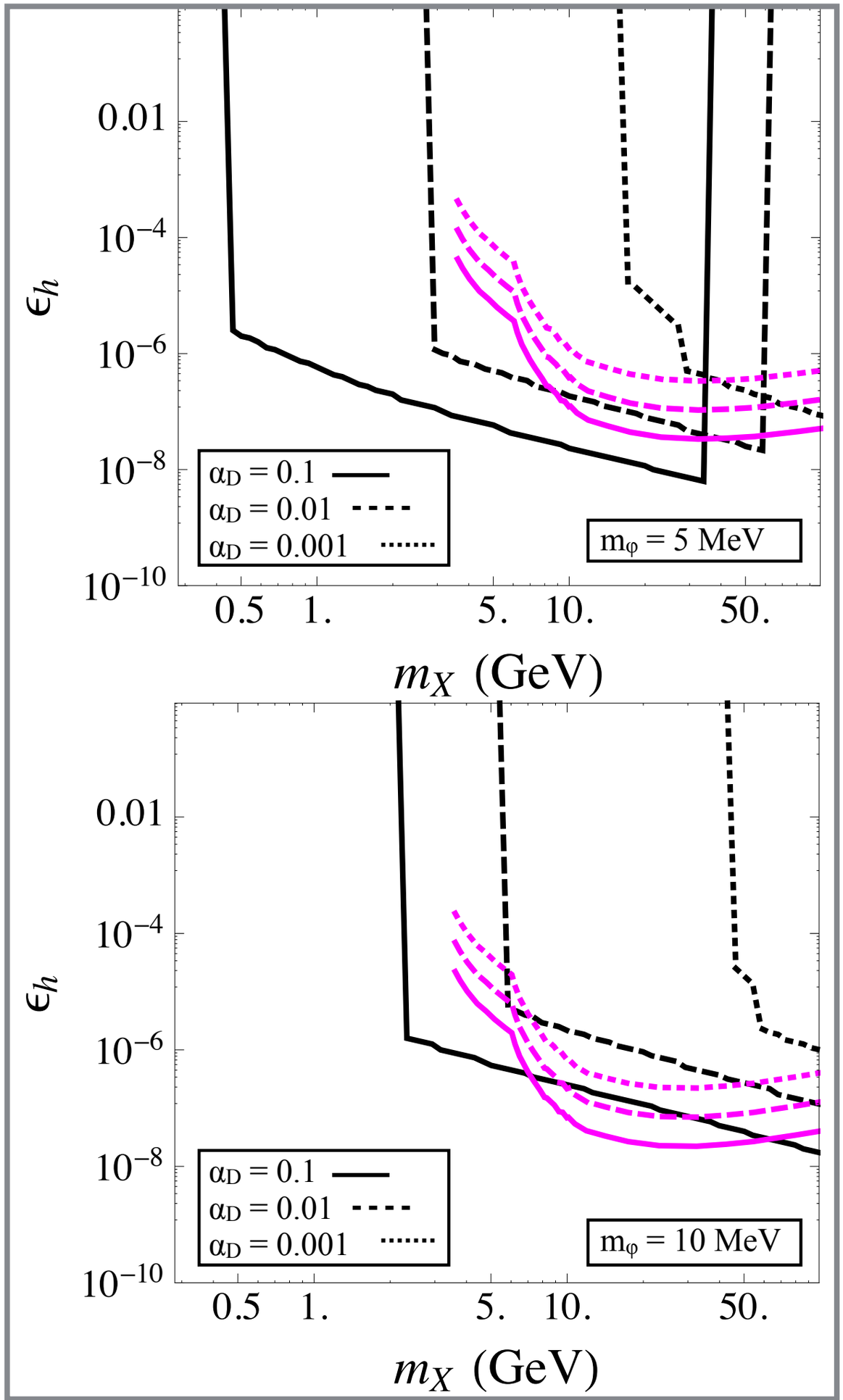


1. Direct detection

$$\mathcal{L} \supset a\phi(|H|^2 - v^2/2)$$

$$\epsilon_h \equiv \frac{\sqrt{2}av}{m_h^2}$$

Note dependence on mass of mediator… and the dark gauge coupling



2. ADM Higgs portal has velocity-dependent halo self-interactions

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

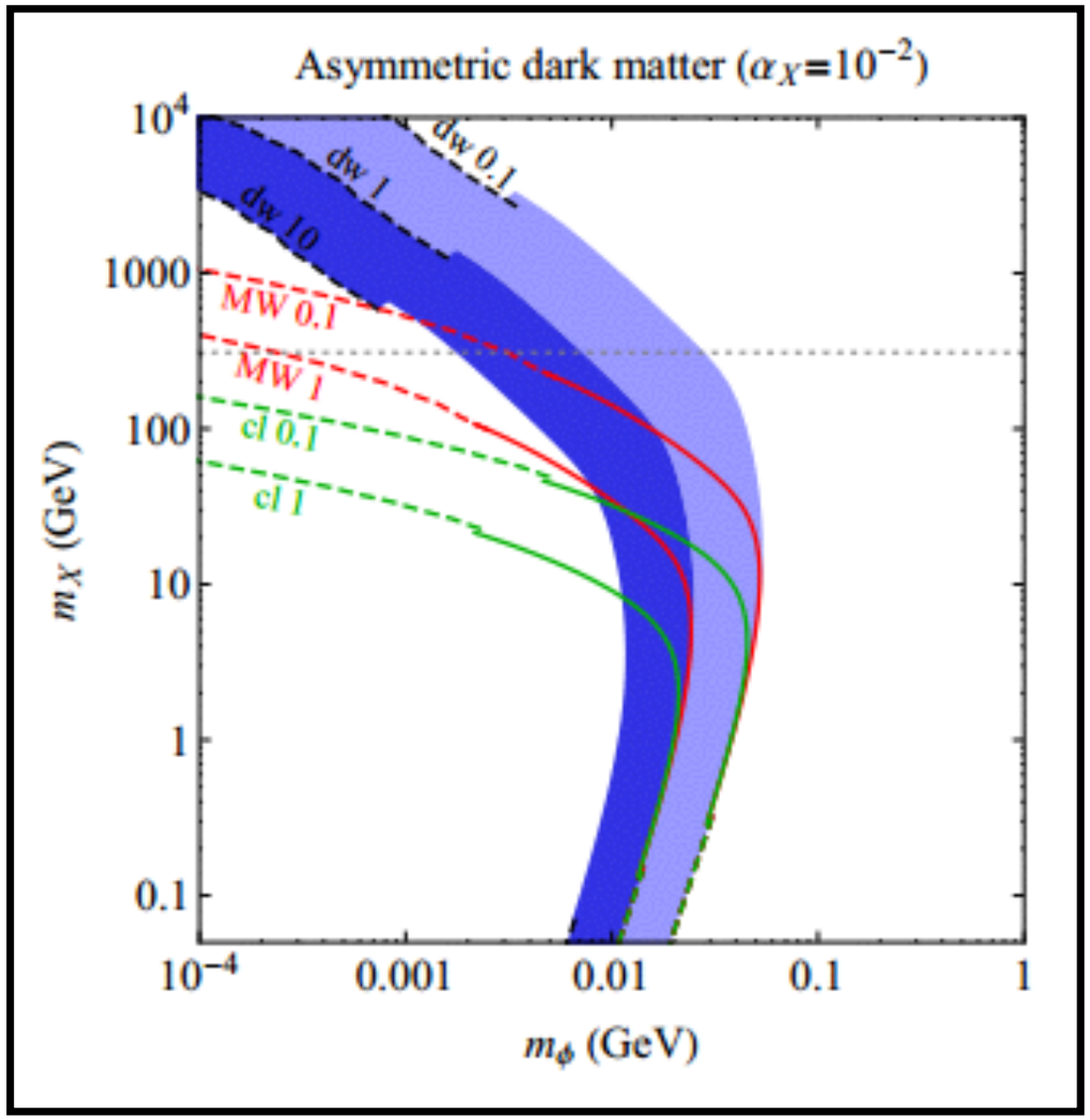
$\sigma/m < 1\ \mathrm{cm}^2/\mathrm{g}$, $\sigma/m < 1\ \mathrm{cm}^2/\mathrm{g}$

But the preferred cross-section to core dwarf halos (10 km/s) is

$\sigma/m \sim .1\text{-}10\ \mathrm{cm}^2/\mathrm{g}$

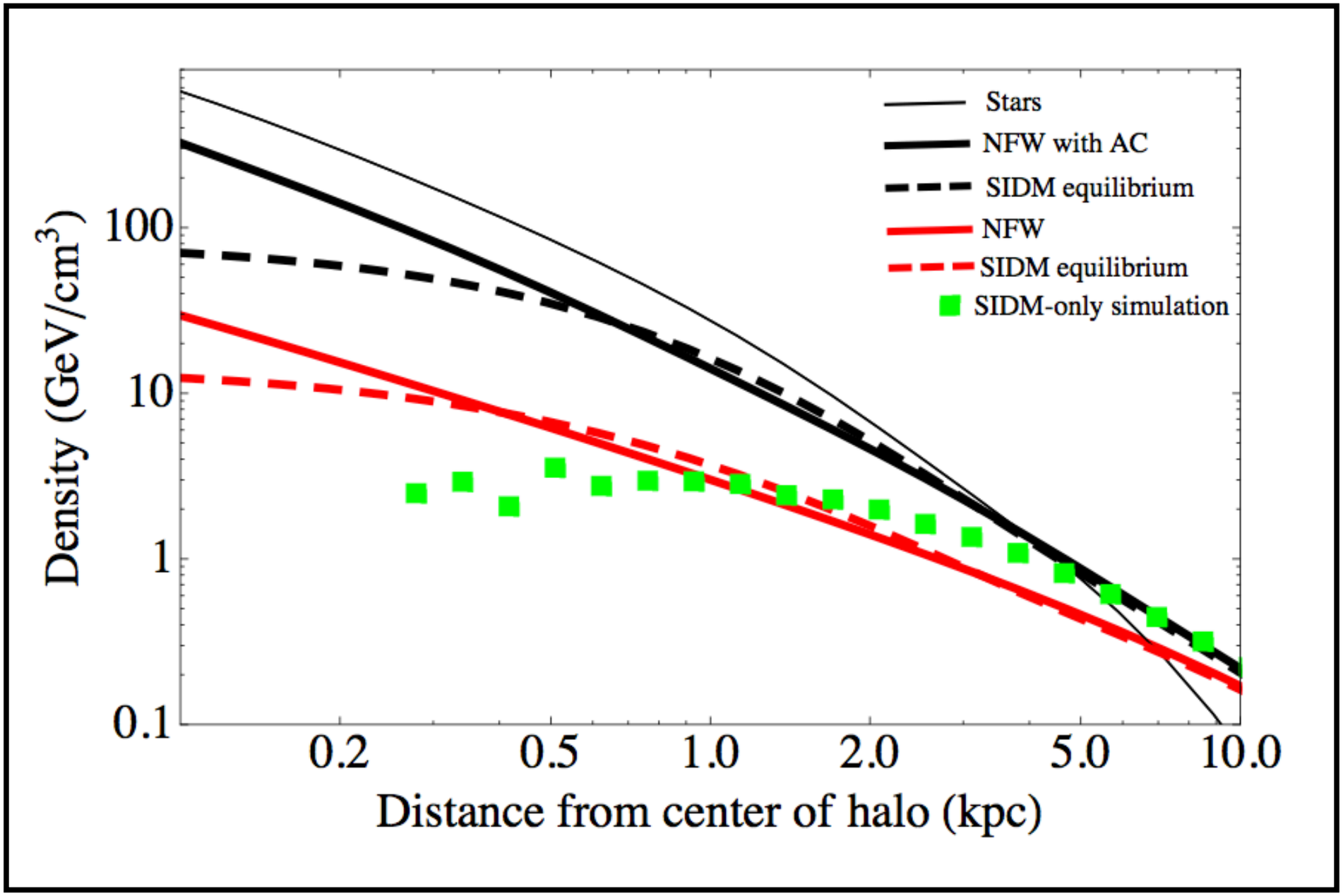
Velocity dependent cross-section provided by light mediator.

$$\mathcal{L} \supset \alpha_D \phi X \bar{X}$$



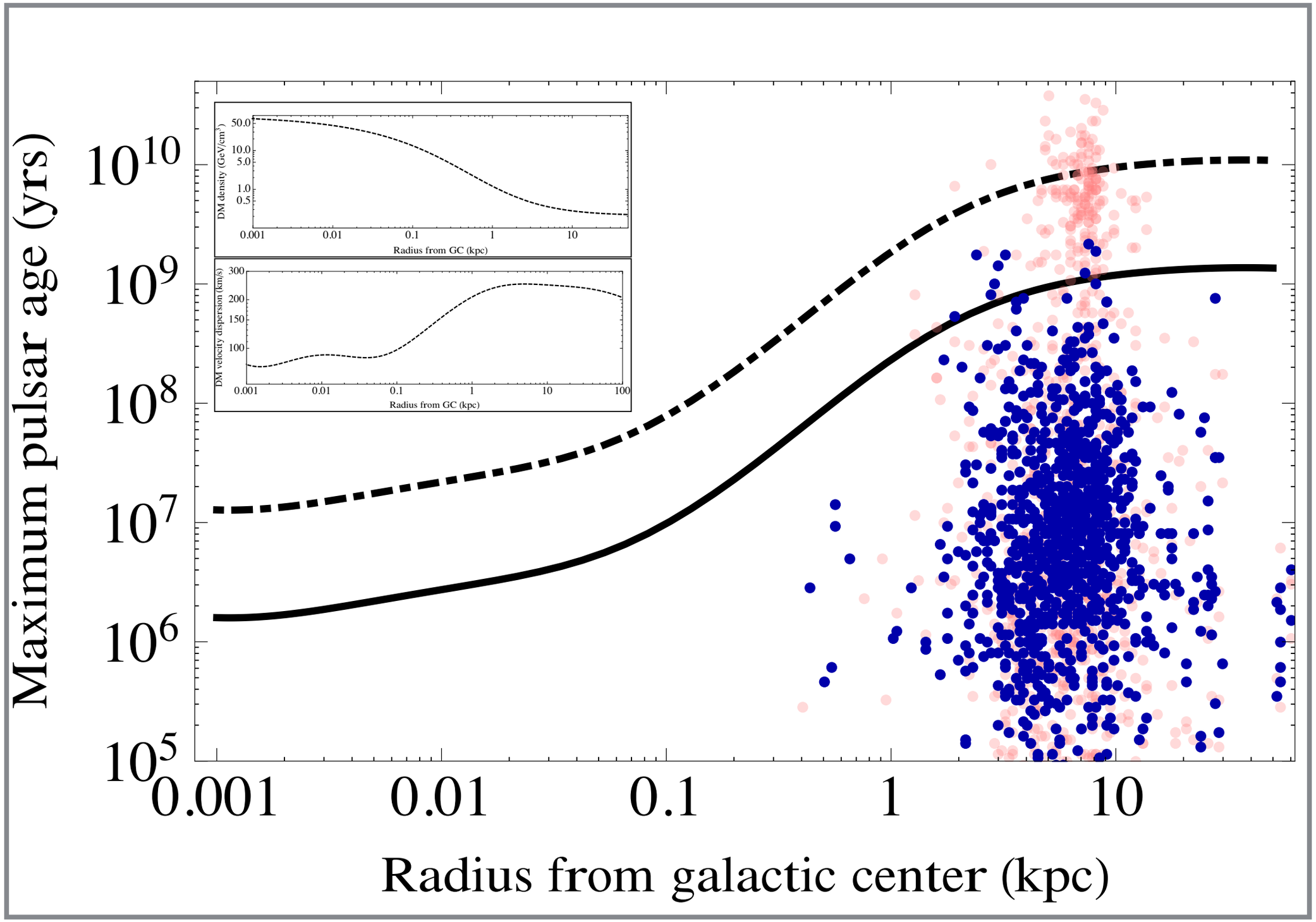
Tulin, Yu, Zurek (Pospelov Ritz, Buckley Fox, Loeb Weiner)

2b. Baryonic potential drives self-interacting halo core



Kaplinghat, Keeley, Linden, Yu

3. Pulsar age versus distance curves would signal Higgs portal asymmetric dark matter in our galaxy.



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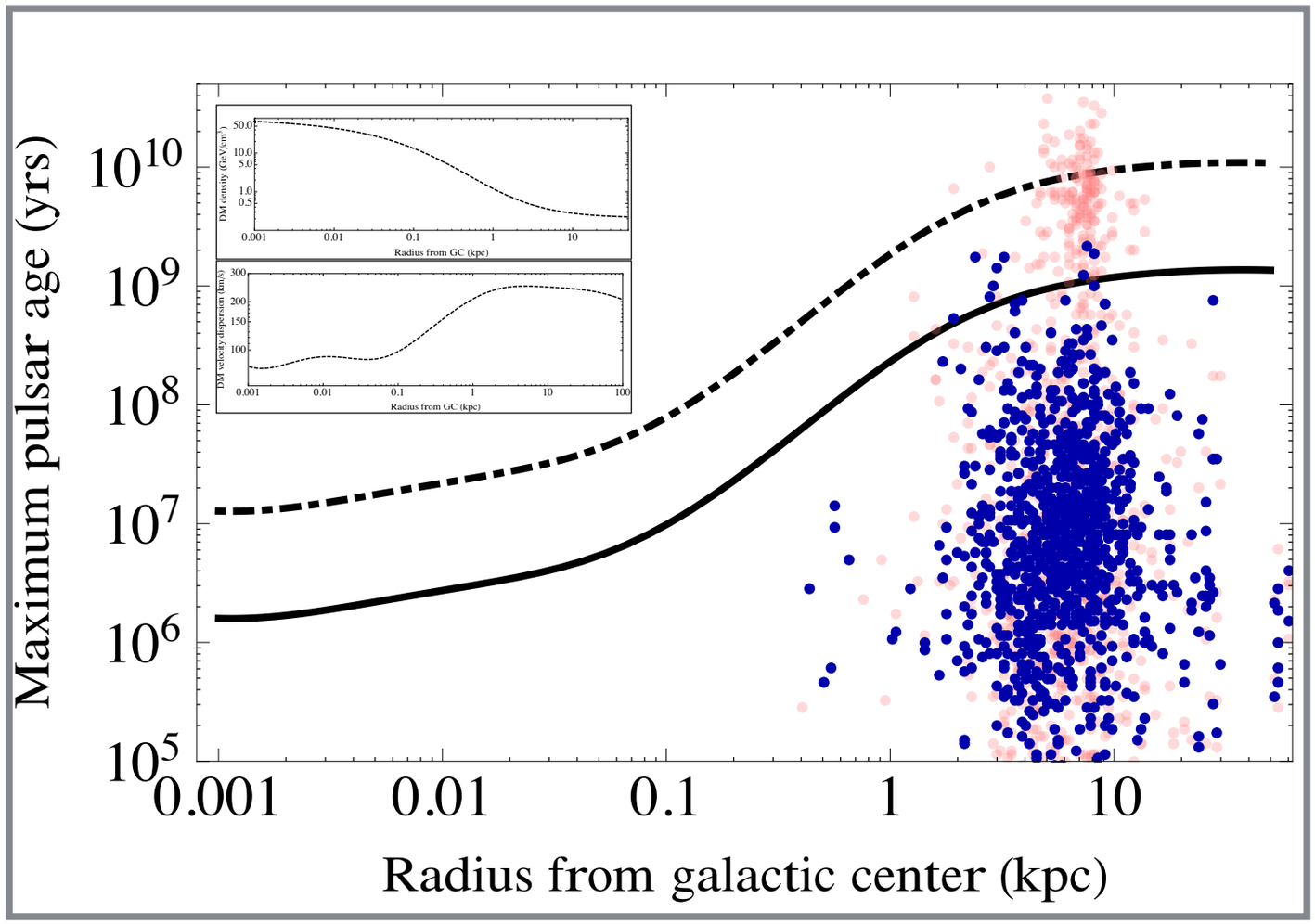

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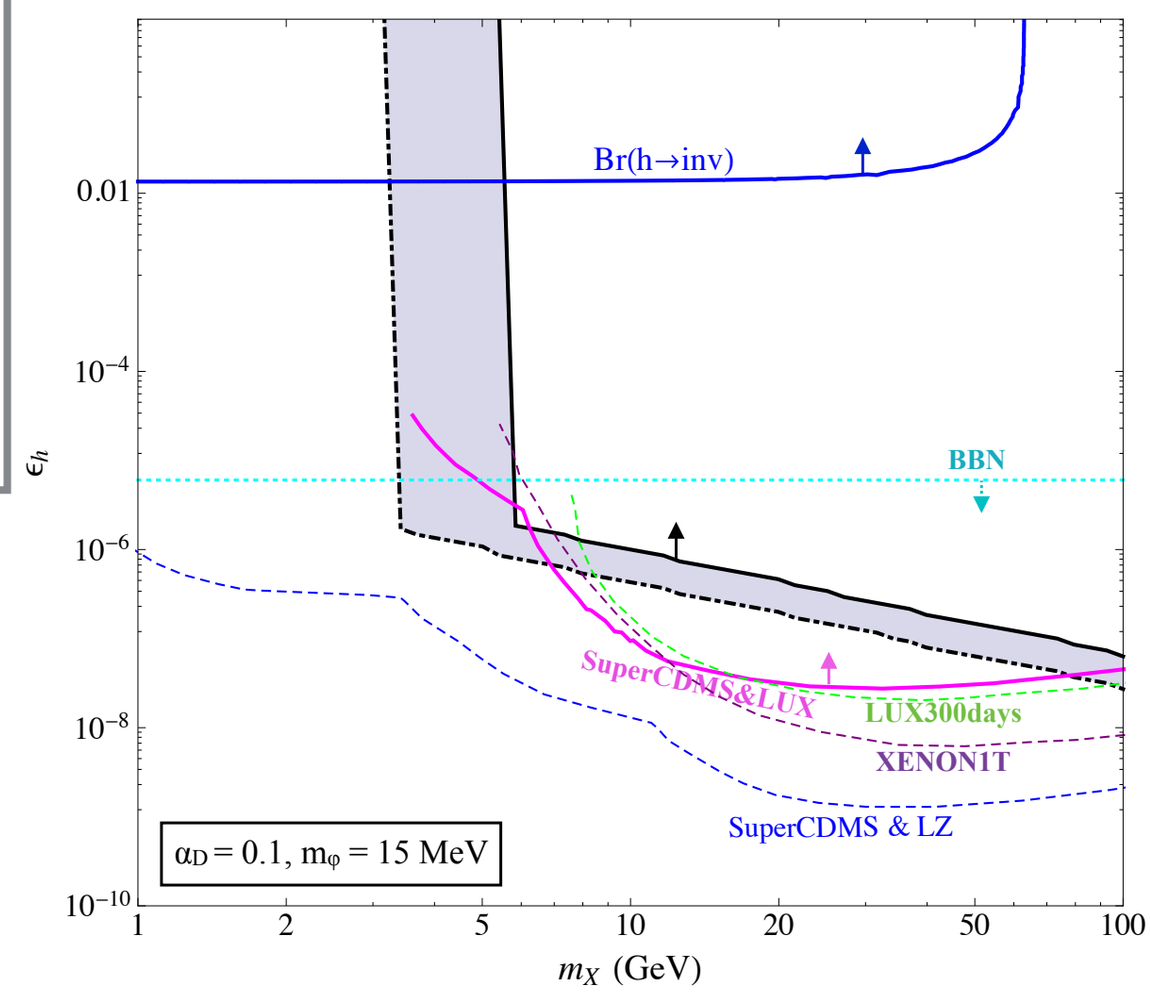


★ Pulsars missing from the galactic center could be a signature of asymmetric dark matter.

★ Asymmetric Higgs portal dark matter collapses pulsars.

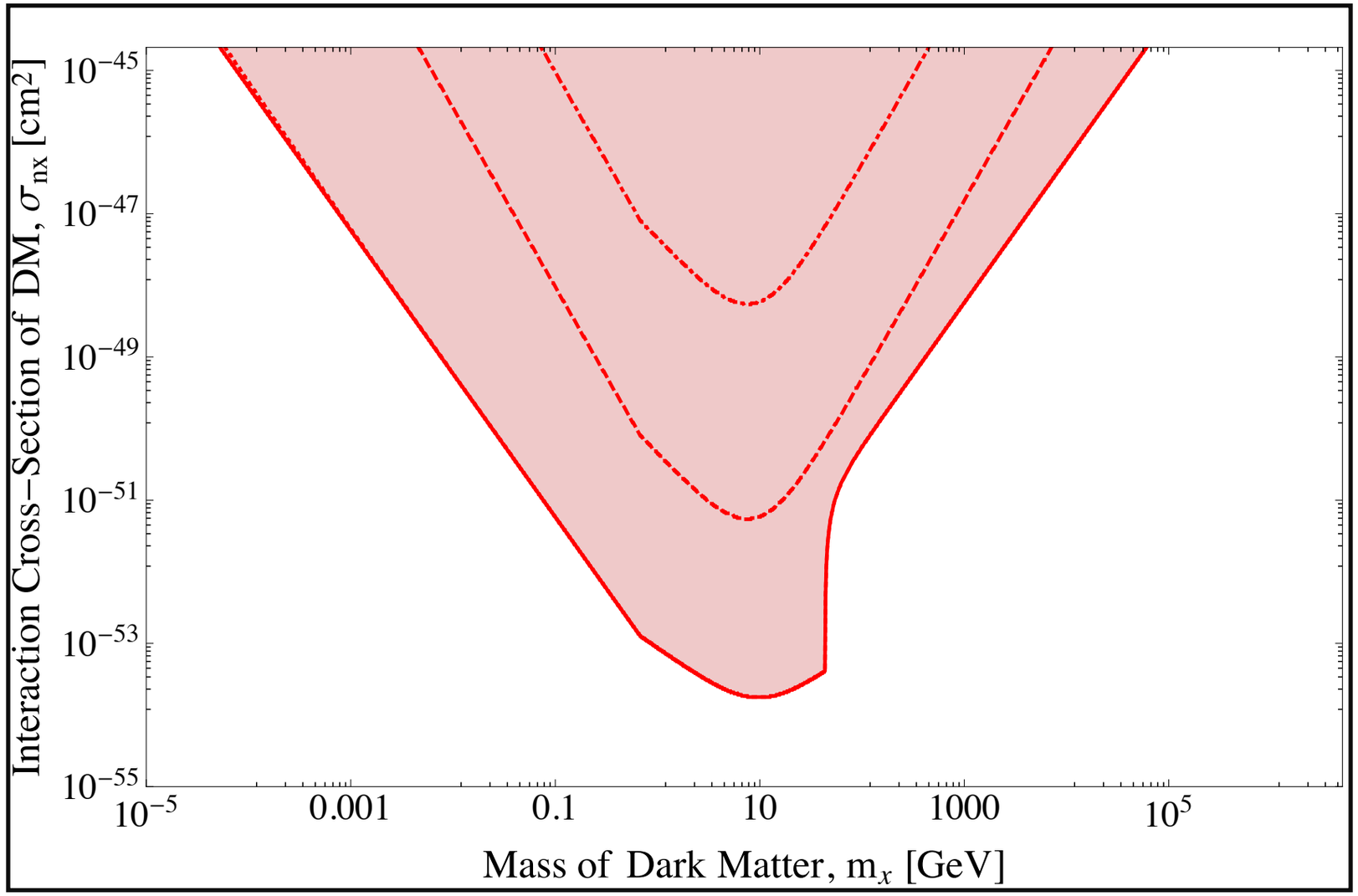
★ Maximum pulsar age curves could be found by future radio surveys.

Ongoing work:

★ Any PeV mass asymmetric dark matter collapses galactic center pulsars for any $\sigma_{nX} > 10^{-9}$ pb

★ Fuller and Ott (1412.6119) have shown that galactic center pulsar collapse could be the source of fast radio bursts.

Bonus Slides



Tiny self-annihilations lift collapse limit.

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