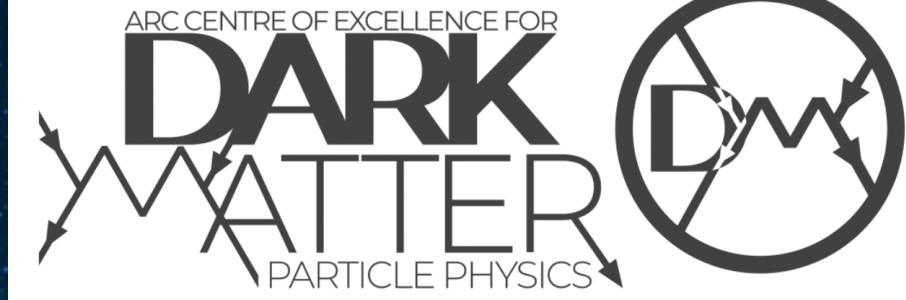




THE UNIVERSITY OF  

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MELBOURNE



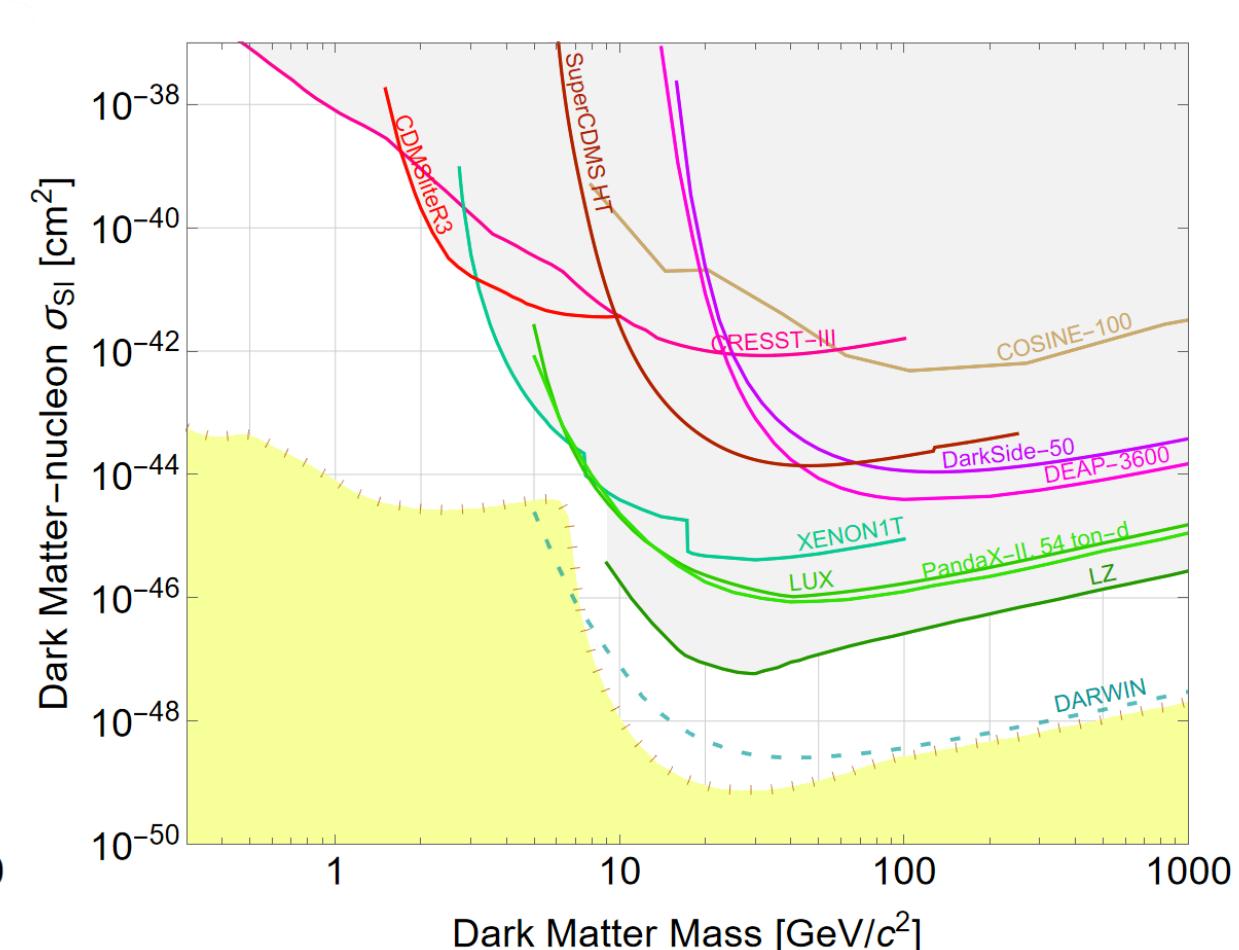
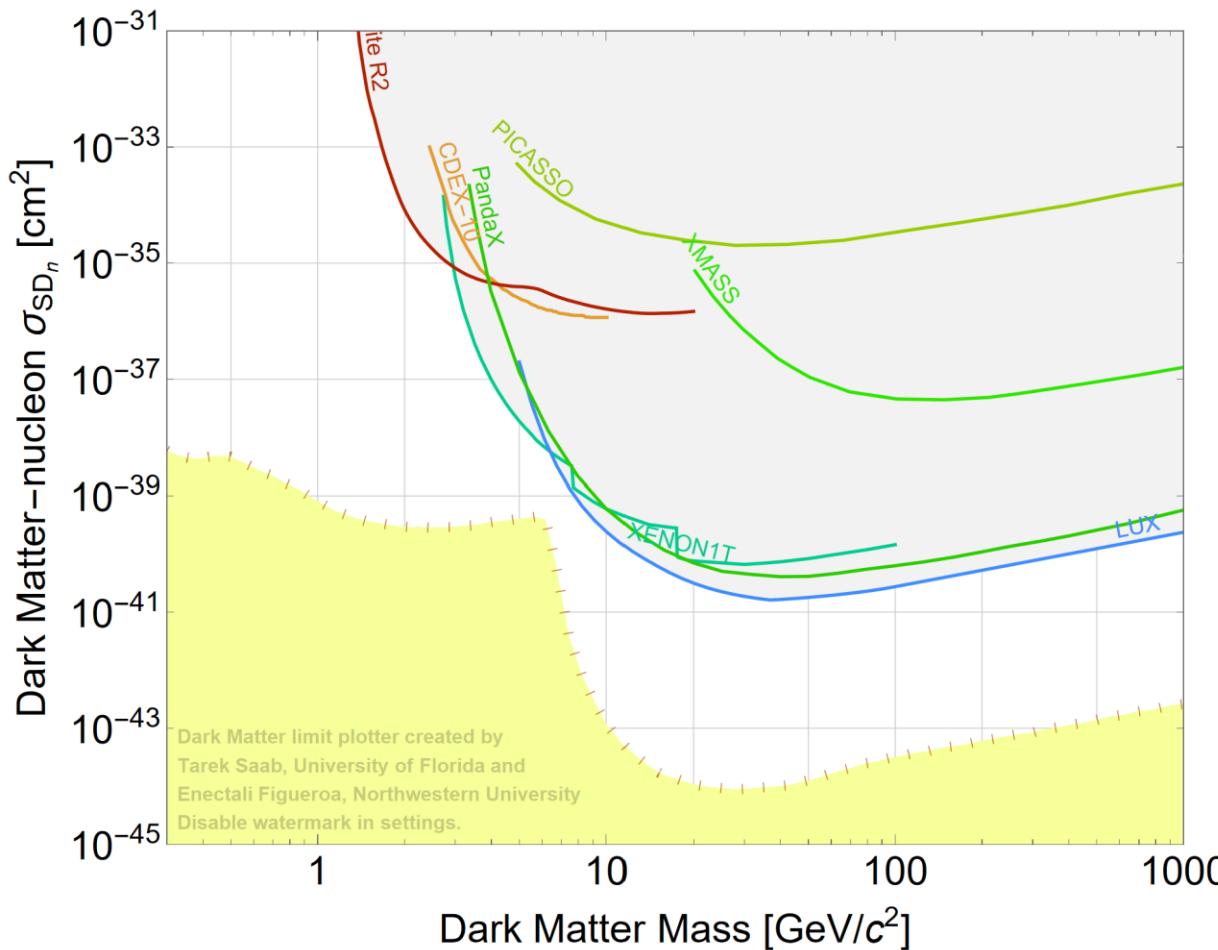
# Dark Matter Capture in White Dwarfs

Based on works: N.F. Bell, G. Busoni, S. Robles, M.E. Ramirez-Quezada and MV: 2104.14367  
+

MICHAEL VIRGATO

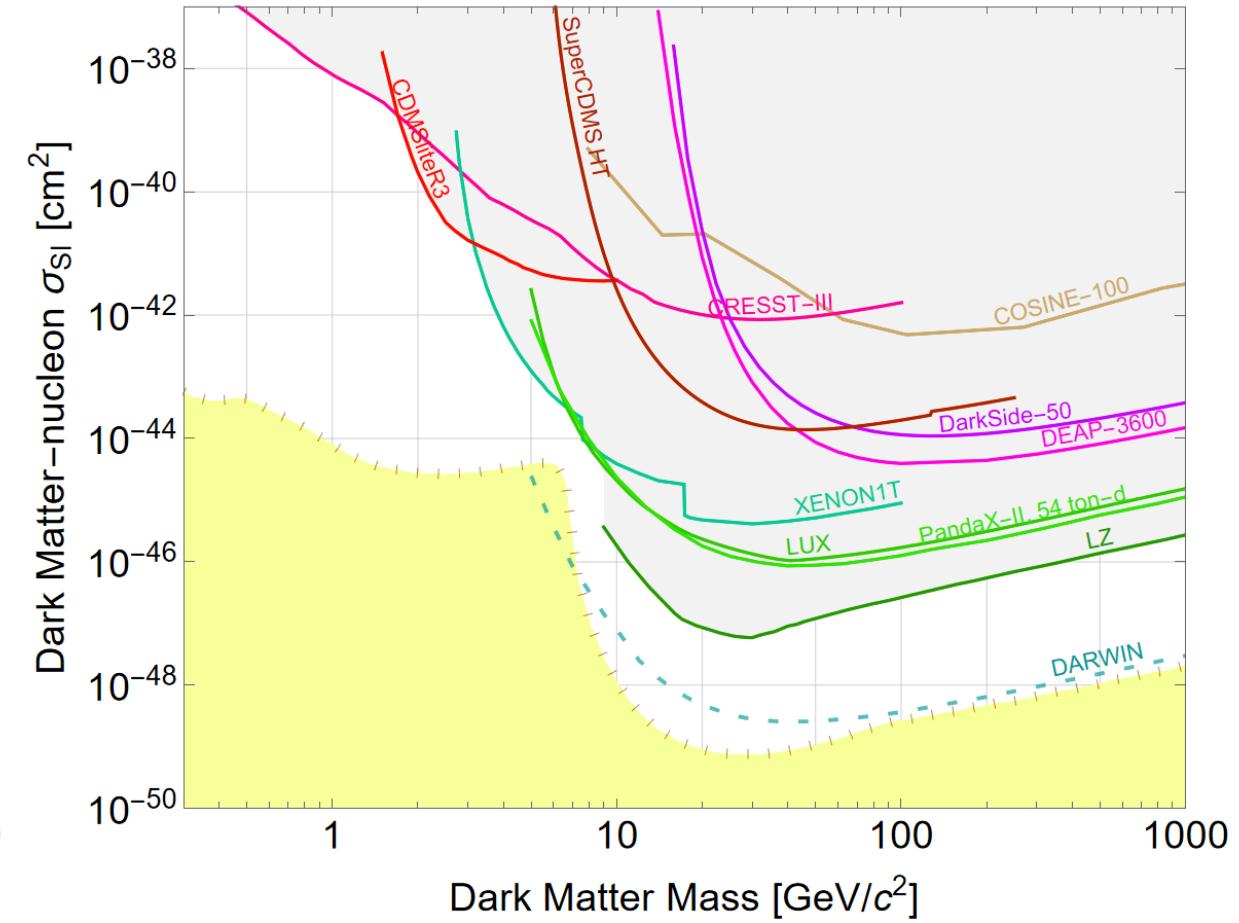
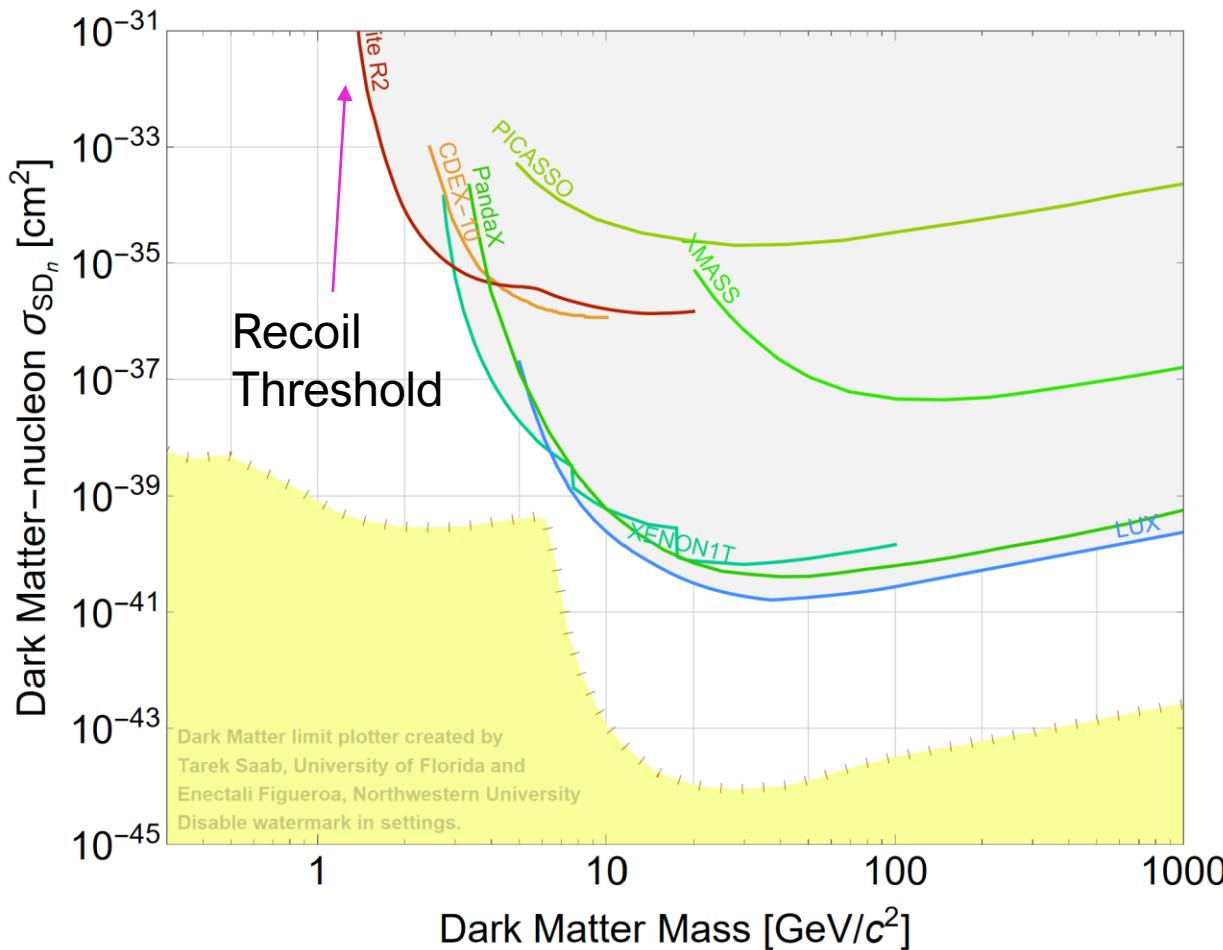
SUPERVISOR: NICOLE BELL

LEPTON PHOTON 2023



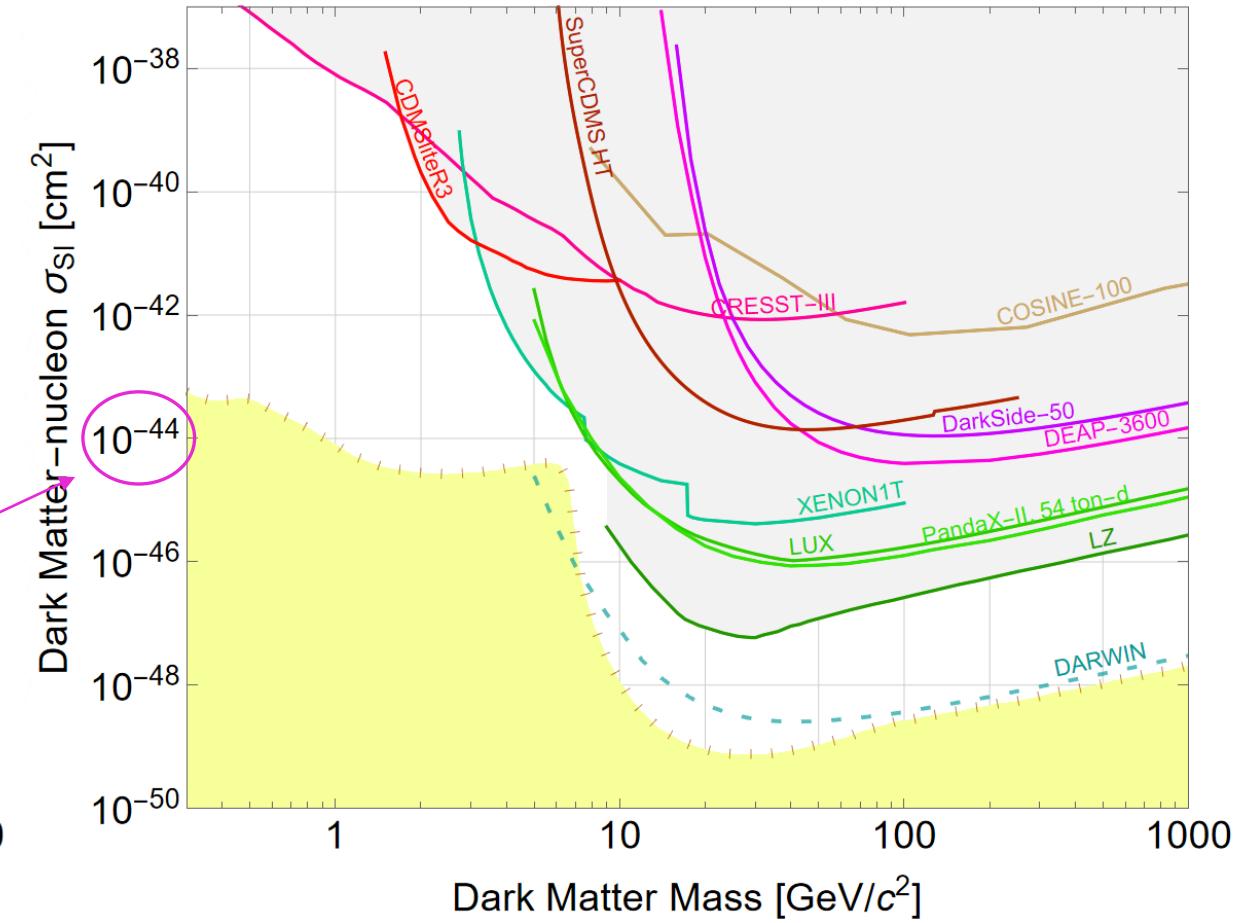
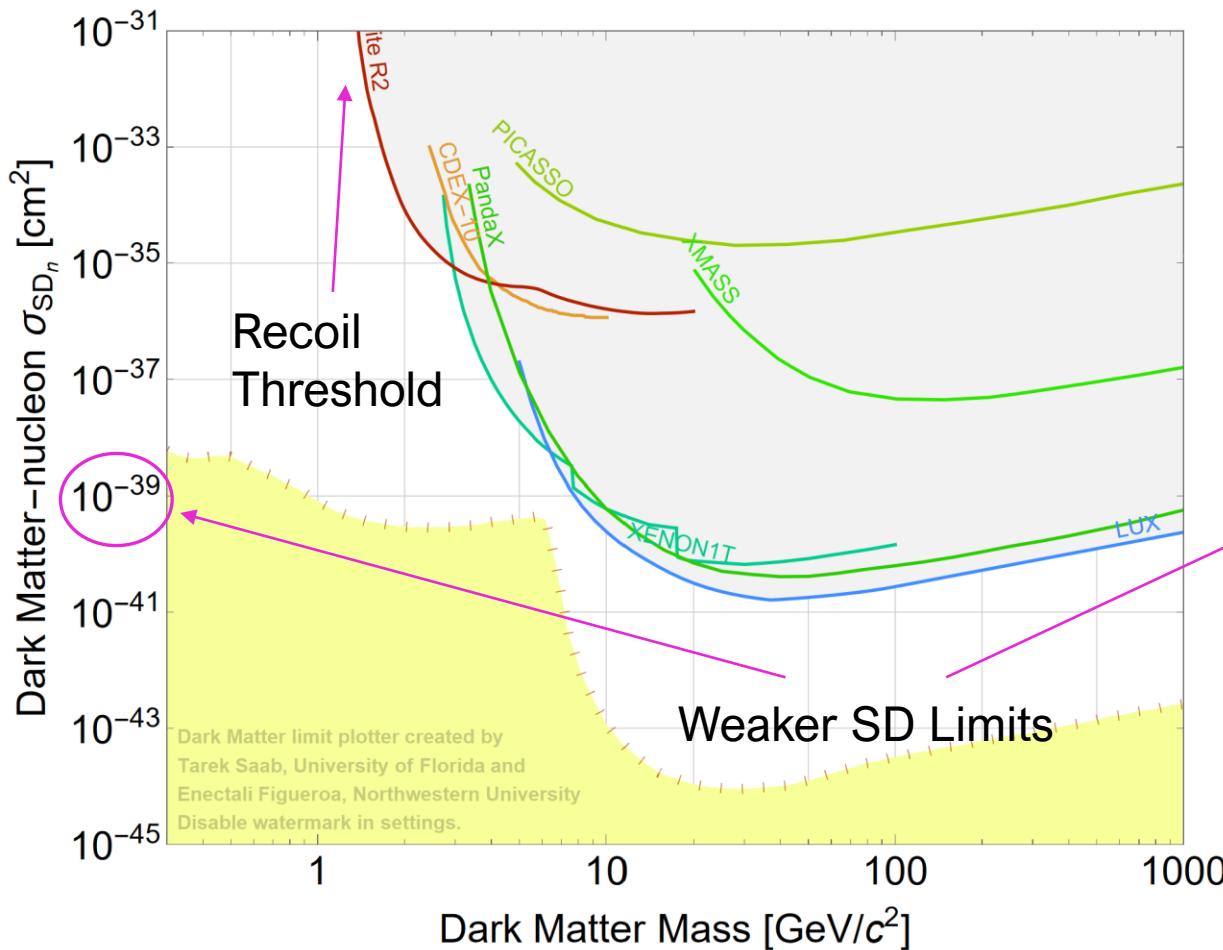
# Direct Detection Bounds

Current upper bounds for spin-dependent (**left**) and spin-independent (**right**) DM-nucleon cross sections



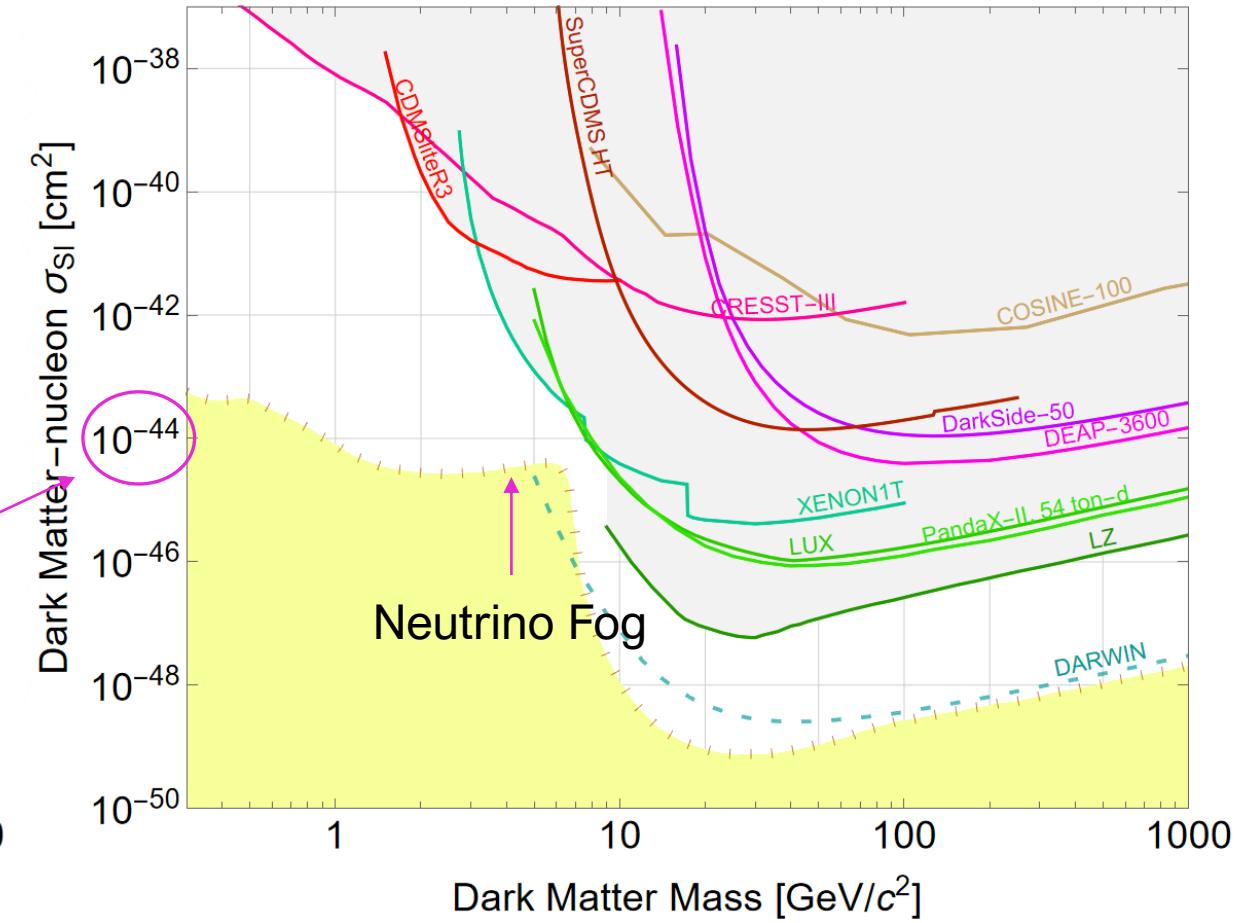
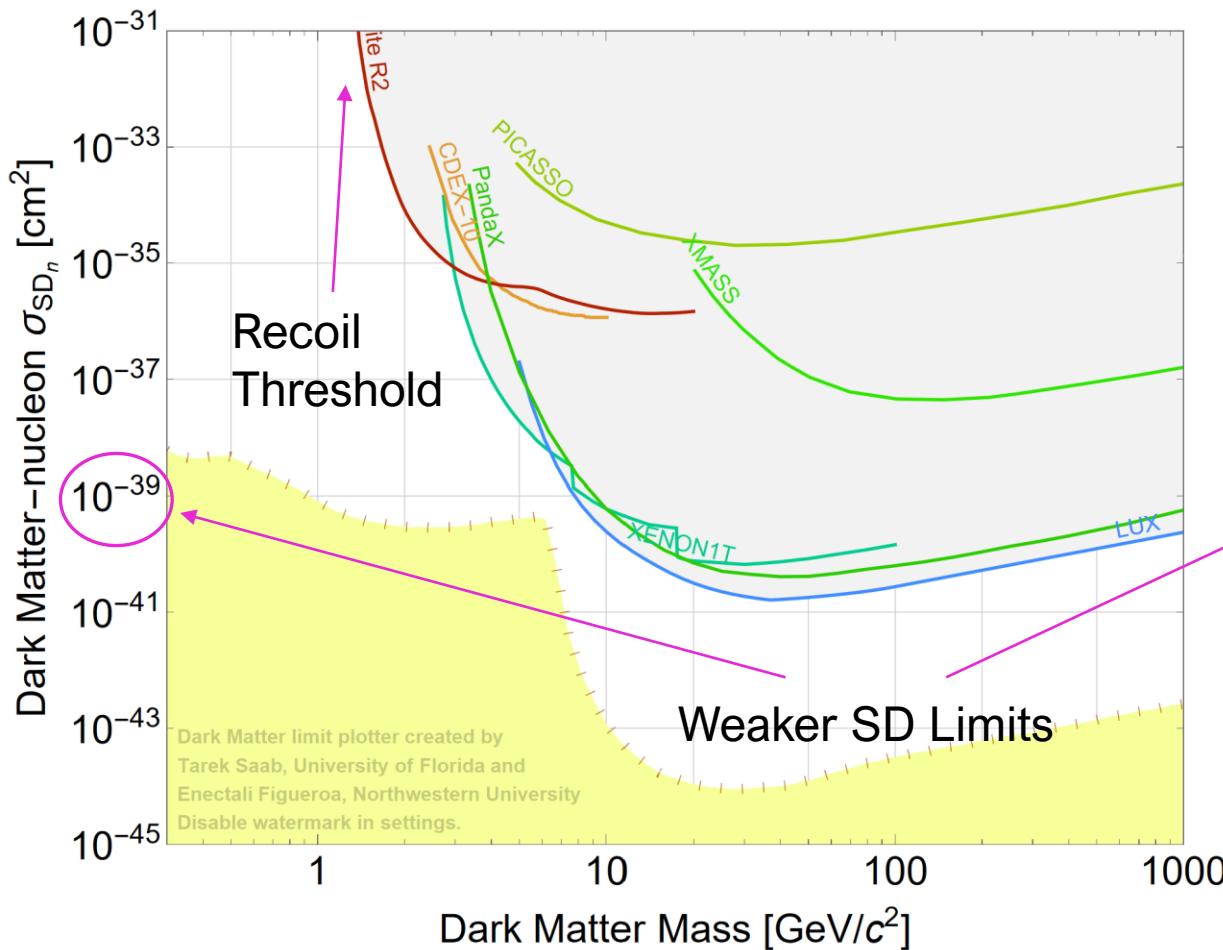
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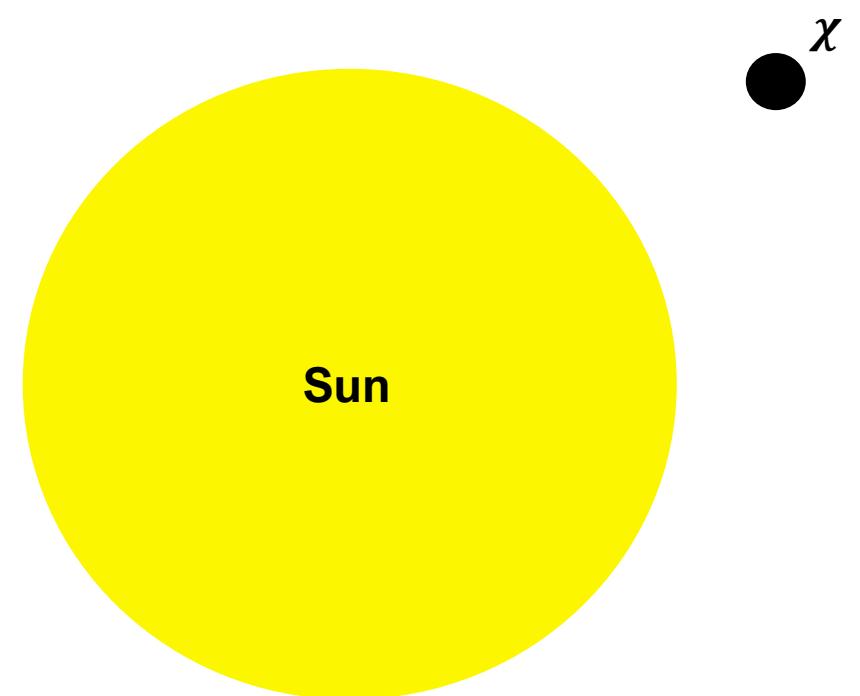


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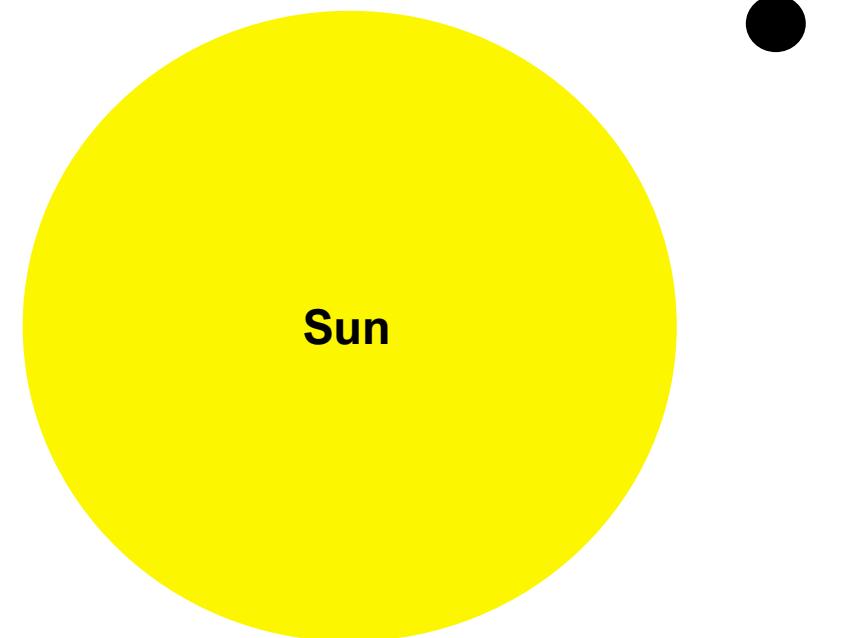
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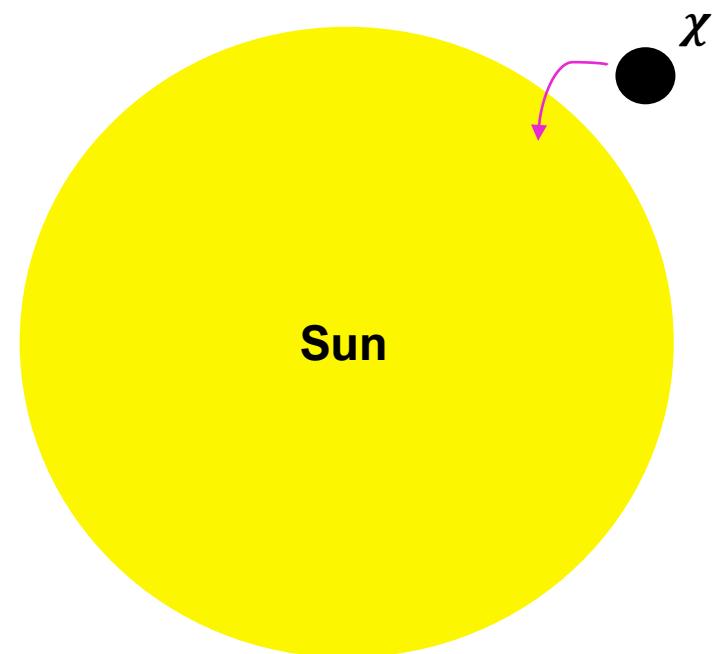
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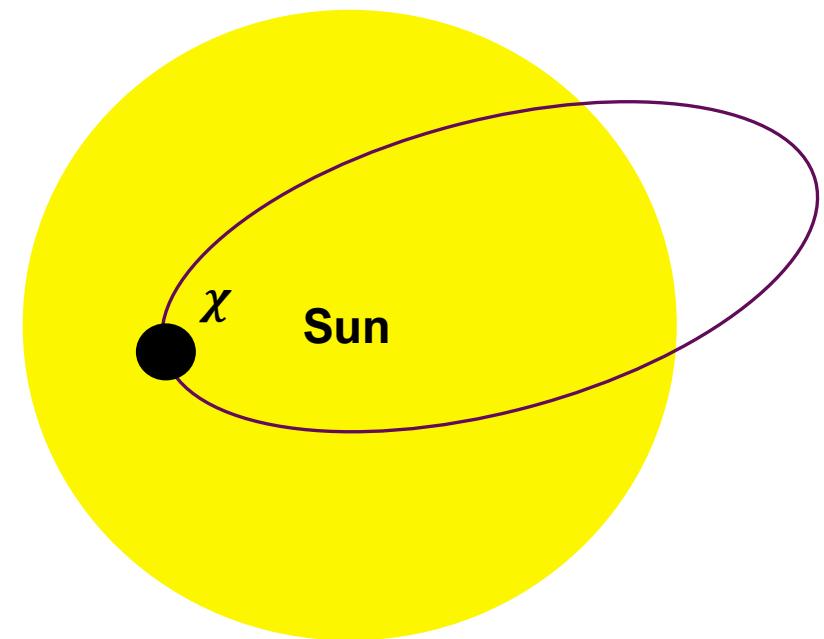
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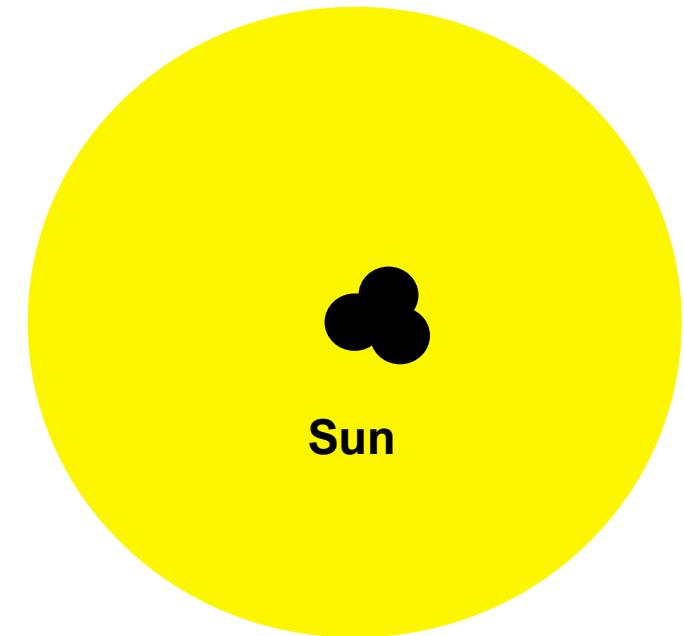
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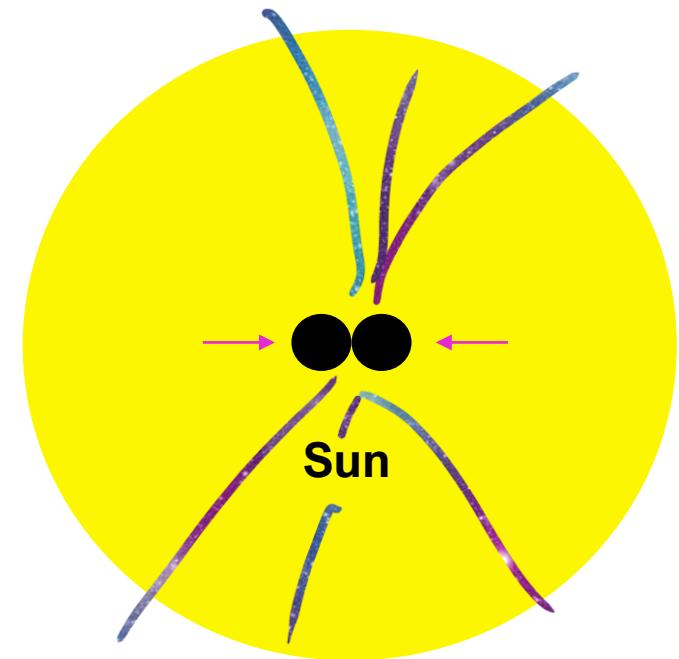
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  - May then annihilate to produce visible signals



# Evolution of DM within the Sun

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Capture                      Annihilation                      Evaporation

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**Can only probe  
 $m_\chi > m_{evap}$ !**

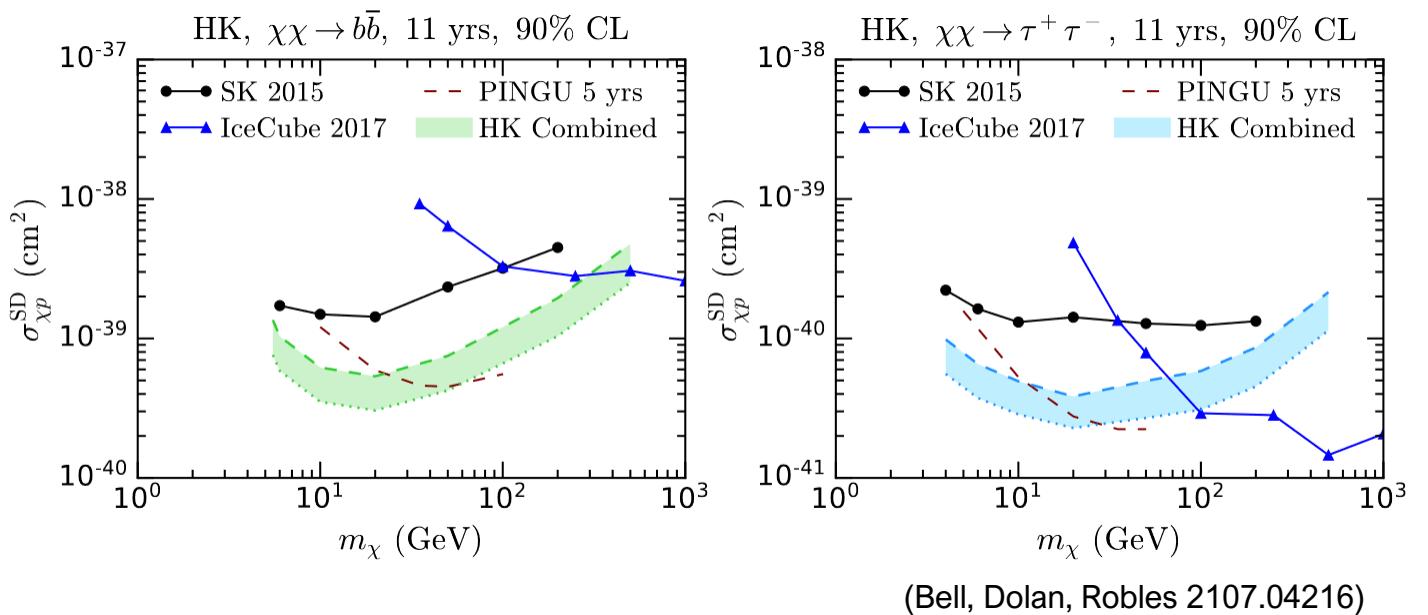
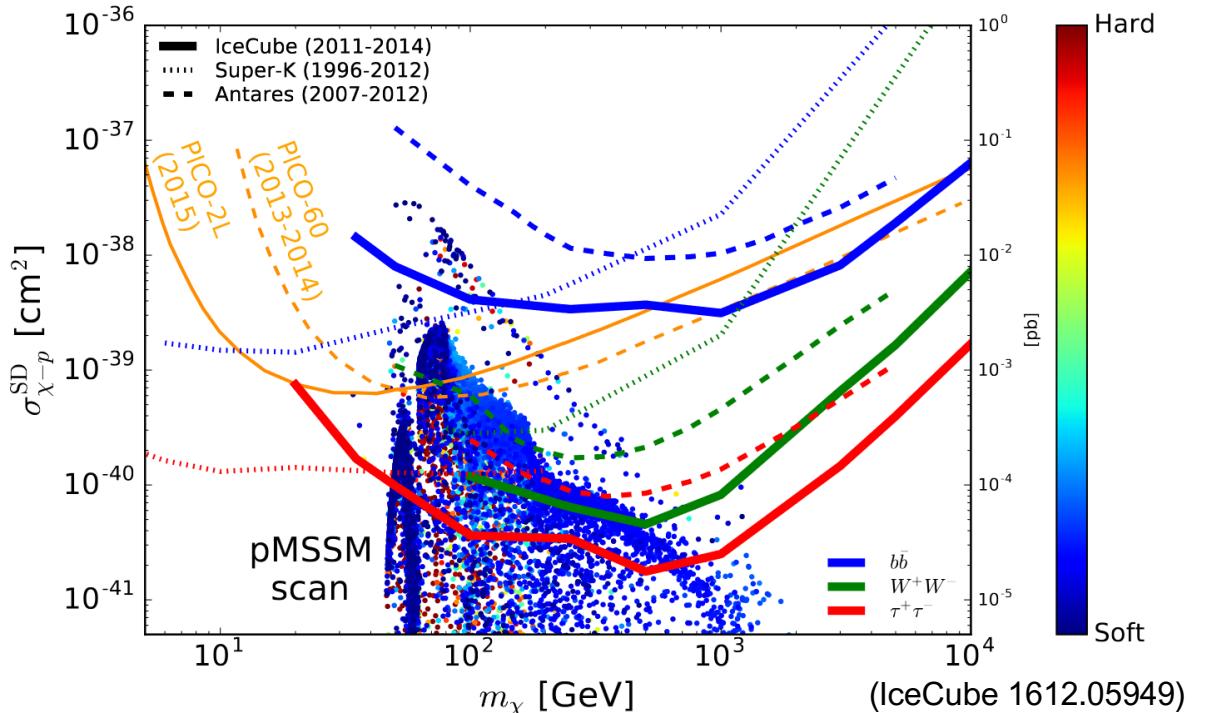
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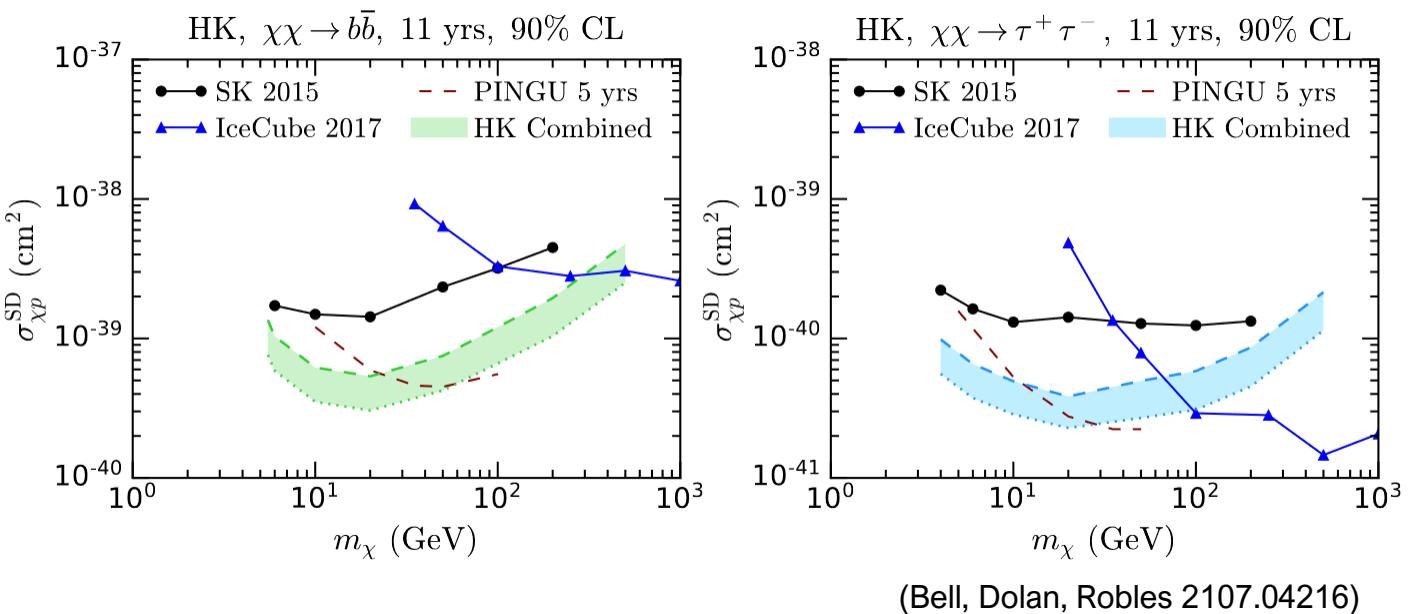
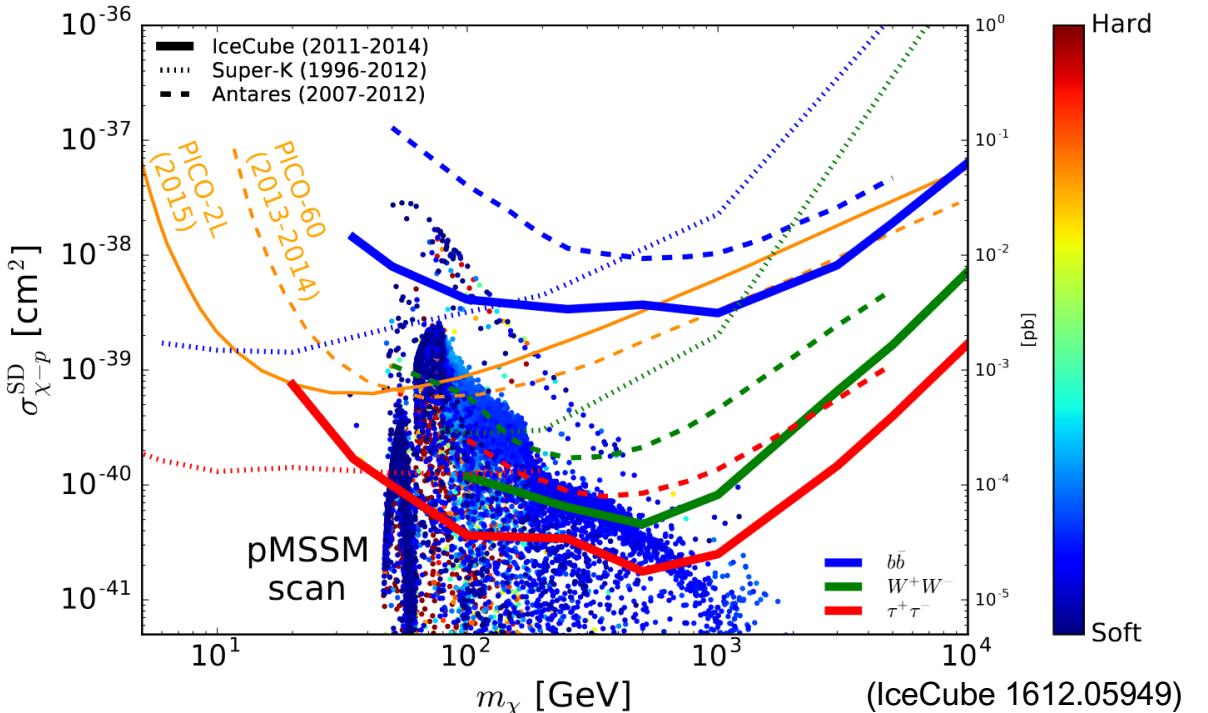
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- DM annihilates efficiently after reaching equilibrium
- DM annihilates to neutrinos or long-lived mediator



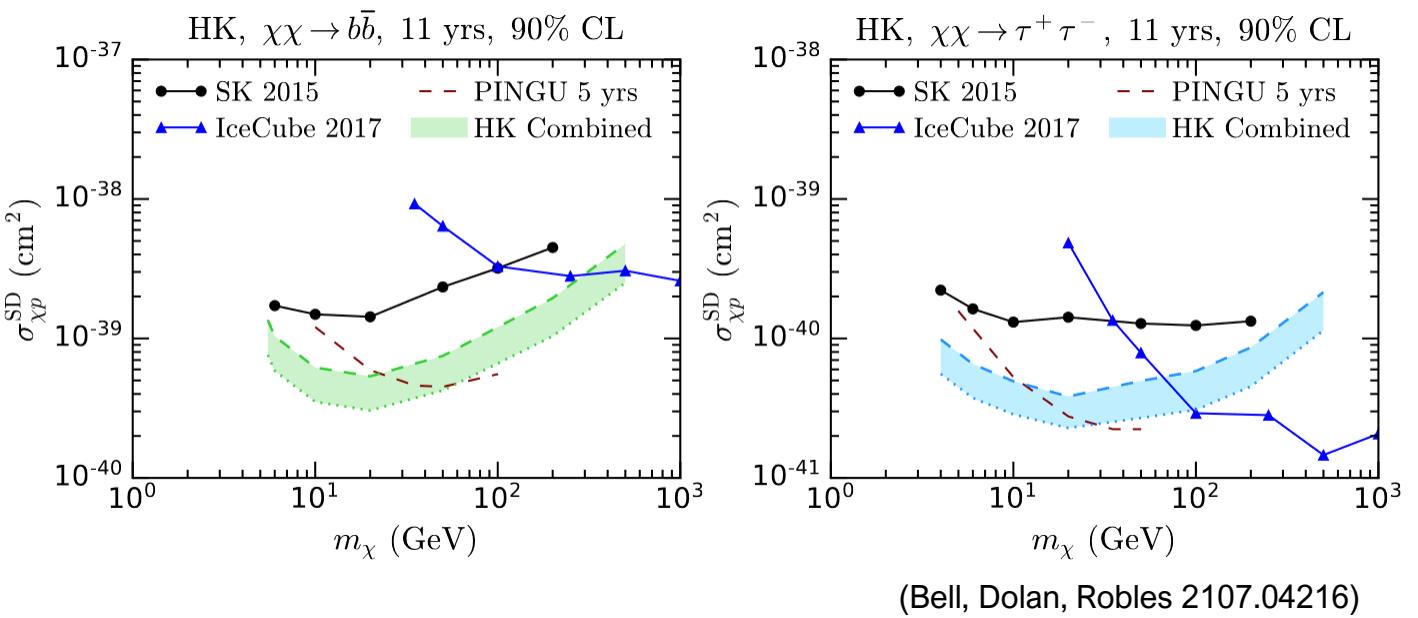
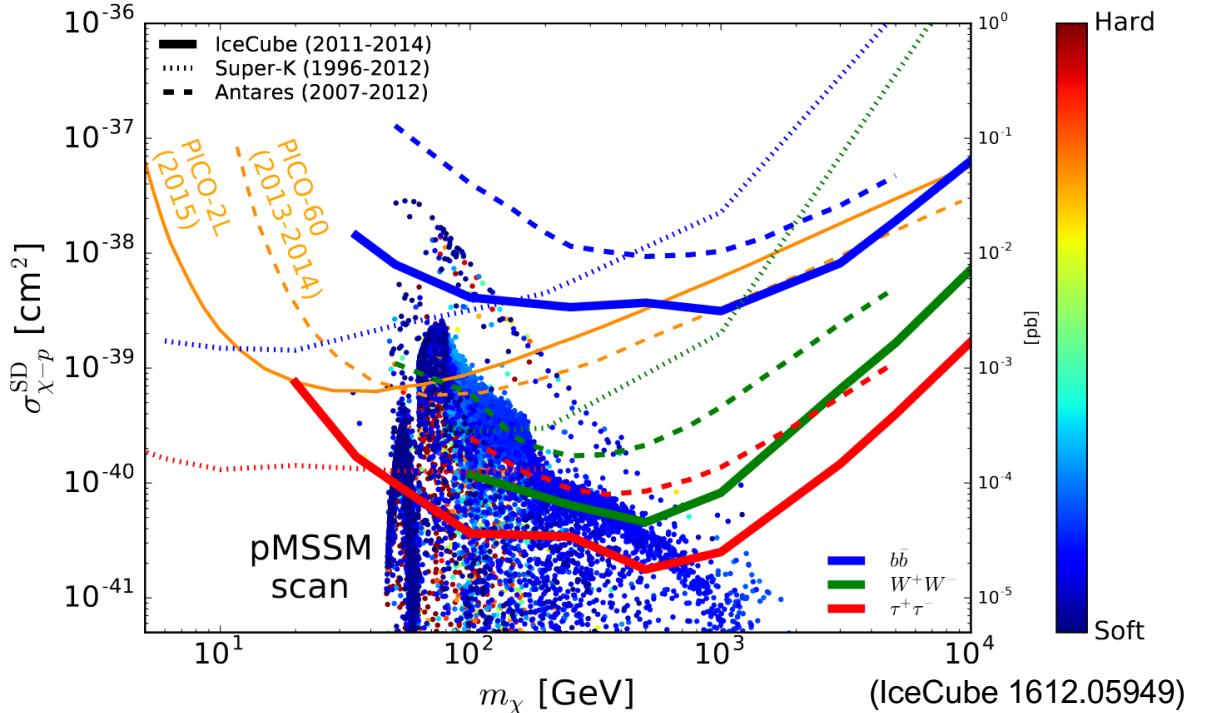
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- Evaporation masses range from  $\sim 0.1 \text{ keV}$  (NS) to  $\sim 0.1 \text{ MeV}$  (WD)
- Main modifications from capture in the Sun:
  - Relativistic kinematics (targets and DM)
  - Correct treatment of degenerate targets (Garani et.al 1812.08773)

# Observable Signals

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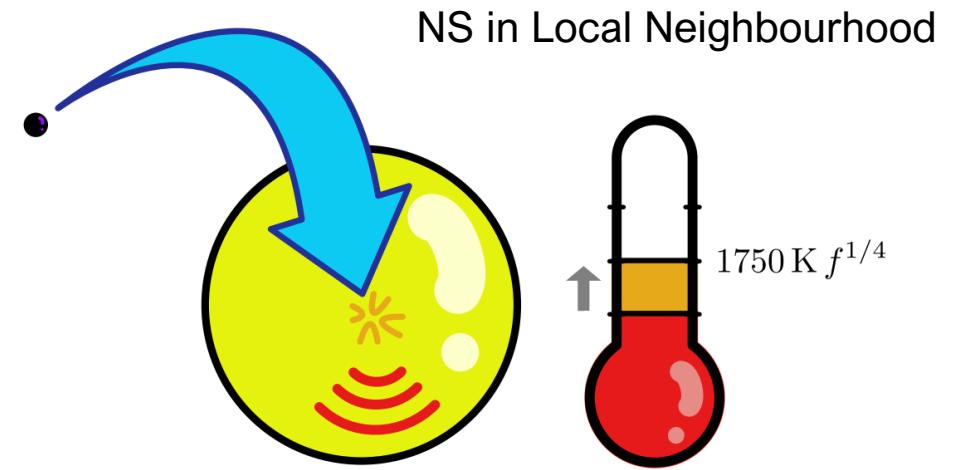
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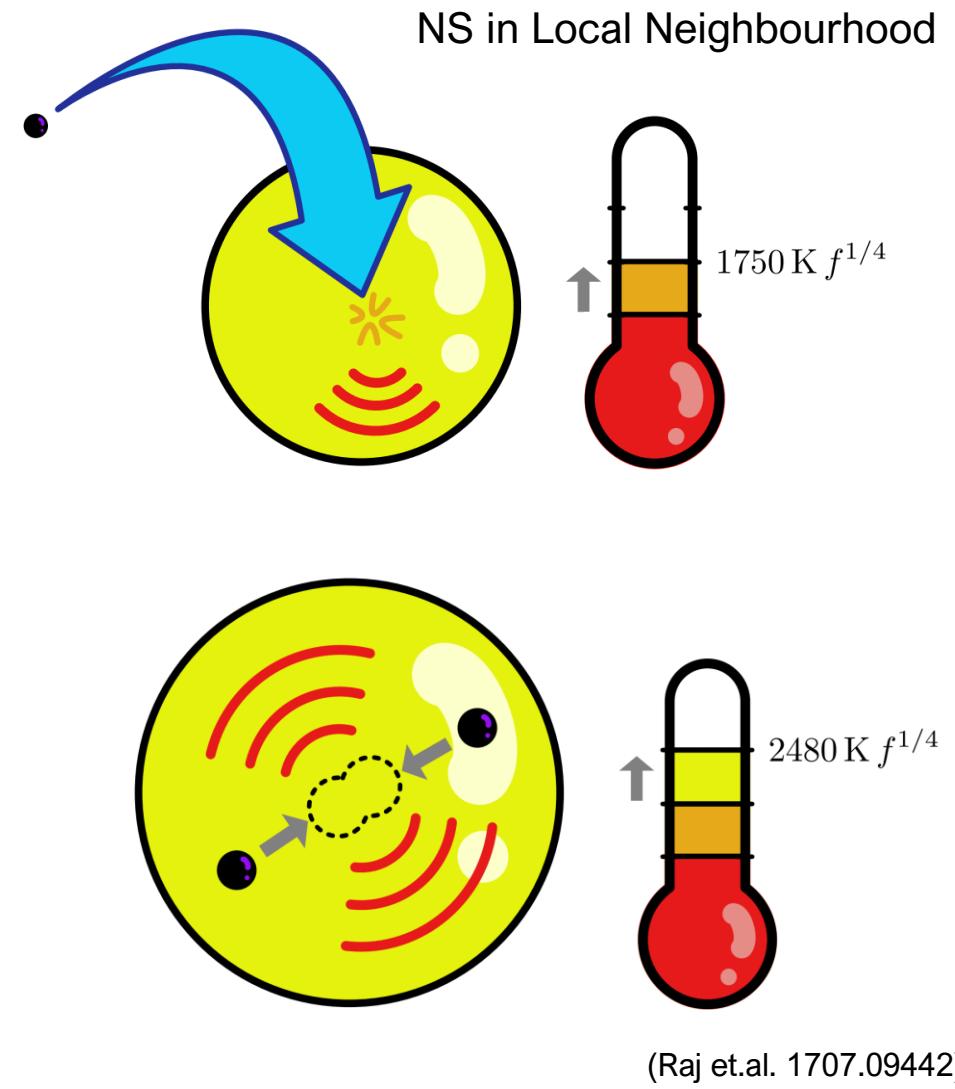
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(Raj et.al. 1707.09442)

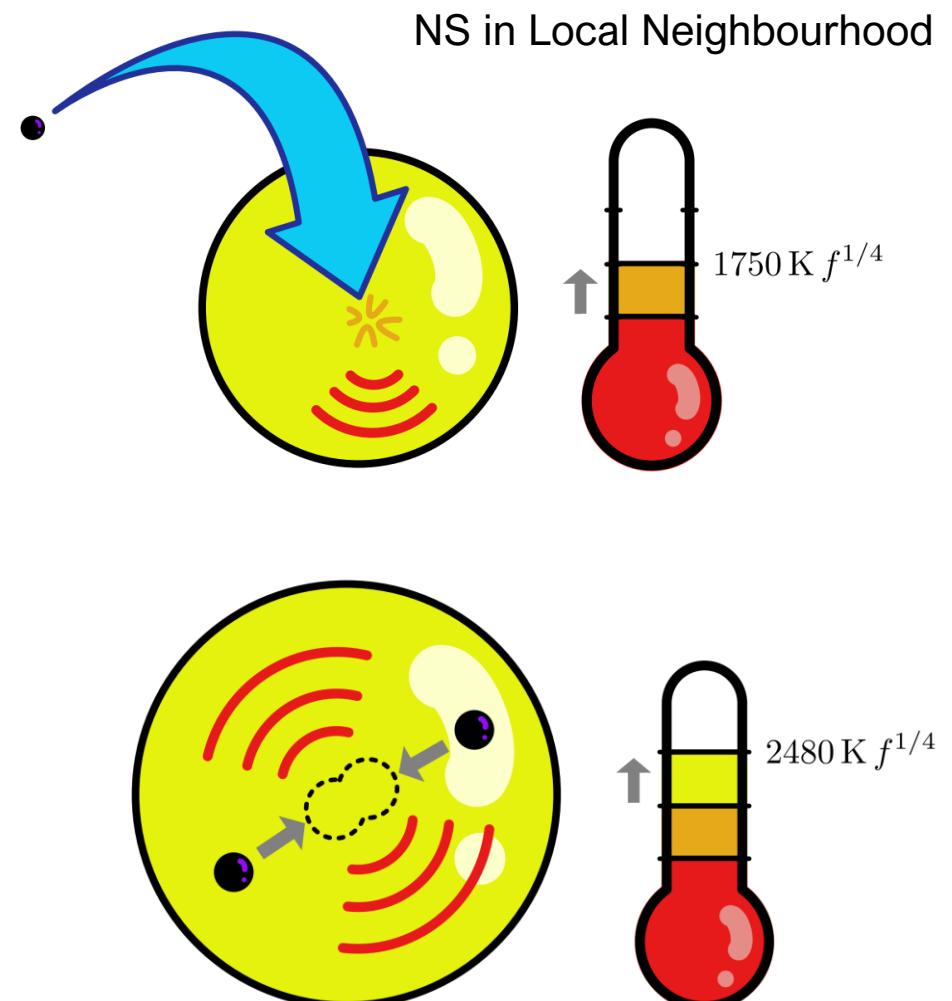
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- DM induced Heating (Baryakhtar et.al. 1704.01577)
  - Kinetic energy from scattering to thermalise
  - Mass energy from annihilations
  - WDs only have annihilation heating
- Observing old, cold WD can leads to strong constraints
  - WD cool to  $\sim 10^5 K$  in  $\sim 10$  Gyr



(Raj et.al. 1707.09442)

# Survey Dark Matter with EFT

- Focus on Dimension-6 EFT operators for Dirac fermion DM e.g.

Spin Independent

$$\frac{y_q}{\Lambda^2} (\bar{\chi}\chi)(\bar{q}q) \quad \frac{1}{\Lambda^2} (\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)$$

D1

D5

Spin Dependent

$$\frac{y_q}{\Lambda^2} (\bar{\chi}\gamma_5\chi)(\bar{q}\gamma_5 q) \quad \frac{1}{\Lambda^2} (\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu q)$$

D4

D7



$\Lambda$ : EFT cutoff

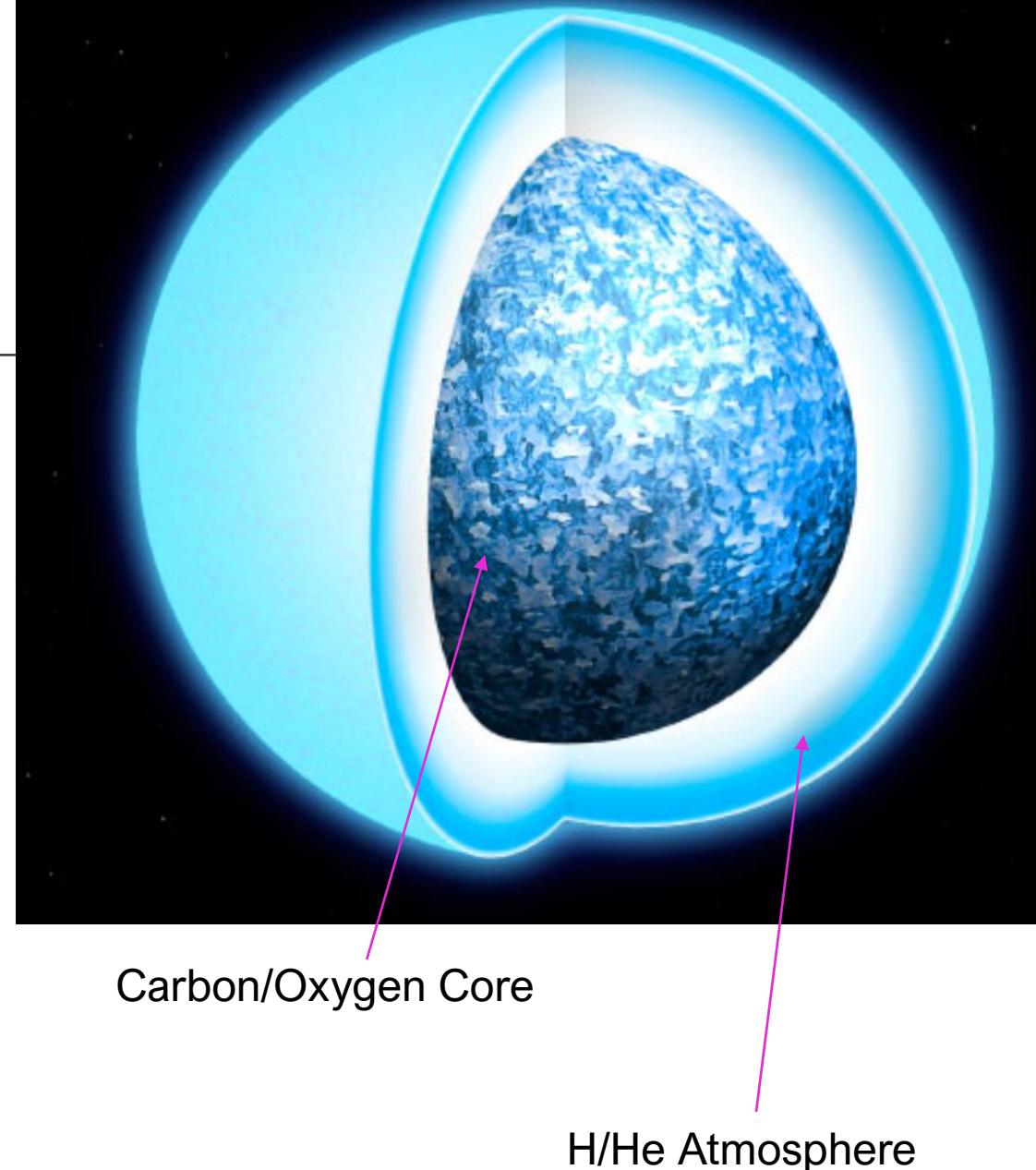
# White Dwarfs

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DM CAPTURE IN GLOBULAR CLUSTER M4

# White Dwarfs

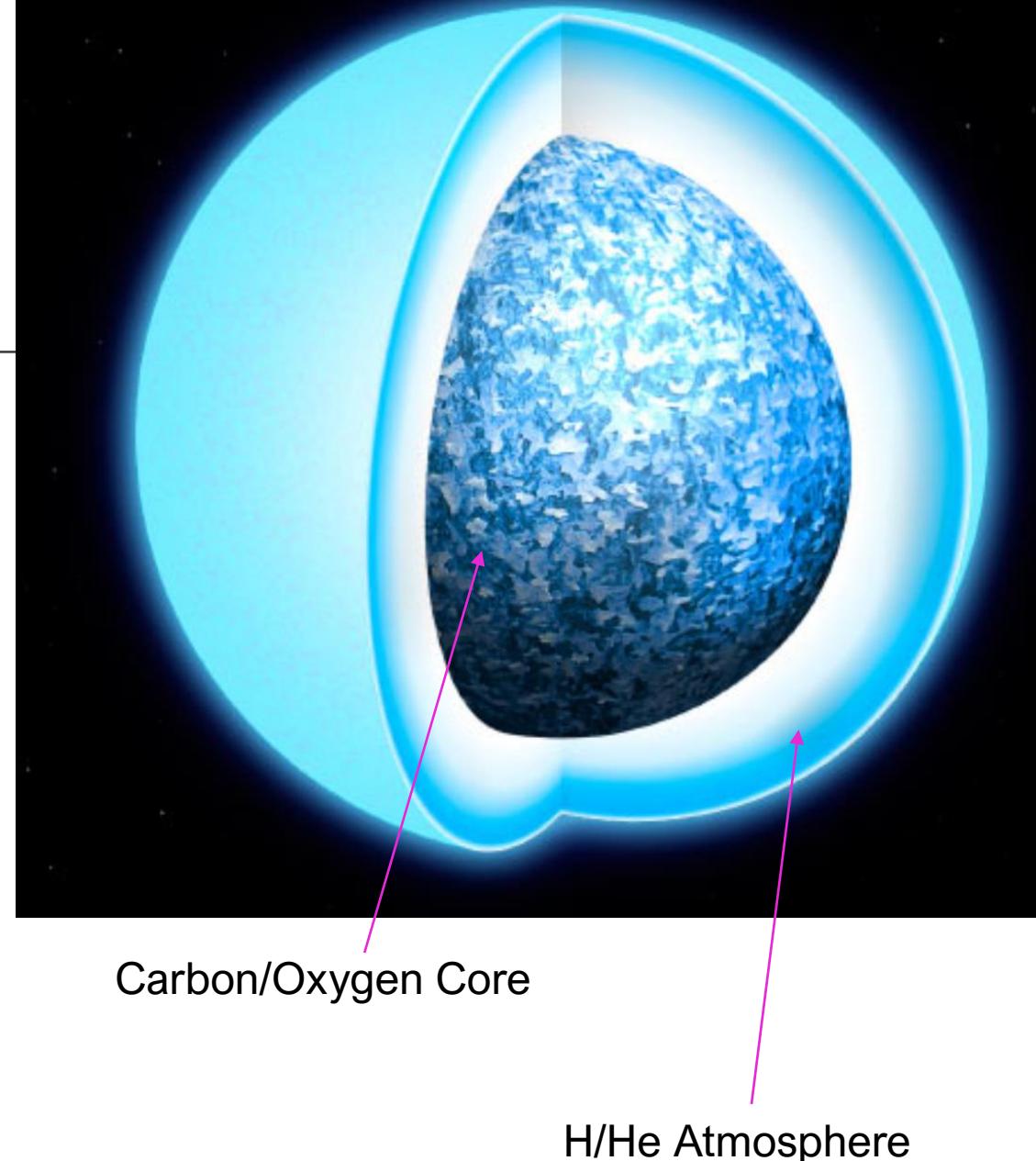
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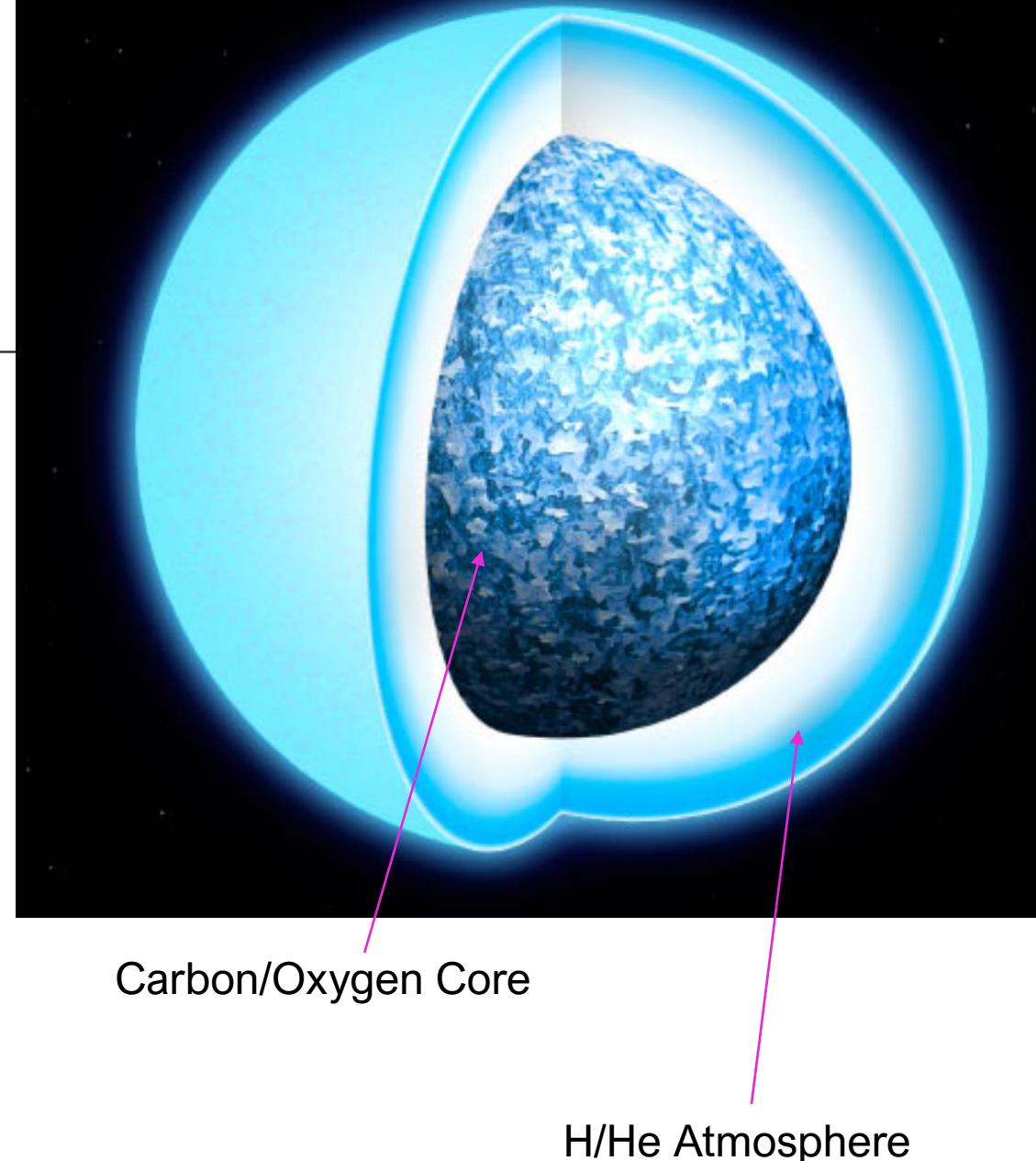
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# White Dwarfs

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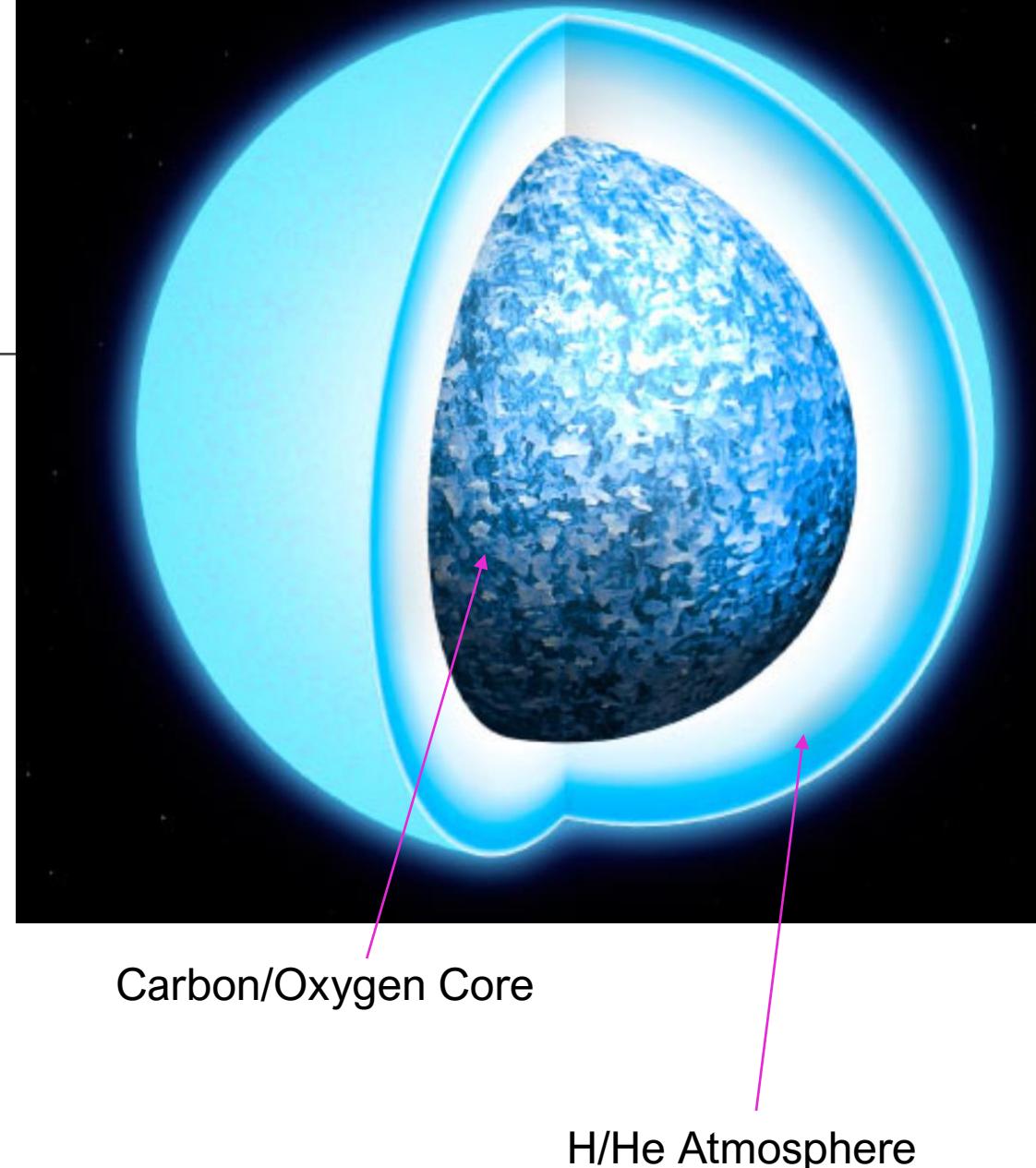
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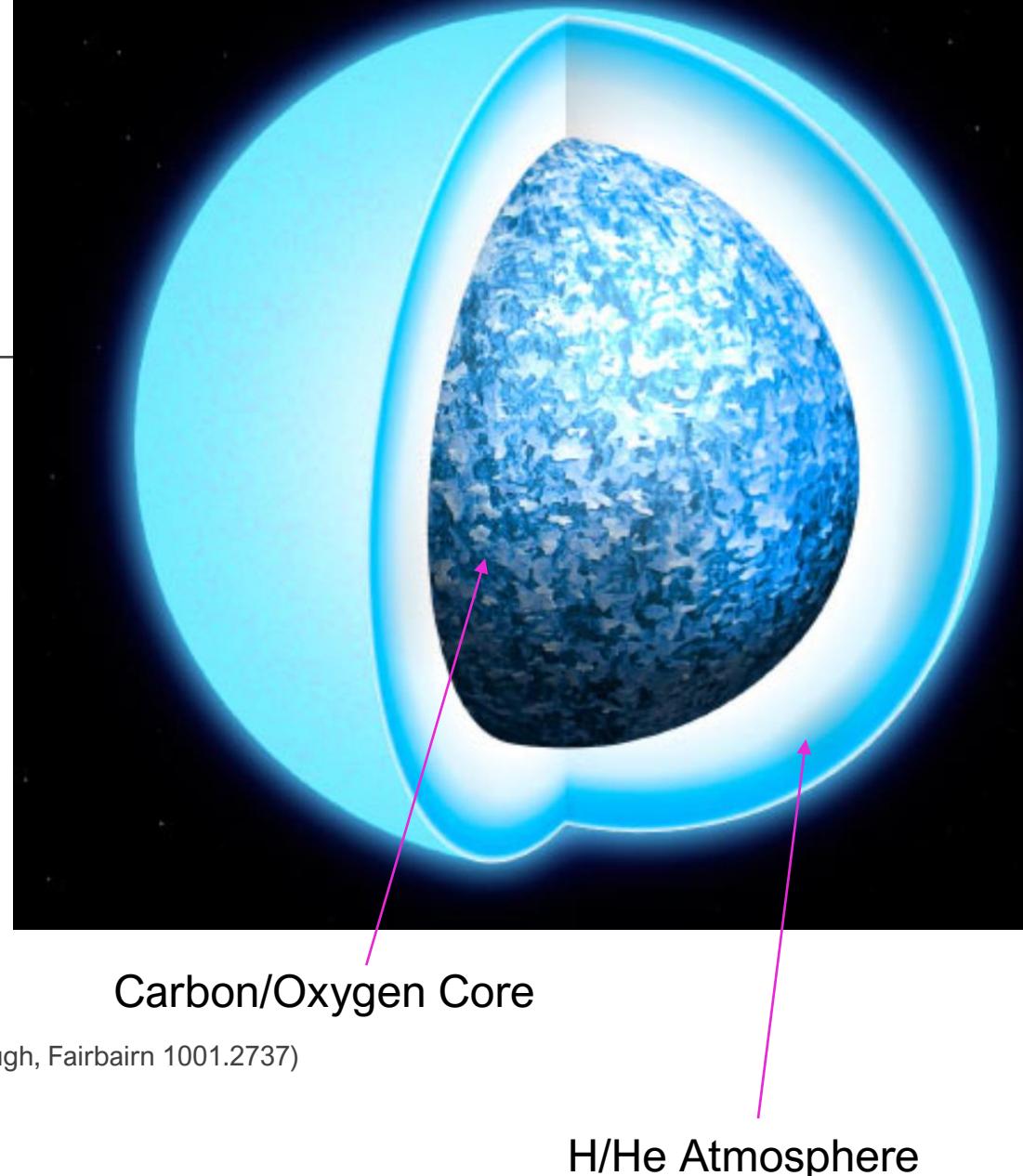
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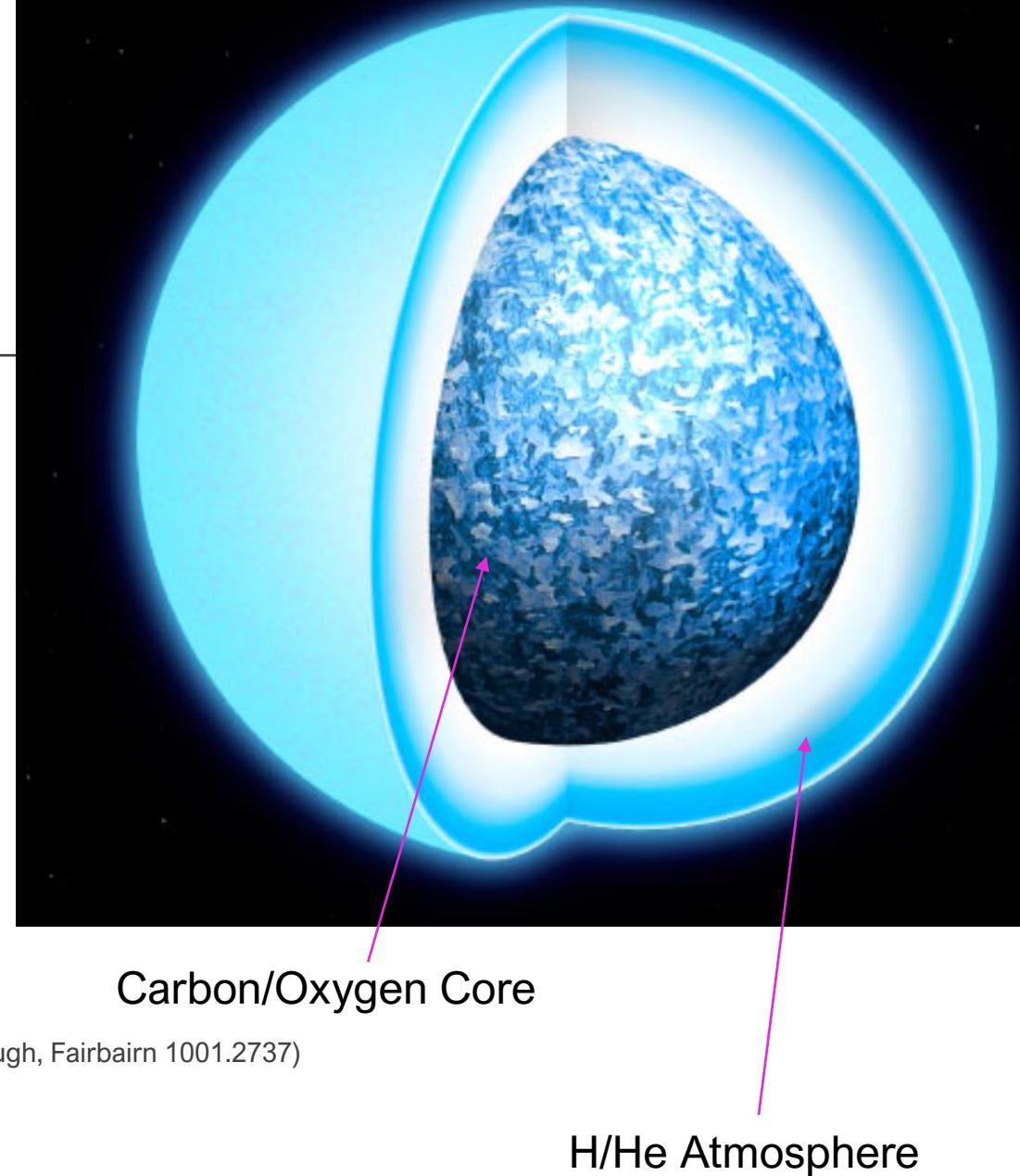
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- Look to Globular Cluster Messier 4 (M4)
  - Closest GC ( $1.9 \text{ kpc}$ )
  - Age  $11.6 \text{ Gyrs}$
  - $\rho_\chi = 798 \text{ (532) } GeV/cm^3$  for (un)contracted halo (McCullough, Fairbairn 1001.2737)



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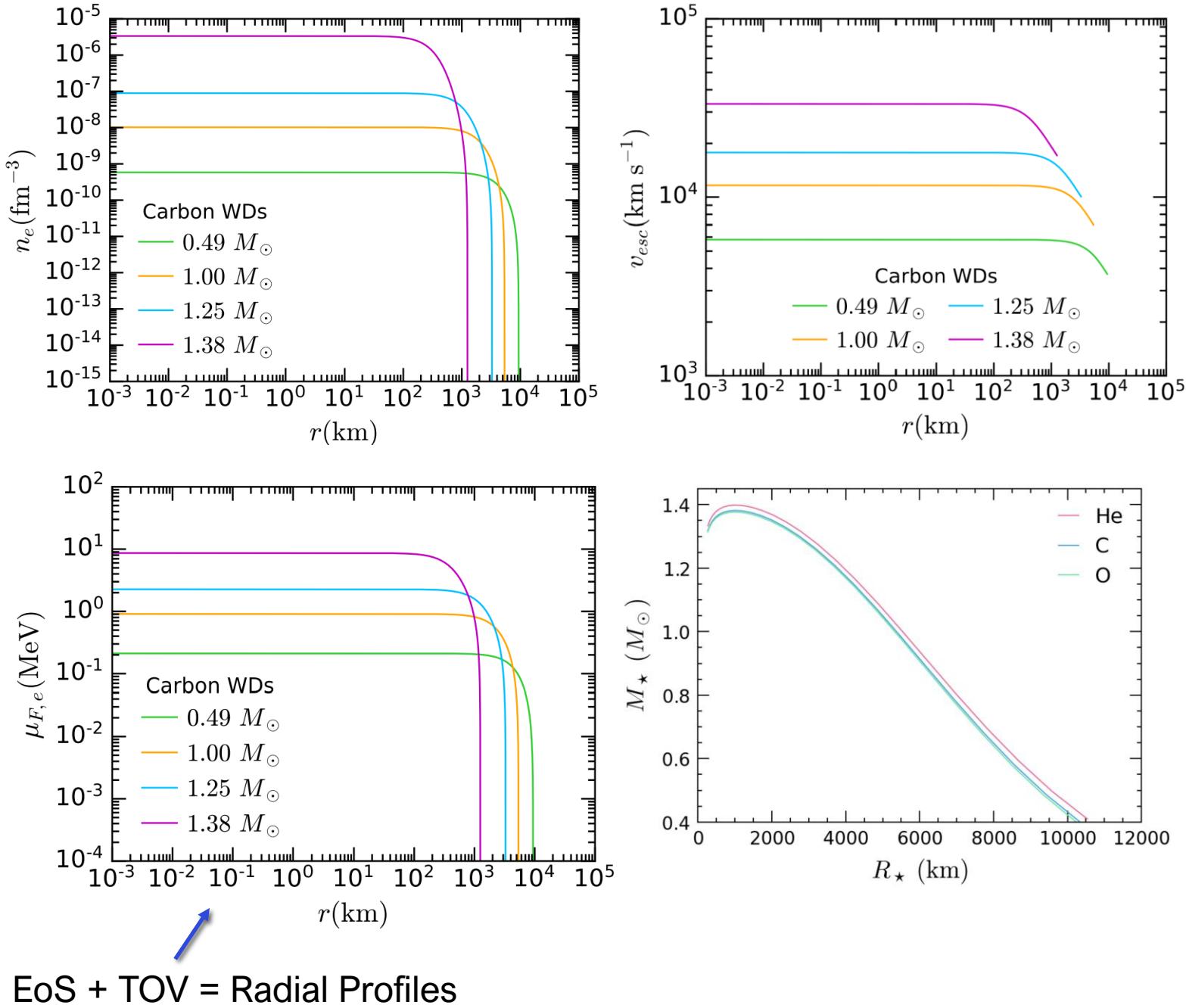
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  - May/may not contain DM...



# White Dwarf Structure and Equation of State

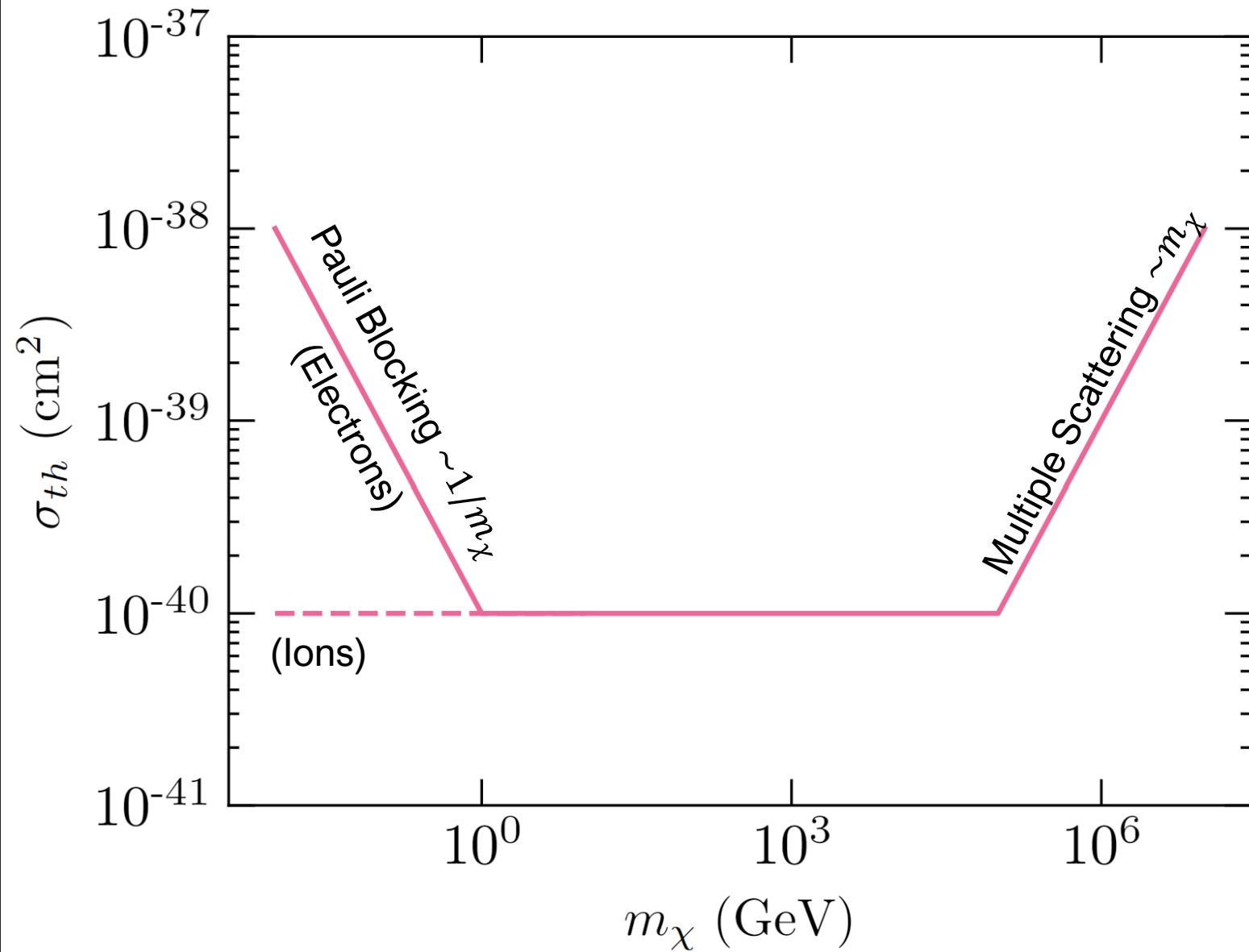
- Adopt Feynman-Metropolis-Teller EoS
- Incorporates self consistently:
  - $e - e$ ,  $e - N$ ,  $N - N$  Coulomb interactions
  - **Beta Equilibrium**
  - **Finite size of nucleus**
  - **Relativistic effects**



# Geometric Limit and Threshold Cross Section

- Capture rate saturates at

$$C_{Geom} \sim 10^{32} s^{-1} \left( \frac{m_\chi}{1 \text{ GeV}} \right)$$



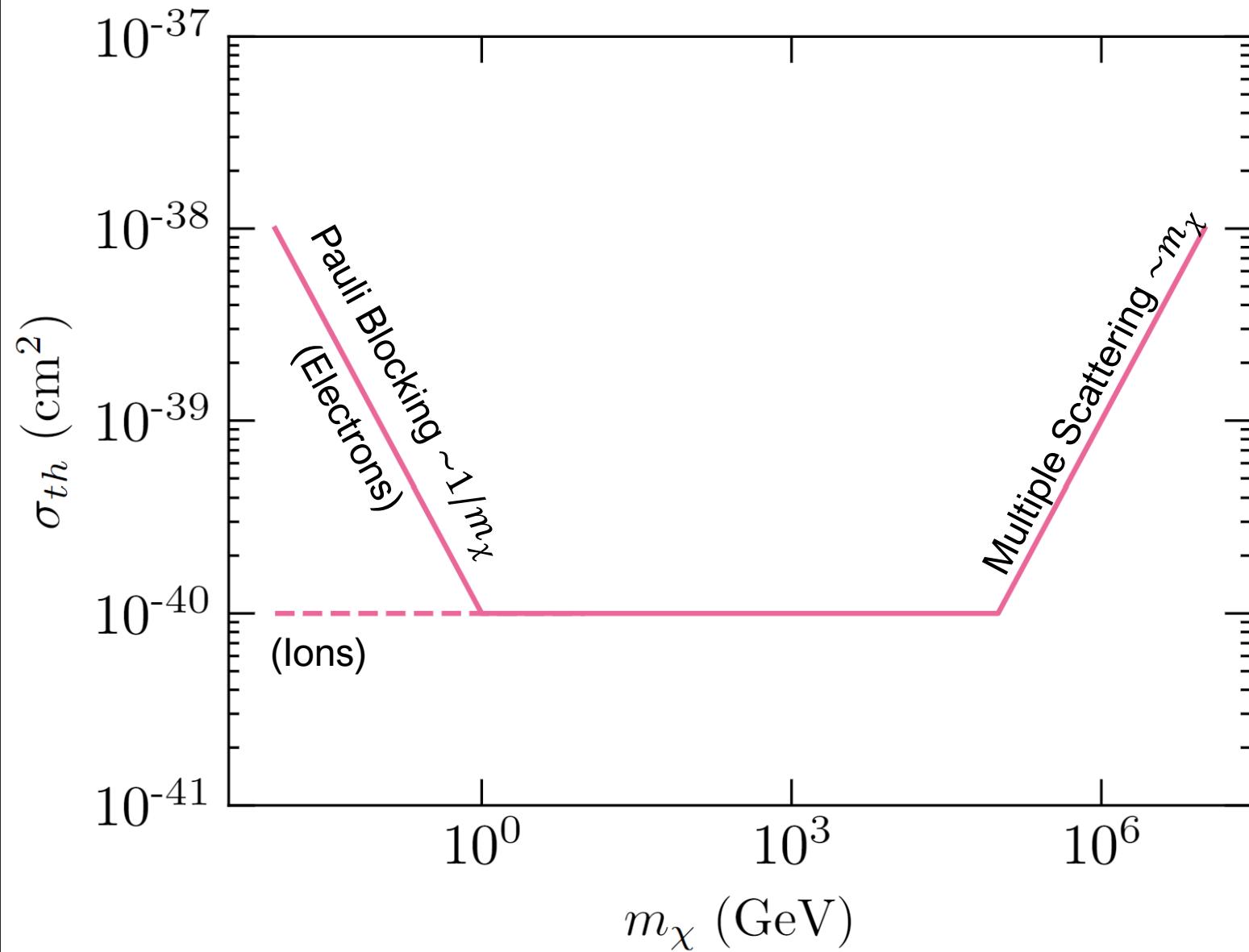
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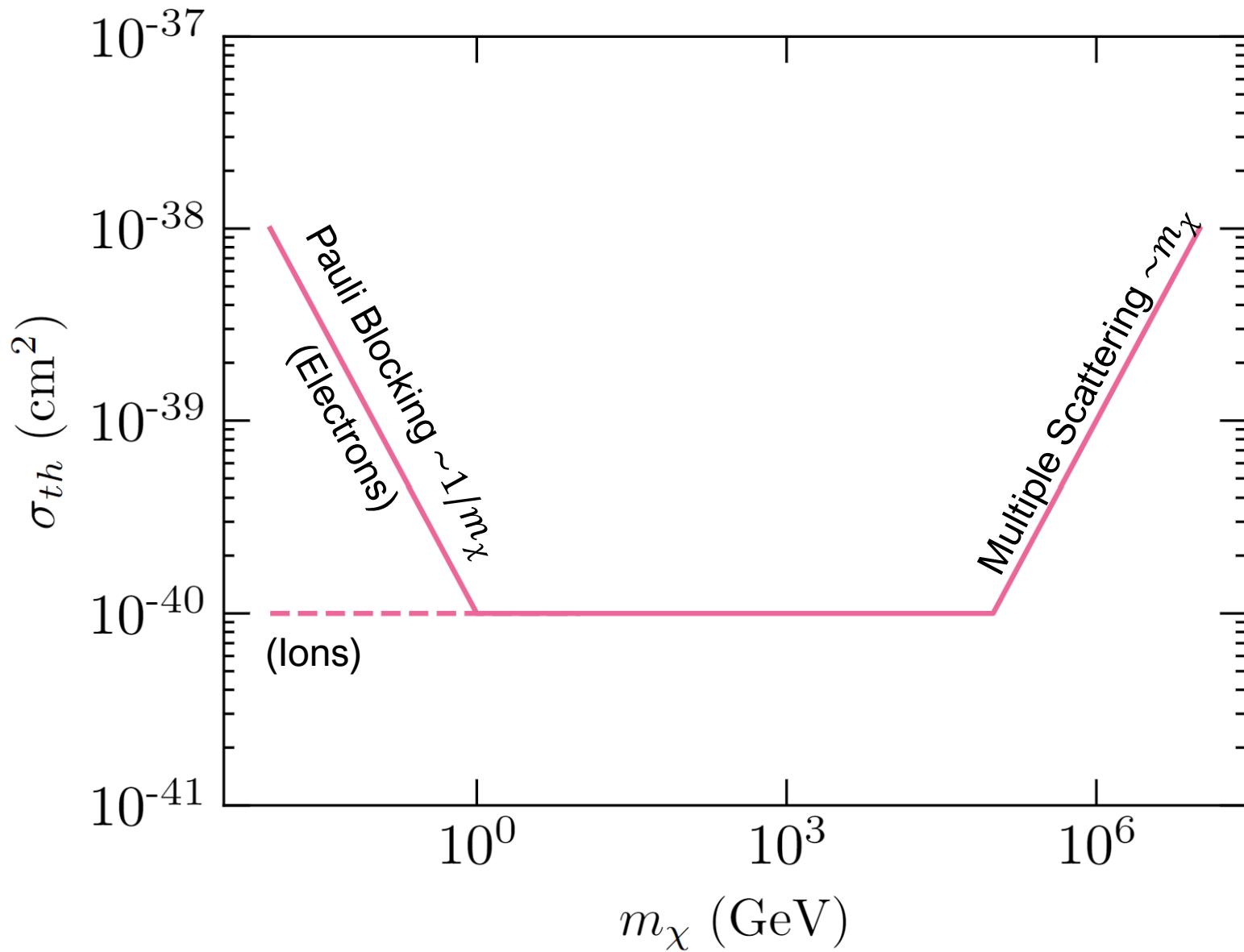
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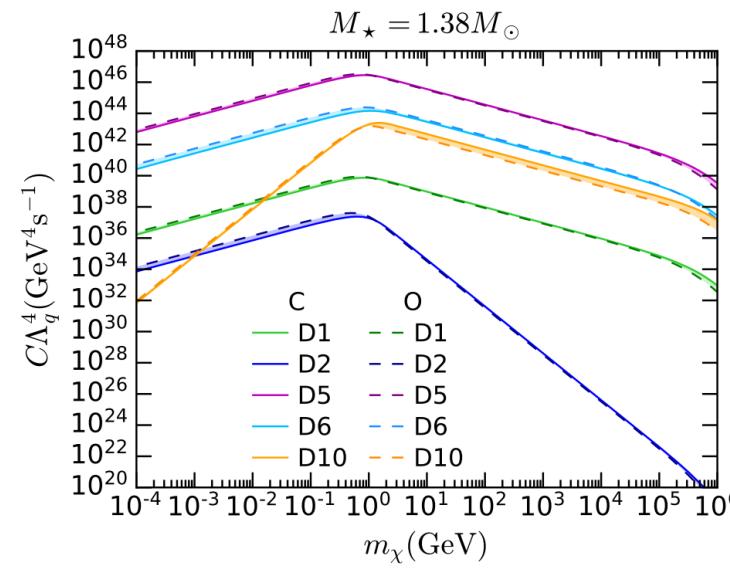
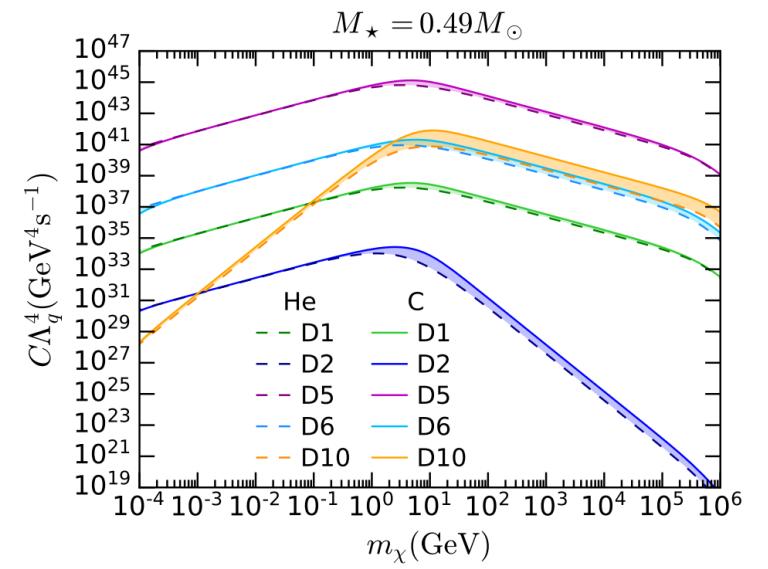
- Additional effects alter this:

- $\sigma_{th,0} \frac{MeV}{m_\chi}$ ,  $m_\chi \lesssim 1 \text{ MeV}$  (Pauli Blocking)
- $\sigma_{th,0} \frac{m_\chi}{10^5 \text{ GeV}}$ ,  $m_\chi \gtrsim 10^5 \text{ GeV}$  (Multi-Scatter)



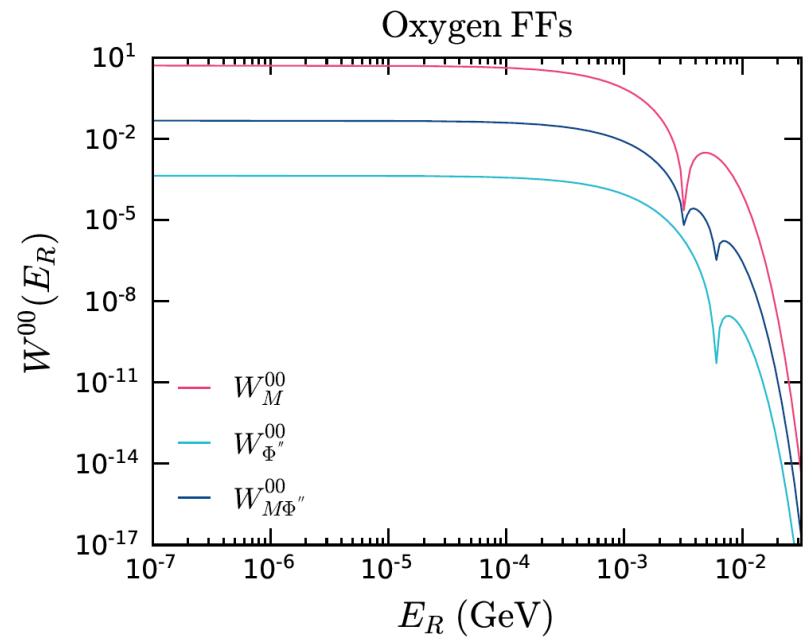
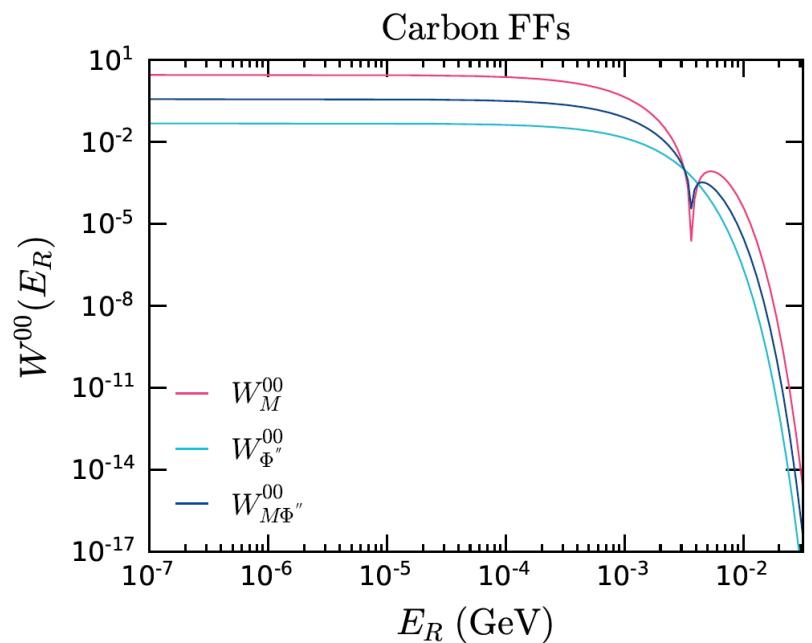
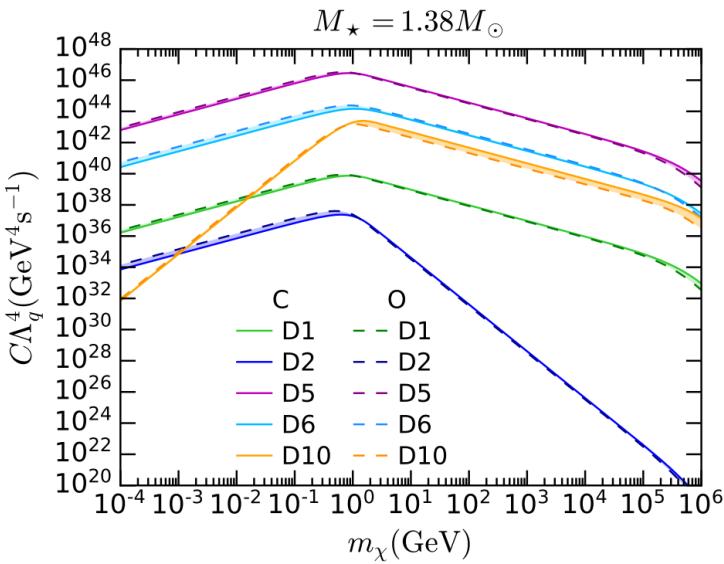
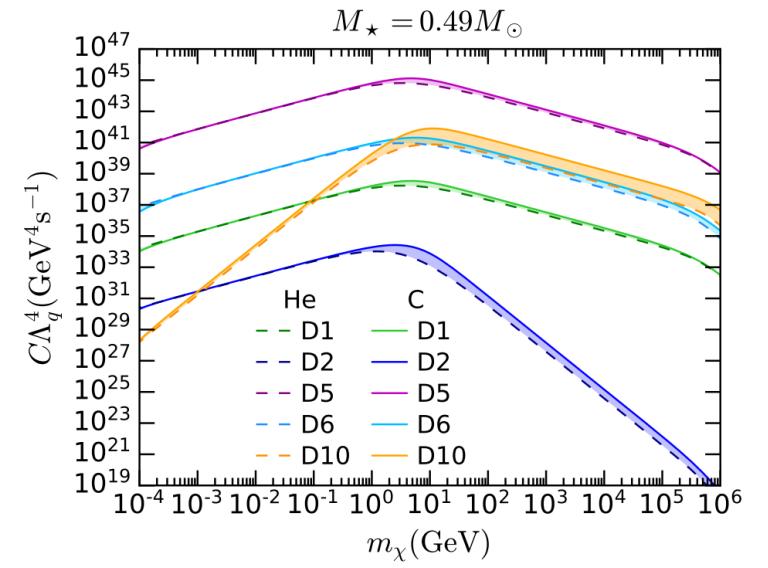
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- Gould formalism for the Sun applicable



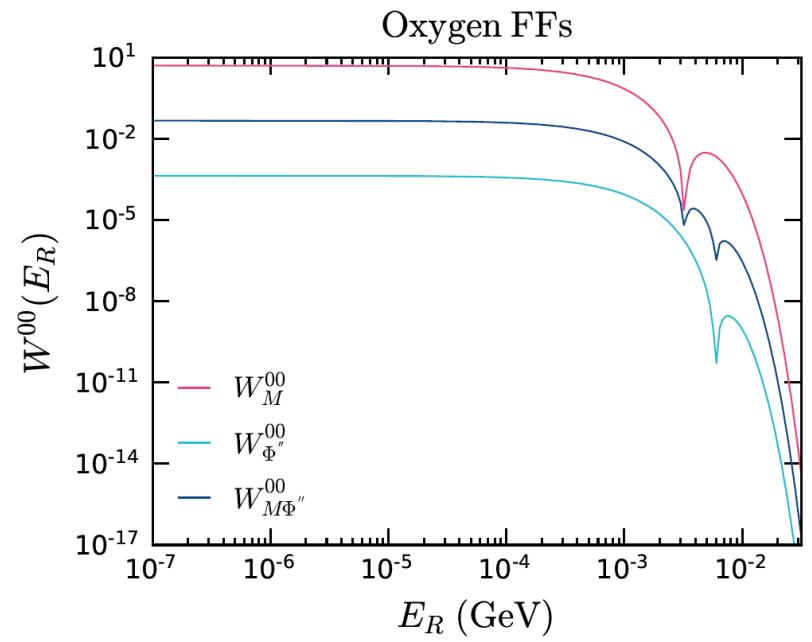
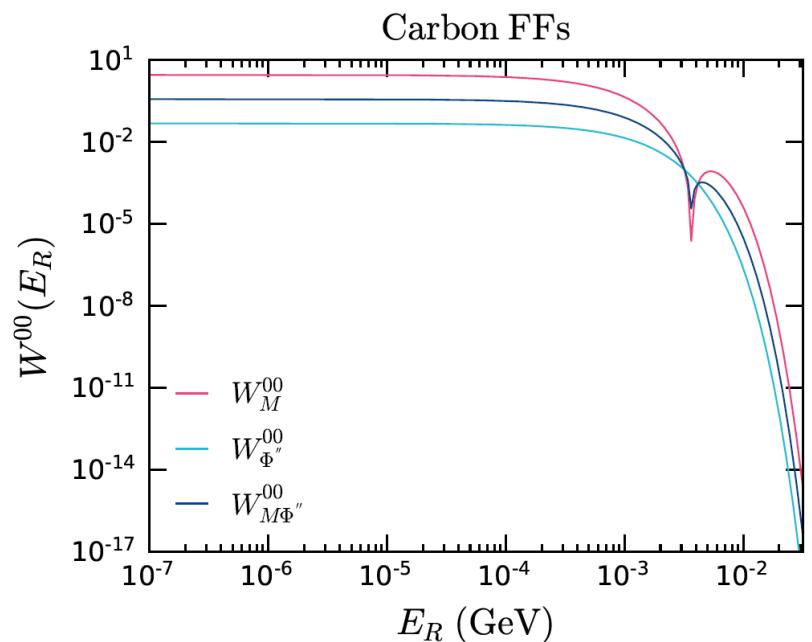
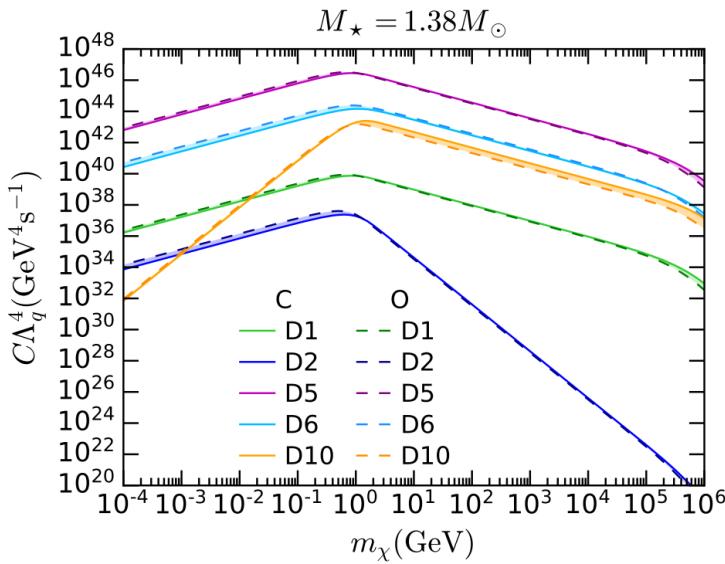
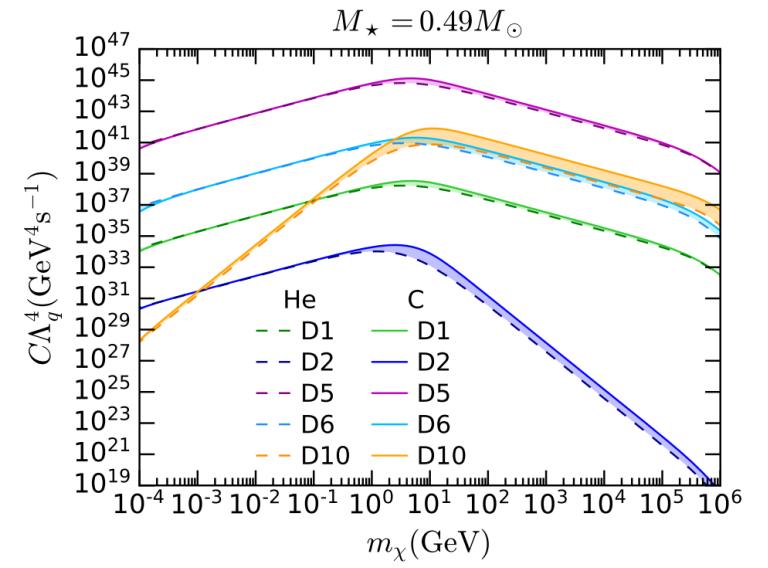
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  - Suppress interaction rate at high momentum transfer

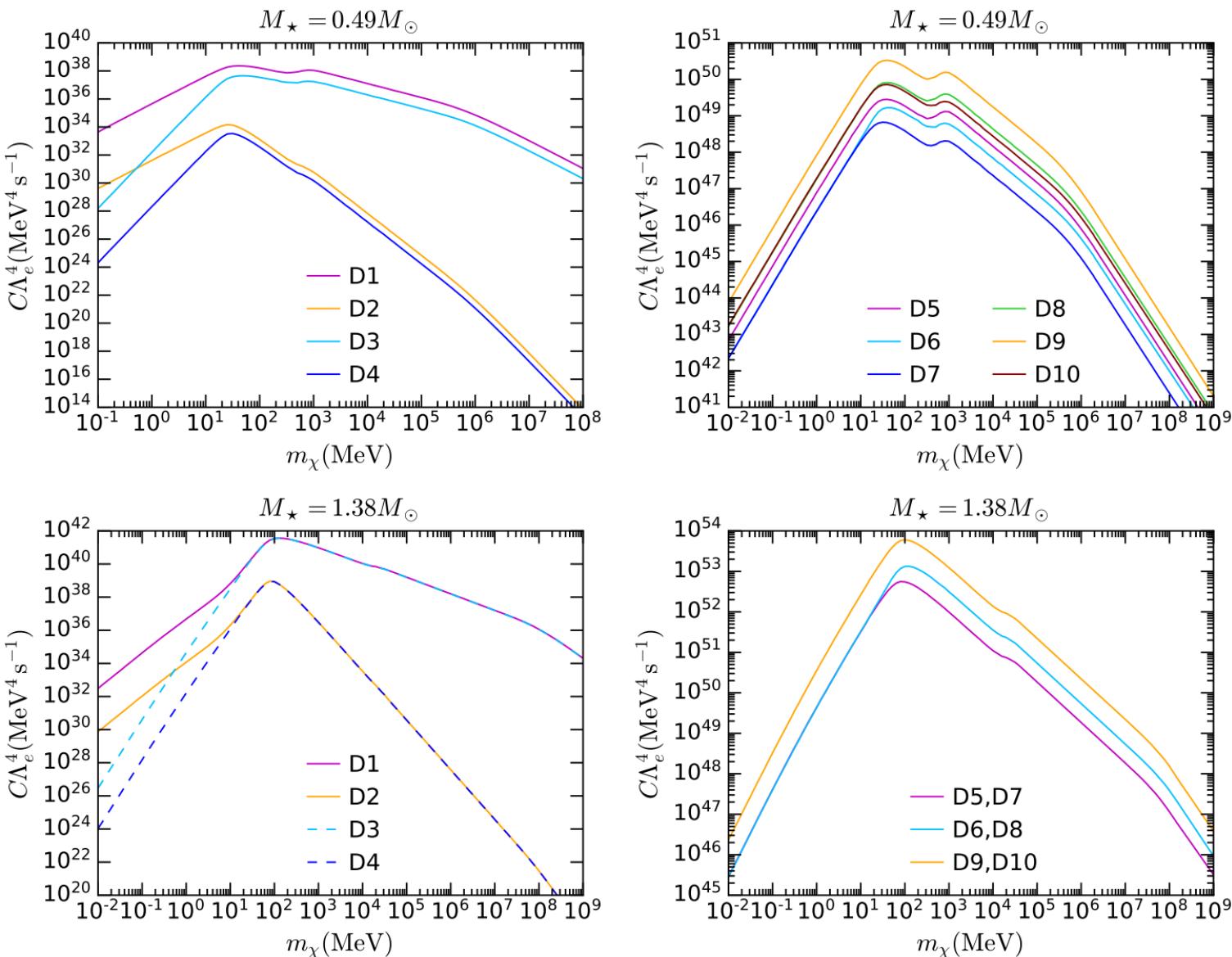


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- He/C/O targets  $\rightarrow$  Spin-Independent interactions only

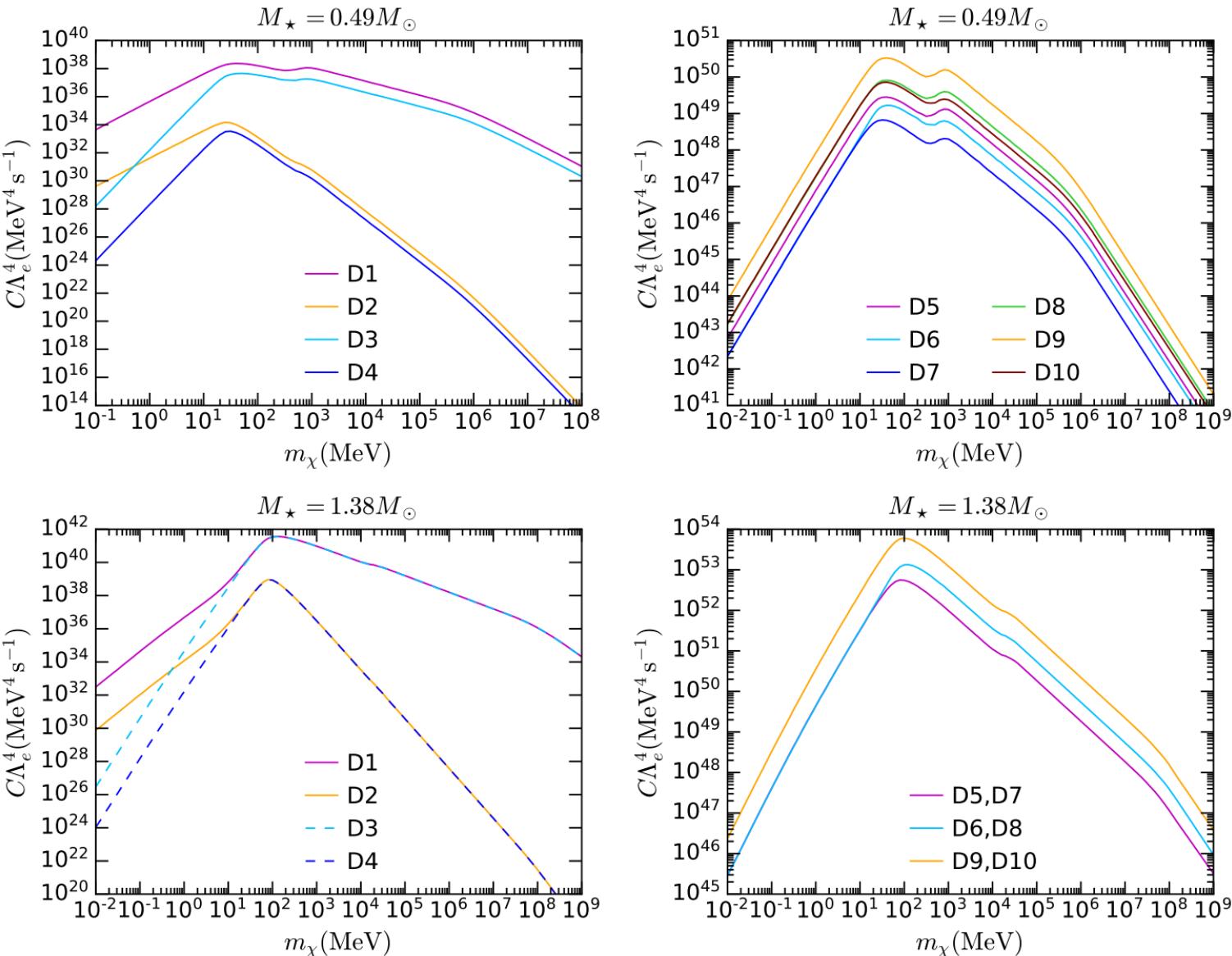


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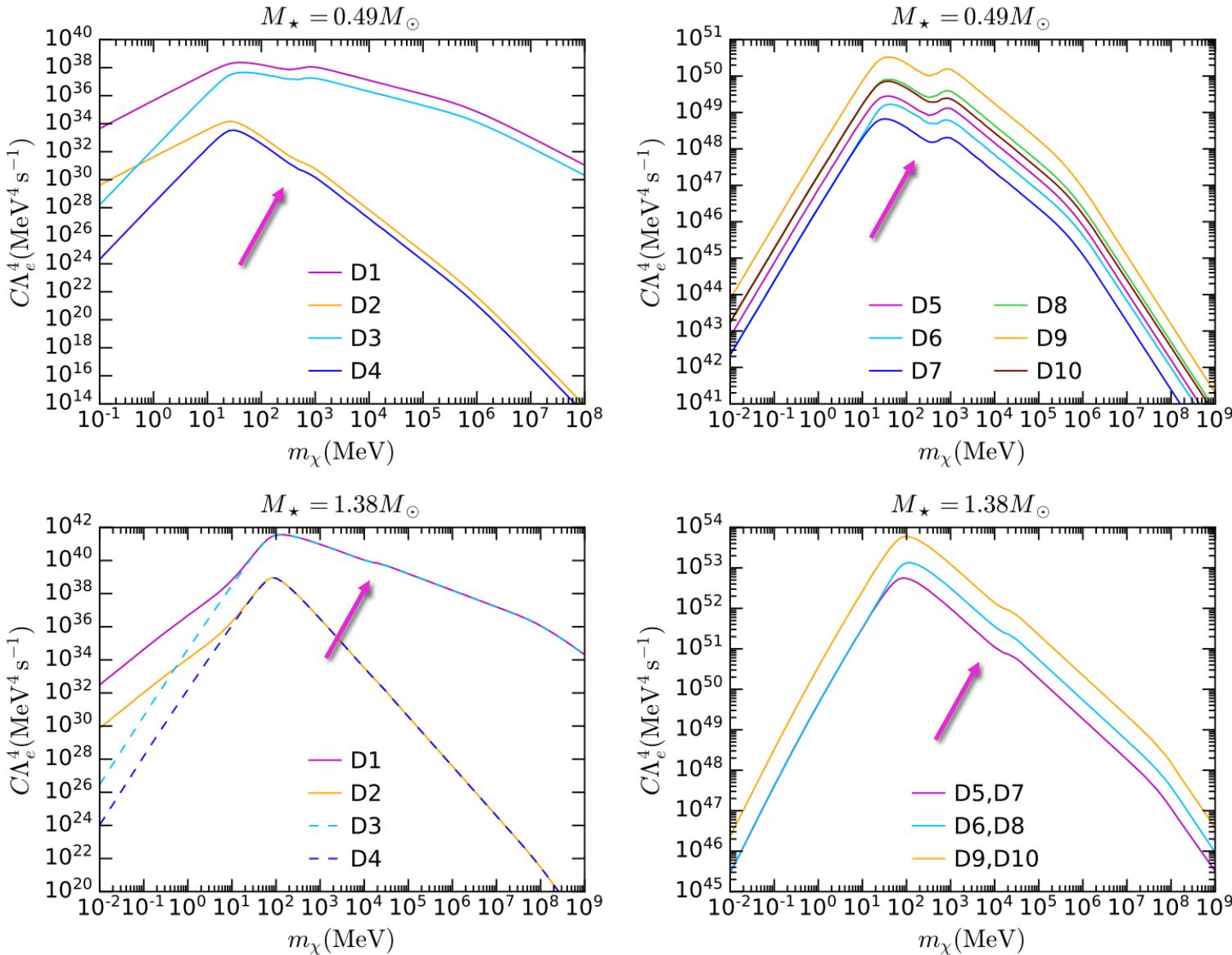
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Bell, Busoni, Robles, Ramirez, MV 2104.14367

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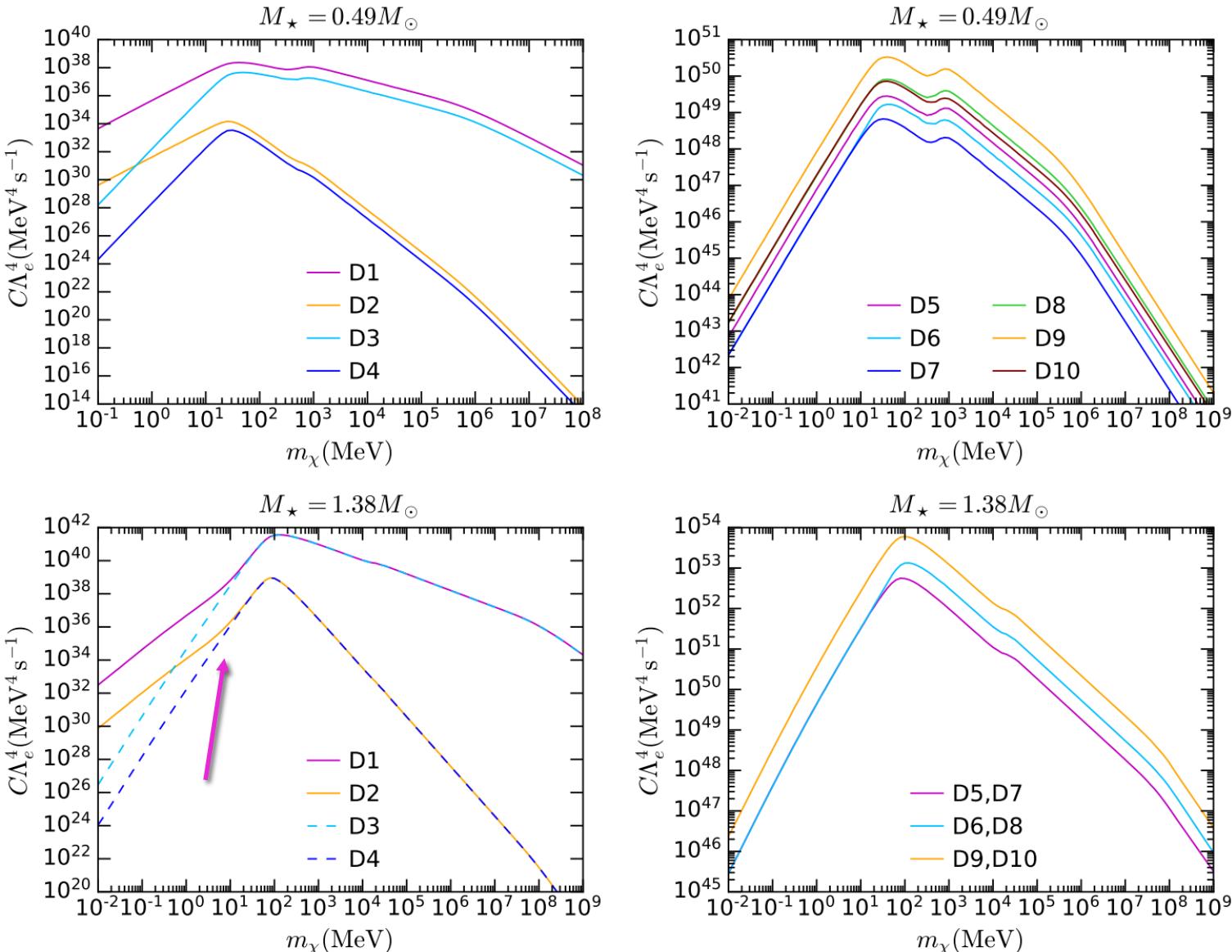
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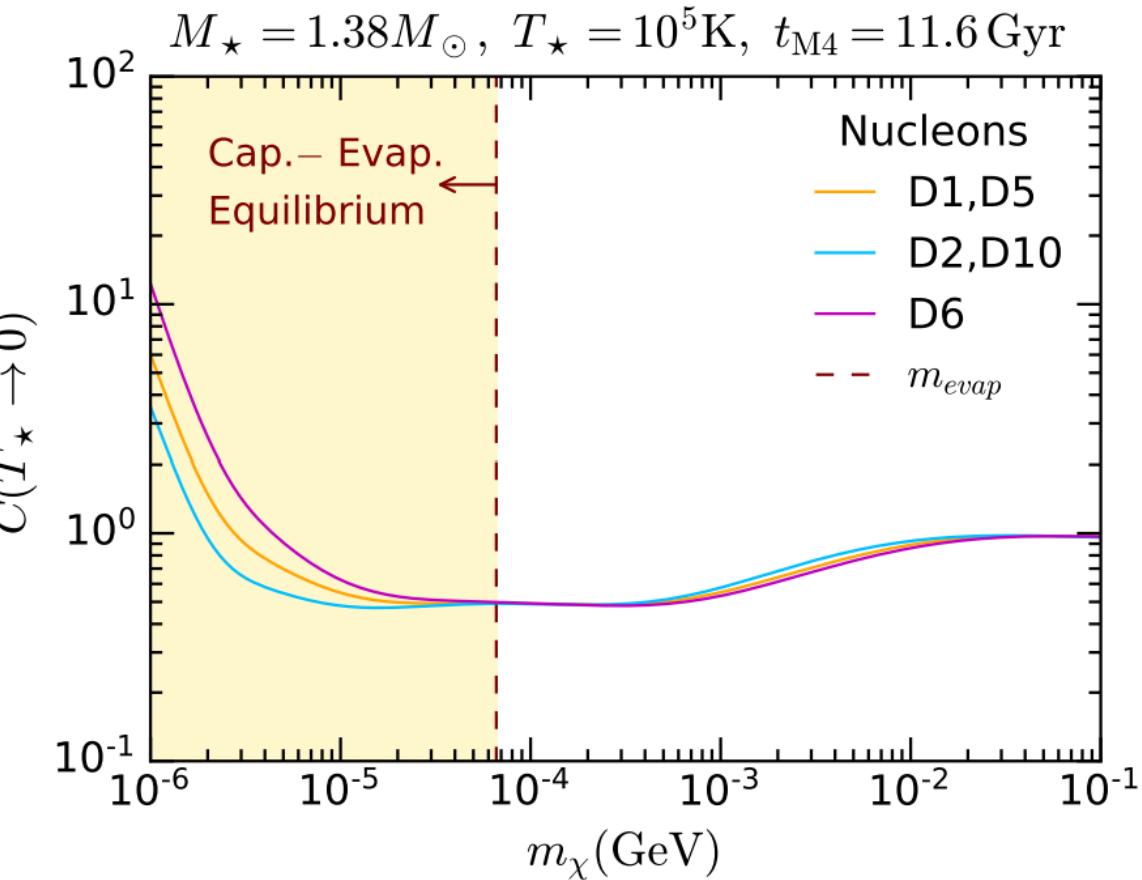
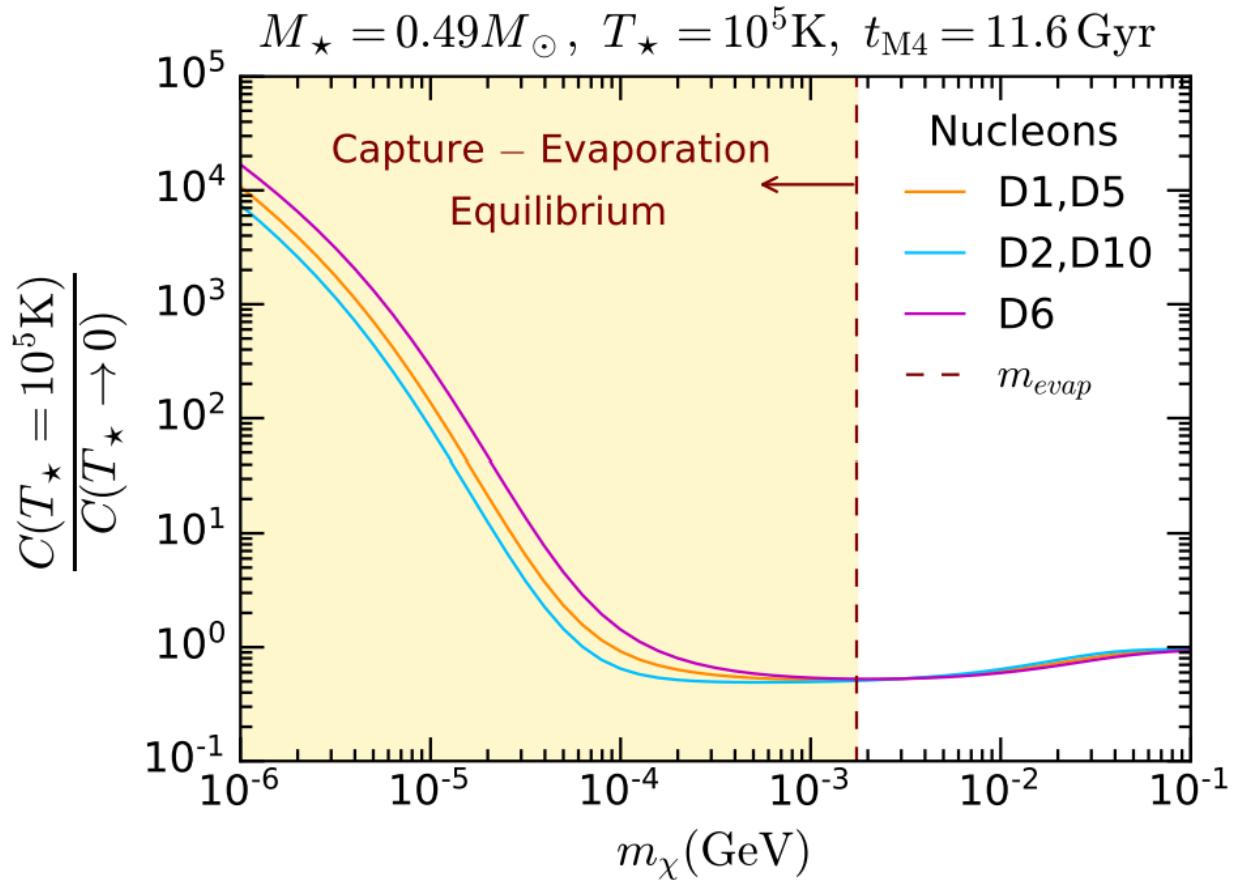
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- Heavy WD, light DM: Change in kinematics:
  - $\frac{m_e}{m_\chi}$  terms dominate cross section



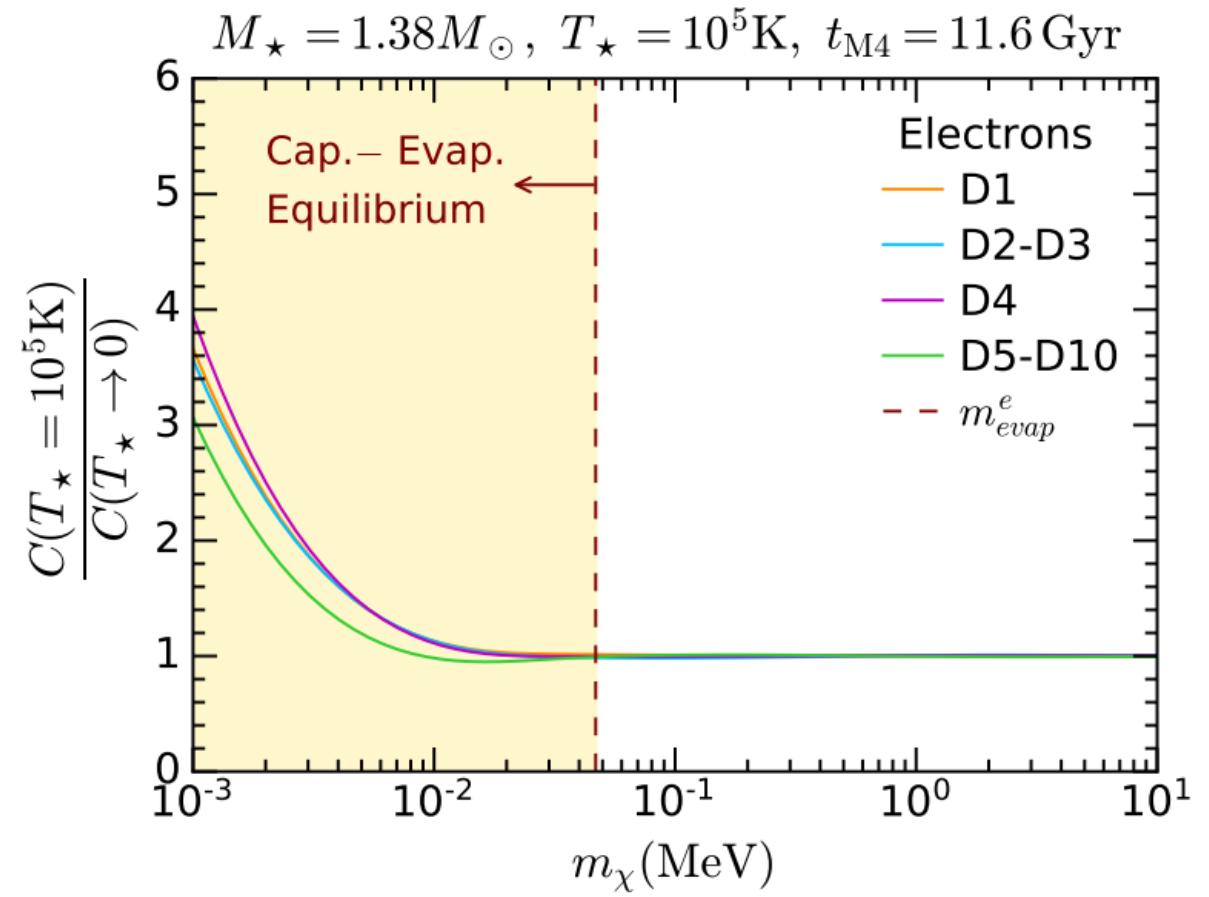
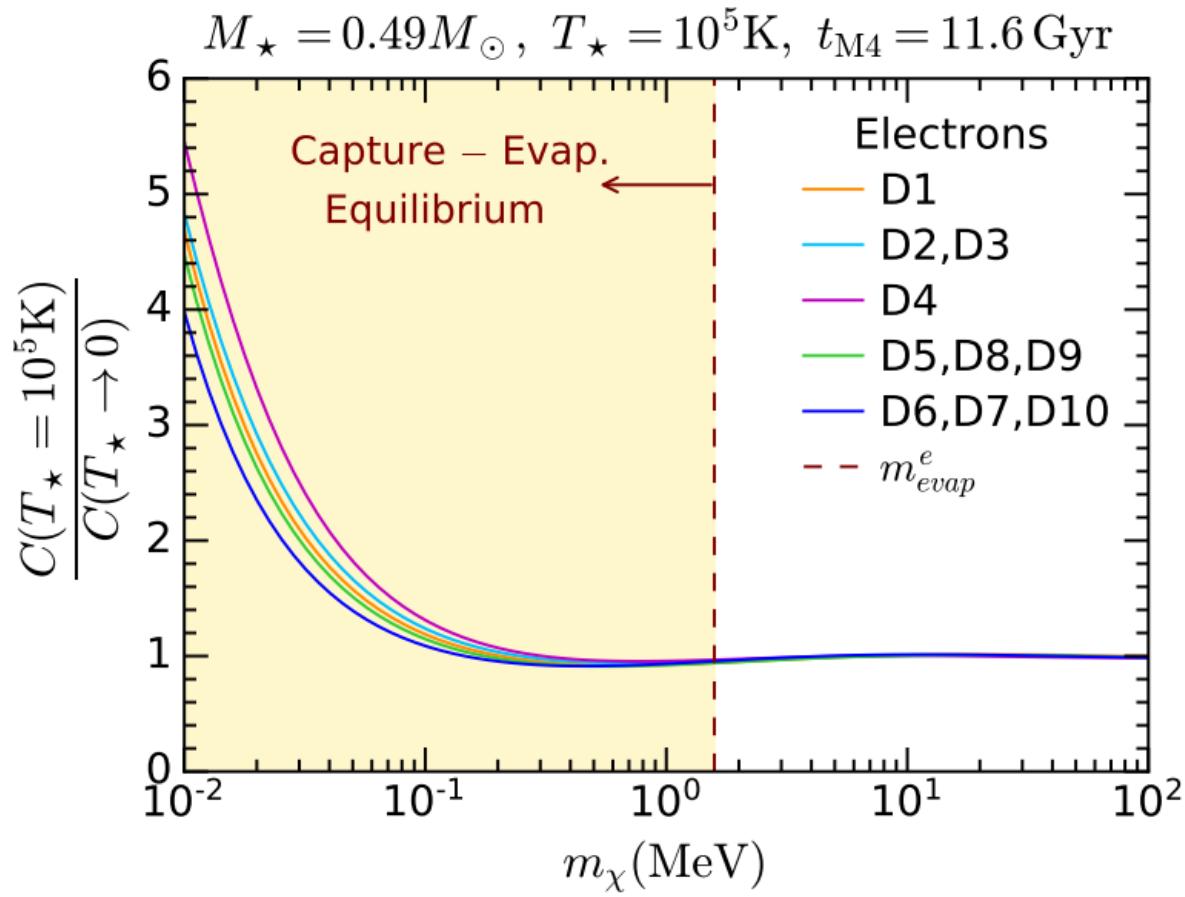
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# Finite Temperature Effects: Ions

- $T_\star = 10^5\text{K}$  consistent with GC age and estimated evolutionary sequences
- DM can up-scatter and evaporate



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# Finite Temperature Effects: Electrons

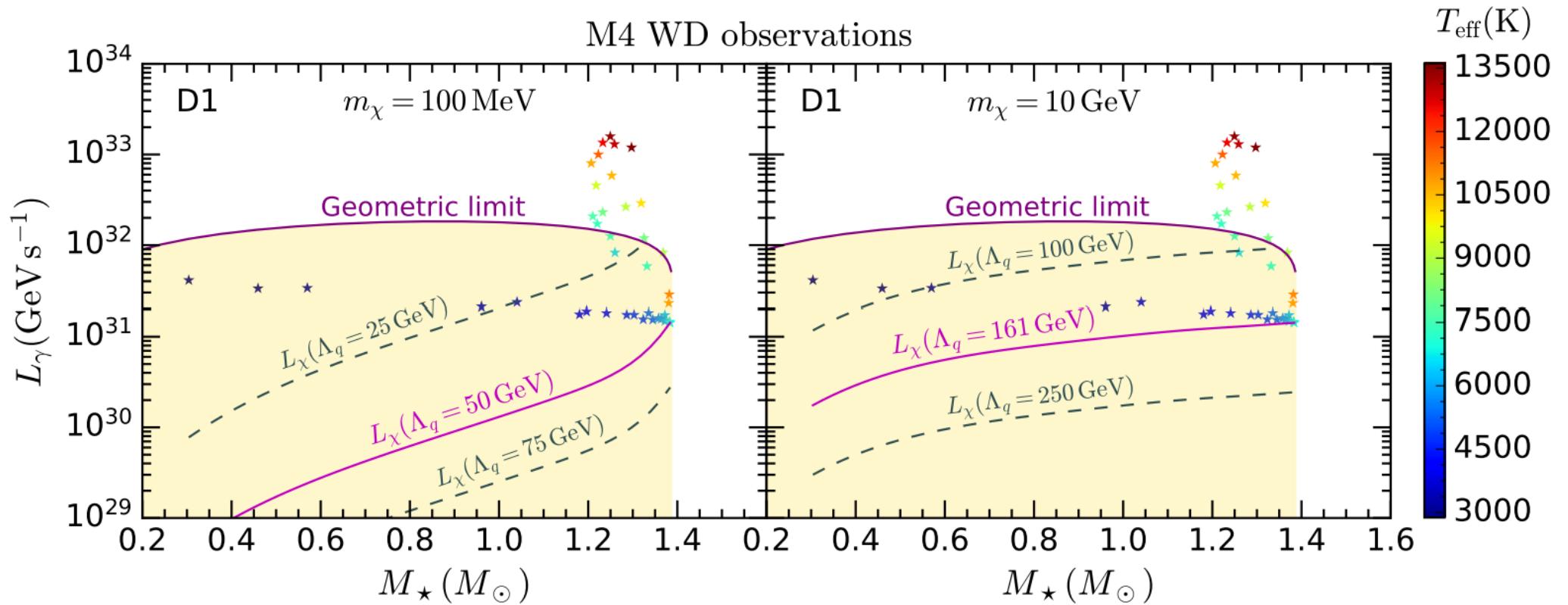
- Fermi-Dirac distributions spread out reducing Pauli Blocking
- DM can up-scatter and evaporate

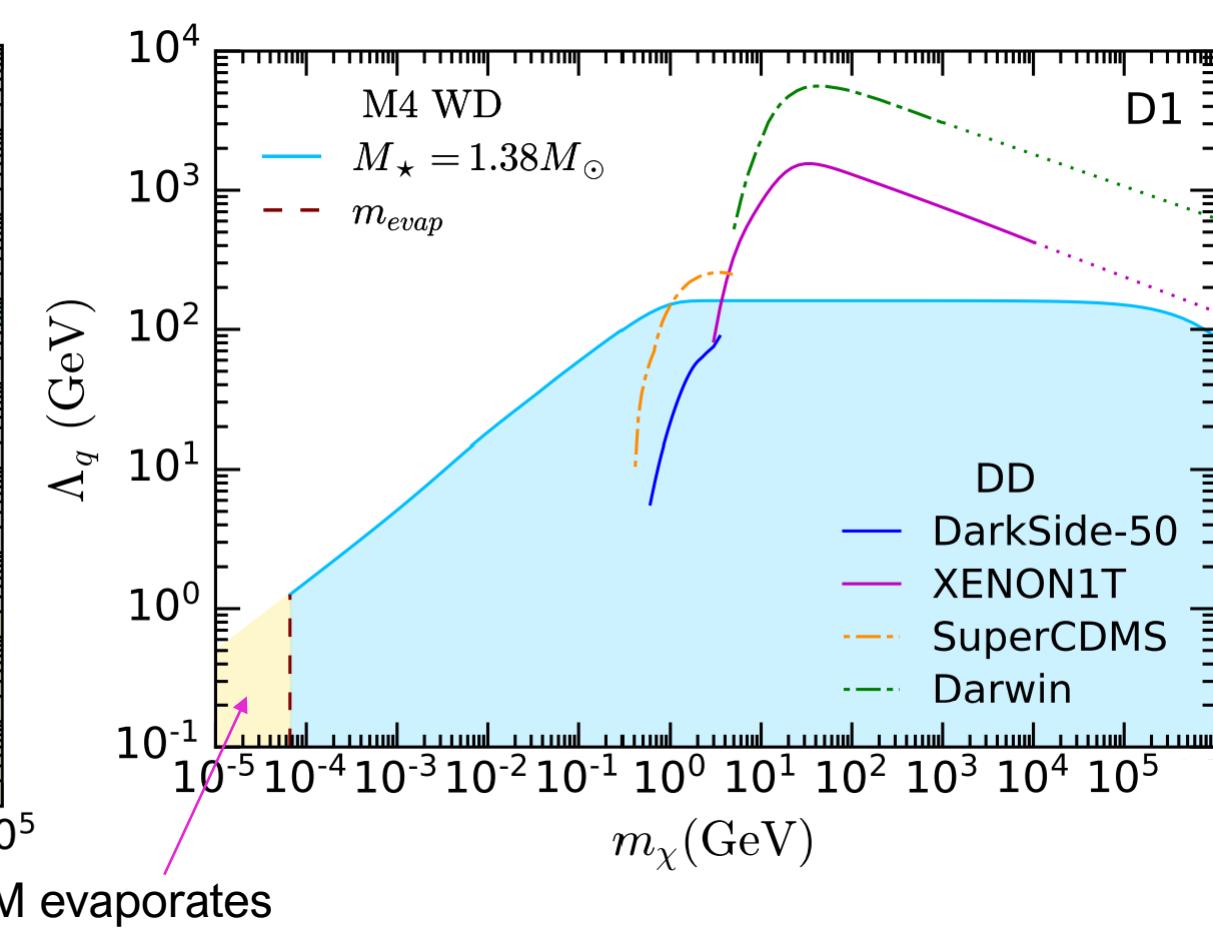
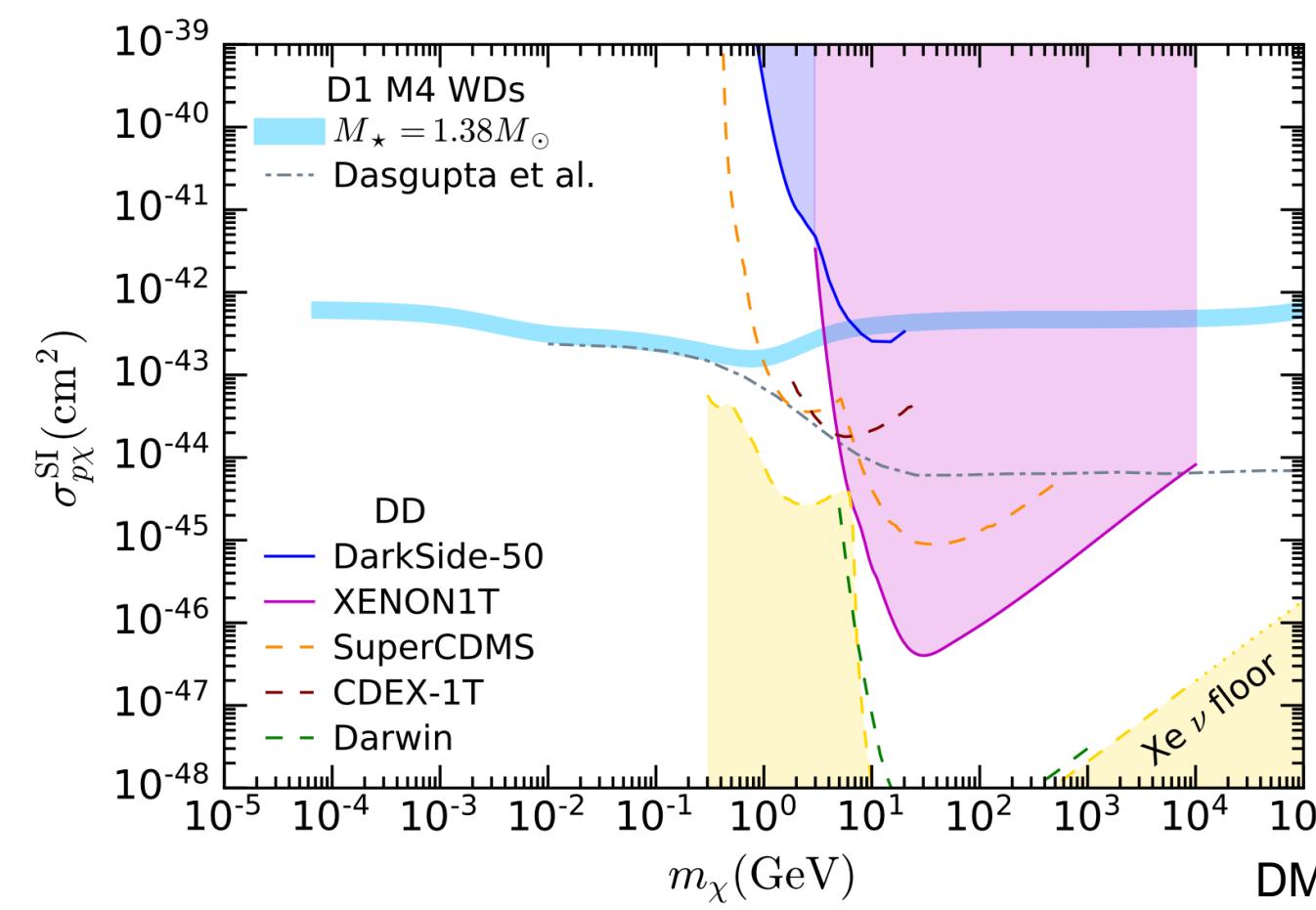
# Constraints from White Dwarf Heating

- DM in capture-annihilation equilibrium:

$$L_\chi^\infty = m_\chi C(m_\chi, \Lambda)$$

$$\tau_* \sim 11.6 \text{ Gyr} > \tau_{eq} + \tau_{therm}$$



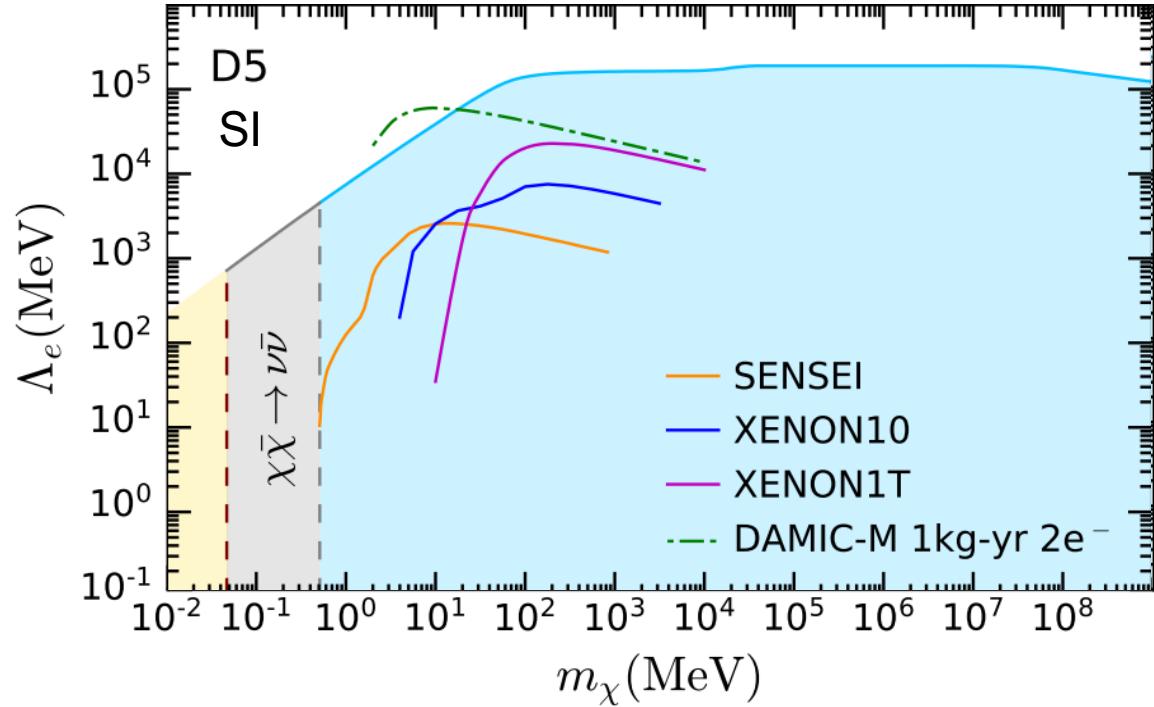


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# Prospective Heating Constraints: Ions

Relies on DM existing in M4

Can potentially reach beyond direct detection



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# Prospective Heating Constraints: Electrons

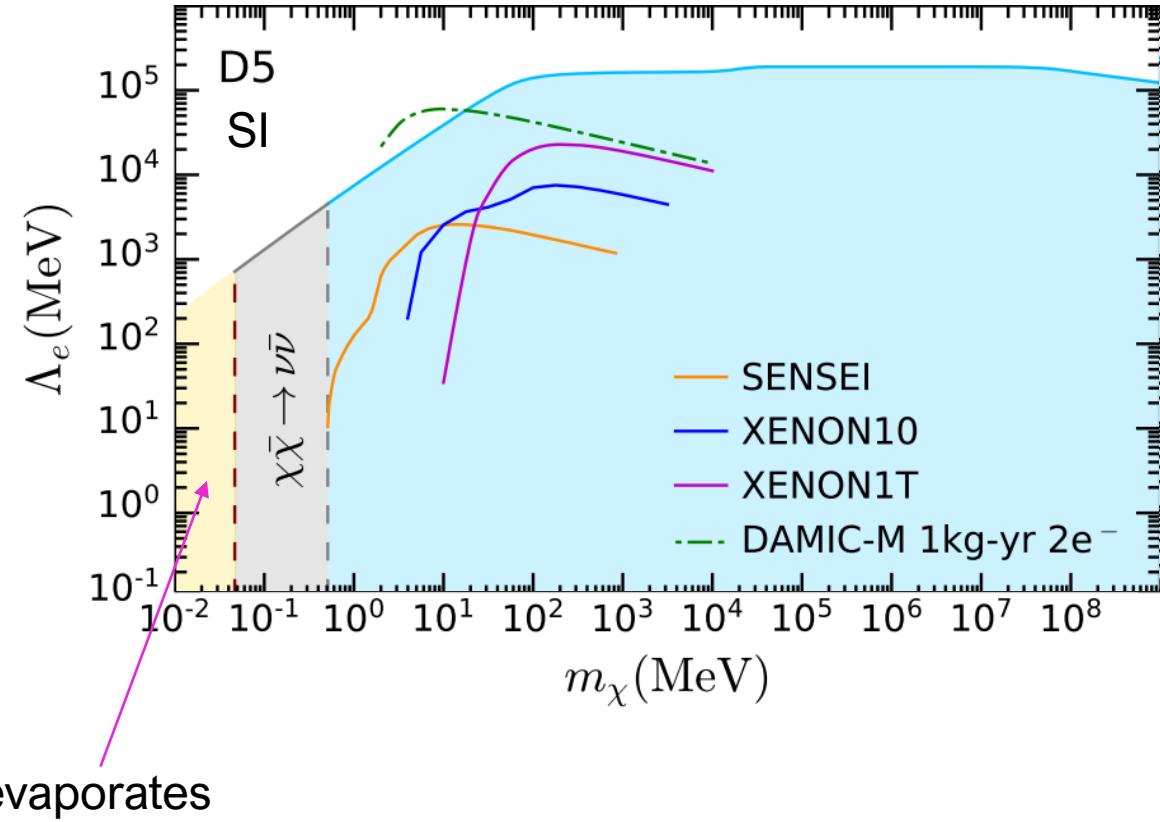
Relies on DM existing in M4

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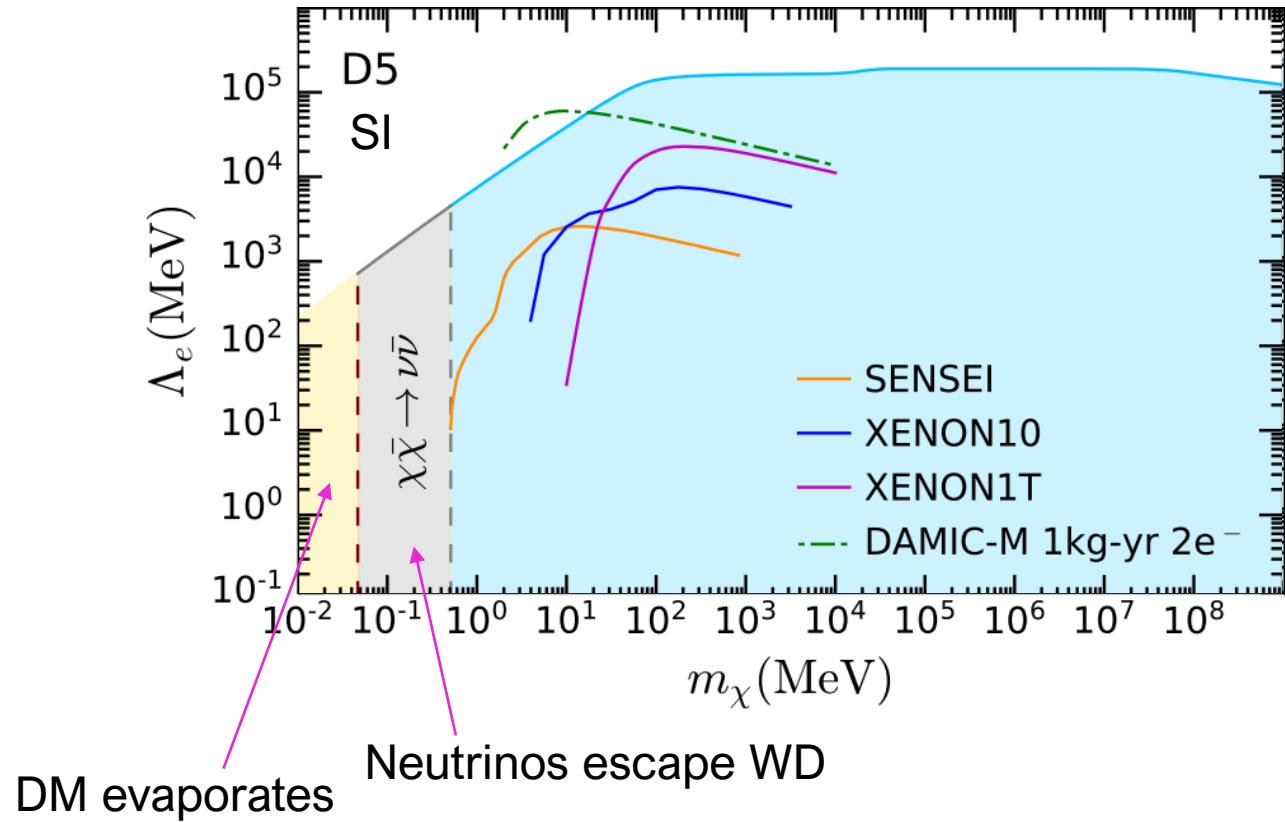
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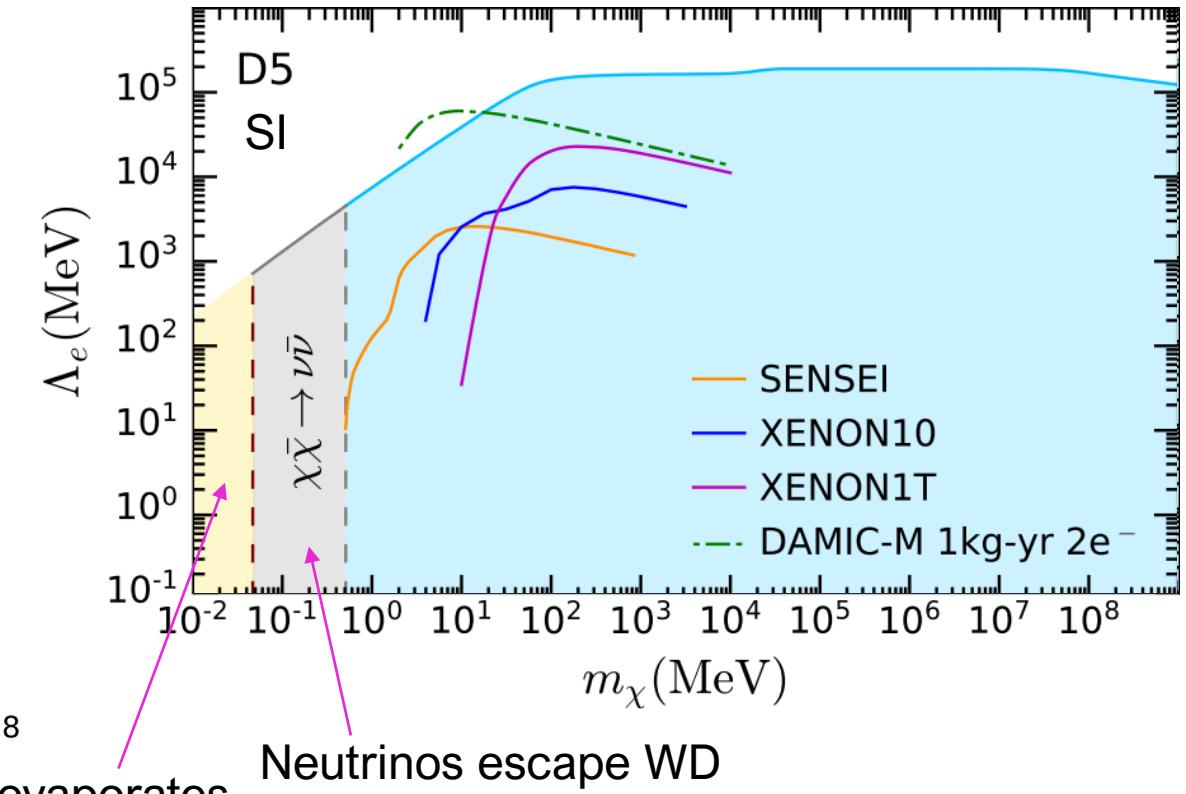
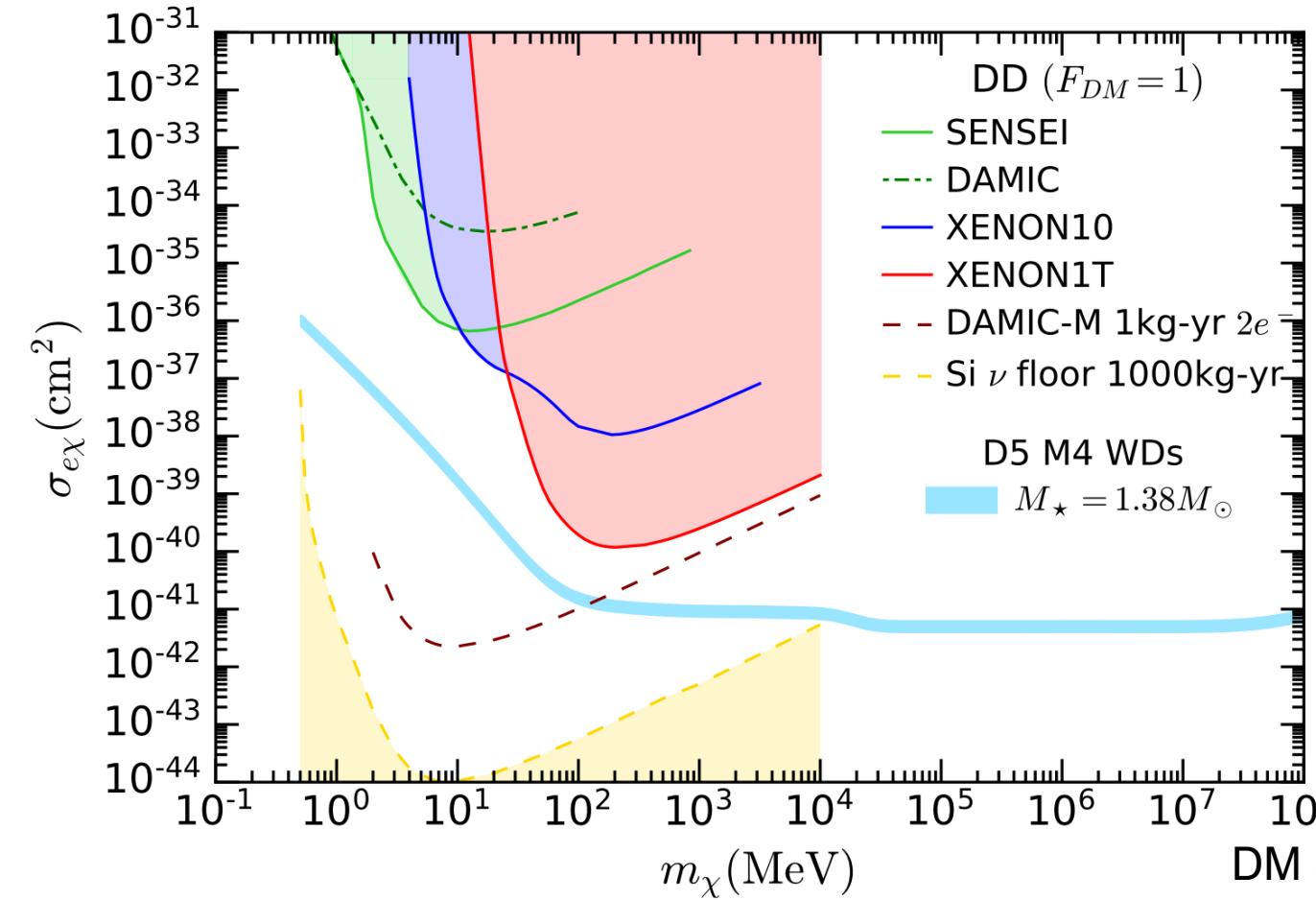


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Thank you

Questions?

# Capture Rate

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- Total capture rate is then

$$C = \frac{4\pi}{v_*} \frac{\rho_\chi}{m_\chi} \text{Erf} \left( \sqrt{\frac{3}{2}} \frac{v_*}{v_d} \right) \int_0^{R_*} dr r^2 \frac{\sqrt{1 - B(r)}}{B(r)} \Omega^-(r)$$

Gravitational Focusing

Interaction Rate:

$$\Omega^-(r) = \int dt dE_e ds \frac{d\sigma}{dcos\theta_{cm}} \frac{E_e}{2\pi^2 m_\chi} \sqrt{\frac{B(r)}{1 - B(r)}} \frac{s}{\beta(s)\gamma(s)} f_{FD}(E_e)(1 - f_{FD}(E'_e))$$

Differential cross section

Relativistic kinematics

Pauli Blocking

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