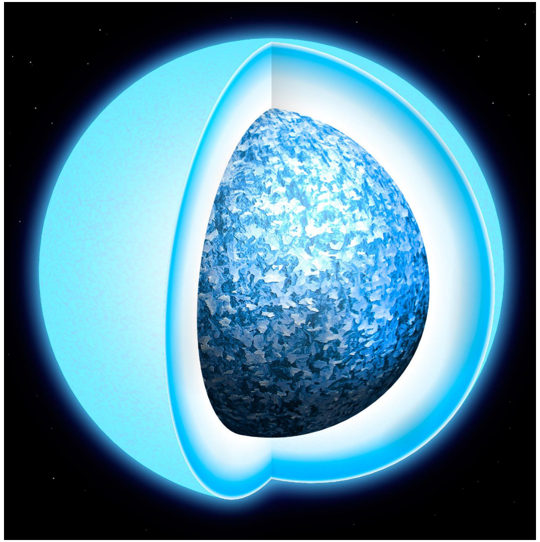
Constraints on DM interactions using WDs

Maura E. Ramirez-Quezada

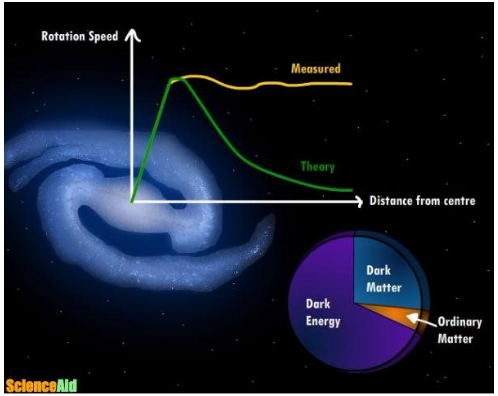
With Nicole Bell, Sandra Robles, Giorgio Busoni and Michael Virgato

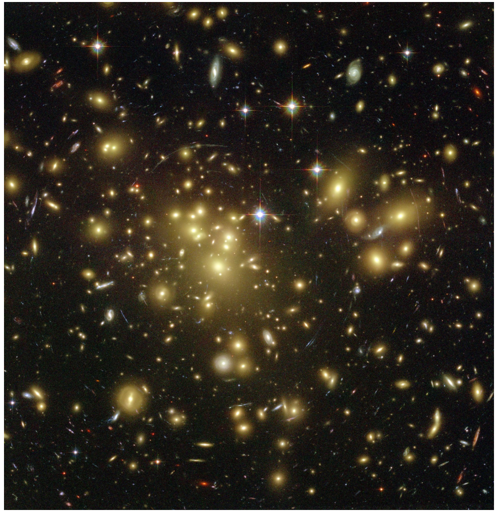
arXiv:2104.14367

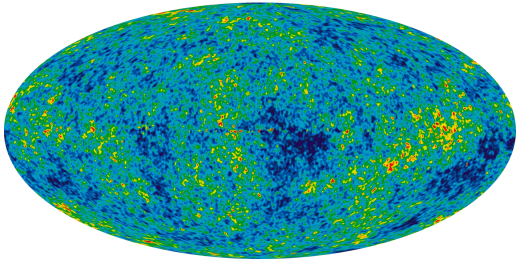
Outline



- Introduction
  - Dark matter capture
- Capture in WDs
  - Capture by scattering on ions
    - Finite temperature effects and DM evaporation
- Results
- Summary


Rotation Speed
Measured
Theory
Distance from centre
Dark Matter
Dark Energy
Ordinary Matter
ScienceAid

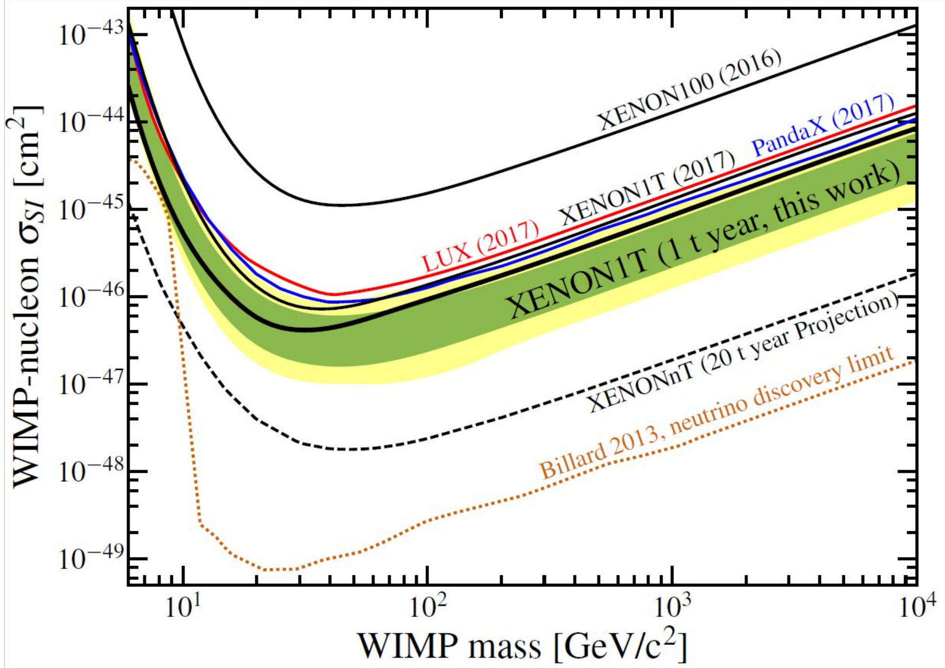




DM direct detection searches

XENON collaboration (PRL) 2018

Limitations



- Background is still a challenging
- sensitivity is limited by their threshold energy and target mass
- Non-relativistic regime of DM interactions

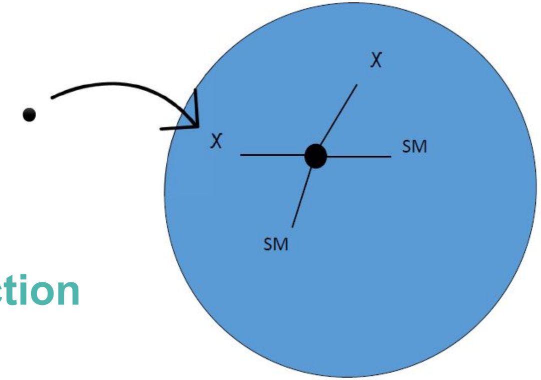
An alternative approach

Capture in compact objects

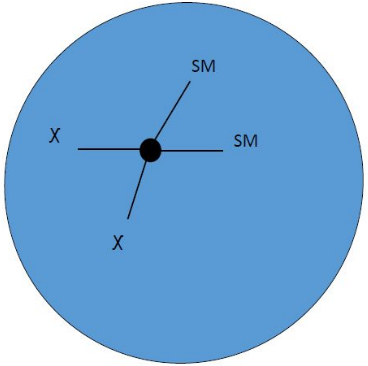
DM can accumulate in the core of these objects in considerable amounts

Complementary to direct detection experiments.

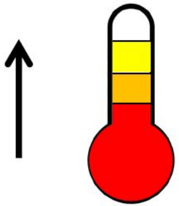
- Velocity (momentum) dependent interactions.
- Sub-Gev regime



1. Capture



2. Annihilation

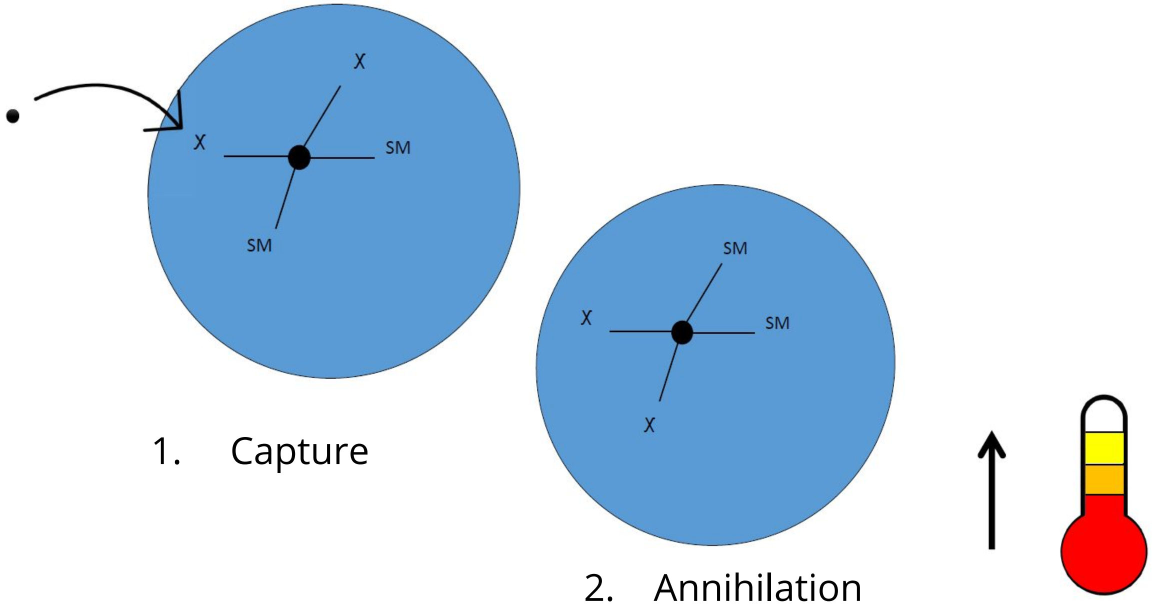


An alternative approach

DM scatters off stellar material

- ➢ If loses enough energy it becomes gravitationally bound to the star

- ➢ Accumulates and annihilates in the centre of the star.



White Dwarfs

Here we are using M4 WDs

$$\rho_\chi = 798\,\mathrm{GeV}/\mathrm{cm}^3$$

arXiv:1001.2737

We assume a **Maxwell Boltzmann** (MB) distribution,

$$f_{MB}(u_\chi)$$

DM capture rate due to scattering on ions: assuming WDs are made of only **one element:** Carbon → **Inner structure**

DM interactions

We calculate bounds on the cutoff scale of the dimension 6 EFT SI operators that describe DM interactions with WD targets: Including the response function of carbon

$$\text{cut off scale} \rightarrow \Lambda_q$$

- ➢ We decompose the EFT operators in the basis of non-relativistic operators (NR)
- ➢ We then use these coefficients, and the nuclear response functions to obtain the DM-ion scattering amplitude

$$\overline{|\mathcal{M}_T|}^2 = \frac{m_T^2}{m_N^2} \sum_{N,N',i,j} C_i^N C_j^{N'} F_{ij}^{NN'}(q_{tr}^2)$$

1501.03729

DM interactions

We calculate bounds on the cutoff scale of the dimension 6 EFT SI operators that describe DM interactions with WD targets: Including the response function of carbon

Name	Operator	Coupling	$M_N^{\rm NR}$
D1	$\bar{\chi}\chi\ \bar{N}N$	ic_N^S/Λ_q^2	$4\frac{ic_N^S}{\Lambda_q^2}m_\chi m_N \mathcal{O}_1^{\rm NR}$
D2	$\bar{\chi}\gamma^5\chi\ \bar{N}N$	ic_N^S/Λ_q^2	$-4\frac{ic_N^S}{\Lambda^2}m_N \mathcal{O}_{11}^{\rm NR}$
D5	$\bar{\chi}\gamma_\mu\chi\ \bar{N}\gamma^\mu N$	c_N^V/Λ_q^2	$4\frac{c_N^V}{\Lambda_q^2}m_\chi m_N \mathcal{O}_1^{\rm NR}$
D6	$\bar{\chi}\gamma_\mu\gamma^5\chi\ \bar{N}\gamma^\mu N$	c_N^V/Λ_q^2	$8\frac{c_N^V}{\Lambda_q^2}(m_\chi m_N \mathcal{O}_8^{\rm NR} + m_\chi \mathcal{O}_9^{\rm NR})$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\ \bar{N}\sigma^{\mu\nu}N$	ic_N^T/Λ_q^2	$8\frac{ic_N^T}{\Lambda_q^2}(m_\chi \mathcal{O}_{11}^{\rm NR} - m_N \mathcal{O}_{10}^{\rm NR} - 4m_\chi m_N \mathcal{O}_{12}^{\rm NR})$

1501.03729

Capture rate

- Assuming that the WD is optically thin to DM scattering , the capture rate is given by

$$C_{opt,thin} = \frac{\rho_\chi}{m_\chi} \int_0^{R_\star} 4\pi r^2 \int_0^\infty du_\chi \frac{f_{MB}(u_\chi)}{u_\chi} w(r)\Omega^-(w)$$

- An absolute upper limit on the capture rate arises when we assume the maximum capture probability: Geometric limit

$$C_{geom} \propto \frac{1}{m_\chi}$$

- We introduce the Star Opacity by including the optical factor in the capture rate computation

$$\eta(\tau_\chi) = e^{\tau_\chi}$$

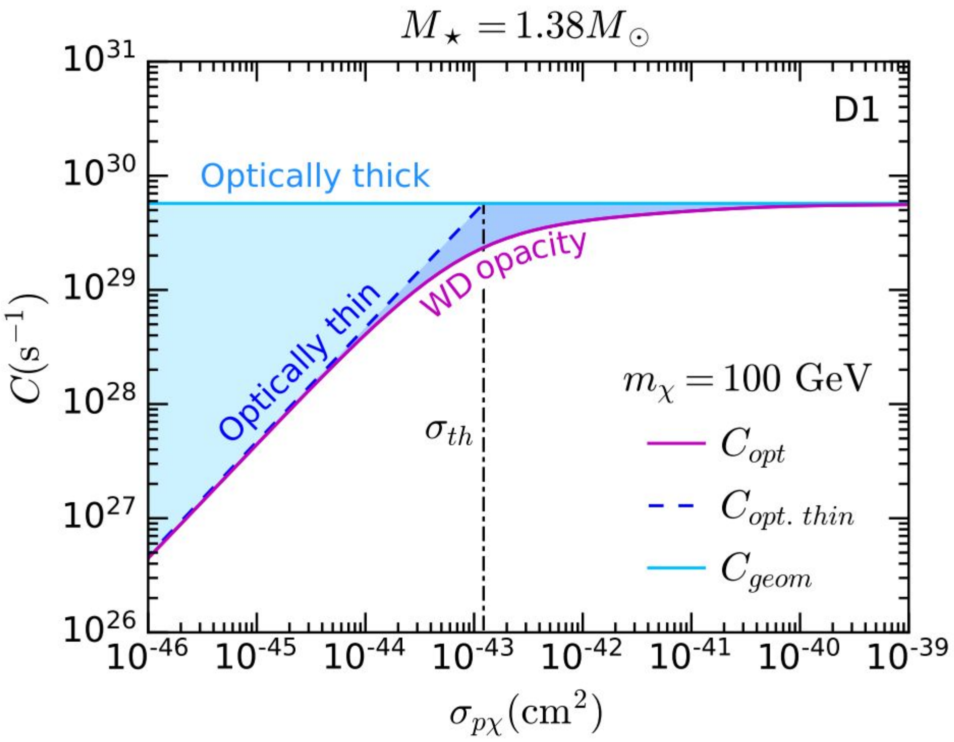
Capture rate

- Geometric limit:

$$\Omega^{-}(w) \rightarrow 1$$

- Optically thin limit:

$$\eta(\tau_\chi) \rightarrow 1$$



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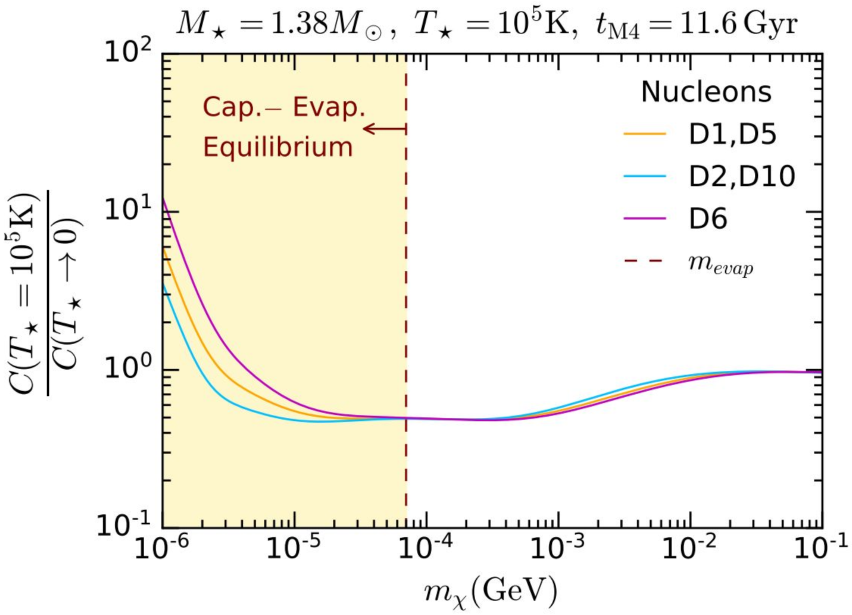
Other considerations: Finite temperature

For WDs in M4 finite temperature effects are expected to be important when

$$v_T > v_d$$



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Other considerations: Evaporation

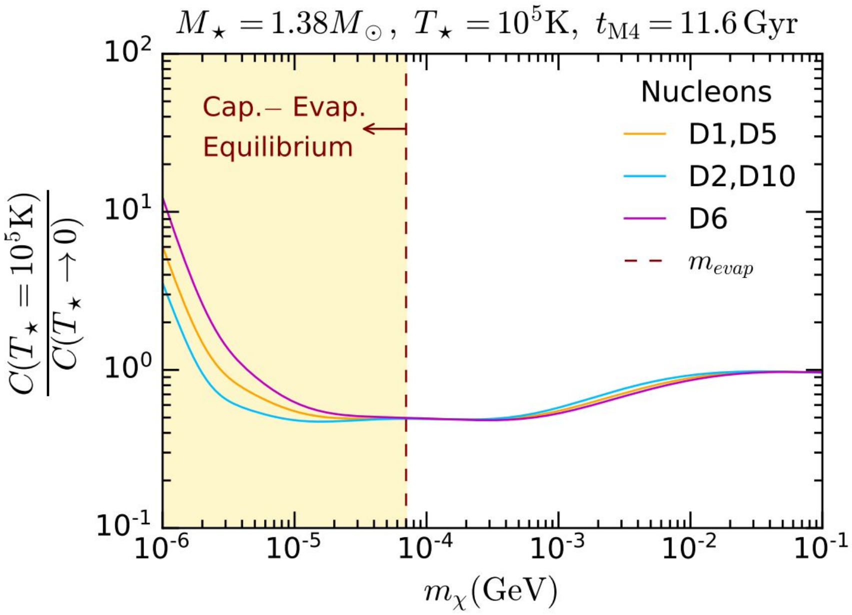
Accreted DM accumulated in the WD core could also escape from the star: this is the so called evaporation

- Final DM velocity greater than the local escape velocity

- we can estimate the evaporation mass m_{evap} as the DM mass for which

$$E(m_\chi)t_\star \sim 1$$

Other considerations: Evaporation



$$m_{evap} \sim 70\mathrm{keV}$$

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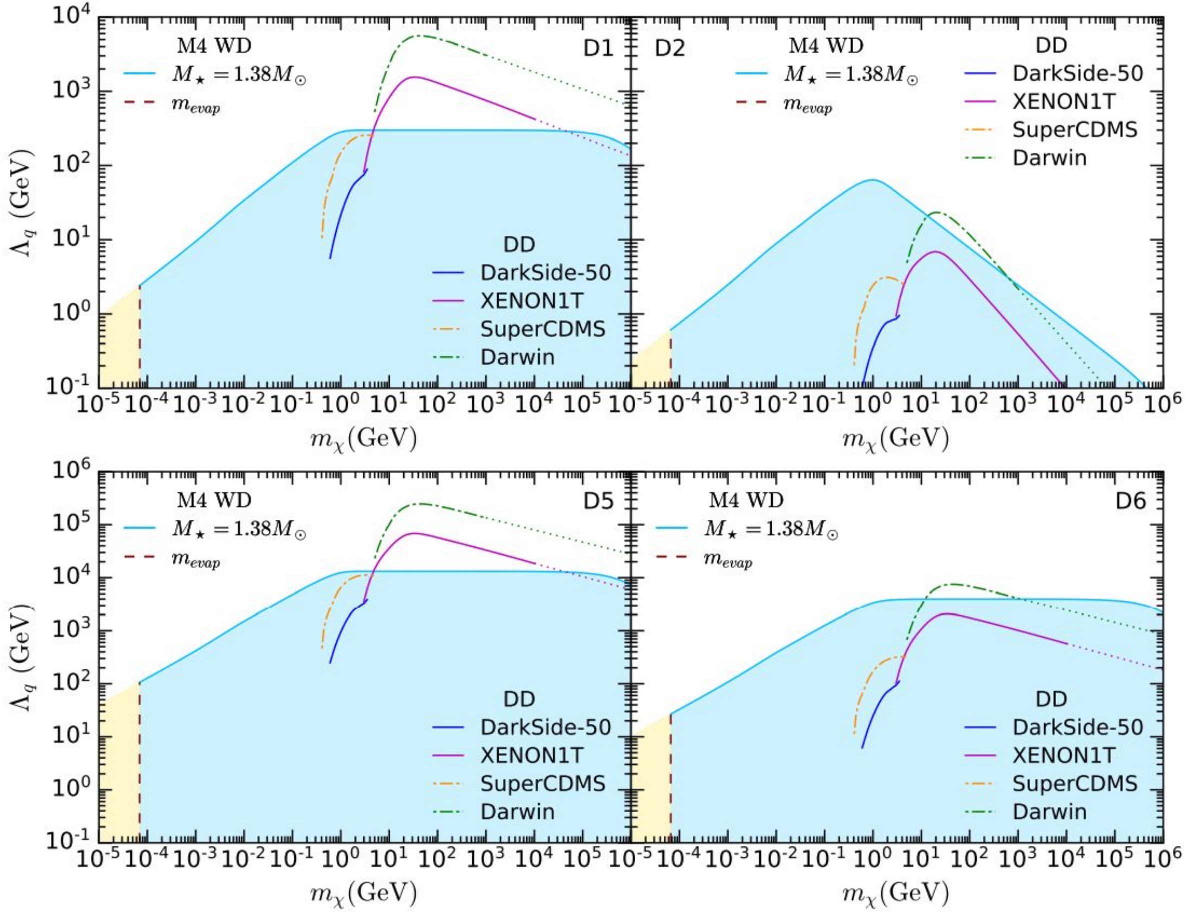

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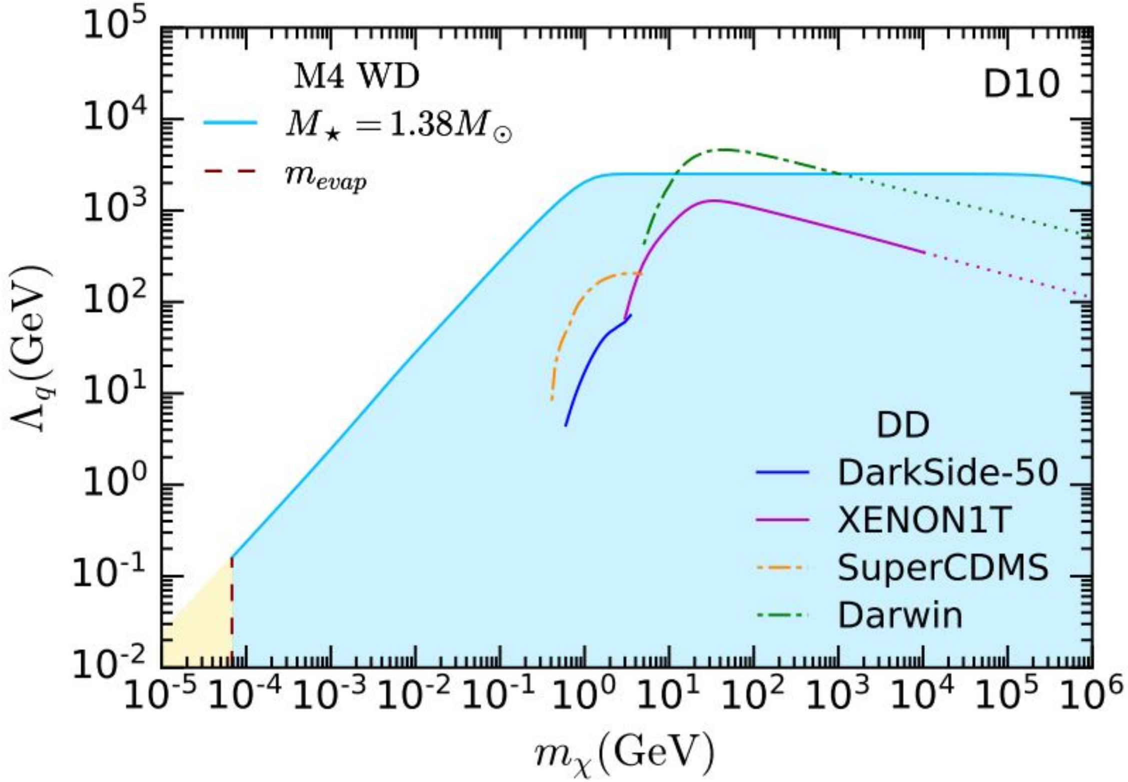
M4 WD
$M_\star = 1.38 M_\odot$
m_{evap}
D10
DD
DarkSide-50
XENON1T
SuperCDMS
Darwin
Λ_q(GeV)
m_χ(GeV)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^0 10^1 10^2 10^3 10^4 10^5 10^6

Summary

- We have discussed DM capture in compact objects as complementary to DD experiments.
- We have introduce M4 WDs to set constraints on DM interactions
- We have discussed the SI dimension 6 EFT operators.
- The capture rate in
    - Optically thin limit
    - Geometric limit
    - Complete treatment (Star opacity)

Summary

- Discussed some other considerations in this calculation:

    - Temperature effects
    - Dark matter evaporation

- Limits on the cut-off scale: WDs improve constraints in the **Sub-GeV** mass region

Thank you