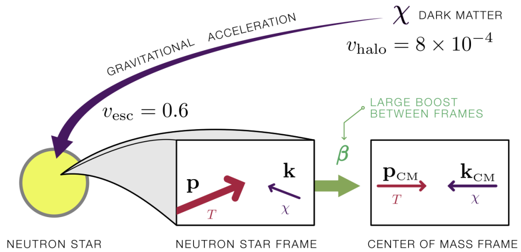
"Electron Capture Dark Matter in Neutron Stars" by Joglekar, Raj, Tanedo, Yu

2004.09539 : full paper
1911.13293 : letter , 1704.01577, 1707.09442 : only p/n

Main idea : neutron star heated by DM falling to it.

→ Observe temperature of NS.



Outline : 1. Neutron Star Model

2. Dark kinetic heating of NS

3. Formula for capture rate

4. Results : Constraints on EFT suppression scale Λ.

1. Neutron Star Model

They assume $M_* = 1.5\, M_\odot$, $R_* = 12.6$ km, $\rho_{DM} = 0.42$ GeV/cm^3.

# of target particle : $\langle n_T \rangle = Y_T \cdot \frac{M_*}{m_n} \Big/ \frac{4\pi}{3} R_*^3$.

Component	Y_T	$\langle n_T \rangle$ [cm^{-3}]	p_F [MeV]	E_F [MeV]
e^-	0.06	1.27×10^{37}	146	146
μ^-	0.02	4.23×10^{36}	50	118
p^+	0.07	1.48×10^{37}	160	951
n	0.93	1.97×10^{38}	373	1011

Fermi momentum   Fermi energy

→ electrons are relativistic $m_e \ll E_F$

⇝ special care is required : main pt of this paper.

2. Dark kinetic heating of NS.

(i) DM is accelerated while falling to NS.

Velocity @ NS surface v_{esc} :

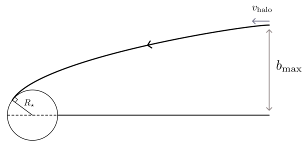
$$E_\chi = \gamma_{esc} m_\chi \simeq m_\chi + \frac{2GM_* m_\chi}{R_*}$$

(maybe $(M_* = M_\odot$?))

$\rightarrow$ $\gamma_{esc} = 1.24$, $v_{esc} = 0.6$: relativistic.

(ii) Maximum impact parameter

$$b_{max} = R_* \cdot \frac{v_{esc}}{v_{halo}} \cdot \gamma_{esc}$$



$\rightarrow$ DM mass that pass through NS during time Δt.

$$\Delta M_\chi = \pi \cdot b_{max}^2 \cdot \rho_\chi \cdot v_{esc} \cdot \Delta t .$$

$\rightarrow$ Dark kinetic heating rate : $\Delta K_{NS} = \underbrace{(\gamma_{esc} - 1) \cdot \Delta M_\chi}_{\text{kin. energy of DM}} \times f$.

f : DM capture rate. main subject of this paper.

$\Rightarrow$ NS temp @ equilibrium : $4\pi R_*^2 \cdot \sigma T^4 = \frac{\Delta K_{NS}}{\Delta t}$. or $T \sim 1600 f^{1/4} \cdot K$

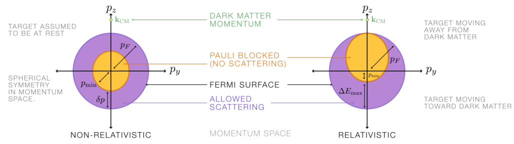
σT^4 : black body radiation.

$\rightarrow$ Target : Cool = old NS. $\gtrsim 10$ Myr.

3. Capture Rate

- Condition of capture : total energy transfer $\Delta E_{tot} > E_{halo} \simeq \frac{m_\chi}{2} \cdot v_{halo}^2$

$\longrightarrow$ namely $f \sim \min\left[1,\ \sigma_\chi \cdot v_{esc} \cdot n_T \cdot \Delta t \,\Big|_{\Delta E_{tot} > E_{halo}}\right]$, $\Delta t \sim \frac{R_*}{v_{esc}}$



3 additional complications

(1) motion of target particle (relevant for electron)
(2) Pauli exclusion principle
(3) capture after multiple scattering.

$[d\sigma \cdot v_{rel}]_{NS} = d\sigma_{cm} \cdot v_{Møl}$

$\longrightarrow$ full formula :
$$f = \underbrace{\sum_{N_{hit}}}_{(3)} \frac{\langle n_T \rangle \Delta t}{N_{hit}} \underbrace{\int d\Omega_F \int_0^{p_F} \frac{p^2 dp}{V_F}}_{(1)} \int d\Omega_{CM} \frac{d\sigma_{CM}}{d\Omega_{CM}} \underbrace{v_{Møl}}_{(1)} \Theta^3(\Delta E)$$

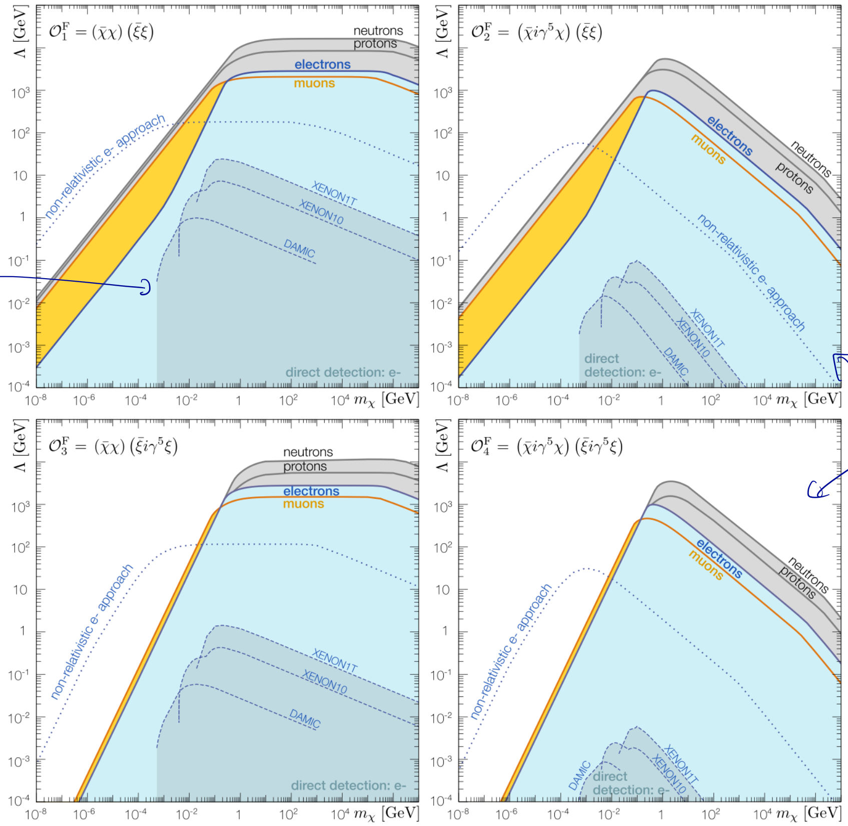
$$\Theta^3(\Delta E) \equiv \underbrace{\Theta\left(\Delta E - \frac{E_{halo}}{N_{hit}}\right) \Theta\left(\frac{\Delta E_{halo}}{N_{hit}-1} - \Delta E\right)}_{(3)} \underbrace{\Theta\left(\Delta E + E_p - E_F\right)}_{(2)} .$$

- Pauli exclusion : important for $m_\chi \lesssim 1\,\mathrm{GeV}$ ($\Leftarrow E_\chi = (\gamma_{esc} - 1) m_\chi \lesssim E_F$.)
- multiple scatt. : important for $m_\chi \gtrsim \max[m_T, p_T] / v_{halo}^2$ ($\Leftarrow$ scattering kinematics)

※ can be divided into smaller regimes $\longrightarrow$ see the paper.

4. Results : Scalar MI

DD only w/ electron.



no velocity suppression.

※ Shaded region : $f = 1$ → Assuming old NS w/ $T \sim 1600K$ observed.

4 Results: Vector Int.