Investigating Dark Matter models with Neutron Stars

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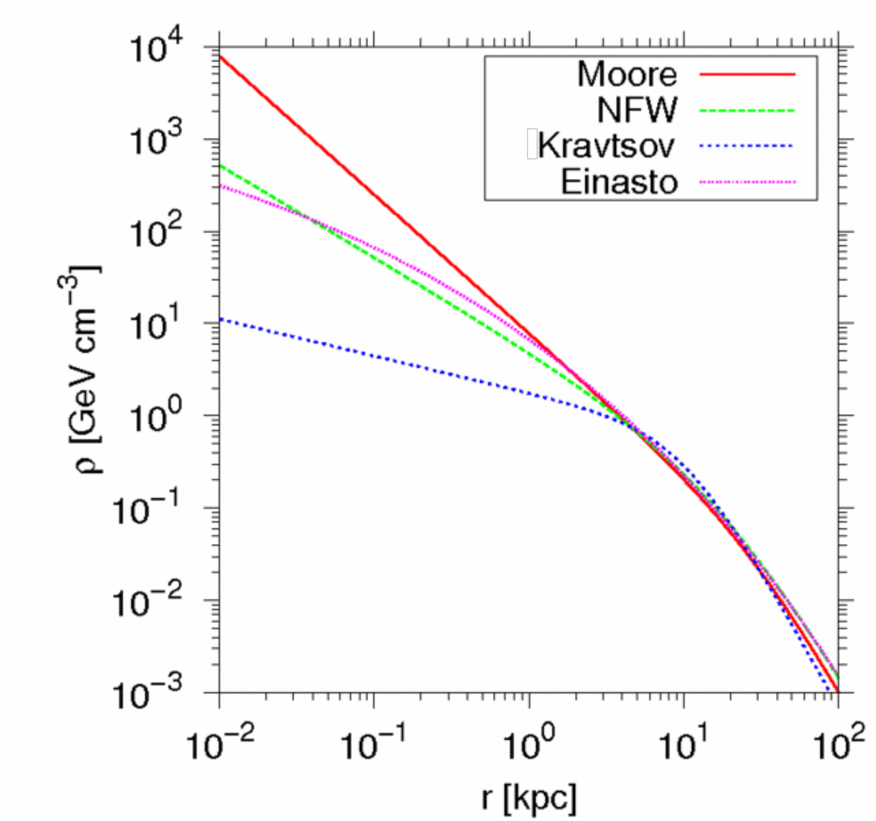
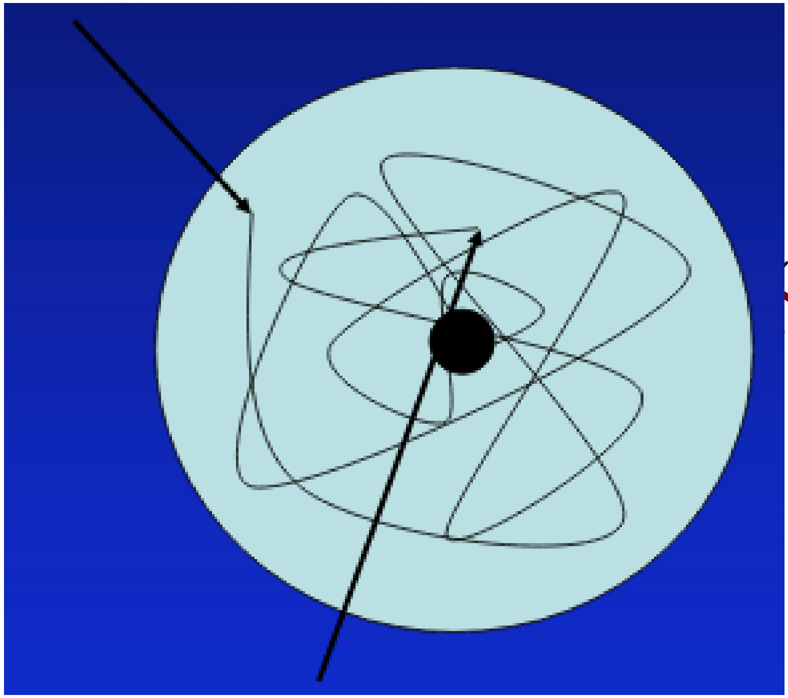
NSs and accretion of dark matter





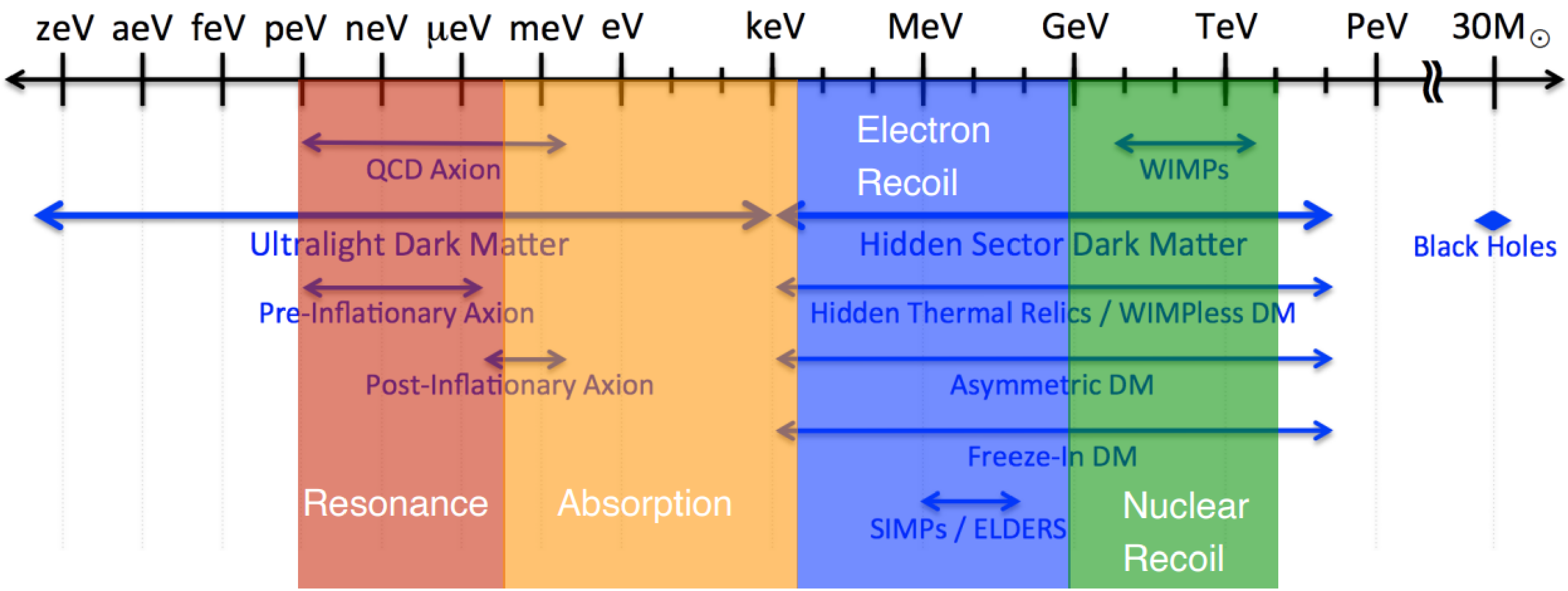
In dense stellar environments DM-nucleon i.e DM-n and also DM-e cross section regulates the DM capture.

$$\sigma_{\chi N} > \frac{m_N R^2}{M} \sim 10^{-45}\,\mathrm{cm}^2$$

$$R/\lambda_\chi \simeq 8.5 \left(\frac{R}{10\,\mathrm{km}}\right)\left(\frac{\sigma_{\chi n}}{10^{-44}\,\mathrm{cm}^2}\right)\left(\frac{\rho_n}{5\rho_0}\right)$$

A. Gould, ApJ 321 (1987)
also Fairbain Kouvaris, Tinyakov,PG..and many more.

Panorama of DM searches



Current Experiments — ADMX — SuperCDMS, DAMIC, SENSEI, … — LZ, Darkside, …

Future Experiments (DM New Horizons) — ADMX+, DM Radio, … — OSCURA

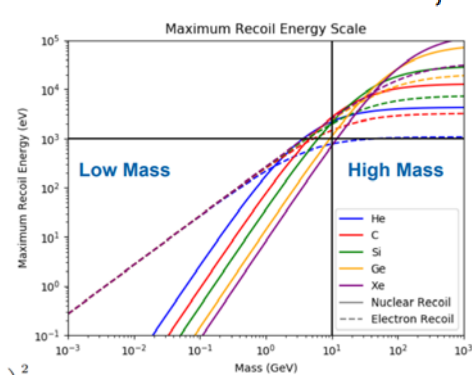
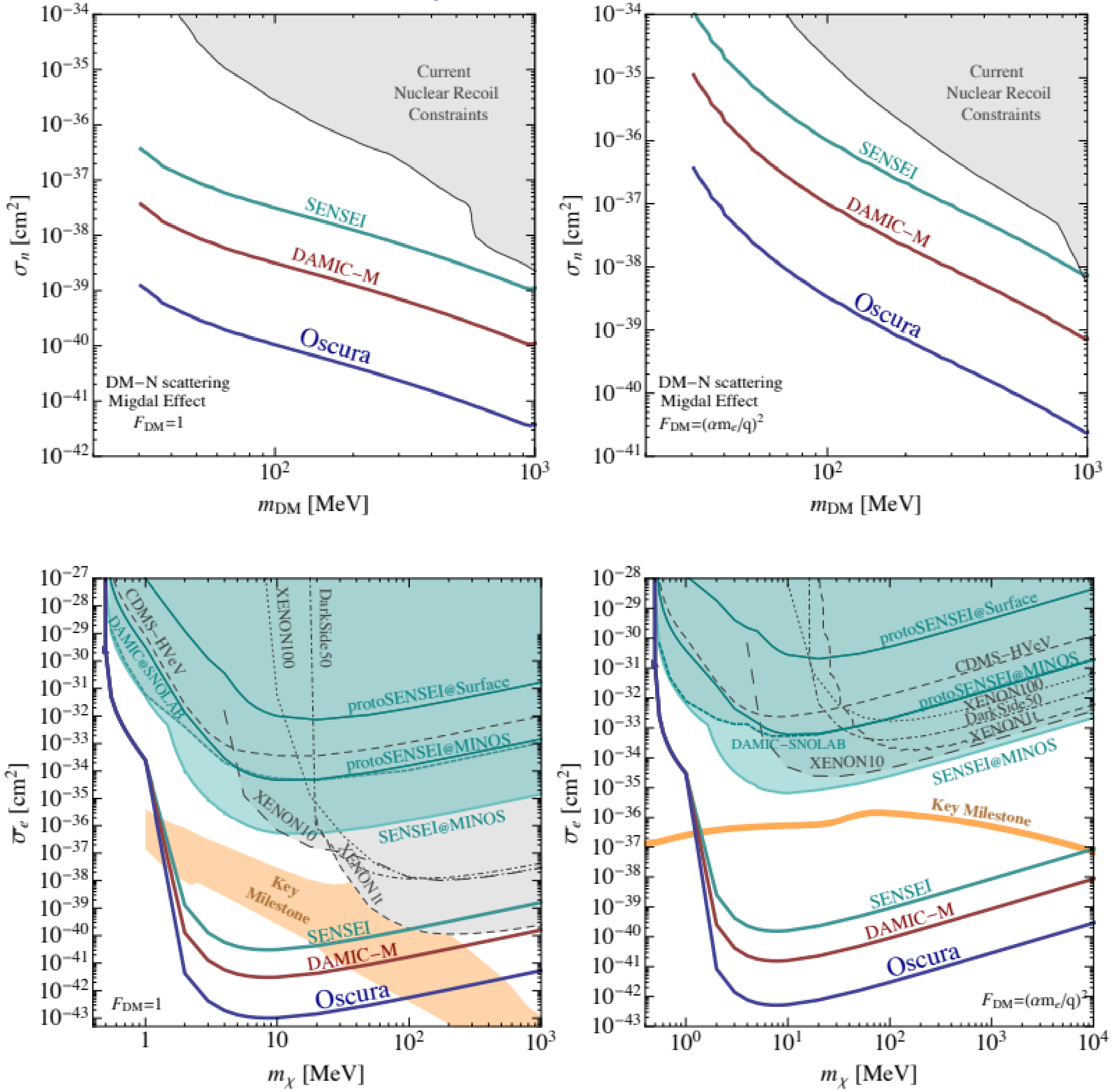


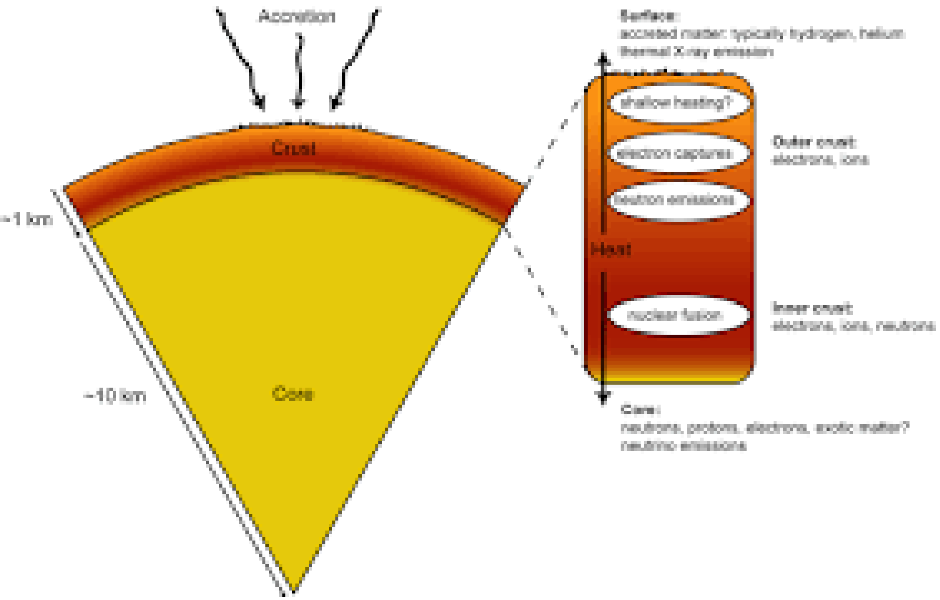
Fig. courtesy SLAC

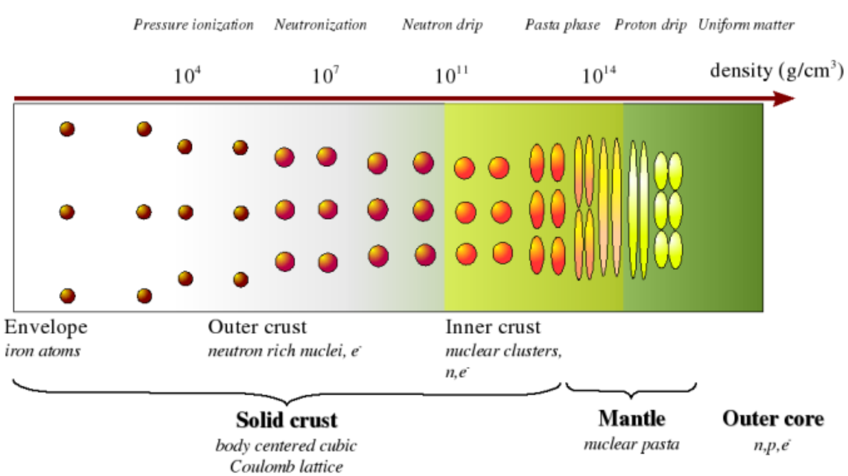
Light DM and projected constraints: n & e



Oscura collab, arXiv:2202.10518v2

Dark matter accretion in NS





- Layered structure: inhomogeneous crust (crystal and pasta phases) +fluid core.

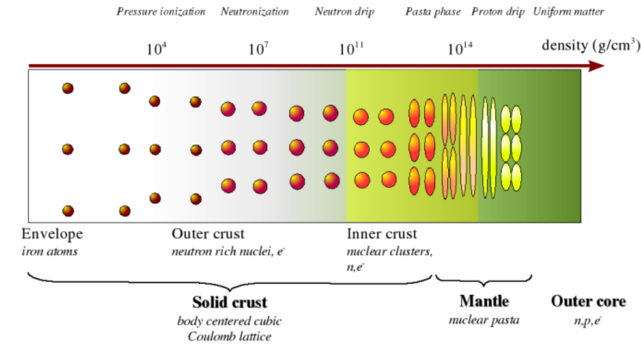
- High compactness:

$$\frac{GM}{Rc^2} \quad \mathrm{sun} : 10^{-6}\, \mathrm{NS} : 10^{-1}$$

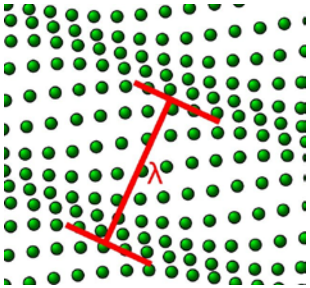
- Capture of DM proceeds: incoming flux

$$F_\chi = \frac{C_\chi}{4\pi R^2} \sim 10^{14} \left(\frac{1\,\mathrm{GeV}}{m_\chi}\right) \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Layer 1: DM Scattering in the NS crust:phonons



$$\mathcal{L}_{\mathcal{I}} = \sum_{N=n,p} g_{s,N} \chi \overline{\chi} N \overline{N} + g_{v,N} \chi \gamma^{\mu} \overline{\chi} N \gamma_{\mu} \overline{N},$$



Cermeño, PG & Silk, PHYSICAL REVIEW D 94, 023509 (2016),
PHYSICAL REVIEW D 94, 063001 (2016)

- Large boost factor $v \approx v_{\infty} + \sqrt{2GM/Rc^2} \sim 0.7c$

- Coupling strengths $g_{v,N}/M_{\phi}^2 \sim 1/{\Lambda_v}^2 \quad g_{s,N}/M_{\phi}^2 \sim m_q/{\Lambda_s}^3$

$$\Lambda_v > 1\,\mathrm{TeV} \quad \Lambda_s > 100\,\mathrm{GeV}.$$

- Interaction rate to produce quantum vibrations in the nuclei network (phonons) given by Fermi Golden rule

$$R_{\vec{k},\lambda} = 2\pi\delta(E_f - E_i)|\langle f|\mathcal{V}|i\rangle|^2$$

Modelling the lattice and DM scattering

DM feels nuclear potential at lattice sites

$$\mathcal{V}(\vec{r}) = \sum_j \delta^3(\vec{r} - \vec{r_j})\, v_0$$

Finite potential allows Born approximation for scattering amplitude

$$f(\vec{p_\chi}, \vec{p_\chi'}) \simeq -\frac{m_\chi}{2\pi} \int e^{i(\vec{p_\chi} - \vec{p_\chi'})\vec{r'}} \mathcal{V}(\vec{r'}) d^3\vec{r'},$$

Obtaining a coherent response

$$\int_{-1}^{1} 2\pi d(\cos\theta_\chi) |\overline{\mathcal{M}}_{\chi\mathcal{A}}|^2 \simeq m_A^2 \left(\frac{Z}{m_p} \sqrt{|\tilde{\mathcal{M}}_p|^2} + \frac{(A-Z)}{m_n} \sqrt{|\tilde{\mathcal{M}}_n|^2} \right)^2$$

and an integrated cross section

$$\sigma_{A,\chi} = 4\pi a^2 = m_A^2 \frac{\left(\frac{Z}{m_p} \sqrt{|\tilde{\mathcal{M}}_p|^2} + \frac{(A-Z)}{m_n} \sqrt{|\tilde{\mathcal{M}}_n|^2} \right)^2}{16\pi (m_\chi + m_A)^2}$$

recovering the low E limit $\sigma_{A,\chi} \to \frac{\mu_{\chi A}^2}{\pi} (Z g_{s,p} + (A-Z) g_{s,n})^2$

Single phonon excitation rate

The single phonon excitation rate
from ground state

$$R_k^{(0)} = \frac{n_\chi n_A^2 V}{4(2\pi)^3 m_\chi^3 m_A c_l} \frac{|\gamma_{NS} m_\chi - |\vec{k}| c_l|}{\sqrt{\gamma_{NS}^2 - 1}} a^2.$$

Where the boost factor is peaked around $E_\chi = \gamma_{NS} m_\chi$

And the phonon dispersion relation is linear $\omega_{k,\lambda} = c_{l,\lambda} |\vec{k}|$

with $c_l = \frac{\omega_p/3}{(6\pi^2 n_A)^{1/3}} \sim 10^{-3} c$ the sound velocity

Results: LDM scattering vs neutrinos

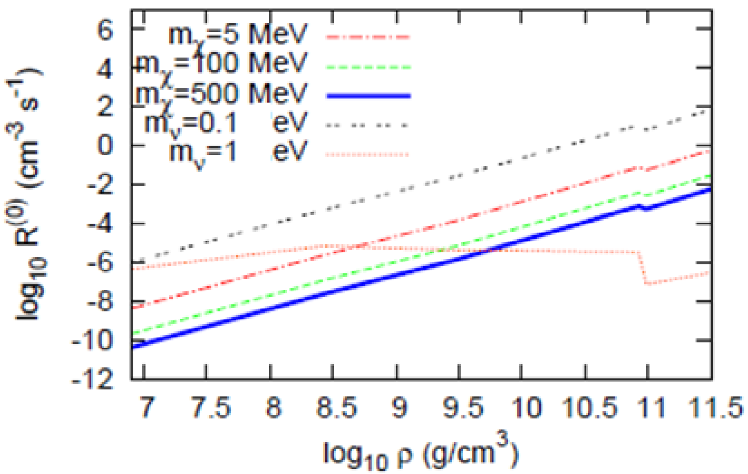


FIG. 1. Single phonon excitation rate per unit volume as a function of density in the outer crust. DM particle masses $m_\chi = 500, 100$ and 5 MeV are used and $n_\chi/n_{0,\chi} = 10$. Neutrino contribution at $|\vec{k}| \to 0$, $R_{\nu 0}$, is also shown for $m_\nu = 0.1, 1$ eV. See text for details.

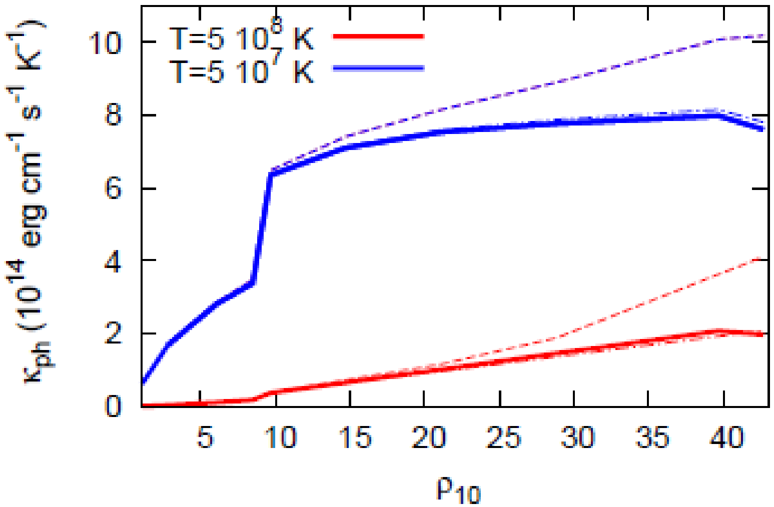
$$m_\nu = 0.1\, eV \to R^0_\nu(|\vec{k}|) = R_{\nu 0} e^{\left(\frac{-1754|\vec{k}|}{1\text{ eV}}\right)}$$

$$m_\nu = 1\, eV \to R^0_\nu(|\vec{k}|) = R_{\nu 0} e^{-\left(\frac{2561.3|\vec{k}|}{1\text{ eV}}\right)}$$

Light DM more efficient than eV cosmological neutrinos in phonon excitation

Cermeño, PG & Silk, PHYSICAL REVIEW D 94, 063001 (2016)

Astrophysical consequences: thermal conductivity



$$\kappa_{ph} \equiv \kappa_{ii} = \frac{1}{3} k_B C_A n_A c_l L_{ph}$$

$$C_A = 9 \left(\frac{T}{T_D}\right)^3 \int_0^{T_D/T} \frac{x^4 e^x dx}{(e^x - 1)^2}$$

$$L_{ph}^{-1} \sim N_{k\lambda} \simeq N_{0,k\lambda} + R_k^{(0)} (1 - N_{0,k\lambda} e^{(\omega_{k,\lambda} + \vec{k}.\vec{v})/K_\chi}) \delta V \delta t$$

$$N_{0,k\lambda} = (e^{\omega_{k\lambda}/k_B T} - 1)^{-1}$$

FIG. 2. Phonon thermal conductivity as a function of density (in units of 10^{10} g/cm^3) for temperatures $T = 5\,10^7$ K (blue), $5\,10^8$ K (red) and $m_\chi = 100$ MeV. Dash-dotted and dashed lines depict the impact of a LDM density $n_\chi/n_{0\chi} = 10, 100$. Solid lines are the standard thermal result with no DM for each case. See text for details.

Cermeño, PG & Silk, PHYSICAL REVIEW D 94, 063001 (2016)

Light DM enhances thermal conductivity up to 100% in the few kpc galactic central regions

Thermal conductivity: LDM vs electrons

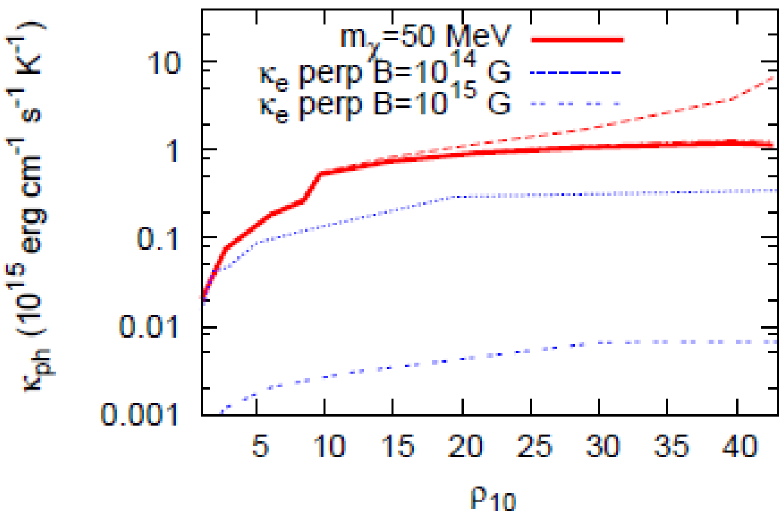


FIG. 3. Phonon thermal conductivity as a function of density (in units of 10^{10} g/cm^3) at $T = 10^8$ K and $m_\chi = 50$ MeV. Solid, dot-dashed and dashed lines correspond to cases with no DM, $n_\chi/n_{0,\chi} = 10, 100$. Perpendicular electron thermal conductivity is also shown for $B = 10^{14}, 10^{15}$ G.

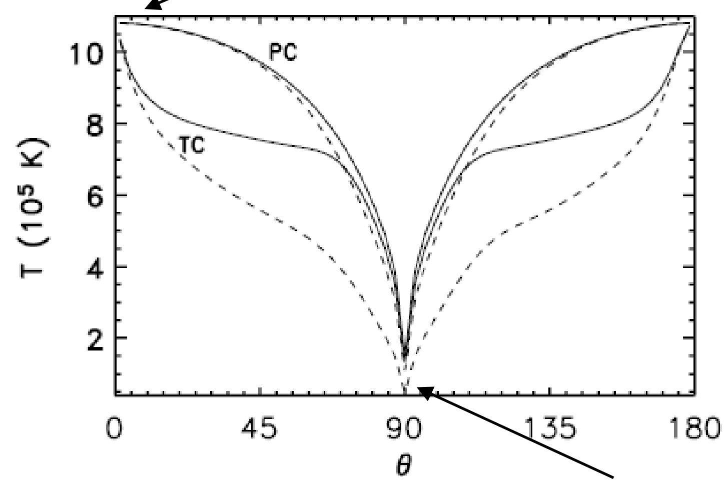
$$\kappa = \kappa_e + \kappa_{ph}$$

$$k_{e\|} \sim 10^{17} - 10^{19}\,\mathrm{erg\,cm^{-1}\,s^{-1}\,K^{-1}}$$

Light DM enhancement above thermal and electron contributions perpendicular to a B field

pole

J. F. Pérez-Azorín, A&A 451 (2006) 1009



equator

Expected surface T anisotropy smoothed by DM enhancement

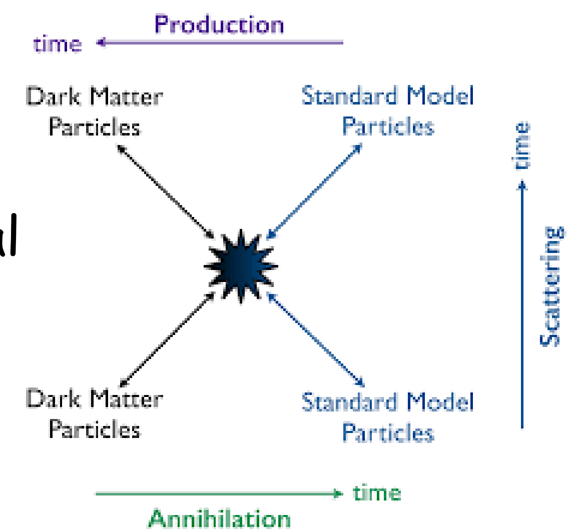
Layer 2: DM scattering and trapping in the NS core

Inside the Neutron stars DM can thermalize during its lifetime provided its strong (SIMP) or weakly interacting nature (WIMP) and mass > few MeV.

For constant density NS a Gaussian distribution can be obtained with a thermal radius defined as

$$n_\chi(r) = n_{0,\chi} e^{(r/r_{th})^2}$$

$$r_{th}(t) = \left(\frac{3 k_B T_c(t)}{2\pi G \rho_c(t) m_\chi} \right)^{1/2},$$



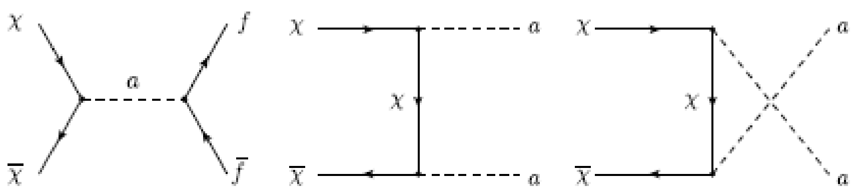
-Fermion/Boson DM can lead to gravitational collapse

-Self-annihilating DM may lead to indirect SM probes (photons, neutrinos)

Secluded models: Neutrino production from Coy DM

$$\mathcal{L}_\mathcal{I} = -i\frac{g_\chi}{\sqrt{2}}a\bar{\chi}\gamma_5\chi - ig_0\frac{g_f}{\sqrt{2}}a\bar{f}\gamma_5 f\,;$$

C. Boehm et al, JCAP 1405 (2014) 009



Cermeño,Perez-Garcia, Lineros, ApJ 863:157 (2018)

$$m_\chi < m_{Higgs}; m_a < m_\chi$$

Model	m_χ [GeV]	m_a [GeV]	g_χ	g_0
A	0.1	0.05	7.5×10^{-3}	7.5×10^{-3}
B	1	0.05	1.2×10^{-1}	2×10^{-3}
C	30	1	6×10^{-1}	5×10^{-5}

Table 1: Parameters used Coy DM. Flavour-universal $g_f = 1$.

- We consider Coy DM in a stellar astrophysical scenario.
- SD momentum dependent and SI one-loop
- Annihilation reactions to pair of fermions (neutrinos)

$$XX \to \nu\bar{\nu}$$
$$XX \to aa, a \to \nu\bar{\nu}$$

- Flavour-universal couplings, DD and relic density constr.

Standard processes with neutrinos

D. Page et al, NPA (2004) 777

Table 11.1 Examples of neutrino emitting processes in neutron star cores[a]

Name	Process	Emissivity[b] (erg cm^{-3} s^{-1})	
Modified Urca (neutron branch)	$n+n \to n+p+e^- + \bar{\nu}_e$ $n+p+e^- \to n+n+\nu_e$	$\sim 2\times 10^{21}\, \mathcal{R}\, T_9^8$	Slow
Modified Urca (proton branch)	$p+n \to p+p+e^- + \bar{\nu}_e$ $p+p+e^- \to p+n+\nu_e$	$\sim 10^{21}\, \mathcal{R}\, T_9^8$	Slow
Bremsstrahlung	$n+n \to n+n+\nu\bar{\nu}$ $n+p \to n+p+\nu\bar{\nu}$ $p+p \to p+p+\nu\bar{\nu}$	$\sim 10^{19}\, \mathcal{R}\, T_9^8$	Slow
Cooper pair formations	$n+n \to [nn]+\nu\bar{\nu}$ $p+p \to [pp]+\nu\bar{\nu}$	$\sim 5\times 10^{21}\, \mathcal{R}\, T_9^7$ $\sim 5\times 10^{19}\, \mathcal{R}\, T_9^7$	
Direct Urca	$n \to p+e^- + \bar{\nu}_e$ $p+e^- \to n+\nu_e$	$\sim 10^{27}\, \mathcal{R}\, T_9^6$	Fast
π^- condensate	$n+ <\pi^-> \to n+e^- + \bar{\nu}_e$	$\sim 10^{26}\, \mathcal{R}\, T_9^6$	Fast
K^- condensate	$n+ <K^-> \to n+e^- + \bar{\nu}_e$	$\sim 10^{25}\, \mathcal{R}\, T_9^6$	Fast

[a] Table from [54].
[b] For each process the "control coefficient" $\mathcal{R} = \mathcal{R}(T/T_c)$ is introduced to take into account the extra temperature dependence due to pairing [92].

Neutrino emissivity from DM

The energy emissivity (energy per unit volume unit time)

$$12 \to 34 \qquad Q_E = 4 \int d\Phi (E_1 + E_2)\, |\overline{\mathcal{M}}|^2\, f(f_1, f_2, f_3, f_4)$$

Phase space element

$$d\Phi = \frac{d^3p_1}{2(2\pi)^3 E_1} \frac{d^3p_2}{2(2\pi)^3 E_2} \frac{d^3p_3}{2(2\pi)^3 E_3} \frac{d^3p_4}{2(2\pi)^3 E_4} (2\pi)^4 \delta^4 (p_1 + p_2 - p_3 - p_4)$$

The matrix element

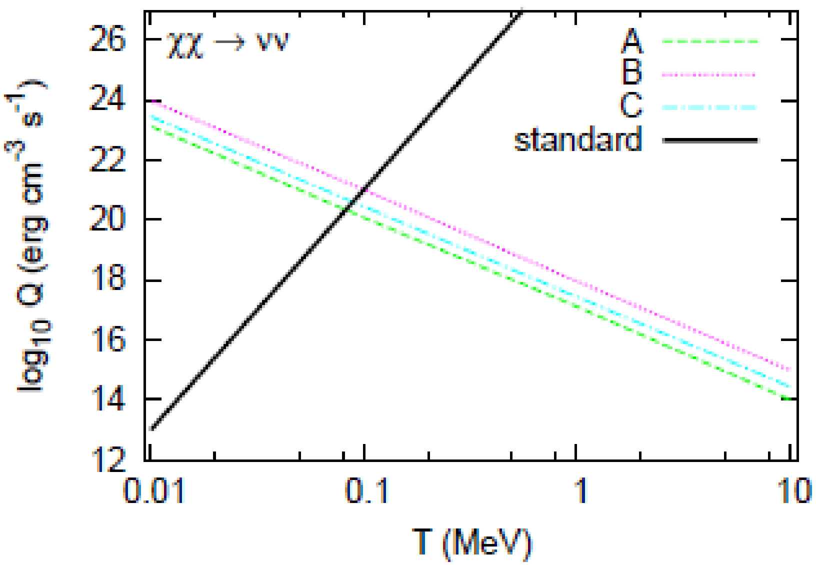
$$XX \to \nu\overline{\nu}$$

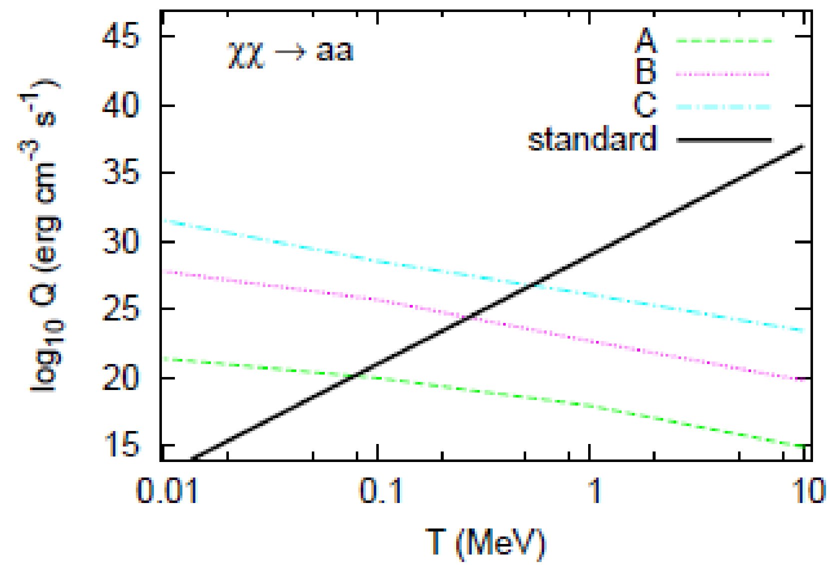
$$|\overline{\mathcal{M}}_{f\bar{f}}|^2 = \frac{g_\chi^2 g_f^2}{4} \frac{s^2}{(s - m_a^2)^2 + E_{\vec{q}}^2 \Gamma^2},$$

$$XX \to aa$$

$$|\overline{\mathcal{M}}_{aa}|^2 = \frac{-g_\chi^4}{2} \left[\frac{(t - m_a)^2 - m_\chi^2 (m_\chi^2 + 2m_a^2)}{(t - m_\chi^2)^2} + \frac{(u - m_a)^2 - m_\chi^2 (m_\chi^2 + 2m_a^2)}{(u - m_\chi^2)^2} + \frac{(s - 2m_\chi^2)(2m_a^2 - s) + 2m_\chi^2 (m_\chi^2 + 2m_a^2 - 2s)}{(t - m_\chi^2)(u - m_\chi^2)} - \frac{2(t - m_a^2)^2}{(t - m_\chi^2)(u - m_\chi^2)} + 2 \frac{2m_\chi^2 - s}{(u - m_\chi^2)} \right], \qquad (5)$$

Cermeño,Perez-Garcia, Lineros, ApJ 863:157 (2018)





The radial fraction where most energy deposition takes place is described by the thermal-to-core radius ratio

$$\xi = (\sqrt{2} r_{\rm th}/R_b)$$

T=1 MeV $\xi \in [0.03, 0.42]$

T=0.1 MeV $\xi \in [0.01, 0.14]$

Neutrino emissivities from Coy DM have genuinely different T behavior than MURCA+ SM processes

Cermeño,Perez-Garcia, Lineros, ApJ 863:157 (2018)

Cooling behaviour in the NS for a LDM case

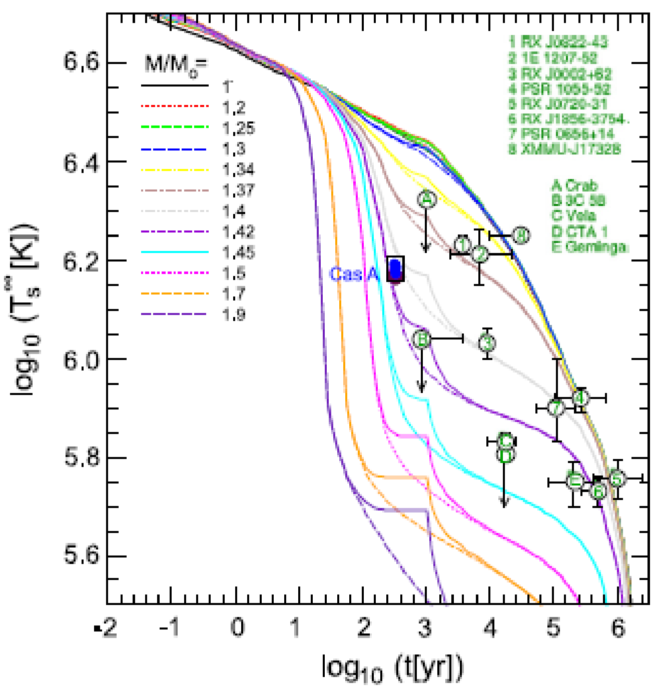
When considering the previous model in cooling calculations (SF and hadronic model)

$$\frac{e^{-\lambda-2\Phi}}{4\pi r^2}\frac{\partial}{\partial r}\left(e^{2\Phi}L\right) = -Q + Q_h - \frac{c_V}{e^{\Phi}}\frac{\partial T}{\partial t},$$

$$\frac{L}{4\pi\kappa r^2} = e^{-\lambda-\Phi}\frac{\partial}{\partial r}\left(Te^{\Phi}\right)$$

$$Q_h \equiv Q_{\chi\chi}(T) = 10^{\alpha}\left(\frac{T}{0.1\ \mathrm{MeV}}\right)^{-3}\ \mathrm{erg\,cm^{-3}\,s^{-1}},$$

with $19 < \alpha < 21.$



LDM m_x=100 MeV is considered

More massive NS could lead to a temporary Temperature plateau halt

Degeneracy for interpretation cooling with admixed DM or only SM processes

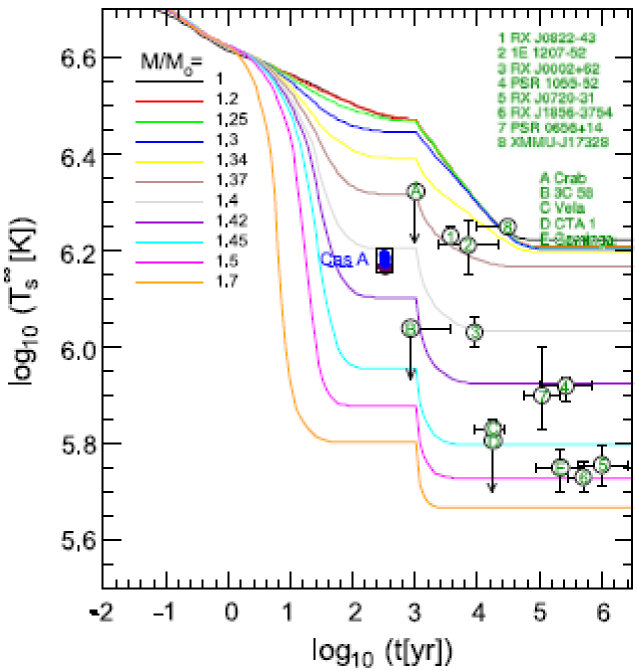
Perez-Garcia, Grigorian, Albertus, Barba, Silk, PLB 827 (2022)

Cooling behaviour in the NS for LDM case

When considering the previous model in cooling calculations

$$\frac{e^{-\lambda-2\Phi}}{4\pi r^2}\frac{\partial}{\partial r}\left(e^{2\Phi}L\right) = -Q + Q_h - \frac{c_V}{e^{\Phi}}\frac{\partial T}{\partial t},$$

$$\frac{L}{4\pi\kappa r^2} = e^{-\lambda-\Phi}\frac{\partial}{\partial r}\left(Te^{\Phi}\right)$$



LDM m_x=100 MeV is considered

Conducting LDM may lead to hotter NS for a given age

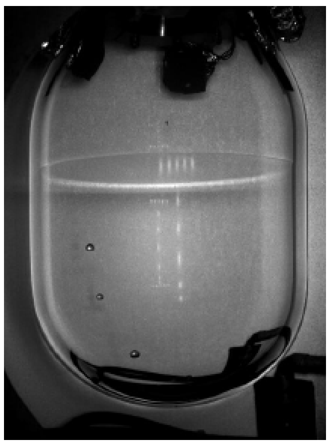
$$\kappa_\chi \sim v_\chi \lambda_\chi n_\chi \quad \text{where} \quad v_\chi = \sqrt{3T/m_\chi}$$

Perez-Garcia, Grigorian, Albertus, Barba, Silk, PLB 827 (2022)

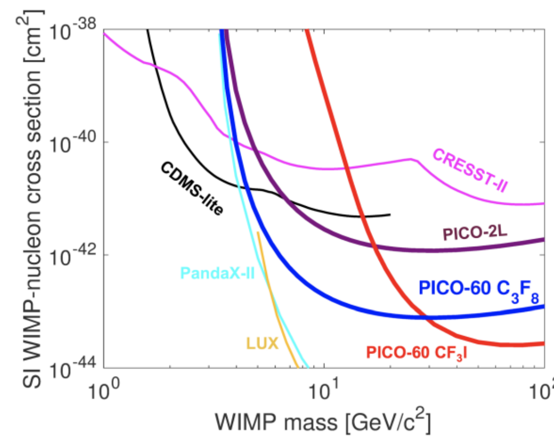
Bubble nucleation: Trojan Horse mechanism. Photon injection in the NS

Inside inner core NS Self-annihilating GeV+ DM could release fractions of energies to impact quark confinement.

$$XX \rightarrow q\bar{q} \rightarrow N\gamma$$

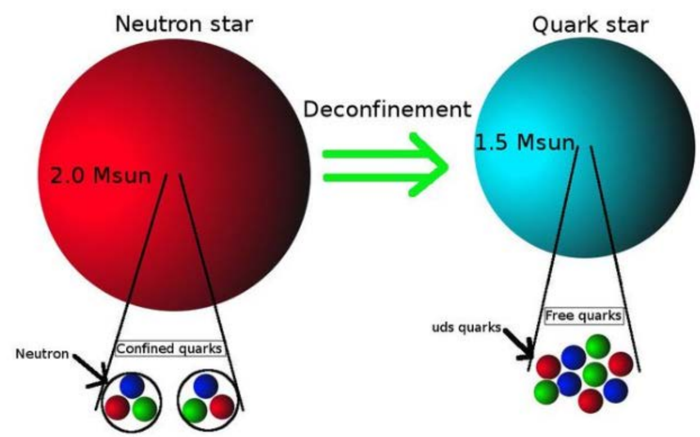


Superheated liquids in PICO underdoing DM-nuclei scattering yields constraints of DM nature



PICO collab, PRL 118 (202-17)

In NS we propose a hadronic system could suffer a phase transition from a metastable phase (Hadron) to a more stable one (Quark-gluon) if right thermodynamical conditions



Pérez-García, Silk& Stone PRL 2010, Herrero, Pérez-García, Silk and Albertus, PRD 100 (2019) 103019

Hadron phase

In dense stellar core of NSs baryons and leptons are believed to be the main ingredient

$$P = P_H + P_L, \ \varepsilon_{tot} = \varepsilon_H + \varepsilon_L; \quad n_b = \sum_B n_B$$

with

$$\begin{aligned} P_H &= -\varepsilon_H + \sum_B n_B \mu_B; \\ P_L &= -\varepsilon_L + \sum_l n_l \mu_l, \end{aligned}$$

$$\mu_B = \sqrt{k_{F,B}^2 + M_B^2} + g_{\omega B}\omega_0 + g_{\rho B}\tau_{3B}\rho_{30}$$

and

Serot & Walecka'86

$$\begin{aligned} \varepsilon_H &= \mathcal{U}(\sigma) + \frac{1}{2}m_\sigma^2\sigma^2 + \frac{1}{2}m_\omega^2\omega_0^2 + \frac{1}{2}m_\rho^2\rho_{30}^2 \\ &+ \frac{1}{8\pi^2}\sum_B M_B^4 \left[(2t_B^2+1)t_B\sqrt{1+t_B^2} - ln\left(t_B + \sqrt{1+t_B^2}\right)\right]; \\ \varepsilon_L &= \frac{1}{8\pi^2}\sum_l m_l^4 \left[(2t_l^2+1)t_l\sqrt{1+t_l^2} - ln\left(t_l + \sqrt{1+t_l^2}\right)\right], \end{aligned}$$

$$t_i = k_{F,i}/m_i$$

Deconfined quark phase

•We consider a deconfined (uds) quark content phase with thermodynamic potential with MIT Bag model Chodos, Jaffe et al'74 with QCD corrections

$$\Omega_q = -\frac{1}{4\pi^2}\left[\mu_q(\mu_q^2-m_q^2)^{1/2}\left(\mu_q^2-\frac{5}{2}m_q^2\right)+\frac{3}{2}m_q^4\, ln\left(\frac{\mu_q+(\mu_q^2-m_q^2)^{1/2}}{m_q}\right)\right]$$
$$+\frac{\alpha_s}{2\pi^3}\left\{3\left[\mu_q(\mu_q^2-m_q^2)^{1/2}-m_q^2,ln\left(\frac{\mu_q+(\mu_q^2-m_q^2)^{1/2}}{m_q}\right)\right]^2\right.$$
$$\left.-2(\mu_q^2-m_q^2)\right\},$$

•With pressure and energy density $P_Q = -\sum_q \Omega_q - B \qquad P = P_Q + P_L$

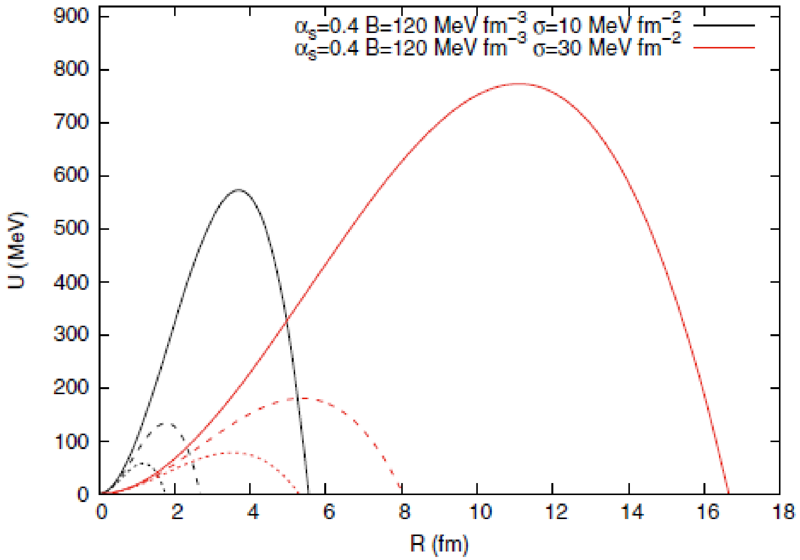
$$\varepsilon_{tot} = \varepsilon_Q + \varepsilon_L;$$

$$\varepsilon_Q = \sum_q(\Omega_q+\mu_q n_q) = \frac{3}{4\pi^2}\left(1-\frac{2\alpha_s}{\pi}\right)(\mu_u^4+\mu_d^4)+\frac{3}{8\pi^2}m_s^4\left[x_s\eta_s(2x_s^2+1)-ln(x_s+\eta_s)\right]$$
$$-\frac{\alpha_s}{2\pi^3}m_s^4\left\{2x_s^2(x_s^2+2\eta_s^2)-3\left[x_s\eta_s+ln(x_s+\eta_s)\right]^2\right\}+B,$$

$$x_s=\sqrt{\mu_s^2-m_s^2}/m_s, \eta_s=\sqrt{1+x_s^2},$$

Confining potentials in LK theory in the NS core

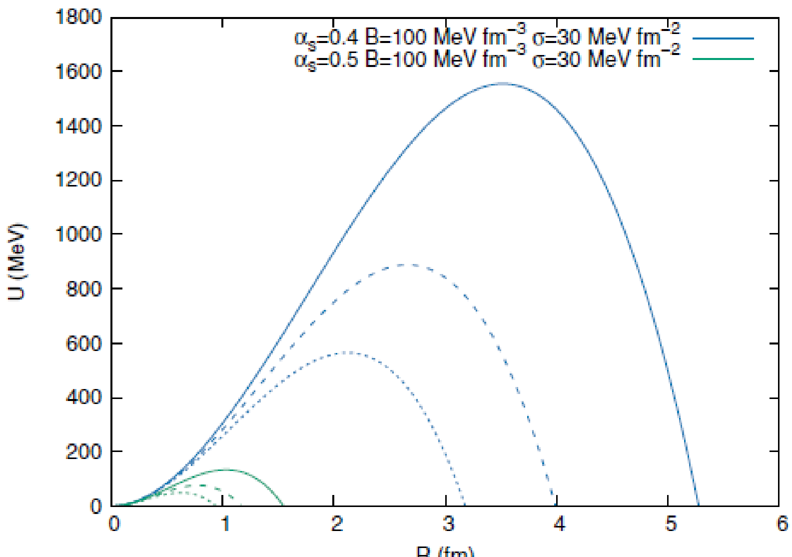
$$70 \leq B \leq 150\,\mathrm{MeV\,fm}^{-3}$$
$$10 \leq \sigma \leq 30\,\mathrm{MeV\,fm}^{-2}$$



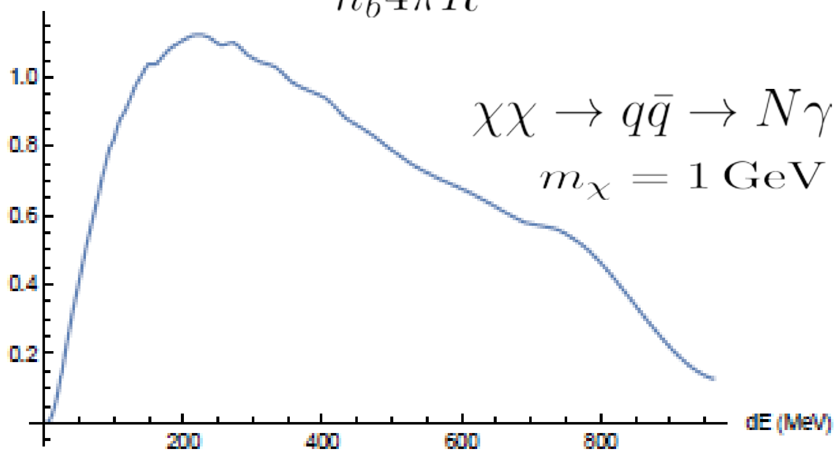
fm size bubbles

Potential barrier lower as pressure goes larger than transition density at $n_b|_H = 5.5 n_0$

QCD corrections drive smaller barriers.



$$E = \frac{\xi m_\chi}{n_b 4\pi R^3} \qquad \xi \leq 0.6$$



$$\chi\chi \to q\bar{q} \to N\gamma$$
$$m_\chi = 1\,\mathrm{GeV}$$

Herrero, Pérez-García, Silk and Albertus, PRD 100 (2019) 103019

Probability of induced nucleation

Oscillation frequency of the fundamental state

$$\nu_0^{-1} = \left.\frac{dI}{dE}\right|_{E=E_0}, \quad I(E) = \frac{2}{c}\int_{R_-}^{R_+} \sqrt{[2M(R)c^2 + E - U(R)]\,[U(R) - E]}\,dR$$

and the probability with (WKB approx)

$$p_0 = exp\left(-\frac{A(E)}{\hbar}\right),$$

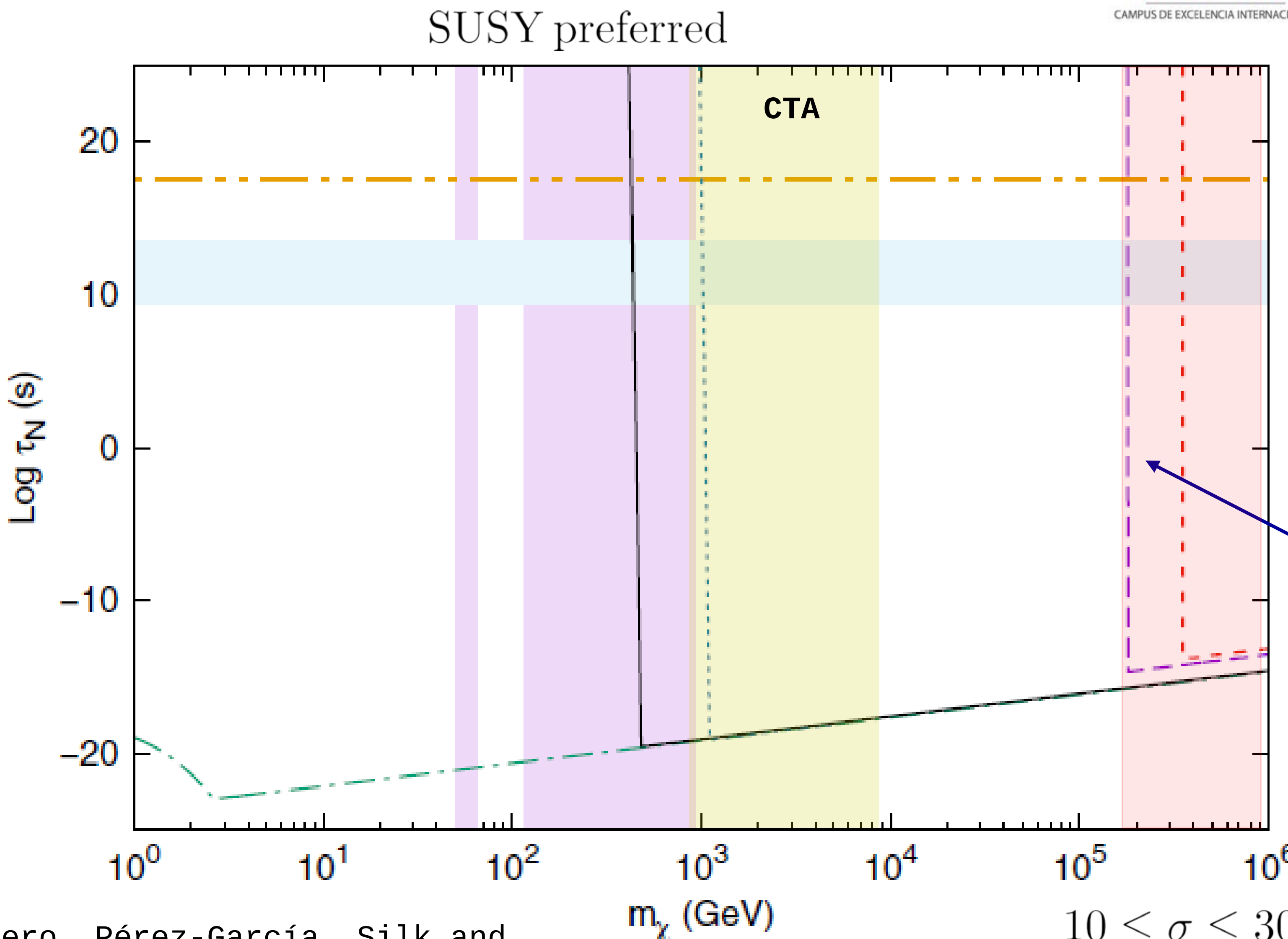
The inject. energy per unit baryon charge inside the baryon bag determines the energetic level of confined Q content

$$E = \frac{\xi m_\chi}{n_b 4\pi R^3}$$

The number of nucleation centers is given by the stable bubble size

$$N_C = \frac{V_{th}}{V_B} \sim \left(\frac{r_{th}}{R_B}\right)^3.$$

and the bubble formation time $\tau^{-1} = \nu_0 p_0$
is corrected as $\tau_N = \tau/N_C$



τ_U

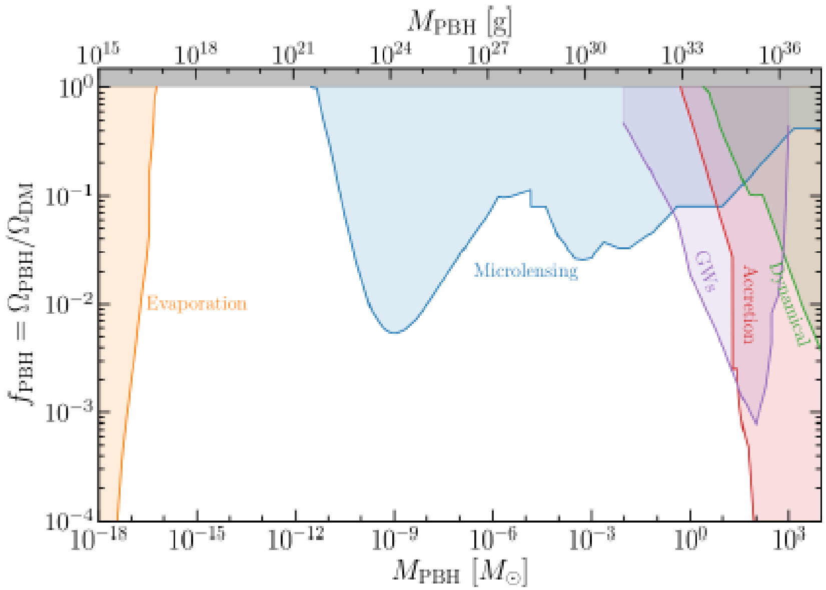
$\tau_{\rm NS}$ *ages*

Values preferred from chiral models, QCD and NS masses

Herrero, Pérez-García, Silk and Albertus, PRD 100 (2019) 103019

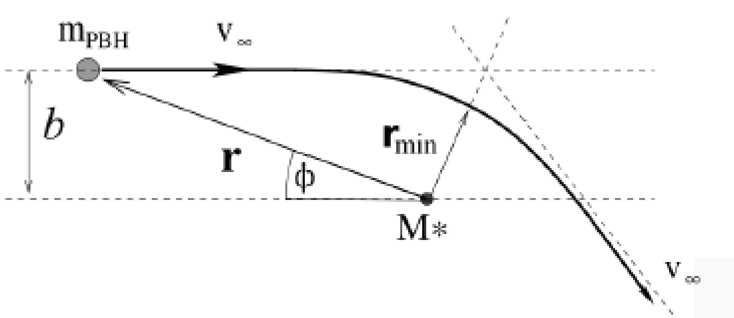
$$10 \leq \sigma \leq 30\,\mathrm{MeV\,fm}^{-2}$$
$$70 \leq B \leq 150\,\mathrm{MeV\,fm}^{-3}$$

Primordial Black holes and NSs



We investigate PBH in allowed window scattering regular NS.

Angular momentum, energy conserved.



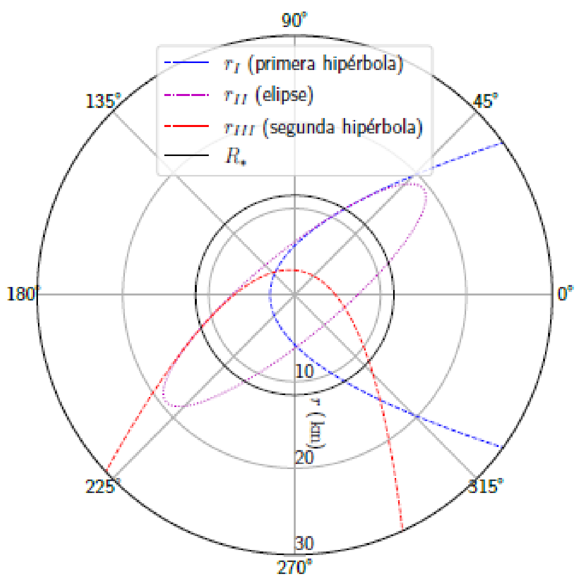
$$r_I(\phi) = \frac{a(e^2-1)}{1+e\cos(\phi-\psi_0)} \qquad (\phi \le \phi_0)$$

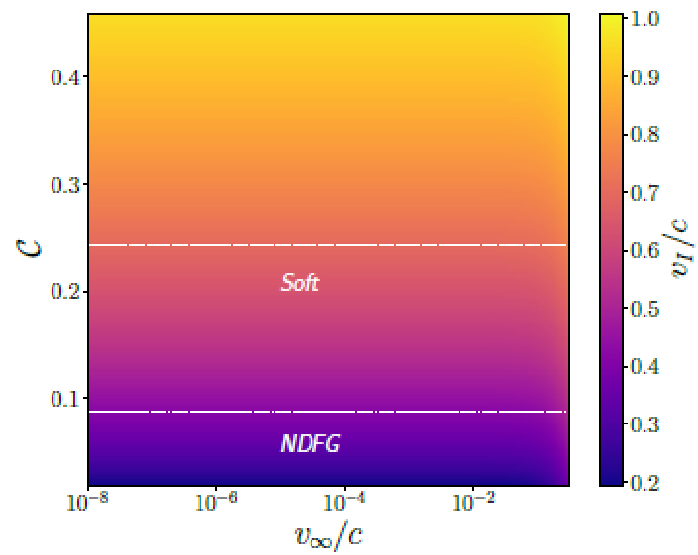
$$r_{II}(\phi) = \frac{\alpha_-}{\sqrt{1-\varepsilon^2\cos^2(\phi-\psi_1)}} \qquad (\phi_0 < \phi < \phi_1)$$

$$r_{III}(\phi) = \frac{a(e^2-1)}{1+e\cos(\phi-\psi_2)} \qquad (\phi_1 \le \phi).$$

PBHs and NSs

•Due to changing grav. potential an idealized set of curves (elipses and hyperbolas) are described.





Martin, Albertus, Pérez-García, in prep. 2022.

•Relativistic corrections are included
•Beyond pure GR dynamics must include:
-Dynamical friction
-Acretion force

$$\vec{F}_{DF} = -4\pi G^2 \frac{P+\epsilon}{c^2} m_{PBH}^2 \ln\Lambda \frac{\vec{v}}{v^3}\left(1+\frac{v^2}{c^2}\right)^2 \gamma^2.$$

Barausse, 2007

$$\vec{F}_{ac} = -\pi\gamma^2 v n m_n b_{n,\min}^2 \vec{v} = -4\pi n m_n \frac{G^2 m_{PBH}^2}{c^2} \tilde{b}_{n,\min}^2 \frac{\vec{v}}{v} \qquad v > c_s,$$

Capela+, 2013

PBHs and NSs

•Colliding or fly-by PBHs may induce changes in rot. frequency

$$|\Delta\nu| = \frac{|\Delta L_{PBH}|}{2\pi I_*} \leq \frac{m_{PBH} b v_\infty}{2\pi I_*}$$

•Typical glitches or anti-glitches can be measured to

$$|\Delta\nu|/\nu = 10^{-12}$$

•So that preliminary estimates for Soft EoS yield numbers around 10 times this values for ms pulsars

$$|\Delta\nu| = \frac{|\Delta L_{PBH}|}{2\pi I_*} \leq \frac{m_{PBH} b v_\infty}{2\pi I_*} \sim \frac{1\times 10^{22}\,\mathrm{g} \times b_c \times 10^{-8} c}{2\pi \times 1{,}5392 \times 10^{45}\,\mathrm{g\,cm^2}} \simeq 2{,}49 \times 10^{-8}\,\mathrm{Hz},$$

Incoming PBH flux may additionally impact these numbers. Work in progress.