Heating up Neutron Stars with Dark Matter

[1807.02840] + in preparation

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Outline

1. Introduction
   - DM Capture by NS
   - Interactions suppressed at low energy
   - Advantages of NS
2. Neutron Star heating
   - Scattering off Nucleons
   - Scattering off Leptons
3. Conclusions
   - Summary

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- Direct Detection: sun rotation in the galaxy originates wimp wind
- non-gravitational interactions $\rightarrow$ may scatter off ordinary matter
- DD: huge detectors on earth at low T $\rightarrow$ DM scattering deposits energy in the detector
- Same mechanism used for Indirect detection in Earth and Sun $\rightarrow$ energy loss may make the DM particle gravitationally bound to the star/planet

- Neutron Stars: very efficient for DM capture
- Mass similar to the Sun, but very small radius $\mathcal{O}(10) Km$
- Very small Cross Sections $\sim 10^{-45} cm^2$ are enough for the NS to capture all the incident DM flux
- DM kinetic energy of the same order of the mass, thanks to gravitational acceleration
- After capture, trapped inside the NS, DM undergoes subsequent scatterings, losing all its energy
- This heating mechanism defines a minimum temperature $(1700K)$ for the NS, assuming equilibrium by radiation loss
- For Cross sections smaller than $10^{-45} cm^2$, NS does not capture the whole flux, and equilibrium temperature is also lower
- Observation of very cold NS with $T < 1700K \rightarrow$ upper bound on $\sigma_{n\chi}$

Outline

- DD usualy considers only SI and SD
- Other operators are suppressed by powers of q_{tr} or v_{rel}
- $\frac{d\sigma}{d\cos\theta} \propto v_{rel}^{2n}, q_{tr}^{2n}, n > 0$
- $q_{tr} \sim v_{rel}\mu \to v_{rel} \ll 1, \quad q_{tr} \ll \mu$
- Effective suppression of $v_{rel}^{2n} \ll 1$ comparing to standard SI and SD

Name	Operator	Interaction
D1	$\bar{\chi}\chi\,\bar{q}q$	SI
D2	$\bar{\chi}\gamma^5\chi\,\bar{q}q$	SI, q^2
D3	$\bar{\chi}\chi\,\bar{q}\gamma^5 q$	SD, q^2
D4	$\bar{\chi}\gamma^5\chi\,\bar{q}\gamma^5 q$	SD, q^4
D5	$\bar{\chi}\gamma_\mu\chi\,\bar{q}\gamma^\mu q$	SI
D6	$\bar{\chi}\gamma_\mu\gamma^5\chi\,\bar{q}\gamma^\mu q$	SI, q^2+v^2
D7	$\bar{\chi}\gamma_\mu\chi\,\bar{q}\gamma^\mu\gamma^5 q$	SD, q^2+v^2
D8	$\bar{\chi}\gamma_\mu\gamma^5\chi\,\bar{q}\gamma^\mu\gamma^5 q$	SD
D9	$\bar{\chi}\sigma_{\mu\nu}\chi\,\bar{q}\sigma^{\mu\nu}q$	SD
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\,\bar{q}\sigma^{\mu\nu}q$	SI, q^2+v^2

- Inelastic Dark matter: 2 states separated by a small mass splitting
- The lighter state χ_1 accounts for the observed relic density. Heavier state unstable on cosmological scales
- Elastic scattering $\chi_1 N \to \chi_1 N$ not allowed
- Upscattering χ_2: $\chi_1 N \to \chi_2 N$ is possible if allowed kinematically
- $\delta m < \frac{1}{2}\mu v_{rel}^2$
- v_{rel} is capped by the galactic escape speed, so there is a maximum $\delta m/m_\chi$ that can be tested on earth
- When allowed, inelastic cross section is $\sigma_{inel} \sim \sigma_{el}\sqrt{1 - \frac{\delta m}{\frac{1}{2}\mu v_{rel}^2}}$

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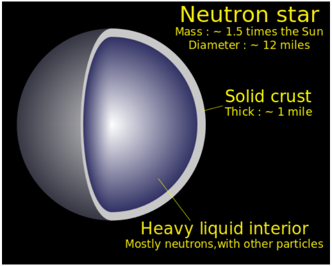
Advantages of NS
Higher energy

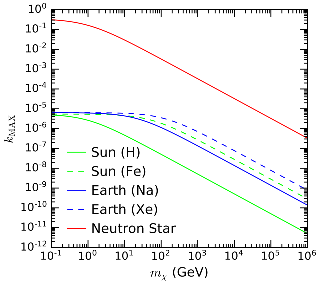
- $v_{rel} \sim 10^{-3}$ on Earth
- $v_{rel} \sim few \times 10^{-3}$ in the Sun
- $v_{rel} \sim 1$ on Neutron Stars!
- In [1704.01577] is suggested how to use convert lower limits on observed NS to upper limits on DM-matter interactions
- In [1707.09442] follows up in the idea for q^2 and q^4 operators
- In [1807.02840] we study elastic and inelastic EFT operators limits arising from neutron star temperatures



Advantages of NS

Larger Mass splittings

- DM loses energy during capture
- Remaining energy lost during thermalization
- $\approx$ the whole kinetic energy is transferred to the NS
- Inelastic DM: maximum mass splitting depends on target
- NS allows much larger δm than on earth
- At high DM mass, $\delta m < 330 MeV$



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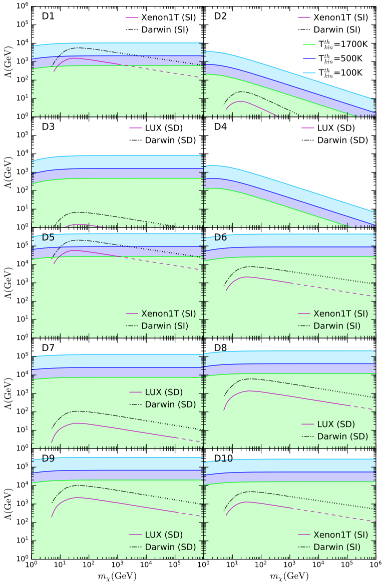
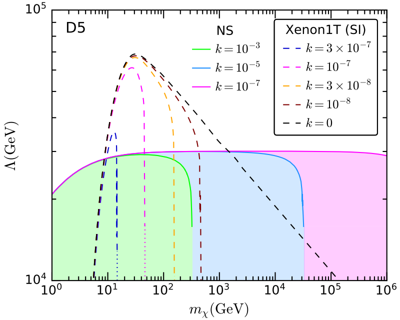
Neutron Star heating

Scattering off Nucleons





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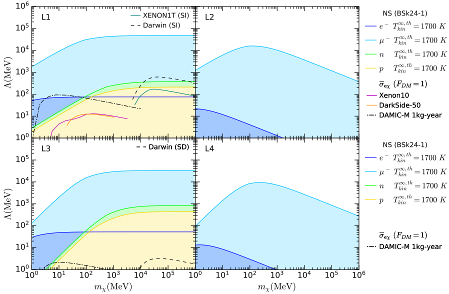
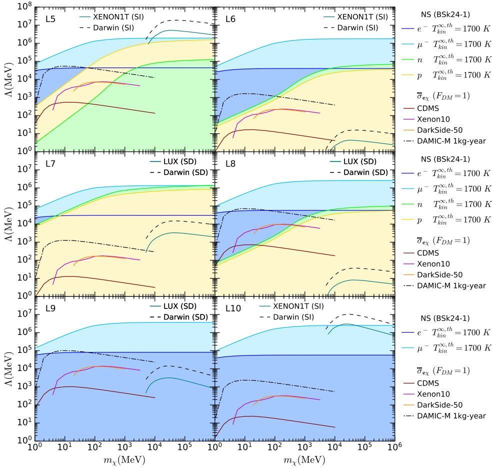
Scattering off Leptons





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- Neutron Stars: an interesting possibility to place upper bounds on DM cross sections
- High energy scattering washes away low energy suppression
- Higher reach on inelastic scattering
- Prospected limits competitive with current bound for unsuppressed operators (D1,D5)
- Prospected limits orders of magnitude stronger for suppressed operators
- Current coolest NS of $\mathcal{O}(10^4)K$
- Prospects for observation in the coming decade