Evaporation on GeV-ish DM in the Sun

Analysis of light DM Evaporation in the Sun

Based on: in preparation (Busoni, De Simone, Scott, Vincent)

G. Busoni

CoEPP
University of Melbourne

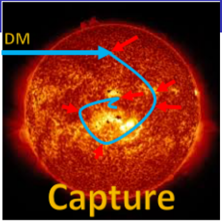
CosPA 2016, 29 Nov 2016

Outline

1. Introduction and Motivations
   - Dark Matter in the Sun
   - Sound speed profile in the Sun
2. Our Work
   - Multiple Scattering
   - Evaporation

Outline

1. Introduction and Motivations
   - Dark Matter in the Sun
   - Sound speed profile in the Sun
2. Our Work
   - Multiple Scattering
   - Evaporation



- Same concept as in DD
- After interacting, the particle may remain trapped in the Sun gravitational well

- Input to calculate Capture Rate C:
  - Sun Physics: temperature and abundance profiles
  - DM mass, density and velocity distribution (assume MB)
  - DM-proton c.o.m. differential cross section

$$\frac{d\sigma}{d\cos\theta} = \sigma_0 + \sigma_{v,i}\left(\frac{v_r}{v_0}\right)^{2i} + \sigma_{q,i}\left(\frac{q_{tr}}{q_0}\right)^{2i}$$

- Usually DD experiments consider only σ_0

Astrophys. J. 321 (1987) 560,571; Astrophys. J. 352 (1990) 654.

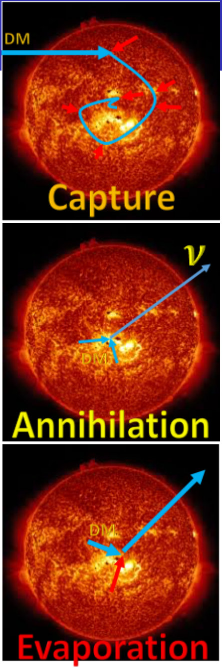
Introduction

Annihilation and Evaporation

- If DM is not Asymmetric, it can annihilate
  - Annihilation term proportional to N^2
  - Neutrino products possible DM signal
- If DM is light, a subsequent scattering may let it escape (evaporation)
  - Evaporation term proportional to N

$$\frac{dN}{dt}(t) = C - EN(t) - AN^2(t)$$

> For light DM, Evaporation sets an upper bound on the captured DM particles!



- For $A = 0$, the solution for the previous equation is

$$N(t_\odot) = \frac{C}{E}\left(1 - e^{-Et_\odot}\right) = Ct_\odot \frac{1 - e^{-Et_\odot}}{Et_\odot}$$

$$N(t_\odot) = \begin{cases} N(t_\odot) = Ct_\odot & \text{if } Et_\odot \ll 1 \\ N(t_\odot) = \dfrac{C}{E} \ll Ct_\odot, & \text{if } Et_\odot \gg 1 \end{cases}$$

Contribute of evaporation given by the factor

$$\gamma_E = \frac{1 - e^{-Et_\odot}}{Et_\odot}$$

Outline

1. Introduction and Motivations
   - Dark Matter in the Sun
   - Sound speed profile in the Sun
2. Our Work
   - Multiple Scattering
   - Evaporation

Motivations

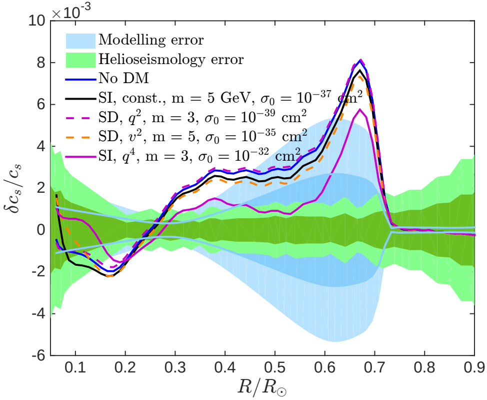
Solar Abundance Problem and Energy Transport in the Sun

Disagreement between photospheric analyses and Helioseismology

- Surface Helium Abundance
- Sound Speed Profile
- Convection Zone Depth
- Neutrino Fluxes

Model	χ^2
SSM	276
$\sigma_{\mathrm{SI}}, q^2$	31

Arxiv:1504.04378, 1605.06502



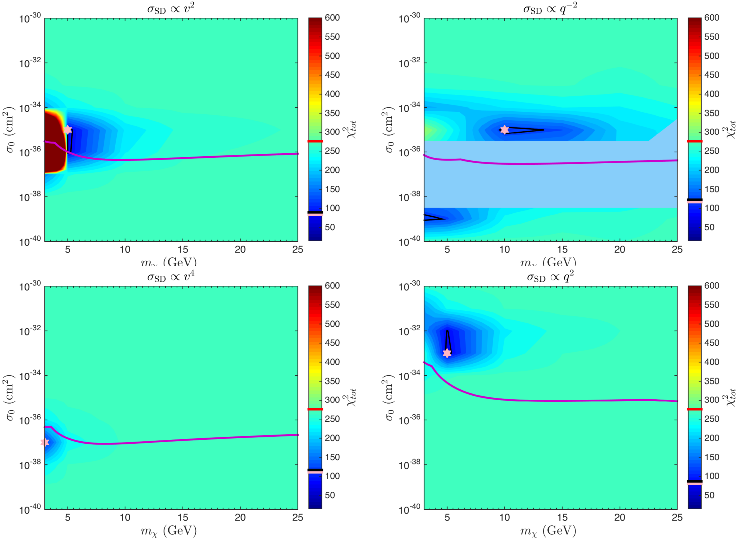
Motivations

Solar Abundance Problem and Energy Transport in the Sun

- Best fit points usually at low m_χ
  - To improve agreement one needs to affect energy transport
  - Energy transport con be efficient only for $1GeV \lesssim m_\chi \lesssim 10GeV$
- Evaporation effect usually neglected, but very important below $m_\chi \sim 4GeV$
  - Best fit points at low DM mass are more like to survive DD constraints
- Usually feature also large cross sections
  - Most best-fit points are excluded by DD, but some regions for SD are still allowed
  - Regions affected by Evaporation may produce new best-fit points at low DM mass and large cross sections, in regions still allowed by DD

Motivations

Implementing Evaporation in...



Arxiv:1504.04378, 1605.06502

Outline

- The probability of absorption/interaction of a flux of particles travelling in a medium is given by

$$\frac{dN}{dx} = -n(x)\sigma_0 N(x) \to N = N_0 e^{-\int_0^x n\sigma_0 dx}$$

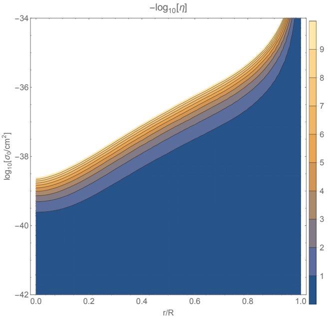
So the interaction rate is

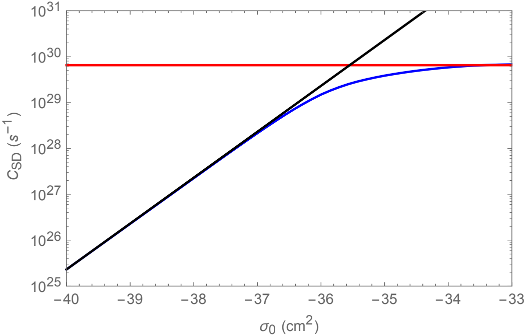
$$R \sim \int dV N(x) n(x) \sigma_0 v_r = \int dV N_0 e^{-\int_0^x n\sigma_0 dx} n(x)\sigma_0 v_r$$

- Usual assumption: optically thin: $e^{-\int_0^x n\sigma_0 dx} \sim 1$

$$R \sim \int dV N_0 n(x) \sigma_0 v_r$$

Our Work
Multiple Scattering





$$\eta = e^{-\int_0^x n\sigma_0 dx}$$

This can be relevant for velocity-suppressed cross sections that can get to the optically thick regime while satisfying DD bounds

Outline

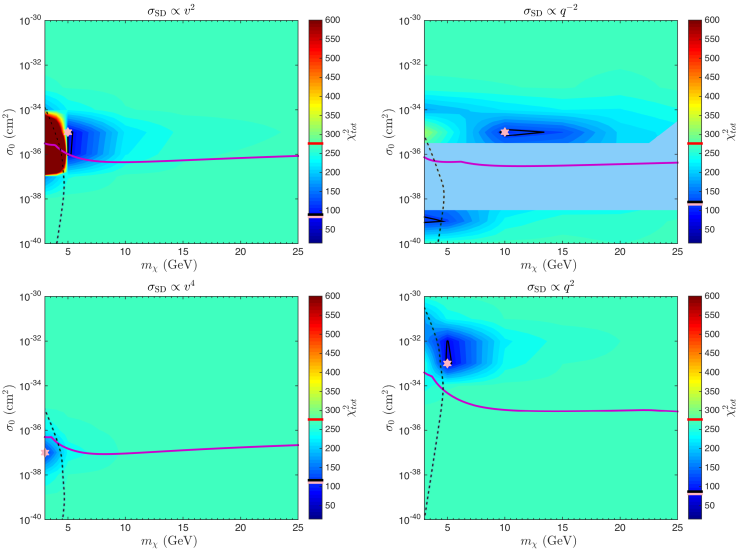
Our Work

Evaporation

- Formalism similar to Capture rate calculation
- Needs more assumptions
  - DM space and velocity distribution in the Sun: Isothermal + LTE
  - Relative weight isothermal/LTE (numerical simulations: Kundsen transition)
- More computationally intensive
  - For Capture, one can make the approximation $T_N = 0$ (nucleon temperature has negligible effects on C)
  - Evaporation depends dominantly on T_N
  - Capture: $1D/2D$ integrals of smooth functions
  - Evaporation: $5D$ integrals of very peaked functions

Our Work

Results (SD)

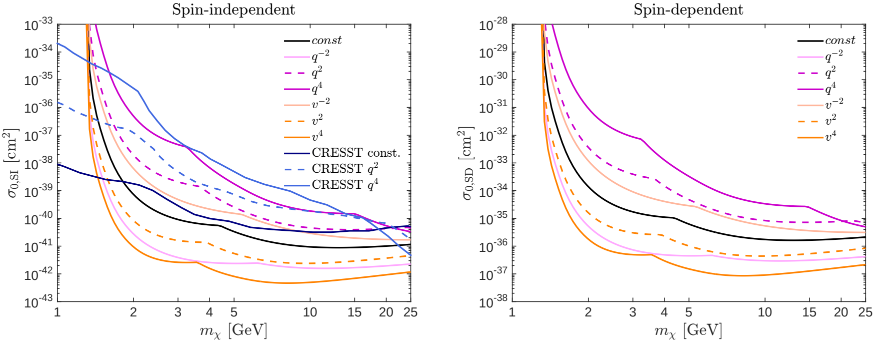


Summary

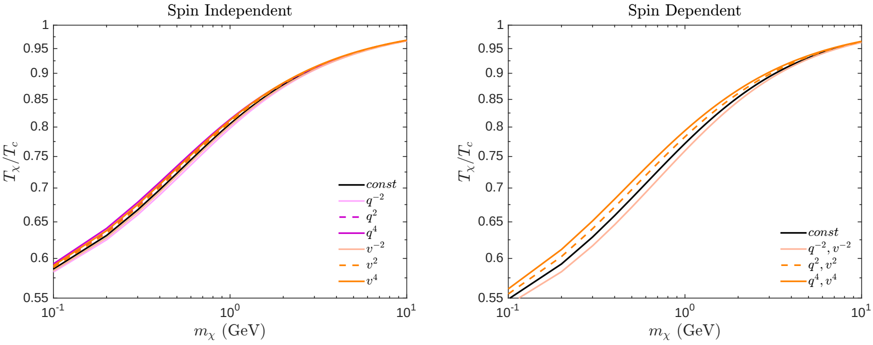
- DM in the Sun adds up to typical Direct/Indirect/Collider Search
- Important effects that are usually neglected
  - Multiple Scattering and transition to saturation for Capture
  - Evaporation for low DM masses
  - Velocity/momentum suppressed cross sections
- Interesting possibility
  - Better agreement between Solar Models and Helioseismology due to DM
- SD results show some regions of parameter space need refined analysis with evaporation effects included
- SI results being generated now, paper out in a few weeks

Backup Slides

DD constrains



DM Temperature



Kundsen Transition