Dynamics of WIMPs in the Solar System and Implications for Direct and Indirect Detection

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COSMO 08

Scattering in the Solar System

- "Particle physics" scattering usually considered:
  - Capture by elastic scattering of halo WIMPs in the Sun: Neutrinos from subsequent annihilations may be observable.
  - Capture by elastic scattering of halo WIMPs in the Earth
  - Scattering (elastic or otherwise) in direct detection experiments.

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  - $\mathcal{O}(100)$ x ? – Capture by elastic scattering of halo WIMPs in the Earth
  - $\mathcal{O}(1)$ x ? – Scattering (elastic or otherwise) in direct detection experiments.
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  - ? (But probably tiny) Capture by elastic scattering of halo WIMPs in the Sun: Neutrinos from subsequent annihilations may be observable.
  - Depends on scattering in the Sun → Capture by elastic scattering of halo WIMPs in the Earth
  - → Scattering (elastic or otherwise) in direct detection experiments.
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Do full Monte Carlo simulations!

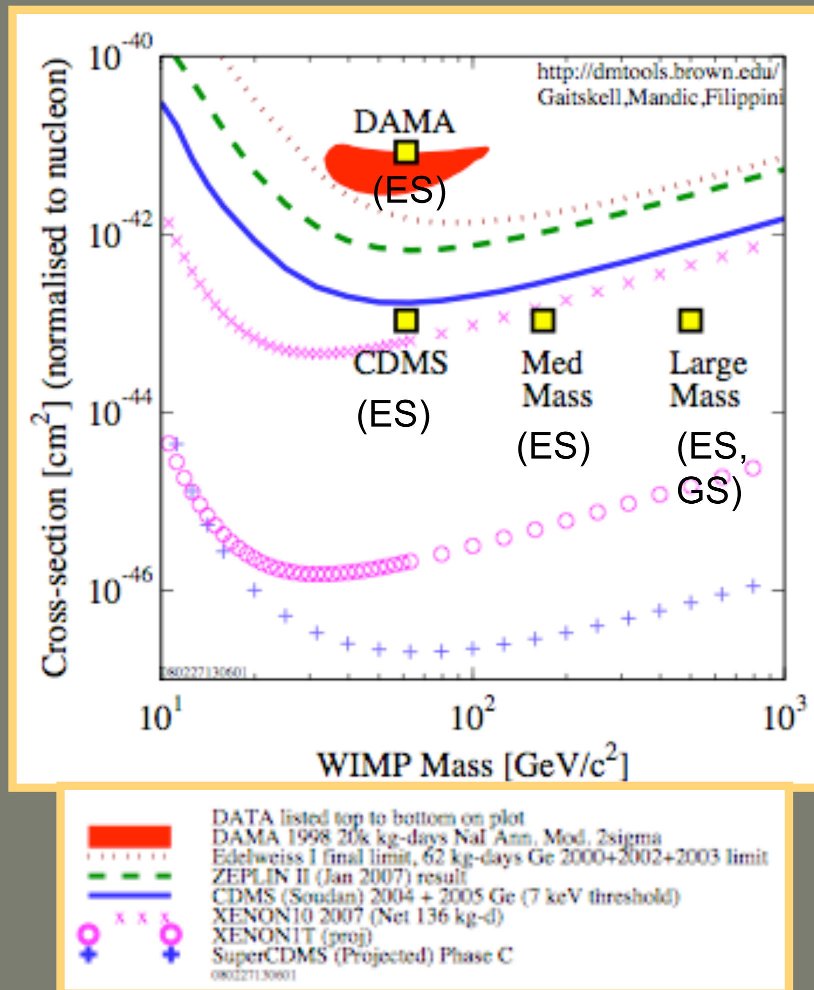
Monte-Carlo WIMP orbit/scatter simulations

- Goals
  - Find the distribution function of WIMPs bound to the solar system as a function of WIMP mass and type and strength of elastic scattering interaction (direct detection, neutrinos from the Earth).
  - Characterize the WIMP lifetimes (neutrinos from the Sun).

Outline:
- Methods
- Results (distr. functions, detection possibilities)
- Discussion

Simulations & Initial Conditions

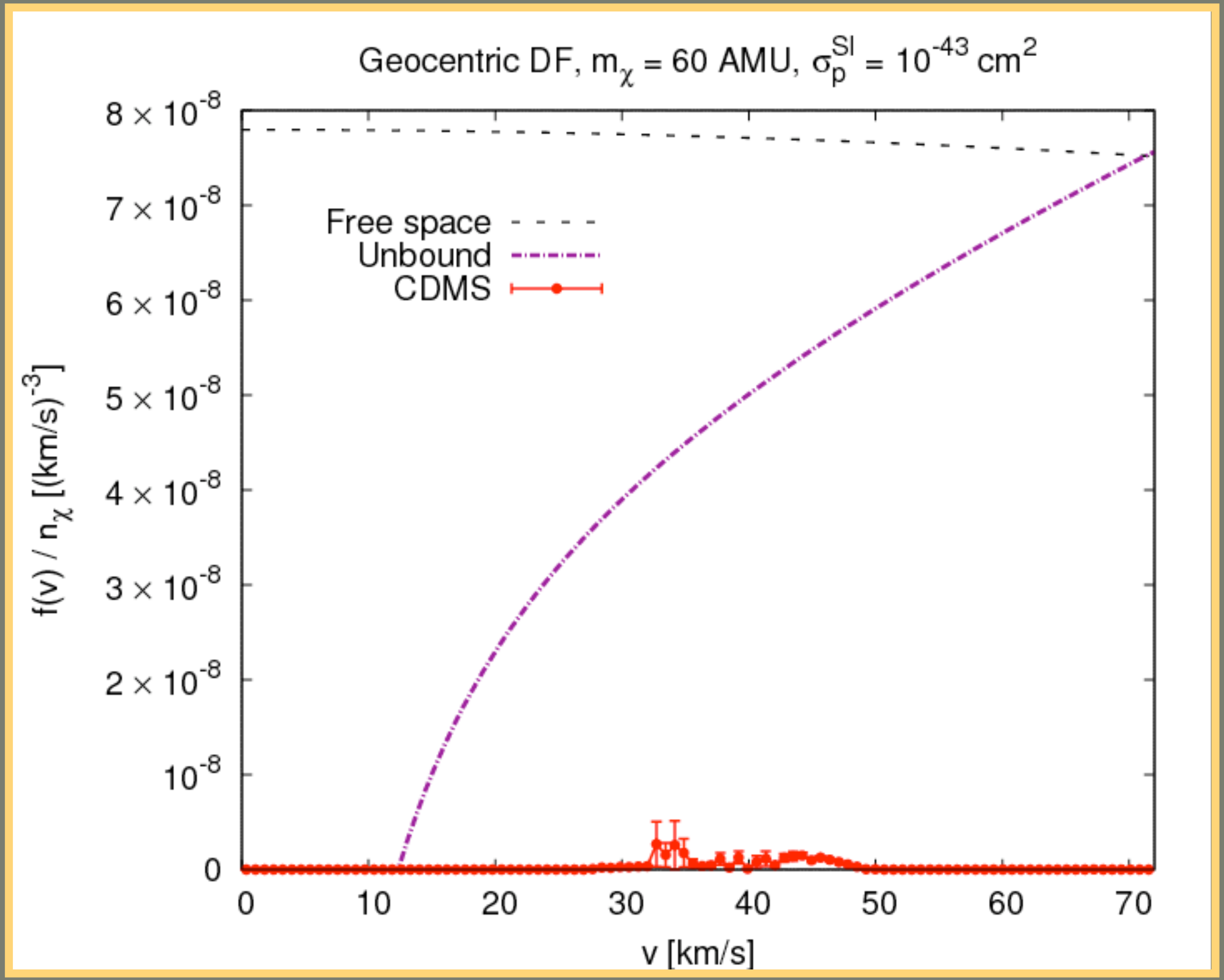
- Capture by elastic scattering:
  - Start at the initial scatter in the Sun.
  - 1.1×10^6 Earth-crossing particles for DAMA, 1.5×10^5 for others.
- Capture by gravitational scattering:
  - Start with the incoming halo flux at 1000 AU, and only WIMPs in capturable phase space.
  - ~ 9×10^9 particles
- σ_p^{SD} = 0 (generalize later)



Integration

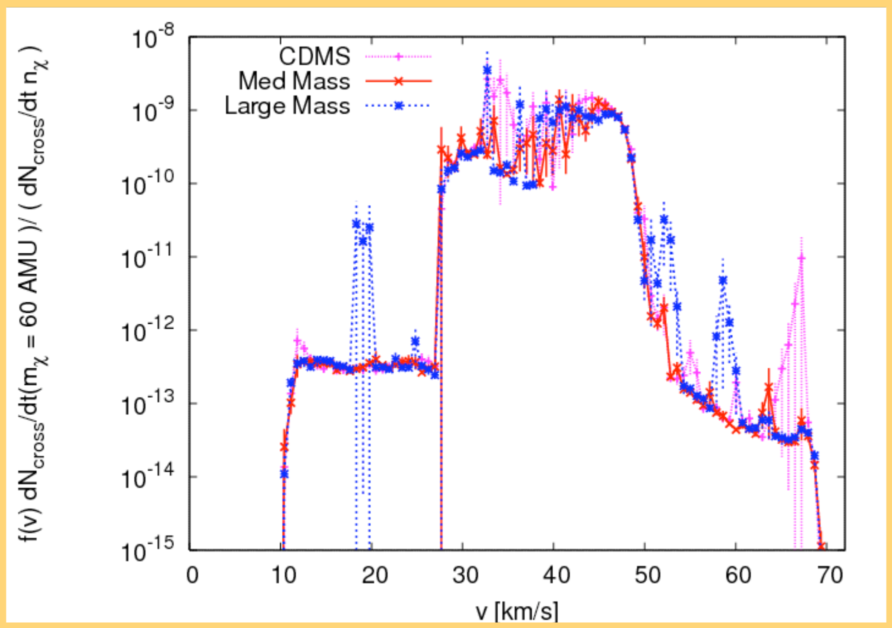
- Sun: BS(OP) model
- We use a simplified solar system consisting of Jupiter and the Sun only to test the code and to more easily understand the results (I will come back to the question of the other planets).
- We use a symplectic integrator with an adaptive time step (Mikkola & Tanikawa 1999, Preto & Tremaine 1999) unless a WIMP:
  - Is in the Sun.
  - Goes near a planet.
- MC treatment of scattering in the Sun.
- Integration is terminated if:
  - The particle rescatters onto an ``uninteresting'' orbit.
  - The particle is ejected.
  - $t > t_\odot$

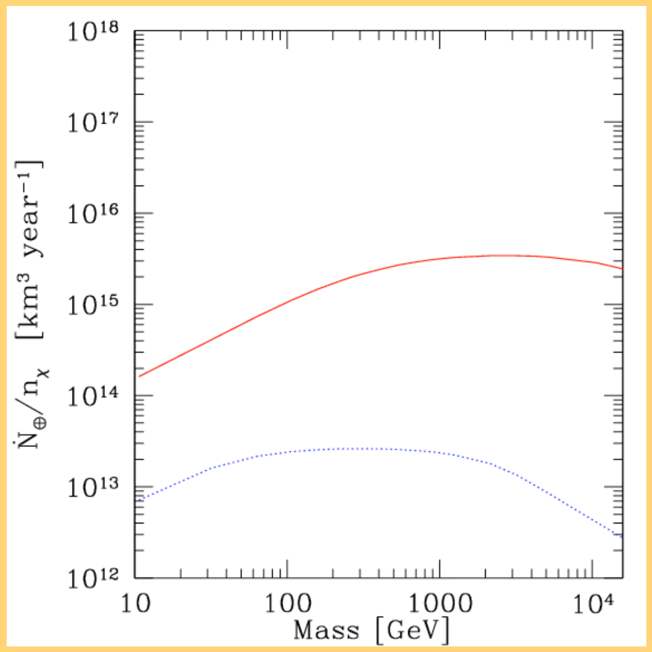
Results: Capture by Elastic Scattering



Mass Dependence

$\sigma_p^{SI} = 10^{-43}$ cm^2

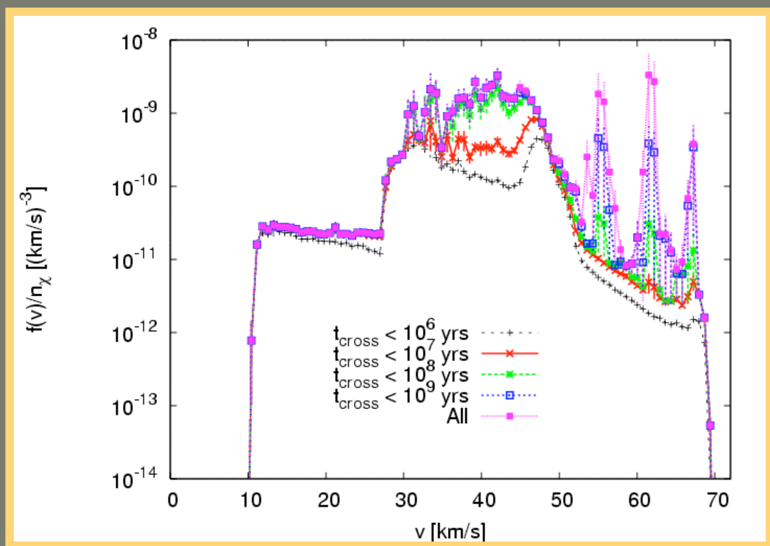


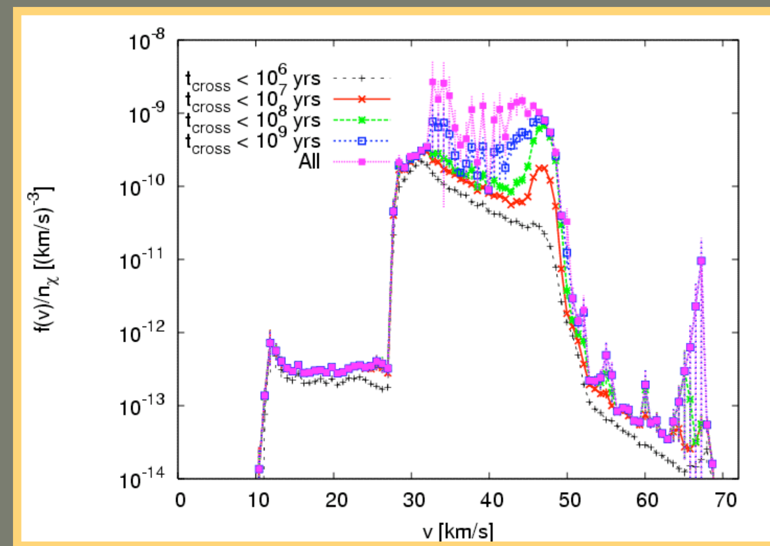


$f \propto dN_\oplus/dt$ $\quad$ $(dN_\oplus/dt \,/\, n_\chi \propto m^{-1}_\chi$ for $m_\chi >> m_A)$

There appears to be no mass dependence beyond that related to $dN_\oplus/dt$ for this mass range, although there could have been.

Cross Section Dependence



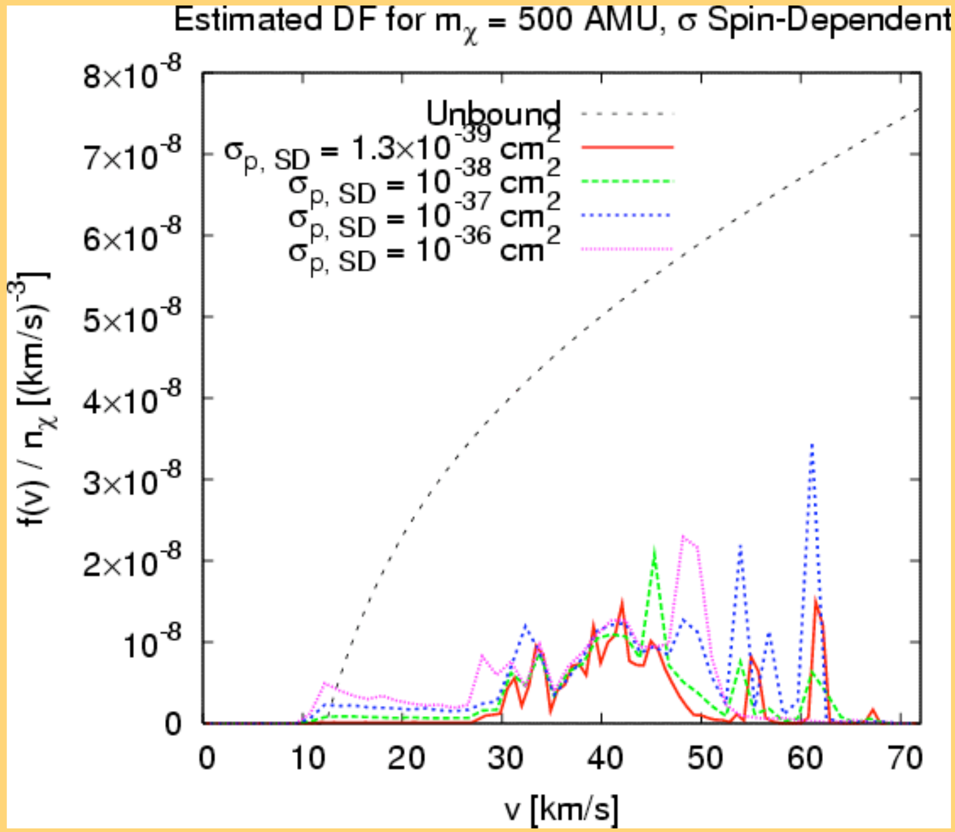


- High plateau:
  - ~ 0.1% of Earth-crossers with a < 1.5 AU have $t_{life} \sim 10^5\ T_\chi / \tau$ instead of $t_{life} \propto T_\chi / \tau$.
  - Reaches equilibrium if $t_{life} < t_\odot$ ($t_{life} \propto (\sigma_p^{SI})^{-1}$ and $dN_\oplus/dt \propto \sigma_p^{SI}$)
  - The high plateau grows as a function of cross section until it reaches equilibrium.

Max. Distribution Function and Generalization to Spin-Dependent Interactions

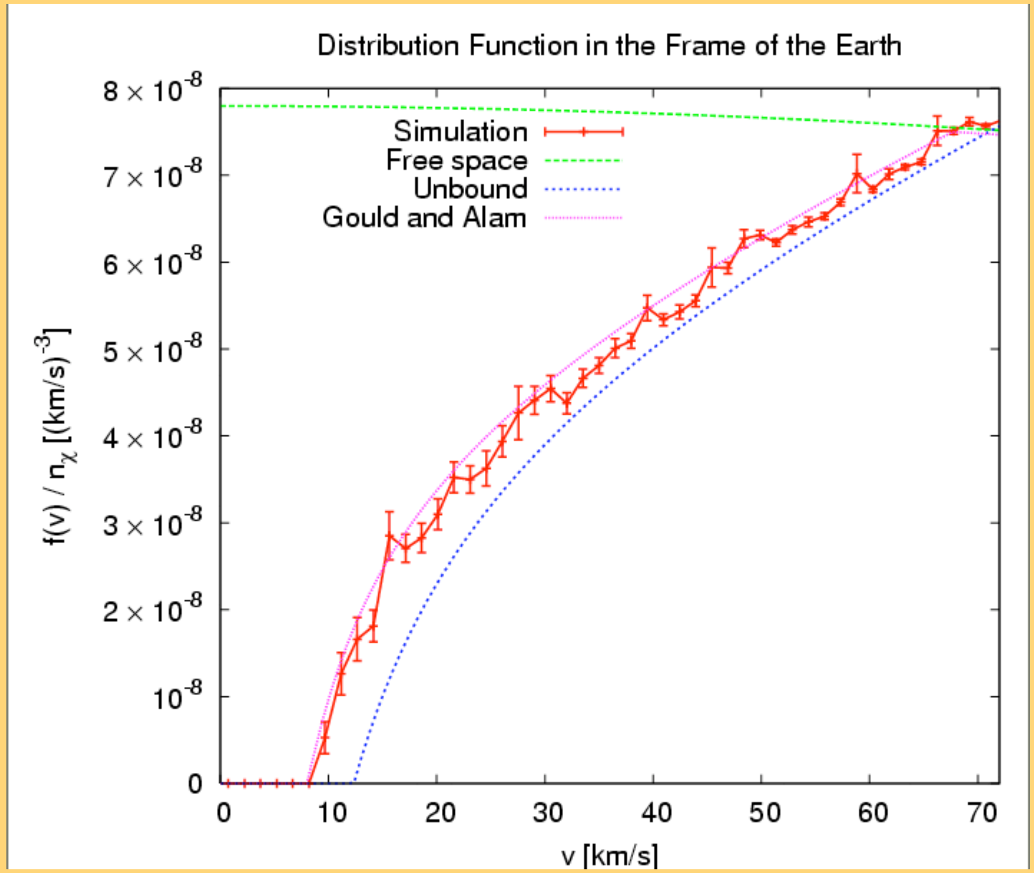
This is about as big as it gets:

- $dN_\oplus/dt\,/n_\chi$ is large without suffering from the severe kinematic suppression that affects the total capture rate.
- WIMPs reach equilibrium on timescales $\ll t_\odot$
- For σ_p^{SI}, max. size is reached for $m_\chi \sim 2$ TeV, $\sigma_p^{SI} \sim 10^{-42}$ cm^2
- For σ_p^{SD}, max. size is reached for $m_\chi \sim$ a few hundred GeV and $\sigma_p^{SD} \gtrsim 10^{-40}$ cm^2

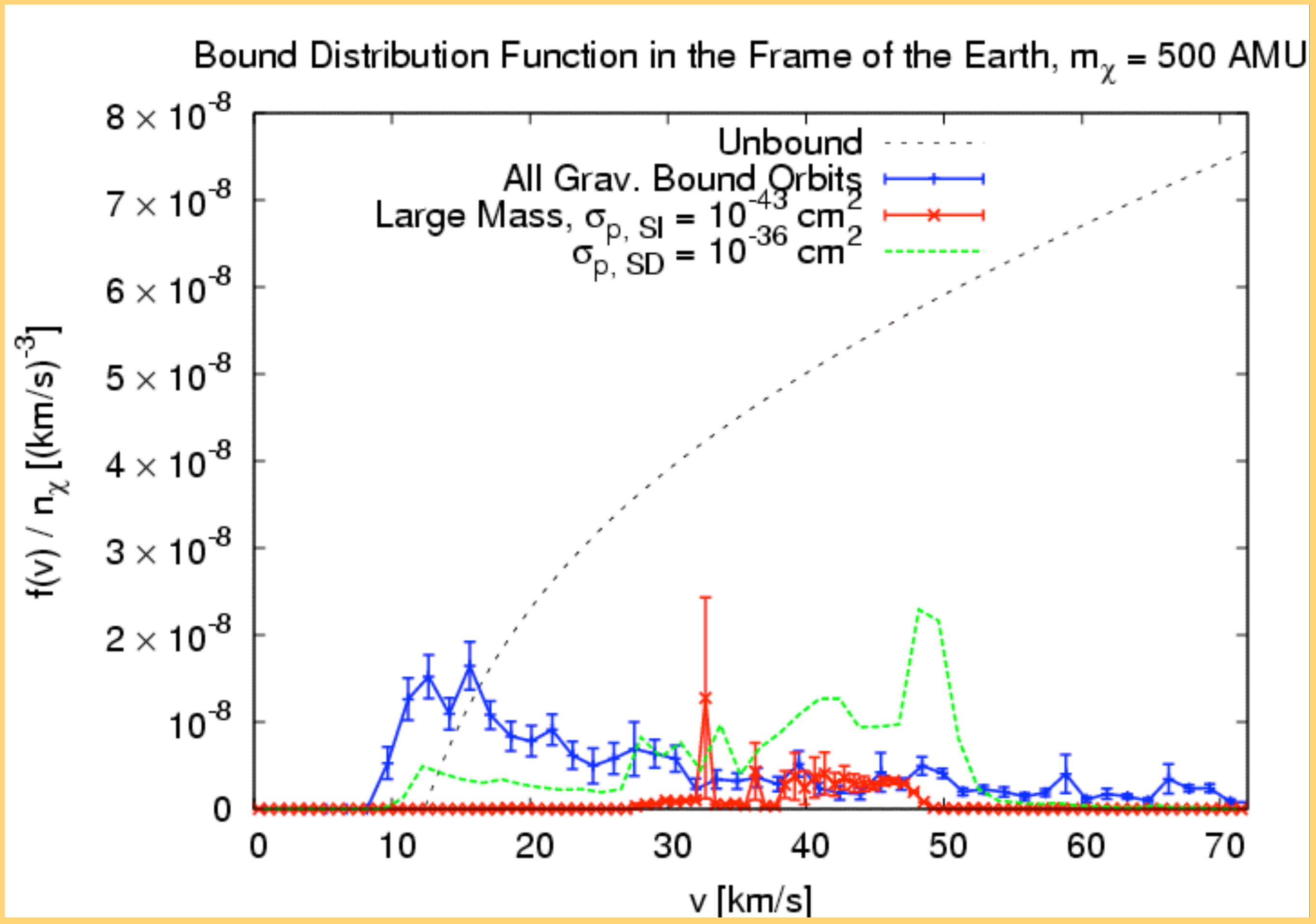


Results: Gravitational Capture

- The curve roughly matches Gould & Alam's theoretical curve for filling Jupiter-crossing orbits to the same density as unbound orbits.
- The bound distribution function only decreases by a factor of 2 if the Sun were infinitely optically thick to WIMPs, and appears so be similarly affected if the Galactic tidal field strips all WIMPs from the solar system if they cross 1000 AU.

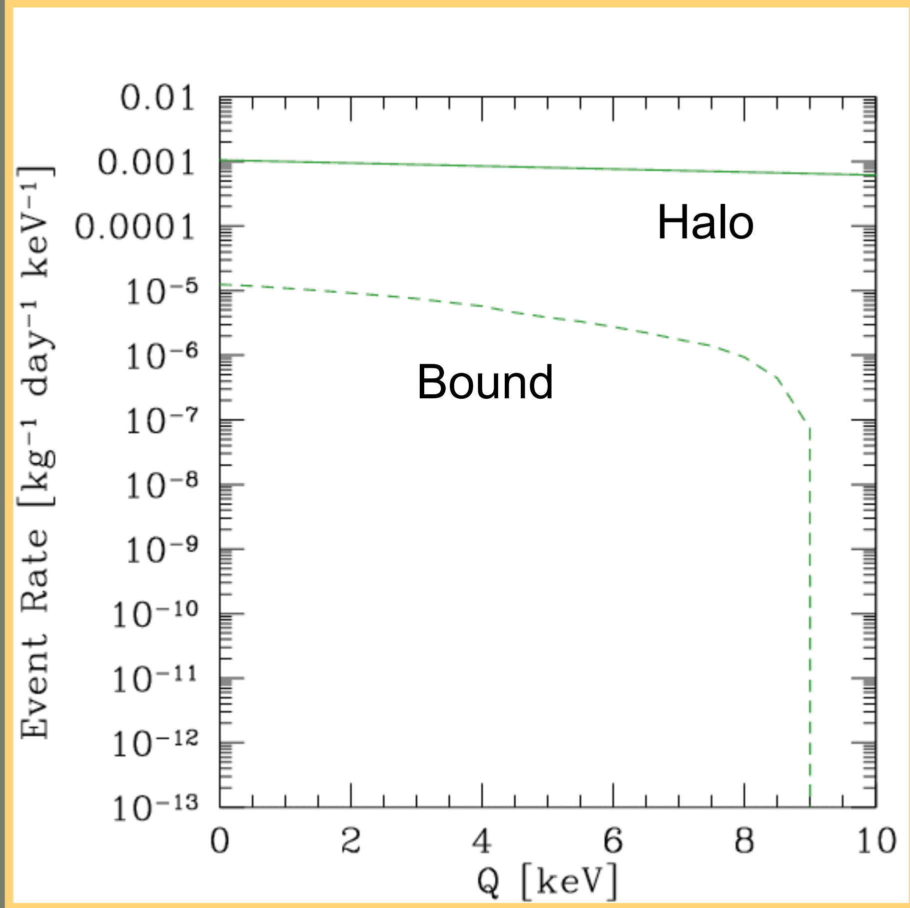


Results: Combined

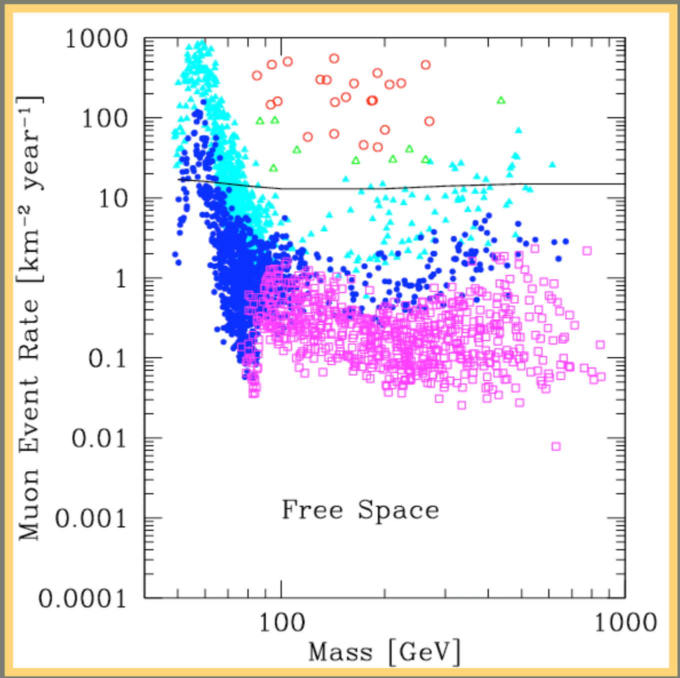


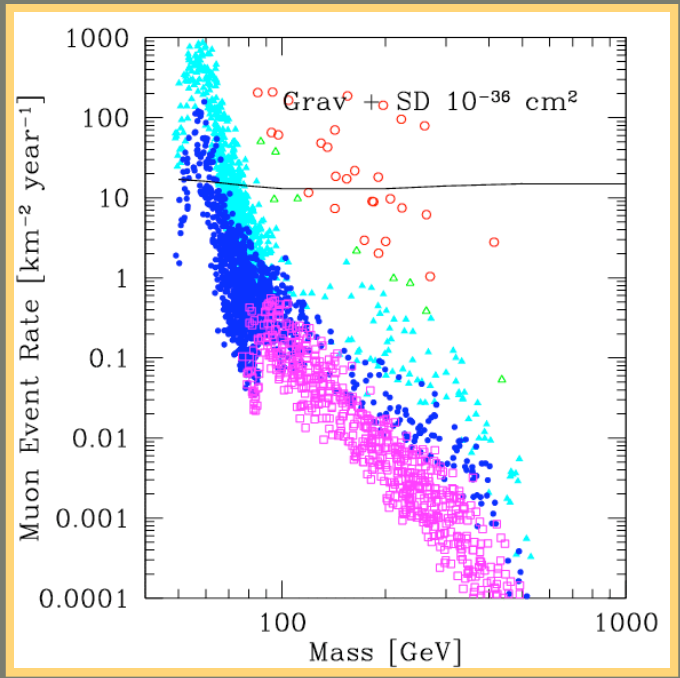
Direct Detection

This is the biggest signal assuming $m_\chi = 500$ GeV, ^{131}Xe target.



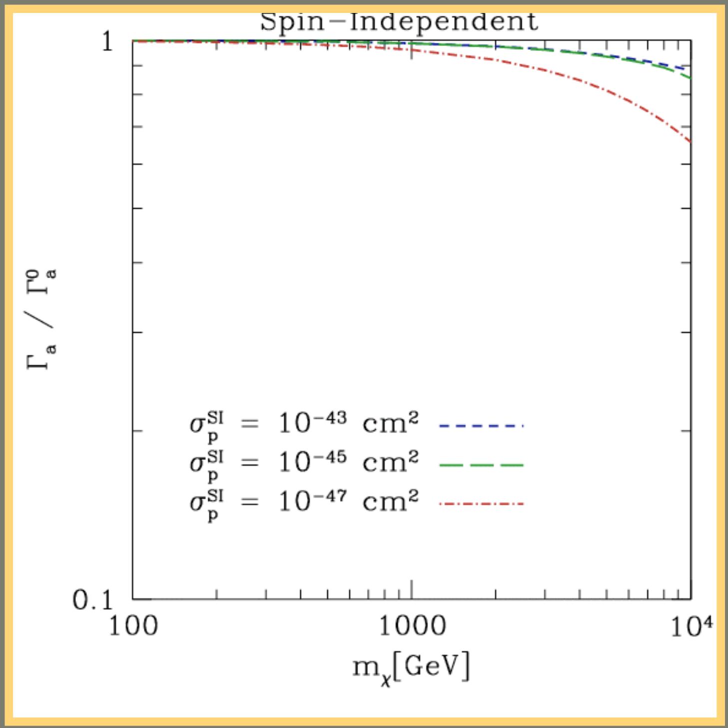
Neutrinos from the Earth

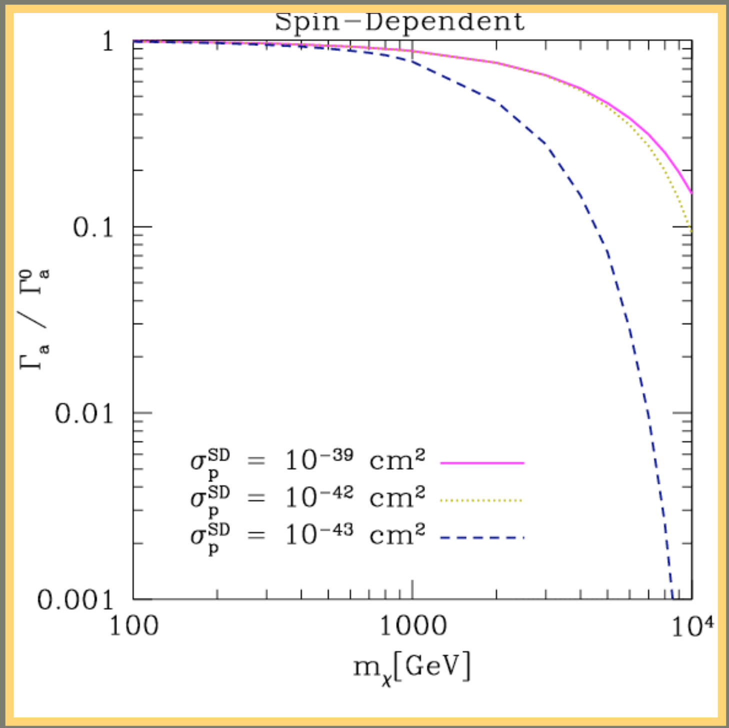




- Maximal signal vs. free space distribution function (using DarkSUSY 7-parameter scan).

WIMP Capture and Annihilation in the Sun (the effects of $t_{life} > t_{\odot}$)





Summary

- The bound population is small:
  - < 1% increase in the direct detection rate.
  - It is unlikely that neutrinos from the Earth will be detectable.
- The annihilation rate of WIMPs in the Sun is moderately to strongly suppressed for m_χ > 1 TeV if spin-dependent interactions dominate in the Sun.
- How will these results hold up if the other planets are included?
  - Annihilation in the Sun: this is not likely to change because the lifetimes of all particles for a given semi-major axis would need to change.
  - Bound distribution function:
    - Capture by elastic scattering: How robust are the long-lifetime orbits?
    - Capture by gravitational scattering: How much will resonances matter? How will the distribution function depend on the opacity of the Sun?
  - To know for sure, we are planning full solar system simulations.