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Conversion of Neutrino Fluxes from Dark Matter Self-annihilations in the Sun to WIMP-nucleon Scattering Cross Sections

Carsten Rott

carott@mps.ohio-state.edu

Center for Cosmology and AstroParticle Physics
The Ohio State University



Thanks to my collaborators !

Takayuki Tanaka, Yoshitaka Itow

Solar-Terrestrial Environment Laboratory, Nagoya University,
Furo-cho, Chikusa-ku, Nagoya, 464-8601, Japan

John Beacom

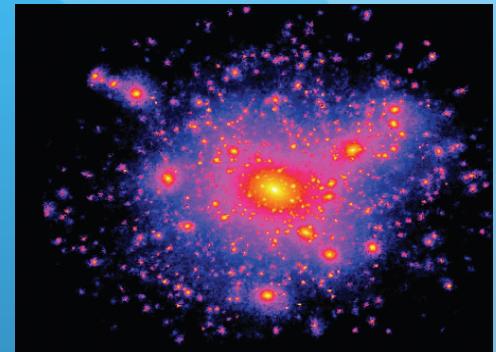
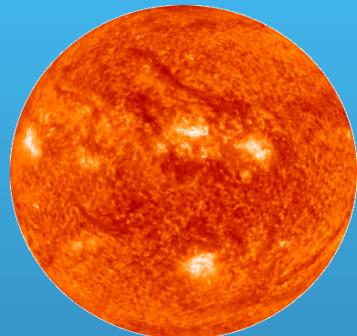
Dept. of Physics and Center for Cosmology and Astro-Particle
Physics, Ohio State University, Columbus, OH 43210, USA

Overview

- Motivation
- How to compare neutrino signals from dark matter self-annihilations in the Sun to direct detection experiments ?
- What uncertainties need to be considered ?
- Conclusions

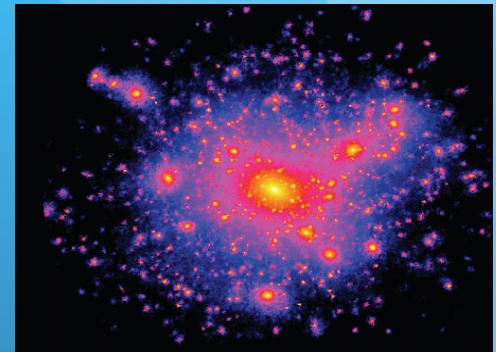
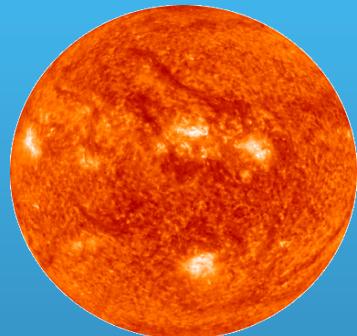
Indirect Detection with Neutrinos

Neutrinos and Dark Matter ...



Solar	Earth	Halo
Neutrino Flux, Scattering cross-section	Neutrino Flux, (Scattering cross-sections)	Neutrino Flux, Self-annihilation cross-section
Muons	Muons	Muons, Cascades
Background off-source on-source, simulations	Background simulations	Background off-source on-source, simulations
$M_{WIMP} \sim < \text{TeV}$	$M_{WIMP} \sim < 100 \text{GeV}$	All M_{WIMP}

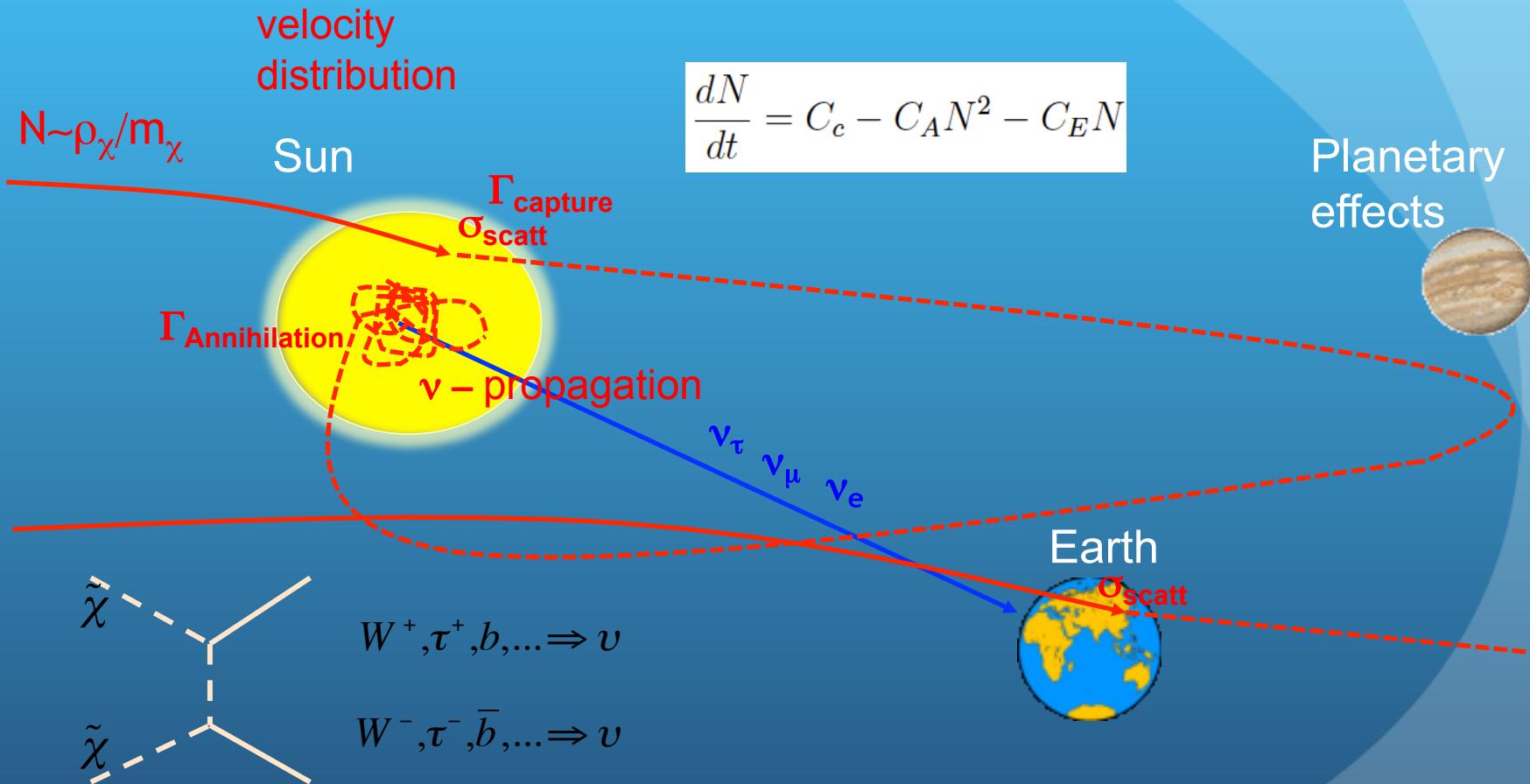
Neutrinos and Dark Matter ...



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Solar WIMPs

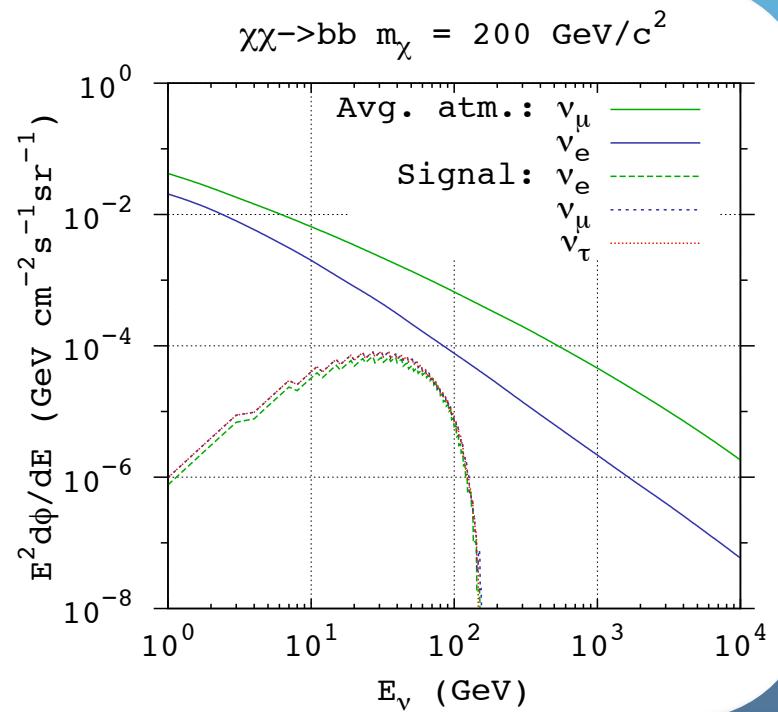
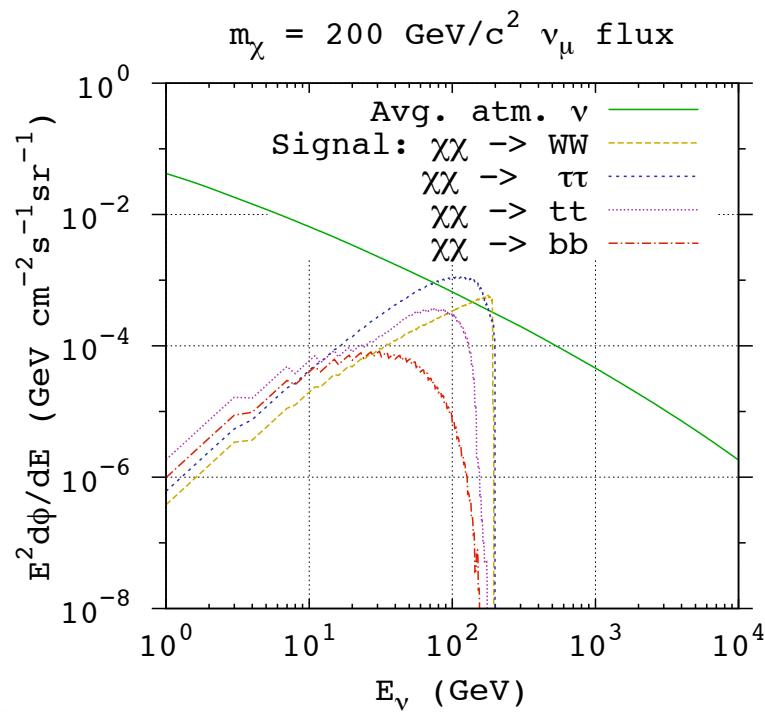
Indirect Detection Principle: Neutrinos from the Sun



$$\frac{dN}{dt} = C_c - C_A N^2 - C_E N$$

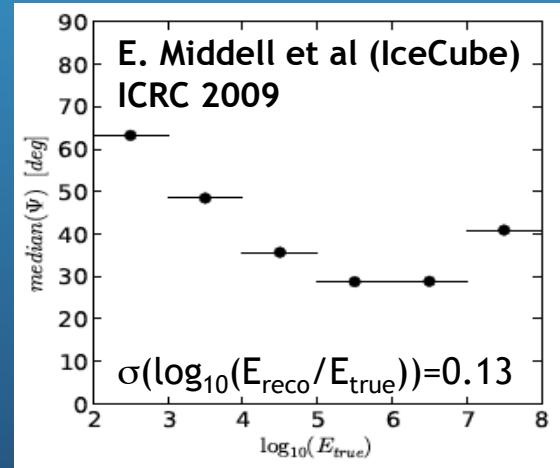
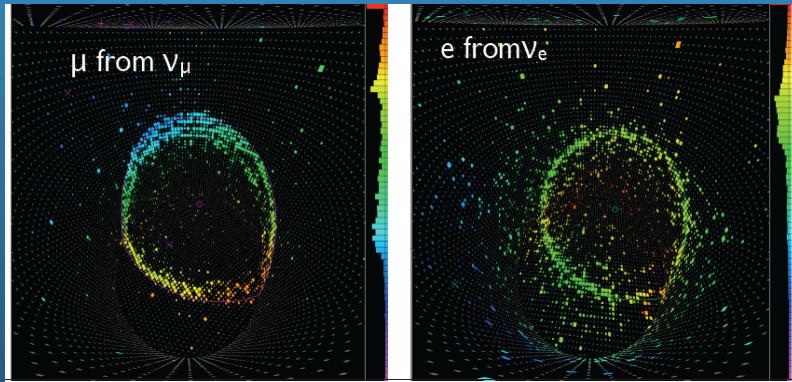
Signal and Background

- Atmospheric Neutrino Flux (Honda)
- Signal flux neutrino + anti-neutrinos



Goal: Solar WIMP searches with all flavors

- Obvious advantages of muons
 - Pointing accuracy (background discrimination)
 - Increased effective area due to muon range
- Super-K has demonstrated electron neutrino sensitivity (Ashie et al. PRD 2005 (hep-ex/0501064))
- Promising results already with partially completed IceCube detector
- Improved sensitivity with Deep Core

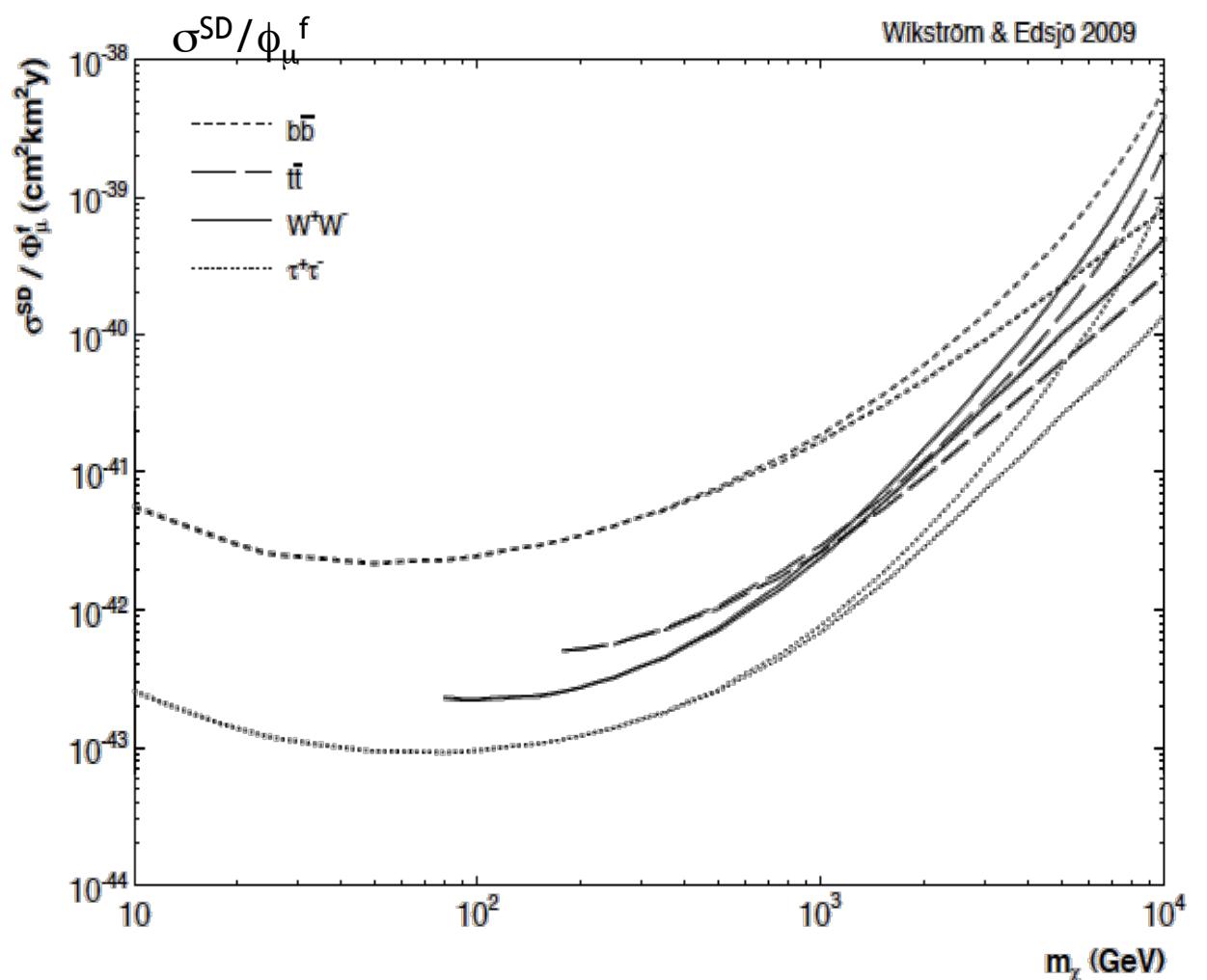


Flux Conversion

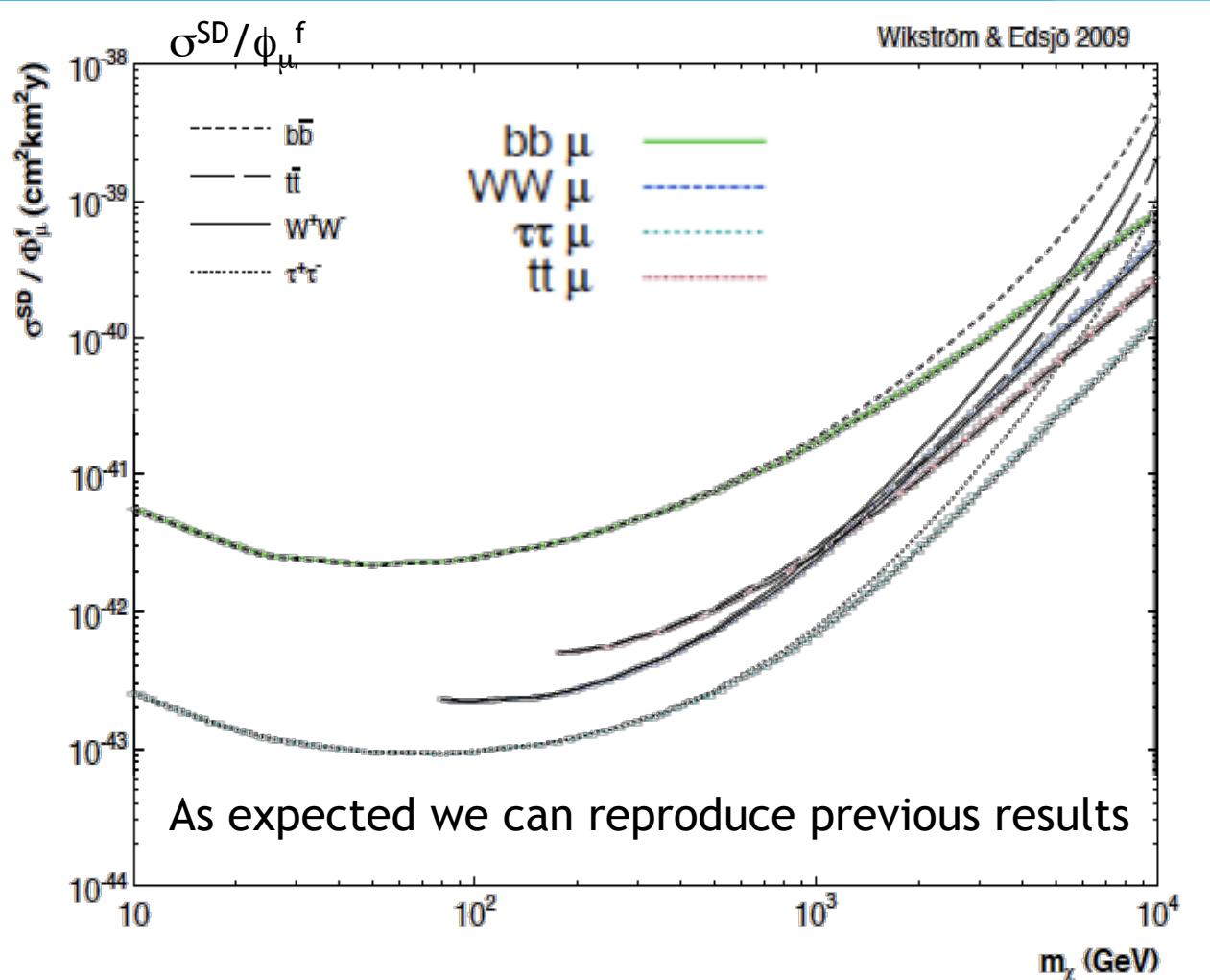
Flux Conversion

- Muon flux
 - M. Kamionkowski et al., Phys. Rev. Lett. 74 (1995) 5174
 - Wikstrom & Edsjo, JCAP04 (2009) 09. arXiv 0903.2986
- Neutrino flux
 - DarkSUSY [P. Gondolo et al., JCAP, 0407, 008 (2004)]
 - This work is based on a study using DarkSUSY version 5.0.4

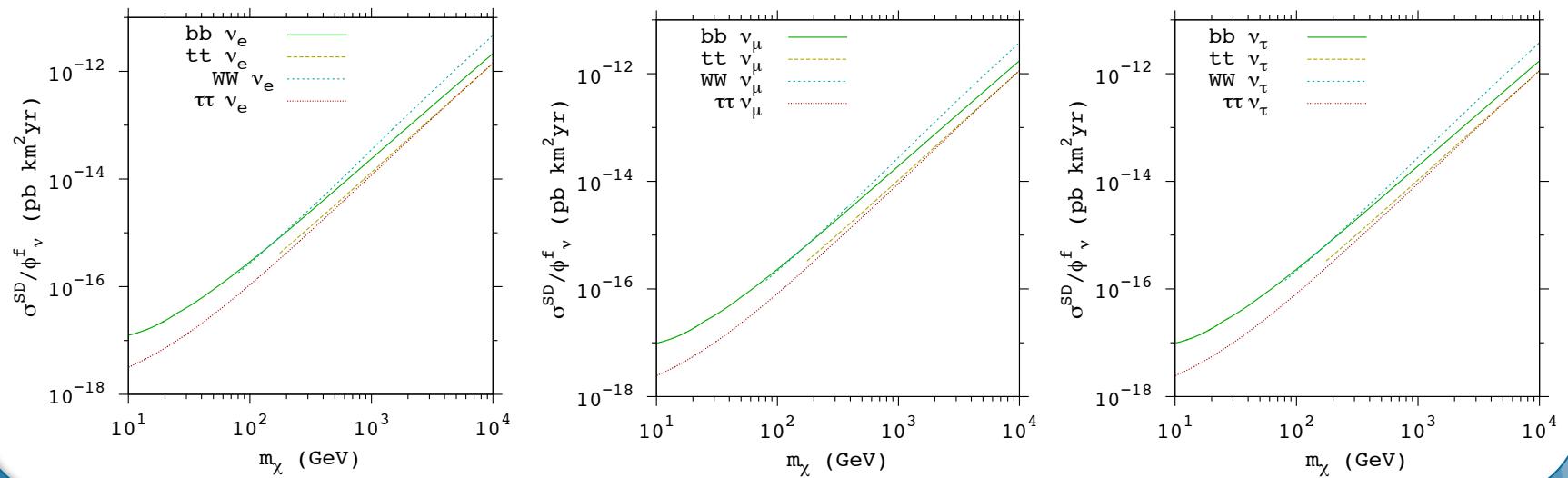
Comparison to previous results



Comparison to previous results

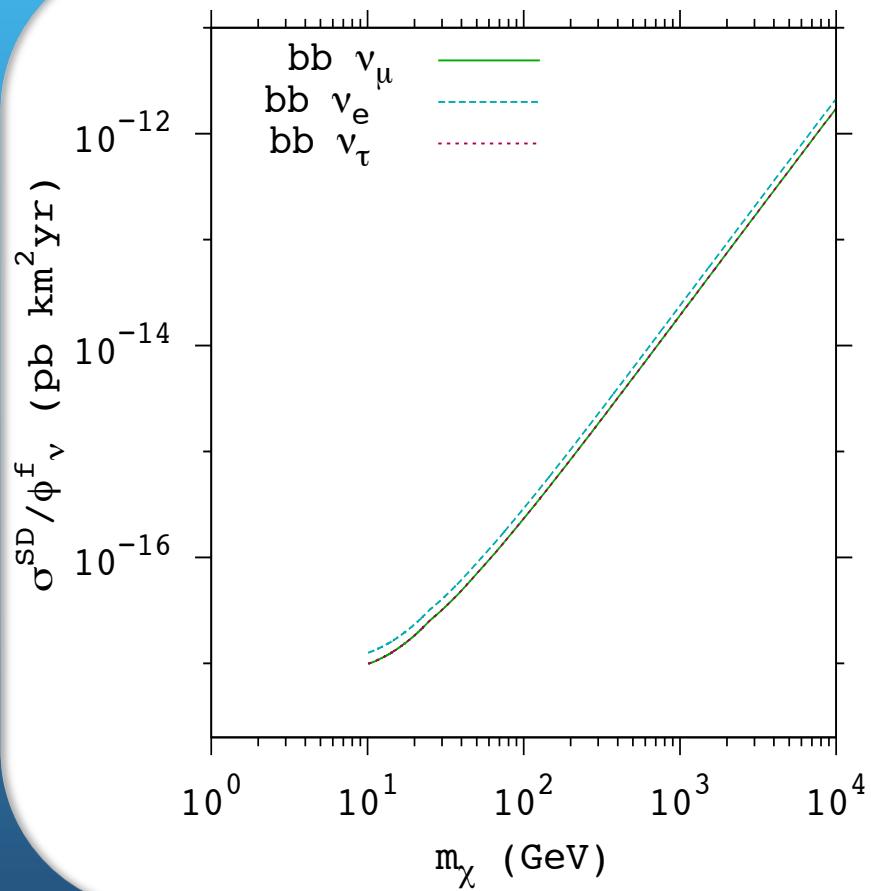


Flux Conversion by flavor



- Set $\sigma^{\text{SI}}=0$
- Neutrino energy threshold $E_\nu=1\text{GeV}$

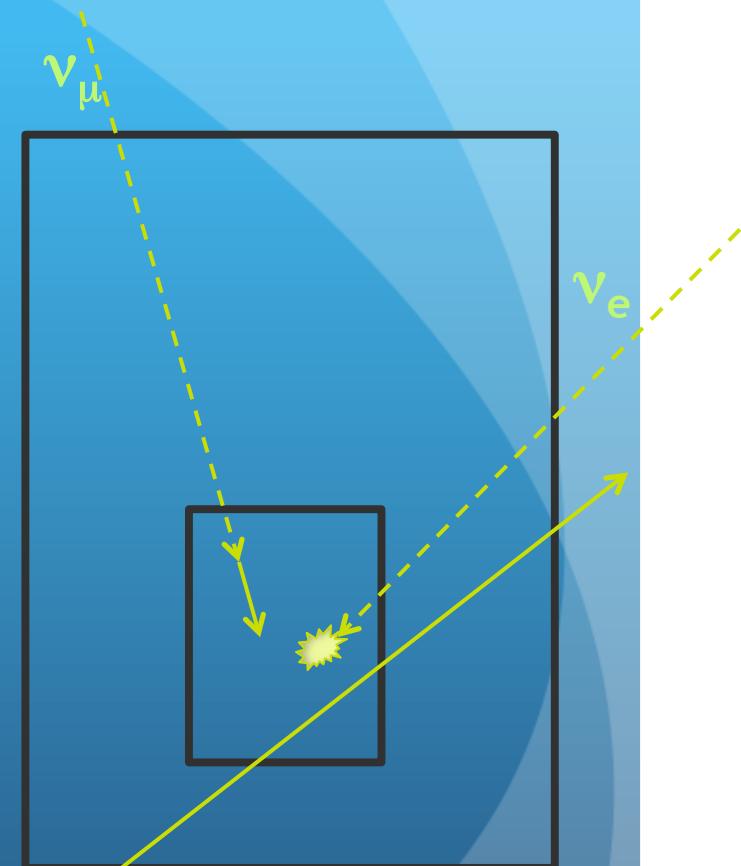
Flux Conversion by annihilation channel



- Conversion factor very similar for the different neutrino flavors
- Differences caused by injection spectrum and oscillations
 - ν_μ and ν_τ identical

Neutrinos vs. Muons

- Vertex Contained Events
 - Treat all flavors in a similar way
 - Flavor ratios might hold additional information on the observed DM flux
 - Better energy resolution
 - If $L_\mu(E_\nu) < L_{\text{detector}}$ small benefit for effective area
 - Utilize all data (not just up-going (Sun is below horizon))
- Less dependence on “muon propagation”
- Optimistic on cascade angular resolution

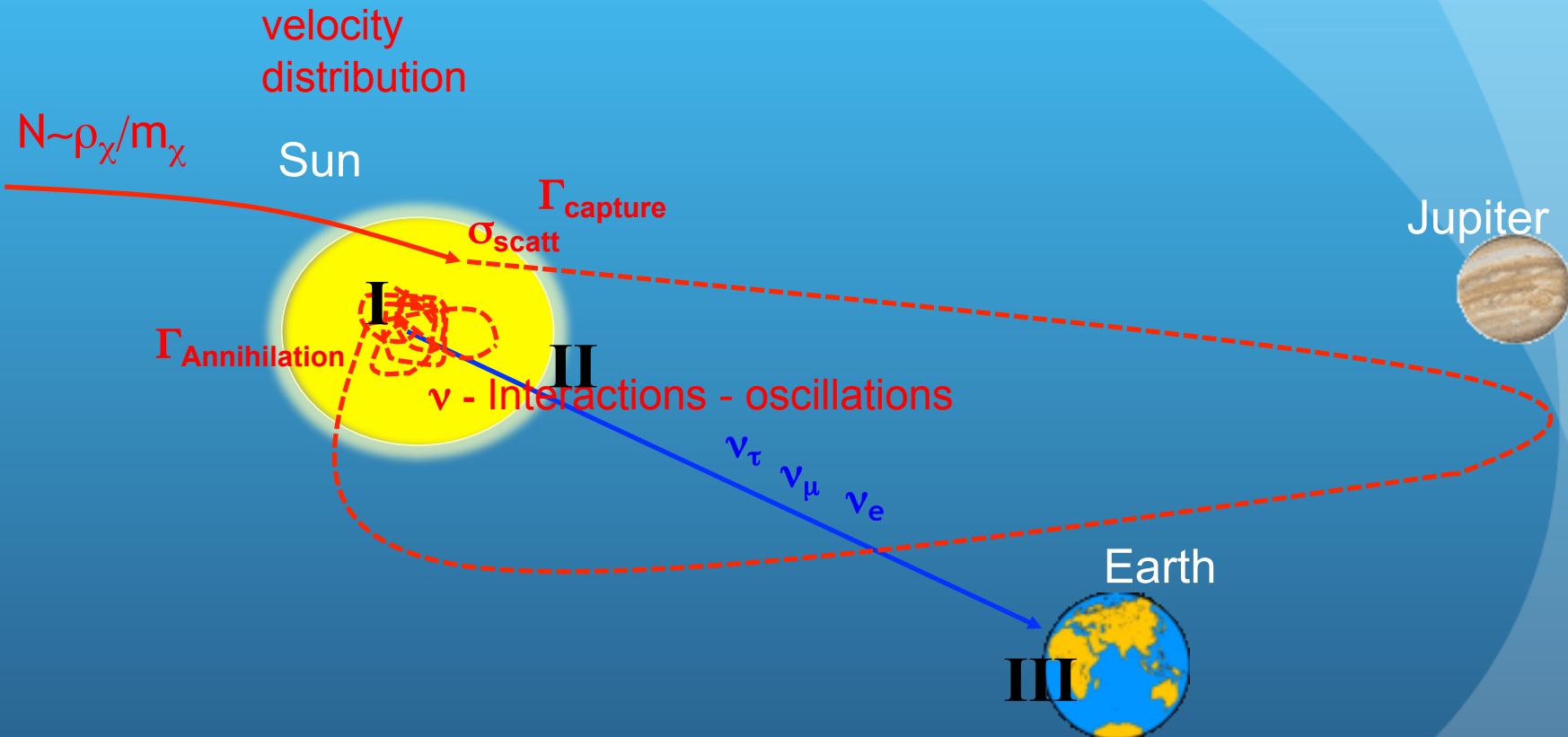


Uncertainty Discussion

Uncertainties

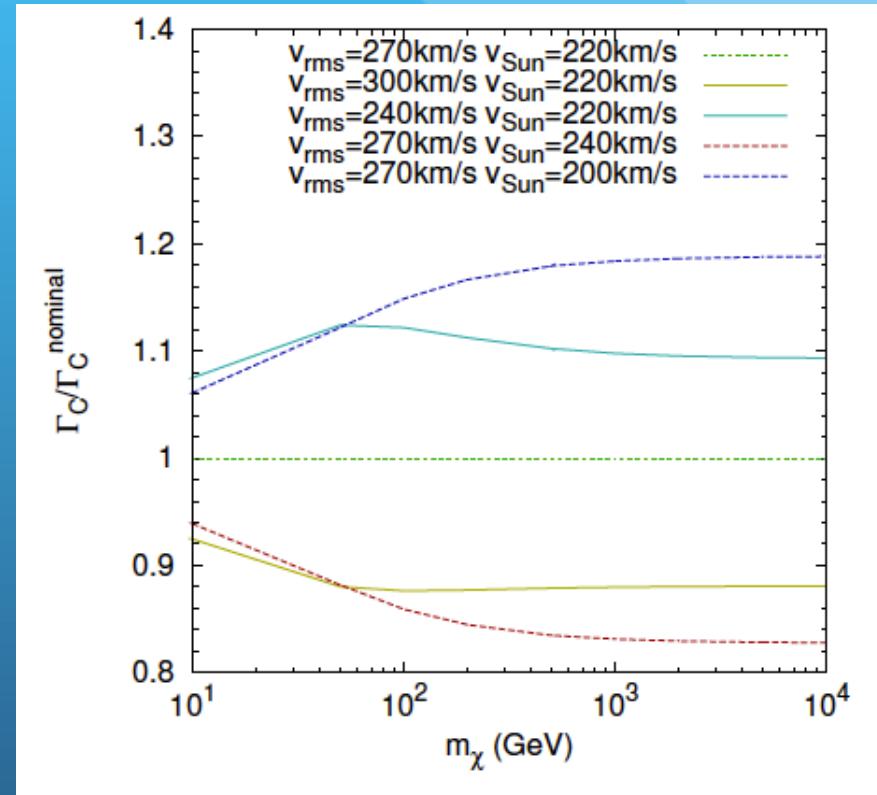
- Divide uncertainties conveniently into three uncorrelated categories:
 - I. Annihilation Rate at Equilibrium
 - Capture Rate
 - Suppression factors
 - II. Neutrino Propagation
 - Matter effects in the Sun
 - Vacuum oscillations Sun -> Earth
 - III. Neutrino Detection
 - Detector site and Detector related effects

Indirect Detection Principle: Neutrinos from the Sun



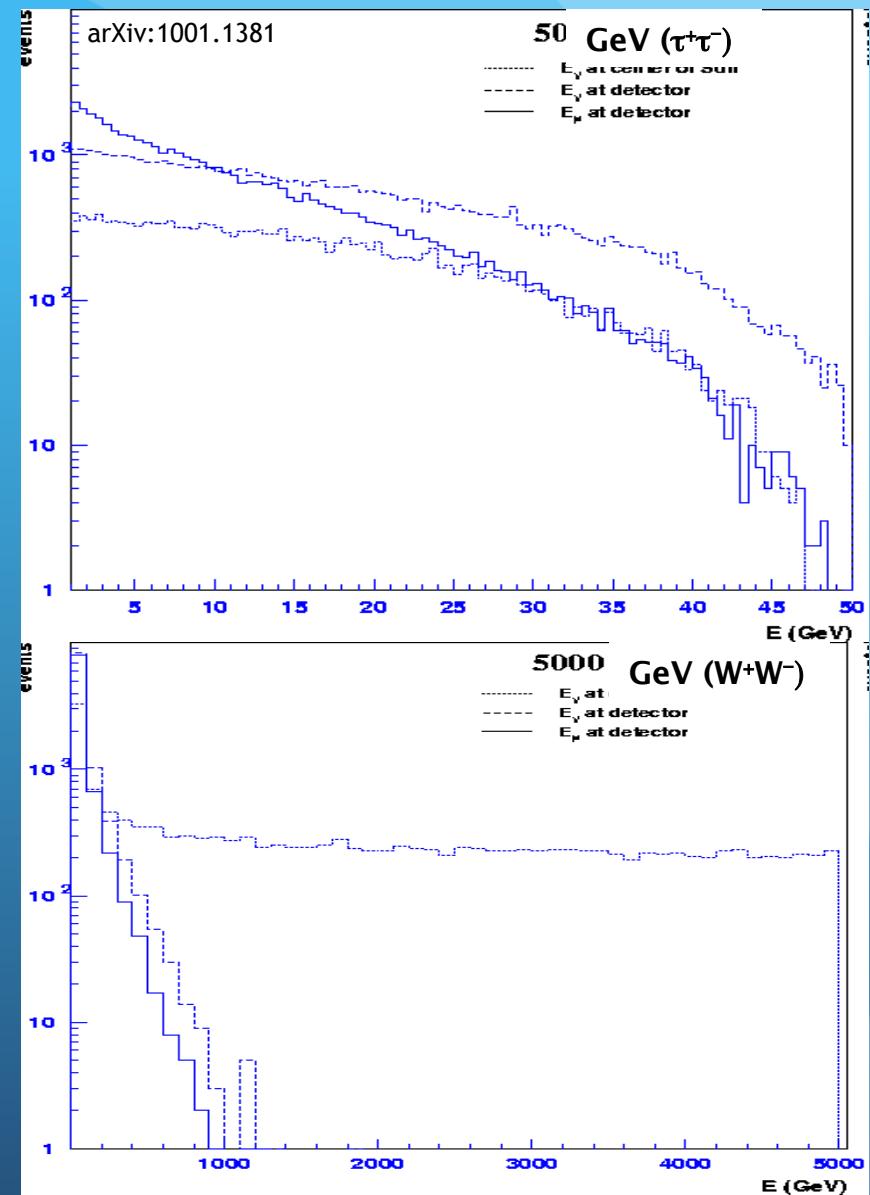
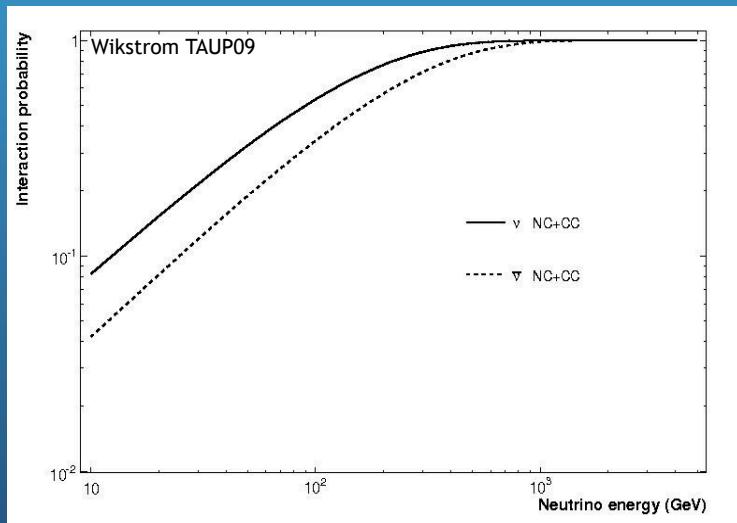
I: Halo Uncertainties on Capture Rate

- Dark Matter Density
 - $\Delta\Gamma_A / \Gamma_A = \Delta\rho_{DM} / \rho_{DM} = 10\%$
 - $dN/dt = C_C - C_A N^2 - C_E N$
- Velocity Distributions
 - $\Delta\Gamma_A / \Gamma_A \sim \Delta v_{rms} / v_{rms}$
 - $\Delta v_{sun} / v_{sun}$ complex dependence
- Sub structure
 - Can be ignored $\langle \rho_{DM}(8.5\text{kpc}) \rangle$
 - Smooth halo well motivated at 8.5 kpc (CDM Simulations)
 - Extreme cases -> “Deviation from equilibrium”
 - Conversion factor can not easily be derived with out detailed knowledge of solar substructure history
- Suppression of capture, composition, evaporation



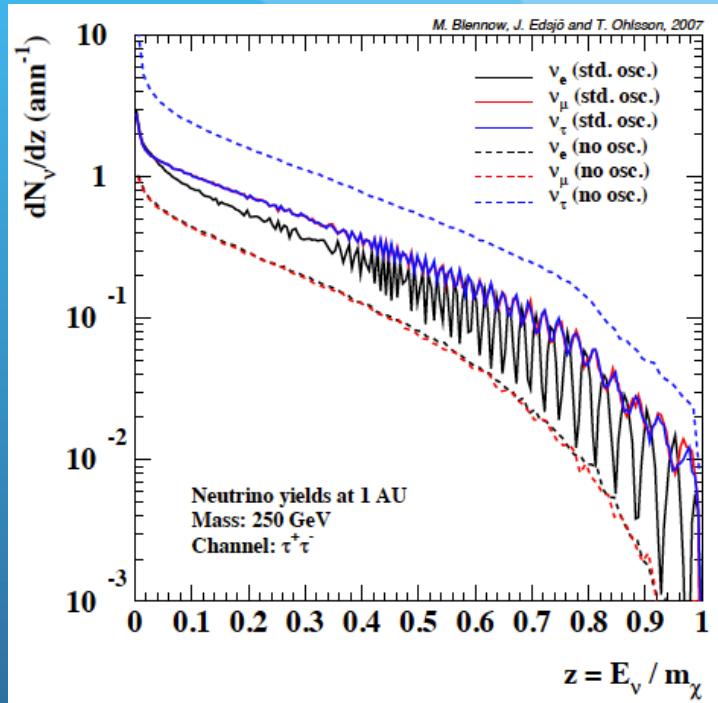
II: Propagation

- High energy neutrinos (1TeV) do not escape the Sun → Indirect dark matter searches from the **Sun** are “low-energy” analysis in neutrino telescopes.



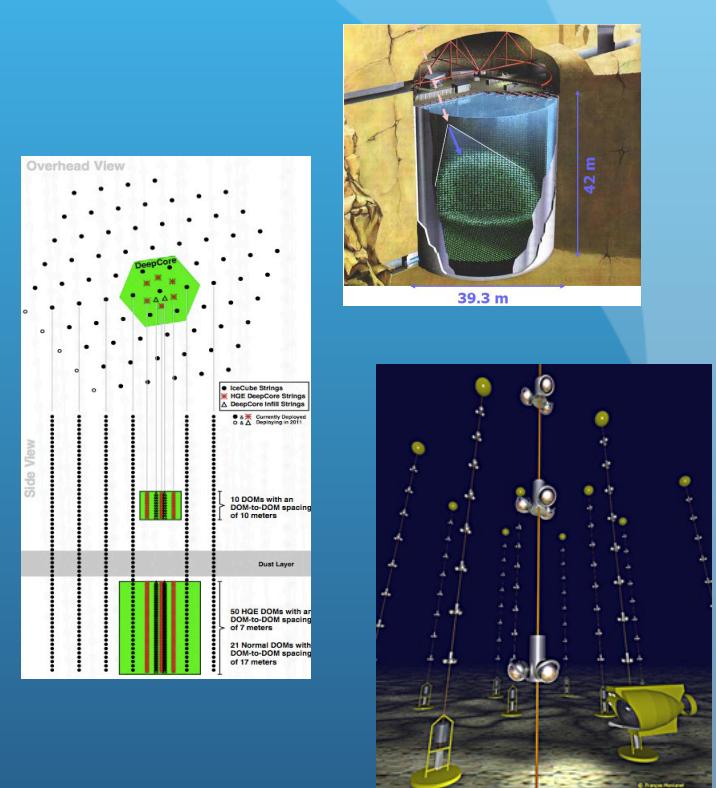
II: Neutrino Propagation

- Matter Effects Sun
 - Oscillations
 - Absorption - tau regeneration
- Vacuum oscillations
- Has been discussed extensively elsewhere:
 - P. Crotty, *Phys. Rev. D* 66, 063504 (2002) [arXiv:hep-ph/0205116].
 - M. Blennow, J. Edsjo, T. Ohlsson (IDM 2008)



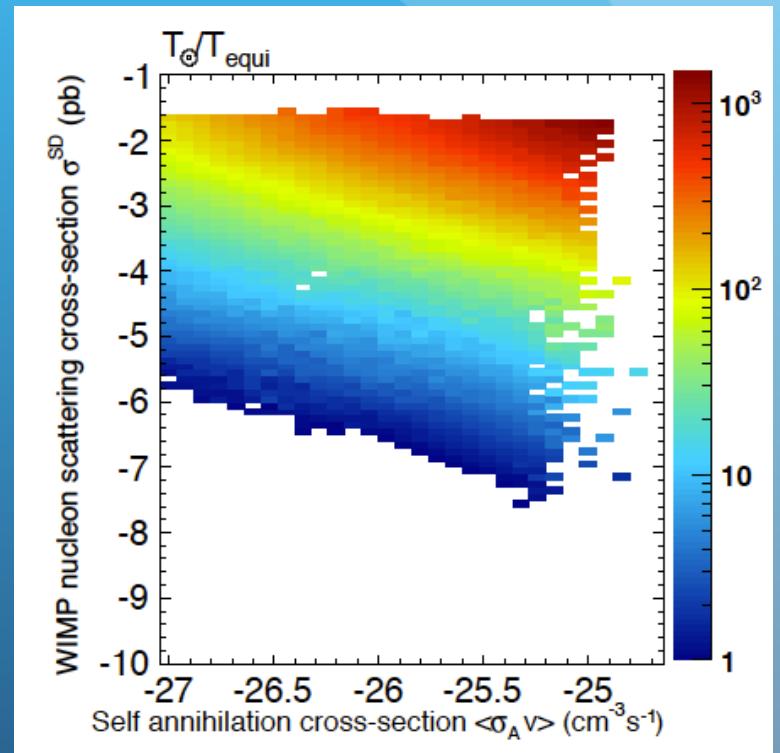
III: Uncertainty Neutrino Detection

- Matter effects (Earth)
- Neutrino cross sections
- Muon Propagation (for tracks)
- Detector related
 - ~20-25% Systematic Uncertainties on signal acceptance
 - Light propagation in optical medium
 - Absolute Optical Sensor Efficiency

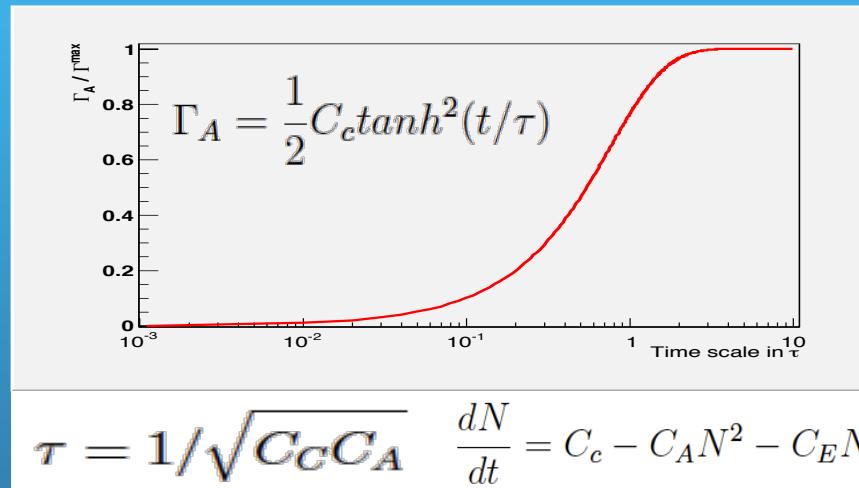


Impact of equilibrium time scale

- Majority of SUSY models yield systems in equilibrium
 - $T_{\text{equi}} \sim 10^8$ years $\ll T_{\text{sun}} \sim 4.5 \times 10^9$ years
- Systems perturbed from equilibrium can be treated using a scale factor correction
- Systems perturbed due to sub structure require more complex treatment

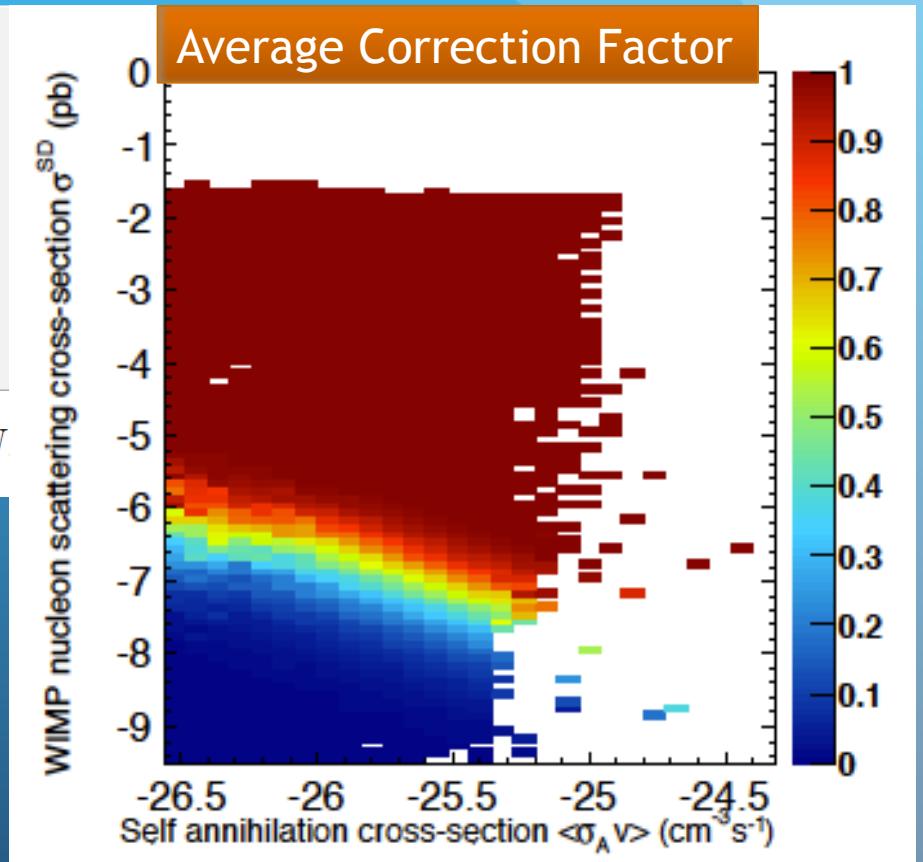


Equilibration time / Flux Correction



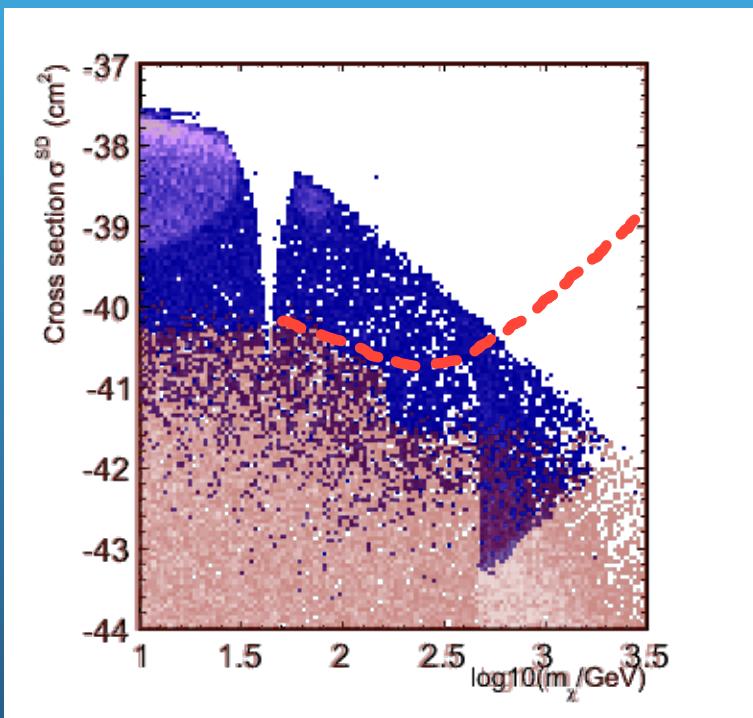
Equilibrium time scale τ determined by:

- Scattering cross section,
- Self annihilation cross section,
- WIMP mass



MSSM-7 Parameter Scan

IceCube + Deep Core Sensitivity
(Muons - 1800 days)



Scan

Models not excluded
(accelerator bounds
on chargino and
neutralino mass have
been removed
 $(T_{\text{equi}} > 4.5 \times 10^9 \text{ years})$
 $(T_{\text{equi}} < 4.5 \times 10^9 \text{ years})$

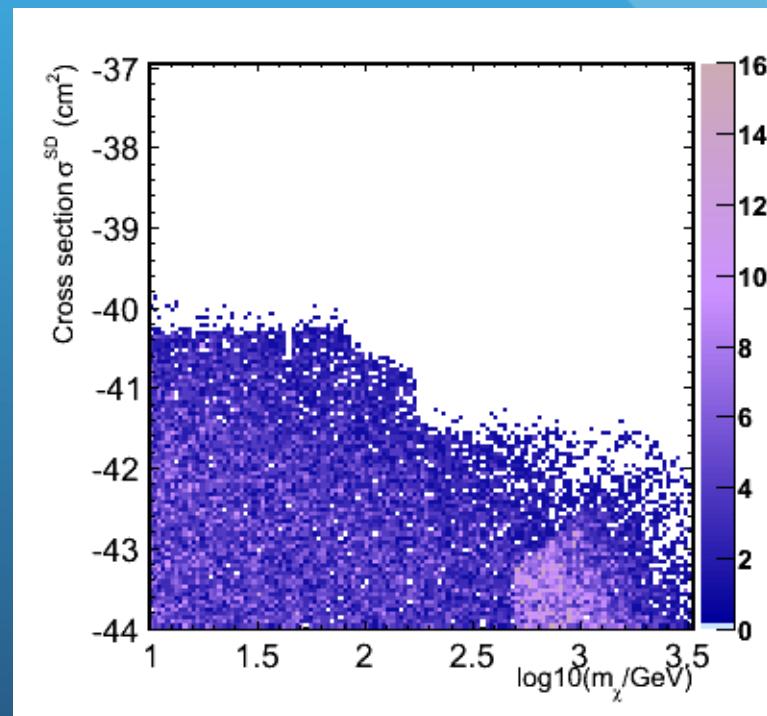
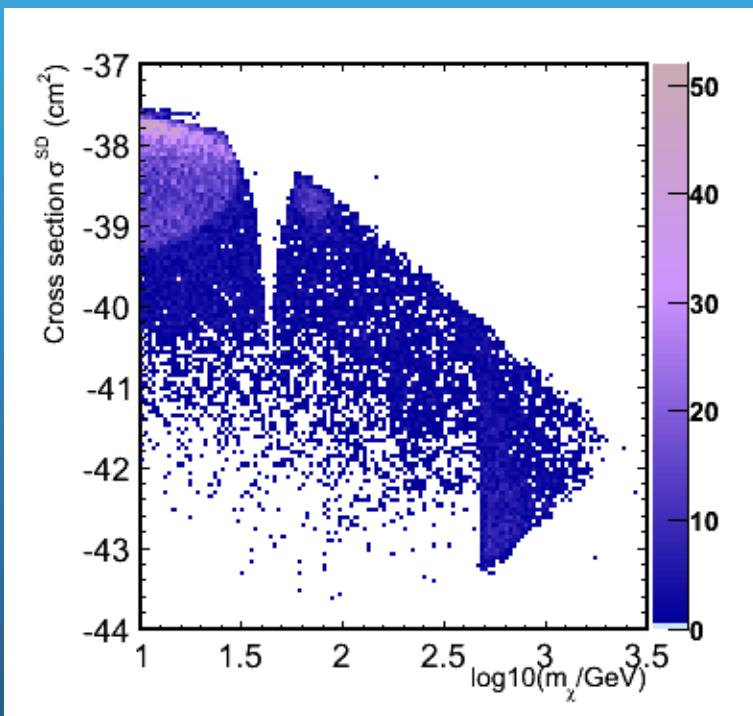
Conclusions

- We studied the comparison of neutrino fluxes from the Sun with the direct detection experiments using DARKSUSY
- We provide a procedure for the treatment of systematic uncertainties associated with the flux conversion
- Detection of signals will require extensive treatment of uncertainties

MSSM-7 Parameter Scan

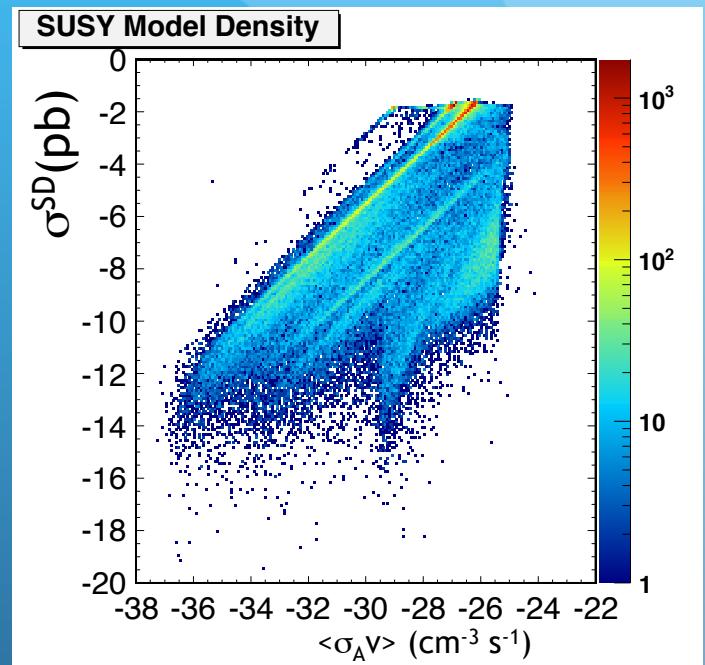
Allowed
 $(T_{\text{equi}} < 4.5 \times 10^9 \text{ years})$

Allowed
 $(T_{\text{equi}} > 4.5 \times 10^9 \text{ years})$



SUSY Parameter Space Scan

- We perform a SUSY parameter scan (MSSM-7)
 - Higgsino mass parameter μ [10,30000]
 - Gausino mass parameter M_2 [10,30000]
 - Mass of CP-odd Higgs boson M_a [10,30000]
 - Mixing angle $\tan\beta$ [1,60]
 - Common mass scale factor m [10,30000]
 - Squark mass parameter A_t : A_t/m [-3,3]
 - Squark mass parameter A_b : A_b/m [-3,3]
- Parameters are specified at the electroweak scale
- Models are required to be consistent with:
 - WMAP cosmology
 - Accelerator constrains
 - Constraints for chargino and neutralino are not considered, this allows scans down to 10GeV



Flux Conversion ... earlier works

- Muon Flux for SI and SD cross sections

