Neutrinos from WIMP annihilations in the Sun including neutrino oscillations

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Abstract. The prospects to detect neutrinos from the Sun arising from dark matter annihilations in the core of the Sun are reviewed. Emphasis is placed on new work investigating the effects of neutrino oscillations on the expected neutrino fluxes.

1. WIMP capture and annihilation in the Sun

Weakly Interacting Massive Particles (WIMPs) in the Milky Way halo can scatter in the Sun and be gravitationally bound to it. Eventually, they will scatter again and sink to the core of the Sun. In the core, WIMPs will accumulate and can annihilate and produce neutrinos.

2. Neutrino interactions

On the way out of the Sun, neutrinos can participate in both charged- and neutral-current interactions. Neutral-currents degrade the energy of the neutrinos, whereas charged-currents give a charged lepton. Electrons and muons are stopped before they can give neutrinos, which means that electron and muon neutrinos are lost, while tau leptons will decay and produce new neutrinos (regeneration).

Then, what about the spectra beyond the Sun? At the surface of the Sun, some of the neutrinos have interacted, and thus, the flux at high energies is degraded. However, some of these neutrinos reappear at low energies both from neutral-current interactions and tau decays.

3. Neutrino oscillations

We use a completely general three-flavor neutrino oscillation scheme (with matter effects included) and a realistic solar model [1]. Thus, at the surface of the Sun, we obtain the fluxes in a general format (including both amplitudes and phases of the neutrino oscillations). Furthermore, in our computations, neutrino oscillations and interactions are treated simultaneously. We have used the following values of standard neutrino oscillation parameters (which are the central values from Ref. [2] with no CP violation in neutrino oscillations and a normal neutrino mass hierarchy): $\theta_{12} = 33.2^\circ, \theta_{13} = 0, \theta_{23} = 45.0^\circ, \delta = 0, \Delta m^2_{21} = 8.1 \cdot 10^{-5}\,\mathrm{eV}^2, \Delta m^2_{31} = 2.2 \cdot 10^{-3}\,\mathrm{eV}^2$.

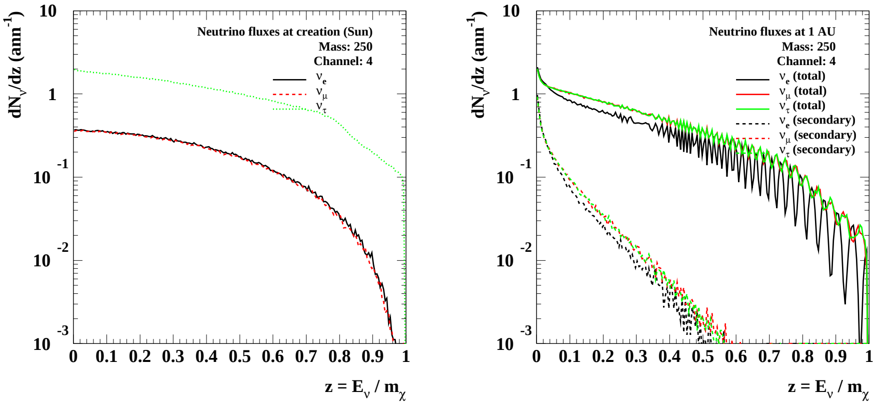

Figure 1. *Left:* Initial neutrino fluxes at the center of the Sun. *Right:* Neutrino fluxes at 1 AU.

4. Propagation to and in the Earth

First, for the propagation to the Earth, vacuum neutrino oscillations to the Earth are included in the same three-flavor neutrino setup. In addition, effects of the eccentricity of the Earth's orbit are included. In Fig. 1, we plot the initial neutrino fluxes at the center of the Sun, *i.e.*, at the point of production, as well as we show an example of the propagation of neutrinos from the center of the Sun to the distance of the Earth, *i.e.*, on the distance of 1 AU).

Second, for the propagation in the Earth, matter effects are included in the neutrino oscillations as well. Our simulations are made with a time stamp to include effects of the Earth's distance to the Sun (due to the eccentricity of the orbit) and rotation (affects the distance traversed in the Earth).

5. Summary and conclusions

For typical WIMP masses (*i.e.*, 10–10^5 GeV), neutrino oscillations effectively: 1. average ν_μ and ν_τ on the way out of the Sun, 2. average $\nu_{\rm e}$ and ν_μ/ν_τ on the way to the Earth, and 3. wash out the remaining oscillation patterns in the spectra due to the eccentricity of the Earth's orbit.

Note that the full scheme described above is implemented as a complete event-based Monte Carlo code. In addition, it should be mentioned that other computations of neutrinos from WIMP annihilations have been performed, such as the study by Cirelli *et al.* [3]. However, their results are not event-based.

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