Earth WIMP search with IceCube

Jan Kunnen for the IceCube Collaboration
Outline

1. Indirect Earth WIMP detection with neutrinos
   I. how,
   II. status,
   III. theoretical predictions

2. The IceCube Neutrino Detector

3. Signal and Background

4. Expected Sensitivity

5. Summary and Conclusion
Indirect WIMP detection with neutrinos: WIMP capture
Indirect WIMP detection with neutrinos: WIMP annihilation
Current limits on neutrino induced Muon flux coming from Earth WIMPs

Most recent result dates from AMANDA. No Earth WIMP analysis with IceCube yet. Time to pick up the analysis again!

A. Achterberg et al. / Astroparticle Physics 26 (2006) 129-139
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History of the Earth Capture Rate

Capture rates

First calculations. Free space
Earth in grav. pot. of Sun
DM diffusion in solar system
Asteroids? Solar depletion
Num. study of solar depletion
Analytical treatment


Freese, etc  Gould  Gould  Gould & Alam  Lundberg & Edsjö  Sivertsson & Edsjö

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Seems like it is interesting to look at Earth WIMPs again!

History of the Earth Capture Rate

Capture rates

Freese, etc Gould Gould Gould & Alam Lundberg & Edsjö Sivertsson & Edsjö

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Why are low velocities needed for Capture in the Earth?

Capture only occurs when a WIMP scatters off a nucleus to a velocity less than the escape velocity.

Capture on Fe, only if WIMP velocity is lower than

$$u_{\text{cut}} = 2 \frac{\sqrt{M_\chi M_{Fe}}}{M_\chi - M_{Fe}} v_{\text{esc}}$$

Or, alternatively, for a given velocity, we can only capture WIMPs up to a maximal mass.
The WIMP velocity distribution at the Earth

Most of the WIMPs in the Dark Halo have too high velocities to be captured by the Earth.
The WIMP velocity distribution in case of a dark disc

Simulations indicate existence of a thick disc of dark matter.

Baryonic disc of the Milky Way draws satellites closer to the disc plane.

Result: thick disc of dark matter with

\[ 0,25 < \frac{\rho_d}{\rho_h} < 1,5 \]
Predicted Muon Flux with and without Dark Disc

The IceCube Neutrino Observatory

Detector completion In December 2010

5160 DOMs on 86 strings

Central part : DeepCore
- Deployed in deepest, clearest ice
- Lowers energy threshold to ~10 GeV
- IceCube as active veto (muon shield)
Signal and Background
Removing the background:
the AMANDA Earth WIMP analysis

WIMP signal

Data is dominated by atmospheric muons

Atmospheric Neutrinos
Removing the background: the AMANDA Earth WIMP analysis

15% WIMP signal left

2.5% atmospheric Neutrinos left

Atmospheric muon background reduced by a factor \( >10^8 \).

Data is now dominated by atmospheric neutrinos

Data agrees well with background predictions at all levels
Selecting the interesting events

1. IceCube has a dedicated online filter to select Earth WIMP neutrinos.
2. High level filters have to be developed.

Some parameters to base our selection on:

- Reconstructed zenith angle
- Veto layers
- Energy cuts
- ...
The predicted Muon flux with expected sensitivity

Since we are looking for vertical tracks, each string practically acts as a single detector → going from 19 AMANDA strings to 86 IceCube strings is a huge increase in efficiency.
More details about my analysis

Similar to Solar, Galactic Centre, ... analyses, but in this analysis we cannot just define an off-source region \(\rightarrow\) need to rely on simulations and extra-polation methods.

In order to work as model independent as possible, we select neutrinos coming from the center of the Earth, up to a certain energy, without further assumptions as signal.

We look for a bump in the neutrino rate from the direction of the center of the Earth.
Summary and Conclusion

1. Indirect Earth WIMP detection with neutrinos
   I. How -> WIMP capture and annihilation
   II. Status -> No IceCube limits yet
   III. theoretical predictions -> high capture rate, dark disc ?

2. The IceCube Neutrino Detector

3. Signal and Background

4. Expected Sensitivity -> We will cut in the theoretical phase space!
BACKUP SLIDES
A simulated upgoing neutrino

Type: NuMuBar
E(GeV): 8.15e+01
Zen: 177.73 deg
Azi: 7.45 deg
NTrack: 1/1 shown, min E(GeV) == 78.84
NCasc: 7/7 shown, min E(GeV) == 2.69
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What should be optimized?
The effective area!

\[ A_{\text{eff}} = \frac{\text{observed event rate}}{\text{incoming flux}} \]
What should be optimized?

The effective area!

$$A_{\text{eff}} = \frac{\text{observed flux}}{\text{generated event rate}}$$
The WIMP velocity distribution at the Earth

Sivertsson & Edsjö, 2012

Unbound (at solar system), Gauss (free space)
Unbound (at Earth in Sun’s frame)
Unbound (at Earth in Earth’s frame)
Bound (at Earth in Earth’s frame)
Total (at Earth in Earth’s frame)
Bound (with hole, at Earth in Earth’s frame)
Total (with hole, at Earth in Earth’s frame)
Earth Capture Rate

\[ \sigma_{SI} = 10^{-42} \text{ cm}^2 \]

\[ \text{Capture rate in the Earth, } C \text{ (s}^{-1}) \]

\[ \text{WIMP mass, } M \text{ (GeV)} \]
Removing the background: the AMANDA Earth WIMP analysis
Removing the background: the AMANDA Earth WIMP analysis

<table>
<thead>
<tr>
<th>cut</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>cut 1</td>
<td>$\theta(DW) &gt; 65^\circ \text{ OR } (\text{usdhits} \geq 3 \text{ AND } \text{upratio} &gt; 0.42)$</td>
</tr>
<tr>
<td>cut 1 b</td>
<td>$N_{\text{hits}} &lt; 350$</td>
</tr>
<tr>
<td>cut 2</td>
<td>$\theta(16it_{DW}) &gt; 80^\circ \text{ OR } \theta(16it_{lf}) &gt; 80^\circ$</td>
</tr>
<tr>
<td>cut 3</td>
<td>$\theta(32it) &gt; 140^\circ$</td>
</tr>
<tr>
<td>cut 4</td>
<td>$N_{\text{dir}}(-15:75) &gt; 5$</td>
</tr>
<tr>
<td>cut 5</td>
<td>$P_{ha} + P_{he} &gt; 0.8$</td>
</tr>
<tr>
<td>cut 6</td>
<td>$r_{aline} &gt; 0.5$</td>
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<tr>
<td>cut 7</td>
<td>$N_{\text{dir}}(-15:25) &gt; 5$</td>
</tr>
<tr>
<td>cut 8</td>
<td>$\frac{\log\mathcal{L}(\text{casc})}{\log\mathcal{L}(\mu)} &gt; 0.96$</td>
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<td>cut 9</td>
<td>$L_{\text{dir}}(-15:25) &gt; 50\text{m}$</td>
</tr>
<tr>
<td>cut 10</td>
<td>$P_{ha} + P_{he} &gt; 0.95$</td>
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<tr>
<td>cut 11</td>
<td>$</td>
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<tr>
<td>cut 12</td>
<td>$0 \text{ rad} &lt; \sigma_{\theta} &lt; 0.11 \text{ rad}$</td>
</tr>
<tr>
<td>cut 13</td>
<td>$N_{\text{dir}}(-15:25) &gt; 6$</td>
</tr>
<tr>
<td>cut 14</td>
<td>$\theta(32it) &gt; 170^\circ$</td>
</tr>
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Angular Resolution

The angular resolution below 300 GeV is dominated by the increasing kinematic angle between neutrino and muon.