DM-Ice
A Search for Dark Matter at the South Pole

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Dark Matter Underground and in the Heavens 2011
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18 - 29 July, 2011
Bounds on Dark Matter from Terrestrial Experiments

Spin-Independent

Spin-Dependent


One, maybe two signals.

One claim for discovery: DAMA
Bounds on Dark Matter from Terrestrial Experiments

Spin-Independent

Spin-Dependent

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One claim for discovery: DAMA

J.I. Collar, arXiv:1106.0653
Possible Sources of Annual Modulation

• **Environmental Effects/Backgrounds**
  - Ambient temperature variation
  - Muon flux depend on temperature/pressure in the upper atmosphere
  - Spallation neutrons from muons interaction in rock
  - Radon diffusion from rocks may be varying with time
  - detector and lab maintenance timing

Many of these factors tend to have periodicity of 1 year

• **Detector Effects**
  - quenching factor
  - channeling
  - Xenon scintillation function
  - “Nygren effect”

• **Astrophysical Uncertainties?**
  - $f(v)$? $v_{esc}$? $v_0$? co-rotating?

• **Dark Matter Physics**
  - inelastic scattering
  - iso-spin violation
  - spin-dependent
Possible Sources of Annual Modulation

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• Dark Matter Physics
  – inelastic scattering
  – iso-spin violation

Repeat experiment in different environment. Look for annual modulation with NaI(Tl) in Southern Hemisphere.
Why South Pole?

- The phase of the dark matter modulation is the same.
- Many environmental variations are either opposite in phase (e.g. muon rate) or absent (e.g. temperature, neutrons).
- > 2500 m.w.e. of overburden with clean ice.
  - Clean ice $\rightarrow$ no lead/copper shielding necessary. No radons.
  - Ice $\rightarrow$ neutron moderator.
  - Ice as an insulator $\rightarrow$ No temperature modulation.
- Existing infrastructure
  - NSF-run Amundsen-Scott South Pole Station
  - Ice drilling down to 2500 m developed by IceCube
  - Muon veto by IceCube/DeepCore
  - Infrastructure for construction, signal readout, and remote operation
DM-Ice Sensitivity and a DAMA-Like Signal

Sensitivity

Model-Independent: Assume DAMA-like signal, statistics

<table>
<thead>
<tr>
<th></th>
<th>2 NAIAD</th>
<th>NAIAD size</th>
<th>DAMA size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years</td>
<td>17.0 kg</td>
<td>44.5 kg</td>
<td>250 kg</td>
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<tr>
<td>NAIAD background</td>
<td>1</td>
<td>0.45</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.77</td>
<td>1.25</td>
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<tr>
<td></td>
<td>5</td>
<td>1.00</td>
<td>1.61</td>
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<td></td>
<td>7</td>
<td>1.18</td>
<td>1.91</td>
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<tr>
<td>50% NAIAD background</td>
<td>1</td>
<td>0.63</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.09</td>
<td>1.77</td>
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<tr>
<td></td>
<td>5</td>
<td>1.41</td>
<td>2.28</td>
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<td></td>
<td>7</td>
<td>1.67</td>
<td>2.70</td>
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<tr>
<td>Double DAMA background</td>
<td>1</td>
<td>0.85</td>
<td>1.37</td>
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<tr>
<td></td>
<td>3</td>
<td>1.47</td>
<td>2.38</td>
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<tr>
<td></td>
<td>5</td>
<td>1.90</td>
<td>3.07</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2.25</td>
<td>3.64</td>
</tr>
<tr>
<td>DAMA background</td>
<td>1</td>
<td>1.20</td>
<td>1.94</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.08</td>
<td>3.37</td>
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<tr>
<td></td>
<td>5</td>
<td>2.69</td>
<td>4.35</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.18</td>
<td>5.14</td>
</tr>
<tr>
<td>1/10 DAMA background</td>
<td>1</td>
<td>3.80</td>
<td>6.15</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6.58</td>
<td>10.65</td>
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<tr>
<td></td>
<td>5</td>
<td>8.50</td>
<td>13.75</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>10.06</td>
<td>16.27</td>
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</table>

- 5-σ detection of DAMA-like signal with a 250-kg / 2-year running time (2 - 4 keV) and comparable backgrounds to DAMA

arXiv:1106.1156

DM-Ice 250kg Concept

**Design Concept**
- Large pressure vessel
- Portable detector, hermetically sealed for in-ice (water?) deployment
- Segmented crystals with ~250 kg mass (e.g. 38@6.5kg)
- 1500 kg total including pressure vessel
- 2 detectors to mitigate deployment risk

**Current Activities**
- R&D on low background crystals
- Designing pressure vessels
- Investigating low background PMTs
- Customizing electronics
DM-Ice 250 kg Concept

Dr. Reina Maruyama

DM-Ice 250 kg Concept

250kg NaI Detector Array Deep in the Ice

Local muon veto in ice

250 kg NaI detector array in pressure vessel

Local muon veto in ice

~2500m


arXiv:1106.1156
Overburden at -2500 m (2200 m.w.e.)

- ~85 muons/m²/day at bottom of IceCube
- IceCube/DeepCore veto reduces rate by ~1-2 orders of magnitude.
- Ice is a neutron moderator
Radiopurity of Antarctic Ice

Purity

• -2500 m at South Pole is ~100,000 years old
• Most of the impurities come from volcanic ash
  • ~ 0.1 ppm
• Ice is nearly as clean as materials used for ultra-low background experiments.
  • U ~ 0.1ppt, Th ~ 0.1ppt, K ~ 100 ppt

scattering/absorption studies in ice
Muon Rate Seasonal Modulation

South Pole

- Muon modulation at the South Pole is 10% and is strongly correlated with the atmospheric temperature, maximum muon rate occurs in mid-January.
- Modulation is larger than the 2% effect at LNGS.

Muon Rate at Gran Sasso vs. South Pole

• LVD:
  Selvi, Proc. 31st ICRC.

• Opposite Muon modulation at the South Pole:
  Tilav, Proc. 31st ICRC. (2009)
**DM-Ice-17 deployed in 2010**

**Detectors:**
- Two 8.5 kg NaI detectors (total: 17 kg)
- crystals from NAIAD

**Goals:**
- Assess the feasibility of deploying NaI(Tl) crystals in the Antarctic Ice for a dark matter detector
- Establish the radiopurity of the antarctic ice / hole ice
- Explore the capability of IceCube to veto muons

*Installed Dec. 2010*
DM-Ice-17 Detector

- 36 cm (14”)
- 2 IceCube mainboards + HV control boards
- 5” ETL PMTs from NAIAD (2)
- NAIAD NaI Crystal (8.5 kg)
- quartz light guides (2)
- PTFE light reflectors (2)
- Stainless Steel Pressure Vessel
- DM-Ice
- DOM 59
- DOM 60
- 35 m extension cable
- 7 m
DM-Ice-17

DM-Ice prototype functioning well
– taking data, stable operation since March 2011
– data transmitted over satellite

Data

Preliminary

239 keV: Pb-212 from Th chain
352 keV: Pb-214 from U chain
609 keV: Bi-214 from U chain
860 keV: TI-208 from Th chain
1173 keV: Co-60
1460 keV: K-40
DM-Ice-17

Background Simulations
assumed U, Th, and K concentrations

<table>
<thead>
<tr>
<th>Material</th>
<th>$^{238}$U (ppm)</th>
<th>$^{232}$Th (ppm)</th>
<th>nat K (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>drill ice [27]</td>
<td>0.076±0.046</td>
<td>0.47±0.14</td>
<td>&lt;262</td>
</tr>
<tr>
<td>Antarctic ice</td>
<td>$10^{-4}$</td>
<td>$10^{-4}$</td>
<td>0.1</td>
</tr>
<tr>
<td>PMT [26]</td>
<td>30</td>
<td>30</td>
<td>60000</td>
</tr>
<tr>
<td>steel PV [27]</td>
<td>0.2</td>
<td>1.6</td>
<td>442</td>
</tr>
<tr>
<td>NaI</td>
<td>0.005</td>
<td>0.005</td>
<td>10</td>
</tr>
</tbody>
</table>

estimated contributions to event rate

<table>
<thead>
<tr>
<th>Material</th>
<th>event rate in NaI (cpd/kg/keVee)</th>
</tr>
</thead>
<tbody>
<tr>
<td>drill ice</td>
<td>0.8</td>
</tr>
<tr>
<td>Antarctic ice</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>photomultiplier tubes</td>
<td>0.01-0.02</td>
</tr>
<tr>
<td>steel PV</td>
<td>0.2-0.6</td>
</tr>
<tr>
<td>NaI crystal</td>
<td>~0.3</td>
</tr>
</tbody>
</table>

Goal: ~ 1 cpd/kg/keV

Reducing the backgrounds

**drill water/ice**
- won’t reuse circulate water
- minimize volume of drill ice around detector

**steel pressure vessel (PV)**
- can use better material, custom steel
- may be able to use Cu or Ti for full detector

**NaI crystal**
- purify raw materials

Optimizing analysis, background studies with radio-assay & Monte Carlo simulation

arXiv:1106.1156
Summary & Conclusions

• We have an opportunity for a unique annual modulation experiment in Southern Hemisphere.

• Backgrounds and systematics very different from any other underground location.

• Two NaI(Tl) detectors (17 kg) installed and operating in the South Pole ice since Dec 2010

• 250 kg experiment currently under design.

• An unambiguous discovery of DM requires signal in multiple experiments with different targets.

see arXiv:1106.1156
DM-Ice Collaboration

**UW-Madison**
Francis Halzen*, Karsten Heeger, Albrecht Karle*, Reina Maruyama*, Walter Pettus, Antonia Hubbard*, Bethany Reilly

**University of Sheffield**
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**University of Alberta**
Darren Grant*

**Penn State**
Doug Cowen*

**Fermilab**
Lauren Hsu

**University of Stockholm**
Seon-Hee Seo*

* IceCube collaboration members