DeepCore and Galactic Center Dark Matter

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Overview

- Motivation
- Probing for Dark Matter with Neutrinos
- Testing the dark matter self-annihilation cross section
  - IceCube Galactic Halo Analysis
  - IceCube Galactic Center Analysis
- Deep Core Plans
- Conclusions
Motivation
Strategies for WIMP Detection

- **Direct Detection**
  - Recoil effects - WIMP scattering of nucleons

- **Indirect Detection**
  - **Neutrinos** – annihilation signals from WIMPs accumulated in the Sun or Earth
  - Photons, **Neutrinos** – Milky Way Halo, Cosmic Flux, ...
  - Anti-matter (e+, D, pbar) – local neighborhood (few kpc)

- **Production**
  - LHC, Tevatron, ILC, ...

see previous talks from Matthias Danniger and Erik Strahler for details on Solar WIMPs
# Neutrino Dark Matter Searches

<table>
<thead>
<tr>
<th>Solar</th>
<th>Earth</th>
<th>Halo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scattering cross section (Neutrino Flux)</td>
<td>Neutrino Flux</td>
<td>Self-annihilation cross section</td>
</tr>
<tr>
<td>Muon neutrinos</td>
<td>Muon neutrinos</td>
<td>All Flavors</td>
</tr>
<tr>
<td>Tracks</td>
<td>Tracks</td>
<td>Tracks, Cascades</td>
</tr>
<tr>
<td>$E_\nu&lt;1\text{TeV}$</td>
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<tr>
<td>Background on/off-source / simulations</td>
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<td>$M_{\text{WIMP}}&lt;\text{TeV}$</td>
<td>$M_{\text{WIMP}}&lt;100\text{GeV/TeV}$</td>
<td>All $M_{\text{WIMP}}$</td>
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Galactic Halo WIMPs

- Annihilation $\sim \rho^2$
- Decay $\sim \rho$

$\chi$
Dark Matter self-annihilation products and theoretical constraints

- Variety of particles generated in annihilation process
- Neutrinos are least detectable messenger -> conservative upper limit on total $<\sigma_A>$
- Smoking gun: Observed particle spectra may show feature at $E=M_{WIMP}$
- MilkyWay better than cosmic signal

Credit: Sky & Telescope / Gregg Dinderman

Beacom, Bell, Mack (2008)
Halo Profiles

Edge-on Galaxy NGC891 (mag10). This is one of the finest examples of an edge-on galaxy -- definitely one of my favorites. It is a small cigar-shaped galaxy with a beautiful dust lane running through its center.
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Halo Profiles

Two IceCube analyses:
1) Search for an anisotropy in the neutrino candidate sample
2) Look at the Galactic Center (down-going events)

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IceCube Detector

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Galactic Halo and Center Analyses

(1) Galactic halo analyses uses the IceCube 22 string detector active 2007-2008

(2) Galactic center analyses uses the IceCube 40 string detector active 2008-2009
Neutrino Flux from annihilations

Line of sight integral:

\[ l_{\text{max}} = \sqrt{(R_{MW}^2 - \sin^2 \psi R_{sc}^2) + R_{sc} \cos \psi} \]

\[ J(\psi) = \frac{1}{R_{sc} \rho_{sc}^2} \int_0^{l_{\text{max}}} \rho^2 (\sqrt{R_{sc}^2 - 2l R_{sc} \cos \psi + l^2}) d\ell \]

\[ J_{\Delta \Omega} = \frac{1}{\Delta \Omega} \int_{\cos \psi}^{1} J(\psi') 2\pi d(\cos \psi') \]

Expected differential neutrino Flux:

\[ \frac{d\Phi}{dE} = \frac{1}{2} < \sigma_A v > J(\psi) \frac{R_{sc} \rho_{sc}^2}{4\pi m^2} dN \]

Measure integrated flux

Isotropic emission


Moore

NFW

Kravtsov

DarkSUSY
275.7 days of livetime collected with IceCube operating in the 22-string configuration (2007-2008)

5114 Events after selection from -5° to +85° declination

Track selection criteria have been well established for the IceCube point source search, for simplicity and minimization of systematic effect we apply the same selection criteria (Astrophys.J.701:L47-L51,2009.)

Do we see any effects on Dark Matter in our neutrino sample?
Galactic Halo IceCube 22

- Compare regions of equal “size” (on vs. off-source)
- This technique allows to reduce systematic uncertainties
- No excess flux in the region, closer to the galactic center
- Rotate regions in 60° steps as systematic cross check
- Distribution is flat
Galactic Halo Analysis - IceCube 22

- No anisotropy was observed in IceCube data – constrain the dark matter self-annihilation cross-section
- Preliminary IceCube constraints using 275 days of data and the 22 string dataset can probe already some of the preferred parameter space
  - No systematic uncertainties included
  - Only small dependence on halo models
- Annihilation into $\nu\nu$ could also be interpreted as upper limit on total dark matter annihilation cross section (Beacom, Bell, Mack 2008)
- Significantly more data has been collected already

KKT: Annihilation does not alter halo profiles significantly a large self-annihilation cross section was invoked in order to reconcile predicted cuspy density profiles with the flatter ones inferred from observation, requiring KKT

The unitarity bound: (Lui)

The unitarity of the scattering matrix, together with a few reasonable assumptions, imposes interesting particle mass bounds as well as other physical constraints.

The optical theorem [10] is a powerful consequence of the unitarity of the scattering matrix $S$, i.e. $S^\dagger S = 1$
Galactic Halo Analysis - IceCube 22

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- Preliminary IceCube constraints using 275 days of data and the 22 string dataset can probe already some of the preferred parameter space
  - No systematic uncertainties included
  - Only small dependence on halo models
  - Probe already regions of interest

Green Area: PAMELA-Fermi-HESS allowed region [P. Meade, M. Papucci, A. Strumia, T. Volansky, [0905.0480]]
Systematic Uncertainties

- **Signal acceptance:**
- **MC/data disagreement (horizontal events)**
- **Ice properties / DOM efficiency**
- **Theoretical uncertainties (cross section, bed rock,...)**

- **Background:**
  - Majority of systematics cancel out (as we use the data itself)
  - “existing” large scale anisotropy
    - Uneven “exposure”
    - Neutrino anisotropy caused by cosmic ray anisotropy
Systematic Uncertainties

Uneven exposure (~0.1%)  CR anisotropy (~0.2%)

- Track reconstruction efficiency varies in detector coordinates
- In equatorial coordinates this reconstruction efficiency is smeared out (as the detector rotates)
- Uneven detector up-time can however reduce this smearing effect
- Detector down-time correlates with satellite visibility (maintenance mode)
- Detector uptime in sidereal days defines this impact

CR Flux anisotropy translates into atmospheric neutrino anisotropy


Systematic uncertainties of the background well under control
Galactic Center Analysis
Galactic Center IceCube – 40 strings

- Dark Matter profiles are peaked at the galactic center (GC)
- As the galactic center is above the horizon these events are down-going in IceCube
- Use down-going starting events to reduce atmospheric muon background
Galactic Center - IceCube 40

- Effective Area for muon neutrinos from Galactic Center 61°
  - This analyses uses “low energy” selection
  - “high energy” selection used for point source search (details see talk J-P. Huelss DPG 2010)

Optimize the size of the on-source region
- \( \delta = 8° \)
- compare the amount of events in the on- and off-source region
  - ~800k background events expected (and observed)
Galactic Center

- Preliminary IceCube 40 Galactic Center Limits at 90% C.L.
- Significant improvement in sensitivity over 22 string analysis
- Galactic Center limit depend strongly on choice of halo model
- Opportunity to probe halo models

Arxiv:0912.5183
J.Huelss DPG
Galactic Center

- Neutrino constraints from IceCube are very competitive and start to probe preferred regions from the PAMELA positron excess and Fermi electrons.

- The IceCube/Deep Core subdetector is designed to obtain a clean neutrino sample of starting events, which will substantially improve our sensitivity for WIMPs in the 100 GeV range.

Arxiv:0912.5183
J.Huels DPG
Deep Core

- What’s next?
  - IceCube can perform a variety of Dark Matter Analyses to test the self-annihilation cross-section and lifetime
    - Galactic Center
      - Mandal Buckley Freese Spolyar Murayama
    - Galactic Halo
    - Diffuse (extra galactic)
      - Beacom Bell Mack (2008)
    - Stacking (Dwarf Spheroidals)
      - Sandick Spolyar Buckley Freese Hooper (2010)
    - Lines / Bumps Search
  - Deep Core will extend IceCube’s reach to lower energies, new neutrino flavors and make the Galactic center more accessible
Conclusions

- Neutrino Searches can be used to constrain both the WIMP-proton scattering cross section (Solar WIMPs) and the self-annihilation cross section (Galactic Halo).

- Observations in lepton channels (if interpreted as DM signals) favor models with high-mass leptophilic WIMPs.
  - Neutrinos are powerful to test such models and have a crucial part in obtaining a more complete picture.

- Using the partially instrumented detector and one year of data, IceCube can already provide very interesting constrains on the dark matter self-annihilation cross-section.

- Stay tuned many new exciting results to come soon.
  - IceCube is essentially completed now.
  - DeepCore taking data and analyses on-going.

- Novel Searches for Dark Matter Workshop (July 5-6, 2010) at OSU
  - [http://ccapp.osu.edu/workshops/DMsearch/workshop.html](http://ccapp.osu.edu/workshops/DMsearch/workshop.html)