Dark Matter Searches with AMANDA and IceCube

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IDM 2008
Overview

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2. The AMANDA and IceCube detectors
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1. Neutrinos from WIMP annihilations in Sun and Earth

Indirect detection of Dark Matter
Neutralino annihilations in Sun $\rightarrow$ neutrinos

- $\rho_\chi$: neutralino density
- $\chi$: neutralino
- $\sigma_{\text{scatt}}$: scattering cross section
- $\Gamma_{\text{capture}}$: capture cross section
- $\Gamma_{\text{annihilation}}$: annihilation cross section
- $\nu_\mu$: neutrino
- $\chi\chi \rightarrow q\bar{q}$: neutralino annihilation
- $\chi\chi \rightarrow l\bar{l}$: lepton pair
- $W^\pm, Z, H$: Standard Model particles
- $\nu_{\text{int.}}$: neutrino interaction
- $v_{\mu}$: detected neutrino

Diagram showing the process from neutralino annihilation in the Sun to neutrino detection on Earth.
Neutralino models considered

- Assume MSSM with R-parity conservation
- Neutralino $\chi_0^1$ (LSP) is popular CDM candidate: weakly interacting, stable, massive
- search for neutralinos accumulated in Sun or centre of Earth
- Consider 7 masses
- and 2 annihilation channels

\[ 50 \text{ GeV} < m(\chi_0) < 5000 \frac{\text{GeV}}{c^2} \]

\[
\begin{align*}
\chi\chi & \rightarrow W^+W^- \rightarrow \nu & \text{hard } E_\nu \text{ spectrum} \\
\chi\chi & \rightarrow b\bar{b} \rightarrow \nu & \text{soft } E_\nu \text{ spectrum}
\end{align*}
\]

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**Dark Matter in AMANDA & IceCube – IDM 2008**
Signal simulation

- WIMPSIM generator (J. Edsjö) based on DarkSusy

- Used for:
  - Optimisation of filters, tuning of cuts
  - Calculation of selection efficiencies $\rightarrow$ effective volume $V_{\text{eff}} - E_{\nu}$ dependent
  - Calculation of upper limits on neutralino annihilation rates if no signal found
Neutrino detection

Cherenkov light pattern emitted by the muon is registered by an array of photomultiplier tubes (PMT)

3 km ice layer

South Pole station

Photomultiplier tubes

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Signal and background

**B G**
A few 1000 atmospheric neutrinos per year from northern hemisphere

**signal**
Max. a few neutrinos per year from WIMPs

**B G**
~10^9 atmospheric muons per year from southern hemisphere
2. The AMANDA and IceCube detectors
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• Bartol Research Inst., Delaware
• Anchorage University
• Pennsylvania State University
• UC Berkeley
• UC Irvine
• Clark-Atlanta University
• Univ. of Maryland
• University of Wisconsin-Madison
• University of Wisconsin-RiverFalls
• LBNL, Berkeley
• University of Kansas
• Southern Univ., Baton Rouge

• RWTH Aachen
• Humboldt Univ., Berlin
• Universität Dortmund
• MPIK Heidelberg
• Universität Mainz
• Universität Wuppertal
• DESY, Zeuthen

• Uppsala University
• Stockholm University

• EPF Lausanne

• University Utrecht

• Chiba University

• Universite Libre de Bruxelles
• Vrije Universiteit Brussel
• Université de Mons-Hainaut
• Universiteit Gent

• Univ. of Canterbury, Christchurch

IceCube Collaboration

~250 scientists – 30 groups
Amundsen Scott South Pole Station

IceCube observatory
Ø1km
At 1.5-2.5 km depth

Hot water drilling

AMANDA

Control room
**IceTop**

Air shower detector
threshold ~ 300 TeV

- 2004-2005: 1 String
- 2005-2006: 8 Strings
- 2006-2007: 13 Strings
- 2007-2008: 18 Strings

**InIce**

- 80 Strings, with
- 60 Optical Modules
- 17 m between Modules
- 125 m between Strings

**IceCone status**
March 2008

**AMANDA**

- 19 Strings
- 677 Modules

**IceCube status**
March 2008

Completion 2011

total of 40 Strings
3. Main results

Neutralinos in the Sun
Neutralinos in the centre of the Earth
Neutralinos in the Sun

- Use data with Sun below horizon (90°<θ<113.5°): March-September
- Near horizontal muon tracks

Several levels of filtering to remove atmospheric muon background

1 TeV WIMP, hard channel selection efficiency ≈ 20%

Data ≈ Σ(atm BG)

Atm. ν

Atm. µ
Neutralinos in the Sun

- Angular resolution
  - $[4^\circ-5^\circ] < 500\text{GeV AMANDA}$
  - $3^\circ \geq 500\text{GeV IceCube}$

- Results from:
  AMANDA 2003: 150.4 days
  IceCube 2007 (22 strings): 104.3 days

- Signal selection efficiency $\mathcal{O}(20\%)$ – dependent on $E_\nu$
- BG from off-source data
- no evidence for signal in 250 days lifetime
Neutralinos in the Sun

- Test hypothesis that muons come from Sun
- $\rightarrow$ 90% C.L. upper limit on signal strength $\mu_s$
- $\rightarrow$ $\nu$ to $\mu$ conversion rate

$$\Gamma_{\mu\nu} \leq \frac{\mu_s}{V_{eff} \cdot t}$$

Neutralino annihilation rate

Muon flux

$$\phi_\mu \left( E \geq E_{th} \right) = \frac{\Gamma_A}{4\pi R_\odot^2} \int_{E_{th}}^\infty dE_\mu \frac{dN_{\mu}}{dE_\mu}$$
Results solar neutralinos

- **AMANDA II 2003**
- **IceCube-22 2007**

- Upper limits on muon flux from neutralino annihilations in the Sun
- Excl. systematic errors: ~34%

- Compare to MSSM predictions & direct WIMP searches

- Excluded by CDMS + XENON10
  + allowed by CDMS + XENON10
Neutralinos in the centre of the Earth

- Near vertical upgoing muons

- AMANDA B10 1997-99 : 422 days
- AMANDA II 2001-03 : 361 days – focus on low masses

- BG estimated from simulation

- No signal found in ~800 days of livetime
Neutralinos in the centre of the Earth

- Upper limits on muon flux from neutralino annihilations in the centre of the Earth
- Incl. systematic errors:~36%

Excluded by CDMS + XENON10
+ allowed by CDMS + XENON10
4. Expected Improvements
Expected improvements

- Full AMANDA statistics 2001-06: factor $\sqrt{6}$ improvement

- IceCube: growing detector (IC80 in 2011) & more statistics improvement mainly at 500 GeV and above

- Addition of DeepCore: better sensitivity at 50-250 GeV
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- Full AMANDA statistics 2001-06: factor $\sqrt{6}$ improvement
- IceCube: growing detector (IC80 in 2011) & more statistics improvement mainly at 500 GeV and above
- Addition of DeepCore: better sensitivity at 50-250 GeV
DeepCore: optimised for GeV-TeV

- 6 extra strings with 60 DOMs at 7.5m spacing
- dense core of 13 strings = 514 PMTs
- At bottom of IceCube in very clear ice: $\lambda_{\text{scat}} \sim 40\text{m}$
- First string in 08-09
Access to Southern hemisphere:
use IceCube as veto against atmospheric $\mu$ from Southern hemisphere
5. Summary and outlook
Summary and outlook

- Indirect search was performed with AMANDA & IceCube for neutralinos in Sun and centre of Earth
- No evidence for signal
- Upper limits were set on possible muon fluxes – complementary with direct searches
- Improvements in sensitivity expected in coming years: more statistics, larger detector and addition of DeepCore