Recent results from the AMANDA neutrino telescope

Andreas Groß
(University of Dortmund)
for the AMANDA collaboration

http://amanda.uci.edu
Astronomical Messengers

Source, e.g. Supernova,
Aktive Galactic Nucleus AGN
Gamma Ray Burst GRB

Source region, e.g. surrounding dust clouds, Galaxies...

Interstellar dust clouds

Satellite experiments

Fluorescence detector

Air shower array

Air shower

Atmosphere

Earth

Underground detector

Protons / charged particles

Intergalactic magnetic fields

B

v-Astronomy
The AMANDA II $\nu$–telescope

- Geographic south pole (Amundsen Scott Station)
- 677 PMT on 19 strings
- Detection of Čerenkov light (muon tracks + cascades) in ice

Upgoing events: Earth shields all particles except $\nu$
Cosmic Accelerators

How is it possible to accelerate particles to TeV-EeV? Where is it possible? Do we get $\nu$?

- Fermi-acceleration at shock waves
- Pion-production by $p\gamma$ (or pp) reactions
- High energy needed $\rightarrow$ Grav. potential of black holes

Or top-down scenario: decay of new heavy particles

- Power law $\alpha \sim -2$
- $\nu$ sources emit $\gamma$
- AGN, GRB, $\mu$Quasar, SNR
Analysis-Strategies

• How to identify extraterrestrial ν?
  – Energy spectrum ➔ Diffuse analysis
  – Arrival direction ➔ Point source analysis

• Selected source candidates
• All-sky search
• Source stacking
• Time-dependent analysis
• Special point sources
  • Gamma Ray Bursts (GRB)
  • Sun/Earth: indirect WIMP searches
Diffuse neutrino spectrum

Muon in ice:
\[ \frac{dE}{dx} = a + bE; \quad a/b = 500 \text{ GeV} \]

- Energy estimate for single event: Neural net
- Regularized unfolding:
  - Limited acceptance
  - Finite resolution

Limit on \( E^{-2} \) flux (90% C.L.):
\[ E^2 \Phi < 2.6 \times 10^{-7} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]
Point source analysis:
Event sample 2000-2003

- Improved background rejection by new pattern recognition method
- Blindness strategy:
  Event selection optimized with randomized RA
- Sensitivity (90% C.L.):
  $\sim 0.6 \times 10^{-8} \text{cm}^{-2}\text{s}^{-1}$ above 10 GeV

Map of arrival directions of individual $\nu$
AMANDA-Sensitivity: ν to γ ~1:1

If ν_μ : γ = 1:1 (at earth)

• Mrk 421 in high state: ~ 200 days required to reach AMANDA sensitivity limit

• Correction for ν oscillations: ν_μ : γ = 1:1 at earth corresponds to ν_μ : γ = 2:1 at source

γ–spectrum corrected for absorption on cosmic IR background
Point Source Analysis:
Preselected source candidates

- Select known gamma-ray sources
  - extragalactic: AGN
    - 13 Blazars (5 TeV Blazars, 8 GeV Blazars)
    - 3 close AGN (u.a. M87)
  - galactic:
    - 8 Microquasars
    - SNRs (Crab, ...)
- Highest Excess: Crab nebula 10 events at a background of 5.36 (Expected within 33 candidates, not significant)

- All (northern) sky search for clustering
- Highest significance: $3.35 \sigma$ before correction for trial factor
- Random skymaps show: Chance probability 92%
- No evidence for a point source
Point Source Analysis: Source stacking of AGN

- Method from gamma-ray astronomy
  - Idea: Search for cumulative signal of a source class
  - Increase sensitivity for generic sources
  - Systematic selection required

- Classification of AGN
  - Axisymmetric AGN model
  - Radio-loud ↔ Radio-weak
  - Compact sources (young AGN)
Source stacking: Selection of sources

How many sources of each type?
How to sort them?

➔ Use phenomenological aspects

• Relate $F_{\nu}$ to $F_{\gamma}$ (pion decay)

• Optical thickness: $E_{\gamma} < E_{\nu}$ (?)
  - Not only TeV flux relevant, but also GeV, keV, IR, ...

➔ For most source classes: Optimum ~ 10 sources
Results from source stacking

11 source classes evaluated (data from the year 2000 with 699 events, 4 year data in prep.)

<table>
<thead>
<tr>
<th>sample</th>
<th>$N_{src}$</th>
<th>$N_{obs}$</th>
<th>$N_{bg}$</th>
<th>$n_{lim}$</th>
<th>$f_{lim}$</th>
<th>$f_{lim}/src$</th>
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<tbody>
<tr>
<td>GeV blazars</td>
<td>8</td>
<td>6</td>
<td>5.3</td>
<td>6.3</td>
<td>4.0</td>
<td>0.5</td>
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<td>unid. GeV sources</td>
<td>12</td>
<td>9</td>
<td>6.31</td>
<td>9.0</td>
<td>6.4</td>
<td>0.5</td>
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<tr>
<td>IR blazars</td>
<td>11</td>
<td>7</td>
<td>10.17</td>
<td>3.0</td>
<td>2.0</td>
<td>0.2</td>
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<td>keV blazars (HEAO-A)</td>
<td>3</td>
<td>2</td>
<td>2.47</td>
<td>3.5</td>
<td>2.8</td>
<td>0.9</td>
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<tr>
<td>keV blazars (ROSAT)</td>
<td>8</td>
<td>4</td>
<td>6.68</td>
<td>2.4</td>
<td>1.6</td>
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<td>TeV blazars</td>
<td>5</td>
<td>4</td>
<td>4.53</td>
<td>4.1</td>
<td>2.8</td>
<td>0.6</td>
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<tr>
<td>GPS and CSS</td>
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<td>7</td>
<td>6.14</td>
<td>6.4</td>
<td>4.3</td>
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<td>FR-I galaxies</td>
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<td>0</td>
<td>0.56</td>
<td>1.9</td>
<td>1.3</td>
<td>1.3</td>
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<td>FR-I without M87</td>
<td>20</td>
<td>9</td>
<td>11.50</td>
<td>3.9</td>
<td>2.7</td>
<td>0.1</td>
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<tr>
<td>FR-II galaxies</td>
<td>17</td>
<td>10</td>
<td>13.42</td>
<td>3.7</td>
<td>2.7</td>
<td>0.2</td>
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<tr>
<td>radio-weak quasars</td>
<td>11</td>
<td>4</td>
<td>7.55</td>
<td>1.9</td>
<td>1.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Comparison: Sensitivity to individual sources ~ 2
(same units, same data set)

PRELIMINARY

Limits are given for the integral flux above 10 GeV in $10^{-8}$ cm$^{-2}$ s$^{-1}$
Search for time-variable point sources

Blazars and microquasars: Highly variable photon flux

- GeV + TeV blazars: Sliding time window of 40 days + multi-wavelength analysis (selected at keV)
- Results: No significant excess (12 sources tested)
- 1ES 1959+650: PRELIMINARY
  - 1 doublet in sliding time window (p=0.32)
  - Multi-wavelength (x-ray selected): N=2, BG=1.57
1ES 1959+650:

- Looking at the event times (blindness violation):
  Additionally to the events found in the multi-wavelength analysis:
  1 event coincident with 'orphan flare' (TeV, not keV) seen by Whipple
- Time distance to next keV selected event: 32 days
- Chance probability cannot be calculated 'a posteriori' (no discovery)
Search for $\nu$ from GRB

- Sources localized in time and space
- Expectation: Waxman-Bahcall spectrum
Results for $\nu$ from GRB

In blind window:
Precursor: $-110s < t < -10s$
Main burst: $-10s < t < t_D + 1s$
$t_D$: Burst duration

Sensitivity to Waxmann-Bahcall spectrum: $E^2 \Phi < 3 \times 10^{-8}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$

<table>
<thead>
<tr>
<th>Year</th>
<th>$N_{\text{bursts}}$ (BT+IPN)</th>
<th>$N_{\text{BG, Exp}}$</th>
<th>$N_{\text{Obs}}$</th>
<th>Event U.L.</th>
<th>MRF</th>
<th>MRF (Sensitivity)</th>
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<td>66</td>
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<td>0</td>
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<td></td>
<td>17</td>
<td>0.06</td>
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<td>2.38</td>
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<td>2003</td>
<td>19</td>
<td>0.10</td>
<td>0</td>
<td>2.34</td>
<td>52</td>
<td>54</td>
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<tr>
<td></td>
<td>18</td>
<td>0.06</td>
<td>0</td>
<td>2.38</td>
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<tr>
<td>01-03</td>
<td>51</td>
<td>0.24</td>
<td>0</td>
<td>2.19</td>
<td>16</td>
<td>20</td>
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<td>50</td>
<td>0.16</td>
<td>0</td>
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<td></td>
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<tr>
<td>00-03</td>
<td>139</td>
<td>1.25</td>
<td>0</td>
<td>1.47</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

PRELIMINARY
indirect WIMP search

- Dark matter accumulates in high density regions
- Earth and Sun: No particle acceleration to TeV
- If \( \nu \) flux from there \( \rightarrow \) WIMPS
- Signal expectation: use Monte Carlo (DARKSUSY)
- No significant excess above background, limit on muon flux

Results (2001) for solar WIMPS

\['\text{\'hard\' channel: } \chi \chi \rightarrow W^+ W^-\]
indirect WIMP search

- Dark matter accumulates in high density regions
- Earth and Sun: No particle acceleration to TeV
- If \( \nu \) flux from there \( \rightarrow \) WIMPS
- Signal expectation: use monte carlo (DARKSUSY)
- No significant excess above background, limit on muon flux

Results (97-99) for earth WIMPS

'excluded by CDMS'

'hard' channel: \( \chi\chi\rightarrow W^+W^- \)
The (near) future: IceCube

- 2-3 orders of magnitude improvement in sensitivity
- 80 strings, 4800 optical modules (OMs)
- Surface array IceTop for Air Showers

First string deployed, all modules work, first muons observed
Summary

- AMANDA is operating, large variety of physics analysis
- Neutrino spectrum up to 100 TeV measured
- No evidence for extraterrestrial $\nu$ up to now
  - Diffuse analysis
  - Point sources:
    - Preselected sources, all-sky search
    - Source stacking and time-dependent analysis
    - GRB coincidence analysis
    - WIMP searches
- IceCube under construction, first string operating, analysis strategies of AMANDA can be used
  - Expectation: „sure“ point sources ($\nu$ to $\gamma > 1:50$)