The AMANDA Search For High Energy Neutrinos From Gamma Ray Bursts

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Abstract. We have searched three and a half years of AMANDA data for high energy muon neutrinos from gamma-ray bursts (GRBs). The data was recorded from 1997 through 1999 by the AMANDA-B10 detector and in 2000 by the AMANDA-II detector. AMANDA is a Čerenkov detector embedded 1.5 to 2 km deep in the transparent ice of the South Polar plateau. We searched for neutrino candidates from the direction of, and coincident with, GRBs detected by the Burst and Transient Source Experiment (BATSE). The current result is consistent with no signal. A preliminary event upper limit for GRB neutrino emission is presented as well as a description of AMANDA’s cubic-kilometer successor, IceCube.

AMANDA

The Antarctic Muon and Neutrino Detector Array (AMANDA) is a three-dimensional array of photo-multiplier tubes (PMTs) deployed in the deep, transparent ice of the South Polar plateau. See Figure 1 and Table 2. The array of PMTs detects the light produced by the Čerenkov emission of muons that are traveling through the ice at speeds greater than c/n, where n is the index of refraction of the ice, about 1.33. AMANDA detects muons induced by cosmic rays bombarding the southern hemisphere, but it also detects muons that have been produced by neutrinos from the northern skies that have traveled through the earth and interacted in the ice or rock near the array. Since only neutrinos can pass through the entire earth, the earth can be used as a filter to tag upgoing neutrino-induced muons. At TeV energies, the path of the muon is aligned with the direction of its parent neutrino to about 1° and neutrino astronomy is possible.

If GRBs produce muon neutrinos or electron neutrinos that oscillate to muon neutrinos, then AMANDA can search the northern hemisphere for neutrinos that are coincident in time and location with known GRBs1. For a detailed discussion of the mechanism that would produce GRB neutrinos, please see [1] in these proceedings.

When the time and location of GRBs are known, the AMANDA search for high energy muon neutrinos from GRBs becomes an almost background-free search. The work described here utilizes GRB detections made by BATSE from 1997 until it was turned off in May of 2000.

1 Electron and tau neutrinos leave different, unique signatures in the detector and will be studied in other analyses.
FIGURE 1. The Antarctic Muon and Neutrino Detector Array.

ANALYSIS

AMANDA data recorded during the hour before and hour after a BATSE GRB were extracted. These two hours of data are used to characterize the background event rate at the time of the GRB. Ten minutes of data surrounding the BATSE trigger time are strictly excluded from the analysis until final quality cuts have been determined. This statistically blind approach to data analysis ensures that quality cuts are not biased by the presence or absence of signal events. The data recorded around the GRB time was required to be complete and stable.

The sensitivity of AMANDA-B10 varied with zenith angle and quality cuts were optimized for ten different zenith bins, from directly upgoing to the horizon. Most background events are due to misreconstructed downgoing muons created by cosmic rays striking the southern hemisphere. The temporal and directional information provided by BATSE reduces this background rate.

Quality cuts remove almost all of the remaining events. A “direct hit” in AMANDA is one that is minimally scattered in the ice (<75 nanoseconds) before being detected by a PMT. In AMANDA-II, each event was required to have at least 15 direct hits. The direct hits in each event were also required to be smoothly distributed along the muon’s reconstructed path. This requirement further increases confidence in the track’s direction.

Additionally, GRB neutrinos will have energies greater than atmospheric muons. See Figure 2. The energy deposited in the detector is related to the number of PMTs
that see light in each event. In this analysis, at least 26 PMTs were required to participate. Muon and neutrino effective areas are shown in Figure 3. The particle’s energy is reported at its closest approach to the center of the detector.

FIGURE 2. On the left, the energy of muons at the center of the AMANDA-B10 detector, from background cosmic rays and from the predicted Waxman-Bahcall [2] GRB neutrino flux. On the right, GRB signal generated by Monte Carlo simulations before (solid) and after (dashed) quality cuts.

FIGURE 3. On the left, the muon effective area as a function of energy averaged over zenith angle. On the right, the effective neutrino area as a function of energy for a few declinations. Both plots are for AMANDA-II.

RESULTS

Results are shown in Table 1. Quality cuts were optimized via the Model Rejection Potential (MRP) technique [3]. In the absence of a positive detection, this technique predicts an event upper limit sensitivity of 3.4, based only on the expected background and averaged over all possible no-signal outcomes. The total event upper limit is based on the expected background and the actual number of events observed. It is calculated according to [4]. The current result is consistent with no GRB muon neutrino signal. Two different studies of the AMANDA-II data from 2000 were
conducted. The results of these analyses, labeled 2000A and 2000B, are consistent and both are shown in Table 1.

Several models for coincident neutrino emission lie below our current upper limit. Additional searches by AMANDA-II and the increased effective area of IceCube (see below) will confirm or rule out these predictions. In addition, some GRB models predict neutrinos at times distinctly before the onset of the gamma-ray emission, after it has stopped, or at less than TeV energies [5,6]. These predictions will require differently optimized analyses.

### Table 1. Preliminary Results of the 1997-2000 GRB neutrino analysis.

<table>
<thead>
<tr>
<th>Year</th>
<th>GRBs Examined</th>
<th>Total Background</th>
<th>Events Observed</th>
<th>Event Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>78</td>
<td>0.06</td>
<td>0</td>
<td>2.41</td>
</tr>
<tr>
<td>1998</td>
<td>94</td>
<td>0.20</td>
<td>0</td>
<td>2.24</td>
</tr>
<tr>
<td>1999</td>
<td>96</td>
<td>0.20</td>
<td>0</td>
<td>2.24</td>
</tr>
<tr>
<td>2000A</td>
<td>44</td>
<td>0.83</td>
<td>0</td>
<td>1.72</td>
</tr>
<tr>
<td>2000B</td>
<td>44/68</td>
<td>0.40/0.64</td>
<td>0/0</td>
<td>2.05/1.90</td>
</tr>
<tr>
<td>Total</td>
<td>312</td>
<td>1.29</td>
<td>0</td>
<td>1.45</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>312</td>
<td>1.29</td>
<td>0</td>
<td>3.4</td>
</tr>
</tbody>
</table>

### ICECUBE AND FUTURE WORK

### Table 2. South Pole Neutrino Telescope

<table>
<thead>
<tr>
<th>Detector</th>
<th>Deployed</th>
<th>Number of PMTs</th>
<th>Strings</th>
<th>Volume [m³]</th>
<th>Approx. Effective Area [m²]</th>
<th>Angular Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMANDA-B10</td>
<td>1995-1997</td>
<td>302</td>
<td>10</td>
<td>2 x 10⁷</td>
<td>1 x 10⁴</td>
<td>~3.5°</td>
</tr>
<tr>
<td>AMANDA-II</td>
<td>1997-2000</td>
<td>677</td>
<td>19</td>
<td>6 x 10⁷</td>
<td>3 x 10⁴</td>
<td>~2°</td>
</tr>
<tr>
<td>IceCube</td>
<td>2004-2010</td>
<td>4,800</td>
<td>80</td>
<td>1 x 10⁹</td>
<td>1 x 10⁶</td>
<td>~0.7°</td>
</tr>
</tbody>
</table>

IceCube [7] is the cubic-kilometer successor of AMANDA. See Table 2 for details. IceCube will be an ideal instrument to search for neutrinos from GRBs detected by SWIFT and GLAST [8]. In the mean time, further studies are underway with AMANDA-II. One analysis [9] utilizes post-BATSE GRB detections made by the Third Interplanetary Network (IPN3). Another effort [1] is being conducted to more accurately predict the neutrino emission of GRBs by accounting for the burst’s distance, internal Lorentz boost factor, spectrum, and inherent energy.

### REFERENCES