# The Search for Neutrinos from GRBs with AMANDA

Kyler Kuehn*, for the IceCube Collaboration and the IPN Collaboration

* Department of Physics and Astronomy, University of California, Irvine, CA 92697

## Abstract

Here we report on the combined analysis of over 400 GRB time periods that occurred during seven years of AMANDA observations. AMANDA has seen no neutrinos correlated with these bursts, thus we report a neutrino flux limit that is the most stringent observational limit to date. In light of the new observational opportunities afforded by Swift, we also discuss the future potential for GRB neutrino detection with AMANDA's successor, IceCube. Finally, we briefly discuss the expansion of AMANDA's transient point-source search to other phenomena, such as jet-driven supernovae and gamma-ray dark bursts.

## Introduction

The Antarctic Muon and Neutrino Detector Array (AMANDA-II) consists of 677 photomultiplier tubes housed in Optical Modules placed beneath the surface of the ice at the South Pole. This array of detectors is capable of observing the Čerenkov radiation from neutrino-induced muon events above energies of approximately 50 GeV. AMANDA has been searching the heavens since 1997 for high-energy neutrinos from a variety of astrophysical sources, including Gamma-Ray Bursts (GRBs). AMANDA's GRB neutrino search relies on spatial and temporal correlations with numerous ground- and space-based observatories, such as BATSE, HETE, and the other instruments of the Interplanetary Network (Figure 1).

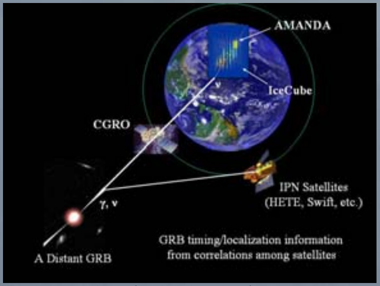


Figure 1. A schematic view of correlated observations of a gamma-ray burst.

Numerous different models exist for neutrino emission from GRBs. Neutrino emission may occur in coincidence with photon emission, or perhaps as a precursor (up to 100 seconds prior) to photon emission. Depending on the characteristics of the central engine and the circumburst environment, the predicted neutrino flux may vary significantly, as the supranova and the Waxman-Bahcall models show (Figure 2).

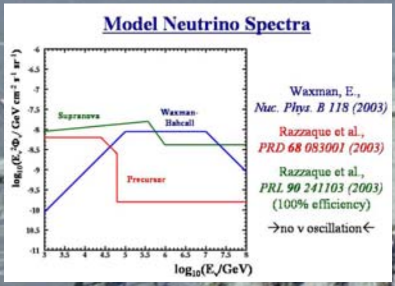
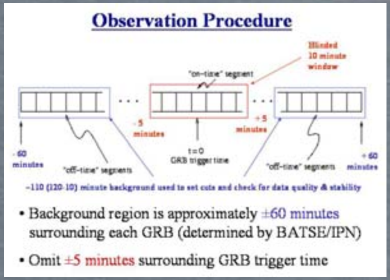


Figure 2: Theoretical predictions for neutrino emission from GRBs.

## Analysis Procedure

AMANDA's observation procedure initially retains "blindness" during each GRB, allowing for optimization of data selection criteria while minimizing the possibility of false positive detections. For each GRB, a two-hour period is examined around the burst, excluding the 10-minute window immediately surrounding the burst (Figure 3). The two-hour "off-time" period is examined to ensure detector stability and to determine the background rate for each burst. Selection criteria are then determined by comparing Monte Carlo simulations of neutrino signals with the observed background events.



- Background region is approximately ±60 minutes surrounding each GRB (determined by BATSE/IPN)
- Omit ±5 minutes surrounding GRB trigger time

Figure 3: Schematic description of background and "on-time" windows for a sample GRB.

## Analysis Procedure (cont'd)

While spatial and temporal information for each burst serve as the primary criteria for data selection, secondary criteria include the number of hit optical modules (i.e. those participating together in a single event), the angular resolution of the reconstructed event track, the uniformity of the hit optical modules, and the $\chi^2$ probability of each reconstructed track. These criteria are selected to minimize the Model Rejection Factor*, defined as

$$\frac{\text{Event Upper Limit } (= \mathrm{FC}^{\dagger}[90\%])}{\text{Expected Signal (simulations)}}$$

* Hill, G., and K. Rawlins, *Astropart. Phys.* **19** (2003) 393-402

† Feldman, G., and R. Cousins, PRD **57** (7) 3873

The reconstructed track from a simulated event is shown in Figure 4. The colors of the optical modules represent relative timing of the hit (red = earliest hit, blue = latest hit, black = OM not hit). The track points back (within ~3°) to the source of the muon neutrino.

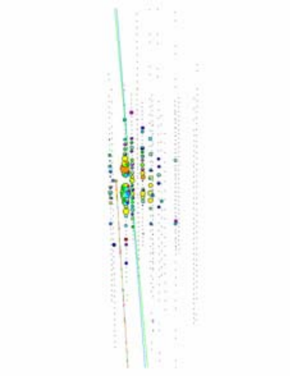
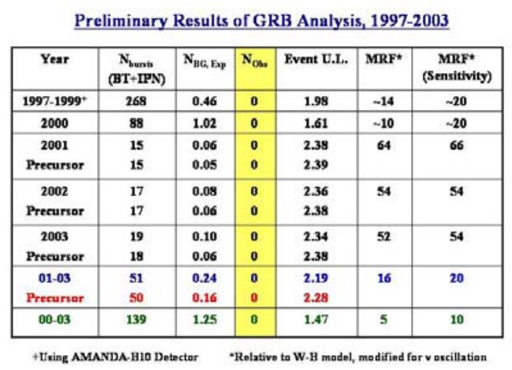


Figure 4: A simulated AMANDA event, with reconstructed tracks.

## Results

The results of seven years of AMANDA observations are shown in Table 1.

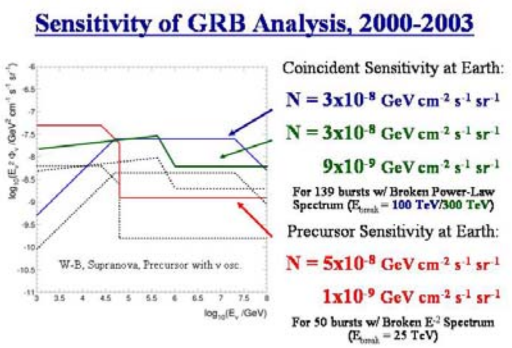


Preliminary Results of GRB Analysis, 1997-2003

| Year | $N_{\text{bursts}}$ (BT+IPN) | $N_{\text{BG, Exp}}$ | $N_{\text{Obs}}$ | Event U.L. | MRF* | MRF* (Sensitivity) |
|---|---|---|---|---|---|---|
| 1997-1999⁺ | 268 | 0.46 | 0 | 1.98 | ~14 | ~20 |
| 2000 | 88 | 1.02 | 0 | 1.61 | ~10 | ~20 |
| 2001 | 15 | 0.06 | 0 | 2.38 | 64 | 66 |
| Precursor | 15 | 0.05 | 0 | 2.39 | | |
| 2002 | 17 | 0.08 | 0 | 2.36 | 54 | 54 |
| Precursor | 17 | 0.06 | 0 | 2.38 | | |
| 2003 | 19 | 0.10 | 0 | 2.34 | 52 | 54 |
| Precursor | 18 | 0.06 | 0 | 2.38 | | |
| 01-03 | 51 | 0.24 | 0 | 2.19 | 16 | 20 |
| Precursor | 50 | 0.16 | 0 | 2.28 | | |
| 00-03 | 139 | 1.25 | 0 | 1.47 | 5 | 10 |

+Using AMANDA-B10 Detector *Relative to W-B model, modified for ν oscillation

From the observation of zero events for all of these bursts, we are able to derive neutrino flux limits for various theoretical models (Figure 5). The limits are approaching the predictions of several important models, including Razzaque et al.'s supranova model and the Waxman-Bahcall model. Because the precursor search was introduced at an intermediate stage of the analysis procedure, the limit on precursor neutrinos is significantly less restrictive.



Coincident Sensitivity at Earth:

$N = 3\times10^{-8}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$

$N = 3\times10^{-8}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$

$9\times10^{-9}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$

For 139 bursts w/ Broken Power-Law Spectrum ($E_{\text{break}}$ = 100 TeV/300 TeV)

Precursor Sensitivity at Earth:

$N = 5\times10^{-8}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$

$1\times10^{-9}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$

For 50 bursts w/ Broken $E^{-2}$ Spectrum ($E_{\text{break}}$ = 25 TeV)

Figure 5: Flux sensitivity of GRB search, 2000-2003

## Results (cont'd)

In addition to the specific models detailed here, the AMANDA results can be applied to any desired theoretical spectrum by means of the Green's Function Fluence method. Based on the observation of 139 bursts from 2000 to 2003, we are able to set a (spectrum-independent) fluence limit that is a significant improvement over previously-reported results (Figure 6). To calculate the flux limit for any desired spectrum, one needs only to fold that spectrum into the fluence limit shown here.

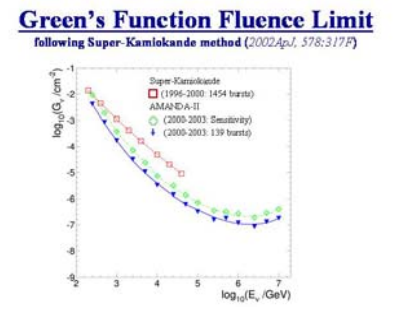


Figure 6: Green's Function Fluence Limit for 139 GRBs from 2000-2003.

## Conclusions and Outlook

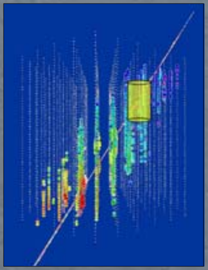
We report here on the analysis of over 400 GRBs occurring over seven years of AMANDA observations. The detection of zero events during the relevant time periods results in a flux limit that is close to several theoretical predictions for neutrino emission from GRBs. While these results represent the bulk of the GRB time periods contained within the AMANDA data, there are approximately 100 additional GRBs from 2001-2003 that have not yet been examined. These bursts are taken from the archives of the InterPlanetary Network; most have localization errors much larger than the angular resolution of AMANDA, so a different procedure is currently being developed to analyze the time periods surrounding these bursts.

As AMANDA's successor, IceCube, continues its observations, there are two primary benefits to the search for neutrinos from GRBs in the Swift era:

First, localizations are much more accurate than those derived from BATSE or other IPN satellite observations. Though there are approximately 400 bursts with precise localizations in seven years of AMANDA data, localizations for the 100 additional bursts would have improved AMANDA's flux limits considerably. As Swift continues to observe bursts and provide precise localizations, the bursts will be incorporated with much greater efficiency into AMANDA/IceCube observations.

Second, distance determinations for GRB hosts provides an important new tool for neutrino flux predictions. Here we have discussed results based on models with "averaged" burst properties. However, burst-to-burst variation in total flux, redshift, peak energy, and other variables can significantly impact the expected neutrino flux (the expected flux for GRB030329, for example, is nearly a factor of 10 higher than the "average" burst). While the averaged burst properties served as a useful tool when redshift estimates were missing or inadequate, IceCube's observations will lead to much more precise results when the predicted flux for each burst can be determined individually.

Finally, the transient point source search described here will also be broadened in scope as IceCube continues the legacy of AMANDA. While all of the bursts included in these results were observed by various photon observatories, gamma-ray dark or "failed" GRBs are hypothesized to occur at as much as 100x the rate of standard bursts. Even if the photons from these bursts are not observed, the neutrino signature may still be detectable by this method if spatial and temporal localization information can be derived from other observations (such as afterglows or correlated supernovae). Additionally, some supernovae are hypothesized to emit relativistic jets of material in a manner similar to GRBs. These GRB-like supernovae are also a promising candidate for neutrino emission detectable by IceCube or other km-scale detectors.



**IceCube is currently under construction, and an intermediate stage of the detector is already operational.**

## Acknowledgements

We acknowledge the support of the following agencies:
National Science Foundation--Office of Polar Programs, National Science Foundation—Physics Division, University of Wisconsin Alumni Research Foundation, Department of Energy, and National Energy Research Scientific Computing Center (supported by the Office of Energy Research and Department of Energy), the NSF-supported TeraGrid systens at the San Diego Supercomputing Center (SDSC), and the National Center for Supercomputing Applications (NCSA); Swedish Research Council, Swedish Polar Research Secretariat, and Knut and Alice Wallenberg Foundation, Sweden; German Ministry for Education and Research, Deutsche Forschungsgemeinschaft (DFG), Germany; Fund for Scientific Research (FNRS-FWO), Flanders Institute to encourage scientific and technological research in industry (IWT), and Belgian Federal Office for Scientific, Technical, and Cultural Affairs (OSTC); The Netherlands Organisation for Scientific Research (NWO).