# The Search for Neutrinos from Gamma Ray Bursts with AMANDA

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**Abstract.**
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 opportunities afforded by Swift, we also discuss the future potential for GRB neutrino detection with AMANDA's successor, IceCube. Finally, we discuss the application of AMANDA's transient point-source search to other phenomena, such as jet-driven supernovae and failed GRBs.

**Keywords:** Neutrino astronomy, Gamma-Ray Bursts, AMANDA, IceCube
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## INTRODUCTION

The Antarctic Muon and Neutrino Detector Array (AMANDA) 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 Cherenkov radiation from neutrino-induced muons above energies of approximately 50 GeV [1]. AMANDA has been searching the heavens since 1997 for high-energy neutrinos from a variety of astrophysical sources, including gamma-ray bursts (GRBs). This GRB neutrino search relies on spatio-temporal correlations with numerous ground- and space-based observatories, such as BATSE, HETE, and the other instruments of the Interplanetary Network [2].

A variety of different models exist for neutrino emission from GRBs. Neutrinos may be emitted in coincidence with or 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 [3, 4, 5]. The search for neutrino emission will help to test models of hadronic acceleration in the fireball or other GRB scenarios, and the search for precursor neutrinos may constrain models of GRB progenitors [6, 7].

## 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

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[1] for a full authorlist, see http://icecube.wisc.edu/pub_and_doc/conferences/conference-papers.html

positive detections. For each GRB, a two hour period is examined around the burst, excluding the 10-minute window immediately surrounding the burst. The 110 minute "off-time" period is examined to ensure detector stability and to determine the background rate for each burst. Selection criteria are then determined for each annual subset of bursts by comparing simulated muon neutrinos with the observed background.

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 along the reconstructed track, and the likelihood of each reconstructed track. These criteria are selected to minimize the Model Rejection Factor (MRF) [8], which is defined as the 90% event upper limit divided by the expected number of signal events derived from simulations.

## RESULTS

New results from the combination of seven years of AMANDA observations are shown in Table 1. From the observation of zero events for all of these bursts, we are able to derive neutrino flux limits for representative theoretical models[2]. The observed limits are approaching the predictions of several important models, including the supranova model and the Waxman-Bahcall broken power-law model (Figure 1, left panel).

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 (as detailed in [11]). Based on the subset of 139 bursts searched by AMANDA from 2000 to 2003, we are able to set a spectrum-independent fluence limit that is a significant improvement over previously-reported results (Figure 1, right panel). To calculate the flux limit for any desired spectrum, one needs only to fold that spectrum into the fluence limit shown here.

## 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 $\sim$100 poorly localized GRBs in the archives of the Interplanetary Network that have not yet been examined. Because the standard selection criteria rely heavily on accurate determination of burst positions, a different procedure is currently being developed to analyze the time periods surrounding these bursts.

As AMANDA's successor IceCube [12] continues its observations, there are two primary benefits to the search for neutrinos from GRBs in the Swift era. First, localizations

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[2] We similarly obtained a null result from a search of 153 non-triggered BATSE GRBs [9, 10]; however, these bursts are not incorporated into the models and thus are excluded from our flux limits.

**TABLE 1.** Preliminary Results of GRB Analysis 1997-2003

| | $N_{Bursts}$ | $N_{BG,Exp}$ | $N_{OBS}$ | **Event Upper Limit** | **MRF** * **(Sensitivity)** | **MRF (Observed)** |
|---|---|---|---|---|---|---|
| 1997-1999† | 268 | 0.46 | 0 | 1.98 | 20 | 14 |
| 2000 | 88 | 1.02 | 0 | 1.61 | 20 | 10 |
| 2001 | 15 | 0.06 | 0 | 2.38 | 66 | 64 |
| 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 | 54 | 52 |
| Precursor | 18 | 0.06 | 0 | 2.38 | | |
| 01-03 | 51 | 0.24 | 0 | 2.19 | 20 | 16 |
| Precursor | 50 | 0.16 | 0 | 2.28 | | |
| 97-03 | 407 | 1.71 | 0 | 1.27 | 7 | 3 |

* for Waxman-Bahcall, modified for oscillations

† using AMANDA B-10

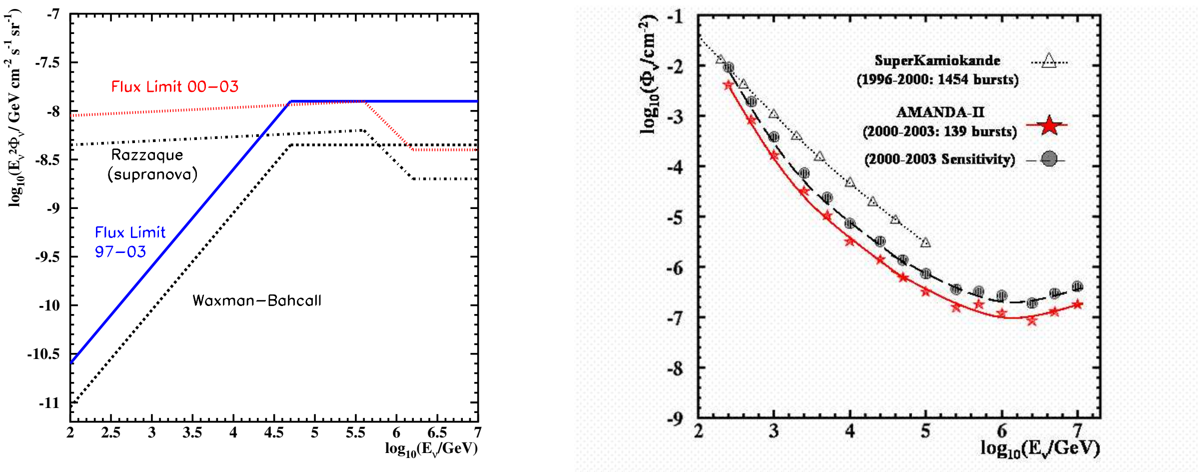

**FIGURE 1. Left Panel:** Flux limits for AMANDA-II observations and theoretical predictions for two representative neutrino spectra. **Right Panel:** Green's Function Fluence Limit for AMANDA-II observations of BATSE and IPN triggered bursts, compared to results from the GRB search of Super-Kamiokande. AMANDA's sensitivity is based upon the expected background and signal events prior to observations.

are much more accurate than those derived from BATSE or other IPN satellite observations. Precise localizations for the ∼100 poorly-localized bursts would have allowed significant improvement of AMANDA's flux limits; as Swift continues its observations, such bursts will be incorporated much more effectively into AMANDA/IceCube observations. Second, Swift provides us with opportunities to take advantange of important new tools 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 100 higher than the average burst [13]). While the averaged burst properties served as a useful tool when such information was missing or inadequate, Swift observations will aid us in determining with much greater precision the predicted neutrino flux for each individual burst.

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 100× the rate of standard bursts [7]. 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 [14].

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