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RECENT RESULTS IN THE SEARCH FOR MUON NEUTRINOS FROM GAMMA-RAY BURSTS WITH AMANDA

KYLER KUEHN, for the AMANDA Collaboration*
*Department of Physics and Astronomy, University of California
Irvine, California 92697-4575 USA*

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The Antarctic Muon and Neutrino Detector Array (AMANDA) has been searching the heavens for astrophysical neutrino sources (both discrete and diffuse) since 1997. AMANDA currently consists of 677 photomultiplier tubes buried within the ice near the South Pole, which are used to detect Cherenkov radiation caused by extremely high energy neutrinos traveling through the nearby ice. Here we describe AMANDA's technique for searching for potential neutrino signals from gamma-ray bursts, and we present preliminary results from several years (1997-2003) of observations. We also briefly discuss the current status and future potential of an expanded search for GRBs (using the full dataset from 2001-2003 and beyond).

Keywords: neutrino astronomy; particle astrophysics; gamma-ray bursts.

1. Introduction

Gamma-ray bursts (GRBs) are among the most energetic phenomena in the universe. All are characterized by prodigious gamma-ray emission, hypothesized to occur as a result of the collapse of a massive star or the merger of compact objects. Aspects of these theories have been corroborated by recent observations¹; however, many questions about the nature of GRBs still remain. One of the most promising techniques currently available to answer such questions is to use underwater or under-ice detectors to observe high-energy neutrinos from these sources^{2,3}. The search for neutrino emission will help to test the fireball^{2,3,4} or other GRB scenarios, and the search for precursor neutrinos may constrain models of GRB progenitors^{5,6}.

AMANDA uses the ice at the South Pole to detect Cherenkov radiation from neutrino-induced muons from both atmospheric interactions and astrophysical sources⁷, including, potentially, GRBs. In its initial configuration (AMANDA-B10, operational from 1997-1999), the detector consisted of an array of 302 photodetectors housed in optical modules (OMs) beneath the surface of the ice cap; the current configuration of 677 OMs (operational since 2000) is known as AMANDA-II.

*For full author list, see <http://amanda.uci.edu>.

2 *Kyler Kuehn, for the AMANDA Collaboration*

2. Observation and Analysis

The AMANDA GRB search relies on spatial and temporal correlations with photon observations other instruments. For each GRB, we search for coincident neutrino emission during the entire burst duration, plus the associated timing errors, plus the 10 seconds prior to the burst start. To determine the background rate for each burst, a further period of one hour and 50 minutes of data is analyzed—from one hour before the burst to one hour after the burst. The 10 minute period during and immediately surrounding the burst is excluded, to ensure that the analysis is not biased by the act of setting data quality cuts. In addition, the event rate per 10 second time bin during the background period is compared to the expected (temporally uncorrelated) distribution of background events. This test determines if there are significant fluctuations in data rate due to any intrinsic instability in the detector which could be misinterpreted as a signal event. All data included in this analysis satisfy the criteria established for stable detector operation.

The data quality cuts are determined by minimizing the Model Rejection Factor⁸, based on a comparison of observed background events with Monte Carlo simulations of signal events. Beyond temporal coincidence, some of the the cuts relevant for this analysis are the angular mismatch between the burst position and the reconstructed event track (based upon a maximum-likelihood pattern recognition algorithm applied to the timing of the "hit" OMs), the angular resolution of the reconstructed event track, and the uniformity of the spatial distribution of the hit OMs. The detector's effective area (A_{eff}) is determined after all cuts are applied, and provides a measure of the sensitivity of the detector as a function of energy. Due to the modest background rejection requirements, AMANDA-II has an A_{eff} significantly larger than any other currently-operating neutrino detector (greater than 50,000 m^2 at 100 TeV).

3. Results and Discussion

The initial AMANDA data (from 1997-2000) were searched for emission coincident with 312 bursts detected by BATSE's online triggering system⁹. As reported elsewhere¹⁰, zero events were observed, which results in an observed flux limit for muon neutrinos of $4 \times 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$ (assuming a Waxman-Bahcall neutrino energy spectrum²). Since these initial observations, an independent search of the 2000 data was performed, which confirmed the initial results. Additionally, the coincident analysis was expanded to include bursts which were discovered in offline searches of BATSE's archival data^{11,12}, as well as bursts detected by other satellites of the InterPlanetary Network¹³. The search for 139 of these bursts from 2000-2003 also resulted in zero observed events, leading to an even more stringent flux limit of $3 \times 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$. Additionally, we searched this subset of bursts for a precursor neutrino signal up to 110 seconds prior to the burst trigger time. No events were observed during the precursor period of these bursts; therefore, a flux limit of $5 \times 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$ is derived for the precursor spectrum predicted

by Razzaque *et al.*⁵.

Though a particular neutrino energy spectrum has been assumed thus far, the results of this analysis can be presented in a model-independent form, based on the Green's Function fluence method (as presented by the Super-Kamiokande Collaboration¹⁴). The results of this method can be folded into any desired theoretical spectrum to derive a flux limit for that specific spectrum. The Green's Function fluence limit for AMANDA-II extends several orders of magnitude beyond the range of the Super-Kamiokande limit, and is significantly (up to a factor of 10) lower compared to the Super-Kamiokande results in the region of overlap, primarily due to the much larger effective area of AMANDA-II.

4. Conclusions and Outlook

AMANDA has searched for neutrino emission from nearly 500 GRBs based on temporal and spatial coincidence with photon detections from numerous other observatories. Thus far, zero neutrino events have been observed during these bursts (and in a precursor search of a subset of these bursts). These results lead to flux limits that are approaching the predicted fluxes for several canonical GRB models. AMANDA is continuing its search for neutrino emission from various sources; even in the absence of a detection, the final results from AMANDA's observations from 1997-2004 should result in an improvement of the flux limits particularly for GRBs. After 2004, the expansion of AMANDA known as IceCube¹⁵ will begin operation, and its increased collecting area should allow it to swiftly overtake its predecessor. Furthermore, the Swift satellite will provide many more GRB localizations (perhaps as many as 100 per year¹⁶, which will provide a significantly larger dataset for the continuing search for neutrinos from Gamma-Ray Bursts.

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