29th International Cosmic Ray Conference Pune (2005) **5**, 131–134

The Search for Neutrinos from Gamma-Ray Bursts with AMANDA

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The Antarctic Muon and Neutrino Detector Array (AMANDA), located at the South Pole, has been searching the heavens for astrophysical neutrino sources (both discrete and diffuse) since 1997. The AMANDA telescope detects Čerenkov radiation caused by high-energy neutrinos traveling through the nearby ice; here we describe AMANDA's technique to search for neutrinos from gamma-ray bursts, both concurrent with the photon emission and prior to it (during the "precursor" phase). We present preliminary results from several years (1997-2003) of observations, and we also briefly discuss the current status and future potential of an expanded search for GRBs.

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 observations [1, 2]; however, many questions about the nature of GRBs still remain. One of the promising techniques currently available to answer such questions is to use underwater or under-ice detectors to observe possible high-energy neutrinos from these sources [3, 4]. The search for neutrino emission will help to test models of hadronic acceleration in the fireball [3, 4, 5] or other GRB scenarios, and the search for precursor neutrinos may constrain models of GRB progenitors [6, 7]. AMANDA uses the ice at the South Pole to detect Čerenkov radiation from neutrino-induced muons from both atmospheric interactions and astrophysical sources [8], including, potentially, GRBs. In its initial configuration (AMANDA B-10, operational from 1997-1999), the detector consisted of an array of 302 photo-detectors housed in optical modules (OMs) beneath the surface of the ice cap; the upgraded configuration of 677 OMs (operational from 2000 to 2004) was known as AMANDA-II.

2. Observation and Analysis

The AMANDA GRB search relies on spatial and temporal correlations with photon observations of other instruments, such as the Burst and Transient Source Experiment [9] or the satellites of the InterPlanetary Network [10]. For each GRB, we search for coincident neutrino emission during the entire burst duration, plus the 10 seconds prior to the burst start (plus corrections associated with uncertainties in burst timing). We also perform a search for precursor neutrino emission from 110 seconds prior to the burst trigger up to 10 seconds before the trigger. To determine the expected background rate for each burst, a larger 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 from the background region, to ensure that the data selection criteria are not chosen in a biased fashion (a "blind analysis"). In addition, the event count 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 the GRB searches satisfy these criteria established for stable detector operation.

The data selection criteria for the coincident and precursor searches are determined by minimizing the Model

Rejection Factor [11], which is defined as the 90% event upper limit derived from observed background events divided by the expected number of signal events determined from Monte Carlo simulations of the predicted neutrino flux. For the coincident search, the predicted flux is derived from the Waxman-Bahcall model [3] (corrected for neutrino oscillations), and for the precursor search, the predicted flux is derived from the model of Razzaque *et al.* [6]. In addition to temporal coincidence, several other selection criteria were used in these analyses, including: the angular mismatch between the burst position and the reconstructed event track (based upon a maximum-likelihood pattern recognition algorithm applied to the photon arrival time at each OM), 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 selection criteria are applied, and provides a measure of the detector's sensitivity to neutrino-induced muons passing through (or nearby) the detector. Though the selection criteria for the coincident and precursor searches differ slightly, both require only modest background rejection, giving AMANDA-II an A_{eff} larger than any other currently-operating neutrino detector (Figure 1).

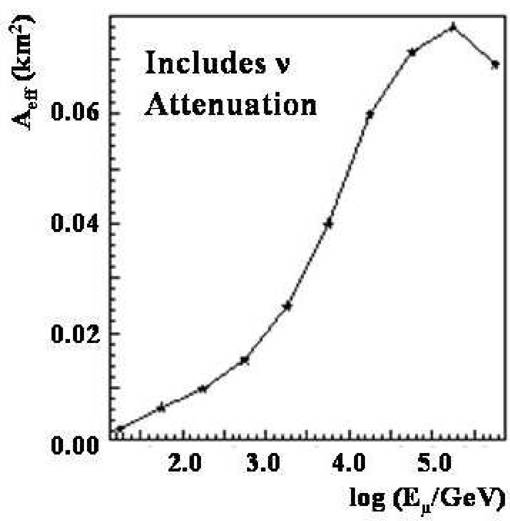

Figure 1. Angle-averaged muon effective area as a function of muon energy, utilizing the data selection criteria from the year 2000 coincident GRB search.

3. Results and Discussion

AMANDA data from 1997-2000 were searched for emission coincident with 312 bursts detected by BATSE's online triggering system. As reported elsewhere [12], zero events were observed, which results in an observed upper limit on the muon neutrino flux of 4×10^{-8} GeV cm^{-2} s^{-1} sr^{-1} (assuming a Waxman-Bahcall energy spectrum). Since the time of these observations, the coincident analysis has been expanded to include bursts detected by other satellites of the InterPlanetary Network. This search for 139 BATSE + IPN bursts from 2000-2003 also resulted in zero observed events, leading to an even more stringent upper limit of 3×10^{-8} GeV cm^{-2} s^{-1} sr^{-1}. These observations specifically exclude significant neutrino emission from GRB030329 (for a more detailed independent analysis of this unique burst, see [13]). [1] Additionally, we searched the 2001-2003 subset of bursts for a precursor neutrino signal; no events were observed. Therefore, an upper limit of 5×10^{-8} GeV cm^{-2} s^{-1} sr^{-1} is derived for the precursor neutrino flux predicted by Razzaque *et al.*. The observations are summarized in Table 1 and the flux upper limits are shown in Figure 2.

Table 1. Gamma-Ray Bursts Included in the AMANDA Observations

Year	N_{Bursts}	N_{BG}	N_{0bs}	Event U.L.	MRF	MRF (Sensitivity)
2000	88	1.02	0	1.61	9	13
2001	15	0.05	0	2.38	64	66
Precursor	15	0.06	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		
00-03	139	1.25	0	1.47	5	10
Precursor	50	0.16	0	2.28		

Though specific neutrino energy spectra have been assumed thus far, the results of these analyses can be applied to other energy spectra as well, by using the Green's Function fluence method as presented by the Super-Kamiokande Collaboration [16]. By folding the energy-dependent sensitivity of the detector into a desired theoretical spectrum, one can straightforwardly derive a flux limit for that specific spectrum. The Green's Function fluence limit for AMANDA-II (Figure 3) extends several orders of magnitude beyond the energy range of the Super-Kamiokande limit. It is also significantly (up to a factor of 10) lower compared to the Super-Kamiokande results in the overlapping energy region, primarily due to the much larger effective area of AMANDA-II.

4. Conclusions

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 in correlation with these bursts. These results lead to upper limits on the fluxes that are approaching the predictions for several canonical GRB models. However, it has been observed that the individual bursts vary significantly in their expected neutrino spectra; therefore we are also constructing an analysis procedure based on more detailed models that incorporate individual burst parameters [13]. 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 upper limits particularly for GRBs. In February of 2005, AMANDA's successor experiment known as IceCube [17] began operation, and its increased collecting area will allow it to swiftly improve upon the limits of its predecessor. Furthermore, the Swift satellite, operational since December 2004, is expected to localize as many as 100 additional GRBs per year [18], which will provide a significantly larger dataset for the continuing search for neutrinos from gamma-ray bursts.

[1] Not included in this flux limit are the non-triggered BATSE bursts discovered in offline searches of BATSE's archival data [14, 15]; we searched for coincident emission from twenty-six such bursts and observed zero neutrinos.

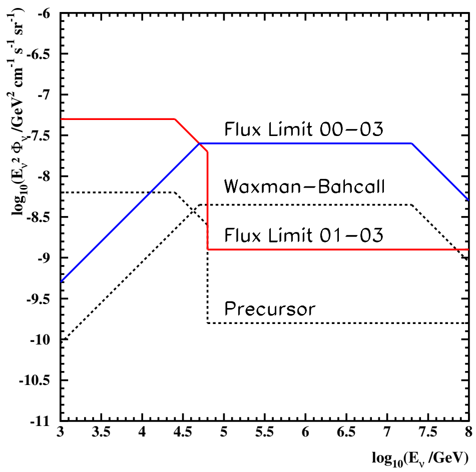

Figure 2. Flux Limits for AMANDA-II observations (solid lines) and flux predictions for precursor and coincident spectra (dashed lines)

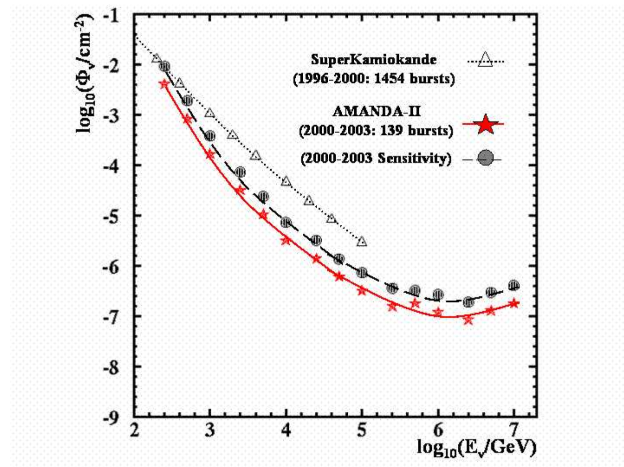

Figure 3. Green's Function Fluence Limit for AMANDA-II observations of BATSE and IPN triggered bursts. Note that the Super-Kamiokande results also include non-triggered BATSE bursts.

5. Acknowledgements

K.Kuehn would like to thank E. Waxman and S. Razzaque for productive and thought-provoking discussions, as well as S. Desai for detailed discussions regarding the Super-Kamiokande GRB analysis.

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