Project Findings

Findings submitted 2001

The data from the Austral winter 1997 has been analysed. The searches made, and results, are summarised below.

Atmospheric neutrinos The successful search for atmospheric neutrinos has been reported in a publication to Nature. Over 300 atmospheric neutrinos were found at a rate consistent with expectations. The energy range of these events makes them the highest energy neutrinos detected by any experiment. These neutrinos are being used to verify the correct operation and understanding of the detector, paving the way for other physics analyses. A detailed publication on this analysis is being prepared for submission.

Diffuse sources A search for a source of diffuse extra-terrestrial muon-neutrinos (for example from the sum of all active galaxies in the universe) has led to the best limits on such fluxes of any existing neutrino detector (e.g. Baikal) or previous detector (e.g. Frejus). The 90% confidence level limit for an assumed E^{-2} spectrum is $\Phi_{90}E^2 < 0.9 \times 10^{-6}$ GeV cm^{-1} s^{-1} sr^{-1}, which is sufficient to rule out many of the early model predictions (1990-1996) of neutrino production in active galaxies. A comparable limit $\Phi_{90}E^2 < 7.3 \times 10^{-6}$ GeV cm^{-1} s^{-1} sr^{-1} has been set for electron-neutrinos.

Point sources Searches have been made for cosmic objects that may be emitting neutrinos in numbers sufficient to stand out above the atmospheric neutrino background. Some active galaxies have been observed in high energy gamma-rays, and these have been searched for neutrino emission, the detection of which would confirm the hadronic nature of the acceleration mechanisms in these objects. No significant excess of events from any of these sources has been seen, leading to upper limits on the flux of neutrinos. In the case of Markarian 501, a source observed in gamma-rays, the neutrino flux limit is only a factor 10 above the level of the observed gamma-ray flux.

Gamma-ray bursts The origin of the gamma-ray emissions from gamma-ray bursts (GRBs) is still unknown. The gamma-rays from these energetic objects are detected by earth orbiting satellites, and detecting neutrinos in time and spatial coincidence with these objects would signify a hadronic acceleration mechanism is at work. The AMANDA B10 data has been searched for evidence of neutrino emissions in spatial and temporal coincidence with the BATSE observations. No significant excess of events has been found, and limits have been placed on the fluxes of neutrinos from these objects.

Supernovae The expected burst of low energy neutrinos from a stellar collapse can be detected by the AMANDA detector, by looking for a brief increase in the counting rates of the detector optical modules caused by the interaction of these low energy neutrinos with the ice in the detector. The AMANDA B10 detector can monitor 70% of the galaxy at 90% efficiency. A 90% confidence level upper limit of < 4.3 such collapses per year for our galaxy is found.

WIMPs Weakly Interacting Massive Particles (WIMPs), predicted by supersymmetric extensions of the standard model, are a candidate for the cold dark matter thought to exist in the universe. Such particles will become gravitationally trapped in the earth's centre, where they will annihilate with each other producing neutrinos. The AMANDA B10 data has been searched for an excess of events from the earth's centre. No such excess events have been found, and limits have therefore been placed on some supersymmetric models.

Monopoles The existence of magnetic monopoles was suggested by Dirac in 1931. These are also predicted by grand unification theories, where monopole masses in the range $10^8 - 10^{17}$GeV are predicted. A relativistic monopole would appear in the AMANDA detector as a track with a brightness 8300 times that of a minimum ionising muon, and thus very bright track-like events are searched for. An upper limit on the flux of monopoles has been placed at a level $\Phi < 0.62 \times 10^{-16}$ cm^{-1} s^{-1} sr^{-1}.

Updated findings - August 2002

Updated results from the AMANDA B10 1997 data set

Atmospheric neutrinos Following the reporting of the successful search for atmospheric neutrino in the journal Nature, and more detailed publication on this analysis has been written and accepted for publication in Physical Review D. This describes the complete set of analysis methods used in the two atmospheric neutrino analyses, and discusses the systematics of the detector behaviour in great detail.

Diffuse sources The upper limit on an extra-terrestrial flux of electron neutrinos has been reported in a paper submitted to Physical Review D. This limit, for an assumed E^{-2} spectrum is at a level of $\Phi_{90}E^2 < 6.5 \times 10^{-6}$ GeV cm^{-1} s^{-1} sr^{-1}. The search for a source of diffuse high energy extra-terrestrial muon neutrinos is near completion, following the final checks on the systematic detector effects. The result will be a 90% confidence level limit on an assumed E^{-2} spectrum at a level approximately for an assumed E^{-2} spectrum is $\Phi_{90}E^2 < 0.9 \times 10^{-6}$ GeV cm^{-1} s^{-1} sr^{-1}, which as discussed previously, will rule out many of the early model predictions (1990-1996) of neutrino production in active galaxies.

Point sources The results of the point source analysis have been submitted to the Astrophysical Journal. For a source with an E^{-2} differential energy spectrum and declination larger than 40 degrees, a limit $E^2\Phi_{90} < 10^{-6}$ GeV cm^{-2} s^{-1} is found for an energy threshold of 10 GeV.

Gamma-ray bursts The full results from the 1997 data search for neutrinos from gamma-ray bursts are near completion.

Supernovae The results of the search for supernovae explosions have been published in Astroparticle Physics. In the absence of a detection, a 90% confidence level upper limit for such bursts in our galaxy of 4.3 events was obtained.

WIMPs The WIMP analysis results have been accepted for publication in Physical Review D. The AMANDA B10 data has been searched for an excess of events from the earth's centre. No such excess events have been found, and limits have therefore been placed on some supersymmetric models.

Cosmic ray composition from SPASE-AMANDA coincidence events The analysis of coincidence data between the SPASE-2 air shower array and the AMANDA detector has lead to two major results. The first result of the coincident analysis allowed a system and Monte-Carlo independent calibration of the AMANDA detector. Both the sensitivity of optical sensors as well as the angular resolution of the AMANDA setector were determined. The SPASE-2 array has an angular resolution of 1 to 1.5 degrees, better than that of AMANDA, therefore it has been used to determine the resolution of AMANDA with the precision required for the subsequent physics analysis. The coincident analysis of SPASE and AMANDA data was then used to determine the mass composition of high energy cosmic rays in the energy range from 0.5 to 7 PeV. The results shows a significant increase towards a heavier mass composition. The analysis shows a unique mass independent energy resolution of 12% in the logarithm of the primary cosmic ray energy. It was shown that this composition analysis is very robust with respect to uncertainties in Monte-Carlo models. This is often a difficulty in this type of analysis with other methods. The analysis of these data lead to a dissertation (Rawlins, 2001). Two drafts for journal publications of both results are in the AMANDA internal review process.

Analysis of data from the AMANDA-II detector

In the austral summer 1999-2000, the AMANDA-II detector was completed with the addition of six strings to the existing AMANDA-B10 array. Three distinct data sets are considered, each from the years 2000, 2001, and 2002.

year 2000 data The first analysis of the year 2000 data set has been completed. A first simple atmospheric neutrino search demonstrated the simple extraction of 3-4 atmospheric neutrinos per day; a more sophisticated analysis will bring this number up to 4-5. The first analysis in search of a diffuse source of extra-terrestrial neutrinos has analysed 20% of the data, and for the full data set, the expected performance will surpass that of the B10 detector by about a factor of three. First analyses for point source and gamma-ray burst searches are near completion.

year 2001 data Initial on-line filtering of the 2001 data yielded many neutrino candidates; a full processing of the data set is imminent.

year 2002 data Atmospheric neutrinos are being extracted by the on-line filtering at the south pole at the expected rate.

Updated findings - July 2003

The major findings of the AMANDA detector are summarised in table 1, and outlined in more detail here.

Final results from the AMANDA B10 1997 data set

Diffuse neutrino search results The search for a diffuse flux of extra-terrestrial neutrinos produced the strongest constraint of any neutrino detector on these fluxes. The final 90% confidence level limit on an assumed E^{-2} spectrum is $\Phi_{90}E^2 = 8.4 \times 10^{-7}$ GeV cm^{-1} s^{-1} sr^{-1}. Limits on specific model predictions were also set, and some models were found to be excluded. Limits were also set on the flux of prompt charm induced neutrinos produced in the earth's atmosphere. During the course of this work, two new statistical techniques were developed, firstly the "model rejection potential" method for optimising the data selection cuts, and secondly, a new likelihood ratio test for the incorporation of systematic uncertainties into the limit calculations.

UHE neutrino search The UHE analysis is near completion, yielding the most restrictive limits in the energy region above 1 PeV.

Other analyses Previously discussed analyses, submitted to refereed journals, have passed through the reviewing process and appeared in press.

Cosmic ray mass composition with 1998 SPASE-AMANDA coincident data

The 1998 SPASE-AMANDA data has yielded information on the mass composition near the knee of the primary cosmic ray spectrum, with a trend toward heavier primaries observed.

Initial results from the AMANDA-II 2000 data set

Diffuse neutrino search Preliminary results for the diffuse flux searches, conducted with both muon and cascade detection channels, have been produced. The limit for the muon channel for an assumed E^{-2} spectrum is $\Phi_{90}E^2 = 4 \times 10^{-7}$ GeV cm^{-1} s^{-1} sr^{-1}, using half of the 2000 data set. For the cascade channel (sensitive to all flavours of neutrino), the initial limit is $\Phi_{90}E^2 = 6 \times 10^{-7}$ GeV cm^{-1} s^{-1} sr^{-1}.

Point source search A publication is close to submission, which reports on the search for point sources. No significant excess has been observed, and limits on potential sources are approaching a level of sensitivity where the neutrino flux is equal to the gamma-ray flux observed by atmospheric Cherenkov detectors. The limits for some potential neutrino sources, observed by gamma-ray experiments, are shown in table 1. The sky map from the analysis is shown in figure 1.

Gamma-ray bursts The BATSE satellite was decomissioned in May of 2000, however 44 GRBs were seen and the AMANDA-II data has been analysed in a search for coincident neutrinos. No neutrino events were seen in coincidence with these bursts, allowing limits to be placed on the neutrino fluxes.

UHE neutrino search AMANDA-II data have been searched for ultra-high energy neutrino events. No excesses of events above the atmospheric muon background have been observed.

Table 1
Summary of significant findings of the AMANDA detector. The symbol * denotes that the analysis has obtained the most constrictive limits of all experiments conducting that type of search.

Atmospheric neutrinos	observed consistent with expectations
Diffuse upgoing neutrinos*	limit on ν_μ E^{-2} flux in energy range $10 - 1.5 \times 10^3$ TeV: $\Phi_{90} E^2 = 4 \times 10^{-7}$ GeV cm^{-1} s^{-1} sr^{-1}
Diffuse cascade neutrinos*	limit on all flavor E^{-2} flux in energy range $80 - 7 \times 10^3$ TeV : $\Phi_{90} E^2 = 6 \times 10^{-7}$ GeV cm^{-1} s^{-1} sr^{-1}
Diffuse UHE neutrinos*	limit on ν_μ E^{-2} flux in energy range $10^4 - 10^6$ TeV: $\Phi_{90} E^2 = 7.2 \times 10^{-7}$ GeV cm^{-1} s^{-1} sr^{-1}
Point source neutrinos*	limits on sources ν_μ E^{-2} flux in energy range 0.5-200 TeV : Mkr 501 $\Phi_{90} E^2 = 1.8 \times 10^{-7}$ GeV cm^{-1} s^{-1} Mrk 421 $\Phi_{90} E^2 = 3.5 \times 10^{-7}$ GeV cm^{-1} s^{-1} Crab $\Phi_{90} E^2 = 2.4 \times 10^{-7}$ GeV cm^{-1} s^{-1} SS 433 $\Phi_{90} E^2 = 0.7 \times 10^{-7}$ GeV cm^{-1} s^{-1}
Gamma-ray burst neutrinos*	No neutrinos observed in coincidence with GRB : constraints on hadronic production models
WIMPs (earth)	Constraints on models comparable to other experiments with much longer livetime
Supernovae neutrinos	Upper limit on number of stellar collapses in our galaxy : < 4.3 per year
SPASE-AMANDA composition	Cosmic ray composition grows heavier in the “knee” region

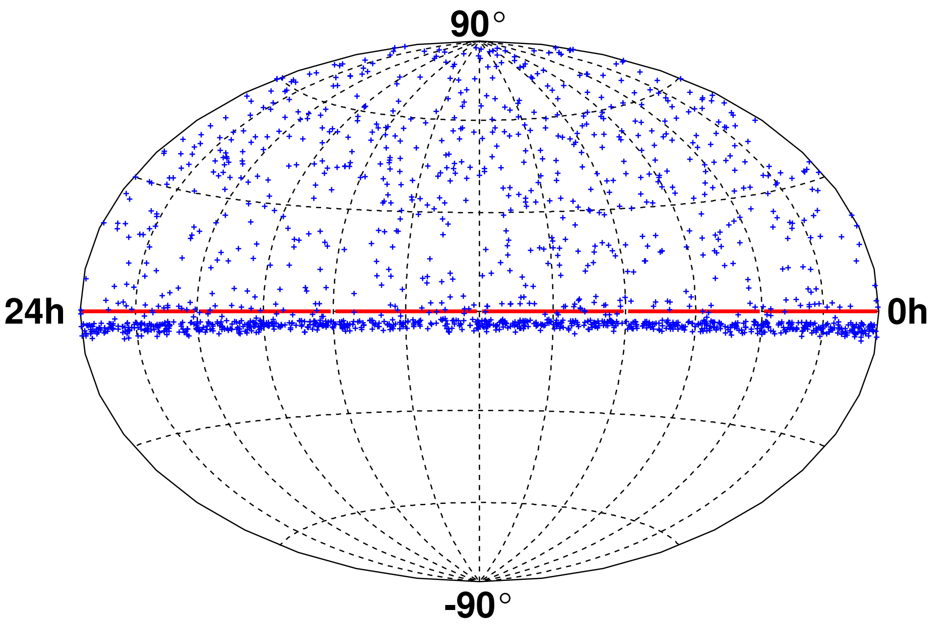

Fig. 1. Skymap of 699 neutrino events observed from arrival directions below the horizon at the south pole (i.e. from declination greater than zero degrees) in the 2000 point source analysis. These events are mostly atmospheric neutrinos and misreconstructed downgoing muons. No evidence for an excess of neutrinos above these backgrounds is present, leading to limits across the sky, and on individual sources.