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THE AMANDA NEUTRINO TELESCOPE

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We present recent results from the Antarctic Muon And Neutrino Detector Array (AMANDA), located at the South Pole in Antarctica. AMANDA-II, commissioned in 2000, is a multipurpose high energy neutrino telescope with a broad physics and astrophysics scope. We summarize the results from searches for a variety of sources of ultra-high energy neutrinos: TeV-PeV diffuse sources by measuring either muon tracks or cascades, neutrinos in excess of PeV by searching for muons traveling in the down-going direction and point sources.

Keywords: Neutrino Detector; Neutrino Telescopes; Neutrino Astronomy; Antarctic Ice; Ultra High Energy Neutrinos; AMANDA.

Introduction

AMANDA is the first neutrino telescope constructed in transparent ice, and deployed between 1500 m and 2000 m beneath the surface of the ice at the geographic South Pole in Antarctica. It is designed to search for neutrinos that originate in the most violent phenomena in the observable universe. Galactic objects like Supernova Remnants and extragalactic objects such as Active Galactic Nuclei and gamma ray bursts (GRB) are expected to be the powerful engines accelerating protons and nuclei to the highest energies, which eventually interact to generate neutrinos. Although not explicitly discussed here, the detector has measured atmospheric neutrinos and searched for neutrinos correlated with GRB[1].

1. The Detector

The AMANDA-II neutrino telescope[2] is an array of 677 Optical Modules (OM) arranged in 19 strings. The best sensitivity of the detector is achieved for neutrinos with E_ν between 10^3-10^6 GeV. Down-going atmospheric-μ's and up-going ν's are the major contribution to the background. The muon tracks are reconstructed with a maximum likelihood approach which models the arrival times and amplitudes of Cherenkov photons recorded by the photomultiplier tubes, achieving an angular resolution of 1.5°-2.5°. Above a few PeV, the Earth becomes opaque to neutrinos, and only those moving down or horizontally can reach the detector. Such events need to be separated from large muon bundles from down-going atmospheric air shower events.

2. Search for Diffuse Neutrino Flux

This section presents three different methods to search for the diffuse flux of neutrinos. Fig.1 (left) summarizes the results of the two search methods sensitive to all ν-flavors. The experimental limits assume a 1:1:1 ratio of neutrino flavors at the Earth due to oscillation. The dotted and dashed lines represent a sample of model predictions, adjusted for oscillation if appropriate, which have been excluded by these analyses (see[3,4] for details). The leftmost (rightmost) solid line is the AMANDA limit obtained from the cascade (UHE) analysis. The length of the experimental lines corresponds to the energy interval that contains 90% of the signal for a spectrum proportional to E^{-2}.

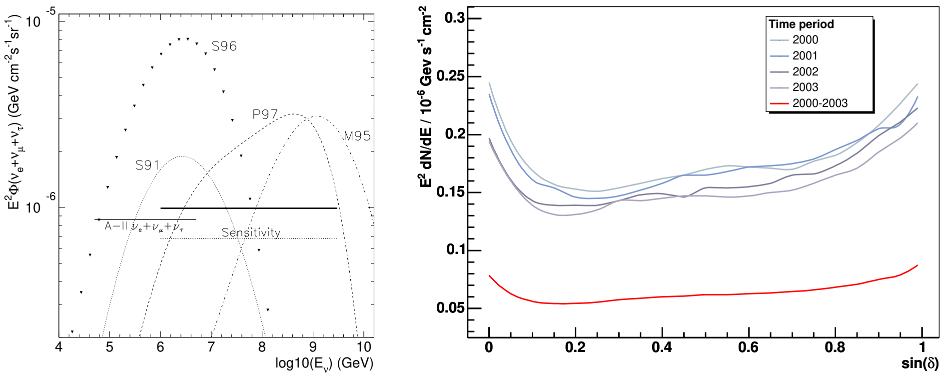

Fig. 1. **Left**: AMANDA-II limits for the diffuse flux of all ν-flavors calculated for an E^{-2} spectrum. **Right**: AMANDA-II sensitivities from a point source as a function of declination angle for E^{-2} spectra above E_ν = 10 GeV at 90% C.L. Individual curves are presented for the indicated years of operation. Bottom curve includes full data set.

The cascade analysis[3] delivers excellent energy resolution of 0.1-0.2 in $\log(\Delta E/E)$ and improved sensitivity to all ν-flavors. AMANDA is sensitive to ν-induced cascades from any direction, but with relatively modest angular resolution of 30°-40°. The diffuse flux limit from the cascade analysis is $E^2\Phi_{\nu_{all}}(E) \leq 8.6 \times 10^{-7}$ GeV $\cdot$ cm^{-2} $\cdot$ s^{-1} $\cdot$ sr^{-1} derived for an E^{-2} spectrum at 90% confidence level (C.L.). As indicated in Fig.1 (left), 90% of the signal lies within the energy interval between 50 TeV $< E_\nu <$ 5 PeV. Strategies for the UHE analysis[4] were developed to separate signal from background based on the large amount of Cherenkov light generated by interactions of neutrinos with $E_\nu > 10^{15}$ eV. Five events were observed, while 4.6 events were expected. This corresponds to a flux limit for an E^{-2} spectrum of $E^2\Phi_{\nu_{all}}(E) \leq 0.99 \times 10^{-6}$ GeV $\cdot$ cm^{-2} $\cdot$ s^{-1} $\cdot$ sr^{-1} at 90% C.L., in the energy range of 1 PeV $< E_\nu <$ 3 EeV (see Fig.1 (left)). The energy spectrum of atmospheric-ν's provides a third analysis tool[5] to search for a diffuse source of high energy neutrinos. The measured atmospheric E_ν spectrum extends to 300 TeV, and agrees with theoretical parameterizations. Since the spectrum of observed events is consistent with atmospheric-ν's, it was used to set a preliminary limit on a potential extraterrestrial ν_μ-flux with spectral dependence of E^{-2} to $E^2\Phi_{\nu_\mu}(E) \leq 2.6 \times 10^{-7}\ \mathrm{GeV} \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1}$ at 90% C.L., in the energy range of 100 TeV $< E_\nu <$ 300 TeV. The combined systematic uncertainty is typically 30%, although the value varies slightly with the analysis method.

3. Search for Point Sources

AMANDA-II has surveyed the entire northern sky since 2000 for non-statistical excesses in small regions of the sky[6]. None were found so far. Fig. 1 (right) summarizes the preliminary results of a 4-year combined analysis showing the expected sensitivity, based on the assumption of no signal as a function of declination for E^{-2} spectra above E_ν = 10 GeV. A final sample of 3369 events was observed, which is in good agreement with the expected number of 3438 from atmospheric-ν's. An unbinned sky search was performed for statistical fluctuation. No fluctuation exceeded 3.4σ, which is compatible with random fluctuation in the spatial distribution of atmospheric-ν's. Due to the large number of search bins a fluctuation of at least this magnitude would occur in 40% of similar data samples.

4. Conclusion

AMANDA has yet to observe an extraterrestrial neutrino source, but "*she*" has demonstrated the cost-effectiveness and robustness of the technique. The detector is very versatile; it addresses many different neutrino physics subjects and sets the most stringent upper limits on Galactic and extragalactic ν-fluxes. The improved search for diffuse fluxes, which has ruled out several predictions, along with the extended four-year search for point sources has started to constrain the enormous parameter space that exist in many models of neutrino production. The reported experimental limits on the diffuse ν-flux are less than an order of magnitude above the Waxman-Bahcall bound[7].

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