Results from the AMANDA Neutrino Telescope

J. D. Zornoza[a]*, for the IceCube collaboration

[a]UW-Madison, 222 W. Washington Ave. Madison, WI 53705 (USA).

High-energy neutrinos are very promising probes for Astrophysics. Neutrinos interact very weakly, so they are unique sources of information at high energies. However, since they interact very rarely, very large detectors are needed to observe them. The detection principle in a neutrino telescope is based on the observation of the Cherenkov light produced by the muons generated in the interactions of muon neutrinos. Other signatures, such as cascades from electrons produced by electron neutrinos, are also identifiable. AMANDA-II, with 677 optical sensors, has demonstrated the feasibility of such a detector in the Antarctic ice and provided important Physics results. In this presentation we will review this scientific output, which includes the first sky map using neutrinos from the Northern Hemisphere, the measure of the atmospheric neutrino spectrum, the study of astrophysical objects like gamma-ray bursts, active galactic nuclei, soft-gamma repeaters or supernovae and limits on the neutralino flux from the Sun and the Earth.

1. Introduction

Neutrino astronomy is one of the most promising fields in Astrophysics. There are several aspects that make neutrino unique tools to study the Universe. Other more conventional messengers like photons or cosmic rays are limited by their interactions with radiation and matter at high energies. Moreover, magnetic fields deflect charged particles. Neutrinos, on the contrary, only interact weakly, which makes them very special probes. Due to this fact, they are also very difficult to detect, so very large detectors are needed.

The principle for detecting high-energy cosmic neutrinos was proposed by Markov several decades ago [1]. The idea is to detect the Cherenkov light emitted by the relativistic muons produced in the CC interactions of the muon neutrinos with the surrounding matter. The information of the time and position of the photon hits can be used to reconstruct the direction of the muon (and hence that of the neutrino, since at high energies they are almost collinear). Other signatures are also possible. In particular, the cascades produced in the NC interactions of neutrinos of all flavors and in the CC interactions of electron and tau neutrinos (although the fluxes expected from the latter are very small). Muon-events are seen as long tracks ($\sim$km), so they can be reconstructed with good angular resolution ($\sim$2-3 deg). On the contrary, the size of the tracks produced in cascade events is short compared with the distance between optical modules, so they are seen as spheres of light, making difficult to reconstruct the direction.

The AMANDA detector is working in its present configuration since 2000. It consists of 677 8-inch photomultipliers, housed in pressure-resistant glass spheres, distributed along 19 strings, as shown in figure 1. The distance between optical modules in the same string is 10-20 m. The detector is a cylinder-shaped, with a height of 500 m and a diameter of 200 m.

The optical properties of the medium are important for the angular resolution and the effective area of the detector. In deep Antarctic ice, the absorption length is $\sim$110 m and the scattering length is $\sim$20 m. Another relevant parameter is the level of dark noise, which is very low ($\sim$400 Hz). This makes the reconstruction easier and also to use AMANDA as a supernova-neutrino detector (for these low energy neutrinos, the reconstruction of the track is not possible, so

*Supported by the Marie Curie Ougoing International Fellowship Program

a correlation between an increase on the average rate in the photomultipliers and the supernova explosion is looked for).

The main sources of physical background for these detectors two. On the one hand, the muons produced by cosmic rays in the atmosphere. In order to avoid this background, the sensors are buried deep in the ice (1500-2000 m). Since the flux of down-going muons is high, even at these depths, only up-going events are accepted. The down-going events which could be reconstructed as up-going have to be cleaned by careful analysis. The second kind of background comes from the atmospheric neutrinos produced also by cosmic rays interacting in the atmosphere. This is an irreducible background which can be eliminated only by time/space constraints (point-like sources analysis) or using the fact that the spectral index for this neutrinos is softer than for cosmic signals (diffuse analysis).

2. Scientific results

As mentioned before, neutrino telescopes are a multi-scope tools. We show a selection of some important results obtained in these years.

- Point-like sources

  The AMANDA experiment produced the first neutrino map of the Northern sky. The results from this analysis show that the observed distribution of events is compatible with the expected background of atmospheric neutrinos. The maximum deviation is 3.4σ, which is expected in 92% of experiments with only background [2]. The limits on the cosmic neutrino flux are shown in figure 2, as a function of the declination.

  Alternative analysis have been carried out in order to improve the sensitivity to cosmic signals. For instance, the events of sources of the same kind of AGNs can be stacked in order to improve the statistics [3]. This allows to improve the source limit by a factor three, typically.

  Another approach is to look for correlations with active periods in electromagnetic observations in transient events (blazars: X-rays, microquasars: radio). When there is evidence about the variable character of the source but the electromagnetic observations are limited, a sliding-window can be used. The length of this window is 20 days for Galactic sources and 40 days for extra-Galactic sources. Although no positive correlation has been found, it is worth to note that three events were observed in coincidence with a orphan flare of 1ES 1959+650. However, this was noticed *a posteriori*, so it is not possible to estimate its statistical significance.

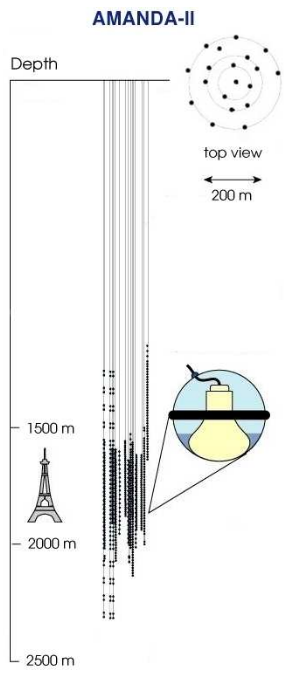

Figure 1. Sketch of the AMANDA detector. It consists of 677 optical modules distributed along 19 lines buried at 1500-2000 m in the Antarctic ice.

- Diffuse fluxes

  The integrated flux from all the non-

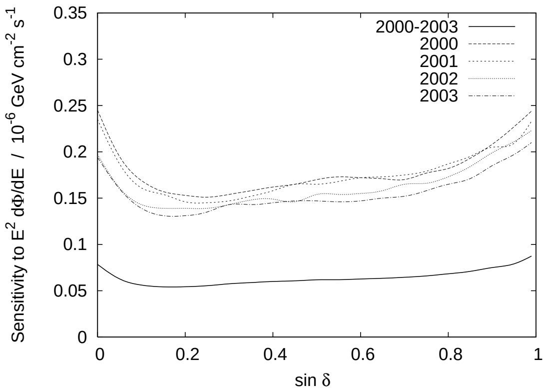

Figure 2. Sensitivity to point-like sources as a function of the declination for a E^{-2} signal. It can be seen the improvement following the increase in statistics.

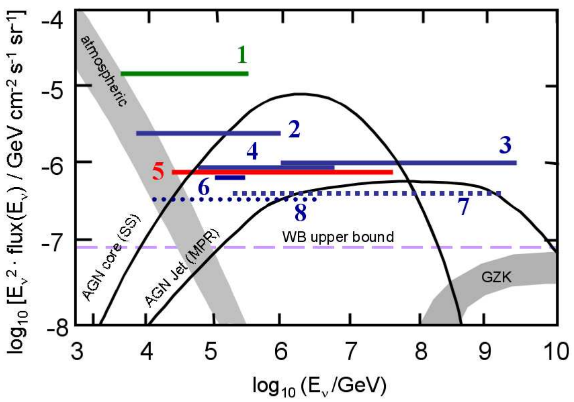

Figure 3. Limits and sensitivity to all-flavor neutrino fluxes (E^{-2}). The legend is as follows: 1) Macro, 2) AMANDA B10, 3) AMANDA B10 UHE, 4) AMANDA-II cascades, 5) Baikal cascades, 6) AMANDA II (unfolding analysis), 7), AMANDA II UHE, 8) AMANDA II (using 2000-2003 data). Oscillation effect is included.

resolved sources in the sky produced a diffuse flux which is expected to follow an energy spectrum harder than the one of atmospheric neutrinos. Therefore, an excess over this background at high energies has been looked for. The analysis performed up to now indicate no excess, so an upper limit at $E^{-2}d\phi/dE = 1.1\times10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1} has been set [4]. Figure 3 shows this results compared with other experiments (multiplied by three for oscillations).

- GRBs and SGR 1860-20

  In events like gamma-ray bursts (GRBs) and the giant flares from soft gamma-ray repeaters (SGRs), the rejection of background is easier, since we can use information of both the location and time of the event.

  For GRBs, AMANDA-II has searched for neutrinos from more than 500 GRBs. No signal has been detected above the background, so limits have been set [5].

  On the other hand, the analysis of the giant flare from SGR 1860-20 (above the horizon of AMANDA) neither found any event in coincidence with the corresponding time and space window. Therefore, we set limits on the down-going gamma-ray flux (since those would have produced muons in the interactions with the atmosphere) and neutrinos [6].

- Neutralino search Weakly Interacting Massive Particles (WIMPs) are one of the best candidates for explaining the cold dark matter component of the Universe which is inferred from several experiments. The lightest neutralino is the most stable supersymmetric particle, if R-parity is conserved. Therefore, if neutralinos exist, they would accumulate in massive bodies like the Sun or the Earth. As long as the density of these particles increases, the rate of neutralino interaction increases. Neutrinos can be produced from the ulterior interaction of the secondaries from the neutralino annihilation. Hence, neutrino telescopes are the only detectors for which the neutralino interactions in these objects could be accessible. Another possible source of neutralino-induced neutrinos is the Galactic Center. No signal from these sources has been detected. In figure 4, the limits set AMANDA-II to the flux of muons from the Earth.

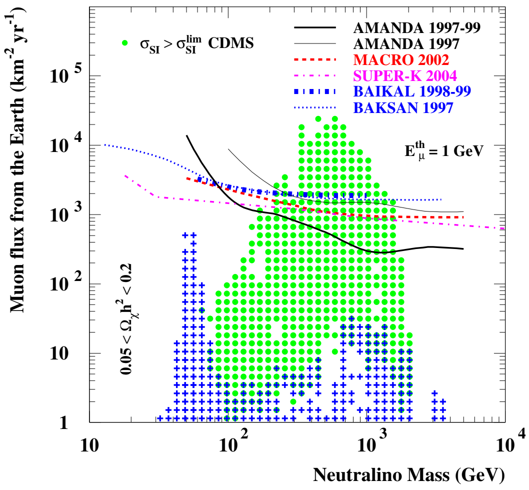

Figure 4. Limit to the muon flux (90%CL) produced by neutralino annihilations in the Earth. Hard neutrino spectrum is assumed. Limits by other experiments are also shown. Dots cover the parameter space excluded by CDMS; crosses show the predictions for cosmologically relevant MSSM models.

3. Conclusions

After several years of operation, the AMANDA-II neutrino telescope has produced many relevant scientific results. Among them, we can mention the first map of the Northern Hemisphere neutrino sky, the limits in the diffuse and point-like neutrino cosmic fluxes, and the constrains in the search for the neutralino. The analysis of the remaining data to analyze from AMANDA will improve all these results. Moreover, IceCube, the next step in neutrino astronomy (also in the South Pole, with 9 out of 80 strings already deployed) will also begin to produce scientific results very soon.

REFERENCES

1. A.M. Markov, Proceedings of the Rochester Conference, New York, (1960)
2. M. Ackermann for the IceCube collaboration, "Search for High Energy Neutrino Point Sources in the Northern Hemisphere with the AMANDA Neutrino Telescope", ICRC Pune (2005).
3. M. Ackermann and others (IceCube collaboration), "On the selection of AGN neutrino source candidates for a source stacking analysis in neutrino telescopes", accepted by Astrop. Phys.
4. J. Hodges for the IceCube collaboration, "Search for diffuse flux of extraterrestrial muon neutrinos using AMANDA-II data from 2000 to 2003", ICRC Pune (2005).
5. K. Kuehn for the IceCube Collaboration, "The Search for Neutrinos from Gamma-Ray Bursts with AMANDA", ICRC Pune (2005); M. Stamatikos for the IceCube Collaboration, "Probing for leptonic signatures from SGR030329 with AMANDA-II", ICRC Pune (2005).
6. A. Achterberg and others (IceCube collaboration), "Limits on the high-energy gamma and neutrino fluxes from the SGR-20 giant flare of December 27th 2004 with the AMANDA detector", submitted to Phys.Rev.Lett., eprint: astro-ph/0607233.