Astroparticle physics with the AMANDA neutrino telescope

Bruny Baret for the IceCube Collaboration [1]
Inter-university Institute for High Energies, Vrije Universiteit Brussel, Pleinlaan 2, Brussels 1040, Belgium.
E-mail: bruny.baret@vub.ac.be

Abstract. The AMANDA neutrino telescope at the South Pole has been taking data successfully since 1997. This detector opened a new window on a wide range of physics including atmospheric neutrinos, indirect searches for WIMP dark matter and possible astrophysical sources of high energy neutrinos such as Gamma Ray Bursts and Active galactic Nuclei. With the detection of several thousand atmospheric neutrinos it has proved the feasibility of using the South Pole icecap as a Cherenkov medium for the detection of high energy neutrinos, and provided much useful technical information for its successor experiment IceCube of which it is now the low energy extension. We present here a selection of the various searches performed and the increasingly stringent limits obtained over many years of operation.

1. The AMANDA neutrino telescope
The AMANDA muon and neutrino telescope consists of an array of photomultipliers buried in the deep ice of the geographical South Pole. Its main operating principle is to detect the Cherenkov light yield in the ice by a relativistic muon produced by the interaction of a high energy neutrino in the vicinity of the detector. It was completed in 2000 with a total of 677 optical modules arranged on 19 strings instrumenting a cylinder of 200m diameter between 1500m and 2000m below the surface. The physical background comes from the interaction of cosmic rays with the atmosphere. Atmospheric high energy muons not stopped by the ice sheet can be suppressed by looking through the Earth. Atmospheric neutrinos, which won’t be absorbed by the Earth will have to be suppressed by energy based cuts. The AMANDA telescope sees respectively $10^9$ and $10^3$ such events per year.

2. Point Source Searches
Point Sources are one of the main motivations for neutrino telescopes. Indeed Active Galactic Nuclei are thought to be accelerators of very high energy cosmic rays and gamma ray emission has already been detected from such objects. But an uncertainty remains on the mechanism taking place there. Both hadronic phenomena, through decay of photo-produced pions, or electromagnetic ones, like inverse Compton scattering of surrounding radiation on accelerated leptons, could yield the observed spectra. The detection of such objects via neutrinos would be a strong indication in favor of hadronic models.
2.1. Steady point sources
A time integrated search was done with the data collected by AMANDA between 2000 and 2004 with 4282 reconstructed neutrinos [2] representing 1001 days of live time. Both a full northern sky search and the search for preselected gamma-ray sources have been performed taking into account muon and tau neutrinos and anti-neutrinos. The highest excess on the northern sky survey is of \(3.7\sigma\). But the probability of such a deviation or higher due to background is 69%. This is estimated from 100 equivalent sky surveys of events randomized in right ascension (i.e. with no source).

When using a source catalogue, the highest significance is at the location of the GeV blazar 3C273 with 8 observed events for 4.7 expected from background, corresponding to a 1.2\(\sigma\) deviation. No significant excess has thus been observed and the declination averaged point source flux upper limit at 90% confidence level is then \(\Phi = 11.1 \times 10^{-11} \text{ TeV}^{-1} \text{cm}^{-2} \text{s}^{-1}\) for the benchmark flux \(d\Phi/dE = \Phi_0 \left(\frac{E}{\text{TeV}}\right)^{-2}\) between 1.6 TeV and 2.5 PeV. It is interesting to note that limits are dependent on the spectral shape of the source flux considered since the effective area strongly depends on the energy of the incident neutrino. Some specific models are then already excluded by AMANDA data [3].

2.2. Stacking analysis
The final data set has also been searched for a signal due to the cumulative neutrino fluxes coming from generic classes of AGN [4], which is a way to reduce the background while enhancing the hypothetical signal. Here only muon neutrinos and anti-neutrinos were considered. No significant excess was found either, yielding flux upper limits on generic classes of AGNs from \(0.34 \times 10^{-11}\) for GeV blazars to \(4.11 \times 10^{-11} \text{ TeV}^{-1} \text{cm}^{-2} \text{s}^{-1}\) for FR-I type galaxies [2].

3. Gamma Ray Burst search
Like AGNs, Gamma Ray Bursts are thought to be acceleration sites of very high energy hadrons, yielding high energy neutrinos by interaction of these with the surrounding medium through pion photo-production. A search has been performed in the AMANDA data in the period 1997-2003 for spatial and temporal correlation with more than 400 GRBs [5]. No signal was found yielding the upper flux limits shown on fig.1 where one model is already excluded. For the Waxman-Bahcall model both long- and short-duration bursts are included. For the other spectra, only long-duration bursts are included. Including short-duration bursts would improve the flux upper limits by approximately 13%. While the analysis was restricted to bursts located in the Northern Hemisphere (2\(\pi\) sr), all flux upper limits are for the entire sky (4\(\pi\) sr).

4. Diffuse Search
If individual sources are too weak to be detected, several unresolved sources distributed isotropically over the sky could combine to make a detectable signal. Such flux predictions have been made [6] considering that hadrons are accelerated at objects such as AGNs and GRBs. The idea here is to suppose that extra-terrestrial neutrinos have a harder energy spectrum, typically a power spectrum of index \(-2\), than atmospheric neutrinos. One has then to search an excess of events at high energy on the expected atmospheric neutrino energy spectrum. Such an analysis was performed using the data collected by AMANDA during the period 2000-2003 [7]. No excess was observed yielding an upper limit of \(E^{-2} dN/dE < 7.4 \times 10^{-8} \text{ GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}\), which is the most stringent to date.

5. Indirect Dark Matter search
The Dark Matter candidate considered here is the neutralino from the Minimal Supersymmetric extension of the Standard Model. As WIMPs, these particles will scatter weakly on normal
matters and lose energy. Eventually, they will be trapped in the gravitational field of heavy celestial objects, like the Earth and the Sun. The neutralinos accumulated in the center of these bodies can annihilate pairwise. The neutrinos produced in the decays of the Standard Model annihilation products can then be detected with a high energy neutrino detector as an excess over the expected atmospheric neutrino flux.

In order to cover a large parameter space, a soft and hard channel (coming respectively from $b\bar{b}$ and $W^+W^-$ annihilations) were considered for masses ranging from 50 GeV to 5000 GeV. The search for a signal coming from the center of the Earth was done using the AMANDA data sets from 1997-1999 and 2000-2003, and the search for a signal from the Sun using the 2001 data set [8]. No excess was found, fig.2 displays the limit on a muon flux from the Sun, which with only one year of data is competitive with other indirect searches.

---

[1] The IceCube author list is referenced in the proceedings of the 30th International Cosmic Ray Conference (ICRC 2007), Merida Yucatan, Mexico, Jul. 2007
[2] A. Achterberg et al. (IceCube Collaboration) Phys.Rev. D 75, 102001 (2007).
[3] M. Ackermann, proceedings of The Multi-Messenger Approach To Unidentified Gamma-Ray Sources: 3rd Workshop On The Nature Of Unidentified High-Energy Sources 4-7 Jul 2006, Barcelona, Spain
[4] A. Achterberg et al. (IceCube Collaboration) Astropart.Phys. 26, 282-300 (2006)
[5] A. Achterberg et al. for the IceCube Collaboration and K. Hurley et al. for the IPN Collaboration, arXiv:0705.1186 submitted to Astrophysical Journal.
[6] E. Waxman and J. Bahcall, Phys. Rev. D 59, 023002 (1998).
[7] A. Achterberg et al. (IceCube Collaboration) Phys.Rev. D 76, 042008 (2007).
[8] D. Hubert and A. Davour (for the IceCube Collaboration), proceedings of the 30th International Cosmic Ray Conference (ICRC 2007), Merida Yucatan, Mexico, Jul. 2007.