EXPLORING THE UNIVERSE WITH THE ANTARES NEUTRINO TELESCOPE

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The ANTARES Collaboration is currently constructing a large neutrino telescope in the Mediterranean sea. The telescope will use a three-dimensional array of photomultiplier tubes (PMTs) to detect the Cherenkov light emitted in sea water by neutrino-induced muons. The array of 12 strings, which hold 900 PMTs, is planned to be deployed at a depth of about 2500 m near Toulon (France), 40 km off the coast. The scientific objective of ANTARES is to detect high-energy neutrinos, which may be produced at astrophysical sources – sites of the cosmic-ray acceleration, such as quasars, gamma-ray bursters, microquasars and supernova remnants. The objectives also include the indirect search for WIMPs by looking for neutrinos from neutralino annihilations in the centres of the Sun, the Earth and the Galaxy. In 2003 two strings have been successfully deployed and connected to the electro-optical cable, which transmitted data to shore station.

1 Introduction

High-energy neutrino astronomy opens a new window on the Universe, complementary to existing gamma-ray observations. Neutrinos can be produced in pp or $p\gamma$ interactions of accelerated protons (or heavier nuclei) with matter or photons via the decay of charged pions (and possibly kaons). Neutrinos escape from the source and travel large distances to the Earth without being absorbed, scattered or deflected by magnetic fields. Thus they can deliver information directly from the sites of cosmic-ray acceleration, whereas high-energy gammas and protons can be absorbed either close to the source or on their way to the Earth, and protons are also deflected by magnetic fields. High-energy neutrinos can also be produced in the annihilation of neutralinos (favourite supersymmetric candidate for non-baryonic dark matter) accumulated in the centres of celestial bodies.

Several projects are now underway to construct large-scale neutrino detectors underwater or under ice, such as Baikal, AMANDA, NESTOR, ANTARES, NEMO, IceCube [1], with Baikal and AMANDA already running and producing interesting results.

2 Detector design

ANTARES (**A**stronomy with a **N**eutrino **T**elescope and **A**byss environmental **RES**earch) [2] will detect the Cherenkov light emitted by secondary particles produced in neutrino interactions in sea water or the rock below the sea bed. The detector is optimised for detecting muons from charged-current reactions of muon neutrinos, but will also be sensitive to other neutrino flavours and to neutral-current reactions. It will consist of 12 lines (or strings) which will be anchored to the sea bed at distances of about 60-75 m from each other and kept vertical by buoys. Each string will be equipped with 75 optical modules (OMs) [3] arranged in triplets (storeys, see Figure 1) subtended by titanium frames which also support water-tight titanium containers for the electronic components. Each OM glass sphere houses one 10-inch PMT, oriented at 45° to the downward vertical. The storeys will be spaced at a vertical distance of 14.5 m and interconnected with an electro-optical-mechanical cable supplying the electric power and the control signals, and transferring the data to the bottom of the string. Submarine-deployed electro-optical cables connect the strings to the junction box (JB) which then sends the data to shore via the main electro-optical cable. Each string will carry several optical beacons for timing calibration and acoustic transponders used for position measurements. The detector will be complemented by an instrumentation line supporting devices for measurements of environmental parameters and tools used by other scientific communities (for instance, a seismometer).

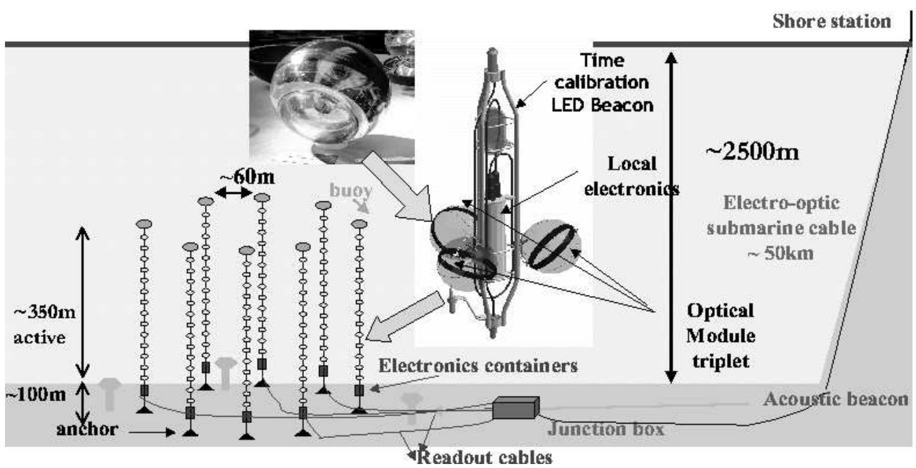

Figure 1: Schematic view of the ANTARES detector.

The PMT signals are processed with custom-designed ASIC chips which measure the arrival time and charge for signals. All signals above an adjustable threshold (usually corresponding to a fraction of one photoelectron pulse) are sent to shore, where an online filter running on a PC farm selects event candidates and reduces the data recorded on tape to about 1 MB/s.

3 ANTARES performance and sensitivity

Muons produced by muon neutrinos are finally identified and reconstructed by offline algorithms. Relative and absolute positions of OMs will be measured with an accuracy of ~ 5 cm and ~ 1 m, respectively. From the arrival times of the photons at the PMTs and the OM positions, the trajectories of muons will be reconstructed. The resulting angular resolution estimated from simulations is about $0.2° - 0.3°$ for neutrino energies $E_\nu > 10$ TeV. At smaller energies the angle between the reconstructed muon and the parent neutrino direction is dominated by the kinematics of the charged current interaction. The muon energy, E_μ, is determined from the muon range at small energies and from the Cherenkov intensity due to radiative energy losses at high energies. The energy resolution is about $30-40\%$ in $\log E_\mu$ for $E_\mu > 10$ TeV. The effective area of ANTARES depends on the neutrino energy, the efficiency of reconstruction and selection cuts. For well reconstructed muon tracks (accuracy better than 1°) the effective surface area increases from about 5×10^{-3} km^2 at $E_\nu \sim 0.1$ TeV to more than 0.05 km^2 at $E_\nu > 100$ TeV. The Earth, however, becomes opaque to very-high-energy neutrinos.

Atmospheric down-going muons and up-going neutrinos constitute the physical background for ANTARES. Atmospheric muons, in particular muon bundles, can be erroneously reconstructed as up-going muons expected from neutrino interactions. This background is currently under study, preliminary results showing that the large depth and sophisticated reconstruction algorithm can help to suppress it sufficiently to be sensitive to astrophysical neutrinos. The signal from atmospheric neutrinos is indistinguishable from astrophysical neutrinos. This background, however, is negligible in a search for point sources of high-energy neutrinos, provided the angular resolution of $< 1^\circ$ can be achieved in practice. For diffuse neutrino fluxes the spectral information becomes crucial with a diffuse spectrum being expected to be harder (power index $\gamma \approx -2$) than conventional atmospheric neutrino spectrum ($\gamma \approx -3.6$ for $E_\nu \gtrsim 1$ TeV).

Detailed simulations have been carried out to assess the physics sensitivity of ANTARES. After 3 years of operation, the ANTARES data will challenge predicted upper limits for diffuse neutrino fluxes [4] and will be sensitive to point source intensities predicted by different models. In Figure 2, the expected ANTARES sensitivity to muon flux induced by neutrinos from point sources is compared to upper limits from other experiments (see the review [5] for details and references). Note in particular the complementary sky coverage of AMANDA and ANTARES.

The search for neutrinos from gravitational centres, such as the Sun, the Earth and the Galactic Centre, yields sensitivity to WIMP annihilation and thus complements direct searches for non-baryonic dark matter. Figure 3 shows expected ANTARES sensitivity to the muon flux from neutralino annihilations in the centre of the Sun for the case of 'hard' neutrino spectrum [6] (assuming 100% annihilations to WW).

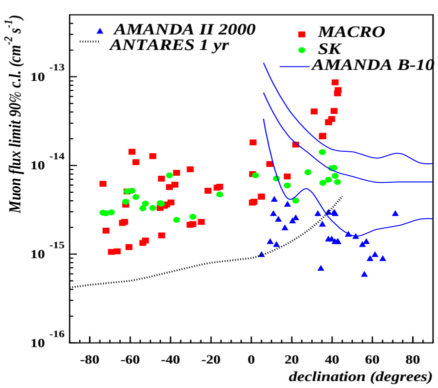

Figure 2: ANTARES sensitivity (1 year of running) to the neutrino-induced muon flux from astrophysical point sources, compared to upper limits from other experiments.

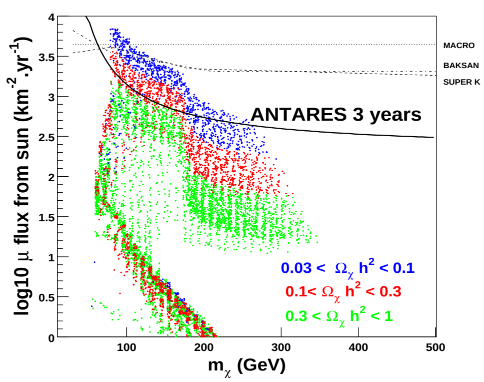

Figure 3: ANTARES sensitivity to the muon flux from neutralino annihilations in the centre of the Sun, compared to upper limits from other experiments and mSUGRA predictions.

4 Recent progress

The first component of the final detector configuration, the main electro-optical cable, was deployed in October 2001 and connected to the shore station. In December 2002, the end of the cable was connected to the JB. Communication with the JB slow control is being maintained since then. Two prototype strings, an optical line with 5 storeys (Prototype Sector Line, PSL) and the Mini Instrumentation Line (MIL – with instruments to monitor environmental parameters), were deployed in December 2002 and February 2003, respectively, and connected to the

JB in an undersea operation by the manned submarine Nautile in March 2003. Communication with both lines was established immediately after connection. The systems were found to be functional with the exception of two failures outlined below. A large quantity of data was acquired and analysed to study the background rate and environmental parameters as functions of time. The lines have been recovered in May (MIL) and July (PSL) 2003.

Two problems occured in the prototype tests. In the MIL, a water leak developed in one of the electronic containers due to a faulty supplier specification for a connector; the design has been modified since then to exclude this problem in the future. The second problem was that the clock signal, sent from shore to the electronic modules to synchronise the readout, reached the bottom string socket (BSS) but not the OMs. The clock failure was due to a damaged glass fibre in the cable between BSS and first storey, caused by the supplier's use of an unsuitable material for the fibre coating.

Due to the absence of the clock signal, no data with timing information at nanosecond precision could be taken. Nevertheless, the long-term operation of the PSL over more than 3 months yielded a lot of information, both on the functionality of the detector and the environmental conditions. In particular, the rate of signals above threshold was monitored continuously for each OM. It was found that the rates exhibit strong time variations, which are attributed to bioluminescent organisms. A continuous rate, varying between about 50 kHz and 250 kHz per OM, is accompanied by short light bursts. The fraction of time covered by the bursts varies from less than 1% to more than 30%. Also monitored were the position and tilt of the PSL storeys. It was found that they move almost synchronously, i.e. the PSL behaves as a pseudo-rigid body in the water current. Correlations of the background rates with the movement of the PSL and hence with the sea currents have been observed. Detailed investigations of the on-line filter requirements imposed by high rates and of relations between water currents, string movements and bioluminescence are under way.

5 Summary and future plans

With the installation of the main electro-optical cable and the junction box – key elements for detector infrastructure – the ANTARES project has entered the construction phase. Prototype detector strings have been successfully deployed, connected to the JB, operated and recovered, verifying the detector design and functionality, yielding a vast amount of environmental data and helping to identify and solve some problems. Failures, which occured in one connector and in the transmission of the clock signal will be avoided in future by implementing small design modifications. Intensive R&D and environmental studies have been performed. The completion of the 12 string detector is scheduled for 2006.

References

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