ANTARES: A HIGH ENERGY NEUTRINO UNDERSEA TELESCOPE*

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Neutrinos can reveal a brand new Universe at high energies. The ANTARES collaboration, formed in 1996, works towards the building and deployment of a neutrino telescope. This detector could observe and study high energy astrophysical sources such as X-ray binary systems, young supernova remnants or Active Galactic Nuclei and help to discover or set exclusion limits on some of the elementary particles and objects that have been put forward as candidates to fill the Universe (WIMPS, neutralinos, topological deffects, Q-balls, *etc.*). A neutrino telescope will certainly open a new observational window and can shed light on the most energetic phenomena of the Universe. A review of the progress made by the ANTARES collaboration to achieve this goal is presented.

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1. Introduction

To explore the Universe a messenger able to bring information from far-away sources is needed. Protons and nuclei are abundantly produced in a variety of sources. Unfortunately, at energies lower than a few EeV they are deflected by magnetic fields and do not point back to their source. Although for very high energies they do keep their directional information the fluxes are very low and they are affected by their interaction with the Cosmic Microwave Background, limiting their mean free path. The neutron is not deflected by magnetic fields, but its lifetime is too short and can travel not more than 10 kpc even for energies in the EeV range. Photons have been the traditional probes of the Universe, however, for energies above roughly a TeV

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their interaction with low energy photons (infra-red, CMB and radiowave) limits their range to at most a few tens of Mpcs.

Neutrinos are stable and neutral and they interact weakly with matter and radiation. Therefore, they can escape from dense sources, travel long distances and keep the directional information of their source. On the other hand, their very small cross-section requires huge detectors to obtain the necessary statistics.

2. Neutrino sources

Neutrinos can be produced by "cosmic beam dumps" in cosmic accelerators. Indeed, protons and nuclei accelerated by astrophysical objects can interact with matter and radiation to produce pions. Charged pions in turn produce neutrinos in their decays either directly or through the decay of their daughter muons. Diffuse neutrinos are produced when the cosmic rays interact with matter, such as the Earth's atmosphere, the Galactic plane or the CMB. In general, the fluxes from diffuse neutrinos will be low but observable with a sufficiently large detector. Neutrinos coming from pointlike sources will give a dwell of information about astrophysical objects. Large objects with high magnetic fields with huge plasma flows lead to the production of high energy protons. These protons can produce neutrinos by beam dumping. Objects like supernova remnants, binary X-ray systems and in particular, Active Galactic Nuclei are possible candidates for sources. Gamma ray bursts are another possible source of high energy neutrinos. These phenomena, now observed at a rate of one per day, could be due to highly relativistic shocks within a concentrated fireball and therefore could give rise to the production of neutrinos. Although the expected neutrino fluxes from GRBs are small, the correlation with the time of the signal and the direction of their source will allow their observation.

Neutrinos can also be produced in the interaction or decay of very heavy elementary particles. The neutralino could be the lightest supersymmetric particle and, if R-parity is conserved, could be stable. Neutralinos would have been produced in large amounts just after the Big Bang and be part of the dark matter of the Universe nowadays. In this case, they will be moving in the Galaxy halo at a few hundreds of km/s. They can lose energy by elastic scattering on nuclei in the Earth and the Sun and concentrate in their cores due to gravity. Their annihilation would then copiously produce neutrinos. Other more exotic heavy objects which in their decay would produce high energy neutrinos have been put forward, such as monopoles or cosmic strings.

Neutrino oscillations can also be studied in ANTARES using the atmospheric neutrinos produced in the cosmic ray showers at the other side of the Earth. By studying contained vertical muons almost parallel to the ANTARES strings, values of L/E_ν from 100 to 1300 km/GeV can be explored, thus having access to the region in Δm^2 and $\sin^2\theta$ suggested by Superkamiokande.

3. Detector design

Neutrinos are detected by means of the muons they produce in their interaction with the matter just before the detector. Muons in turn are detected by means of the Cherenkov light that they emit when traversing the water. This light can be seen by a matrix of photomultipliers. In order to reduce the number of down-going neutrinos coming from normal cosmic ray showers, the detector will be located under the sea, around 2 km below the sea surface.

A matrix of photomultipliers will be set in place by means of strings (see Fig. 1). Several studies have been or are being carried out to this end.

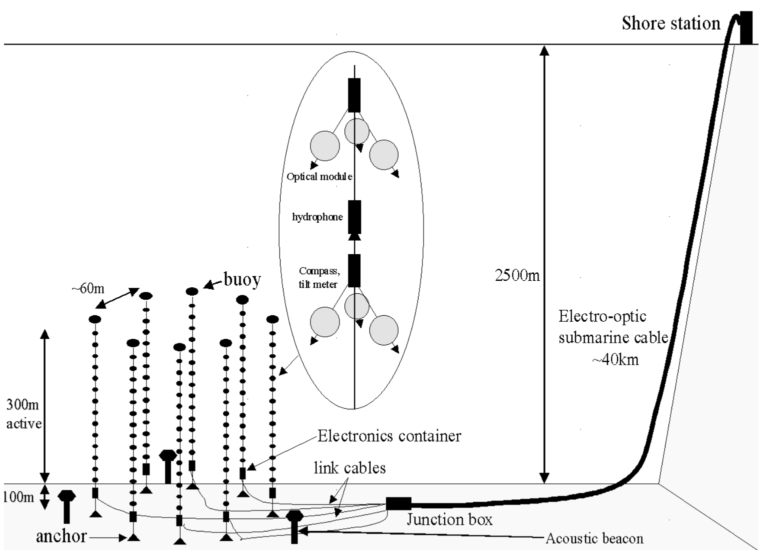

Fig. 1. Schematic view of the first phase of the ANTARES detector

3.1. Optical modules

Optical modules consist of a pressure-resistant glass sphere housing a shield against earth magnetic field, a photomultiplier (PMT) and the readout electronics (see Fig. 2). The choice of a PMT model must be based on several parameters: anode pulse shape and height, photocathode size, quantum efficiency, TTS, dark current, linearity and dynamic range. Several hemispherical PMTs have already been tested: Hamamatsu R5912, 5912-02, R2018-3, R7081-20 and Electron Tubes 9353KB, 9355KB. Optical modules as a whole must also be characterized. This is carried out using a water tank and the Čerenkov light coming from vertical cosmic muons traversing it.

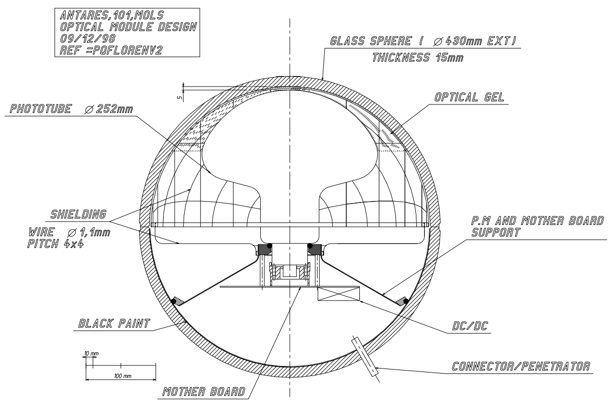

Fig. 2. Sketch of an optical module. The photomultiplier is protected from the water pressure by a pressure-resistant glass sphere of an outer diameter of 17 inches.

3.2. Electronics, cables, connections

Dedicated electronics for the stand-alone tests have been developed. Digital data transmission studies are well under way. Slow control of the detector (acoustic positioning, high voltage control, optical module calibration) is also in a well advanced phase of development. The electro-optical cable connecting the detector to the shore (~40 km) has already been succesfully deployed. The procedure to connect the electro-optical cable and the lines has been tested using a small manned submarine, “Nautile”.

3.3. Mechanical studies

The design of the mechanical substructure (strings) may affect the general detector performance. Sea currents, corrosion, deployment and recovery must be taken into account. The position of the optical modules must be known with a precision of $\sim$ 20 cm. Different mechanical studies (hydrodynamical simulation, positioning, *etc.*) have been done or are already in an advanced stage. A full string, complete from a mechanical point of view has already been deployed, tested and recovered during July/August 1998.

A new prototype line (see Fig. 3), connected to the shore by electro-optical cable will soon be deployed.

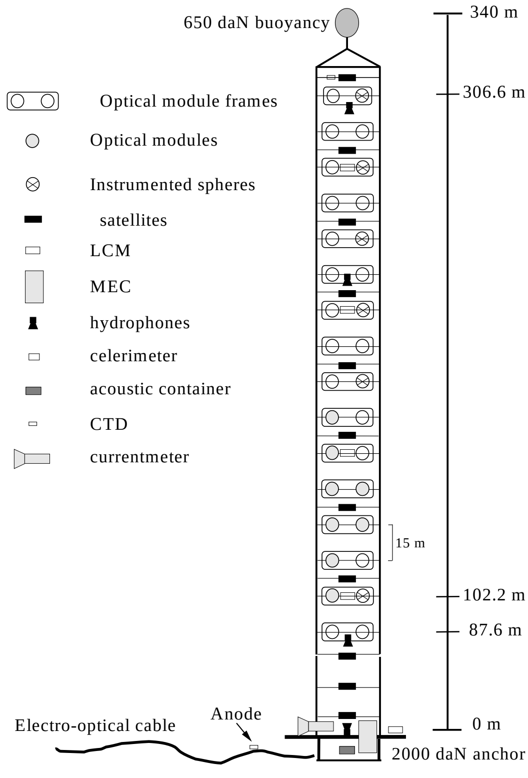

Fig. 3. Sketch of the first string prototype.

3.4. Software

Many efforts are dedicated to the simulation of the physical events and the detector response in order to optimize the detector geometry, adjust trigger schemes, tune muon track reconstruction, investigate backgrounds, detector sensitivity and resolution. The definition of the most suitable geometry for the 0.1 km^2 detector is well advanced.

4. Site measurements

In order to choose the site for the experiment many studies must be carried out *in situ*. Besides depth, some other environmental parameters are important for the final detector performance when selecting a proper site. The selected site is in the Toulon area, off-shore from La Seyne, at $\sim$ 2400m depth (42°50'N-6°10'E). At this location, advantage can be taken of the expertise of IFREMER, INSU-CNRS, CTME-CTSN and France Télécom Câbles. Three dedicated autonomous mooring lines (see Fig. 4) are being used in different tests since 1996 (Kajfasz 1997, Bertin 1997):

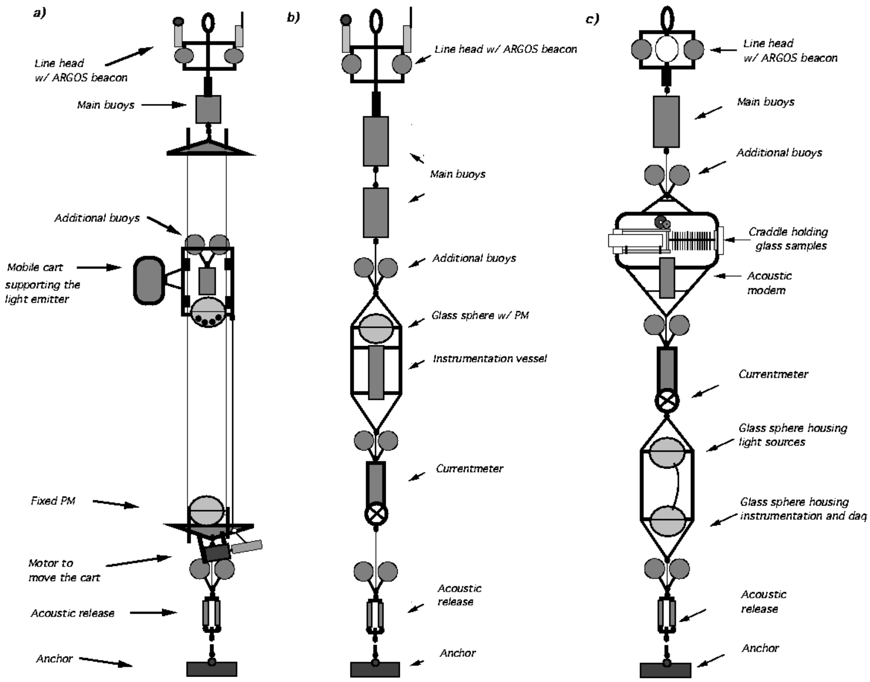

Fig. 4. Mooring lines for the study of (from left to right): biofouling, optical backgrounds and optical properties of water.

4.1. Line 1

Devoted to the study of optical backgrounds due to ^{40}K decays and bioluminiscence (Palanque 1998), this line is composed of an ARGOS beacon, synthetic foam buoys, a current-meter, a pressure resistant sphere housing a PMT, an aluminum vessel housing batteries and DAQ, acoustic releases and a expendable anchor. ^{40}K dissolved in salt water decays emitting electrons of up to 1.3 MeV. Background rate due to ^{40}K has been measured to be 20–40 KHz. Variation of the background in a 8" Hamamatsu tube as a function of the threshold on the output signal has been measured, obtaining that above 120mV ($\sim$2 pe) the background rate during immersion is roughly equal to the laboratory measured rate.

Bioluminiscence is the production of light by many different living beings. Its influence is not well known, showing a great site and time dependence. It is correlated with other environmental parameters such as current velocity. Light is emitted in pulses that vary over a wide range in duration (from milliseconds to minutes) and intensity (from ^{40}K level to 10^{12} photons). Left side of figure 5 shows the signal rate in a period of 1800 seconds. The baseline is due to the ^{40}K and the spikes to the bioluminiscent emissions. The detector dead-time produced by these emissions is of the order of 5%.

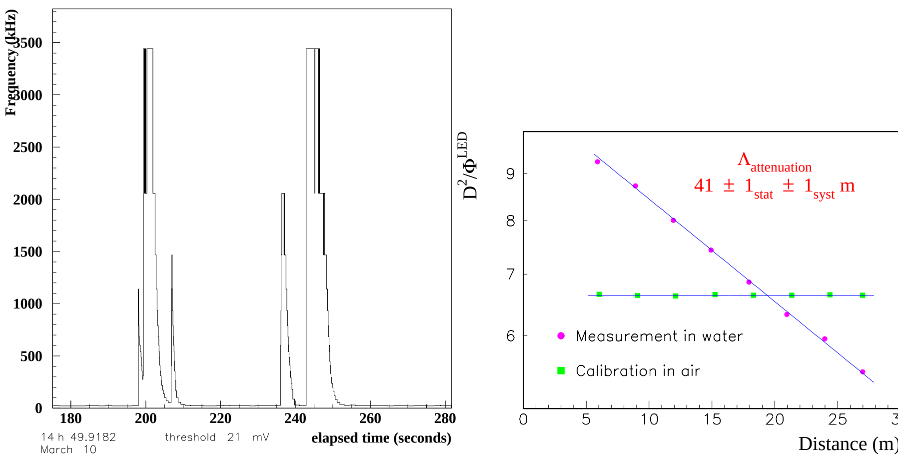

Fig. 5. On the left an optical background measurement, spikes due to Bioluminiscence can be seen. On the right results of the water attenuation length measurement.

4.2. Line 2

This line is dedicated to the study of biofouling and sedimentation on the optical interfaces. Deep sea bacteria tend to colonize the surface of immersed objects, forming a sticky bio-film that makes sediments to hold on to it. This may affect the optical module transparency in long term measurements. This environmental parameter is also site dependent and must be measured *in situ*. Line 2 is equipped in a similar way to Line 1. In this case a pressure resistant glass sphere houses a light source (blue LED) and faces another sphere housing PIN diodes glued at different positions in the inner face of the sphere. Line 2 is also equipped with a cradle holding glass samples. By performing long term immersions it is possible to measure the loss of transparency of an optical module due to biofouling and sedimentation. Measurements show that in the horizontal plane biofouling has a small effect that increases as polar angle decreases. At our site biofouling should not have a significant impact on optical modules with horizontal or down-looking PMTs.

4.3. Line 3

This line is devoted to the measurement of the optical properties of the water. These measurements are delicate and must be done *in situ*. Line 3 consists of a 33 meters long cage structure with a mobile cradle containing the light source and a PMT located at the end of the structure.

A continuous light source (LED) has been used to measure water attenuation. Results can be seen in figure 5. Recent results indicate that light scattering will not degrade substantially the time properties of the signal and will have a small effect on the track reconstruction accuracy.

5. Conclusions

Cosmic high energy neutrinos are a new source of information about the Universe. Neutrinos can come from very dense astrophysical objects, travel long distances without interacting and are not deflected by magnetic fields, thus keeping directional information about their source. They are also at the end of the decay chain or annihilation processes of a number of known or hypothetical elementary particles. They can therefore point to the existence of unknown particles. Neutrino oscillations can also be studied by measuring the range of the muons produced in the water sorrounding the detector. In summary, the detection of cosmic and atmospheric high energy neutrinos can be an extremely rich source of physical information.

The ANTARES collaboration, formed in 1996, has performed an intensive R&D program that is converging into a realistic prototype of an undersea neutrino telescope. Different studies have been and are being performed to achieve this goal. A lot of progress in the construction and deployment of lines has been done. Extensive computer simulations have been carried out to optimize the design of the detector. The environmental parameters of the site such as optical backgrounds, biofouling or optical properties of the water have been measured in more than 20 deployments of autonomous strings, indicating that the environment of the selected site is adequate.

The new phase of the experiment will aim to build and deploy a detector with a surface of the order of 0.1 km^2. This detector should be able to observe diffuse sources and, may be, several pointlike sources. Information about neutrino oscillations can also be obtained with such a detector. The first complete string should be deployed by year 2000 and by the end of year 2003 the full 0.1 km^2 should be operational.

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