A permanent deep undersea observatory for high energy cosmic neutrino detection

V. Bertin

ANTARES, A PERMANENT DEEP UNDERSEA OBSERVATORY FOR HIGH ENERGY COSMIC NEUTRINO DETECTION

V. Bertin (on behalf of the ANTARES Collaboration)

CPPM-Marseille, CNRS/IN2P3 et Université de la Méditerranée,

163 Av. de Luminy, Case 907, F-13288 Marseille Cedex 9

***Abstract* - ANTARES is a Research and Development project studying the feasibility of building and deploying a large undersea high energy neutrino telescope aimed at the observation of galactic and extra-galactic sources. A scalable detector prototype, consisting of at least two mooring lines equipped with large photomultipliers, connected to a shore station by an electro-optical cable, is currently under study. This Demonstrator, which should be installed at a depth of 2300 m off the coast of Toulon (France) by the end of 1999, will be the starting point of a km^2 detector in the forthcoming years. The ANTARES Collaboration is concurrently building and testing autonomous systems in order to measure undersea optical parameters in view of the selection of a site for this future km-scale high energy neutrino telescope.**

I. The ANTARES Project

ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) is a recent international Collaboration which aims at building, installing and running a scalable prototype of a large undersea telescope for the detection and the study of High Energy Cosmic Neutrinos (ANTARES-1997).

The basic idea of such a detector, being now almost 40 years old (Markov-1960), is to install in the ocean an array of optical modules (OMs) to detect the Cerenkov light emitted by a muon when it travels through water. An enrichment of muons produced by neutrino interactions in the Earth can be achieved by shielding the detector against atmospheric muons, when the apparatus is deployed at a few thousand meters undersea, and by looking at upward-going muons. A reconstruction of the trajectory of the muon, pointing to less than a degree to the direction of the initial neutrino source, can be obtained from the precise measurement of the arrival times of the Cerenkov photons on each photomultiplier (PMT) contained in the optical modules.

The motivations of building such a detector for the study of High Energy Cosmic Neutrinos, coming both from Astrophysics and Particle Physic, has been detailed elsewhere (Moscoso-1997). It is nevertheless worthwhile to note that it will certainly open a new observational window on the most energetic phenomena of the Universe, such as young supernova remnants or Active Galactic Nuclei’s, and help to discover or rule out some of the elementary particles and objects (Neutralinos, topological defects, Q-balls,...) created during the first second of the Universe, which have been put forward as candidates to explain the still unknown 90% of the mass of the Universe.

As we have learned from past and current tentatives, the realization of such a detector is not trivial and needs R&D studies on different crucial topics such as the mechanical structure of the elementary detector lines, the techniques and scenario used for deployment and recovery, the connection of the detector to the shore with an electro-optical cable for energy supply, data readout and remote control, the monitoring of the optical module positions on the whole structure. In parallel, one needs to perform precise measurements and a long term survey of environmental parameters such as current intensity and variation, light attenuation and scattering in water, biofouling of OMs and bioluminescence activity.

The installation of a permanent undersea observatory extends much beyond the detection of high energy neutrinos. There is indeed interest expressed by oceanologists for long term measurements of deep sea currents, by biologists for bioluminescence and biofouling studies, by geologists for the installation of seismographs at the bottom of the ocean permitting an increase of their mapping of the earthquakes.

The ANTARES Collaboration is thus composed of particle physicists (from Marseille, CEA-Saclay, Mulhouse in France, Valencia in Spain, Oxford and Sheffield in UK), of astronomers and astrophysicists (from Marseille, CEA-Saclay and Oxford), and of sea scientists (from COM-Marseille, IFREMER-Brest, IFREMER-Toulon). In addition, we benefit of the expertise and support from people having a great knowledge in sea engineering such as IFREMER, France Telecom Câbles, engineers from the French navy (DGA/CTME, DGA/CTSN).

II. The ANTARES Program

A. Towards a km-scale detector

The goal of the project is to design and build a km^2 scale detector, size which is necessary to study the low cosmic neutrino flux.This is planned to be achieved in three stages:

1) Phase 1 (1997-1999)

Dedicated to the study of the most important parameters entering the design of a undersea neutrino detector (mechanical structure studies, deployment techniques, positioning, connection to shore, detector optimization, site studies). This 3-year R&D program should lead to the installation of a realistic three dimensional detector (*Demonstrator*) on a Mediterranean site off-shore Toulon (France) at a depth of 2300 m (ANTARES site: 42˚50'N-6˚10'E). This Demonstrator will consist of at least two mooring lines of about 300 m high, each equipped with about 50 OMs and their electronic, as well as the necessary instrumentation for calibration and positioning. All lines will be connected together by a manned submarine and to an electro-optical cable linked to a shore station. A schematic view of the ANTARES Demonstrator is shown on Fig. 1.

The ANTARES Collaboration is concurrently developing autonomous systems in order to measure the crucial undersea environmental parameters which play a role in the design of the detector. These devices will also be used in the selection of a site for the future large scale neutrino detector.

2) Phase 2 (2000-2002)

Once the feasibility is proven, the next step will be to complete a detector of about 0.1 km^2 effective area. It should allow us to perform some neutrino physic studies and investigate the long term operation issues.

3) Phase 3 (2002-2005)

Deployment of new lines will continue until a 1 km^2 effective area detector is completed. This is the natural scale for a high energy cosmic neutrino telescope.

B. Work in progress

1) First detector line

The first line of the Demonstrator is now almost completed and should be installed on the ANTARES site in October 1998 and connected before immersion to a 4-fiber electro-optical cable. This 40 km cable has already been deployed by France Telecom in May 1998 between the off-shore site and the ANTARES shore station in La Seyne sur Mer. The transmission of electric power, including the sea return, and data through the cable has been tested successfully.

This first detector line is 350 m high. It is made of two vertical mechanical supporting cables, separated by 2 m and supporting 16 frames with a pair of optical modules. The first frame is placed at 100 m above ground, the others being placed every 15 m above this one. An OM is made of a 8" or 10" hemispherical PMT shielded against Earth magnetic field by a μ-metal cage and housed in a Benthos sphere with a high voltage converter, some front-end electronics and a calibration LED.

The main goal of this line is to learn about the complex deployment procedure with the electro-optical cable, as well as the mechanical behavior of the detector during the deployment phase and when it rests at the bottom of the sea. Even if mechanically complete, this line will only be equipped with 8 OMs, the other ones being replaced by empty glass spheres. It is also fully equipped as far as cabling and electronic containers. The line also contains all the sensors used for the precise localization of the detector elements and for the environment parameters recording.

Special care has been taken on corrosion aspects by using titanium to make the electronic containers and the cable endings, and composite materials for the OM supporting frames. Insurance quality procedures are followed by, for example, systematically testing all containers or OMs in a pressure tank.

2) Detector positioning system

The positioning of the detector is an important R&D subject. In order to be able to point-back at a potential neutrino source from the reconstructed muon tracks, one need to know the absolute position and orientation of the detector with respect to the sky. An absolute localization of the anchor of the detector within 1 meter should be achieved by Long BaseLine acoustic triangulation from a boat coupled to a DGPS system.

In addition, one should know the relative positions of all optical modules within 20 cm in order to achieve a good reconstruction of the muon track. The first detector line will be equipped with a high frequency (40-80 kHz) acoustic positioning system based on four rangemeters dialoguing with four external transponders placed about 250 m around the line. This system, developed by the GENISEA company, should achieve a precision of 10 cm on the position of each rangemeter. In addition, a set of twelve tiltmeters-compass sensors is regularly placed along the detector line to monitor the string shape.

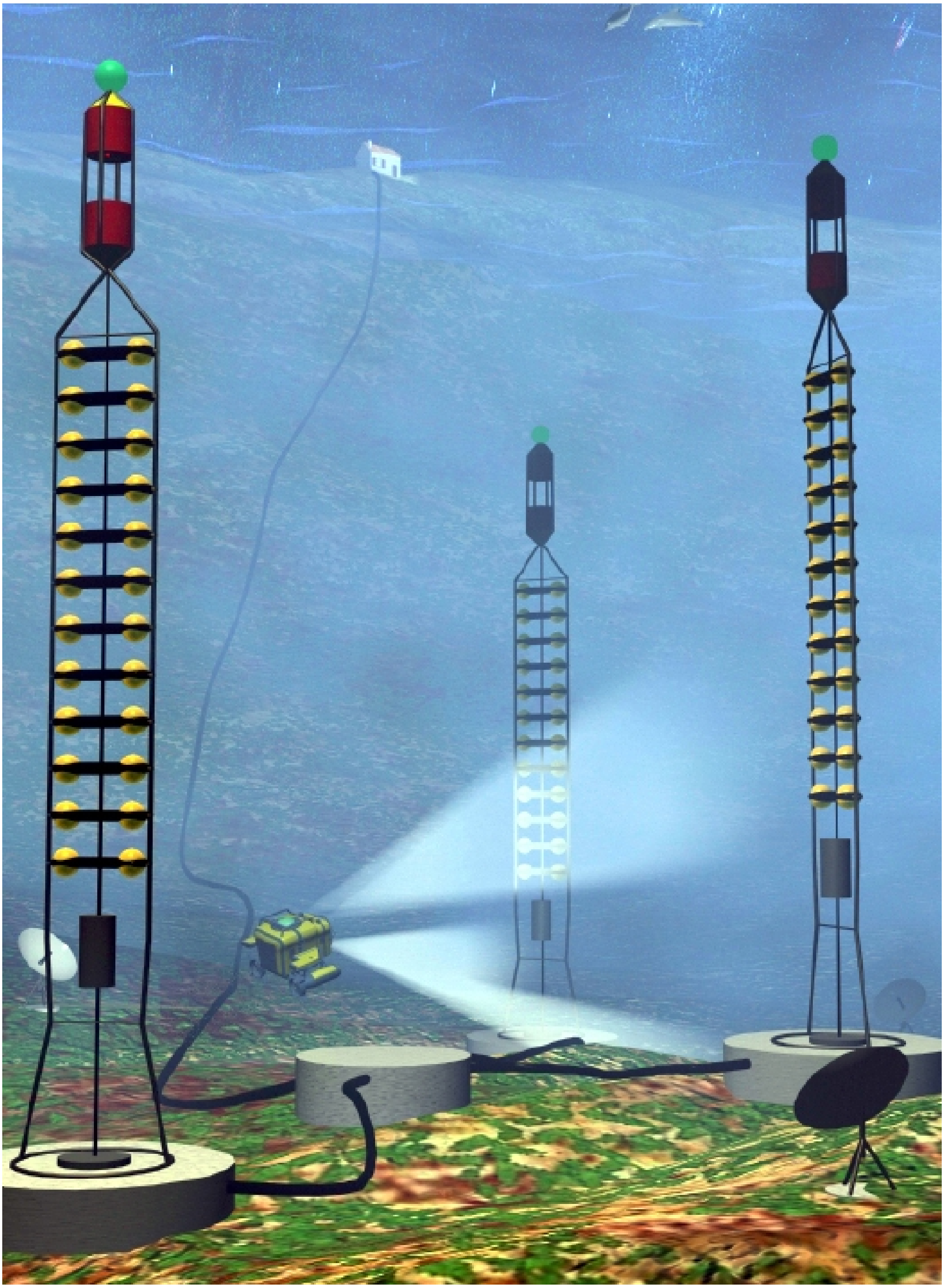

Fig. 1 Schematic view of the ANTARES Demonstrator

This first line will also be equipped with a 75 kHz ADCP, placed on the anchor of the string, which will measure the sea current on the full height of the detector. This should provide precious information to improve the current tentatives of line shape simulation submitted to sea currents.

3) Deployment and undersea connection

Detector line deployment and undersea connection to a network are two crucial aspect which are addressed by specific tests.

In July 1998, immersions of the first detector line by 400 m and 2300 m depth will be performed in order to validate the deployment procedure. These tests will be done with the dynamical positioning ship *CASTOR II*. An autonomous version of the detector, as far as energy and data readout, has been realized in order to perform a full test of the instrumentation acquisition and control electronic system.

In October 1998, ANTARES will use the IFREMER submarine *Nautile* for a week in order to perform undersea connection tests and validate the chosen electrical connector. In addition, a precise exploration and mapping of the ANTARES site sea ground will be performed.

III. Site evaluation studies

Some environmental parameters are critical for the final mechanical design, the detector performances and the deployment site choice of an undersea neutrino telescope. In order to have a better knowledge in these parameters, three dedicated autonomous mooring lines are being used in different tests since 1997.

A. Optical background studies

The first line is devoted to the study of the optical background due to ^{40}K radioactive β-decays and bioluminescence. The line is equipped with one to three optical modules housing 8” phototubes, a battery sphere, an electronic container with a data logger, a current meter, syntactic foam buoys and an acoustic release. The apparatus recorded single and coincidence counting rates of the phototubes above a given threshold. Several measurements have been performed on the ANTARES site for periods lasting from 1 to 120 days.

The counting rate of a 8” phototube above 0.3 photoelectron shows a continuous level around 30 kHz due to ^{40}K activity and spikes with typical duration of a few seconds coming from bioluminescence bursts. An example of a recorded spectrum is shown on Fig. 2 as well as the counting rate distribution of the phototube. The measurements show that the bioluminescence activity is strongly correlated with the

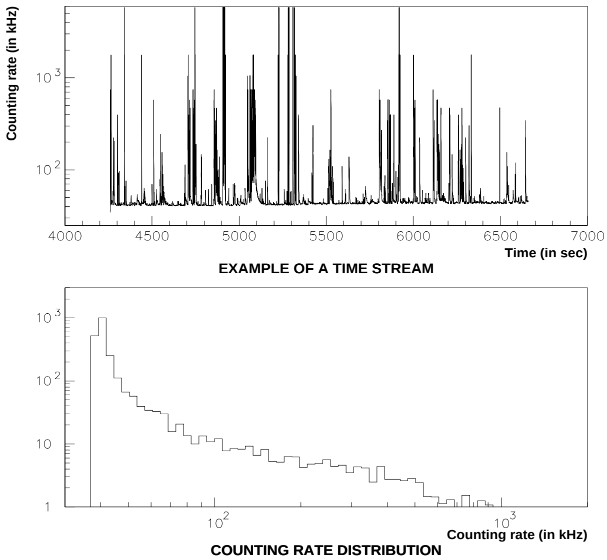

Fig. 2 Optical background measurement with a 8” PMT above 0.3 p.e.

water current and that it also produces a continuous signal on the phototube which superimpose to the constant ^{40}K background. Coincidences measurements between OMs have also been performed showing that bioluminescence activity can very often be seen simultaneously by PMTs distant by 1 meter (correlation of 70%), and that a high activity can even be recorded by phototubes placed 18 m apart.

B. Biofouling and sedimentation studies

The second line is dedicated to long term monitoring of the OM transparency which can be affected by biofouling and sedimentation deposition on the Benthos sphere. This apparatus, very similar to the first line, is equipped with a sphere housing a light source (blue LED) facing another sphere containing PIN photodiodes glued at different positions and polar angles on the inner surface of the sphere.

A first three months measurement has been performed with the light source placed above the vertical axis of the diode sphere. It showed a fast decrease of the transparency of the top pole of the sphere reaching a light transmission loss greater than 50% in 90 days. The effect is quickly decreasing as one move down to larger polar angles. A second test has been done with the light source facing the horizontal equatorial plane of the detector sphere for a total monitoring period of 8 months. The measurements, presented in Fig. 3, show a transmission loss of only few percents on the different photodiode locations. Both tests were performed on the ANTARES site. At our site, biofouling should thus not have a significant impact on optical modules with horizontal or down-looking PMTs.

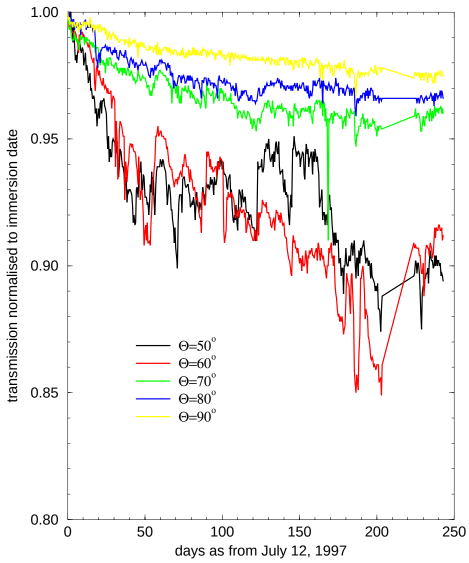

Fig. 3 Evolution of the light transmission on a glass sphere on a 8 months period

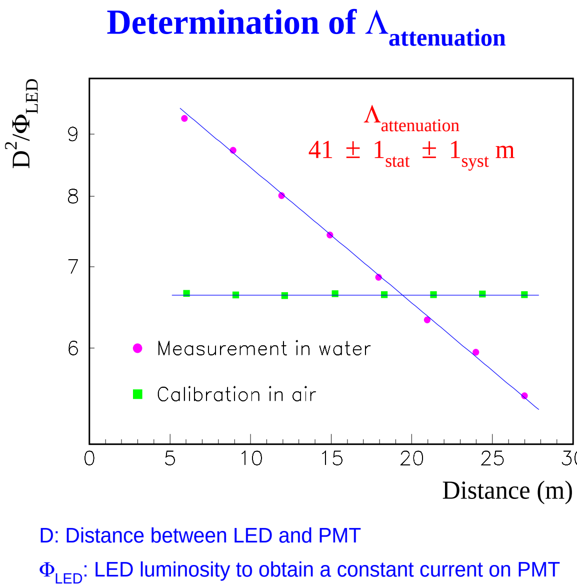

Fig. 4 Measurement of the sea water attenuation length

C. Light attenuation measurement

This third line is dedicated to the precise measurement of the optical properties of the water on the sea site. The line includes a 33 m long cage structure with a mobile cradle containing a light source and a PMT located at the end of the structure.

A first measurement has been performed with a continuous light source (blue LED) emitting at 466 nm to measure the light attenuation in water. The results, shown in Fig. 4, give an attenuation length of:

$$\Lambda_{att}(466\mathrm{nm}) = 41 \pm 1(\mathrm{stat}) \pm 1(\mathrm{syst})$$

In July 1998, a second measurement has been done on the ANTARES site with a pulsed LED and a TDC in order to separate the absorption and scattering parts of the attenuation length. Preliminary results indicate that the scattering length for isotropic (Rayleigh-like) scattering is in excess of 100 meters. This should lead to an absorption length of about 55 meters.

IV. Conclusion

The ANTARES Collaboration is performing an intensive R&D program which should lead to the installation of a realistic and scalable prototype of an undersea neutrino telescope in the Mediterranean sea at a depth of 2300 meters. The deployment of the first detector line is about to be achieved, while a serie of *in-situ* measurements are in progress to control the crucial environmental parameters for such a detector.

The oceanographic community is welcome to join us in our exciting work, both to help us in the realization and understanding of the site quality measurements, and to bring new idea on long term measurements which can be performed with this future permanent observatory.

ACKNOLEDGMENTS

The author wish to thank the Organizing Committee of OCEANS'98 to let him attend to this Conference, in order to present the ANTARES project and progresses.

REFERENCES

The ANTARES Proposal, F. Blanc at al, astro-ph/9707136 (1997), see also http://antares.in2p3.fr/antares

M.A. Markov, in Proc. 1960 Annual International Conference on High Energy Physics at Rochester (1960).

L. Moscoso, in Proceedings of the 32nd Rencontres de Moriond on *Very High Energy Phenomena in the Universe*, Les Arcs, France (1997).