The NESTOR underwater neutrino telescope project

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Elsevier use only: Received date here; revised date here; accepted date here

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Abstract

The NESTOR collaboration is continuing its efforts towards deploying an underwater neutrino telescope. Further site studies (e.g. water light transmission measurements, sedimentation rates, etc.) are being carried out within the context of characterizing a site that may host the proposed KM3NeT infrastructure. In addition, following the successful deployment of a single floor of a NESTOR tower in 2003, five floors are now in the final stages of preparation. The use of these five floors in a form of a truncated tower together with four autonomous strings to be located some 300 m away from the tower is being contemplated. This arrangement, named NuBE (for Neutrino Burst Experiment), that may allow the detection neutrinos in coincidence with Gamma Ray Bursts, will be described.

PACS: 13.15+g, 91.50-r, 95.55.Vj, 95.85.Ry, 98.62.Js, 98.70.Sa,

Keywords: neutrino astronomy, astroparticle physics; active galactic nuclei; deep-sea technology; marine sciences

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1. Introduction

The NESTOR project [1] has had as its objective the deployment of a neutrino telescope of a tower-like structure composed of hexagonal floors. The deployment site is a deep part of the Mediterranean Sea, an area that includes its deepest point. Deployments of prototype and test structures have been carried out in the past and have culminated with the successful deployment of a single floor in 2003.

1. The NESTOR tower

The NESTOR underwater neutrino telescope is composed of floors in the form of hexagonal rigid stars, as shown in Figure 1, with a diameter of 32 m

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and floor to floor separation of 20 m. At the end of each lightweight titanium arm of the star there are two optical modules (OMs) [2] which are transparent glass spheres capable of withstanding the deep-sea pressure. Each OM houses a large hemispherical (15 inch diameter) phototube (PMT). In each pair of OMs one is upwards looking and one is downwards looking. A full tower will have 12 floors and thus 144 optical modules and a height of 220 m.

In the center of each arm there is a titanium sphere that houses the electronics [3] of each floor. The signals from the PMT's are carried over coaxial cables to the sphere where they are digitized by waveform digitizers and the data is sent by digital optical fiber to the junction box in the anchor unit. Triggering, in the form of coincidences between the various OMs is also generated in the electronics. The required coincidence level can be remotely controlled. The junction box is connected to shore via an electro-optical cable that carries data and control signals via optical fiber in both directions and brings electrical power to the tower in the form of 300V DC.

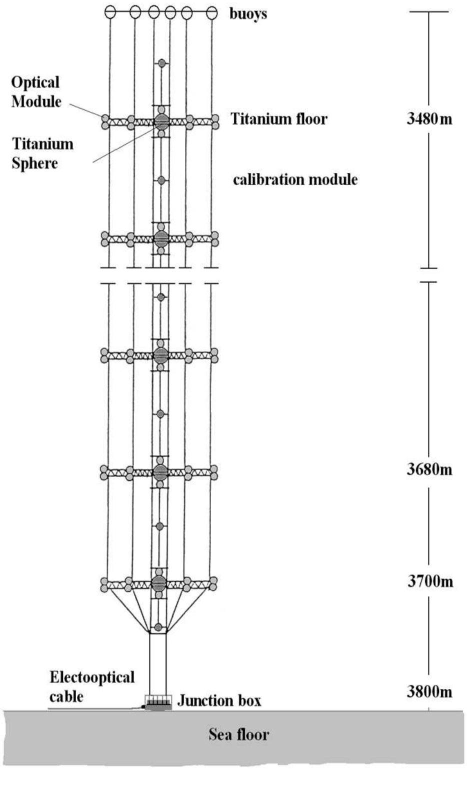

Figure 1. The NESTOR tower

Multiple towers arrayed in a hexagonal grid, with tower to tower separation of 120 m will form the complete neutrino telescope.

2. The site

The site is located in the open sea off the southeastern tip of the Peloponnese in the vicinity of the town of Pylos. Possible deployment sites are indicated in Figure 2. One of the extremely desirable features of this region of the Mediterranean Sea is the existence of four sizeable plateaus at depths ranging from 3000 to 5200m that can accommodate a neutrino telescope. Thus, the closest site at 13 km from the nearest landfall and 3000 m depth allows for convenient deployment and can be used for tests, while the area at 48 km and at a depth of 5200 m allows for the deployment of a detector with reduced background from the downgoing muons from cosmic rays and higher sensitivity to very high energy neutrinos (since for energies above a few hundred TeV the Earth is opaque for neutrinos, for example at 350 TeV only ~50% of the neutrinos pass through a full earth diameter) [4].

3. The 2002-2003 deployments

Construction and deployment of a multidisciplinary deep-sea station, at a depth of 4100m was achieved in January 2002 [5]. This deep-sea station, developed in the project LAERTIS [6], also serves the purpose of being the bottom platform for a deep-sea neutrino telescope. It was operated with power from and data transfer to shore in real-time via an electro-optical cable. Recovery and redeployment operations with payload exchange were performed. Data from temperature and pressure sensors, a compass, a light attenuation meter, a water current meter and an ocean bottom seismometer were transmitted to shore.

An important feature of the deployment and recovery procedure developed by NESTOR lies in allowing the instrument package, once deployed at the seafloor, to be recovered, modified or serviced at the surface and be deployed again, without recourse to manned submersibles or remotely operated

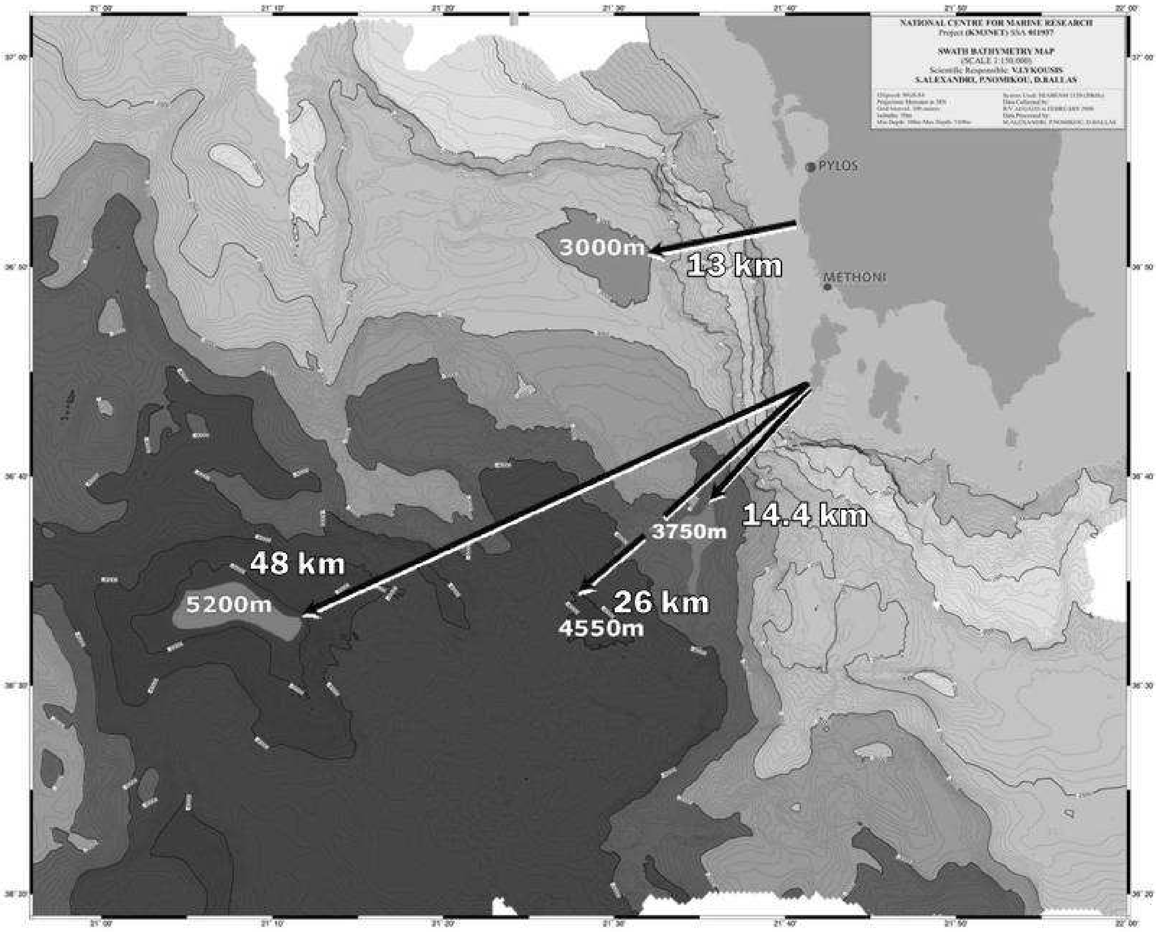

Figure 2 : Bathymetry of the NESTOR site, distances in km and nautical miles (nm) to the nearest landfall are indicated. Four plateaus that are potential sites for an underwater neutrino telescope and their depths (3000, 3750, 4550, and 5200 meters) are shown.

vehicles. The feasibility of this procedure has been demonstrated in repeated redeployments.

In March 2003, the NESTOR collaboration successfully deployed a test floor of the detector tower, fully equipped with 12 optical modules, final electronics and associated environmental sensors [2]. In this operation, the electro-optical cable and the deep-sea station, previously deployed at 3850 m, were brought to the surface, the floor was attached and cabled and redeployed to 3800 m. The diameter of the floor deployed in 2003 was 12m.

The detector was continuously operated for more than a month and over 5 million events were accumulated, investigating different trigger modes, coincidence levels and photomultiplier thresholds. In addition, several million calibration triggers were taken at various photomultiplier high voltage settings. The readout and DAQ chain performed well and with practically zero dead time. The monitored experimental parameters, operational and environmental, remained stable within acceptable tolerances.

The PMT pulse height distributions, the trigger rates and the total number of photoelectrons inside the trigger window as functions of the signal thresholds and coincidence level settings, as well as the arrival time distribution of the photoelectrons, agree very well with Monte Carlo predictions based on the atmospheric muon flux parameterization of Okada [7], the natural K^{40} radioactivity in the sea water, and the PMT dark currents and afterpulses.

Several studies have been made to ensure that the event selection trigger was unbiased and that the signals from the PMTs can be attributed to the expected sources. In addition, calibration in the sea using LED flasher units mounted above and below the detector floor provided a rigorous test on the time stability of the detector as well as a measurement of the resolution of the arrival time of the signals. For about 1.1% of the total experimental time bioluminescent activity has been observed around the detector. This caused about 1% dead time and is consistent with previous measurements at the same site performed with autonomous devices [8]. Events collected during such periods of activity were easily identified and rejected.

The prolonged period of running under stable operating conditions made it possible to measure the cosmic ray muon flux as a function of the zenith angle θ [9, 10]. For this measurement only events with six or more photomultiplier pulses coincident inside a time window of 60 ns were used to reconstruct tracks, employing first the information on the arrival time and then the amplitude of the digitised pulses. A Monte Carlo package [3, 10] has been developed to simulate the detector response to atmospheric muons arriving at the detector depth, using the energy and angular distributions taken from the Okada parameterisation. Simulated muons are propagated through water, taking into account energy loss, secondary particle production and multiple scattering. A detailed simulation of the Cherenkov light detection, K^{40} background contribution, trigger selection and photomultiplier waveform digitisation was included.

The vertical intensity and the zenith angle distribution of cosmic ray muons at the detector depth have been measured and are consistent with previous underwater measurements [11] and with phenomenological predictions. The measured muon intensity parameterised as $I=I_0\cos^{\alpha}(\theta)$, at a depth of 3800 m water equivalent, is found to be:

$$\alpha = 4.7 \pm 0.5\ (\text{stat}) \pm 0.2\ (\text{syst})$$

$$I_o = [9.0 \pm 0.7(\text{stat}) \pm 0.4\ (\text{syst})] \times 10^{-9}\ \text{cm}^{-1}\text{s}^{-1}\text{sr}^{-1}$$

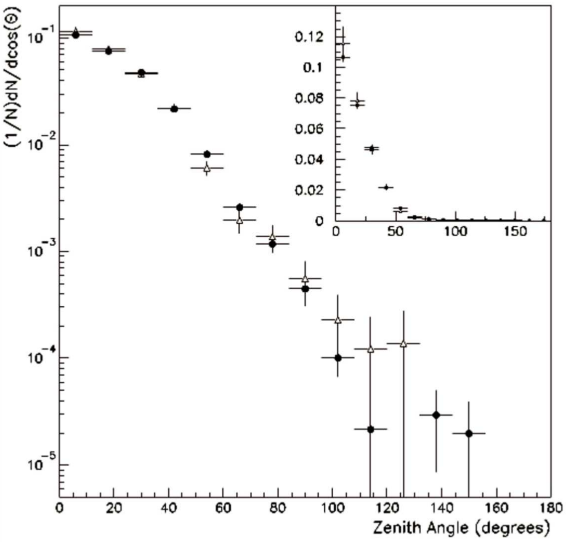

Figure 3. Distribution of the zenith angle of reconstructed tracks for the data (open triangles) and Monte Carlo (solid points) event samples. The insert shows the same distributions on a linear scale. Figure taken from [3].

4. NuBE – NESTOR

The most violent phenomena observed in the Universe are the Gamma Ray Bursts (GRB). There are 300-400 such GRBs reported per year and their mechanism is not well understood. The observation of neutrinos produced at such GRBs will provide significant new constraints to the proposed models of GRBs. The relativistic fireball model of GRBs due to Waxman and Bahcall [12] predicts a measurable flux of neutrinos in the 100 TeV energy range. The model predicts that a neutrino detector with an effective area of ~2 km^2 will be able to detect 40 to 200 neutrino induced muons in a year due to GRBs. Other models of GRBs (AGN, topological strings, and other burst mechanisms) also predict high energy neutrinos produced contemporaneously with the GRB.

The NESTOR collaboration has at this time ready for deployment five floors of a NESTOR tower. These floors can be used to deploy a mini-tower that can serve as part of NuBe – the Neutrino Burst Experiment [13]. The use of this mini-tower together with four autonomous strings of detectors leads to a detector with the required detection area of ~2km^2.

GRBs have durations of .1 to 100 s, and this can be used to define a time window for detection of such coincidences with the gamma ray signals observed by the space borne gamma ray detectors on satellites. Very high energy neutrino interactions (100 TeV) lead to muons that have a very long range (>5km, 18 km for 100 TeV muon) in the sea water, and also have a very high Cherenkov light output due to catastrophic brehmstrahlung along their path which leads to a bundle of particles travelling together with them (for a 100 TeV muon we expect on the average some 77 particles along its path). Such an intense light flash can be detected in an OM at distances up to 300m in water with light attenuation length of 55m (as measured at the Pylos site [14]). In addition muonless neutrino interactions (e.g. electron shower, τ lepton production, and hadronic shower events) produce short (~10m) but extremely intense showers that again can be detected at similar distances in the sea.

As a result a sparse detector can be used for the detection of neutrinos from GRBs. The proposed

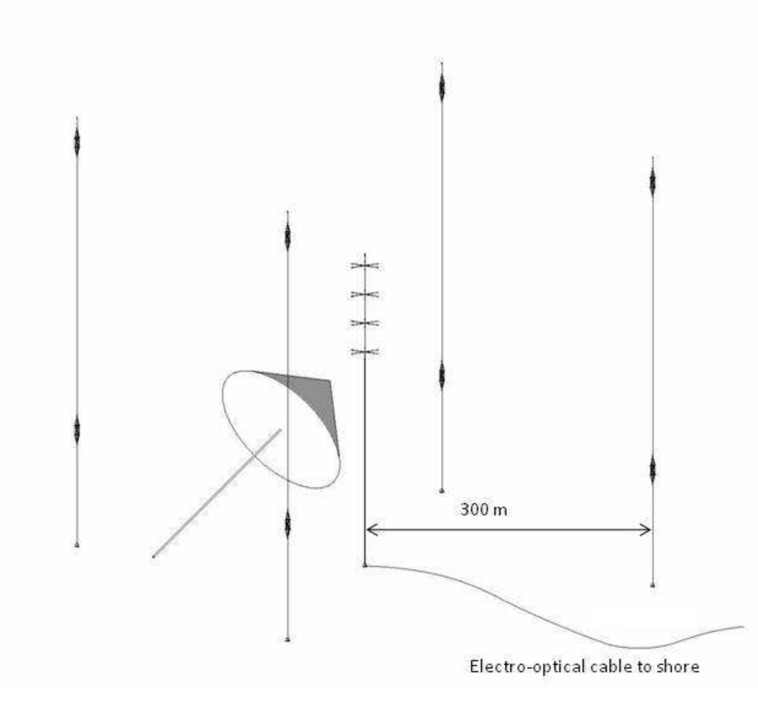

Figure 4: The NuBE detector.

detector consists of the NESTOR mini-tower in the middle and of four autonomous strings placed at a distance of 300m from the tower, as shown in Figure 4.

Each string, shown in Figure 5, is composed of two independent photon detector nodes (with 16 PMTs each) separated by ~ 300m along the string. The strings are built with very low power electronics and will run on batteries for a year. Data will be stored locally while selected triggers will transmitted to the tower's junction box acoustically and then to the shore station via the electro-optical cable. A high energy neutrino event will lead to local triggers in more than one node (or floor), with the coincidence among many nodes determined by comparing local clock values off-line. The string clocks will also be periodically synchronized using bright flashes of the calibration light pulser on the tower.

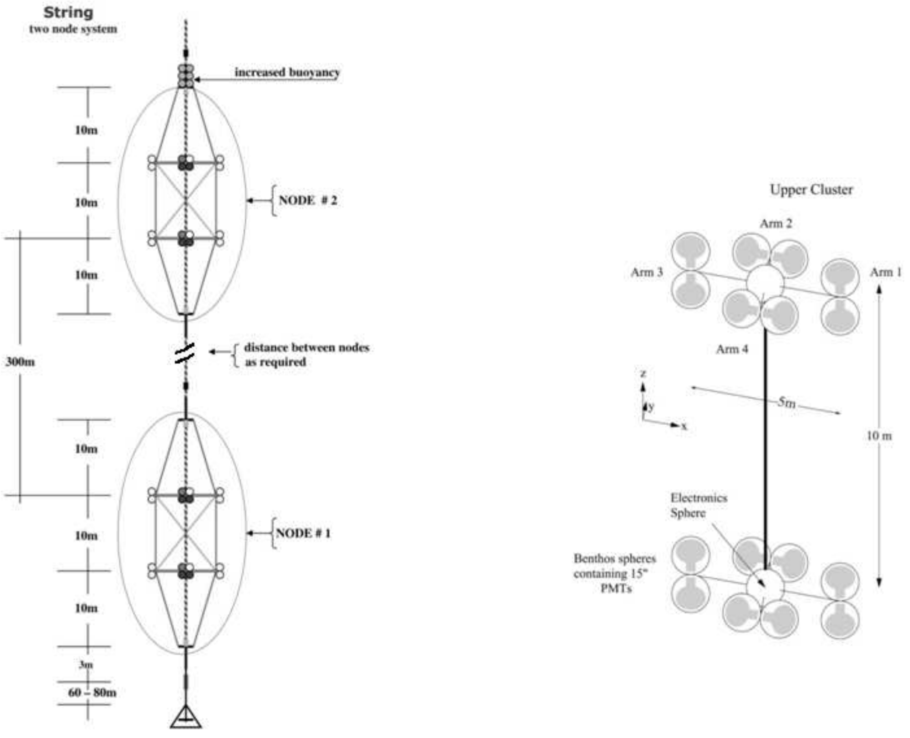

Figure 5. An autonomous NuBE string

An event signal will be a local trigger in any node or floor occurring in coincidence within the light travel time across the array (~ 3μs) with a local trigger in another node. The coincidence that signals the high energy events is determined off-line, after the strings are retrieved. Muonless (i.e. showering) events which hit three or more nodes provide the incident direction to within as little as FWHM ~ 25 degrees. If a muon is detected in the tower then we expect an angular reconstruction to a FWHM ~ 5 degrees. The good angular resolution capability for muons in the tower provides robust verification of the correlation of a GRB based on time coincidence, because it will allow us to directly compare to the position determined by the satellite. It should also be noted that the requirement that coincidences occur within a 100s window of a GRB observed by a satellite reduces the probability of random events to a level of $\sim 10^{-6}$ per year.

5. Other activities

Most of the members of the NESTOR collaboration are participants in the KM3NeT Design Study and they recognize the fact that the advent of the large neutrino telescope envisioned in that study diminishes the importance of building a smaller device. Therefore most of the activity is being directed towards KM3NeT related tasks.

Such activities that to some extent are uniquely carried out by the NESTORians are:

a. Continuing the investigation of tower-like structures with much larger transverse dimensions (up to100m diameter).
b. Continuing and extending the studies of the properties of the various sites. Measurements include water light transmission at various wavelengths, sedimentation rates, bio fouling rates, bioluminescence, etc. New instruments have been constructed and the plan is to conduct campaigns that will allow these measurements to take place at all of the possible sites. In this way systematic uncertainties introduced by the use of different instrumentation will be eliminated.
   Preliminary results from these studies are becoming available and will be made public in the near future.
c. The construction and outfitting of a vessel, the Delta-Bereniki. This is a triangular platform (50m x 50m x 40m) with a central well and a heave compensated bridge crane. She will have three flotation cylinders at each apex, and in each cylinder there will be a fully steerable water-jet propulsion engine. The platform will ride ~4m above the sea level and will be able to keep position to within a meter for seas up to Beaufort sea state 4.
   She will be the first vessel fully dedicated to use by the neutrino astronomy community and will prove invaluable as both a deployment vessel for the detector, and as a means of conducting test deployments. A photograph and a sketch of the Delta-Bereniki can be found in the KM3NeT contribution to these proceedings [15].

References

[1] The NESTOR (**N**eutrino **E**xtended **S**ubmarine **T**elescope with **O**ceanographic **R**esearch) Collaboration presently has members from the NESTOR Institute for Astroparticle Physics of the National Observatory of Athens, the University of Athens, the University of Bern, CERN, the University of Crete, the University of Kiel, the Lawrence Berkeley Laboratory, the Institute of Nuclear Physics of the NCSR Demokritos (Greece), and the Institute for Nuclear Research of the Russian Academy of Sciences; the spokesperson is L.K. Resvanis. For earlier references please consult L.K. Resvanis, Proc. of Neutrino Oscillations in Venice, Venice, Italy, 2006.

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