Status of the ANTARES Project

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Abstract

ANTARES is a deep-sea neutrino telescope project. Tests have been carried out over the last two years to evaluate sites, procedures and performance. The deployment of detectors and underwater electrical connections have been tested successfully at a depth of 2400 m in the Mediterranean Sea near Toulon, and the optical characteristics of the proposed site have been measured. A detector with an effective area of about 0.1 km^2 will be deployed in 2002-2003.

1 ANTARES project goals:

ANTARES is a project to build a deep-sea telescope to detect high-energy neutrinos. The collaboration was formed in 1996, based on a close cooperation between particle physicists, astrophysicists, and experts in marine technology. Since then, many of the technical aspects relating to the construction and operation of this device have been addressed, and its sensitivity has been evaluated for the principal physics goals.

The ANTARES scientific program includes astrophysics (neutrino astronomy), cosmology (searches for dark matter in the form of neutralinos), and particle physics (neutrino oscillations). Neutrino astronomy provides the principal motivation for a deep-sea detector because it opens a new window for studies of the cosmos, probing regions of the universe that are opaque to photons and hadrons and energy domains well above the regime of man-made accelerators. The advantages of neutrinos are that they are electrically neutral so their trajectories will not be affected by magnetic fields, stable so that they can reach us from distant sources, and weakly interacting so that they can penetrate regions which are opaque to photons and hadrons.

The existence of astrophysical sources of high-energy neutrinos can be inferred from the existence of high-energy cosmic-ray protons. Gamma rays and neutrinos result from the decays of pions photo-produced during the acceleration of the protons. The protons are deviated by cosmic magnetic fields, but the gamma rays and neutrinos point back to their sources. Candidate sources of high-energy neutrinos include galactic sources such as X-ray binaries and supernova remnants, and extragalactic sources such as active galactic nuclei (AGN) and gamma-ray bursters (GRB). The AGN could provide a detectable source of diffuse high-energy neutrinos (Stecker, et al., 1991). Both AGN and GRB are potential point sources of high-energy neutrinos. The detection of known objects is enhanced by the excellent angular resolution expected at ANTARES.

Dark matter could be detected via high-energy neutrinos if supersymmetric neutralinos make up part of the missing mass. Relic neutralinos from the early universe would accumulate at the core of heavy bodies such as the earth, the sun, or the center of our galaxy (Jungman, Kamionkowski, & Griest, 1996). Because they are Majorana particles, pairs of neutralinos will annihilate. The annihilation products include neutrinos with typical energies around 1/3 to 1/2 of the neutralino mass. The angular distribution of neutrinos from neutralino annihilation in the earth's core would provide information on the neutralino mass (Edsjö, 1997). ANTARES would be sensitive to this effect because of its good angular resolution and its low energy threshold.

Neutrino oscillations can be studied in ANTARES with a base-line length of the order of the diameter of the earth. Atmospheric neutrinos are emitted in the decay of hadrons produced by the interaction of cosmic rays with atmospheric nuclei. Charged-current interactions of muonic neutrinos produce muons in the detector. The background of atmospheric muons is strongly suppressed by absorption in the sea, and completely eliminated in the case of upward-going muons. Contained vertically upward-going muons can be measured for energies from 5 to 60 GeV, corresponding to L/E_ν of about 1250 to 100 km/GeV, respectively, if the muon takes half of the neutrino energy. For the Super-Kamiokande oscillation parameters ($\Delta m^2 = .0035\, eV^2$, $\sin^2 2\theta = 1$)

(Fukuda, et al., 1998), the first dip in the survival probability occurs at 350 km/GeV, at the maximum of the ANTARES sensitivity. The minimum value of L/E_ν can be reduced to about 10 km/GeV if partially-contained muons are analyzed over the full upward-going hemisphere. The expected performance for neutrino oscillations is given in a related talk presented at this conference (Moscoso, 1999).

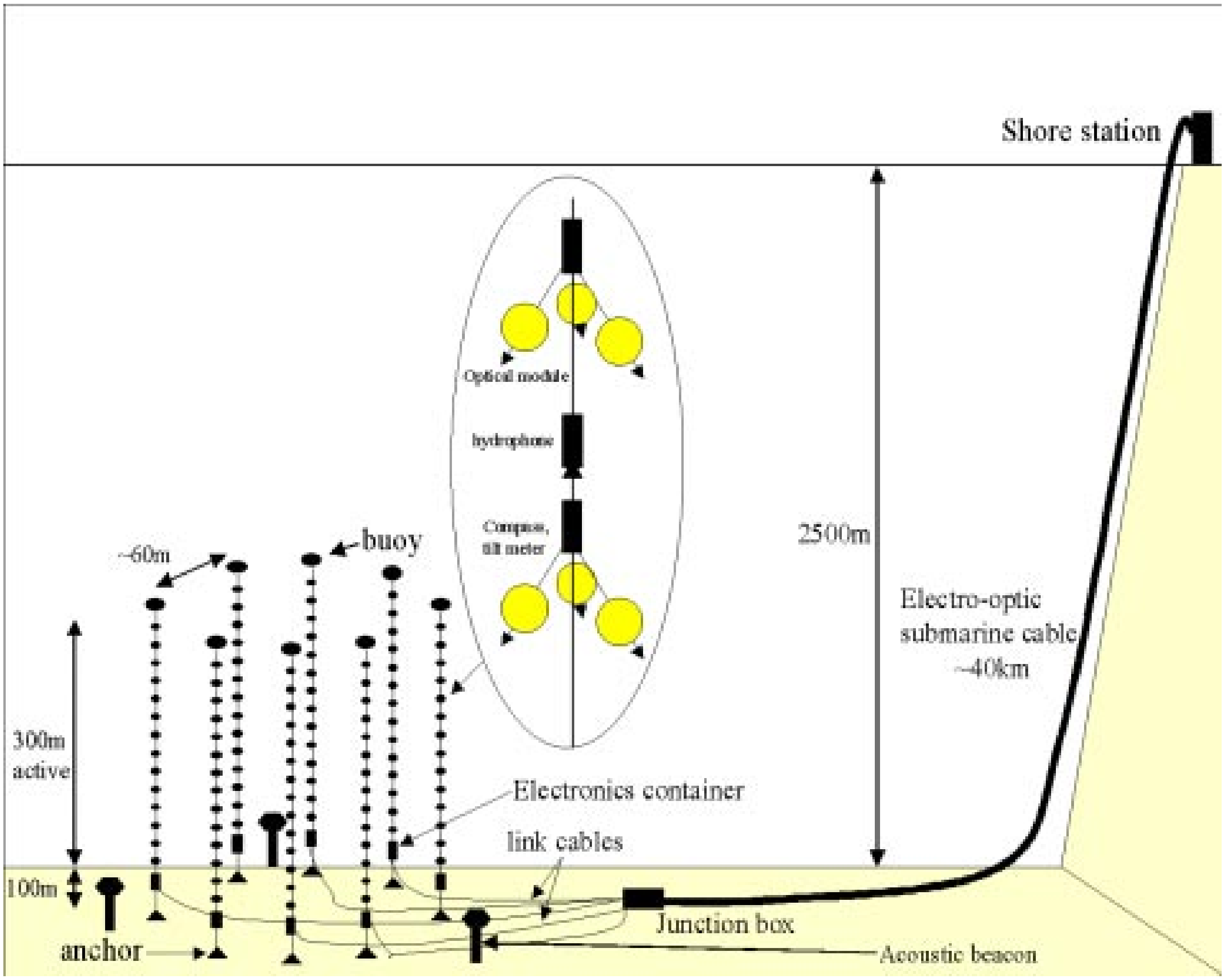

Figure 1: Schematic diagram of the first phase of the ANTARES detector.

2 Detector design:

A schematic of the future ANTARES detector is shown in figure 1. Each string is composed of standard segments consisting of three optical modules, a local control module and an electro-mechanical cable. The photomultiplier tubes in the optical modules are oriented down at 45°. Special containers house calibration equipment. A string-control module at the bottom of the string receives and transmits slow-control commands and data. The string-control modules from different strings are linked to a common junction box by electro-optical cables which will be connected to the junction box after deployment of the strings using a manned submarine. A standard deepsea telecommunications cable links the junction box to a shore station where the data are filtered and recorded. The 0.1 km^2 detector will consist of four ‘dense’ strings with 41 segments spaced vertically 8 m apart, and nine ‘sparse’ strings with 21 segments spaced 16 m apart. The total height of the strings is 420 m. The strings are placed in a spiral, with minimum horizontal spacing of 60 to 80 m.

The response of the detector depends on the geometry. The energy threshold is about 5 GeV for the dense strings, and 10 GeV for the sparse strings. Below 100 GeV, the energy of contained muon events is determined from the muon range. Above 1 TeV, the muon energy can be estimated within a factor of 3 from its average energy loss. The muon trajectory is reconstructed from the arrival times of Cherenkov photons. The estimated timing error is 1.3 ns, leading to an angular precision of $\pm 0.2°$ for high-energy muons. The Cherenkov yield for a 10-inch photomultiplier tube is 52 photo-electrons for a 1 GeV muon passing the optical module at a distance of 1 m.

The off-shore electronics is based on front-end digitization and digital data transmission. An ASIC called the Analogue Ring Sampler (ARS) is under development. For single-photo-electron pulses (99% of the photomultiplier pulses), timing information will be stored in a pipeline memory until the second-level trigger arrives. For more complex signals, the chip samples the signal and holds an analog wave form on 128 switched capacitors. The 8-bit dynamic range can be increased to between 14 and 20 bits by reading out one or two of the dynode outputs in addition to the anode signal.

The off-shore trigger logic will be as simple and flexible as possible. The first-level trigger requires a coincidence of two of the three optical modules serviced by a single local-control module. The second-level trigger is based on combinations of the first-level triggers. If a second-level trigger occurs, the full detector will be read out. The third-level trigger will be made in a farm of processors on shore. The first-level trigger rate will be about 150 kHz and the second-level rate a few kHz. The third level will select about 100 Hz of events to be recorded for off-line analysis. Details of the ANTARES electronics and trigger are described in posters presented at this conference (Feinstein, 1999).

3 Prototype tests and production schedule:

A suitable site for a neutrino telescope requires deep, transparent water and proximity to shore facilities. A site 20 nautical miles off the French Mediterranean coast, near Toulon, at a depth of 2400 m has been explored. Optical background, biological fouling of optical surfaces, undersea currents, and meteorological conditions have been studied at this site, using special test strings. A low level background rate varying from 20 to 47 kHz was measured with an 8-inch Hamamatsu photomultiplier tube housed in a 17-inch pressure-resistant Benthos glass sphere. Bursts of luminescence lasting about one second and giving peak counting rates up to several MHz were observed, correlated with the speed of the undersea currents. Fouling of the optical surfaces depended on the orientation, with lower rates for downward-looking surfaces. For vertical surfaces, the transmission loss after one year is about 1.5%. The attenuation length for blue light (466 nm) was measured to be $41 \pm 1 \pm 1$ m. Details of these studies are given in a separate talk presented at this conference (Palanque-Delabrouille, 1999).

Complete prototype strings have also been immersed to test deployment techniques, instrumentation, and slow controls. Twenty different deployment/recovery cycles have been completed. Two deployment techniques have been used: horizontal deployment, in which the full detector is laid out on the surface of the sea before the release of the anchoring weight, and vertical deployment, in which the anchor is the first item immersed. The dynamic forces are reduced in the horizontal deployment, but the positioning accuracy of the vertical deployment is better. The recovery of the string is activated by an acoustical signal from the surface which disconnects the string from its anchoring weight. The undersea electrical connection of the string-control modules to the junction box has been tested successfully by the IFREMER crew of the “Nautile” submarine during one of these operations.

A prototype string planned for immersion next month is shown in figure 2. The 350 m string will be anchored on the sea floor and maintained vertically by a large buoy at the top of the string. Two cables support 16 optical module frames placed every 15 m starting from 95 m above the sea floor. Each of the 16 frames holds two 17-inch glass spheres with center-to-center separation of 1.6 m. Eight of the spheres will contain photomultiplier tubes, oriented horizontally so that downward-going muons can be detected.

The prototype will be equipped with a positioning system to allow the reconstruction of the position of each optical module on the string with a precision of about 10 cm. Tiltmeters and compasses will measure local tilt angles and orientations. They will be installed in titanium spheres on 12 of the optical module frames and in 6 of the unequipped glass spheres. The string will also hold four rangefinders communicating with four external transponders at fixed positions 200 m away on the sea floor to allow a precise 3D localisation of a few points on the string by acoustical triangulation. The string will be linked to a shore station 40 km away by means of an electro-optical cable. Slow control communications as well as experimental data will be sent over the four optical fibers in this cable. The slow-control network, based on an industrial field-bus technology (WorldFip), will control the power distribution, the readout electronics, the acoustic system, and the readout of sensor data.

The first seven strings of the 0.1 km^2 detector will be built in the period 1999-2001 and deployed in 2002, with three dense strings and four sparse strings, for a total of 621 optical modules. The remaining six strings will be deployed in 2003. The full detector will contain 1059 optical modules. The cost will be about 15 MEuro.

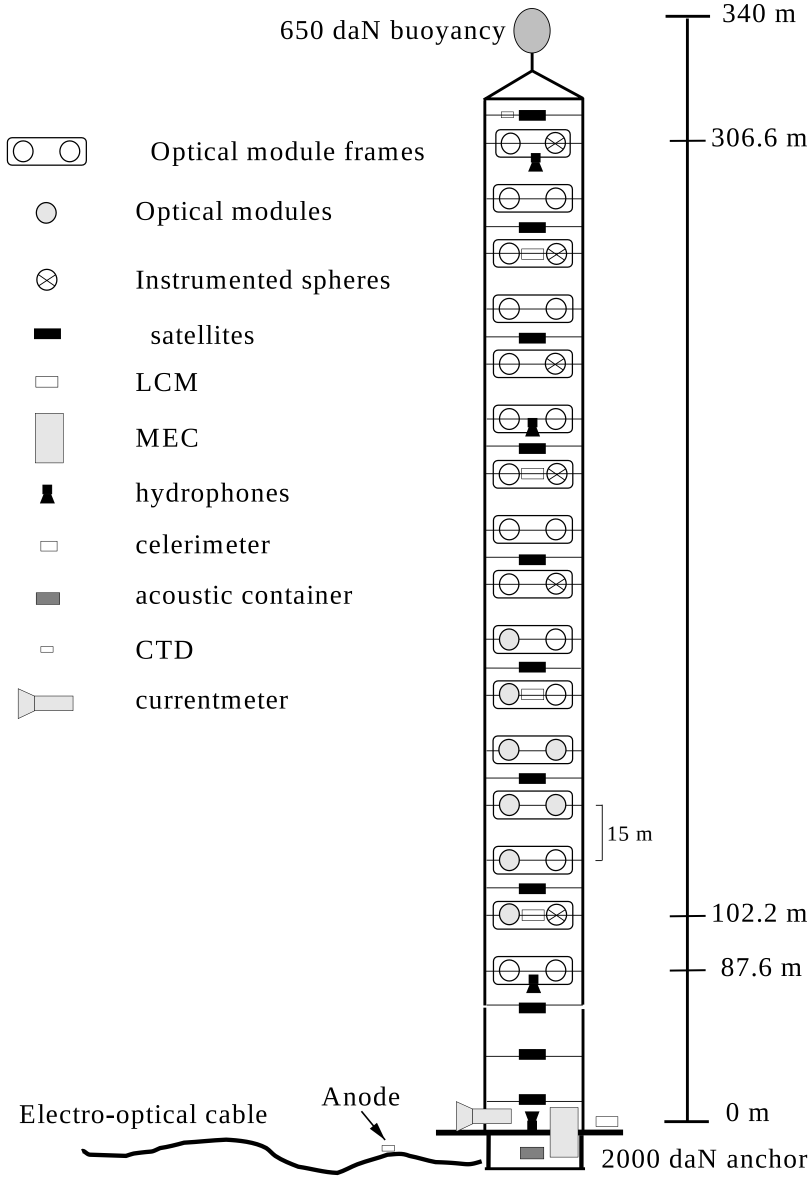

Figure 2: Schematic view of the prototype string.

References

Edsjö, J. 1997, Aspects of neutrino detection of neutralino dark matter, Ph.D. thesis, University of Uppsala
Feinstein, F. 1999, Electronics and DAQ system for ANTARES, poster session at this conference
Fukuda, Y. 1998, Phys. Rev. Lett. 81, 1562
Jungman, G., Kamionkowski, M., & Griest, K. 1996, Phys. Rep. 267, 195
Moscoso, L. 1999, Expected performance of the ANTARES experiment, presented at this conference
Palanque-Delabrouille, N. 1999, Environmental parameters at the ANTARES site, presented at this conference
Stecker, F.W. et al. 1991, Phys. Rev. Lett. 66, 2697, (Errata 1992, Phys. Rev. Lett. 69, 2738)