

Towards Acoustic Detection of UHE Neutrinos in the Mediterranean Sea – The AMADEUS Project in ANTARES¹

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Abstract. The acoustic detection method is a promising option for future neutrino telescopes operating in the ultra-high energy regime. It utilises the effect that a cascade evolving from a neutrino interaction generates a sound wave, and is applicable in different target materials like water, ice and salt. Described here are the developments in and the plans for the research on acoustic particle detection in water performed by the ANTARES group at the University of Erlangen within the framework of the ANTARES experiment [1] in the Mediterranean Sea. A set of acoustic sensors will be integrated into this optical neutrino telescope to test acoustic particle detection methods and perform background studies.

1. Introduction

Towards the detection of neutrinos with energies exceeding 100 PeV, the use of acoustic pressure waves produced in neutrino-induced cascades is a promising approach which is investigated by several running and planned projects, see e.g. [2,3]. The acoustic wave originates from the heating of the medium in the vicinity of the evolving cascade – a mechanism which is described by the thermo-acoustic model [4]. Once generated, the sound wave propagates in a flat disk shape perpendicular to the main axis of the cascade. In a sensor, the resulting signal is bipolar in time and has its main frequency components in the range from 1 to 100 kHz. The absorption length of sound in sea water at the peak spectral density around 20 kHz is on the order of a kilometre [5]. This would make it possible to instrument efficient acoustic detectors with 200 sensor clusters per km³ [6,7]. Given the expected low flux of neutrinos with energies in excess of 100 PeV, a potential acoustic neutrino telescope must not only have large dimensions, but also has to be operated basically background-free.

To investigate the feasibility of building a detector in the deep-sea based on this method, it is therefore necessary to understand the acoustic background conditions and characteristics of transient noise sources at the site in detail. Especially the knowledge of the rate and correlation length of acoustic background events with neutrino-like signature is a prerequisite for the estimation of the detector sensitivity. Thus the aim of the project *AMADEUS* (ANTARES Modules for Acoustic Detection Under the Sea), described in the following, is to measure the

¹ This work is supported by the German BMBF Grant No. 05 CN5WE1/7.

acoustic conditions of the deep-sea environment at the ANTARES site with a dedicated array of custom-designed acoustic sensors at different distances over a long time scale.

For these studies several additional basic detector elements (*storeys*, cf. Sec. 2), equipped with acoustic sensors, will be installed in the ANTARES neutrino telescope. On these storeys the acoustic sensors will substitute the optical sensors used for Cherenkov detection of neutrinos.

2. The ANTARES detector

Figure 1 shows a sketch of the complete ANTARES detector with the acoustic AMADEUS module, which is further described in Sec. 3.

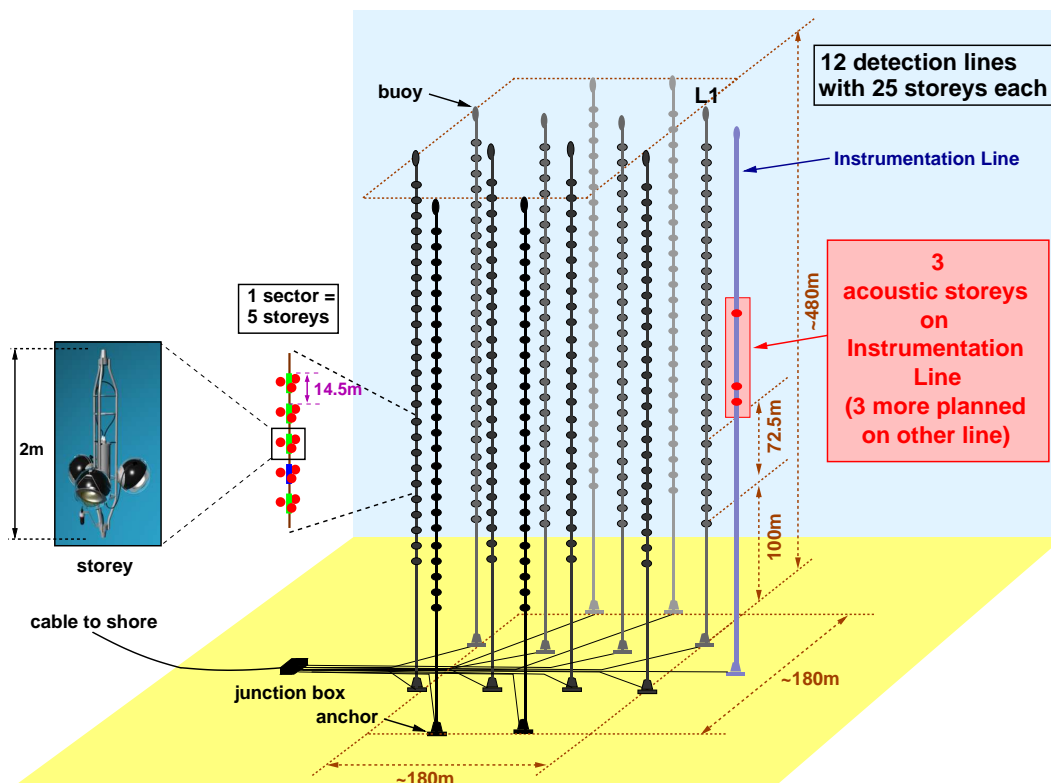


Figure 1. Sketch of the ANTARES detector with the acoustic addition AMADEUS. For further description see text.

The ANTARES detector [1] is currently constructed in the Mediterranean Sea in a water depth of up to 2500 m. Its completion is planned for 2007; the final Cherenkov neutrino telescope will consist of 12 vertical structures (*detection lines*). The Instrumentation Line (*IL*) – an extra 13th line – will be equipped with sensors to monitor environmental parameters in the deep sea and with devices to calibrate the detector. Its installation is planned for mid-2007. Each detection line has a total height of 460 m and comprises 25 *storeys* (cf. left insert in Fig. 1) spaced evenly within the instrumented height of 350 m. The storey is the basic detection element and consists of three Optical Modules (*OMs*) (optical sensors in a pressure-resistant glass housing), a Local Control Module (*LCM*) (for data acquisition-, control- and monitoring hardware) and miscellaneous auxiliary devices on a mechanical support frame. The 12 detection lines will cover a total area of approx. $180 \times 180 \text{ m}^2$ on the sea-floor. The detector is connected to the on-shore control room via deep-sea cables providing electrical power and data transmission. At the writing of these proceedings, two detection lines and a progenitor of the IL have been installed and are operated successfully.

3. The Acoustic Setup AMADEUS

Three storeys on the IL will be equipped with six acoustic sensors each. The vertical spacing for these storeys will be approx. 15 m and 100 m. Together with the sensor spacing of approx. 1 m within the storey, this will provide three different length scales for the investigation of acoustic background sources. Additional three acoustic storeys are planned on one further detector line at a horizontal distance exceeding 100 m. For the integration of acoustic sensors into the ANTARES experiment the data acquisition (*DAQ*) system [8] and some mechanical structures have to be modified. This is done under the premise of preventing any interference with the optical data taking. To optimise resources and to make use of the well-tested, existing system wherever feasible, as little changes as possible to the ANTARES design are targeted.

3.1. Acoustic Sensors

Major changes affect the storey, where the optical sensors are replaced by acoustic ones: hydrophones or so-called acoustic modules (*AMs*) [9]. Artist's views of the resulting acoustic storeys are shown in Fig. 2.

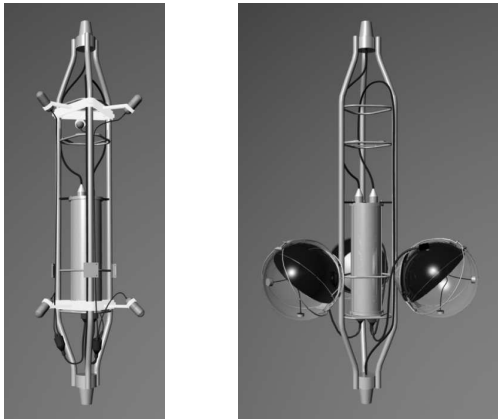


Figure 2. Artist's views of acoustic storeys with six hydrophones (left) and three acoustic modules housing two piezo sensors each (right).

The acoustic sensors are based on piezo ceramics that convert pressure waves into voltage signals, which are amplified for read-out [10]. In the case of the hydrophones, the ceramics and amplifiers are coated in polymer plastics. For the AMs they are glued to the inside of a water-tight sphere. The three storeys on the IL will house hydrophones only, whereas at least one of the storeys planned additionally will house the non-conventional but promising design of AMs [9]. All acoustic sensors are custom-designed. They are tuned to be sensitive over the whole frequency range of interest (around -145 dB re. 1V/ μ Pa) and to have a low noise level.

3.2. Acoustic Data Acquisition

The acoustic signals are preprocessed and digitised within the LCM on each storey by custom-designed electronics boards – the acoustics digitisation boards (*AcouADC-boards*). These boards are integrated into the ANTARES *DAQ* system, which provides nanosecond-scale timing resolution, positioning of the storeys and transmission of the data to the on-shore control room. There are a total of three such boards per storey receiving the data of two sensors each.

3.3. The *AcouADC-Board* and System Performance

The *AcouADC-board* consists of an analogue and a digital part. The analogue part amplifies and filters the acoustic signals coming from the sensors. The system has low noise and is designed to be – together with the sensors – sensitive to the acoustic background of the deep sea over a wide frequency range. A bandpass filter with cut-off frequencies of approx. 1 and 100 kHz is

integrated to avoid the trailing edge of the low frequency noise [11] and aliasing effects from frequencies above the Nyquist frequency of the digitisation.

The acoustic data from the analogue part is digitised with a 16-bit resolution and a maximum sampling rate of 500 kSamples per second ($kSPS$) and then processed in the digital part of the board. There the data can be down-sampled to reduce data traffic and is read out by the ANTARES DAQ system which handles the transmission to the control room. The maximum sample rate per storey is bandwidth-limited to an average of 1.25 MSPS. Thus the data of all six sensors can be transmitted with a sampling of 200 kSPS, or alternatively the data of two sensors at full rate.

The whole data-taking chain is calibrated allowing for precise reconstruction of the acoustic signal from the recorded one within the sensitive frequency range of the set up. The dynamic range achieved is from the order of 1 mPa to the order of 10 Pa (rms over the frequency range from 1 to 100 kHz). This allows for studying both, the acoustic background in the deep sea under all prevailing conditions [11] and transient sounds with neutrino-like signatures.

3.4. On-shore Control Room

The DAQ system will be controlled from the on-shore control room. From there, settings for the analogue part and the data processing in the digital part can be adjusted. An update of the programming code of the AcouADC-board is also possible in situ. A dedicated PC-cluster will be set up to process and store the acoustic data arriving from the storeys. On this cluster different data filtering schemes and triggers will be implemented, and an adequate amount of raw data will be stored.

4. Summary and Outlook

We described AMADEUS, a project to investigate the feasibility of a future neutrino detector using the acoustic detection method in water. With this project, a dedicated array of acoustic sensors will be installed in the deep sea at the ANTARES site in 2007. Long-term studies of the acoustic background noise and signals in this environment will be performed. The main goal is to measure the rate of correlated neutrino-like background events and their correlation length, which is decisive for assessing the sensitivity of a future acoustic detector for ultra-high-energy neutrinos.

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