Acoustic Detection of Ultra-High Energy Neutrinos

Justin Vandenbroucke[1], Nikolai Lehtinen[2], Yue Zhao[3], Giorgio Gratta[3]
[1] Dept. of Physics, University of California, Berkeley, CA 94720, USA
[2] Dept. of Physics, University of Hawaii, Manoa, HI 96822, USA
[3] Dept. of Physics, Stanford University, Stanford, CA 94305, USA

Over the past two years, data have been collected at an array of hydrophones in a search for acoustic signatures of ultra-high energy neutrinos from space. The Study of Acoustic Ultra-high energy Neutrino Detection (SAUND) [1] is a first step towards developing a novel detection method for one of the outstanding problems of both particle physics and astrophysics. The project has produced the first measurement of the ultra-high energy neutrino flux with an acoustic array. It has also provided important technical information that could be used to design a new array dedicated entirely to cosmic ray neutrino detection.

In the past decade several groups have developed undersea arrays of instruments to detect subatomic particles from cosmic radiation. Most of these experiments use arrays of photo-multiplier tubes that detect light emitted by the particles as they traverse water at the speed of light. Even more recently, undersea projects have been initiated to detect the particles acoustically. G. A. Askaryan first considered the possibility of detecting sound from a charged particle traveling through matter in the 1950's [2]. In the 1970's, J. G. Learned worked out the theoretical details [3], and L. Sulak *et al* [4] confirmed them experimentally at a particle accelerator. Acoustic and optical detection are best suited for different particle energies and, to some degree, for different types of particles.

Understanding cosmic rays and neutrinos at very high energies is a key goal of contemporary astrophysics. Cosmic rays are known to be protons and neutrons at low energies. At ultra high energies (10^{20} eV), however, they present an enigma. Standard theory predicts that no cosmic rays should reach the earth above this energy, but a handful may have been detected [5, 6]. If they have, the theory has to be changed. There is a vast array of new theories featuring changes to our understanding of particle physics and/or astrophysics that would accommodate the results.

To resolve the discrepancy between theory and experiment, many more events must be detected. However, the events are very rare at such high energies (1 event/km^2/century above 10^{20} eV), which means a very large detector is necessary. Ocean-based acoustic detectors could be well suited for this: the attenuation length of sound in water is quite long (~1 km at 10 kHz), so a large detector can be achieved by instrumenting a volume of ocean water with a sparse array of hydrophones. At 10^{20} eV, we do not know whether the cosmic radiation is composed of nucleons, neutrinos, or both. However, at this energy only neutrinos pass through the atmosphere and reach the ocean; nucleons are blocked. Hence undersea acoustic detectors are only sensitive to neutrinos, and could help resolve the question of particle composition.

In a previous paper [7], we discussed the possible sensitivity of an existing array operated by the U. S. Navy to ultra-high energy neutrinos. In July 2001, SAUND equipped seven hydrophones at this facility, the Atlantic Undersea Test and Evaluation Center (AUTEC) for neutrino detection. AUTEC features several arrays of bottom-mounted hydrophones spanning 250 km^2 in the Tongue of the Ocean (TOTO) in the Bahamas. The TOTO is a good environment for underwater acoustics: it is a deep-sea cul-de-sac, attaining depths of 1-2 km within several miles of shore; and it has very little boat traffic.

At AUTEC we have been able to run the SAUND system in parasitic mode, turning it on whenever no AUTEC activities are scheduled. In practice this has allowed us to run the neutrino detector with 70% live time. Our detection strategy is to monitor all 7 hydrophones continuously and pass the pressure level of each through a digital filter matched to the theoretical neutrino waveform. The neutrino waveform is predicted to be a simple bi-polar pulse. This has been derived theoretically [3] and demonstrated experimentally [4] (The experiment simulated single ultra-high energy particles with bunches of low energy particles.) When the filter output exceeds threshold, the data acquisition system triggers and captures the waveform. Data have been accumulated in this fashion for an integrated live time of 208 days. In this time we have recorded 25 million single-phone neutrino candidates.

Research conducted by SAUND will aid in the development of a large-scale acoustic neutrino detector, should one be built. Because the neutrino path is a line source, the acoustic radiation of neutrinos is confined to a disk 100 times wider than it is thick. We have worked out the practical consequences of this fact, particularly pertaining to multiple-phone detection. The very slow speed of sound compared to light makes acoustic detection quite different from optical detection, the better-understood forerunner. The type and rate of background events that mimic neutrinos were previously unknown but have now been determined (at least for one site). These backgrounds can be rejected with sufficient waveform analysis. We have determined a successful method of acoustic source localization for the specific situation of neutrino detection. This is necessary both for background rejection and for reconstructing the neutrino energy. We have studied the effects of sound-ray refraction, a difficult effect to account for and one that was not previously considered for neutrino detection. Finally, we have studied how to optimize array location relative to the sea floor and surface, interphone spacing, and geometric configuration.

While SAUND is important primarily as a feasibility study, we have also been able to contribute a new physics measurement with the data collected. Using several criteria to systematically cut the 25 million triggers, we put a limit on the number of neutrinos that likely interacted in the water volume while it was monitored. We converted this to an upper limit on the rate of diffuse neutrinos reaching the Earth at ultra-high energies, the first astrophysics measurement made with an acoustic array.

REFERENCES

[1] http://hep.stanford.edu/neutrino/SAUND
[2] G. A. Askaryan. Sov. J. Atom. Energy 3 (1957) 921.
[3] L.G. Lehtinen *et al.* Astropart.Phys. 17 (2002) 279-292.
[4] L. Sulak et al. NIM 161 (1979) 203.
[5] M. Takeda *et al.* Phys. Rev. Letters. 81 (1998) 1163-1166.
[6] T. Abu-Zayyad *et al.* (HiRes Collaboration) Submitted to Astroparticle Physics 2002.
[7] L.G. Lehtinen *et al.* Astropart.Phys. 17 (2002) 279-292.