HYDROACOUSTIC DETECTION OF ULTRA-HIGH ENERGY COSMIC NEUTRINOS

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An attractive technique to explore for super-high-energy cosmic neutrino fluxes, via deep underwater acoustic detection, is discussed. It is argued that a hydroacoustic array of 2400 hydrophones, which is available in the Great Ocean near Kamchatka Peninsula, could be used as a base for such an acoustic neutrino telescope. The detection volume for registration of neutrino induced cascades with energies 10^{20-21} eV is estimated to be hundreds of cubic kilometers. Some models of extremely high energy elementary particle production in the Universe (for example the topological defect model) may be examined by such a detector.

1 Introduction.

During the last several decades a new branch of physics and the astropysics, namely high energy neutrino astrophysics (or neutrino astronomy), has been pursued aggressively by a relatively small but dedicated community of physicsts. Since first detection of the atmospheric neutrinos with energies $10^9 - 10^{11}$ eV in underground neutrino experiments[1], the target mass scale of the instruments has grown to $\sim 5 \times 10^4$ tons (Super-Kamiokande[2]). In fact neutrino telescopes have become universal instruments for investigation of the microworld (search for proton decay, etc.) as well as cosmic objects (solar neutrinos, neutrinos from SN1987A).

However to search for ultra-high energy (UHE, greater than 10^{15} eV) astrophysical neutrino sources, sites of the most energetic proceses (accelerators) in the Universe, neutrino telescopes of effective detection volumes a cubic km or more, KM3 are necessary[3]. The deep underwater optical neutrino telescopes of 10^7 m^3 in Lake Baikal, in the Mediterranean Sea (NESTOR) and in the deep polar ice (AMANDA in the Antarctic) are under construction now (see [4] and references therein). A KM3 optical neutrino telescope could be developed employing advances in technology for deep underwater Cherenkov detectors[5].

Several alternative methods to optical detection of UHE neutrino interactions have also been discussed and studied both in the laboratory and in the field during last two decades. These employ deep underwater acoustics[6,7,8] and radio wave neutrino detection in cold antarctic ice[9,10,11,12,13]. The energy thresholds for radio and acoustic detection are a few orders of value magnitude greater than 10-50 GeV threshold typical for the deep underwater optical detection (this latter threshold is purely one of economics, whereas the limitation on radio and acoustic detection is one of inherent signal-to-noise on earth). The calculations for RAMAND (Radio Antarctic Muon And Neutrino Detector) threshold have shown[14] that a 1 km^2 RAMAND in central Antarctica should be sensitive to the predicted diffuse flux of neutrinos from Active Galactic Nuclei (AGN) at energies above 50 TeV. For some production models[15,16,17], AGN neutrinos could be effectively detected by RAMAND in the energy interval $10^{14} - 10^{16}$ eV. For example 80 events per a year for a 1 km^2 surface deployed RAMAND can be expected due to the AGN neutrino spectrum by R.Protheroe[18] who took into account proton – photon interactions in blazars.

Neutrino telescopes with target scale greater than 1 km^3 were also suggested for studies of the upper boundary of the energy spectrum of cosmic neutrinos[10]. If elementary particles of maximal masses $10^{24} - 10^{28}$ eV do exist, their interactions and decays could produce neutrinos (and another particles) of superhigh energies (SHE) up to $10^{24} - 10^{28}$ eV[19].

2 SADCO proposal: to search for SHE neutrinos.

The acoustic detection of elementary particles was suggested by G. A. Askaryan in the 1950's. Twenty years later the possibility of construction of a deep ocean acoustic detector to study UHE neutrinos was discussed[6,7,8], but not pursued because at that time the threshold was thought too high. More recently a deep underwater neutrino telescope SADCO with threshold energy above 5 PeV was proposed to be deployed at a depth of 3.5-4 km in the Ionean Sea near Pylos, Greece at the site of the NESTOR optical neutrino telescope[20,21,22]. The sensitive volume of the SADCO neutrino telescope would be not less than 10^8 m^3. With the most optimistic models, dozens of events per year might be seen from the Glashow resonant neutrino interaction. But the main attraction of SADCO is its ability to search for the SHE neutrino interactions (E ¿ 10^{17} eV) in a huge water volume[7].

An acoustic signal is emitted by a neutrino induced cascade mainly in perpendicular direction to the cascade axis in a rather narrow solid angle. The angular thickness of the disk is determined by the transverse size of the effective emitting region (which for high energy particle cascades in water is of the order of a few cm) divided the cascade length (roughly ten meters), or a few milliradians. The initial spectrum peaks at a few tens of kHz. The signal spectrum at large angles and at large distances shifs to a lower frequency region of a few kHz. If SADCO could detect 1 kHz signals produced by SHE cascades at distances of 10 to 50 km its effective detection volume could be tens to hundreds cubic km.

In the framework of some GUT models with X-particle masses of 10^{23} eV and in topological defect (TD) models, calculations of cosmic neutrino fluxes with energies up to 10^{23} have been performed[24]. The search for TD neutrinos should be one of goals for SADCO if the registration volume reaches to hundreds cubic km.

3 Kamchatka hydroacoustic array as a SADCO base in the Ocean

It is very interesting to consider the use of already existing stationary sonar, such as that placed in Kamchatka region, as an acoustic detector of neutrino. This sonar has a large plane phased array with 2400 hydrophones. The array is installed on the sea shelf bottom and connected with on-shore equipment by cable. The sector of view is 120^o. The angular resolution in the horisontal plane is 0.8^o in each of 150 parallel fan-shaped beams (virtual). The vertical angular width is 7^o. The gain of this array is 2500 at 1400 Hz.

One can approximately estimate the detection capability of such a system. Let us assume that a neutrino induces a cascade with an energy $E = 10^{20}\ eV$. An acoustic impulse with time duration of $25 \mu sec$ is generated. The maximum acoustical pressure of such signal at a range 10 kilometers should be 2000 μPa. The level of acoustic pressure at a frequency of 1400 Hz is approximately 19 μPa. As the mean amplitude of sea noise in this frequency range is $100 - 200\ \mu Pa$ (Beaufort Number 0-6), the signal/noise ratio on array would be 0.2-0.01. After beamforming (antenna gain) the output signal/noise ratio should be 10-0.5. In other words such stationary sonar can detect cosmic particles with energy more than $10^{20}\ eV$ and in a very large volume, more than 100 cubic kilometers. Despite the fact that the frequency range of this sonar is not optimal (we would like higher bandwidth) the very large detection volume can compensate the frequency deficit and greatly increases the detection probability of extrmely energetic particles.

From the practical standpoint, the economic benefit of such aan exploration is evident, because this sonar is in operation. Our suggested variant of acoustic detection of elementary particles can thus be very suitable for preliminary search experiments. Moreover this permits the development of different methodologies and algorithms for the detection and recognition of neutrino events. It is expedient to develop and make a special acoustical transducer placed on the ship for simulation of neutrino impulse signals with different space-time parameters. Little else is needed in terms of hardware.

4 Conclusions

We have outlined a program for study of acoustic detection of neutrinos in the oceans employing existing sonar arrays. This program, which requires almost no hardware investment, can begin as soon as support is available for personnel. First it will permit development of detection techniques in the real ocean, something not heretofore available to neutrino physicists. Moreover, the existing equipment should permit a useful physics exploration for neutrinos of extreme energies, not far above energies of cosmic rays arlready observed by extensive air shower arrays. We look forward to tests of this system with a year.

Acknowledgements

One of the authors (I.Zh.) thanks the Russian Foundation of Basic Researches for support (grants 96-02-18594, 97-02-26522) and the Organizing Committee of Rencontres de Moriond for hospitality and support.

References

1. F.Reines et al, Phys. Rev. Lett. 15, 429 (1965); C.V.Achar et al, Phys. Lett. 18, 196 (1965).
2. The Super-Kamiokande project.
3. J.G.Learned, Nucl. Phys. B (Proc. Suppl.) 33 A,B, 77 (1993).

4. T.K.Gaisser, F.Halzen and T.Stanev, Phys. Rep. 258, 173 (1995).
5. V. Chaloupka et al, LBL - 38321, Feb. 1996.
6. G.A.Askaryan and B.A.Dolgoshein, 1976 DUMAND Summer Workshop, Hawaii.
7. T.Bowen, Conference Papers, 15th ICRC, Plovdiv, 6, 277 (1977).
8. J.G.Learned, Phys. Rev. D 19, 3293 (1979).
9. G.A.Gusev, I.M.Zheleznykh, Pisma Zh. Exp. Teor. Fiz., 38, 505 (1983).
10. M.A.Markov, I.M.Zheleznykh, Nucl. Inst. Methods A 248, 242 (1986).
11. I.N.Boldyrev et al, Proc. 3rd Int. Workshop on Neutrino Telescope, ed. Milla Baldo Ceolin, Venezia, p. 337 (1991).
12. J.P.Ralston and D.W.McKay, Nucl. Phys. B (Proc. Suppl.) 14A, 356 (1990).
13. E.Zas, F.Halzen and T.Stanev, Phys. Lett. B 257, 432 (1991); Phys. Rev. D 45, 362 (1992).
14. A.L.Provorov and I.M.Zheleznykh, Astropart. Phys. 4, 55 (1995).
15. F.W.Stecker et al, Phys. Rev. Lett., 66, 2697 (1991).
16. A.P.Szabo and R.J.Protheroe, Astropart. Phys. 2, 375 (1994).
17. K.Mannheim, Astropart. Phys. 3, 295 (1995).
18. R.J.Protheroe, Proc. IUA Coll. 163, ed. D.Wichramasinghe, 1996, in press.
19. M.A.Markov and I.M.Zheleznykh, Proc 1979 Dumand Summer Workshop at Khabarovsk and Lake Baikal, ed. J.Learned, p.177 (1980).
20. A.V.Butkevich et al, Proc. 2nd Int. Conf. on Trends in Astropart. Phys. (1991), Aachen, Tubner-Texte fur Physik B28, 128 (1994).
21. S.K.Karaevsky et al, Proc. 23rd ICRC, Calgary, 4, 550 (1993).
22. L.G.Dedenko et al, Proc. 24th ICRC, Rome, 1, 797 (1995).
23. A.V.Butkevich et al, Proc. Int. School Particles and Cosmology (1995), Baksan, World Scientific, p.306 (1996).
24. G.Sigl, talk at HENA Workshop, 26 May - 9 June 1996, Aspen.