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NEW SUGGESTIONS ON ARCHITECTURE OF AN ACOUSTIC
«NEUTRINO» TELESCOPE

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Architecture of an acoustic neutrino telescope is suggested. Numerical simulation is carried out to determine accuracy, with which it can calculate neutrino paths depending on such parameters as particle energy, distance from a path to the receiver system, and reference level.

It is well known that acoustic distributed receiving systems can be applied to solving a fundamental physical problem on the development of a “neutrino” telescope – a device detecting high-energy cosmic particles [1, 2]. The possibility of detecting acoustic manifestations of neutrino interaction with a medium at the energy more than 10^{16} eV is demonstrated. The essence of the effect is the phenomenon of instant heat of water in a narrow water channel along the axis of a nuclear-electron cascade generated by a neutrino-substance interaction. At high energies in the vicinity of a neutrino path, a narrow long particle beam forms; it is generated by a chain reaction after the first stage of the interaction of neutrino and substance nucleus. The medium is heated due to ionization losses of electrons forming a cylindrical thermoradiation sound source. Water heat causes expansion and an acoustic pulse with a characteristic N-pulse shape of a pressure wave. The wave front close to the cascade axis has a cylindrical shape.

The radius of the thermoacoustic source is determined by the electron distribution over transverse cross-section of the cascade and amounts to several centimeters. The length [3] is equal to $L = (\ln E_n / E_{cr})^{1/2}$, where E_{cr} is the critical electron energy of 73 MeV, at an excess of which a chain reaction occurs in the cascade; E_n is the energy of the particle originating the cascade, and L has dimensionality in meters. Estimate of length L for the threshold value E_n yields a value of order 10 m.

The Landau-Pomeranchuk-Migdal effect limits the cascade length for superenergy particles ($E_n \gg 10^{21}$ eV) due to the Coulomb interaction of particles in the cascade. The pressure amplitude of an acoustic signal in sea water may be approximately estimated by the formula [4]:

$$P_{\max} = 0,44 * R(r) * E_n / (E_0 * r^{1/2}), \quad (1)$$

where P_{\max} is the pressure in Pascal, $E_0 = 10^{18}$ eV, r is the distance from the cascade axis (m), and $R(r)$ is the function taking into account a deviation of the law of sound propagation to the reception point from the purely cylindrical dependence ($1/r^{1/2}$) as a result of limited length of the cascade. Formula (1) is valid for $r > L$. Thus $R(50) = 1$, $R(100) = 0.98$, $R(250) = 0.28$ and $R(500) = 0.12$.

The acoustic pulse shape was calculated by various authors for electron-photon and electron-nuclear cascades in different approximations and models, for example in paper [5].

In spite of sufficient clarity of the theory there is not a single fact of acoustic system detection except for laboratory setups with accelerators, in which acoustic signals from the interaction of high-energy particles with substance are accessible to direct listening. Among the reasons of this are, in particular, a high cost of the suggested constructions and the fact that detection of a “similar” acoustic signal is insufficient to make an unambiguous conclusion on detection of a particle, moreover to determine the direction of its arrival. Meanwhile main hopes are associated and basic data (record of solar neutrino and neutrino fluxes from supernovas) are obtained with neutrino telescopes of a different principle of operation than that of acoustic telescopes. There are several projects of neutrino observation: “DUMAND” was followed by AGASA, “NESTOR”, “Antares”, etc. First of all, they are based on the optical principle using record of glowing from the Cerenkov deceleration radiation in large deep-water volumes.

In the present paper the authors would like to draw attention to the analogy between an acoustic signal from neutrino and a signal from a shock wave from an supersonic source in the air. In both cases the signal has the form of a shock wave: in the first case it is a cylindrical wave, while in the second case it a conical wave. The analogy enables one to employ the algorithm of the solution and the measurement scheme of the receiving system developed for calculation of the path of supersonic source motion in the air using a ballistic wave [6]. This problem was solved in application to determination of

sniper position. An acoustic source produced by a high-energy particle has similar peculiarities: a characteristic signal of a shock wave, an assigned cylindrical type of the wave front, and also is a very rare event. According to the data obtained by Kenji Shinozaki (a participant of AGASA project, Max-Planck Institute, Munich) particles with the energy higher than 10^{18} eV, which according to the modern concept originate in topological defects fall into a squared kilometer of the Earth area not more frequently than once a year.

The receiving system architecture eliminating some problems in constructing the acoustic “neutrino” telescope also follows from this approach. Scheme of the receiving system is shown in fig. 1.

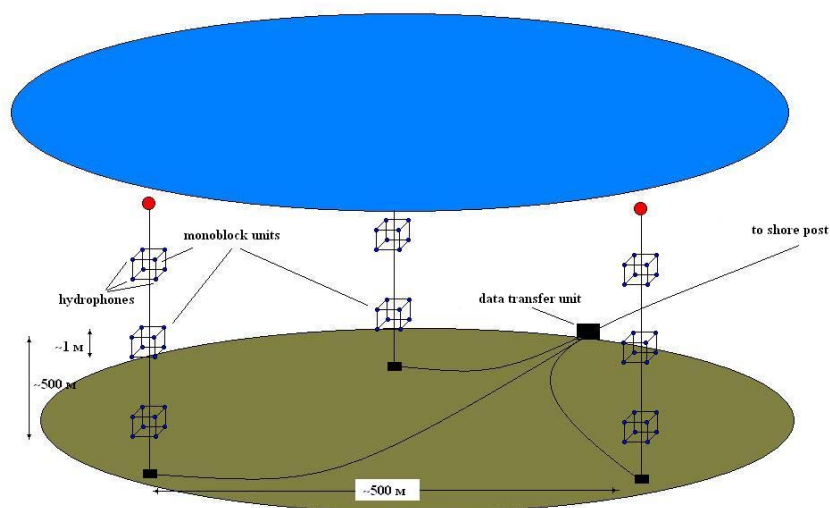


Fig. 1. Scheme of receiving system

The main features distinguishing the suggested construction:

- signals are processed directly in elementary phased cells from several receivers;
- both temporal and spatial peculiarities of signals are used for preliminary processing and isolation of signals, i.e., first similar temporal realizations are isolated and then the type of a wave front is verified;
- separate cells are synchronized to increase an accuracy of determining the cylindrical source axis;
- the receiving system should have a large time for accumulation of information (years) and transfer only previously processed results to the shore;
- a possibility to increase the number of cells in depth and the number of vertical systems.

Sizes of cells and spacing of vertical receiving systems given in fig. 1 are optimized with respect to the acoustic source and the conditions of covering the maximal volume of the medium. An individual cell in the form of a cube comprising eight hydrophones is basically capable of solving the problem of detection and determination of the particle arrival angles. Therefore, numerical simulation results on elementary cell operation are given below.

Let us show the accuracy with which an elementary cell can calculate neutrino paths depending on such parameters as particle energy, distance from a path to the receiving system, and interference level.

In the general case the real and calculated paths are crossing straight lines. Hence the error of telescope operation can be estimated employing two parameters: the angle of crossing and the distance between the paths. Since the task of the telescope is to determine the direction of particle arrival (the second parameter does not influence it), the operation accuracy is estimated only for angular coordinates.

We shall take a receiving system having 8 hydrophones located at cube corners. The length of the cube edge is 10 m. As a signal of a shock wave from the neutrino-generated cascade we use a

model signal from paper [5]. The amplitude of a signal received by each hydrophone depended on the neutrino energy and the distance to a path and was calculated.

The numerical experiment consisted of six stages:

- 1) assignment of correct neutrino path (the flight direction is chosen randomly, but the required distance to the receiving system is assigned rigorously);
- 2) calculation of model (in complete absence of interferences) times of shock wave arrival in hydrophones of the receiving system;
- 3) synthesis of signals received by each hydrophone (particle energy, distance to path, and interference level are taken into account). As an example, fig. 2 deals with signals received by the hydrophone located at a distance of 100 m from the flight path of neutrinos with energies 10^{20} eV, 10^{19} eV, and 10^{18} eV at the interference level 60 dB (relatively to 20 mcPa);
- 4) determination of time of shock wave arrival in hydrophones using the correlation method;
- 5) determination of path using wave arrival times from set of equations (2) relating them with the path parameters;
- 6) finding the crossing angle between correct and calculated paths – determination of measurement error.

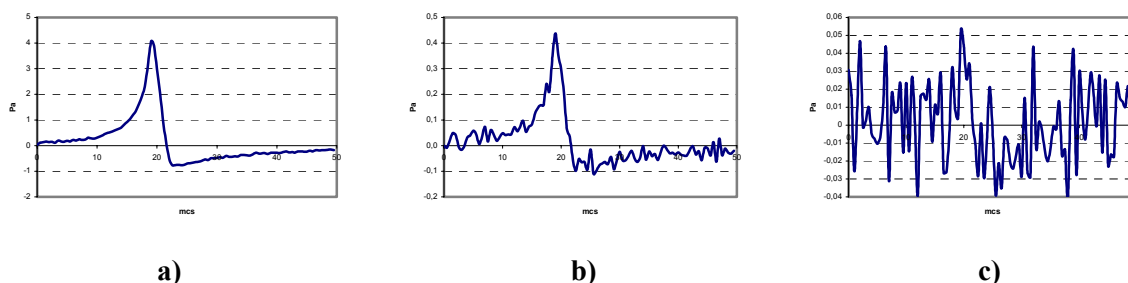


Fig. 2. Shock wave signals from cascades generated by neutrinos with different energies:
 a) $En = 10^{20} \text{ eV}$; б) $En = 10^{19} \text{ eV}$; B) $En = 10^{18} \text{ eV}$

$$\left\{ \begin{array}{l} T_{i1} \cdot C + H = \sqrt{X_i^2 + Y_i^2 + Z_i^2 + H^2} \\ \quad - 2H \cdot (X_i \sin ay - Y_i \cos ay \cdot \sin ax + Z_i \cos ay \cdot \cos ax) \\ \quad - \sqrt{\left[\begin{array}{l} X_i \cdot \cos az \cdot \cos ay \\ + Y_i \cdot (\sin az \cos ax + \cos az \cdot \sin ay \cdot \sin ax) \\ + Z_i \cdot (\sin az \cdot \sin ax - \cos az \cdot \sin ay \cdot \cos ax) \end{array} \right]^2} \end{array} \right. \quad (2)$$

$$i = \overline{2, N}$$

where T_{i1} is the difference between times of wave arrival in the i -th and 1-st hydrophones, N is the number of hydrophones; X_i , Y_i , Z_i are the i -th hydrophone coordinates, and H , ax , ay , az , C are required parameters.

Simulation results on accuracy of telescope operation versus distance to path are shown in figure 3. Simulation is carried out for particles with energies 10^{20} eV, 10^{19} eV, $10^{18,5}$ eV, $10^{18,25}$ eV, and 10^{18} eV at the reference level 60 dB (relatively to 20 mcPa). The algorithm was started up 2000 times to obtain each point of the plot. The obtained results were averaged. As is seen from the plots, the error of determining the path direction for particles with energies higher than 10^{18} eV does not exceed 2.5 degrees for distances up to 200 m, while at distances up to 100 m the error does not exceed one degree.

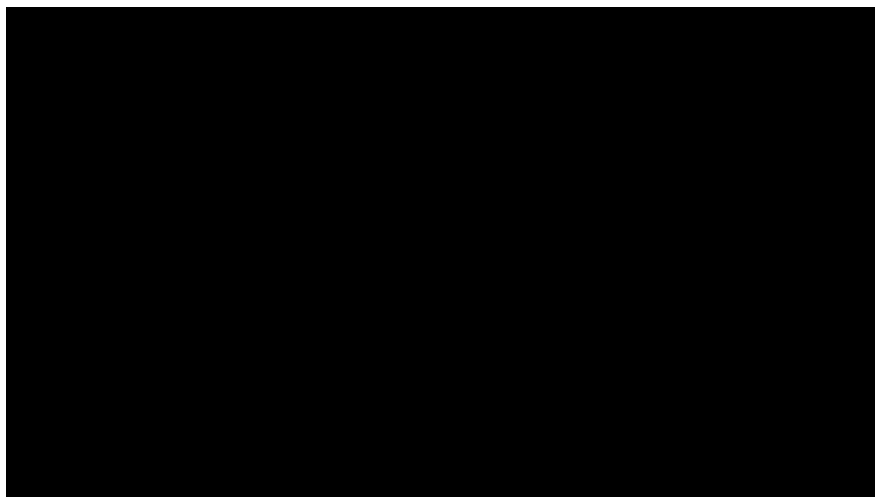


Fig. 3. Angular error of neutrino telescope operation vs distance to path.

Figure 4 deals with simulation results on telescope operation accuracy versus interference level. The neutrino energy is taken to be equal to 10^{19} eV, while the distance to the path is assumed to be 200 m. It is evident that these simulation results can be easily transferred to particles with different energies. Thus, for example, the error value for neutrino with the energy 10^{19} eV at the reference level 80 dB will correspond to that of neutrino with the energy 10^{18} eV at the reference level 60 dB.



Fig. 4. Angular error of neutrino telescope operation vs interference level.

The performed calculations may be employed to choose water area for mounting a receiving system and estimating its efficiency as that of the telescope, i.e., an instrument for construction of the source distribution in the coelosphere.

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