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ATMOSPHERIC NEUTRINOS FOR INVESTIGATION OF THE EARTH INTERIOR

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The neutrino experiment IceCube at South Pole can distinguish between Bulk Silicate Earth model and Hydridic Earth model predictions about the inner Earth density by using neutrino absorption tomography. The result can be obtained during less than ten years of operation. The experiment PINGU at South Pole can check the Hydridic Earth model predictions about the Earth core electron density by using neutrino oscillation tomography. The result will be obtained for the time of operation much shorter than 10 years. The combination of IceCube and PINGU results will give the information about the Earth core chemical element composition.

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INTRODUCTION

There are many articles about rather new subject: neutrino geophysics [1, 2]. Neutrino geophysics usually includes three parts: geoneutrino, neutrino absorption tomography, and neutrino oscillation tomography. We reported about geoneutrino problems at the International Workshop on Prospects of Particle Physics: «Neutrino Physics and Astrophysics» (Resort Hotel «Valday», Valday, Novgorod Region, Russia, 26 January – 2 February, 2014) [7, 8]. We will consider here the possibilities of the neutrino Earth tomography with the use of atmospheric neutrinos crossing the Earth.

The starting point for analyzing the sensitivity of neutrino tomography is the finding of the alternative Earth model which strongly differs from commonly used Bulk Silicate Earth (BSE) model [3]. We found one alternative model [4–6] called the Hydridic Earth (HE) model. The predictions of this model are strongly different from the BSE model predictions. Despite all that, the HE model is still alive up to now.

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1. HYDRIDIC EARTH MODEL

The basic idea of the Hydridic Earth (HE) model is that the planet chemical composition depends on the distance from the Sun. This idea contradicts to the basic idea of BSE model. The basic idea of BSE model is that the Earth chemical composition must be the same as meteorite chemical composition. The meteorites come mostly from the Asteroid Belt. So, the Earth chemical composition must be the same as the Asteroid Belt chemical composition in the framework of BSE model.

The HE model predicts the primordial chemical element composition of the Earth [4–6].

18.3% of the Earth primordial mass is predicted to be hydrogen [6]. The inner Earth would have been and still could be hydrogen-rich. The greater part of primordial hydrogen has escaped to atmosphere and space through the degassing of the mantle. Model suggests that chemical element composition in the Earth core is still the primordial one. The composition is shown in the Table.

Chemical element composition of the Earth core. HE model

Element	Weight %	Mol %
H	18.3	87.4
Na	13.4	2.81
Mg	13.9	2.75
Fe	19.4	1.67
Si	9.03	1.55
Al	8.77	1.57
Ca	8.79	1.06
K	3.4	0.49
Others	5.01	0.7

So, the inner Earth core might consist of hydride compounds which were formed as a result of chemical bounds of hydrogen with other elements: $NaH_n : MgH_n : FeH_n : AlH_n : SiH_n : CaH_n : KH_n$, and others, where average $n = 87.4/(100 - 87.4) = 7$. The inner core is solid but the outer Earth core is liquid. It means that chemical structure of outer core is different from the structure of inner core: average $n < 7$. There is a mixture of hydrides, metals, and free protons in the outer core. The concentration of free protons should be enough to break the crystal lattice of this mixture and to transform this mixture into liquid state.

One of the main objections against HE model is that this model predicts the huge terrestrial heat flux due to high ^{40}K concentration. The heat flux predicted by HE model is about 700 TW [4] contrary to the measured flux equal to 47 TW. In favor of the HE model, one can say that the experimental measurements of the Earth heat flux are sensitive to only one way of heat transfer: the conduction (or diffusion) of heat. There might be other ways of heat transfer. The heat energy could be absorbed on high depths by chemical reactions and then transferred up by the gases. Then this energy is released on small depths or in the ocean by chemical reactions. Other way is the heat transfer caused by free protons appeared in the outer Earth core. By these mechanisms of heat transfer the HE model can explain the increase in ocean temperature observed by ARGO project [9] without contradiction with results of the terrestrial heat flux measurements.

Other way to absorb the heat is the phase transitions which can occur in the outer Earth core.

2. NEUTRINO ABSORPTION TOMOGRAPHY

The possibility of revealing the Earth density distribution using the measurement of neutrinos absorption with energies exceeding 10 TeV when traversing the Earth was investigated in [10]. It was pointed out that the idea of studying the internal structure of the Earth with the kilometer-scale neutrino detectors may be revived using atmospheric neutrinos.

The two Earth models were compared: BSE and Model with the homogeneous matter distribution, with density $\rho_{\rm hom} = 3M_{\rm Earth}/(4\pi R^3_{\rm Earth}) = 5.51$ g/cm^3. Compare with BSE model prediction for the Earth inner core density:

$$\rho^{\rm BSE}_{\rm inner\ core} = 12\text{–}13\ \text{g/cm}^3. \tag{1}$$

The work [10] showed that these models can be distinguished at the level of 5σ by IceCube during 10 years.

What is the Earth core density predicted by HE model?

Here we will follow the idea that the intrinsic Earth composition is unknown. In this case the depth profile of the Earth density has large uncertainty.

The hydrides have very good compressibility because hydrogen has only one electron. The estimations show that hydrides can be compressed up to the density of 24 g/cm^3. Suppose here that the Earth inner core density for HE model is equal to

$$\rho^{\rm HE}_{\rm inner\ core} = 24\ \text{g/cm}^3. \tag{2}$$

Keeping in mind the results of the work [10] we realized that IceCube can distinguish between BSE model and HE model predictions and can have the result during less than 10 years of operation.

3. NEUTRINO OSCILLATION TOMOGRAPHY

The PINGU installation was designed to investigate the neutrino oscillation parameters by using atmospheric neutrinos [11]. The energy and direction of upgoing neutrinos with energies 2–20 GeV are measured. The resonant oscillation of neutrino with energies of 2–6 GeV due to the large magnitude of θ_{13} mixing angle gives us the possibility to investigate the composition of the Earth core. These oscillations are sensitive to electron density:

$$N_e = N_{\mathrm{Av}} \frac{Z}{A} \rho_{\mathrm{core}}. \tag{3}$$

The work [11] uses the idea that the Earth core density is known very well and equals to (1) $\rho^{\mathrm{BSE}}_{\mathrm{inner\ core}} = 12.5$ g/cm^3. But chemical composition can be changed. For iron core the BSE model has

$$\left(\frac{Z}{A}\right)_{\mathrm{BSE}} = 0.466. \tag{4}$$

The value $Z/A = 0.497$ was chosen to investigate the PINGU sensitivity comparing with (4). In this case, the electron density is changed only on 6.6%. The result of [11] is that PINGU could distinguish between these two cases during 10 years of operation for the neutrino mass Normal Hierarchy. The situation will be worse for the neutrino mass Inverted Hierarchy because of roughly twice less statistics. The [11] stressed that knowledge of the neutrino mass hierarchy is critical for understanding the Earth core composition.

Here within the scope of HE model we do not follow the idea that the Earth core density is known very well because the behavior of hydrides under high pressure is unknown.

Let us take for estimation the simplified chemical element composition of the Earth core in the framework of HE model: H (mol 87.4%) + Ca (100% − 87.4% = mol 12.6%). In this case, we will have for the Earth core in HE model:

$$\left(\frac{Z}{A}\right)_{\mathrm{HE}} = \frac{20 \cdot 12.6 + 87.4}{40 \cdot 12.6 + 87.4} = 0.57. \tag{5}$$

Taking the core density for different Earth models from (1) and (2), the Z/A ratios from (4) and (5) and using (3), we obtain

$$\frac{N_e^{\mathrm{HE}}}{N_e^{\mathrm{BSE}}} = 1.2\text{–}2.3. \tag{6}$$

We can see that electron density in HE model is higher than the one in BSE model from 20 to 130% depending on the Earth inner core density. Remember that [11] used the electron density higher only on 6.6%. So, we can conclude that PINGU has a possibility to check the HE model predictions for the operation time much shorter than 10 years obtained in [11].

CONCLUSIONS

1. The IceCube can distinguish between the Bulk Silicate Earth and Hydridic Earth models predictions about the inner Earth density by using neutrino absorption tomography. The result can be obtained during less than 10 years of operation.

2. The PINGU can check the Hydridic Earth model predictions about the Earth core electron density by using neutrino oscillation tomography for the operation time much shorter than 10 years.

3. The combination of IceCube and PINGU results will give the information about the Earth core chemical element composition.

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