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Feasibility Simulation of Neutrino Tomography for Heavenly Body

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1. Introduction

Understanding the Moon has been one of mankind's ultimate dreams. Recently, Korean government revised its roadmap for the Lunar Exploration Project to develop the country's first lunar probe and secure the basic technologies needed for space engineering. Koreans are expected to launch their first lunar orbiter around 2030. The authors have long tried to mount a scientific module with a new concept on the lunar orbiter to probe the inner-structure of the Moon. In this study, the authors try to show that it is possible to do a neutrino tomography of a heavenly body like the Moon. The information of lunar inner structure will be used by scientist, engineers and artists for a number of purposes including learning about the Moon's and Earth's evolution, the lunar mineralogy, and fantastic imagination about the alien who constructed the secret fortress beneath the Moon's crust and so on.

Fig. 1 shows a concept to make a tomography for the Moon by measuring three colored (or flavored) solar neutrinos which attenuate and oscillate through the penetration of the Moon. If we will be able to mount a neutrino detector on a satellite orbiting the Moon, it will be possible to accumulate the neutrino events, which enable the tomography of the Moon.

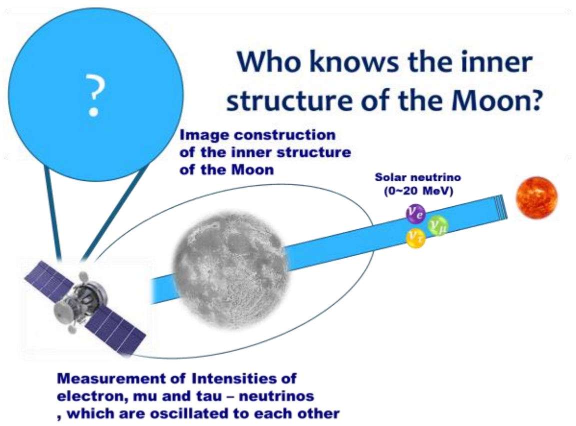

Fig. 1. A concept of the lunar tomography by a solar neutrino measurement.

2. Methods and Results

In this section some of the techniques used to simulate the feasibility of the neutrino tomography for a heavenly body like the Moon are described. The main interaction with the detector and promising detector type are also suggested.

2.1 Response with solar neutrinos

Inverse beta decay (IBD) produces positrons and neutrons with a nuclear reaction that involves an electromagnetic anti-neutron scattering. This has been mainly used to detect electron antineutrinos in many important experiments such as KamLAND, Borexino, SAGE since the first detection of antineutrinos in the Cowan-Reines neutrino experiment. [1] As shown Fig. 2, the typical IBD process can be utilized to reduce the interfering neutron and gamma-rays by utilizing coincidence signals between a capture of secondary neutron and annihilation of positron. Neutrino-nuclear coherent scattering (NNCS) [2] has about 100 times bigger cross-section than IBD. A target nucleus recoils by the neutrino. The resultant recoil energy will be dissipated in the detector media.

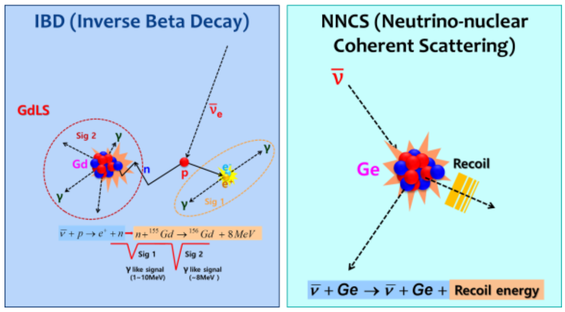

Fig. 2. Comparison of IBD and NNCS for neutrino or antineutrino detection.

2.2 Point Contact P-Type Ge Detector

The NNCS generates a signal with very low energy less than several hundred eV. In this study, we modeled the NNCS using a point contact P-type germanium detector for the solar neutrino detection as shown in Fig. 3.

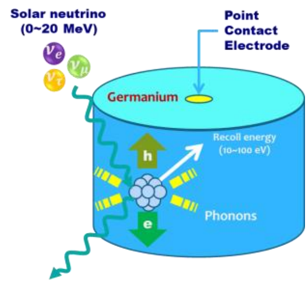

Fig. 3. Detection of solar neutrinos through the NNCS using a point contact P-type Ge detector.

2.3 MSW effect and GloBES simulator

The coherent forward scattering of neutrinos in matter is similar to an electromagnetic process leading to the refraction of light in the medium. The Mikheyev–Smirnov–Wolfenstein effect (MSW effect) is a particle physics process which can explain neutrino oscillations in matter.[3] The propagation through the dense matter changes the energy levels of the propagation eigenstate of neutrinos due to the successive scattering with electrons in matter (weak neutron interaction). Neutrinos in matter have a different effective mass than neutrinos in vacuum. Probability of neutrino oscillation from α neutrino to β neutrino depends upon an equation (1):

$$P(\nu_\alpha \rightarrow \nu_\beta) = sin^2 2\theta_M sin^2\left(\frac{\Delta m_M^2 x}{4E}\right) \quad (1)$$

where θ is a mixing angle between two neutrinos, m the neutrino mass, E the neutrino energy and x the penetration length, respectively.

GLoBES is an abbreviation of a General Long Baseline Experiment Simulator [4], which is a sophisticated software package for the simulation of long baseline neutrino oscillation experiments. It offers the oscillation of the solar neutrinos according to the depth of the penetration through the complex terrestrial structure based on the MSW theory.

2.4 Simulation of Neutrino Tomography

The inner structure of the Moon was modelled by using a lunar seismographical data obtained by the Apollo missions that implied the Moon has a multiple layers like the Earth does. Fig. 4 shows the simulation program coded in Matlab. The recoil energy of the target nucleus by the energetic solar neutrino is recorded in the germanium detector. The energy spectrum shows the three humps due to the electron-, mu- and tau- neutrinos. Accumulative intensities for three neutrinos shown on the left side of the program were recorded by a neutrino detector on the lunar orbiter and they revealed the details of the inner structure like crust, mantle and outer and inner core of the Moon. By using the profiles for three colored neutrinos, it is expected that we will be able to make a colorful image for the Moon. In this simulation, the many disadvantageous features of the real detection and engineering conditions in the space were not fully considered. Especially the crystal damages and high backgrounds induced by the energetic space radiations should be considered to understand the simulation of this study. Details of the simulation and the further works will be shown in the presentation.

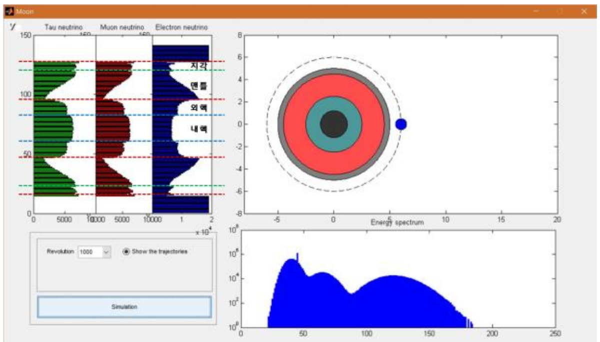

Fig. 4. Simulation program for neutrino tomography of the Moon. (a) accumulative intensities for three colored solar neutrinos, (b) simulation of the detection of neutrinos by lunar orbiter, and (c) the recoil energies of Ge atom in the detector crystal due to the electron-, mu- and tau – neutrinos.

3. Conclusions

In this study, we tried the simulation of neutrino tomography for a heavenly body like our Moon. Solar neutrinos penetrate the heavenly body. The three colored neutrinos change to their colors by varying their intensities. Simulation was based on the oscillation data from the GLoBES code and the MSW effect and shows the possibility of the neutrino tomography for the inner structure of the heavenly bodies. This will be also applicable to the tomography of the Earth and various heavenly bodies like Mars and others.

Acknowledgements

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