The lunar neutrinos

Russian scientists have calculated the spectrum of these amazing elementary particles

Particle physics is at the cutting edge of modern science. One of the most poorly understood and mysterious particles is the neutrino. Neutrinos interact extremely weakly with matter: every second, millions of neutrinos pass through our body, and we do not notice it. Moreover, neutrinos, except for the most energetic ones, pass freely through the Earth. All this makes it very difficult to register neutrinos. But it is precisely the weakness of the neutrino interactions that makes this particle an ideal all-pervading " ray " that allows us to obtain significant information about their sources. Therefore, the measurement of neutrino fluxes is an extremely important and interesting task of modern particle physics and astrophysics. Reliable neutrino detection could have an important practical application: the neutrino signal propagates without interference, unlike conventional electromagnetic waves.

There are both natural and man-made sources of neutrinos. Solar neutrinos, which occur as a result of thermonuclear reactions occurring in the Sun, are widely known. The study of the mysteries associated with solar neutrinos eventually led to the discovery of neutrino oscillations (the mutual transition of three types of this particle into each other on the fly).

Another type of neutrino is geoneutrino; they arise as a result of decays of radionuclides in the Earth. Their study will make it possible to judge the nature of the Earth's internal heat, its structure and even its origin. One more type of neutrino, which is very actively studied at the present time, is atmospheric neutrinos. Cosmic rays, constantly bombarding the atmosphere from space, lead to the formation of a large number of unstable particles, many of which decay and form neutrinos. At present, atmospheric neutrinos are an important tool for studying the properties of neutrinos and, in particular, neutrino oscillations. And a few years ago, in the IceCube experiment (USA) in Antarctica, the so-called astrophysical neutrinos of very high energies were discovered - it is assumed that their sources may be distant astronomical objects, for example, the nuclei of active galaxies.

In addition, huge fluxes of neutrinos should be formed during supernova explosions occurring in the visible part of the Universe. Modern cosmology predicts the existence of relict neutrinos, similar in origin to the relict radiation of photons. It is believed that these neutrinos were formed at the earliest stages of the evolution of the Universe.

The registration of neutrinos and the study of their properties, as well as the characteristics of their sources are engaged in many international scientific centers, including Russian. For example, the solar neutrino flux was measured with a gallium-germanium neutrino telescope as part of the Russian-American SAGE experiment. This neutrino detector, created by scientists from the Baksan Neutrino Observatory, a branch of the Institute for Nuclear Research of the Russian Academy of Sciences (BNO INR RAS), is located in the North Caucasus in the Baksan Gorge in the thickness of the mountain (to minimize the impact of other radiation). The construction of the observatory in the Baksan Gorge began in 1967 and was completed only in the mid-1980s. In 2001, for achievements in the field of research of the neutrino flux from the Sun, the staff of INR RAS were awarded the International Prize named after famous physicist Bruno Pontecorvo.

At present, scientists from the BNO INR RAS are working on a project for a large underground scintillation neutrino telescope, which will be able to carry out experiments on a detailed study of geoneutrinos recorded relatively recently in the KamLAND (Japan) and Borexino (Italy) experiments.

To study astrophysical neutrinos, over the past few years, researchers from INR RAS, the Joint Institute for Nuclear Research, Irkutsk State University, and other organizations have been working annually on Lake Baikal to deploy the largest neutrino telescope in the Northern Hemisphere. This deep-sea Cherenkov detector is a garland of optical modules on cables immersed in water to a depth of about 1 km. The detector is designed to study the natural flux of high-energy neutrinos. Having passed through the Earth's thickness, neutrinos can with some probability interact in the water of Lake Baikal and generate a cascade of charged particles. Cherenkov light from charged particles propagates in the water of the lake and is recorded by the optical modules of the installation.

Much less studied are neutrinos from supernova explosions. They were recorded only once, during the 1987A supernova explosion in the Large Magellanic Cloud. Scientists expect to register a diffuse neutrino background from supernova explosions at the Hyper-Kamiokande facility currently under construction in Japan. A number of neutrino detectors around the world, including in our country, are operating in the waiting mode for a supernova explosion. An even more difficult task is the registration of relic neutrinos, despite the fact that, according to modern concepts, the density of ubiquitous relic neutrinos is currently several hundred per cubic centimeter.

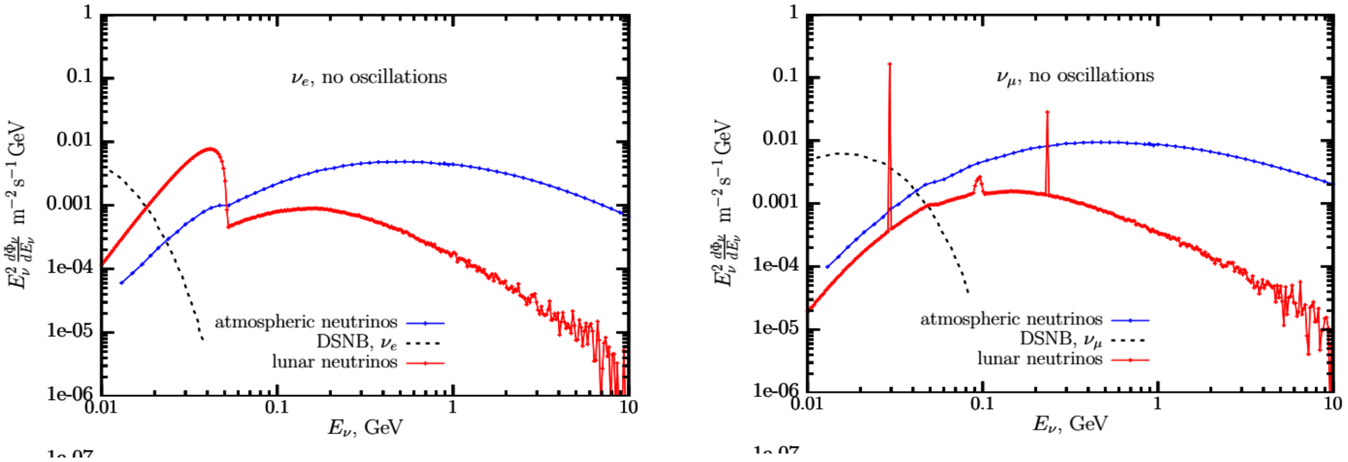
For scientific research, scientists also use technogenic and artificial neutrinos. Thus, huge fluxes of neutrinos are formed in the nuclear reactors of nuclear power plants. Neutrino detectors are located near some nuclear power plants in France, China, Korea, Japan and Russia. The possibility of detecting neutrinos in order to control processes in nuclear reactors has been actively discussed for a long time. In addition, particle accelerators are also powerful directional sources of neutrinos. A number of laboratories use artificial radioactive sources of neutrinos for research.

In light of all these studies, physicists from the Institute for Nuclear Research, Russian Academy of Sciences, turned to the topic of neutrinos coming from the moon. The fact is that a significant part of the neutrinos registered on Earth is formed as a result of the bombardment of the atmosphere by cosmic rays. As a result, strongly interacting particles such as pions and kaons are born. When decaying, they give neutrinos in a wide range of energies. Scientists of INR RAS Sergey Demidov and Dmitry Gorbunov, as a result of numerical simulations, studied the spectrum of neutrinos arising from the interaction of cosmic rays with the Moon. The work (https://arxiv.org/abs/2012.12870) was sent to the authoritative journal Physics Review D.

It is important to note that the main factor that distinguishes the formation of lunar neutrinos from atmospheric ones is the absence of an atmosphere on the Moon. In the Earth's atmosphere, cosmic rays create so-called air showers of particles that decay on the fly and generate a high-energy spectrum of neutrinos. But when interacting with the Moon, a significant proportion of the resulting pions and kaons have time to slow down in its soil before decaying. As a result, the fraction of low-energy neutrinos in the direction to the Moon turns out to be larger, and the fraction of high-energy neutrinos is smaller, and significantly, in comparison with atmospheric neutrinos. This was pointed out in the early studies of prominent Russian physicists Grigory Zatsepin and Lyudmila Volkova, who worked at INR RAS in the 1960s. The flux of high-energy lunar neutrinos was calculated in the work of R.S. Miller and T. Coen. It was shown here that on the Moon at energies above 10 GeV, it is suppressed by about 10,000 times in comparison with the spectrum of atmospheric neutrinos.

The work of Sergei Demidov and Dmitry Gorbunov modeled the low-energy (less than 1 GeV) part of the lunar neutrino spectrum. Physicists have studied the spectrum of these neutrinos and calculated their flux. As a result, it turned out that the spectrum of the produced neutrinos is shifted towards lower energies in comparison with the spectrum of atmospheric neutrinos and, in addition, there are narrow lines directly in the spectrum of low-energy neutrinos associated with neutrinos formed in the decays of stopped pions and kaons. The found features of the spectrum of lunar neutrinos will make it possible to distinguish them from atmospheric neutrinos and also from the diffuse background of neutrinos from supernovae. Interestingly, the spectrum of lunar neutrinos depends on the density of the lunar soil near the surface. Therefore, in the future, the study of lunar neutrinos can help in the study of the properties of the lunar soil. However, it should be noted that, due to the smallness of the total flux of lunar neutrinos, their registration is in itself an extremely difficult task. Thus, theorists came a little closer to clarifying questions about the properties of neutrinos.

Graphs 1 and 2. Spectra of lunar neutrinos (red solid line) for electron (right) and muon (left) neutrinos in comparison with the spectra of atmospheric neutrinos (blue solid line) and diffuse neutrinos from supernovae towards the Moon. The data does not take into account neutrino oscillations (that is, interconversions of different types of neutrinos, which is typical for a given elementary particle).



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