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1. Oscillations of reactor antineutrinos

The Daya Bay collaboration, in which Russian researchers from JINR (Dubna) participate, has presented the most precise new data on oscillations of electron antineutrinos born in atomic reactors [1]. A decrease in the number of antineutrinos as they move away from the reactor provides information about the mixing angle θ_{13}, important for solving the mass hierarchy problem and searching for *CP* invariance violation in neutrino oscillations. In the Daya Bay experiment, conducted in China, an inverse beta decay $\bar{\nu}_e + p \rightarrow e^+ n$ is observed through recording a positron and a neutron captured by gadolinium atoms in eight detectors at a distance of 500 and 1650 m from the reactors. The gadolinium mass makes up 0.1% in a liquid scintillator scanned by photomultipliers. The data for 5.55×10^6 events gave $\sin^2(2\theta_{13}) = 0.0851 \pm 0.0024$. For the direct and inverse mass ordering, this gives $\Delta m^2_{32} = (2.466 \pm 0.060) \times 10^{-3}$ eV^2 and $\Delta m^2_{32} = -(2.571 \pm 0.060) \times 10^{-3}$ eV^2, respectively. The neutrino oscillation hypothesis was first suggested by B Pontecorvo in 1957 [2] (see also [3–5]).

2. Data from the Borexino experiment

Although the neutrino-recording Borexino experiment in the underground Gran Sasso Laboratory (Italy) ended in October of 2021, the processing of its data is presenting interesting new results. The Borexino collaboration has sought coincidences between neutrino events and bursts of gravitational waves observed by the LIGO/Virgo interferometers [6]. Neutrinos might be born together with gravitational waves upon the merging of black holes and neutron stars. Although no coincidences have been found, their absence gave new limits on neutrino emission mechanisms. The Borexino phase III analysis, carried out recently by the Borexino collaboration itself, allowed refinement of the magnitude of the flux and the spectrum of solar neutrinos from the CNO cycle of nuclear reactions in the solar core [7]. The hypothesis on the absence of CNO neutrino recording is ruled out with a significance of 7σ, and the above-mentioned analysis of neutrino spectra gives preference to solar models with high metallicity. Interestingly, an alternative processing of Borexino data, performed by researchers L B Bezrukov, I S Karpikov, and V V Sinev from INR RAS and MEPhI, including neutrinos from the decay of ^{40}K nuclei in the Earth, shows a better agreement with the measured neutrino spectra than the model without ^{40}K [8, 9]. The low-metallicity Sun model becomes preferential. The presence in the Earth of a large amount of ^{40}K must also result in a heightened release of radiogenic heat from Earth's interior.

3. Galactic neutrinos

Our Galaxy, especially the region of its stellar disc, is visible in the entire electromagnetic range from radio waves to gamma rays. The IceCube collaboration, which registers neutrinos with a detector in Antarctica, has presented the first neutrino image of the Galaxy [10]. Gamma photons are produced in the interaction of cosmic rays with interstellar gas in the Galaxy, and F W Stecker predicted in 1979 that neutrinos must be born in the same processes. A flux of these galactic neutrinos was later calculated in detail by V S Berezinskii jointly with T Gaisser, F Halzen, and T Stanev. When examining the southern part of the sky, where the Galactic Center lies, IceCube identified cascade events associated with the neutrino interaction within the detector itself. Although the accuracy of determining the direction from cascade events is lower than from track events, it is easier to filter out the strong background of atmospheric muons in cascade events. Thanks to the use of modern methods of computer data processing, known as 'machine learning,' galactic neutrinos were singled out at a confidence level of 4.5σ. The signal has the form of diffuse inhomogeneous emission concentrated near the Galactic disc. The existence of a galactic-neutrino component in the IceCube data was earlier revealed by Yu Yu Kovalev, A V Plavin, and S V Troitsky on the basis of the analysis of track events [11]. For the role of neutrinos in astrophysics, see [12].

4. Registration of gravitational waves in the NANOGrav project

In 1978, M V Sazhin (Sternberg State Astronomical Institute of Lomonosov Moscow State University, Moscow) proposed a way of recording gravitational waves from massive binaries on the basis of pulsar observations [13]. Gravitational waves passing between pulsars and an observer on Earth must perturb space-time and thus shift signal phases. The NANOGrav collaboration has already had evidence of the existence of an nHz-scale gravitational-wave background, but the statistical significance of the result was low. In June of 2023, NANOGrav presented data for 15 years [14] with a significance of $(3.5-4)\sigma$. Sixty-seven pulsars were observed and correlated phase shifts of their pulses corresponding to gravitational-wave passage were recorded with radio telescopes. The quadrupole character of correlations has made it

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possible to rule out other reasons for phase shifts, including the motion of the Solar System through the inhomogeneous medium affecting radio wave propagation. The NANOGrav observations do not identify individual sources but only register the general stochastic background of gravitational waves. Its spectrum is close to the power law spectrum with exponent $\gamma = 3.2 \pm 0.6$. A similar background with $\gamma \simeq 13/3$ and with the same amplitude could make pairs of supermassive black holes with masses of $(10^8 - 10^{10}) M_\odot$ located in the centers of galaxies and approach following their merging. The extragalactic neutrinos recorded by IceCube [15] were probably born near supermassive black holes. It should not, however, be ruled out that the gravitational-wave background has other, more exotic sources, for example, phase transitions or collapses of domain walls in the early Universe. The registration of a gravitational nHz-range background was simultaneously reported by three other collaborations. Higher-frequency gravitational waves from the merging of black hole of stellar masses and neutron stars have already been observed since 2016 by the LIGO/Virgo/KAGRA interferometers. Earlier, the emission of gravitational waves was indirectly revealed by a change in the binary pulsar orbit.

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