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The Effect of Reactor Neutrinos on Beta-Decay and an Attempt to Experimentally Estimate the Dark Matter Mass of Our Galaxy

B.V. Vasiliev

Independent Researcher, Russia

***Corresponding author**: B.V. Vasiliev , Independent Researcher, Russia; Email: bv.vasiliev@yandex.com

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Abstract

The measuring of the reactor neutrinos effect on the beta-decay rate allows us to obtain the efficiency of neutrino registration in this process. In assumption that the phenomenon of beta-decay is caused by the impact of cosmic neutrinos (in the absence of reactor action), the measured registration efficiency leads to determination of the value of a general cosmic neutrino flux in terrestrial conditions. Extending this terrestrial measuring data to the entire Galaxy makes it possible to estimate the mass of its dark matter. The obtained result is in satisfactory agreement with other estimates of the mass of the Galaxy.

Keywords:* *Neutrino; Beta-decay; Dark matter; Galaxy

Introduction

Dark substance and dark energy are hypothetical types of matter that are not directly observable because they do not participate in electromagnetic interaction. Their introduction to the model of the Universe makes it possible to explain the accelerated expansion observed by astronomers, the features of the movement of rotating galaxies, the magnitude of gravitational lensing, etc. Current estimations suggest that the mass of dark matter is about five times that of baryonic matter of the Universe [1-2]. There are several assumptions about hypothetical candidates for the role of dark matter carriers: vimps, maximons, axions, cosmions, primordial black holes, etc. Compared to this set of probable but unproved hypotheses, neutrinos have a clear advantage-they exist and have real physical properties, correlating with the properties of dark matter particles.

Measuring the Neutrino Flux

Reactions with neutrinos

The mechanism that generates neutrinos in nature is based on reactions in which particles with large magnetic moments (electrons, positrons, or mu-mesons) are born (or disappear) [3]. Therefore, the energy of neutrinos in most cases corresponds to the energy of beta-decay of atomic nuclei. High-high energy and ultra-high energy neutrinos can be generated in reactions in which the decaying particle is pre-accelerated to the corresponding energy. On the other hand, various researchers have repeatedly suggested that the beta-decay of radioactive nuclei may be caused by their interaction with the neutrino stream [3-5]. To prove this assumption experimentally, we need to investigate the correlation between the rate of beta-decay and the magnitude of the time-varying neutrino flux incident on the beta-source. The source of this time-varying neutrino flux may be a nuclear reactor. The pulse reactor has great advantages in setting up such an experiment.

Reactor neutrinos

The IBR-2 reactor (Dubna, Russia) was used as a source for the experiment to search for the effect of reactor neutrinos on beta-decay [6-7]. It has an average power of 1.6 MW and operates in pulse mode. The interval between its flashes is 200 ms. The duration of the flash itself is approximately 0.3 ms. It is known [8] that approximately 200 MeV of energy is released in one act of fission of reactor fuel. Therefore, on average, the IBR-2 reactor produces fuel division acts per second.

$$N_{div} = 5 \times 10^{16} \qquad (1)$$

It is important that the power of this reactor during the flash is about an order of magnitude higher than the power of a stationary reactor with a large flux, which was used in a similar experiment [9]. A pulse reactor makes it possible to accumulate information synchronously with the flash. This is an important advantage because over a long time of measurement, it is possible to sum up the data obtained in the on-off mode of the reactor. This accumulation over a long measurement period is equivalent to multiplying the power of the reactor.

The reactor neutrino generation

At the burning of nuclear fuel, beta-active nuclei are form as fission fragments. Their decay leads to the neutrinos generation.

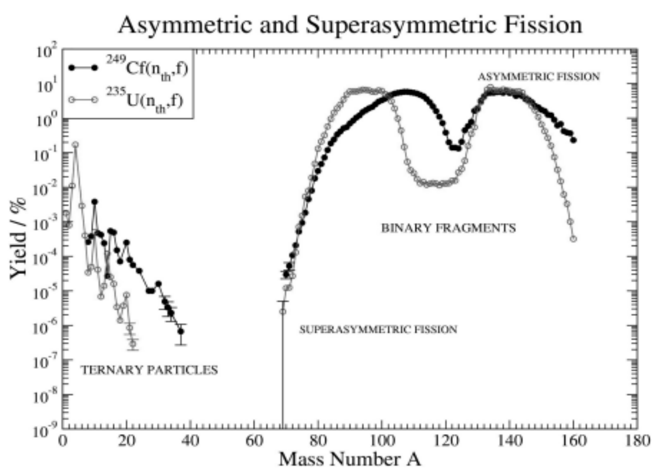

FIG. 1: **Probability of formation of fission fragments of nuclear fuel depending on their mass number [11].**

However, almost all fragments of fission have periods of their half-lives longer than the time interval separating IBR-2 flashes. Therefore, they can be considered as long-lived nuclei. Their decays are not ”tied” to a specific flash of the reactor and can only give a slight increase in the background at the registration. There are very few short-lived isotopes with a half-life of $T_{1/2} < 200$ ms in nature. That isotopes, ^{12}B and ^{13}B, have a half-life of about 20 ms [10]. The probability of forming of this nucleus at a burning of nuclear fuel is very small.

In accordance with Sargent's rule, neutrinos formed during the decay of both isotopes 12B and 13B have high boundary energies [10]:

$$E_\upsilon \approx 13 MeV \qquad (2)$$

The measurement results

Measurements of the effect of the reactor neutrino flux on the beta-decay rate were performed on the sources ^{63}N i [6] and ^{90}Sr/^{90}Y [7]. The results of these measurements on the ^{63}N i isotope are shown in **FIG.2**. This figure shows the peak activity of the reactor generated approximately 3 ms after the start of data logging.

The beta-electron counting before the reactor flash occurs at a some low level, determined by the established amplitude discrimination. The reactor pulse generates a spike in the rate of decay in the source. This follows by the decline of the account, which is linear on a logarithmic scale (i.e. exponential on a linear scale). The exponent corresponds to a half life of approximately 20 ms, which correlates with the reference data for the isotope ^{12}B and ^{13}B [10].

From the results of this experiment, it is possible to calculate the effectiveness of the impact of neutrinos on the beta-source. The total number of neutrinos born in the decays of a short-lived isotope (^{12}B and ^{13}B) and passed through the beta-source over the entire measurement time can be estimated by the formula:

$$\Phi_\Sigma = N_{div} \times \xi \times \frac{S}{4\pi R^2} \qquad (3)$$

Where,

$N_{div} = 5\times10^{16}$ is the number of nuclear fuel fission acts per second (1),

$\xi \approx 10^{-4}$ is probability of the isotope ^{12}B and ^{13}B formation in one act of fuel fission [11],

R ≈ 2000 cm is the distance between the beta-source and the reactor core.

Substituting the corresponding values in the formula Eq.(2), we get the total number of reactor neutrinos of interest

$$\Phi_\Sigma \approx 2\times10^5 \qquad (4)$$

As shown in **FIG.2**, these neutrinos caused in the beta-source approximately additional decays.

$$N_\Sigma \approx 800 \qquad (5)$$

That is, the reactor flow caused additional rate of decays

$$\frac{N_\Sigma}{T} \approx \frac{800}{86400} \approx 10^{-2}\,\frac{beta}{\sec} \qquad (6)$$

This process can be presented as reaction with cross-section σ

$$N(sum) \approx 5\times10^5\,\frac{beta}{\sec} \qquad (7)$$

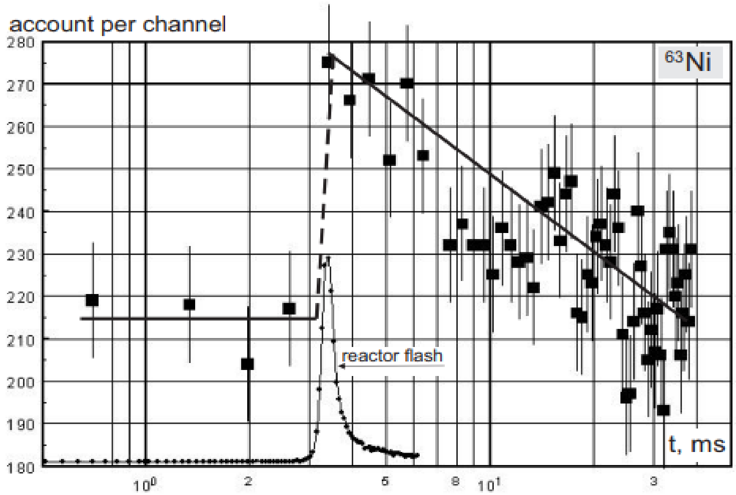

FIG. 2. **Result of accumulation of registered beta-electrons emitted by the source ^{63}Ni [6].**

The measurement time is 24 hours. The level of amplitude discrimination close to the boundary energy was chosen experimentally. On the x-axis, the time is shown in milliseconds, on logarithmic scale.

Thus, the efficiency of neutrino registration in this installation was

$$Y = \frac{N\Sigma}{T} \times \frac{1}{N(sum)} \approx 1.85 \times 10^{-8} \qquad (8)$$

Estimation of the value of the cosmic neutrino flux

We will assume that all decays occurring in the beta source (when the reactor is switched off) are the result of the influence of a stream of cosmic neutrinos on its atoms. This flow can be estimated using the efficiency coefficient of counting reactor neutrinos Eq.(7). Since the total counting rate is known Eq.(6), these decays can be considered a consequence of the effect of the cosmic neutrino flux, which should have the value

$$\Phi_{cosm} = \frac{N(sum)}{Y} \approx 2.7 \times 10^{13} \frac{\nu}{cm^2 \times s} \qquad (9)$$

Taking into account the fact that the velocity of particles in the neutrino stream is equal to the speed of light, we get that the density of neutrinos in terrestrial conditions

$$n_{cosm} = \frac{\Phi_{cosm}}{c} = 10^3 \frac{neutrino}{cm^3} \qquad (10)$$

Assuming that the energy of neutrinos acting on beta-decay is approximately equal to energy of reactor neutrinos (Eq.2.)

$$< E\nu > \approx 13 MeV \qquad (11)$$

It is believed that this is the average energy of neutrinos generated by the Sun [12]. Based on this assumption, we can estimate the mass density in a stream of neutrinos moving at the speed of light (at zero rest mass)

$$\gamma_\nu = n_{cosm} \frac{< E\nu >}{c^2} \approx 8\times10^{-24}\ g/cm^3 \qquad (12)$$

Basic Parameters of the Milky Way Galaxy

The disk of our Galaxy extends for 50 ÷ 90 thousands of light years in all directions from its center. According to the latest estimations [13] diameter of the Galaxy is close to

$$D_{MW} \approx 2\times10^{23} cm \qquad (13)$$

In the assumption, that the thickness of the Galaxy disk is equal

$$H_{MW} \approx 1000\ light-year \approx 9.5\times10^{20} cm \qquad (14)$$

In this case the volume of our Galaxy

$$V_{MW} \approx 2.4\times10^{67} cm^3 \qquad (15)$$

Stars ”living” in this volume have the total mass

$$M_{star} \approx 7\times10^{44} g \qquad (16)$$

The above estimation of the neutrino mass density Equation (11) gives the mass of the entire Galaxy equal to

$$M_{neutrino} = \gamma_\nu \times V_{MW} \approx 8\times10^{44} g \qquad (17)$$

Conclusions

The resulting assessment provides an interesting perspective. However, the question arises on the reliability of the results. It is necessary to analyze the assumptions that were made for the estimation.

1. Measuring the reaction of a beta-source on a stream of reactor neutrinos makes it possible to determine the efficiency of neutrino registration. Knowing it, one can find the local value of the density of cosmic neutrinos. The estimation of the Galaxy mass is based on the assumption that the neutrino density in all regions of the Galaxy is constant and equal to the measured local density. This assumption, strictly speaking, is based on nothing but considerations of simplicity.

2. Astronomers and astrophysicists specializing in the subject give different values of the linear dimensions of our Galaxy, which differ from each other by two times or more.

3. Calibration of the cosmic neutrino flux depends on the accuracy of the determination of the neutrino registration efficiency. This efficiency depends linearly on the probability of the formation of an isotope ^{12}B in a single act of nuclear fuel fission.

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