Study of the sun's neutrino brightness curve with the help of a chlorine-argon neutrino detector

V. N. Gavrin, Yu. S. Kopysov, and N. T. Makeev
Institute of Nuclear Sciences, Academy of Sciences of the USSR

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It is shown that the rate of formation of ^{37}Ar in the Brookhaven solar-neutrino detector oscillates with periods 20 ± 1, 25.5 ± 1.5 months, and ~ 11 years and with a modulation depth $\gtrsim 0.3$ with a confidence level not lower than 99.5%. These oscillations are interpreted as resulting from the modulation of the neutrino flux by gravitational oscillations at the center of the sun. Further experiments for studying the sun's neutrino brightness curve with the help of the chlorine-argon neutrino detector are discussed.

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In Refs. 1-4, arguments were presented in support of the fact that the Brookhaven measurements of the rate of formation of ^{37}Ar in the chlorine-argon neutrino detector should be viewed as an indication of the possibility of pulsations in the solar-neutrino flux with periods ~26 months and ~11 years and that these pulsations are correlated with solar activity and cosmic rays. A critique of these arguments was given in Ref. 5. In what follows, we shall discuss the statistical validity of the conclusions concerning the pulsation of the neutrino flux.

1. 11-year variations. For measurements during 1966-1970,[6] it is easy to separate the period from August 1974 to February 1979 (cycle Nos. 36-58), when the rates of formation of ^{37}Ar, $\bar{r}_i$, were maximum. The average rate of formation of ^{37}Ar according to these $k = 23$ cycles is $\bar{r}_{max} = 0.563$. According to the remaining cycles, $\bar{r}_{min} = 0.289$. Hence, the depth of modulation $m = (\bar{r}_{max} - \bar{r}_{min})/(\bar{r}_{max} + \bar{r}_{min})$ with a period ~11 years is 0.322. Estimating the statistical validity of the conclusion concerning the 11-year modulation with the help of the Student criterion

$$t = \frac{\bar{r}_{max} - \bar{r}_{min}}{\sigma_t}, \qquad (1)$$

where

$$\sigma_t = \sigma\sqrt{\frac{n}{k(n-k)}}, \qquad \sigma = \sqrt{\{\sum_i r_i^2 - k\bar{r}^2_{max} - (n-k)\bar{r}^2_{min}\}/(n-2)},$$

while n is the whole number of measurement cycles, we find $t = 3.25$; i.e., the confidence limit for $m = 0.322$ is not less than 99.7%.

2. Approximately 2-year variations. In order to reveal variations with a period ~2 years, we used the epoch superposition method. The total time of the measurements was separated into intervals with periods (P) from 0.3 to 5 years and a superposition was per-

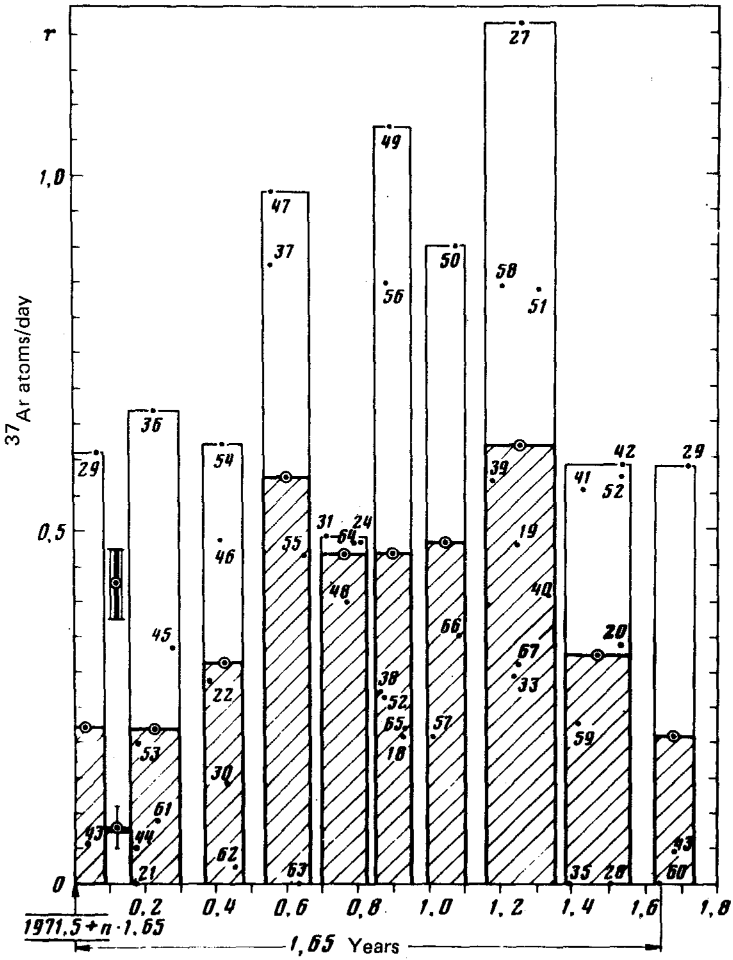

FIG. 1. Component of the sun's neutrino brightness curve with period P_1 = 1.65 years. The numbers near the points indicate the number of the corresponding measurement cycles; the vertical lines delineate the cycles according to which the average counting rate of ^{37}Ar atoms is found. This rate is indicated by points enclosed in circles.

formed; a typical example for P = 1.65 years is shown in Fig. 1. For each superposition, regions with minimum and maximum counting rates for ^{37}Ar were separated and the parameter t was calculated using Eq. (1).

The dependence on P, shown in Fig. 2, reveals two high peaks with maxima at 1.65 and 2.12 years, where $t_{max} \gtrsim 3$. The maximum values of the t criterion and widths of peaks at the level (t_{max} - 1) show that, for confidence intervals not less than 99.5%, the rate of formation of ^{37}Ar in a chlorine detector oscillates with periods $P_1 = 20 \pm 1$ months and $P_2 = 22.5 \pm 1.5$ months and with a modulation depth of $m \gtrsim 0.3$.[1)]

These two lines could be viewed as resulting from the modulation of a periodic process with $P_0 \simeq 22$ months by another periodic process with period $T = 2P_1P_2(P_2 - P_1)$. Taking into account the uncertainty in P_1 and P_2, we find that T lies in the interval 10 yrs $\lesssim T \lesssim$ 30 yrs; i.e., the period 11.136 years, characteristic for the sun,[7] falls exactly into this interval. However, we were not able to separate the "carrier" frequency $\omega_0 = 2\pi/P_0$. On the other hand, there is as yet no justification to take one of the frequencies

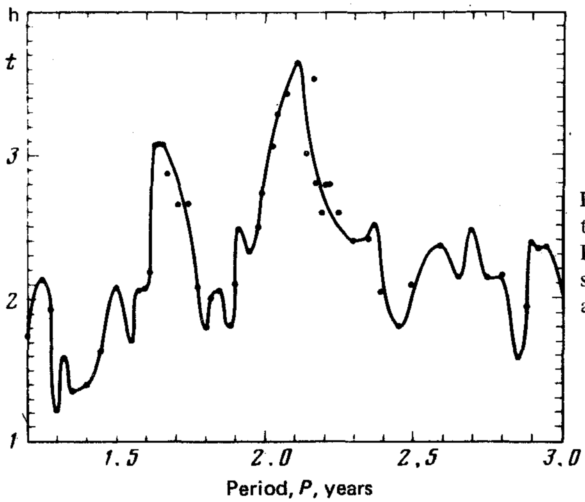

FIG. 2. The Student criterion t as a function of the period P, with which the Brookhaven data were separated and superposed. Each point corresponds to a separate superposition.

$\omega_1 = 2\pi/P_1$ or $\omega_2 = 2\pi/P_2$ as the "carrier" frequency, since it is difficult to view the peaks near 1.25 and 2.7 years as statistically valid. In all probability, the 11-year modulation of the counting rate of ^{37}Ar should be viewed as the result of beating between two periodic processes with periods P_1 and P_2.

3. Interpretation and further experiments. If the variation in the rate of formation of ^{37}Ar is attributed to pulsations in the neutrino flux, then the neutrino brightness curve of the sun, with confidence limits not lower than 99.5%, represents a superposition of two components with periods P_1 and P_2. Within the scope of the seismonuclear mechanism for modulation of the solar neutrino flux, developed in Ref. 8, the presence of two components can be explained by the excitation of two neighboring dipole g modes of the solar core, the matter in which is nearly in adiabatic equilibrium. An important feature of this mechanism is the appearance of a seismic wave, leading by $\pi/2$ the gravitational oscillations of the core. After reaching the surface of the sun, the seismic wave could modulate the solar activity and, because of the phase shift by $\pi/2$, it could cause a negative correlation between the neutrino flux and the solar-activity indices, discovered in Ref. 2. In this connection, further confirmations of pulsations in the neutrino flux and refinement of the characteristic periods would be extremely important both for neutrino spectroscopy of the solar core and for the entire problem of solar-terrestrial coupling.

The statistical validity of the conclusion of pulsations in the neutrino flux could be viewed as adequate if it was possible to obtain $t \approx 6$. Since $t \sim n$, it is necessary to take the number of cycles of measurements of the rate of formation of ^{37}Ar up to $\sim$100; i.e., approximately another ten years of operation of the Brookhaven detector are required. In this respect, the Baksan chlorine-argon detector, whose proposed mass is approximately five times greater than that of the Brookhaven detector, would have much greater possibilities. The same number of ^{37}Ar atoms as in the Brookhaven detector will be formed in the Baksan detector within ten days; i.e., the required 100 exposure cycles could be completed within three years.

On the other hand, establishing a correlation between the counting rates of both detectors would finally solve the problem of pulsations of the solar-neutrino flux.

An important problem is the study of the profile of the sun's neutrino brightness curve, since it carries information on the motion of the solar wind. The double peak structure, noted for both components of the curves, cannot be viewed as statistically valid. In order to clarify its details, further statistical information must be collected and the exposure time must be decreased.

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[1]Analogous periods were discovered by Yu. R. Rivin (IZMIRAN) using harmonic analysis.

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