ON THE SPECTRUM OF NEUTRINOS FROM SN1987A*

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Abstract

To obtain a better fit of KII and IMB data on SN1987A neutrino burst a two-temperature model has been suggested. The temperature of $\tilde{\nu}_\mu, \tilde{\nu}_\tau$ neutrinos is assumed to be twice bigger than for $\tilde{\nu}_e$ neutrinos. Then the ν – oscillations on the way from LMC can provide the suitable mixed $\tilde{\nu}_e$ spectrum even for extremely small oscillation parameter $\Delta m^2 > 10^{-19}\ eV^2$.

Since the Supernova explosion in the Large Magellanic Cloud (SN1987A) dozens of papers associated with this rare phenomenon have been published. The data observed in four underground neutrino detectors, capable to see the neutrino burst, namely KAMIOKANDE II (KII), IMB, also Mt. Blanc and Baksan are under discussion. We have no possibility to comment all this publications, only referring would occupy a lot of place. (See [2,3,4] and references therein.) But in no one of these papers the attention was given to a substantial difference in neutrino spectra, observed by KII and IMB. Only in [1] we discussed the difficulty to fit both data in frame of standard model. In above mentioned papers various ways of analysis were applied using the following features of neutrino signal:

1. Time structure.
2. Angular distribution.
3. Energy characteristics.

Which of these data are most informative to compare the data of 23 February, 1987 at 7:35 UT with a theoretical model ?

We believe that:

1) Time structures of the signals in KII, IMB, and Baksan do not differ from expected one if the given statistics (~ 10) is taken into account. The arrival of the signal in all three installations can be easily synchronized if we remember the uncertainty in the absolute time accuracy in KII and Baksan. (The event in Mt. Blanc at 2:52 UT is a mystery both because of absence of expected correlation with KII and because of a giant total energy emitted in neutrinos .)

The time structure in KII was investigated in [5] by Monte-Carlo simulations. In the first 100 simulated events there was a large variety of time structures. Specific features were observed: narrow bunches of pulses, gaps of several seconds, imitations of "prompt neutronization peak" etc. The statistics in the other installations are less than in KII, the time structure does not differ significantly from KII. Combined processing of events from different installations cannot give something new, because of small

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precision in the clock synchronization. Furthermore, we believe that analysis of $E_\nu(t)$-dependence at given statistics is practically impossible.

2) Angular distribution. At the given number of neutrino events (in KII) and the available angular resolution it is difficult to select ν_e - scattering events. There is some visible concentration of KII events near $\theta = 0$ (direction from SN1987A) . The question is if it can be just the fluctuation of isotropic distribution?

Bernoulli scheme plus Monte-Carlo simulation for angular distribution in KII gives following probabilities of random concentration near $\theta = 0$:

A) The probability for two minimal θ values ($\theta < \theta_x$) to be less than 20° is ≈ 10% (θ_x = 20°).

B) The probability to have the observed or bigger anisotropy for arbitrary θ_x is ≈ 5%.

We consider these probabilities to be not too small, so the most simple hypothesis (full isotropy) cannot be excluded and we shall suppose that all signals are from reaction

$$\tilde{\nu}_e + p \rightarrow n + e^+ \ .$$

Our proposal for the analysis of neutrino signal from SN1987A is the following:

1) One should abandon the attempt to make a multivariant analysis of all the data (t_i, θ_i, E_i) to fit some model.

2) The use of time structure and angular distribution is noninformative, though both are in agreement with standard model .

3) We shall concentrate on the energy distribution of total amount of events recorded during the neutrino burst.

There are essential points to be taken into account:

A) The differences of energy thresholds for different detectors.

B) The differences between fiducial mass of detectors.

C) Because of small numbers of ν events and differences in thresholds one should use an *a priori* form of the energy spectrum of $\tilde{\nu}_e$.

As above mentioned spectrum we use a conventional one :

$$dN_\nu \sim F(E_\nu, T, \alpha) = E^2 / \left(1 + \exp(E_\nu / T)\right) \cdot \exp(-\alpha E^2 / T^2) dE_\nu \qquad (1)$$

Then the energy distribution of observed events is expected as follows :

$$dN_e = C(T,\alpha) \cdot F(E_\nu, T, \alpha) \cdot \Phi_{th}(E_\nu) \cdot \sigma(E_\nu) dE_\nu = C \cdot f(E_\nu, T, \alpha) dE_\nu \ , \qquad (2)$$

where the first term is normalization constant, the second - spectrum of neutrino, third - efficiency of registration, the fourth is $\tilde{\nu}_e p$ cross-section.

We shall apply the maximum likelihood method to look at the consistency of experimental data with assumed temperature T. For the given T and α equation for C is:

$$C(T,\alpha) \cdot \int f(E_\nu, T, \alpha) dE_\nu = 1 \ . \qquad (3)$$

Then likelihood function is:

$$L(T,\alpha) = \prod_{i=1}^{m} C(T,\alpha) \cdot f(E_{\nu_i}, T, \alpha) \ , \qquad (4)$$

where m is the number of observed ν-events, E_{ν_i} is the energy for a given event.

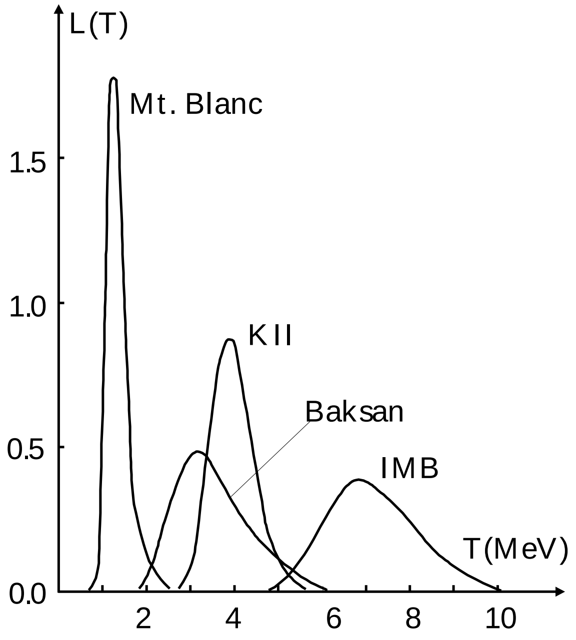

Fig. 1. Likelihood function L(T) for the standard model with α = 0.04.

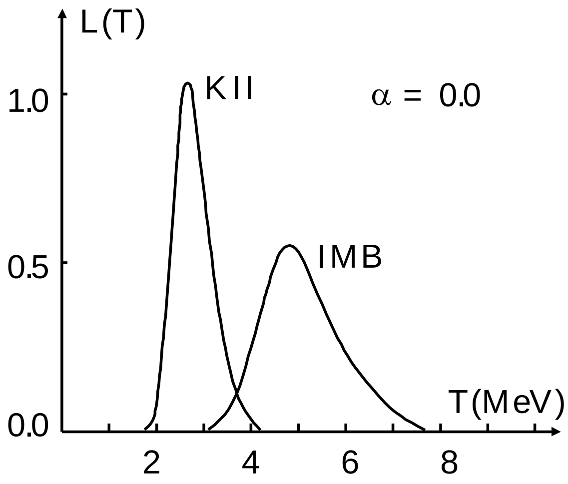

Fig. 2. Likelihood function L(T) for the standard model with α = 0.

Earlier [1] we calculated normalized function $L(T,\alpha)$ for different detectors, when α = 0.04. In fig. 1 these functions are presented for KII, IMB, Baksan and also, for comparison, Mt. Blanc (at 2:52).

Relative position of these curves is practically independent on parameter α. This is illustrated in fig. 2 for KII and IMB, when α = 0. All the difference is that T_{max} is shifted to the left by a factor 1.5. The calculation shows that there is almost linear dependence between T_{max} and α . Let us estimate the probability that events in IMB and KII are caused by the same spectra, in the form of (1). One can use likelihood functions for this. Let the L_1 be the likelihood function for KII and L_2 for IMB. We suggest several ways to estimate the above mentioned probability:

1) "χ^2 - method". Let us assume the Gaussian approximation of functions L_1 and L_2 so, that they are equal in the crossing point and have te same values of L_1 and L_2 at maxima. Then χ^2 - criterion is

$$\chi^2 = -2\ln\left(L_1(T_x) \cdot L_2(T_x) \big/ (L_1^0 \cdot L_2^0)\right)$$

where T_x is the common temperature, - L_1^0, L_2^0 are maximum values of L_1,L_2 . Practically χ^2 has minimum at crossing point, where T = 5.25 MeV and χ^2 = 10. That corresponds to probability P = 0.001 for one degree of freedom.

2) The integral of product of the probability densities L_1,L_2 could be a convenient measure proportional to the probability, but it should be normalized in order to have proper dimension. To calculate the normalization factor we shift curves L_1 and L_2 by a value $\pm\Delta$T so, that their maxima will coincide, then

$$P_2 = \int L_1(T) \cdot L_2(T) \cdot dT \Big/ \int L_1(T - \Delta T) \cdot L_2(T + \Delta T) \cdot dT = 7 \cdot 10^{-3} \ .$$

This calculation overestimates the probability, as it actually suggests that for the shifted position this probability $P = 1$, which of course is overestimation.

3) In the third variant a concordance measure is the integral of probability density multiplied by the probability:

$$P_3 = 2\int_0^\infty \left[L_1(T) \cdot \int_0^T L_2(x)dx \right] \cdot dT = 10^{-3} .$$

4) We consider that the fourth variant may be most reliable:

$$P_4 = \left[\int L_1(T) \cdot L_2(T) \cdot dT \right]^2 \Big/ \left[L_1(T) \cdot L_2(T) \right]_{\max} = 3 \cdot 10^{-3} .$$

All these estimations were calculated with $\alpha = 0.04$. If $\alpha = 0$ the probabilities become ~ 2 times bigger, but still $P < 0.01$.

We believe the obtained probability is small enough to look for a possible deviation from the assumed standard spectrum of neutrinos.

In [1] we suggested that one of the possible ways to fit KII and IBM data is to assume a nonconventional "tail" in the ν - spectrum. The simplest modification of the spectrum (1) is to assume a superposition of two similar spectra but with different temperatures T_1 and T_2. To fit the data we have chosen $T_2 = 2 \cdot T_1$. Then

$$dN_\nu = \left[C_1 \cdot F(T) + C_2 \cdot F(2 \cdot T) \right] dE_\nu . \qquad (5)$$

In this calculation we have taken have chosen $\alpha = 0$ (as not significant). The constants C_1 and C_2 are chosen to satisfy together equation (1) and provide some ratio k of the energy fluxes of the second and first (T_2 and T_1) parts of the spectrum.

The fig. 3 shows the KII and IMB maximum likelihood functions for $k = 0.22$. By increasing the T_2/T_1 ratio one can make the overlapping of the curves better , but what is shown in fig. 3 is really not so bad. The probability that both KII and IMB data belong to the same spectrum ($T_1 = 2.2$ *MeV*, $T_2 = 4.4$ *MeV*, $\alpha = 0$, $k = 0.22$) is 10% which, in our opinion, is good enough. But it is impossible to obtain a good fit for much smaller T_2/T_1 ratio (say, 1.3).

What could be the possible interpretation of the two-temperature model?

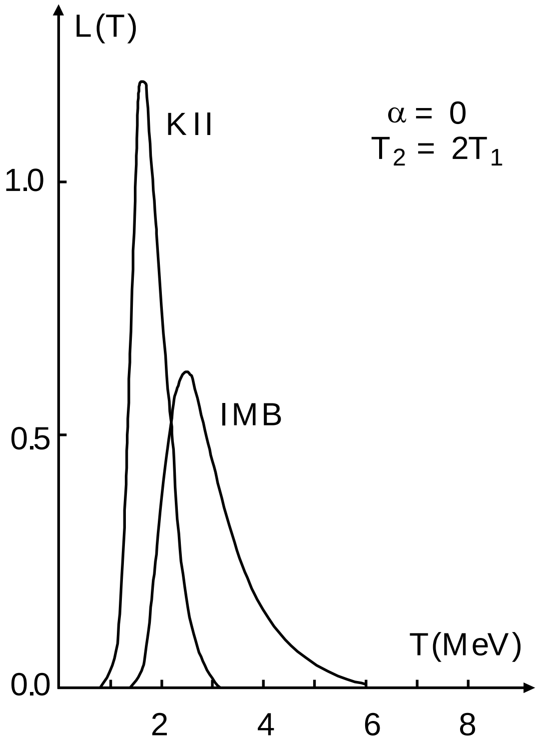

Fig. 3. Likelihood function L(T) for the two-temperature model

We would like to suggest the vacuum oscillation mechanism turning $\tilde{\nu}_\mu, \tilde{\nu}_\tau$ into $\tilde{\nu}_e$ on the way from LMC. Certainly for this we should assume a relatively big mixing (say, more than 20%) but the Δm^2 can be extremely small ($\Delta m^2 > 10^{-19}$ eV^2). The idea is based on the assumption, that the temperature of $\tilde{\nu}_\mu, \tilde{\nu}_\tau$ is bigger than for $\tilde{\nu}_e$. Such a prediction has been obtained in several calculations [6], with the ratio $T_2/T_1 = T(\nu_\mu, \nu_\tau)/T(\nu_e) = 2$, exactly as we have chosen. Similar suggestion has been made by Krauss [7], though in that paper the author tried to explain the results using only conventional model .

It is worthwhile to mention, that using two-temperature model we practically do not change the total energy flux reconstructed from experimental data. In doing this we prefer the method, described in [1], namely:

1. As a zero approximation we use the direct translation of the visible energy flux suggesting 100% efficiency for all the fiducial volume of the detector:

$$E_0 = \left(4\pi R^2 / N_p\right) \sum_{i=1}^{m} E_{\nu_i} / \sigma(E_{\nu_i}) \ .$$

2. For the next approximation we calculate the average relative loss due to inefficiency (threshold effects) depending on assumed temperature T:

$$\lambda(T,\Phi) = \left(\int E_\nu \cdot F(E_\nu, T) \cdot \Phi(E_\nu) dE_\nu\right) / \left(\int E_\nu \cdot F(E_\nu, T) \cdot dE_\nu\right) .$$

3. The corrected total energy in $\tilde{\nu}_e$ E_1 is

$$E_1(T,\Phi) = E_0 / \lambda \ .$$

In the table we give these values for different T.

The first temperatures 3.9, 6.9, 3.1, 1.25 *MeV* corresponds to maximum likelihood for individual detectors ($\alpha = 0.04$). 5.25 corresponds to the crossing point of KII and IMB curves in fig. 1 ($\alpha = 0.04$). 2.2 (4.4) corresponds to the crossing point in fig. 3 (two-temperature model). One

Table (E_0 and E_1 are in units of 10^{52} erg.)

Detector	E_0	Temperature (*MeV*)					

		3.9	6.9	3.1	1.25	5.25	2.2(4.4)
KII	3.6	6.5				5.0	5.5
IMB	0.4		1.7			4.0	10.0
Baksan	9.0			40		15.0	31.0
Mt. Blanc at 2:52	5.5				800		

can see, that there is no problem concerning total energy in the case of KII and IMB. Though there is now a nearly two times difference one should not forget that this is practically inside the statistical error box. There is some problem in the Baksan data to be 3 - 5 times higher, than KII or IMB. The Mt. Blanc data at 2:52 is the biggest problem. If we multiply the obtained energy by a factor of 6 to include all types of neutrinos we come to the conclusion, that 15 solar masses were emitted in the form of low energy neutrinos. The probable solution could be to move the source of the Mt. Blanc signal much nearer to the Earth, (comparing with LMC), say at several *kpc*.

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