NEUTRINO MASS DETERMINATIONS FROM THE SUPERNOVA SN 1987A BURSTS

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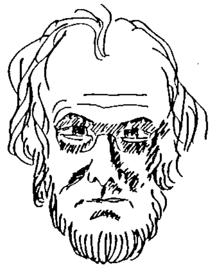

ABSTRACT

The time and energy coordinates of the neutrino signals reported at this conference by the Mont Blanc, Baksan, IMB, and Kamiokande-II detectors, respectively, are fitted to kinematics. The time difference between the Mont Blanc observations and the other observations cannot be due to the mass difference between neutrinos of different species. Under the most conservative hypothesis the electron neutrino mass is found to be < 5 eV. If the first six Kamiokande events originate in one very short burst, the electron neutrino mass is 4.0 ± 0.7 eV.

The neutrino bursts observed on February 23 in four neutrino detectors[1-4] have been attributed to the supernova SN 1987A in the Large Magellanic Cloud. In this short talk I would like to make a few comments on the mass of the electron neutrino from the observed time and energy distributions of the neutrinos.

Two neutrinos of energy E_1, E_2, emitted simultaneously, will be detected with a time difference

$$t = t_2 - t_1 = L/2c \; (m_2^2/E_2^2 - m_1^2/E_1^2), \qquad (1)$$

where L is the distance from the Large Magellanic Cloud. Simultaneously emitted neutrinos of one kind should thus arrive in order of descending energy.

Could the 5-hour time difference between the Mont Blanc observations and the others be due to the different masses of two species of neutrinos? One finds readily that if $E_2 = E_1 = 10$ MeV, then

$$\sqrt{m_1^2 - m_2^2} \approx 800 \text{ eV} \qquad (2)$$

Such a neutrino mass is completely ruled out by cosmological arguments, according to which any neutrino must be lighter than 24 eV.[5]

If emission takes place over a long time interval, the chronology in the energy distribution will be blurred. Ultimately, for very long emission times, the energy distribution approaches complete randomness. Inversely, neutrinos of one kind arriving within t with a completely random energy distribution, will not fit Eq. (1) (except with the unphysical mass $m = \infty$).

Thus we can infer that if the energy spectrum of a neutrino burst yields $m > 24$ eV, we are observing a time distribution at emission time long enough to blur the mass-dependent chronology. On the other hand, neutrino bursts yielding $m < 24$ eV can be analyzed under both the hypotheses of simultaneous emission and slow emission.

In the case of simultaneous emission a neutrino mass may be obtained, whereas in the slow emission case only an <u>upper</u> limit can be obtained. If the energy distribution is observed to be completely random, a <u>lower</u> limit can be obtained om the simultaneous case, whereas no mass information is obtained under the slow emission case.

The four laboratories[1-4] have reported times of arrival, or what matters more for our purpose, time differences with a precision of 0.01 - 0.001 s. For each event the electron energy and its error is known. One can then proceed to make constrained fits of Eq. (1) to the energies in each burst. The results of this are as follows.

The five Mont Blanc events[1] in the energy range 5.2 - 9.8 MeV occurring within 7.008 s exhibit complete randomness. Thus they resemble uncorrelated background events (they are best fitted by $m = \infty$). Under the hypothesis of simultaneous emission they yield

$$m > 14 \text{ eV} \quad (CL = 0.90). \tag{3}$$

The Baksan burst[2] contained only three events within 5.682 s in the energy range 12 - 18 MeV. The best fit yields 40 eV, however with an error bar extending to + ∞. Thus it can only be used to set a lower limit under the hypothesis of simultaneous emission,

$$m > 20 \text{ eV} \quad (CL = 0.90). \tag{4}$$

The IMB burst[3] contained eight events in the energy range 20 - 44 MeV within 5.106 s. They are well fitted by

$$m = 33 +5/-4 \text{ eV}. \tag{5}$$

Clearly they do not fit the hypothesis of simultaneous emission. However, they can be used under the slow emission hypothesis to give the limit

$$m < 39 \text{ eV} \tag{6}$$

The Kamiokande-II events[4] occur in two or three bursts: the first six events occurred in the energy range 6.3 - 20 MeV within 0.686 s, followed by a quiet gap of 0.855 s. Events 7 - 9 in the energy range 19.8 - 35.4 MeV occurred within 0.369 s. Very much later (8.2 s) a long sequence of what looks like background events follows. The first three events of this third burst were tabulated in Ref. 4. Since the events 10-12 obviously could not have been emitted simultaneously with events 1-6 or 7-9, I shall not inlude them in this analysis.

Let me first note that it is completely ruled out (by a probability of 10^{-6}) that all nine events follow a random distribution, let alone a single chronological distribution of decreasing energy. Let me therefore assume that the two bursts occurred at different times, and that in any case the first burst was very short, enough to be considered emanating from simultaneous emission.

Fits of the two bursts (events 1-6 and events 7-9) then yield

$$m_{1-6} = 4.0 \pm 0.7 \text{ eV} \tag{7}$$

and

$$m_{7-9} = 8.5 \pm 2.0 \text{ eV}. \tag{8}$$

From the conflict between these two mass values one concludes that events 7-9 probably were due to slow emission. Taking the conservative view of slow emission for both bursts, one obtains

$$m_{1-6} < 5 \text{ eV} \quad (CL = 0.90), \tag{9}$$

$$m_{7-9} < 11 \text{ eV} \quad (CL = 0.90). \tag{10}$$

I conclude that the only observation consistent with a simultaneous emission is the first Kamiokande-II burst, which determines the electron neutrino mass to be

$$m = 4.0 \pm 0.7 \ \text{eV}. \quad (7)$$

The most conservative hypothesis consists in taking the emission to be slow. One then obtains

$$m < 5.0 \ \text{eV} \ (90 \% \ \text{C.L.}). \quad (9)$$

The Kamiokande-II events 7-12 could not have been emitted simultaneously with events 1-6, this is ruled out by a probability of $< 10^{-6}$.

The other laboratories have only observed slow emission, and their data can therefore not be used to set any better mass limits than what has been known until now.

It is a pleasure to acknowledge stimulating and useful discussions with M.Goldhaber, L.Krauss, S.Petcov, and D.Schramm.

References

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