OBSERVATION OF A NEUTRINO BURST FROM THE SUPERNOVA SN1987A*)

KAMIOKANDE-II Collaboration

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Abstract

A neutrino burst was observed in the KAMIOKANDE-II detector on 23 February, 7:35:35 UT (±1 minute) during a time intervalof 13 seconds. The signal consisted of 11 electron events of energy 7.5 to 36 MeV, of which the first 2 point back to the Large Magellanic Cloud with angles $18^{o} \pm 18^{o}$ and $15^{o} \pm 27^{o}$.

Following the optical sighting on 24 February 1987 of the supernova[1)], SN1987A, a search was made of the data taken in the KAMIOKANDE-II detector. We report here the results of that search.

The KAMIOKANDE-II detector is described in detail elsewhere[2,3)]. The fiducial volume of this analysis contains 2140 tons of water.The Cherenkov light of a 10 MeV electron gives on average 26.3 hit PMT's[4)] (NHIT) at 1/3photoelectronthreshold. The trigger accepts 8.5 MeV electrons with 50% efficiency, and 14 MeV electrons with 90% efficiency over the volume of the detector[5)]. The raw trigger rate is 0.60Hz of which 0.37Hz is due to cosmic ray muons. The remaining 0.23Hz is largely due to radioactive contamination in the water.

Neutrinos of different flavors are detected through the scattering reaction $\nu e \rightarrow \nu e$. The kinematics of this reaction and the subsequent multiple scattering of the recoiling electron preserve knowledge of the incident neutrino direction within approximately 28^o rms at electron energies in the vicinity of 10 MeV. In addition, $\bar{\nu}_e$ are detected through the reaction $\bar{\nu}_e p \rightarrow e^+ n$ on the free protons in the water. This reaction produces e^+ essentially isotropically.

The search for a neutrino burst from SN1987A was carried out on the data of Run 1892, which continuously covered the period from 0709h, 21 February to 2231h, 23 February (UT). Events satisfying the following three criteria were selected: 1) the total number of photoelectrons in the inner detector had to be less than 170, corresponding to a 50 MeV electron; 2) the total number of photoelectrons in the anti-counter had to be less than

30, ensuring event containment; and 3) the time interval from the preceding event had to be longer than 20 micro sec, to exclude electrons from muon decay.

The short time correlation of these low energy contained events was investigated and the event sequence as shown in Fig.1 was observed at 07:35:35UT of 23 February. In Fig.1 we show the time sequence of all low energy events (dots) and all cosmic ray muon events (dashed lines) in the given interval. The properties of the events in the burst (numbered 1 to 12 in Fig.1) are summarized in Table I. Event number 6 has NHIT<20 and has been excluded from the signal analysis. A scatter plot of event energy vs cosine of the angle between the measured electron direction and the direction of the Large Magellanic Cloud(LMC), known to contain SN1987A, is shown in Fig.2. It is seen that the earliest two events point back to LMC with angles $(18 \pm 18)^{o}$ and $(15 \pm 27)^{o}$. The angular distribution of the remainder of the events is consistent with isotropy. A search was also made on a larger data sample of 42.9 days, 9 January 1987 - 25 February 1987, and no other burst candidates were found. From the extended period it was determined that the number of events per 10 second time interval is well described by a Poisson distribution of mean n =0.0121 for events with NHIT $\geq$ 30. Hence the rate of occurrence of 6 events in a 10 second time interval due to a statistical fluctuation is less than one in 7×10^{7} years in our experiment.

The only background process that might conceivably give rise to a burst of events in a short interval of time would be the production of an energetic nuclear cascade by an incident cosmic ray muon. The characteristics of such events have been studied in detail previously as the spallation background for solar ^{8}B neutrino events.[3,6] The relative total rate of spallation leading to one or more low-energy electron events is less than 10^{-3} per incident muon. The measured multiplicity distribution of low-energy events following an incident muon in time yields a probability of multiplicity of 3×10^{-3}. The resultant β-decay electrons with observed energies above 15MeV occur with less than 4% probability. Consequently, the overall probability that any of the muons, $\mu 1$ to $\mu 4$, was the progenitor of the event burst in TableI is much less than $10^{-3} \times 3 \times 10^{-3} \times (0.04)^{4}$ ($= 8 \times 10^{-12}$), where the last factor follows from taking the four events in Table I with $E_e > 15MeV$.

We conclude that the event burst on 23 February, 7:35:35 UT, displayed in Fig.2 and Table 1, is a genuine neutrino burst. This is the only such burst found by us during the period 9 January to 25 February.[7] We therefore associate it with SN1987A. This association is supported by the time structure of the events in the burst, their energy distribution and the uniform volume distribution. Additional support is provided by the correlation in angle of the first two observed events with the direction to SN1987A. Correcting for energy dependent detection efficiency and assuming 9 of the 12 events (event 6 has less than 20 PMT's fired, events 1 and 2 can be considered to be due to $\nu e \to \nu e$) are due to $\bar{\nu}_e p \to e^+ n$ we obtain an integral flux of 1.0×10^{10} cm^{-2} for the burst for $\bar{\nu}_e$ energy above 8.8 MeV. This inturn leads to the $\bar{\nu}_e$ output of SN1987A of 8×10^{52} erg. foran assumed average energy of 15 MeV. This observation is the first direct observation in neutrino astronomy, and coincides remarkably well with the current model of supernova collapse and neutron star formation.

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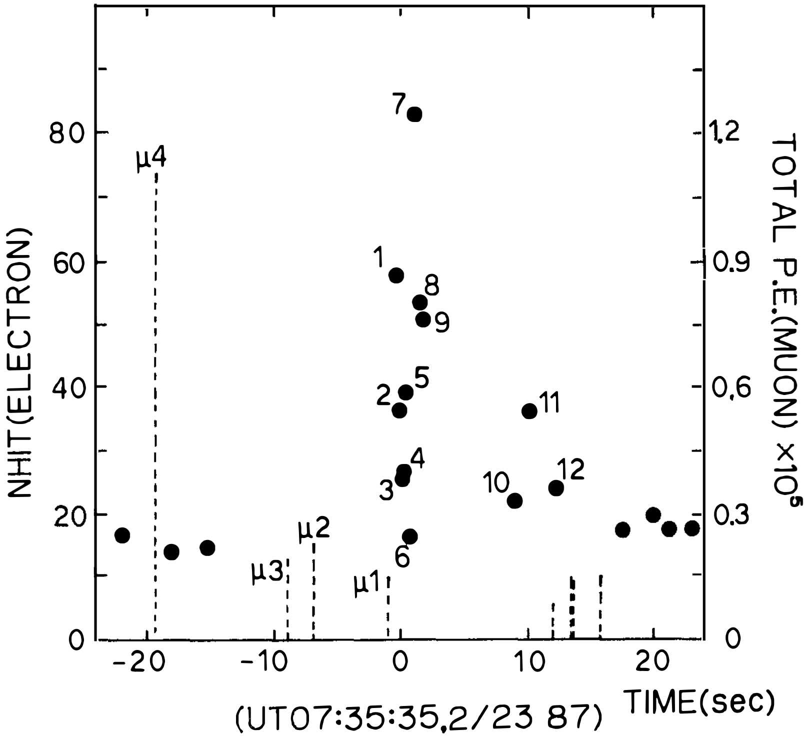
References

*) This paper is written based on a result already published (K.Hirata et al., Phys.Rev.Lett.58(1987)1490.).
1) IAU Circular No.4316.
2) E.W.Beier, in Proceedings of Seventh Workshop on Grand Unification / ICOBAN'86,April, 1986, Toyama, Japan, P.79.
3) KAMIOKANDE-II Collaboration, presented by T.Kajita, in these proceedings.
4) This constant is not the same with ref.3), because the mean attenuation length of the Cherenkov light in the water (>45m) is longer than that of ref.3).
5)This is for the entire volume inside the PMT array. The detection efficiency for a fiducial volume of 780 ton, 2m inside the PMT array is 90% at 10 MeV and 50% at 7.6 MeV.
6) A.Suzuki,in Proceedings of the Twelfth Int.Conf.onNeutrino Physics and Astrophysics,June, 1986, Sendai, Japan, P.306.
7) There is a claim of observing a neutrino burst of 5 events of energy > 7MeV in 7 seconds, on Feb23.124 UT (IAU Circular No.4323),2h 52m UT(Univ.of Torino Preprint), by Castagnoli etal., using a liquid scintillator detector of 90 tons effective mass, situated 5000 hg/cm^2 under Mt. Blanc. If this were a real neutrino burst, our detector should have given about $(5 \pm \sqrt{5}) \times (2140/90) \times (1/1.29) \times 0.3 = 28 \pm 12$ events in 7 seconds at the same UT, where the 2nd factor is the ratio of detector masses,the 3rd factor is the ratio of free protons per unit mass in water and liquid scintillator, and the last factor is ourdetection efficiency for 7 MeV electrons. Wesearched carefullyfor such a burst in our data and found no sign of any burst at or around the claimed UT.

Table I. Measured properties of the 12 electron events detected in the neutrino burst. The electron angle in the last column is relative to the direction of SN1987A.

Event number	Event time (sec)	Number of PMT's (Nhit)	Electron energy (MeV)	Electron angle (degrees)
1	0.	58	20.0 ± 2.9	18 ± 18
2	0.107	36	13.5 ± 3.2	15 ± 27
3	0.303	25	7.5 ± 2.0	108 ± 32
4	0.324	26	9.2 ± 2.7	70 ± 30
5	0.507	39	12.8 ± 2.9	137 ± 23
6	0.686	16	6.3 ± 1.7	68 ± 77
7	1.541	83	35.4 ± 8.0	32 ± 16
8	1.728	54	21.0 ± 4.2	30 ± 18
9	1.915	51	19.8 ± 3.2	38 ± 22
10	9.219	21	8.6 ± 2.7	122 ± 30
11	10.433	37	13.0 ± 2.6	49 ± 26
12	12.439	24	8.9 ± 1.9	91 ± 39



Figurel.
Thetime sequence of events in a 45 second interval centeredon UT 07:35:35, 23 February 1987. The vertical height represents the relative energy of the events. Dots represent low energy electron events in units of the number of hit PMT,NHIT (lefthand scale). Dashed lines represent muon events in units of the number of photoelectrons (righthand scale).Events μ1 - μ4 are muon events which precede the electron burst at time zero.

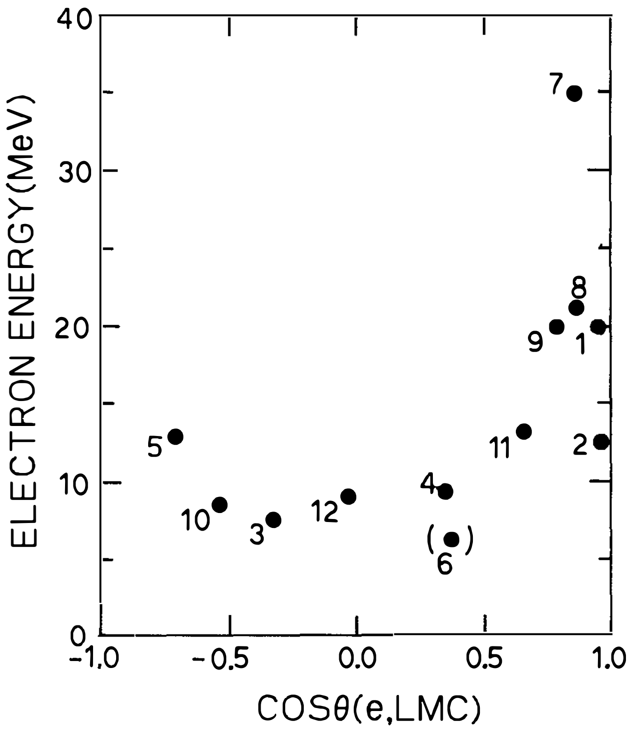


Figure 2.
Scatter plot of the detected electron energy in MeV and the cosine of the angle between the measured electron direction and the direction of the Large Magellanic Cloud. The number to the left of each entry is the time sequential event number from Table I.