Observation of a Neutrino Burst from the Supernova SN1987a

The KAMIOKANDE-II Collaboration

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A neutrino burst was observed in the KAMIOKANDE-II detector on 23 February, 7:35:35 UT (± 1 minute) during a time interval of 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 (LMC) with angles 18° ± 18° and 15° ± 27°.

A new analysis of the special low threshold trigger counts strongly indicates that KAMIOKANDE did not observe any signals at 2:52:36 which is the time claimed by the Mont Blanc group.

1. Introduction

Following the optical sighting on 24 February 1987 of the supernova [1], now called SN1987a, a search was made of the data taken in the detector KAMIOKANDE-II during the period from 1609h, 21 February 1987 to 0731h, 24 February 1987. The results of that search has been published elsewhere. [2]

The KAMIOKANDE detector has been continuously upgraded primarily for detection of low energy neutrino interactions, especially for solar neutrinos. The low energy background which comes mainly from radioactive elements ^{214}Bi in water has been reduced by a factor of almost 10000 since 1985. The remaining background due to unstable elements fragmented from ^{16}O by cosmic ray muons has been systematically studied and a program to remove those background was ready. Then came the information of SN1987a. It was thus quite easy to find a neutrino burst, since necessary programs were all available, and the background rate was quite low. A burst of low energy electron events was clearly seen on the print-out already in the morning of February 28.

2. Detector

The KAMIOKANDE-II detector, directed primarily at nucleon decay and solar ^{8}B neutrino detection, has been operating since the beginning of 1986. It is described in detail elsewhere, [3] but its salient features are shown schematically in Fig.1. The inner detector fiducial volume containing 2140 tons of water [4] is viewed by an array of 20" diameter photomultiplier tubes (PMT), on a 1m x 1m lattice on the surface. The photocathode coverage amounts to 20% of the total inner surface. The attenuation length of the water for Cerenkov light is in excess of 45m. The inner detector is completely surrounded by a water Cerenkov

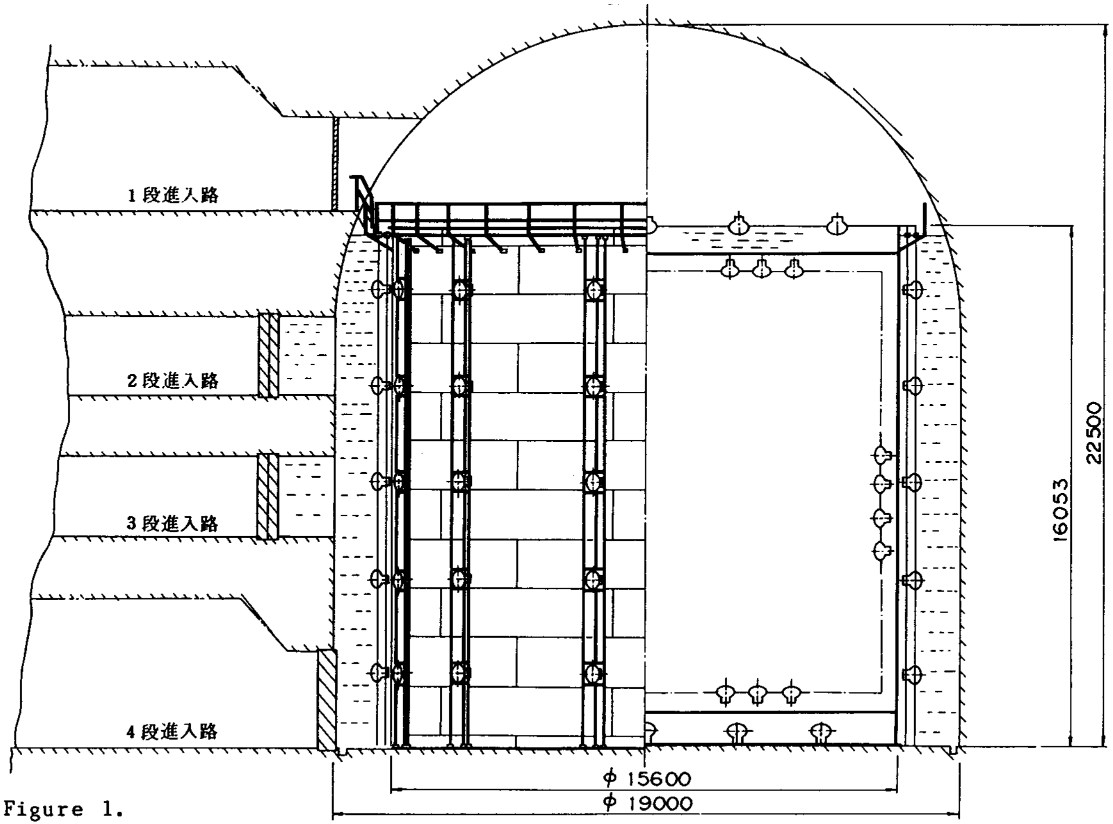

Figure 1.

Schematic view of the KAMIOKANDE-II detector. The inner detector contains 3000 tons of water of which 2140 tons are fiducial volume. It is viewed by 948 20" diameter PMTs mounted on a 1 meter grid on the inner surface. The outer(veto) counter surrounds the inner detector and is viewed by 123 PMTs. Dimensions in the figure are in millimeters.

counter of thickness $\geqq$ 1.4 m to ensure the containment of low energy events. It also is an absorber of γ rays from surrounding rock and a monitor of slow muons which do not produce Cerenkov light in the inner detector but may decay there.

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° 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 Cerenkov light of a 10 MeV electron gives on average 26.3 hit PMT's (NHIT) at 1/3 photoelectron threshold. The energy calibration is obtained by observing $\mu \rightarrow e$ decays and by using the Compton scattered electrons from γ rays of energy up to 9 MeV from (n+Ni) using a Cf neutron source.

The detector is triggered by 20 PMT discriminators firing within 100 ns. Charge and time information for each channel above threshold is recorded. The trigger accepts 8.5 MeV electrons with 50% efficiency, and 14 MeV electrons with 90% efficiency over the volume of the detector [4]. The raw trigger rate is 0.60Hz of which 0.37Hz is cosmic ray muons. The remaining 0.23 Hz is largely due to radioactive contamination in the water.

The electronics consists of ADC and TDC for each PMT. Every TDC and ADC has fast memories of depth 4. Therefore the electronics dead time is essentially determined by the gate width of the circuits, namely 400 ns. The data are stored on magnetic tapes and sent to the University of Tokyo, where they are analysed with the computer M380 stationed at the International Center for Elementary Particle Physics, ICEPP, Facutly of Science.

Reconstruction of the vertex of low energy events is performed with an algorithm based on the time and position of hit PMTs. After the vertex is established, a separate fit is used to obtain the angle of the electron. The distribution of the events presented here is consistent with an uniform volume distribution.

3. Search of a Neutrino Burst

The search for a neutrino burst from SN1987a was carried out on the data of Run #1892, which continuously covered the period from 16:09, 21 February to 07:31, 24 February in Japanese Standard Time, which is UT plus 9 hours. Events satisfying the following four criteria were selected: 1) the total number of photoelectrons per event in the inner detector had to be less than 170, corresponding to a 50 MeV electron; 2) the total number of photoelectrons in the outer detector had to be less than 30, ensuring event containment; and 3) the time interval from the preceding event had to be longer than 20 μ sec, to exclude electrons from muon decay. 4) Events must not be correlated spacially and timely with preceding muons to exclude a burst of events in a short time interval that were the production of an energetic nuclear cascade by an incident cosmic ray muon.

The short time correlation of these low energy contained events was investigated and the event sequence as shown in Fig.2 was observed at 16:35:35JST(7:35:35UT) of 23 February. The event sequence during 0 to 15 sec is shown expanded in Fig.3. The properties of the events in the burst (numbered 1 to 12 in Fig.3) 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.4. It is seen that the earliest two events point back to LMC with angles $(18 \pm 18)^{\circ}$ and $(15 \pm 27)^{\circ}$. 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. Figure 5 shows that from the extended period the number of events per 10 second time interval is well described by a

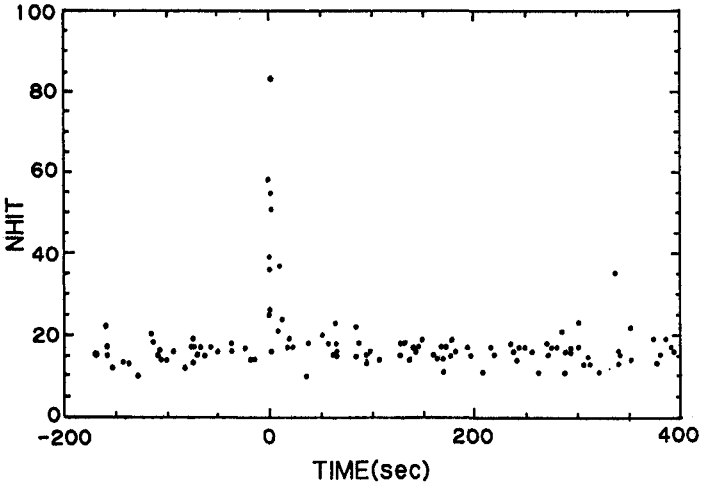

Figure 2.

The time sequence of events in a 600 second interval centered on UT 07:35:35, 23 February 1987. Dots represent low energy electron events in units of the number of hit PMT,NHIT.

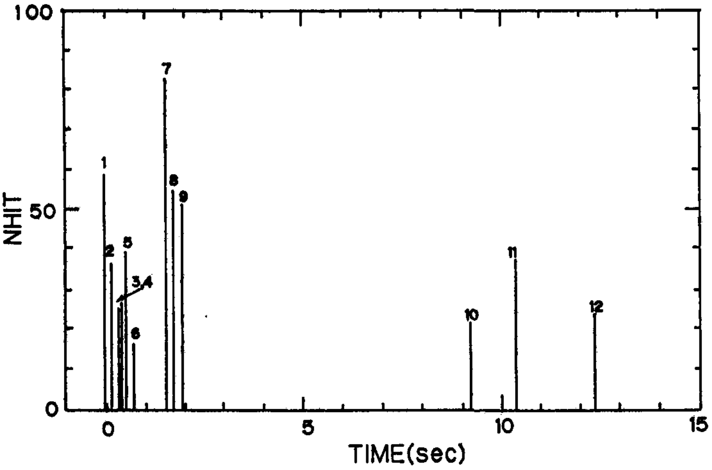

Figure 3.

The time sequence of events during 0 to 15 sec. Solid lines represent low energy electron events in units of NHIT.

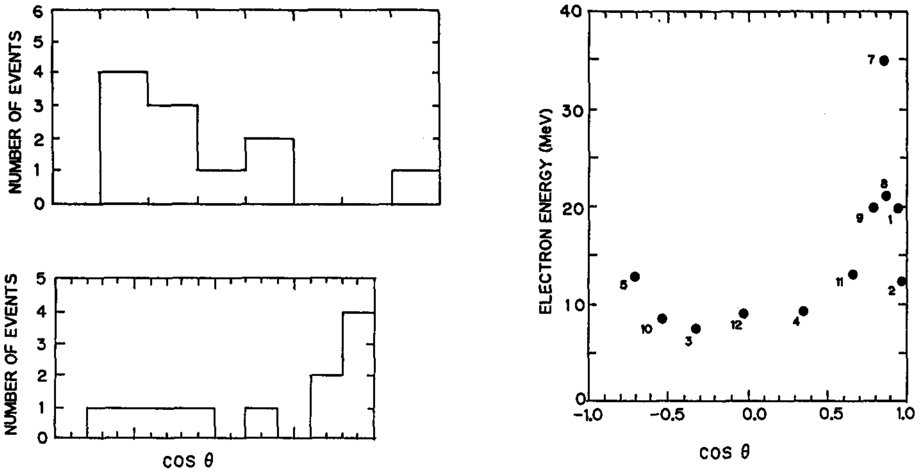

Figure 4.

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. The two projections of the scatter plot are also displayed.

TABLE I.

Measured properties of the twelve electron events detected in the Neutrino burst. The electron angle in the last column is relative to the directrion of SN1987a.

EVENT NUMBER	EVENT TIME (sec)	NUMBER OF PMTs (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	135±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

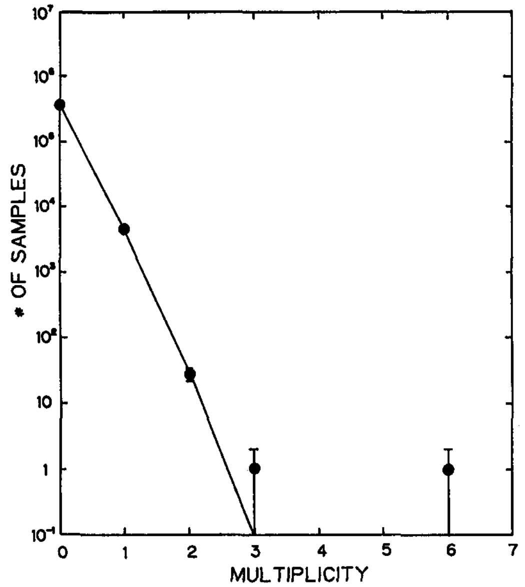

Figure 5.

Distribution of number of event with NHIT $\geqq$ 30 per 10 sec time interval for a data sample of 42.9 days. 9 January 1987 - 25 February 1987. A burst at multiplicity 6 is the observed neutrino burst. The line corresponds to a Poisson distribution with mean 0.012.

Poisson distribution of mean $\bar{n}$ =0.0121 for events with NHIT $\geqq$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 x 10^7 years in our experiment.

4. 2:52:36 UT

M. Aglietta et al. (the Mont Blanc group) have reported the observation of five events in 7 seconds beginning from 2:52:36 UT. [6] This time is about 3:40 earlier than our time. Therefore if this observation is indeed true, the supernova must have banged twice. There has been a large debate about its consistency with the KAMIOKANDE result [7]. It is true that we observed two events near the Mont Blanc time, namely one event with NHIT=30 at 2:52:40 UT and the other with NHIT=20 at 2:52:47 UT. Some people take these two events very seriously and further arbitrarily shift our energy normalization, concluding that the rate of these two events is consistent with Mont Blanc. We, however, wish to stress that occurrence of these two events is just expected from background. Thus they are not strong evidence to support Mont Blanc.

We present here the other argument against the consistency between Mont Blanc and KAMIOKANDE. The KAMIOKANDE trigger system possesses a special low level discriminator output, the rate of which is counted with an online scaler. The low level discriminator has a threshold of approximately 6.4 MeV at 50% efficiency. The scaler count is read out at every event occurrence. The result is shown in Fig.6. The count rates between 2:52 UT and 2:54 UT are compared with the average rate of 9.96 Hz. They are all consistent with background. Since the threshold level is similar with Mont Blanc, one can easily calculate the event rate inferred from the Mont Blanc result:

$$(5 \pm \sqrt{5}) \times 2140/90/1.3/10 = 9.2 \pm 4.1 \text{ Hz},$$

where 5 is the number of events observed by the Mont Blanc

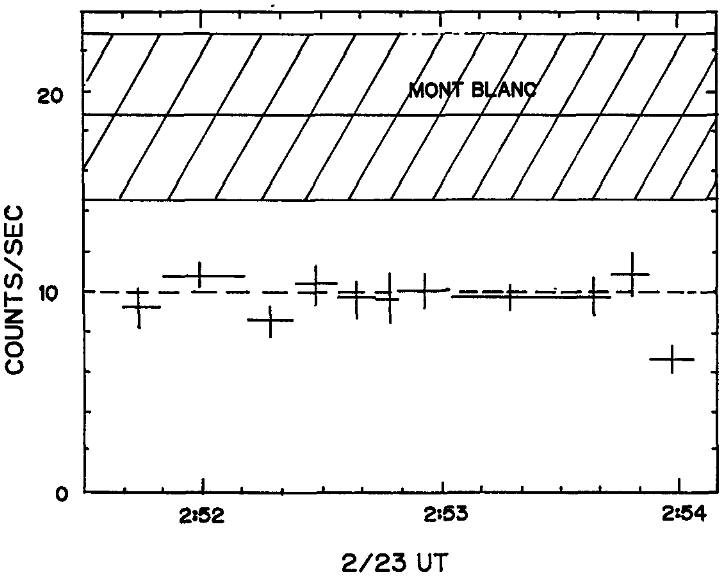

Figure 6.

Scaler count rates with 6.4 MeV threshold as a function of time. Hatched region is the count rate expected from the Mont Blanc burst (5 ± $5^{1/2}$ events, burst period = 10 sec). Our data are well below the burst rate, thus failed to confirm the Mont Blanc result. The dashed line is the expected background rate.

group; 2140 and 90 are the fiducial volumes for KAMIOKANDE and Mont Blanc, respectively; 1.3 is the relative number of protons in unit mass of the two detectors (H_2O and H_2C); a burst period of 10 sec is assumed. If the Mont Blanc observation is indeed true, our scaler must have counted this extra rate above background. As shown in Fig.6, this is clearly not consistent with our result. Unless the threshold energy of Mont Blanc is much lower than 6.4 MeV, the KAMIOKANDE data does not confirm the Mont Blanc result.

5. Conclusion

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. 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. Strong additional support is provided by the correlation in angle of the first two observed events with the direction to SN1987a. The event burst occurred roughly 18 hr prior to the first optical sighting. [1] Correcting for energy dependent detection efficiency and assuming 9 of the 12 events are due to $\bar{\nu}_e p \rightarrow e^+ n$ 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 in turn leads to the $\bar{\nu}_e$ output of SN1987a of 8×10^{52} erg. for an assumed average energy of 15 MeV. Our data between 2:52 UT and 2:54 UT did not confirm the Mont Blanc result, unless the Mont Blanc threshold energy is much lower than 6.4 MeV.

References

[1] IAU Circular No.4316.

[2] K. Hirata et al., Phys. Rev. Lett. 58 (1987) 1490 .

[3] E.W. Beier, Proceedings of 7th WOGU/ICOBAN'86, April, 1986. Toyama, Japan.

[4] 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.

[5] A. Suzuki, Proceedings of the 12th Int. Conf. on Neutrino Physics and Astrophysics, page 306, June, 1986, Sendai, Japan.

[6] M. Aglietta et al., Europhys. Lett. 3(1987) 1315.

[7] A. de Rujula, Phys. Lett. 193(1987) 514.