Correlations between low- and high-energy pulses detected by the LSD installation under Mt. Blanc from 10 February 1987 to 1 July 1987

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The data obtained at the LSD installation from 10 February to 1 July 1987 in a search for correlations among all pulses with energies above 5 MeV have been analyzed. Nine correlated pulse pairs (one high-energy pulse plus one low-energy pulse) were found between 5:42 UT and 10:43 UT on 23 February 1987. The time between the correlated pulses was less than 2 s. The frequency of corresponding random Poisson fluctuations is 1/(10 yr).

1. Introduction. Supernova 1987A occurred in the Large Magellanic Cloud on 23 February 1987. The first optical observation of SN 1987A occurred at 10:40 UT. On this day, some "rare" events (i.e., events whose simulation by the background would occur at a frequency $\ll 1\ h^{-1}$) were detected by four underground installations (LSD, Kamiokande II, IMB, and the Baksan Underground Scintillation Telescope) and also by two gravitational antennas (in Rome, Italy, and in Maryland).[1–4] The LSD underground installation detected a rare event at 2:52 UT (5 pulses over 11 s; the simulation frequency is less than $0.3\ yr^{-1}$). At the same time, the Rome gravitational antenna detected an increase in the energy flux to a level about six times the average background. The Kamiokande II, the IMB, and the Baksan telescope observed rare events 4.7 h later (at 7:35 UT). They detected 11, 8, and 5 pulses, respectively; the respective simulation frequencies would be 10^{-7}, 3×10^{-30}, and $120\ yr^{-1}$. In addition, over a 2-h interval centered near the rare event at the LSD installation (2:52 UT), temporal correlations were observed in pulses detected by three underground neutrino detectors and the two gravitational antennas.[5–8] The probabilities that these correlations would have been simulated by Poisson fluctuations of the background are small (less than 10^{-5} for LSD-Maryland-Rome, 4×10^{-3} for LSD-Baksan, 5×10^{-4} for Maryland–Rome–Kamiokande II, and 5×10^{-2} for Maryland–Rome–Baksan. Because of these low probabilities and because of the temporal coincidence of these correlations with the appearance of SN 1987A, one might suggest that these two phenomena are interrelated.

In this letter we are reporting an analysis of the LSD data carried out in a search for temporal correlations among all events with energies above 5 MeV detected by the LSD from 10 February to 1 July 1987.

2. The analysis and the results. The LDS underground detector, which is in a laboratory under Mt. Blanc, at a depth of 5200 meters water equivalent, is described in detail in Ref. 9. The detector, with a mass of 90 metric tons, consists of 72 counters filled with a liquid scintillator based on white spirit (C_nH_{2n}, $\langle n \rangle = 9.6$). Each counter is monitored by three FÉU-49B photomultipliers. Iron plate around the detector reduces the radioactive background. The mass of the iron is about 200 metric tons. Muons and the secondary particles generated by muons are associated with high-energy pulses (for which an energy of more than 25 MeV is evolved in the detector). Events with an energy evolution in the interval 5–25 MeV, in only one counter, are classified as low-energy pulses, caused primarily by background radioactivity. The average count rate of the high-energy pulses over the period analyzed was 6.0 h^{-1}, and the average count rate of low-energy pulses was 38.2 h^{-1}. In June of 1987, the count rate of low-energy pulses increased to 57.8 h^{-1} after a calibration of the counters and a lowering of the thresholds.

In the search for temporal correlations, the LSD data from 10 February to 1 July 1987 were analyzed. We used time windows $\Delta t = 1$, 2, and 3 s (the time window was the maximum difference between the times of appearance of the first and second pulses of the pair). Only a single unusual group, of nine pairs of correlated pulses, was observed. This group was found on 23 February 1987, between 5:42 UT and 10:13 UT, with the window $\Delta t = 2$ s. The first pulses in the correlated pairs were both high-energy pulses (muons) and low-energy pulses. These nine pairs of pulses were detected at 5:42:48, 5:44:27, 6:22:24, 7:59:18, 8:05:41, 8:29:33, 8:48:21, 9:45:37, and 10:13:04 UT. (The IMB, Kamiokande II, and Baksan installations detected rare events at about 7:35 UT.) Over this time (of 4.5 h), only a single pulse of correlated pulses was detected with a window $\Delta t = 1$ s, while ten pairs were detected with $\Delta t = 3$ s. The frequency at which random Poisson fluctuations would generate nine pairs of correlated pulses with $\Delta t = 2$ s over 4.5 h is about 1/(10 yr).

Figure 1 shows the probability distribution of the number of correlated pairs of pulses over 5 h, along with a corresponding Poisson distribution. The average number of coincidences in the 5-h interval, aside from these nine coincidences, is 1.20. This figure agrees well with the expected count rate of random coincidences: 1.26. Only one 5-h interval, revealed by the first pair of correlated pulses, contains eight pairs (from 5:42 UT to 10:13 UT on 23 February 1987).

Figure 2a shows the distribution of time intervals between the pulses in the pairs for $\Delta t = 2$s for all pairs of pulses, except for the nine pairs on 23 February 1987. Figure 2b shows the same distribution for the nine pairs of pulses ($\Delta t = 3$ s) between 5:42 and 10:13 UT on 23 February 1987. The distribution in Fig. 2b is quite different from the uniform distribution in Fig. 2a. The time intervals between the pulses in six of the nine pairs lie between $\Delta t_{corr} = 1.2$ s and $\Delta t_{corr} = 1.6$ s. The probability for such a random deviation from a uniform distribution is $\sim 3 \times 10^{-3}$.

An analysis of all the data from 10 February to 1 July 1987 revealed no anomalous autocorrelations between low-energy pulses (muons were excluded). In an effort

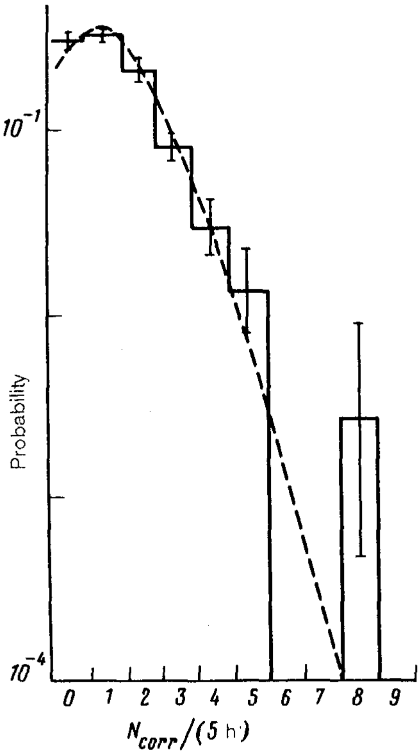

FIG. 1. Probability distribution of the number of pairs of correlated pulses and a corresponding Poisson distribution ($\Delta t = 2$ s). $\langle N_{corr} \rangle_{theo} = 1.26/(5\ h)$.

to detect correlations we also analyzed the low-energy pulses detected by the Baksan installation and the high-energy pulses (muons) detected by the LSD installation between 0:00 UT and 10:00 UT on 23 February 1987 for various time shifts between pulses. No deviations from the expected distributions were found.

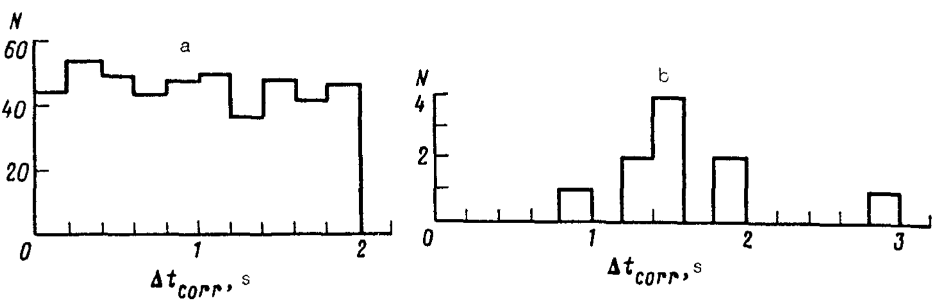

FIG. 2. a: Distribution of time intervals between the pulses in pairs of correlated pulses for a time window $\Delta t = 2$ s. The time interval 5:42 UT to 10:13 UT on 23 February 1987 has been excluded from the data. b: The same as in frame *a*, but for a time window $\Delta t = 3$ s and for the time interval 5:42 UT to 10:13 UT 23 February 1987.

3. Conclusion. Analysis of the data obtained at the LSD installation from 10 February to 1 July 1987 has revealed nine correlated pulses [high-energy pulses (muons) and low-energy pulses, with a time window $\Delta t = 2$ s] in the period from 5:42 UT to 10:13 UT on 23 February 1987, i.e., at a time close to the time of the optical appearance of SN 1987A. The frequency of such a random Poisson fluctuation of the background is $\sim 1/(10$ yr). This result indicates a possible relationship between the temporal correlations of the pulses and the appearance of SN 1987A.

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