Galileo Versus Aristotle: the Case of Supernova 1987A#

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Abstract Most current supernova theories state that this phenomenon lasts a few seconds and ends with a big final explosion. However, these theories do not take into account several experimental results obtained with neutrino and gravitational wave detectors during the explosion of SN1987A, the only supernova observed in a nearby galaxy in modern age. According to these experimental results the phenomenon is much more complex that envisaged by current theories, and has duration of several hours. Indeed, SN1987A exploded on February 23, 1987, and two neutrino bursts, separated by 4.7 hours were detected: the first one at $2^h\ 52^m$ UT and the second one at $7^h\ 35^m$ UT. Furthermore, correlations between the neutrino and two gravitational wave detectors, ignored by most of the scientific community, were observed during the longer collapse time. Since the current *standard* theories, based on some rough simplifications, are a clear example of an Aristotelian attitude, still present in our days, we believe that a more Galilean attitude is necessary, being the only correct way for the progress of science.

Keywords: Supernovae, Individual: 1987a, Neutrinos, Gravitational Waves

1. Introduction

On August 21, 1609, Galileo Galilei showed to the people in Venice the wonders of his new telescope: ships in the sea which were hard to see at naked eyes, the Moon craters, the Jupiter satellites, the Sun dark spots.

A few months later he went to Florence to show to the Grand Duke Cosimo de Medici the four satellites of Jupiter, which he named Medicei. He did not bother at all the desertion of some university professors who, although invited, did not show up to the appointment: no envy, but simply because they had remained loyal to the Aristotelian view of the Universe and they did not see anything that would have forced them to change their own advanced opinions.

Even intelligent people had hard time in convincing themselves that what they could see with the telescope was real, especially for things they could not touch with their hands, like the celestial bodies. It seemed that human nature is made so as not to accept any news that leads off the already marked road, and this characteristics of the human nature has not changed during the centuries.

In this paper we wish to argue that many scientists, in the attempt to explain what

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happened with SN1987A, follow a sort of Aristotelian point of view, ignoring or pretending to ignore facts based on observations.

SN1987A was a unique event during our time, because modern instrumentation was available for measuring phenomena generated by this event. We recall that the first observation of a neutrino burst was real-time detected on February 23, 1987, at $2^{h}\,52^{m}$ UT in the very deep underground Liquid Scintillation neutrino detector (hereafter LSD) inside the Mont Blanc laboratory. This event was immediately communicated (IAU Circular n. 4323 of February 28, 1987) after the information of a visual supernova was available, and soon after was discussed, on March 2, during the Rencontres de Physique de la Valle d'Aoste.

Several days later it was announced that neutrino bursts were also observed in coincidence in the Kamiokande and the IMB detectors, very soon followed by the Baksan experiment. Nevertheless, some important experimental data were, and still are, ignored by many scientists who developed models of supernova explosion. In the following, we draw the attention to three of these observations, which have not been taken into proper consideration even if they are among the most important ones:

- the long duration of the Kamiokande neutrino burst;
- the coincidences between the LSD and Baksan detectors;
- the correlation between neutrino and gravitational wave detectors.

2. Two Neutrino Bursts Detected in Kamiokande

We have received by the Kamiokande collaboration the list of observed events reporting, for each event, the time and the N_{hit}, being N_{hit} the number of photo-multipliers hit in the trigger at each event time. For example, an event with energy 10~MeV gives $N_{\mathrm{hit}} = 26$ and with energy 30 MeV gives $N_{\mathrm{hit}} = 73$; the Kamiokande collaboration has put a threshold at $N_{\mathrm{hit}} = 20$, corresponding roughly to an energy of 7.5 MeV. In total this list contains 1937 triggers, detected during the full day February 23 above $N_{\mathrm{hit}} =20$, giving a rate of about 0.024 pulses per second.

It is well known that Kamiokande (KND in the following) observed a burst of eleven neutrino interactions at $7^{h}35^{m}$ UT with a duration of 12.4 s, with a very low imitation rate from the background, and in coincidence, even if with a poor timing, with the eight neutrino burst observed by the IMB detector [1, 2]. A careful search for bursts [3], however, shows a second cluster of seven pulses in KND at about 20~minutes after the first one, starting at $7^{h}54^{m}$ and with a duration of 6.2 s, with energies $22 < N_{\mathrm{hit}} < 33$ and with an imitation rate from the background of one event every 669 years. One can find an indication of this second cluster in ***Fig4*** of [2] from which, however, one does not realize that the cluster consists of seven pulses well above the background in just six seconds, as shown here in ***Table 1***. We believe that this second pulse, shown in ***Fig1***, escaped to the attention of the Kamiokande collaboration.

Since the IMB detector had an energy threshold above 20 MeV, this detector observed clustered pulses in coincidence with the first KND cluster at $7^{h}35^{m}$ UT made by several high energy pulses, but it did not have the sensitivity to observe clustered pulses in coincidence with the second KND cluster at $7^{h}54^{m}$, made of pulses with energy of the order or less than 15 MeV.

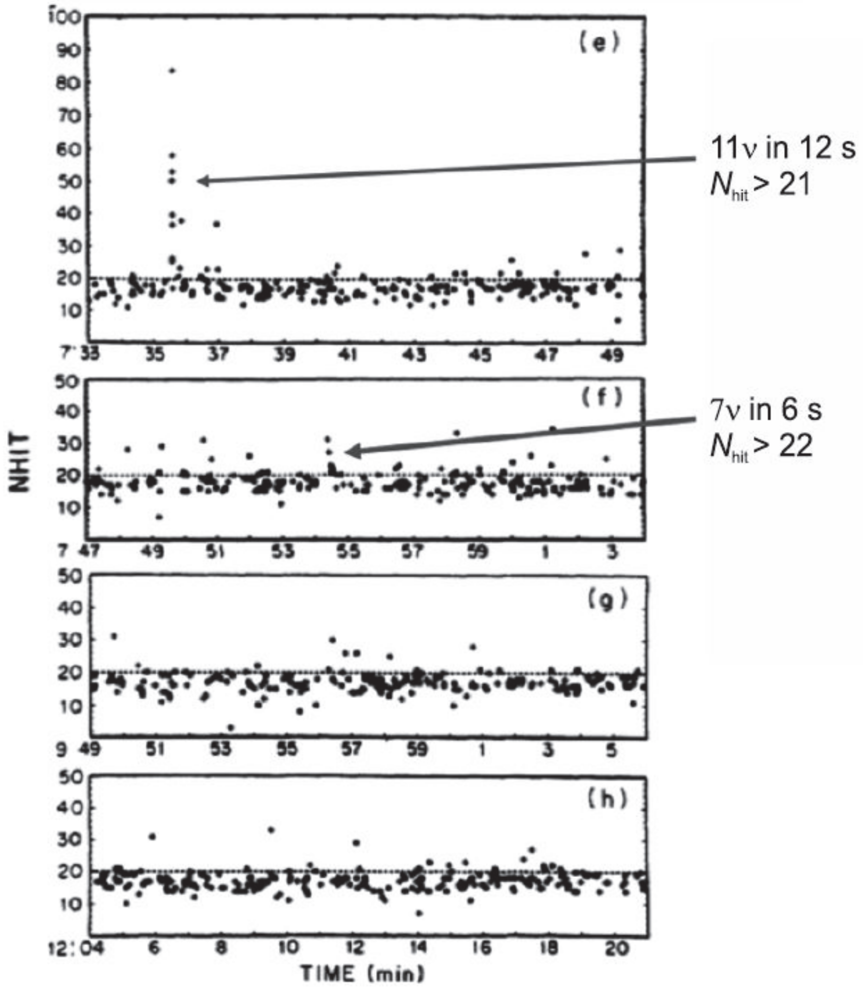

Fig1. *Scatter plot of N_{hit} versus time, as shown in **Fig4** of [2]. The second pulse is barely visible, but it stems out clearly if one process the data.*

Table1. *UT time and N_{hit} of the seven pulses in the Kamiokande second burst. This cluster has duration of 6.2 s and an imitation rate from the background of 669 years*

Hour	min	sec	N_{hit}
7	54	22.26	33
7	54	24.11	29
7	54	25.33	28
7	54	25.34	27
7	54	27.13	22
7	54	28.37	22
7	54	28.46	22

3. Coincidences between LSD and Baksan Neutrino Detectors

Among all neutrino detectors, LSD and Baksan Scintillation Telescope (BST in the following) have very similar characteristics. The data recorded by these two detectors show an extraordinary correlation [4–6] at the time of the LSD burst.

We start by remarking that the Baksan event times, as recorded on the magnetic tapes, have an error of +2 s, −54 s with respect to the UT. Also we recall that the Baksan telescope has recorded a burst of neutrinos, the first of which occurs at the recorded time of $7^h36^m1^s.8$. Comparing with IMB, we find that we must correct the Baksan recorded times by −30.4 s.

In ***Fig2*** we show the number of coincidences between LSD and BST during a one-hour time period versus the correction time t_c for three values of the coincidence window $\delta t = \pm 0.5$, 1.5, 2.5 s.

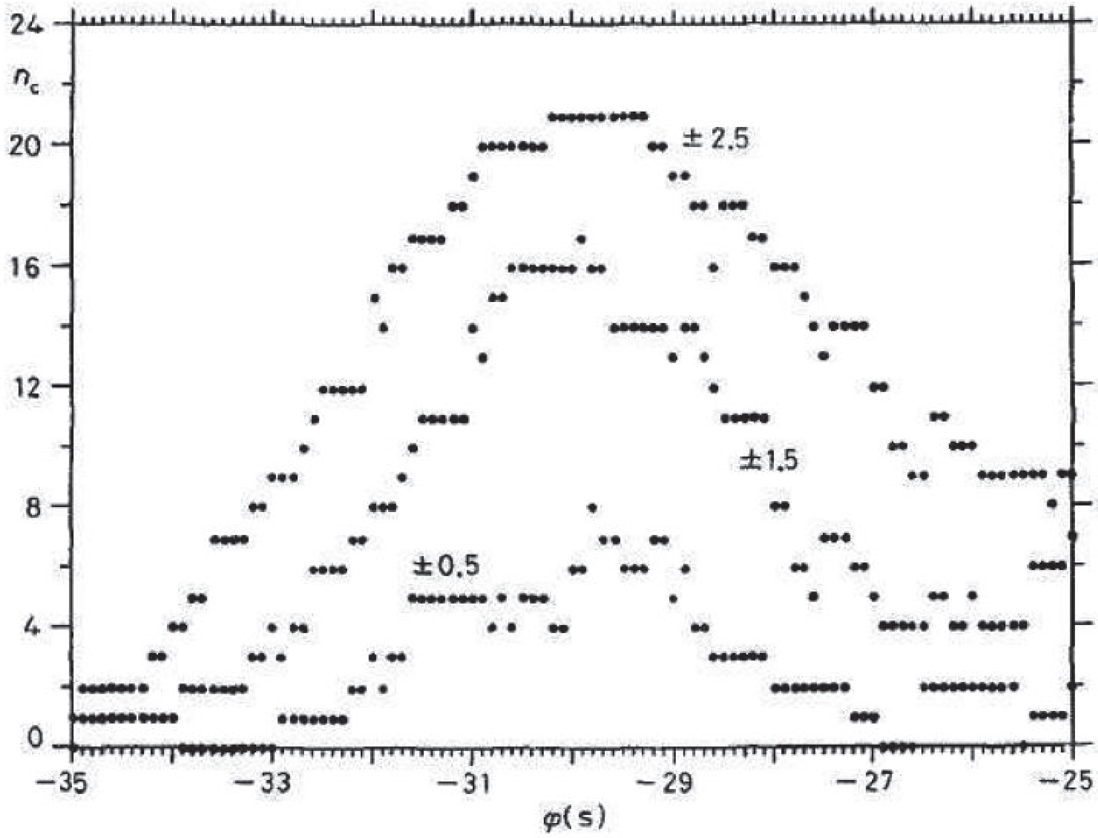

***Fig2**. LSD–BST coincidences for various coincidence windows $\delta t = \pm 0.5$, 1.5, 2.5 s vs. the Baksan correction time. One-hour period, 2^h to 3^h. Figure 11 from [12].*

We notice a striking excess of coincidences[1] for t_c in the interval that agrees with the IMB burst at $7^h35^m41^s.4$.

[1] Prof. A. E. Chudakov was very surprised for this unexpected result, and decided to perform by himself the analysis of the LSD and BST data. The result of his independent analysis confirms the same coincidence excess at the Mont Blanc time [6]. Chudakov even wrote a letter to F. Reines [7] asking to discuss this “crazy” fact of events in coincidence between LSD and Baksan.

For calculating the probability that the observed coincidence excess has been obtained by chance, we estimate the background with the well-known formula

$$n_{bk} = \frac{N_1 N_2 \delta t}{one\ hour}$$

where N_1 and N_2 indicate the neutrino events from LSD and BST in the one hour period. The results are shown in ***Table2***.

Table2. *Probability p to obtain n_c coincidences by chance for the three coincidence windows*

δt	$\bar{n}$	n_c	p
0.5	1.52	8	4.4×10^{-3}
1.5	4.56	17	7.6×10^{-5}
2.5	7.6	21	1.4×10^{-4}

4. Correlation between Neutrino and Gravitational Wave Detectors

The gravitational wave (GW) detectors in Rome and in Maryland recorded several signals in time coincidence between them and with the LSD experiment, for a long time duration that includes the time of the LSD event: 2^h52^mUT. The GW signals preceded the LSD signals by 1.1 – 1.2 s, with an absolute systematic error in timing of the order of 0.5 s [8–10]. The probability that the correlation had occurred by chance was estimated to be very small, of order of 10^{-6} [11]. A summary of the correlations among neutrino and gravitational wave detectors can be found, for example, in reference [12].

This observation was unexpected, because the sensitivity of the detectors seemed to be too small for detecting gravitational waves presumably produced by this extragalactic supernova. Indeed the classical cross-section for the interaction of gravitational waves with matter is far below that needed to detect GW [13–15].

The correlations were studied making use of an algorithm[2], called the *net excitation method* and described in detail in [11, 16], based on the idea to make use of *all available data* in underground detectors, and not only those considered to be produced by neutrino interactions.

The algorithm consist in taking

$$E_{RM}(t) = E_R(t) + E_M(t),$$

where E_R and E_M are the measured energies (also called energy innovations, in Kelvins) of the *events* obtained with the Rome (RO) and the Maryland (MA) detectors at the same time t, 3600 values $E_{RM}(t)$ per hour.

Then the sum $E(t) = \Sigma_i E_{RM}(t_i)$ is computed, where t_i is the time of the i event of the LSD neutrino detector. The summation is extended over a given time interval (say one hour) in which N_ν events of the neutrino detector (most of them certainly due to background) are present.

[2] Suggested by Sergio Frasca.

The background for this algorithm is obtained by calculating $E(t_1, t_2) = \Sigma_j(E_R(t_{1j}) + E_M(t_{2j}))$ at $2N_\nu$ times t_{1j} and t_{2j} chosen randomly within the time interval. In one hour we have many more than 3600 × 3600 independent values of $E(t_1, t_2)$.

The analysis consisted in comparing the value $E(t)$ with the very large number of background values determined by considering non coincident signals RO and MA, observed at times uncorrelated with the neutrino events. In absence of any real signal we expect that $E(t)$ be just one of the many $E(t_1, t_2)$ background values and, on average, we expect that half of the background values be larger than $E(t)$ and half be smaller.

We apply now this algorithm to the data of RO, MA and LSD. We find the result shown in ***Fig. 3a***, where we compare our *signal* $E(t)$ with one million determinations of the background. The algorithm is applied to moving periods of one-hour stepped by 0.1 hour[3].

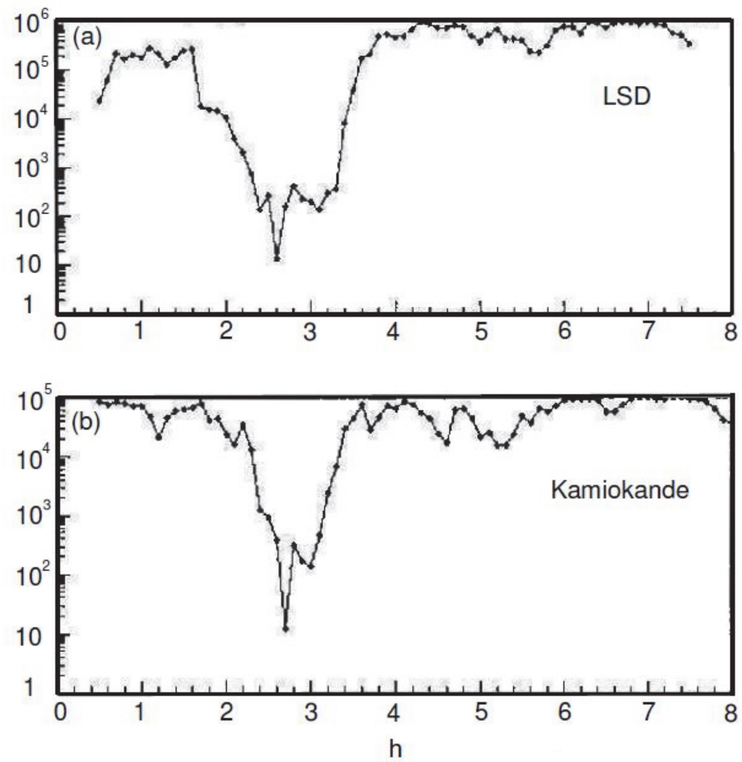

Fig3. (a)*: the n values for N = 1 000 000 obtained for the correlations of Maryland + Rome with LSD during periods of one hour from 0h to 7h. 5 of February 23.* ***(b)****: the same algorithm, for N = 100 000, is applied for the correlation RO, MA and Kamiokande. We notice that all the best correlations occur both at the LSD time. The two correlations are independent, because we make use, in the two cases, of different data for RO and MA.*

When an experimental unexpected result, as that of ***Fig. 3a***, is obtained, usually one repeats the experiment with different data, but in our case we have only one supernova. However, we have different, independent data, namely those obtained by the Kamiokande experiment. Thus, while waiting for the next galactic supernova, we asked Prof. Masatoshi Koshiba to provide the Kamiokande data for a new analysis.

Koshiba was very cooperative and immediately supplied the data which we received on

[3] See also ref. [17].

January 27, 1988. We repeated the analysis applying the same procedure as with the Mont Blanc data and, incredibly, we found just the same correlation at the same time, as shown in ***Fig. 3b***.

At last, in order to estimate the overall probability that the result shown in ***Fig3*** be accidental, we have repeated the same correlation analysis for four independent files of data: RO, MA, LSD and KND [16]. To have a better time resolution, in this new quadruple analysis we have used one-half hour periods stepped by 0.1 hour, and we have obtained the result shown in ***Fig4***. During the period from $2^h\,36^m$ UT to 3h 6m UT, that includes the LSD five-neutrino event at 2.87 hour UT, we have in total 83 independent triggers (32 in LSD and 51 in KND). The sum of the corresponding 83 energy innovations in RO plus the 83 energy innovation in MA in coincidence with the 83 neutrino events, divided by 83, was 74.349 K, while the average background (computed by choosing randomly 83 energy innovations in RO plus 83 in MA, not in coincidence with the LSD and KND data) was 51.771 K during that half an hour period.

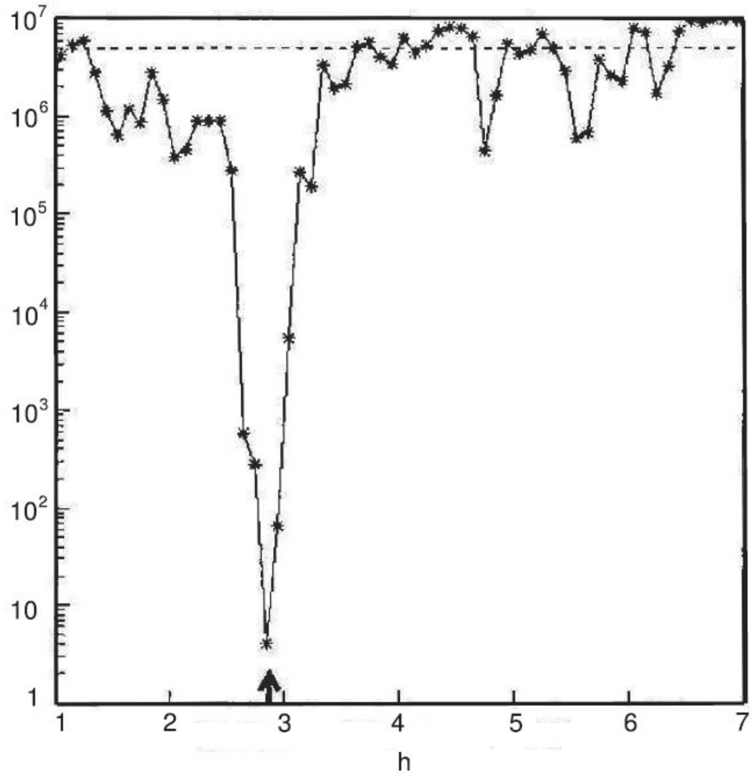

Fig4. *The* net excitation method *is applied on 30-minutes time periods moved in steps of 0.1 hour from 0 to 8 hours UT of February 23, shown on the abscissa scale. As in our previous analysis [4, 11] we have introduced a delay of 1.1 s between the neutrino and the GW signals. On the ordinate scale we show the number of times N, out of 10^7, the GW background determinations are greater or equal than the GW energy innovation obtained in correspondence of the neutrino* events *that includes both the LSD and the KND data. At the LSD time we have N = 4, corresponding to a probability of 4×10^{-7} that the correlation is accidental. The dashed line indicates the expected value in the case of absence of correlation.*

The difference between the signal and the average background is equal to 74.349 − 51.771 = 5.5σ, giving a probability of 1.9×10^{-8} that this result be due to chance, in the case of a normal distribution of the noise. If the data distribution is not exactly Gaussian [16] the probability that this results is accidental is a little bit higher: 4×10^{-7}.

5. Conclusion

One major problem associated with a supernova explosion is the duration of the inner core collapse. According to most theories of supernova explosion, the collapse develops in a few seconds but all the experimental data from supernova 1987A, as shown in this paper, indicate a duration of order of hours. The discrepancies between data and theories could be due, in our opinion, to the fact that most theories do not take into account core rotation and magnetic fields, even if pulsars, i.e. a possible final result of the collapse have the strongest magnetic field and the fastest rotation in the Universe. Furthermore these theories ignore several experimental results, some of them have been described here.

Some unconventional models based on fast rotation and fragmentation of the collapsing core have been suggested soon after the explosion to explain the experimental data from neutrino and gravitational waves detectors [18–21]. These models are supported by the recent observations of the remnant of SN1987A made by NuSTAR (Nuclear Spectroscopic Telescope Array, a satellite launched by NASA on June 2012 to study the X-ray sky) that show a clear evidence of an asymmetric collapse [22]. The asymmetry of the explosion is an essential requirement in support of a collapse in two stages and, eventually, of the emission of gravitational waves.

A typical theory for explaining the long duration of the phenomenon is, for example, that described in [21], where a rotational mechanism of the explosion of a supernova is considered, that leads to a two-stage collapse with a phase difference of about 5 h. It remains, however, no explanation for the signals detected in gravitational wave detectors.

Among the possibilities, if not due to gravitational waves produced by the asymmetric collapse and injected in the direction of the Earth, one should consider the signals due to exotic particles.

But, in any case, we believe that no data should be ignored if they stem out clearly from the observations, as suggested about 400 years ago by Galileo in a world still dominated by Aristotelian views while, in our modern world, a Galilean approach must be considered the only scientific one.

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