On One Group of Experimental Results Related to the Search for Neutrino Radiation from SN1987A: Commentary

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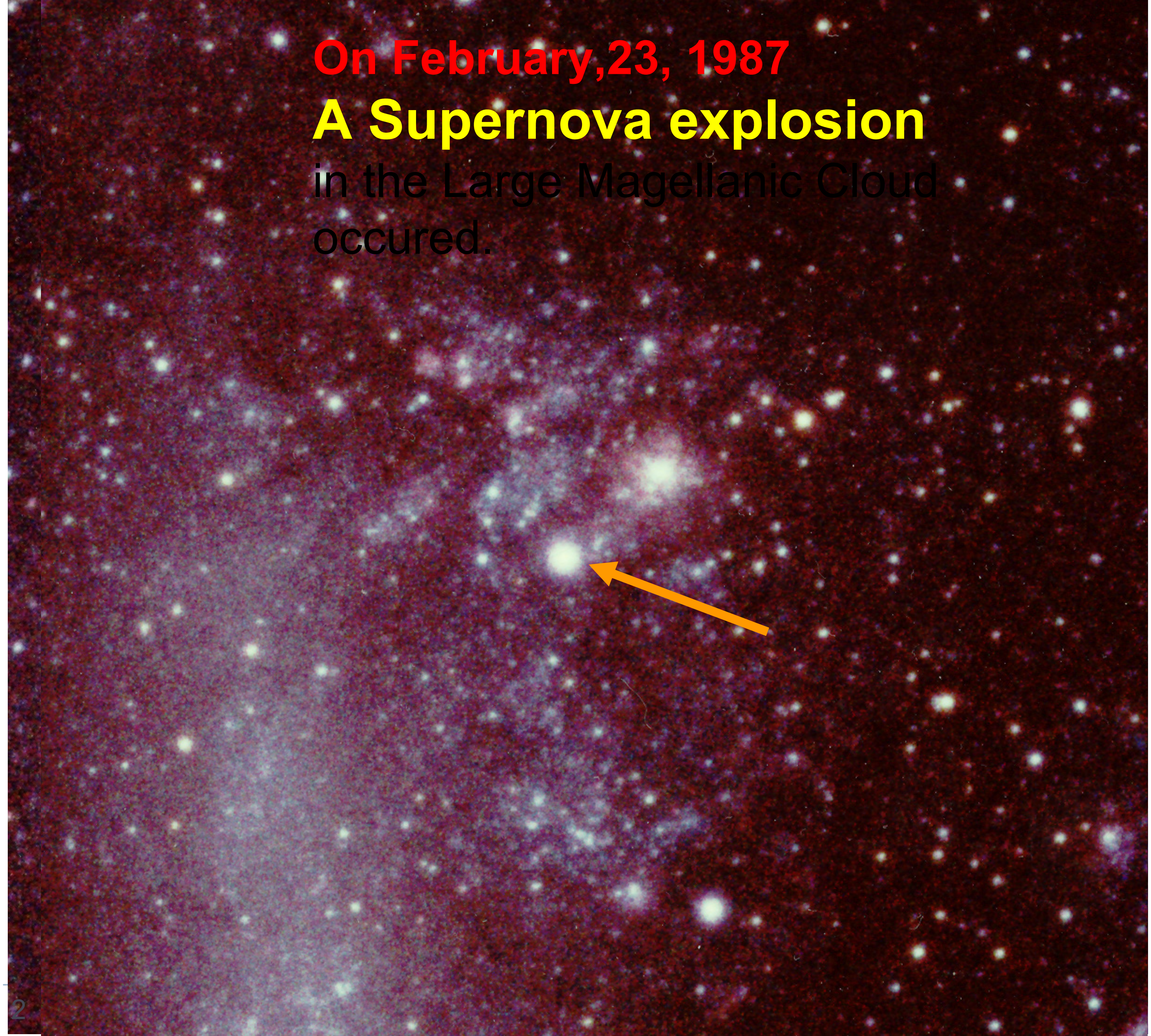
On February,23, 1987

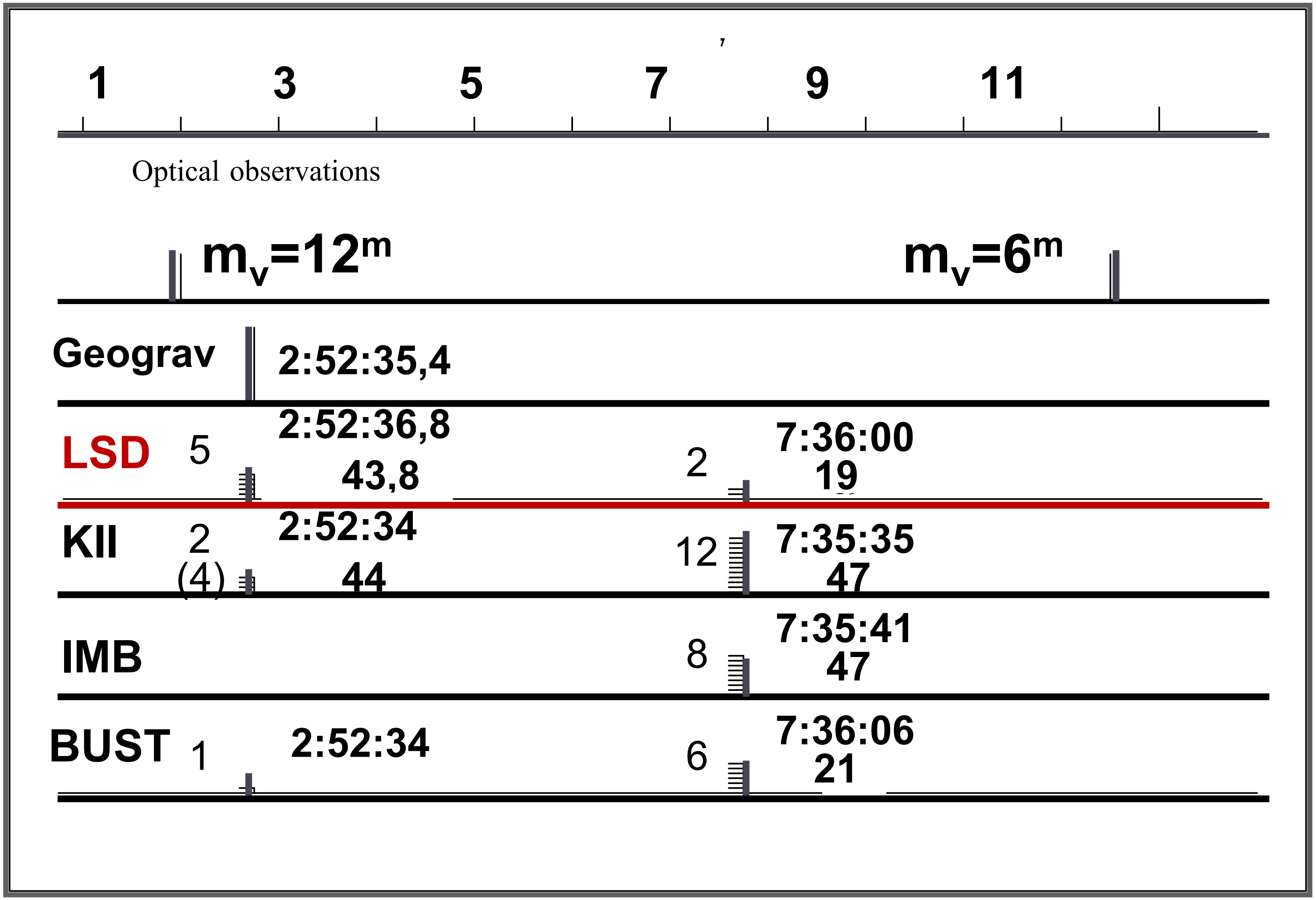
A Supernova explosion

in the Large Magellanic Cloud occured.



Detector	Depth, meters of water equivalent	Fiducial volume, tons	Material	Energy threshold, MeV	Detection efficiency		Background rate s^{-1}
					e^+ spectrum of reaction $\tilde{\nu}_e p \rightarrow e^+ n$	e^- spectrum of reaction $\nu_i e^- \rightarrow \nu_i e^-$	
BUST USSR	850	130 (200) 160	C_nH_{2n} Fe	10	0.6	0.15 (0.54)	0.013 (0.033)
LSD USSR – Italy	5200	90 200	C_nH_{2n} Fe	5-7	0.9	0.4(0.7)	0.01
KII Japan – USA	2700	2140	H_2O	7-14	0.7	0.17 (0.54)	0.022
IMB USA	1570	5000	H_2O	20-50	0.1	0.02 (0.18)	3.5×10^{-6}

February 23, 1987



2:52 UT results and 7:35 UT results correspond to a certain extent to the model of standard collapse (7:35 UT)

Review by Imshennik V.S., Nadyozhin D.K. // Inter. J. Mod. Phys. A **20,** 6597 (2005),

the model of rotating collapsar (2:52 UT; 7:35 UT)

Imshennik V.S., Space Sci Rev, **74**, 325-334 (1995); Astronomy Lett., 34, 375 (2008); Imshennik V.S., Ryazhskaya O.G. // Astronomy Lett., **30**, 14 (2004)

However, a number of questions still remains!

Apart the signals in the four neutrino detectors at 2:52 UT and 7:35 UT on February 23, 1987, there are also other, less well known results obtained at the same detectors on that day. These primarily include the work by the Amaldi–Weber team and the LSD collaboration.

1. **The coincidences between the signals from the Maryland and Rome gravitational antennas and the signals in the LSD and K2 detectors were studied** [Amaldi et al.// Ann.New York Acad. Sci. **571**,561 – 1989; Aglietta et al.//Proc. 21 ICRC, **2**, 246 – 1990, Nuovo Cimento C **14**, 171 – 1991].
2. **LSD – K2 correlations** [Aglietta et al. // Ann. New York Acad. Sci, **571,** 584 – 1989, Nuovo Cimento C **12**, 75 – 1989, Proc. 21 ICRC, **2**, 246 - 1990]
3. **LSD – BUST correlations** [Aglietta et al. Ann. New York Acad. Sci, **571,** 584 – 1989, Nuovo Cimento C **12**, 75 – 1989, Proc. 21 ICRC, **2**, 246 - 1990; Chudakov 1989 Ann. New York Acad. Sci, **571**,577 – 1989]
4. **The double pulses in LSD** [Dadykin et al. // Proc. TAUP'89, 339 - 1989, Izv. AN SSSR, Ser. Fiz., **55**, 4 – 1991; JETP Lett. **56**, 426 1992].

- The results of these works disagreed with theoretical predictions and seemed difficult to understand. The hope that the recording of other stellar collapses much closer to the Earth would clarify the situation then played an important role in shaping the attitude to these works. We share this view.
- **However, given the pessimistic estimates of the rate of collapses, this may not happen soon. Hence, it is not expedient to neglect the information available at present. Therefore, we wish to draw the attention of researchers to the above works and bring them again into scientific use.**
- Despite all of the difficulties in understanding the results of these works, they contain **something that does not allow them to be rejected as a kind of incidents** that commonly happen when experiments are analyzed. Before elucidating our idea, we will have to make several remarks.

About method

First – temporal coincidence.

The technique of searching for neutrinos from stellar collapses is the temporal coincidence between the pulses in various detectors. This practice reduces background pulses and noise and can find something else.

Example: the coincidence of the signals at 7:35 UT on February 23, 1987 in three detectors: K2, BUST, and IMB. This technique helps to find:

•K2 clocks were 7 s slow;
•BUST clocks - 30 s fast relative to the UT standard.

If this effect is not taken into account the excess of coincidences between the pulses from various detectors, does not exist.

Second, studying the coincidences in very narrow time windows

- In a normal mode of operation, the neutrino detectors record pulses with a rate of about $10^{-2}\ s^{-1}$ day by day for many months and years.

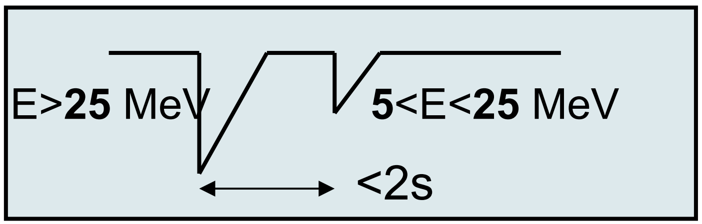
- If n_1 and n_2 are the background pulse rates in detectors *1* and *2* and Δt is the time window =>

$$n_{chance} = 2\Delta t\, n_1 n_2.$$

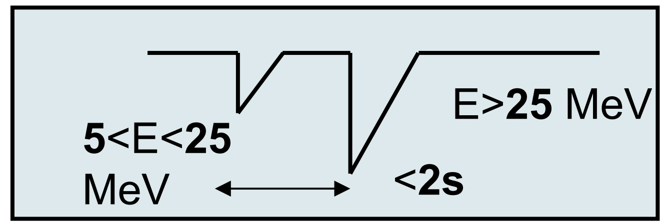
  - **LSD – K2: n_{chance} = 1 per hour;**
  - **LSD – BUST: n_{chance} = 1.5 per hour;**
- The measured rate of coincidences corresponded to these values for the long time intervals studied, up to several tens of days. The only exception is the time interval when the supernova explosion was observed.
- on February 23, 1987:
  - **LSD – K2: $n_{detected}$ = 8 per 2 hours;**
  - **LSD – BUST: $n_{detected}$ = 13 per 2 hours;**

Double pulses in LSD

On February,23, 1987, from 5:42:48 UT to 10:13:04 UT double pulses were detected



or



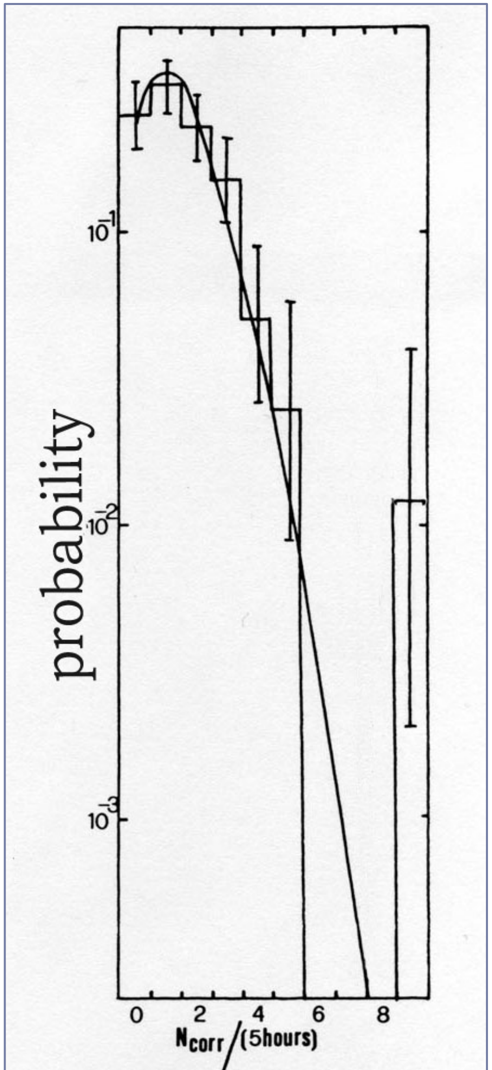
n_{chance}= **0.275 per hour** from statistics ~1 year

$n_{expected}$ = **1.3 per 4.5 hours**

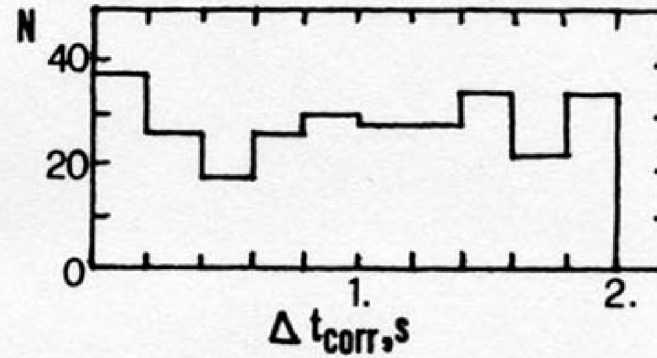
$n_{detected}$ = **9 per 4.5 hours; Dt<2 sec; <t>=1.5 sec.**

Probability of the coincidence by chance with the day of SN:

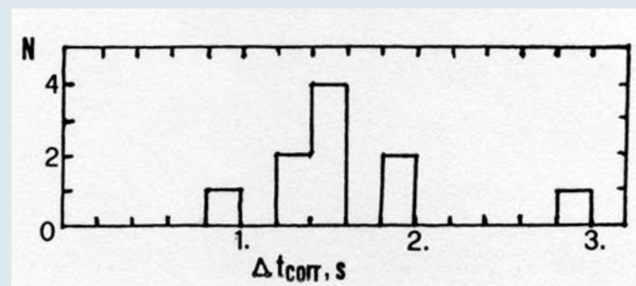
$$1 / 3 \cdot 10^{3}\, years$$



The probability distribution of the counting rate of pairs of correlated pulses per 5 hours and the poissonian fit to this distribution; $<n_{corr}>=1.46/(5 \text{ hours})$, $\Delta T=2$ s



The distribution of time differences between the pulses in the pairs (Δt=2 s) for the whole data set excluding the interval of interest

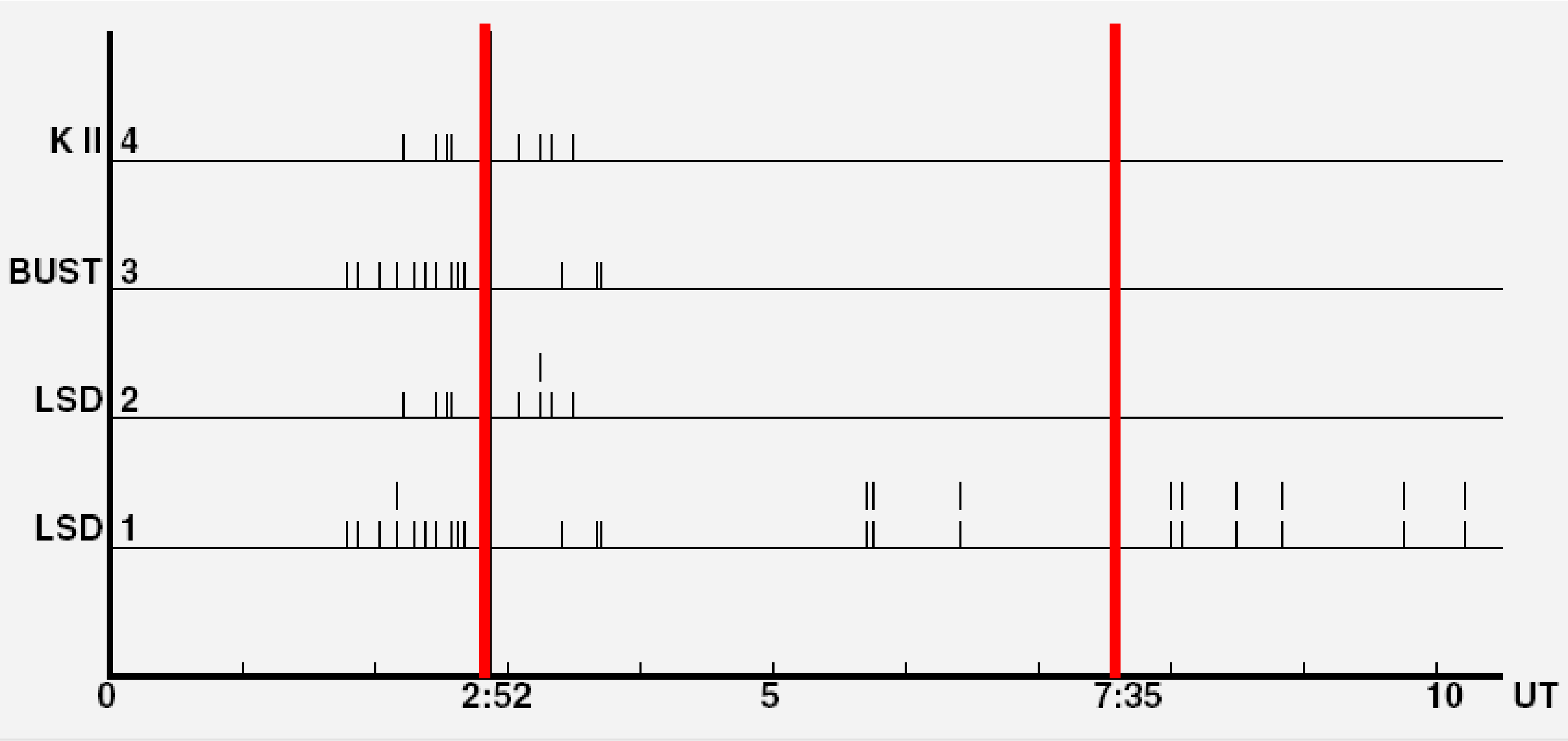


For 10 pairs (Δt=3 s) from 5:42 UT to

9 pairs (Δt=2 s)

10:13UT on February 23, 1987 .

Timing diagram of the BUST pulses coincident with the LSD pulses within 1 s and similar coincidences for the К2 and LSD detectors as well as double pulses in LSD over the period from 0:00 to 10:00 UT on February 23, 1987.



- 2:52 UT and 7:35 UT are two key instants in the evolution of SN 1987A. These instants are marked by the neutrino signals: 5 pulses over 7 s at 2:52 UT in LSD and from 6 to 12 pulses over 10 s at 7:35 UT in each of the three remaining detectors.

- Present day models explain them better or worse.

- Effects related to the excess of coincidences and double pulses still remain outside the scope of these models

Note that in the model of a rotating collapsar:

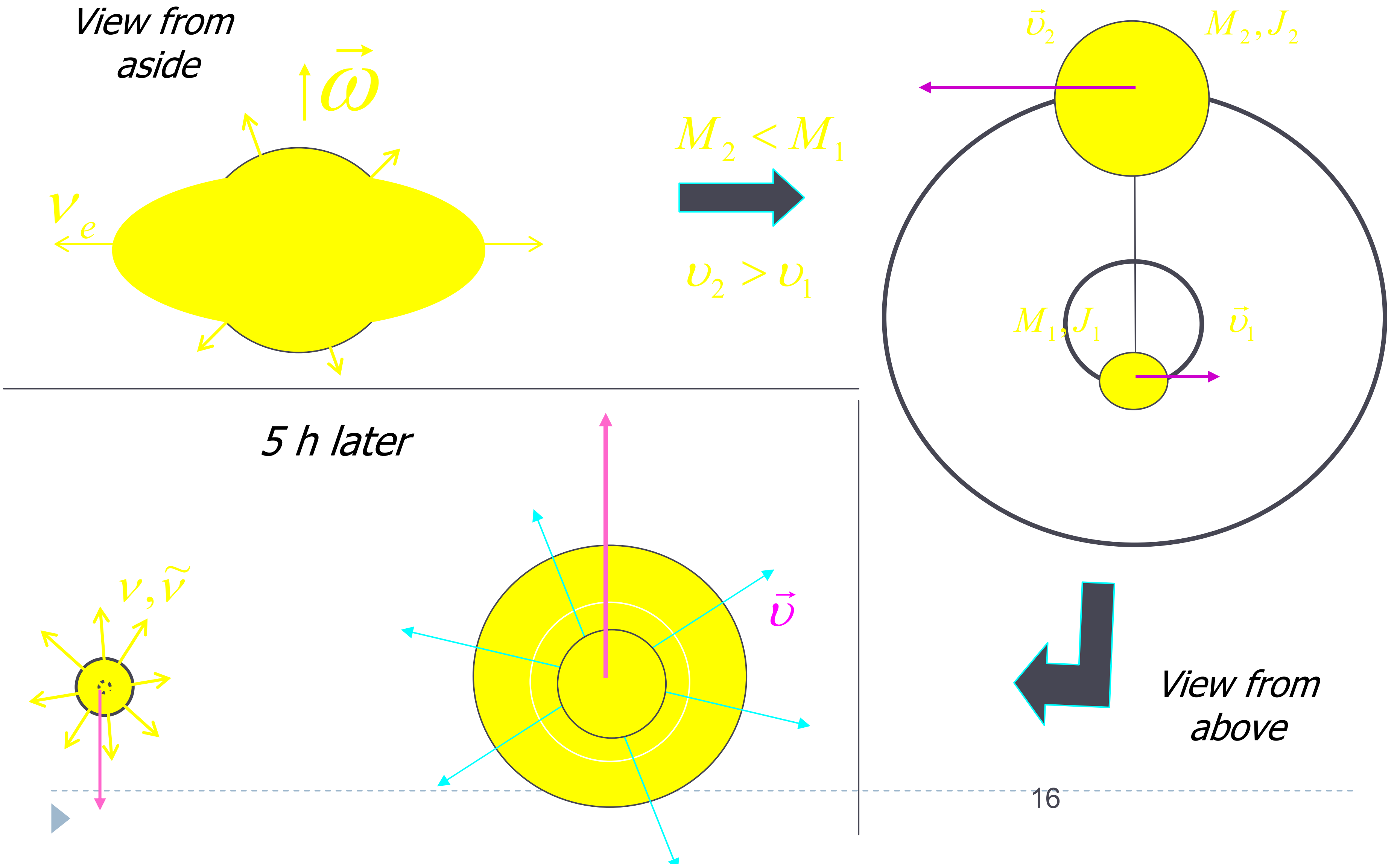
• Strong deformation and fragmentation of the rapidly rotating stellar core is characteristic of the period near 2:52 UT.

• Asymmetric configurations that have high angular momenta and that intensely emit gravitational waves arise at this time [Imshennik V.S., //Astronomy Lett., 34, 375 (2008)]. The time near 7:35 UT is characterized by the fact that the star has already lost the bulk of its angular momentum and became quasi-spherical in shape [Imshennik V.S., Space Sci Rev, **74**, 325-334 (1995); Imshennik V.S., Ryazhskaya O.G. // Astronomy Lett., **30**, 14 (2004)].

A rotating collapsar

The Two-Stage Gravitational Collapse Model

[Imshennik V.S., Space Sci Rev, **74**, 325-334 (1995)]



On the interpretation

The excess of coincidences near 2:52 UT may be indicative of a very-low-intensity pulsed neutrino source operating in the regime of a pulsar at the presupernova stage.

Parameters of neutrino pulsar:

- **Dt~1 sec** – time emission
- **t >> 1 sec** – irregular pulse repeation period
- **t~2 hours** – lifetime period

This undoubtedly phenomenological scheme leaves a number of questions open but basically seems plausible to us.

Double pulses

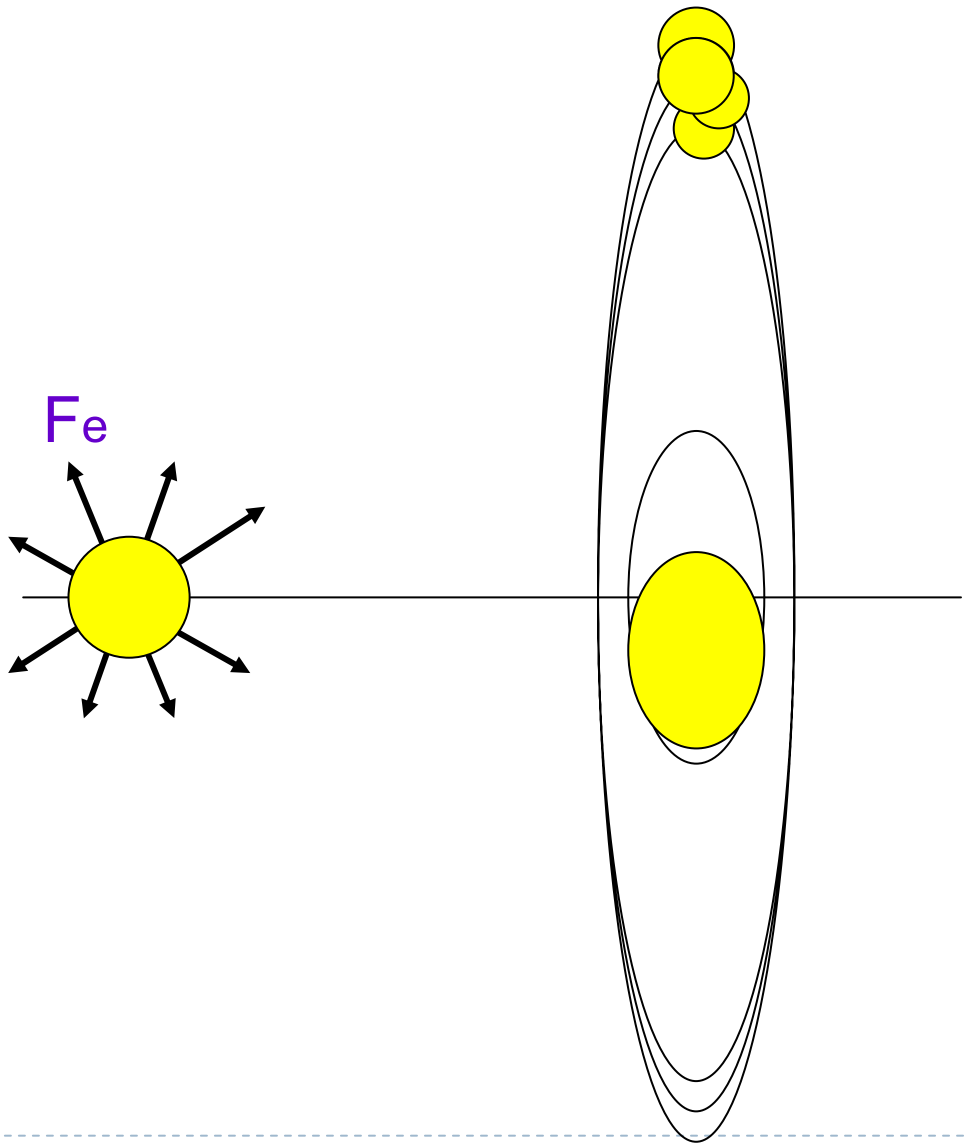
- O.G. Ryazhskaya [Phys. Usp. **49,** 1017 (2006)], V.S. Imshennik and K.V. Manukovskii [Astron. Lett. **33,** 468 (2007)] proposed a mechanism of this phenomenon in the spirit of the ideas of the rotating collapsar model
- The iron nuclei produced during the explosion of a light neutron star and captured by the field of the heavy neutron star move in such eccentric elliptical orbits that their periastron kinetic energy is enough for the pion production. A typical time of 1.5 s between the pair pulses roughly corresponds to the rotation period.

$$Fe + Fe \rightarrow \pi^{\pm} + \ldots$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\tilde{\nu}_{\mu})$$

$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \tilde{\nu}_{\mu}$$

$$\mu^{-} + Fe^{56} \rightarrow \nu_{\mu} + Mn^{56}(Mn^{55}) + \ldots$$



$$J_{Fe}(E > 1\ GeV) \sim 10\% J_{Fe}^{tot}$$

$$(E > 10\ GeV) \sim 3\% J_{Fe}^{tot}$$

$$J_{Fe}(E) \sim \frac{1}{\sqrt{E}}$$

Fe + Fe
Fe + p
Fe + n

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\tilde{\nu}_{\mu})$$

$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \tilde{\nu}_{\mu}$$

$$\mu^{-} + Fe^{56} \rightarrow \nu_{\mu} + Mn^{56}(Mn^{55}) + \ldots$$

About the coincidences between the signals from gravitational antennas and the pulses in neutrino detectors.

- Here, an excess of coincidences was also detected near 2:52 UT. Of course, the sensitivities of the Maryland and Rome antennas are clearly too low to detect gravitational effects at a distance of 50 kpc.
- The situation here could be improved significantly by assuming that the gravitational radiation from SN1987A was anisotropic.

•In any case, the **logic of the experiment**, a periodically repeated coincidence of the signal in a gravitational wave detector with the signal in a neutrino detector within narrow time windows, points to the possible existence of a pulsed source of gravitational radiation (**gravitational pulsar**) operating in the regime of a pulsar synchronously with a **neutrino pulsar**.

Let us think about
the explanation of
these coincidences and
double pulses measured
during SN1987A

Thank you for your attention!

Neutrino detection from a collapsing star makes it possible:

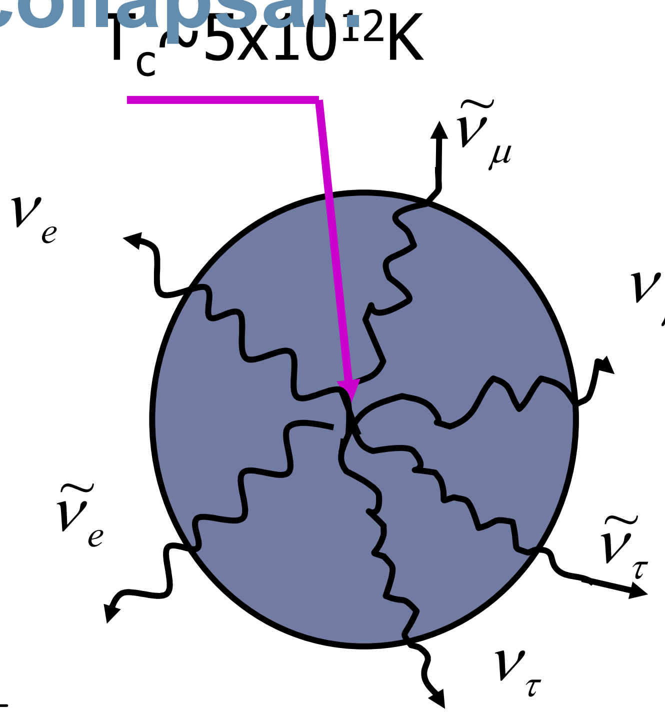
- To detect gravitational collapse even it is “silent” (isn’t accompanied by Supernova explosion);
- To investigate the dynamics of collapse;
- To estimate the temperature in the star center.

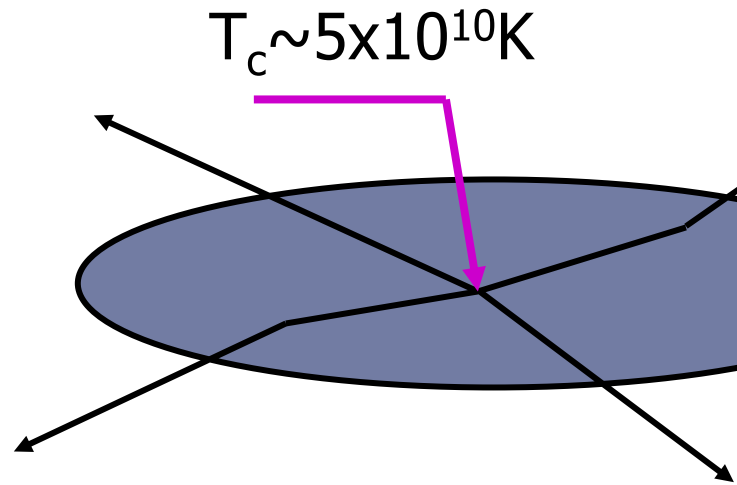
If the star is nonmagnetic, nonrotating, spherically symmetrical the parameters of neutrino burst are the following (Standard model):

Model	**Total energy,** $10^{53} erg$	**Total energy of** $\tilde{\nu}_e$,$10^{53} erg$	**Total energy of** ν_e ,$10^{53} erg$	$\overline{E}_{\tilde{\nu}_e}, MeV$	$\overline{E}_{\nu_e}, MeV$	$E(\nu_e)$ MeV	**Duration, s**
Model I	3-14	0.5-2.3	0.1	12.6	10.5	-	~20
Model II				10	8	25	5

From the theory of the Standard collapse it follows that the total energy, carried out by all types of neutrinos $\nu_e, \tilde{\nu}_e, \nu_\mu, \tilde{\nu}_\mu, \nu_\tau, \tilde{\nu}_\tau$, corresponds to ~ 0.1 of star core mass and is divided among these 6 components in equal parts.

The difference of neutrino emission in the standard model and in the model of rotating collapsar





$$\rho \sim 2.6 \cdot 10^{14} g \cdot cm^{-3}$$

$$\overline{E}_{\tilde{\nu}_e} = 12 MeV$$

$$\overline{E}_{\nu_e} = 10 MeV$$

$$\overline{E}_{\nu_\mu, \tilde{\nu}_\mu, \nu_\tau, \tilde{\nu}_\tau} = (20 - 25) MeV$$

The main reaction:

$$p + e^- \rightarrow n + \nu_e$$

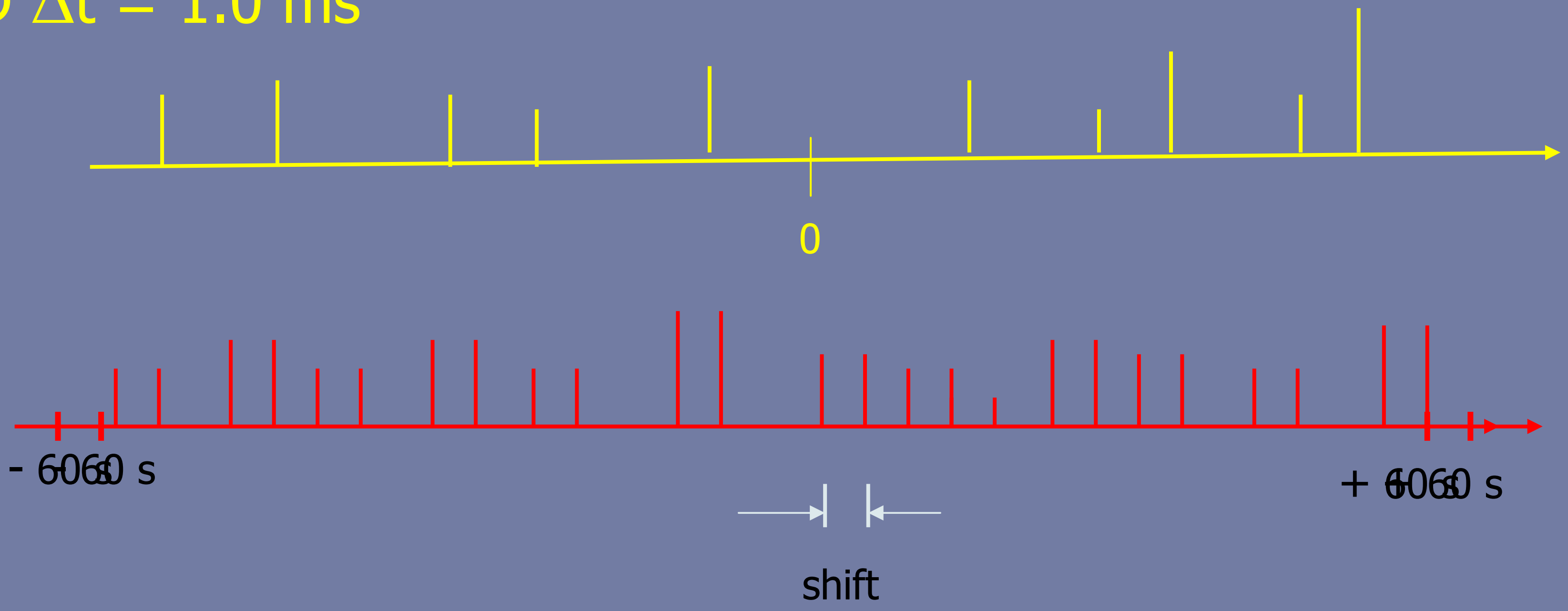
$$\overline{E}_\nu = (30 - 40) MeV$$

- $\varepsilon_{\nu, \tilde{\nu}} = 5.3 \cdot 10^{53} erg$

$$\varepsilon_{\nu_e, \tilde{\nu}_e} \approx \varepsilon_{\nu_e} = 8.9 \cdot 10^{52} erg$$

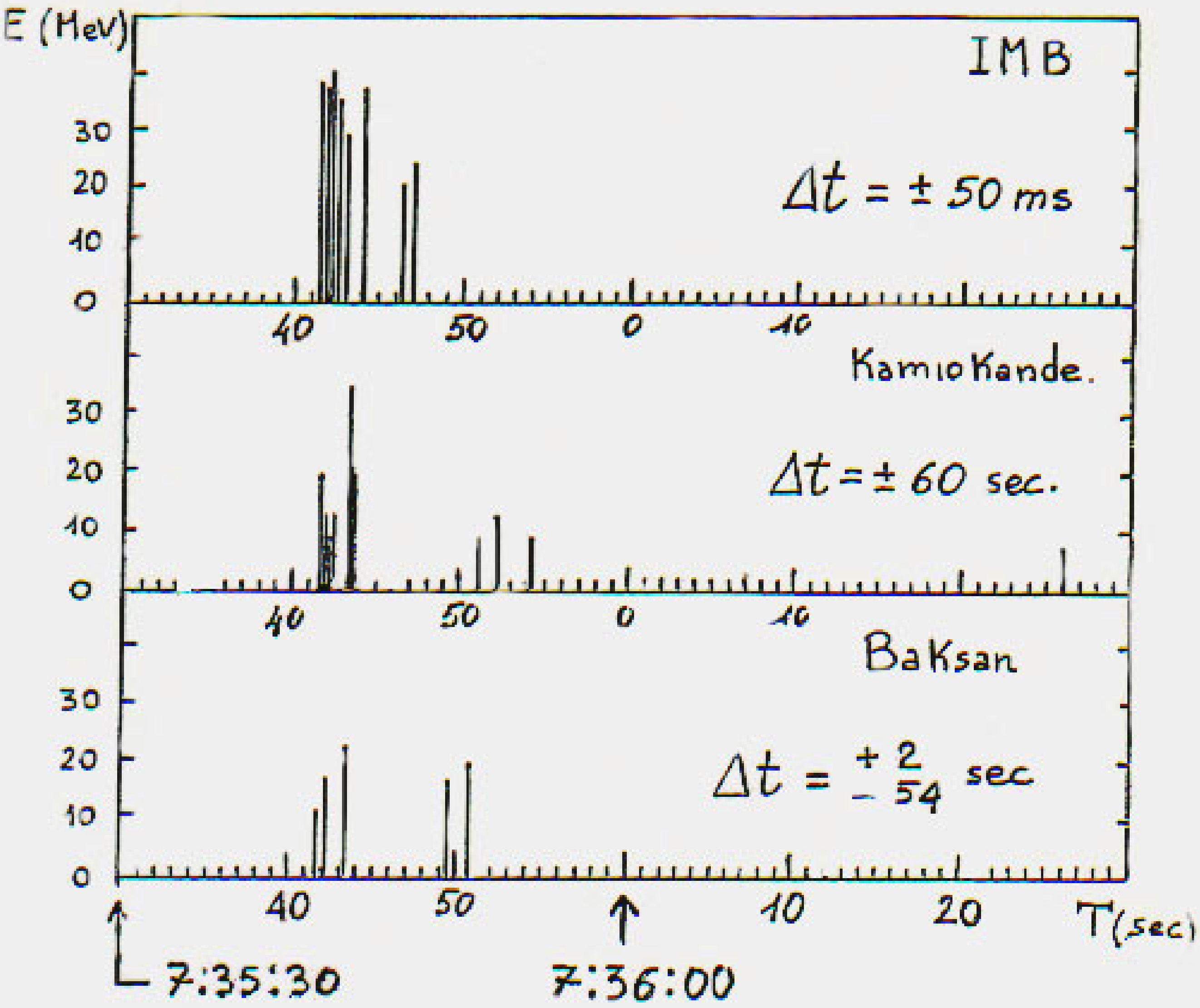
Kamioka-LSD correlations

LSD Δt = 1.0 ms



Kamioka Δt= 60 sec

Feb/23/1987 at 7:35 UT



T_{IMB} - T_{KAM} = 7.7 sec
T_{IMB} – T_{BAK} =-30.4 sec

LSD			Kamiokande				
Event Number	Time	Energy (MeV)	Event Number	Time	Nhit	cos(teta)	Time dif.(sec) LSD-Kam
957	2:11:37.04	6.4	124037	2:11:29.72	23	-0.647	7.31
970	2:29:30.77	7.5	124948	2:29:23.39	21	-0.807	7.37
971	2:31:23.31	6.8	125041	2:31:16.51	20	-0.805	6.80
979	2:36:17.75	6.5	125275	2:36:10.91	20	0.170	6.84 ← **BST**
1017	3:05:35.37	7.1	126600	3:05:28.82	34	-0.028	6.55
1026	3:12:39.10	7.2	126905	3:12:32.57	21	-0.842	6.53
1027	3:12:39.46	7.3	.	.	.	.	6.89
1040	3:28:33.18	7.2	127782	3:28:25.99	39	-0.845	7.19
1044	3:31:06.14	5.5	127904	3:30:59.18	21	0.321	6.96

Coincidences between LSD and K2 in the period from 1:45 - 3:45 UT, Feb. 23 1987.
The coincidence window is 0.5 sec.

LSD				Baksan		
Index	Event Number	Time	Energy (MeV)	Time	Energy (MeV)	Time dif.(sec) LSD-Baksan
1 2 3 4	931	1:47:48.80	8.4	1:48:18.12	22.9	-29.32
1 3 4	934	1:52:22.45	6.3	1:52:52.63	17.5	-30.18
1 2 3 4	945	2:03: 0.48	7.9	2:03:30.04	8.8	-29.56
1 2 3 4	954	2:10:40.10	6.2	2:11:09.70	35.6	-29.60
1 2 3 4	955	2:10:40.32	6.8	.	.	-29.38
2 3	962	2:17: 5.05	7.2	2:17:33.84	22.9	-28.79
2 3 4	966	2:22:31.19	7.5	2:23: 0.33	12.5	-29.14
1 3 4	968	2:26:42.26	7.4	2:27:12.49	35.9	-30.23
1 2 3 4	977	2:34:35.62	6.9	2:35: 5.00	19.2	-29.38
1 3 4	979	2:36:17.75	6.5	2:36:47.80	29.1	-30.05 ← K-II
1 2 3 4	981	2:38:24.89	7.8	2:38:54.41	24.7	-29.52
1 2 3 4	036	3:25:15.53	7.0	3:25:45.11	23.5	-29.58
2 3 4	1047	3:38:21.10	7.8	3:38:50.08	20.6	-28.98
4	1051	3:43: 3.69	6.9	3:43:34.09	22.1	-30.40

Coincidences between LSD and BST in the period from 1:45 UT to 3:45, Feb. 23 1987.
The meaning of the index is:

Index	Coinc.window (sec)	BST time shift (sec)
1	± 0.5	-29.8
2	± 0.5	-29.1 o -29.2
3	± 0.75	-29.5
4	± 0.75	-29.7

Conclusions

- The explosion of SN 1987A occurred twenty years ago. This was not the first supernova explosion in the history of human civilization, but it was the first one when we were ready to measure the neutrino radiation from a star. Twenty years ago, we witnessed the triumph of the model of standard collapse. All happened exactly as was predicted by this model: a simple elegant experiment yielded precisely or almost precisely the result that was expected from it. There was a signal in the smallest of the four detectors that was not supposed to be and, in addition, it was five hours earlier than in other detectors. Nobody wanted even to understand this. Several years later, V.S. Imshennik suggested a remarkable model, the model of a rotating collapsar. It turned out that in the experiment with SN 1987A, all happened precisely or almost precisely as should be according to this model. Some rough edges remained: it is unclear how the angular distributions of the pulses at 7:35 UT in KII and IMB should be understood.
- Giving the theory, models, and predictions their due and treating them with great respect, it would be good not to overlook the experimental results. At some time, this almost happened to the effect recorded at 2:52 UT in LSD. It took the appearance of themodel of a rotating collapsar for the public opinion to be shifted. In our view, this is a manifestation of a dangerous tendency with regard to priorities.

Conclusions

Therefore, leaving the mechanism of the model and its details to specialists, we wish to emphasize that the signal in LSD at 2:52 UT corresponds to
the detection of electron neutrinos with energies 30–45 MeV or muon and tau neutrinos with energies of about 60 MeV at a total neutrino emission energy of □10^{53} *erg*. We do not want to associate this assertion with a specific model.
Note that, as was shown in the previous section, this result is stable with respect to the currently adopted schemes of neutrino oscillations with both direct and reverse hierarchies.
In conclusion, we argue that LSD detected a neutrino signal from SN 1987A on February 23, 1987, at 2:52 UT.