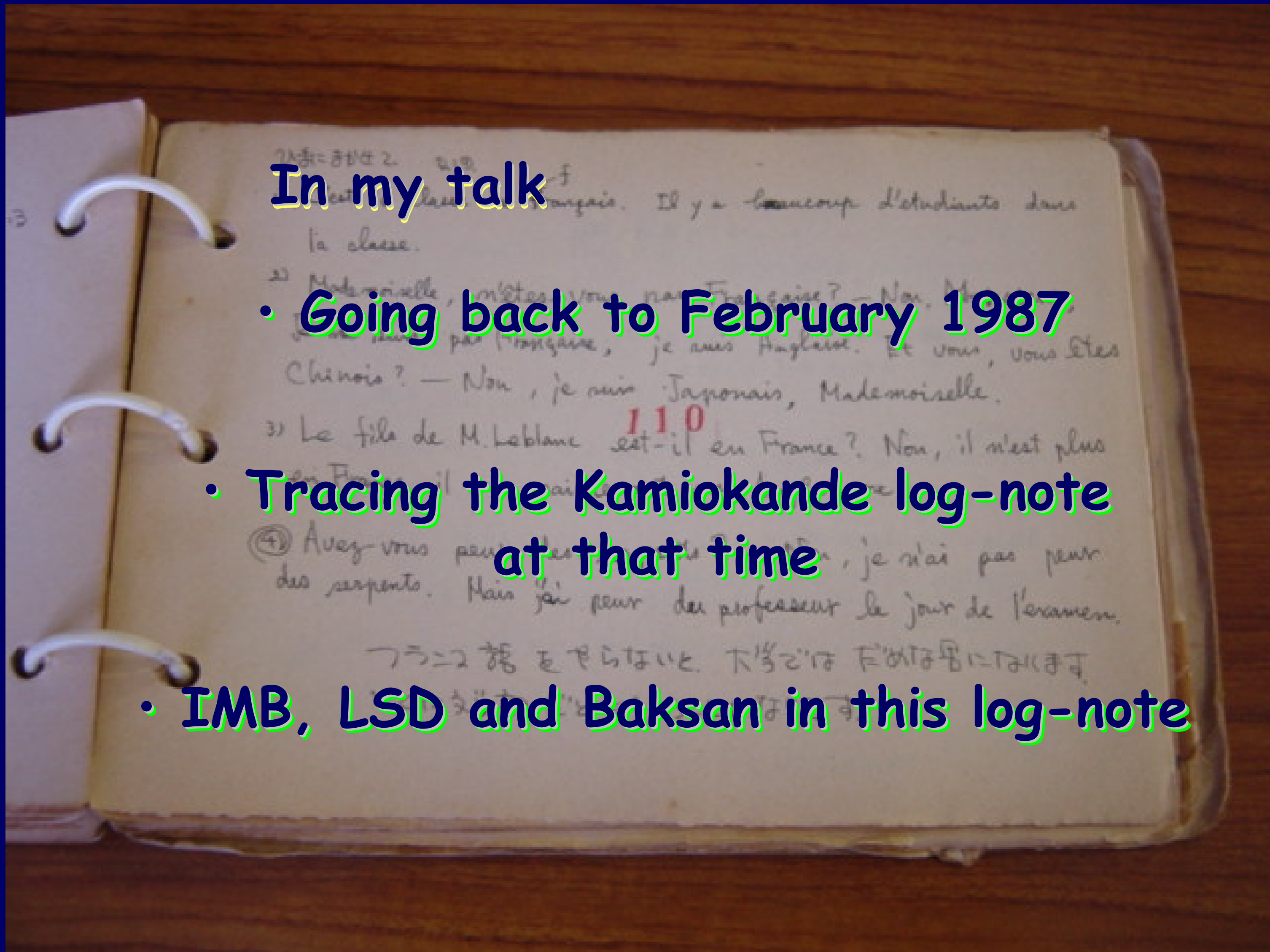
The Discovery of SN1987A Neutrino Bursts

Atsuto Suzuki
(KEK)

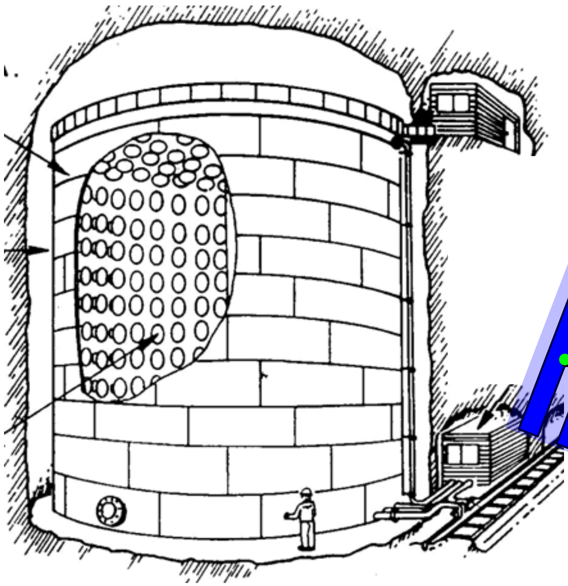
Outline



In my talk

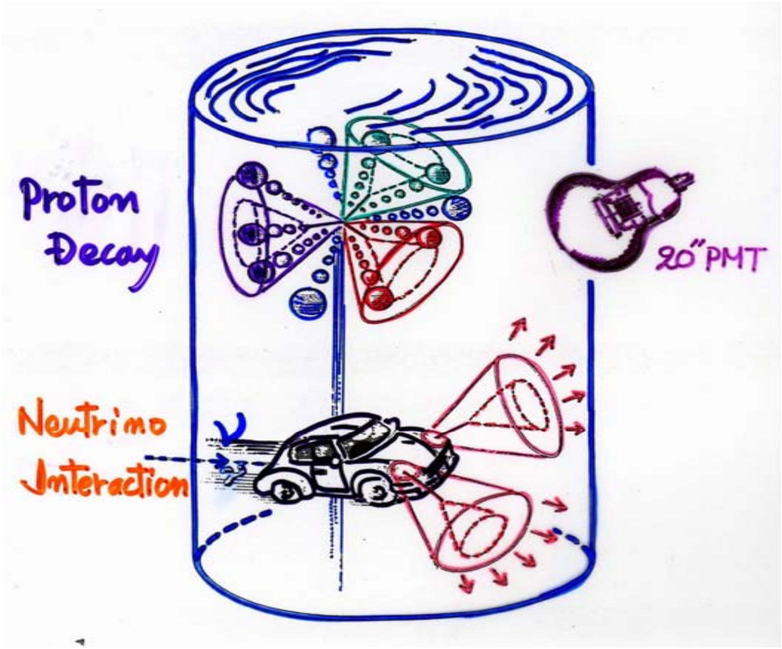
- Going back to February 1987
- Tracing the Kamiokande log-note at that time
- IMB, LSD and Baksan in this log-note

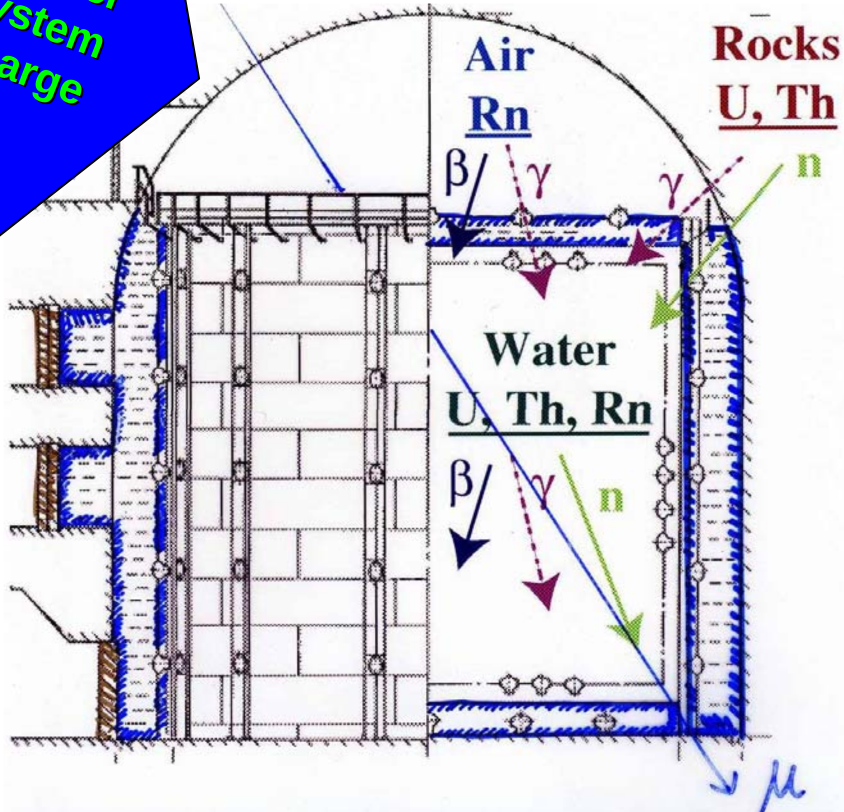
Kamiokande : 3000 ton Water Cherenkov Detector



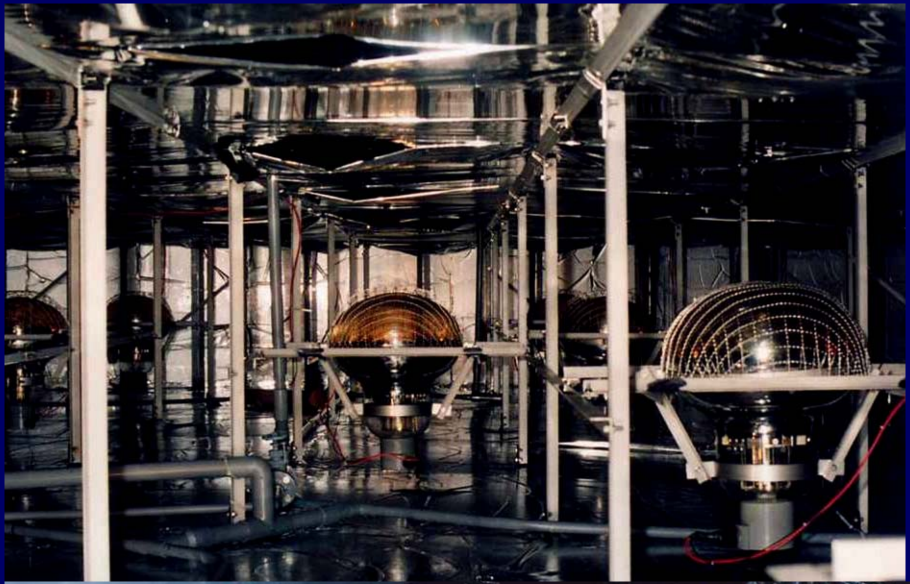
No positive events of nucleon decays for 1/2 year running
→ upgrade the detector to search for solar neutrinos

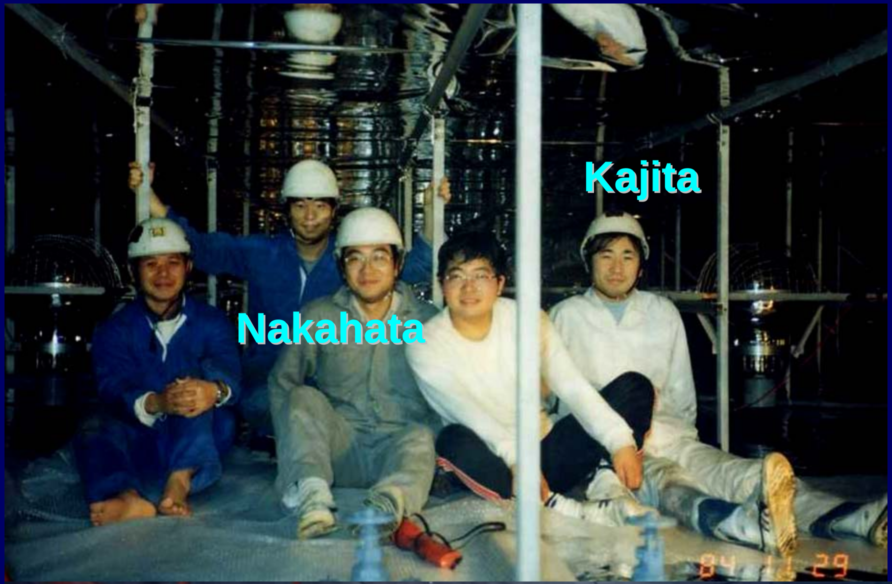
upgrade :
- hermetic, live anticounter
- water purification system
- multi-hit time and charge measurement

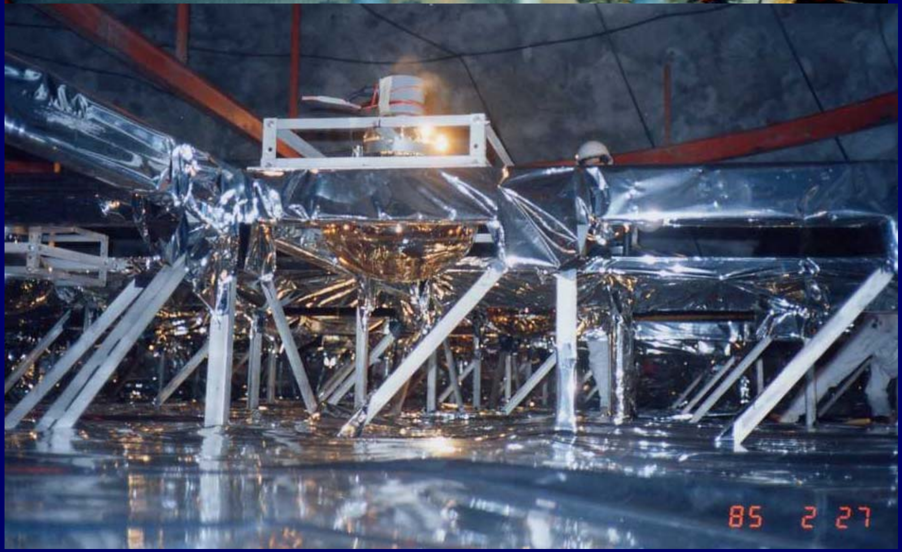




Kamiokande-II Construction
(September, 1984 ~)

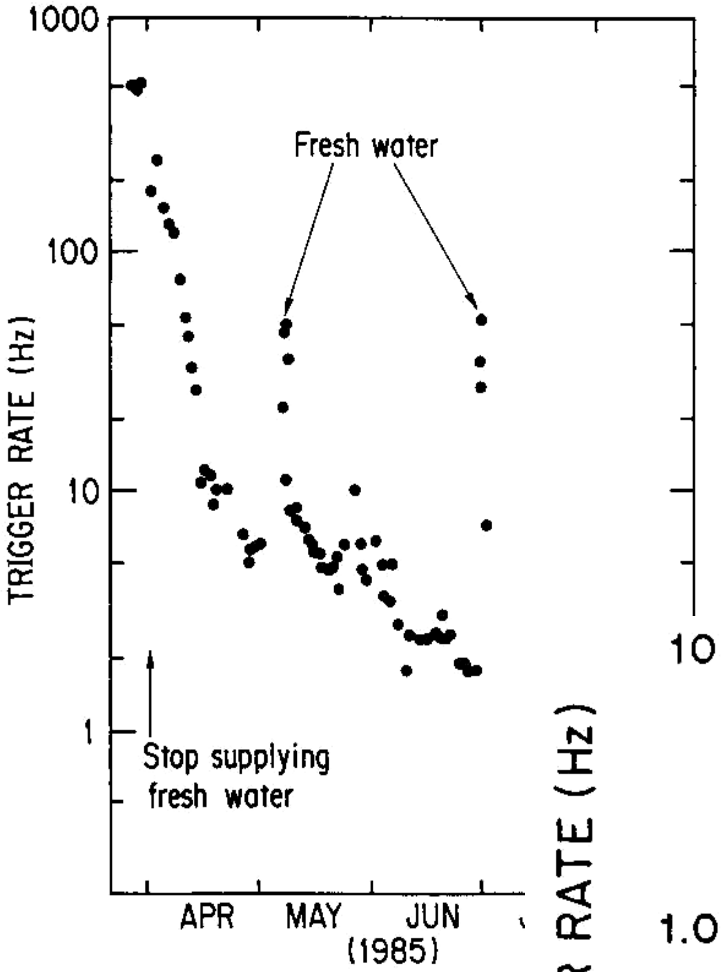


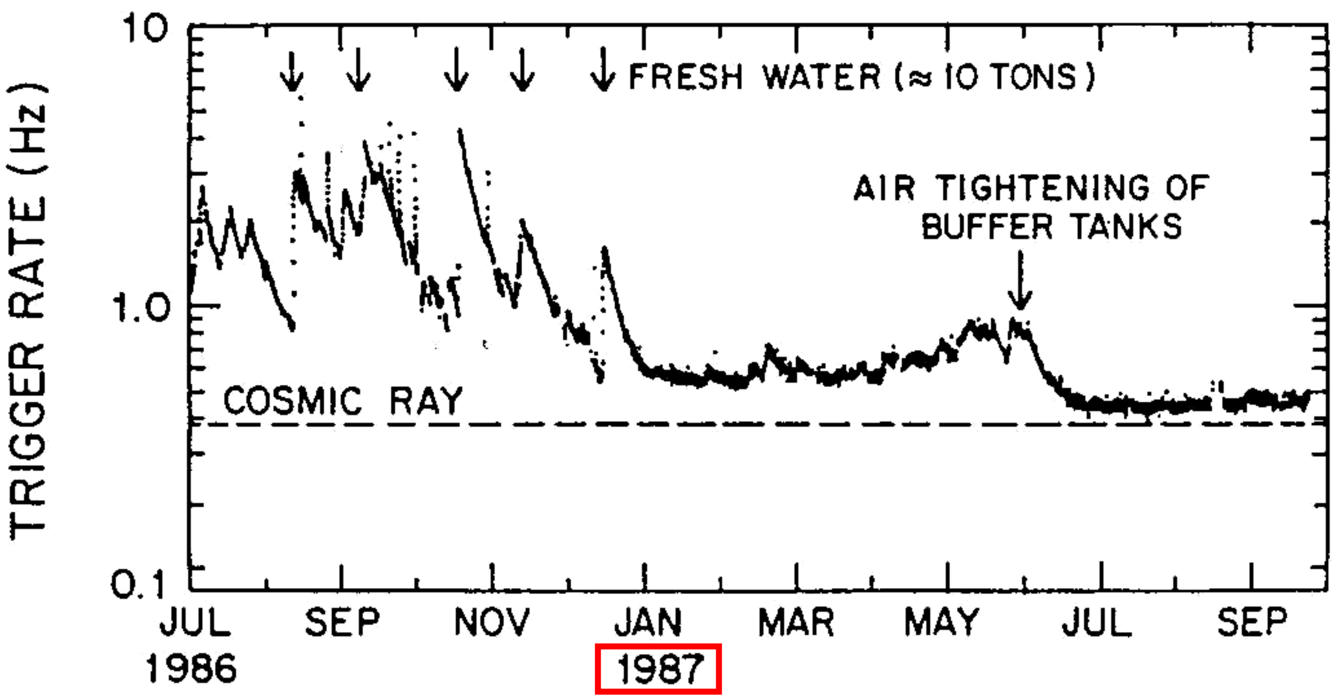




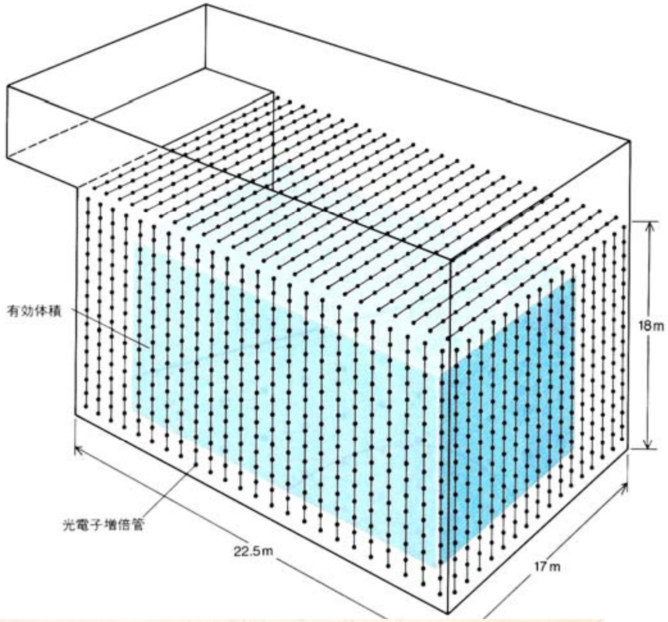
Trigger Rate History in Kamiokande-II

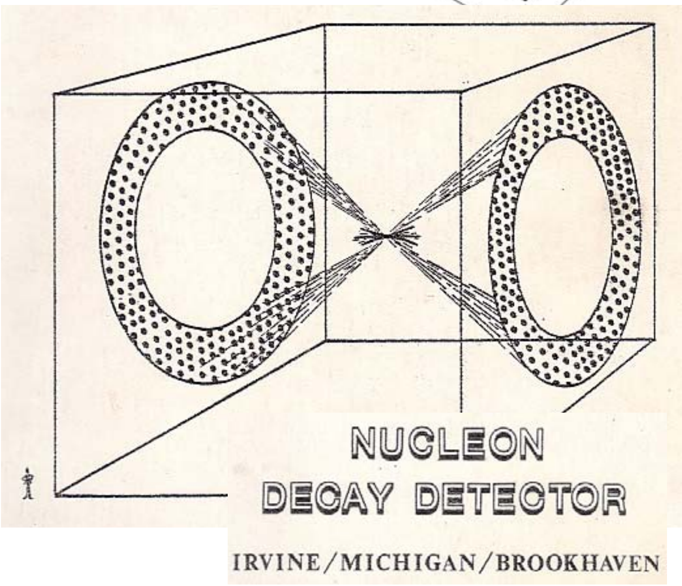
(E_{th} = 8.5 MeV)

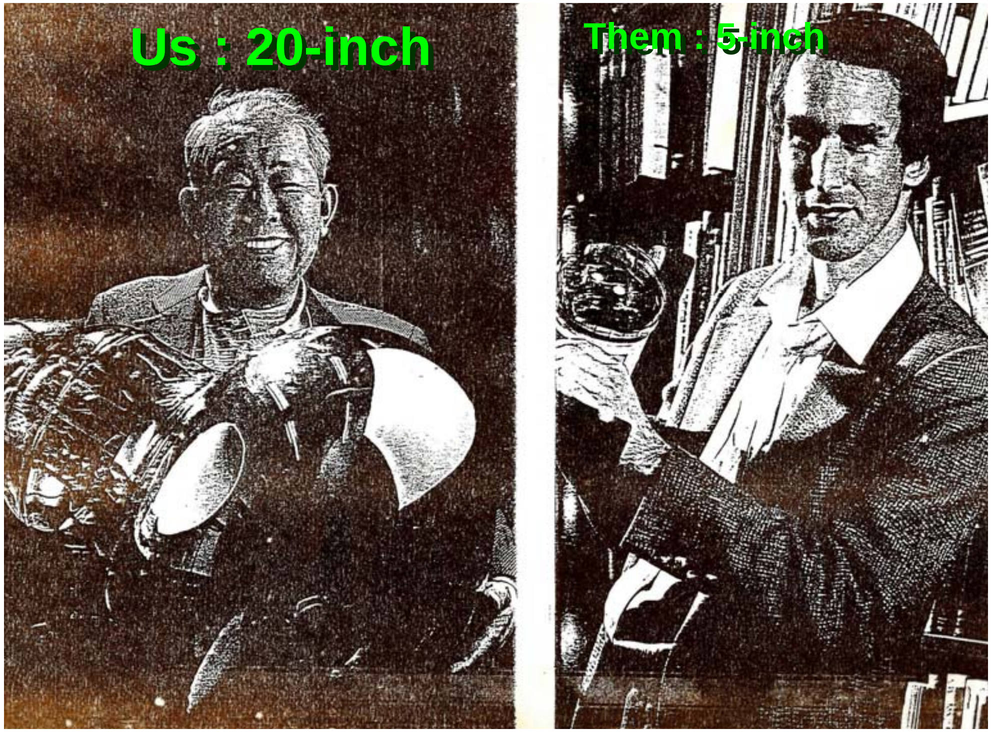




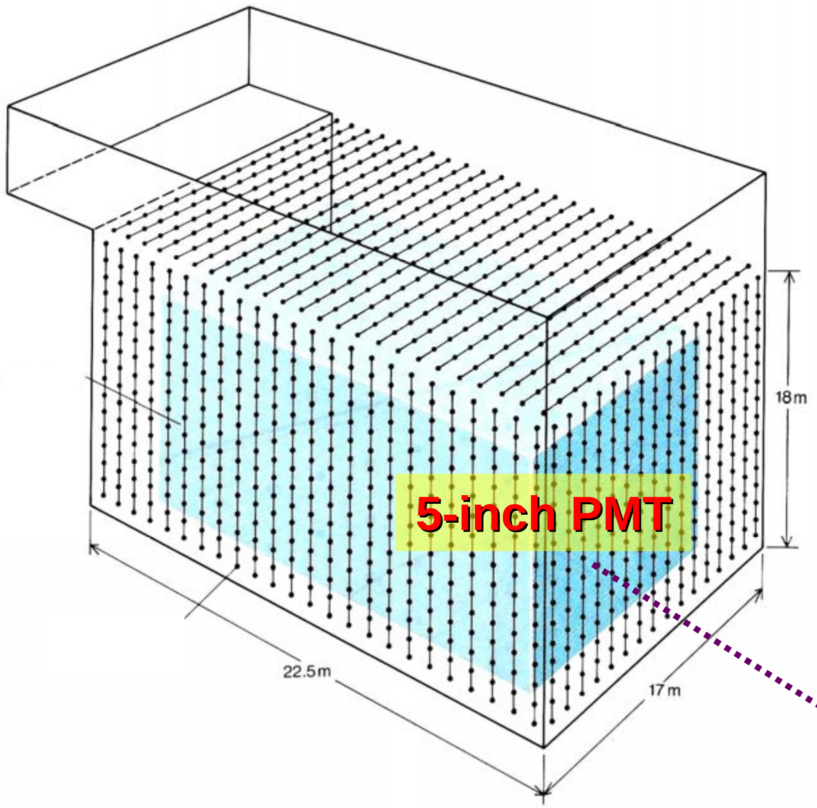
IMB: 8000 ton Water Cherenkov Detector



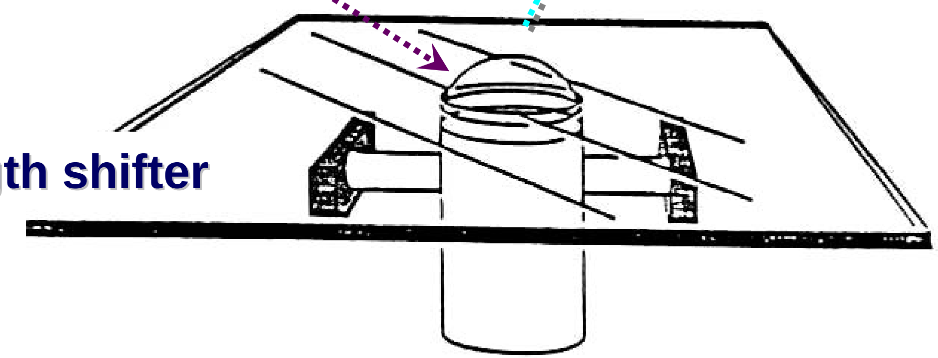




IMB Upgrade



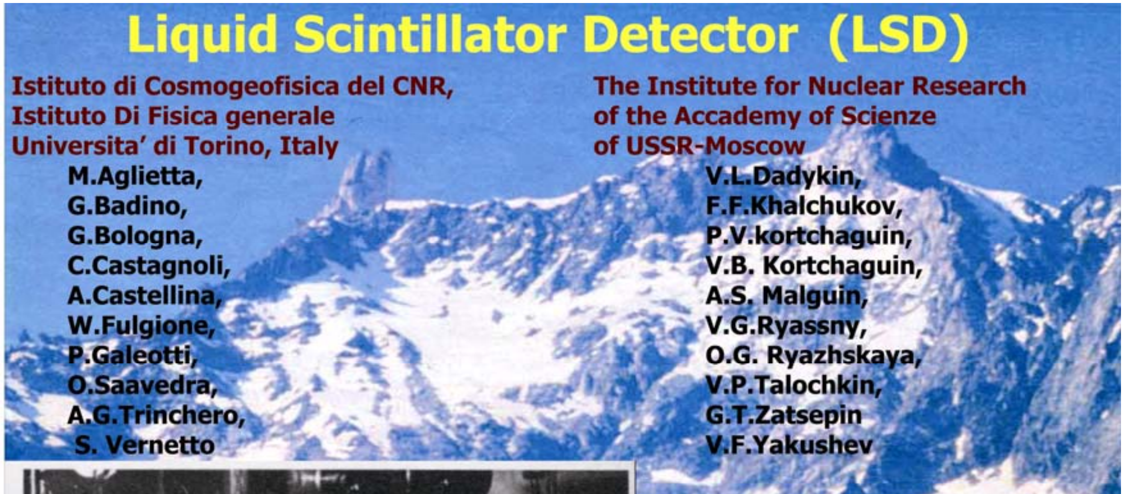
8-inch PMT

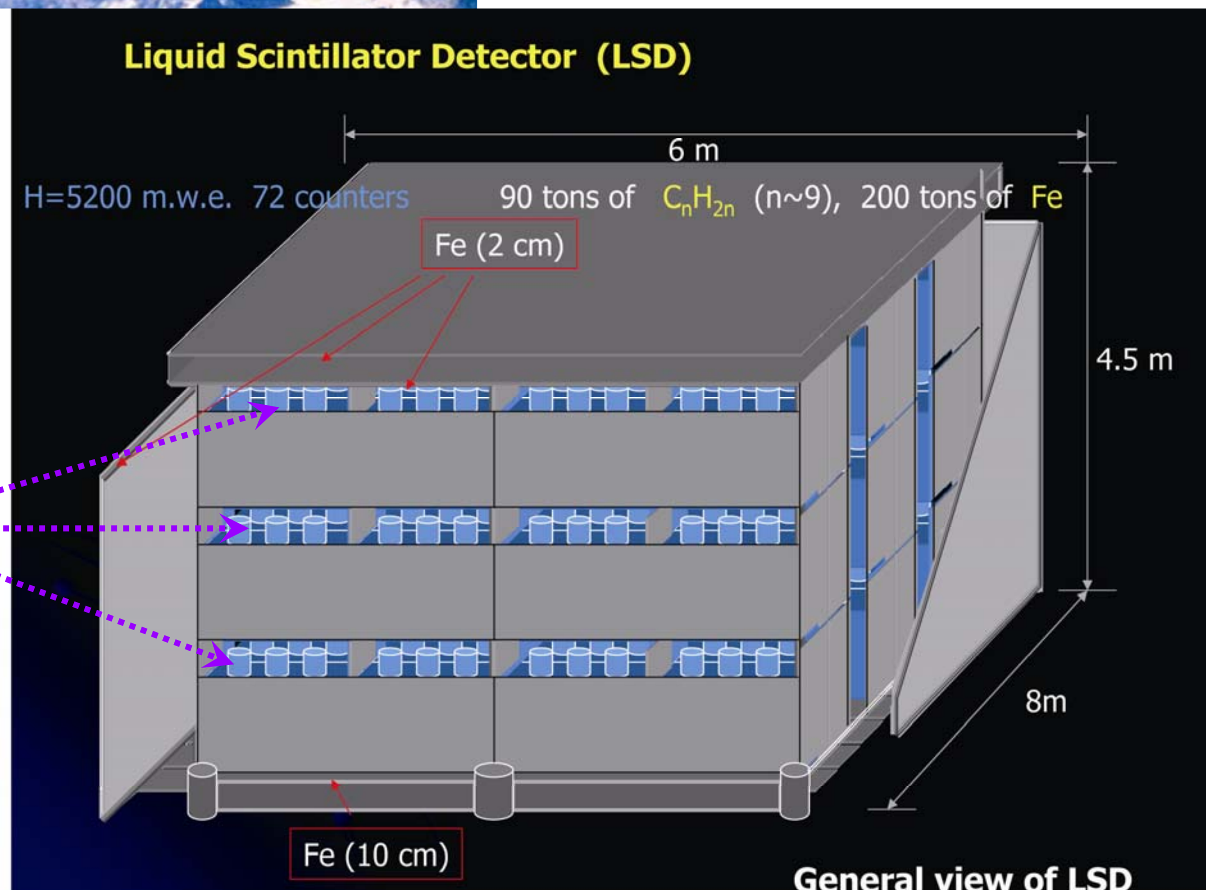


(60 x 60) cm wave length shifter

O. Saavedra (Hawaii, 2007)

LSD in Mont Blanc Underground Neutrino Observatory

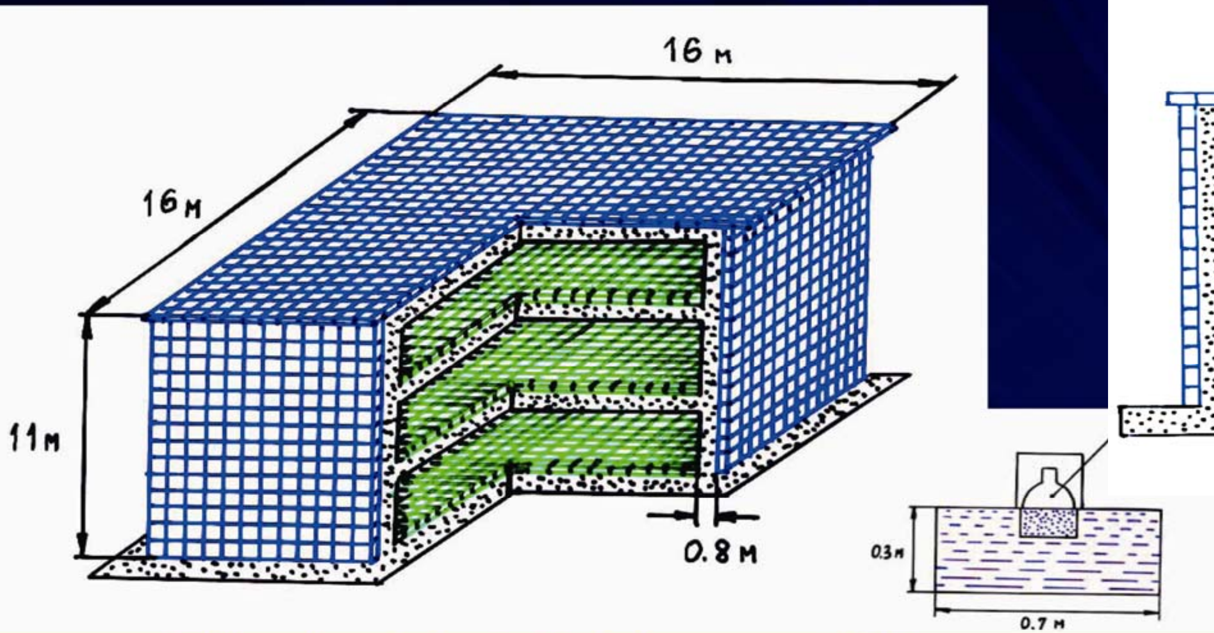


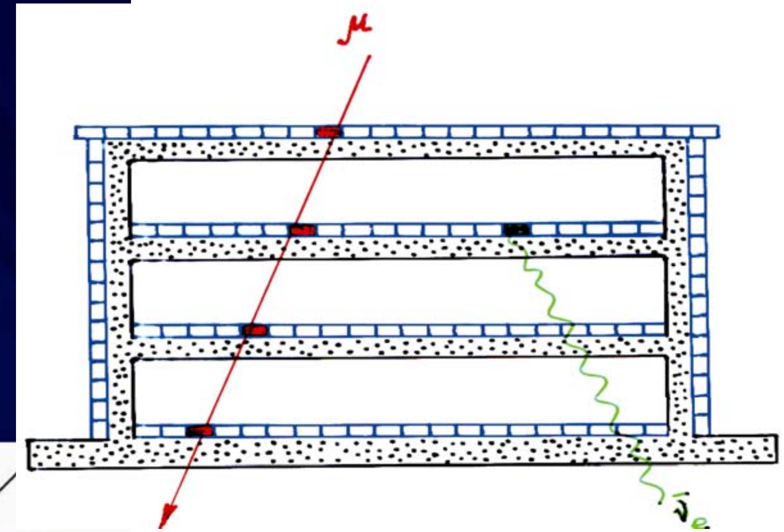


72 counters
(1.0 x 1.5 x 1.0) m^3

E. N. Alexeyev (Hawaii, 2007)

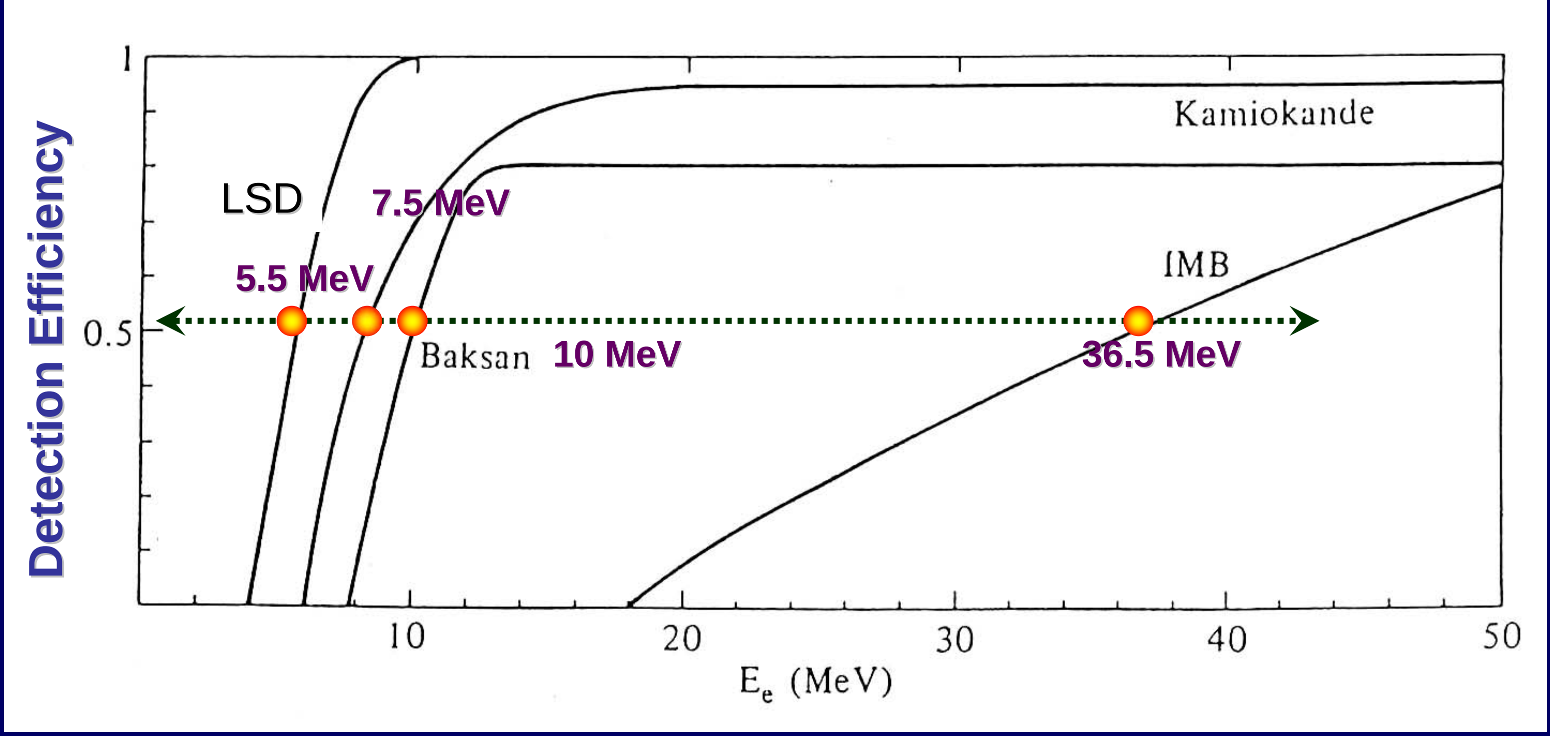
The Baksan underground scintillation telescope



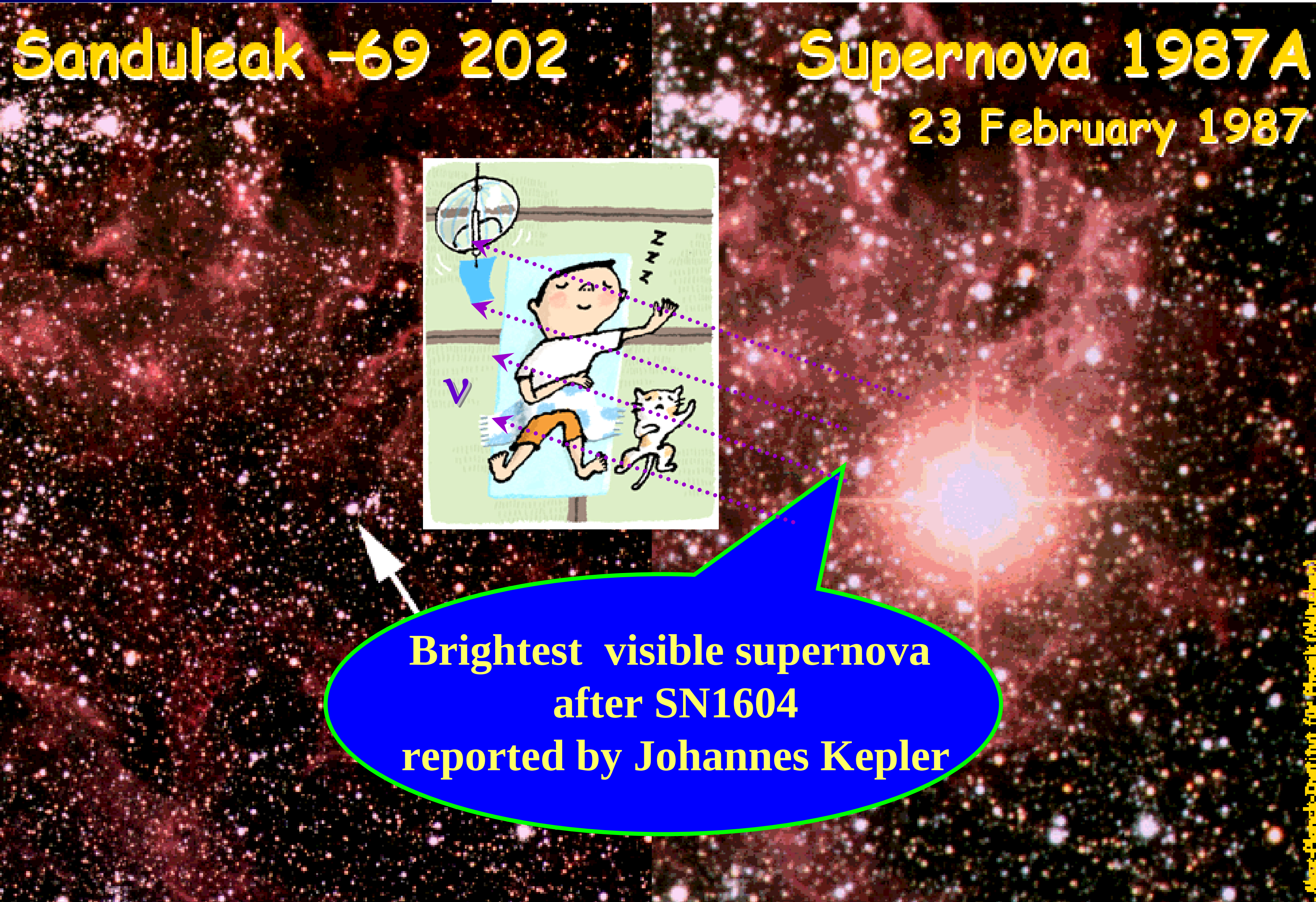


Total number of standard detectors..............3150
Total target mass................................330 tons of oil-based scintillator

Ready for SN Neutrino Bursts



23 February 1987



25 February 1987

Curtain of SN1987A neutrino drama was raised.

Fax from Sid Bludman to E. Beier

UNIV OF PENN – DEPT OF PHYSICS P.01

TO: EUGENE BEIER

SENSATIONAL NEWS! SUPERNOVA WENT OFF 4-7 DAYS AGO IN LARGE MAGELLENIC CLOUD, 50 KPC AWAY. NOW VISIBLE MAGNITUDE 4~5, WILL REACH MAXIMUM MAGNITUDE (~1~0) IN A WEEK. CAN YOU SEE IT? THIS IS WHAT WE HAVE BEEN WAITING 350 YEARS FOR!

SID BLUDMAN
(215) 546-3083

26 February 1987

Data MT (2/20～2/25)
from Mine → U. of Tokyo

The analysis team in Tokyo developed utility programs for finding out burst events, using previous data sample.

[N_{hit} – Time] plot for space-reconstructed events : useful

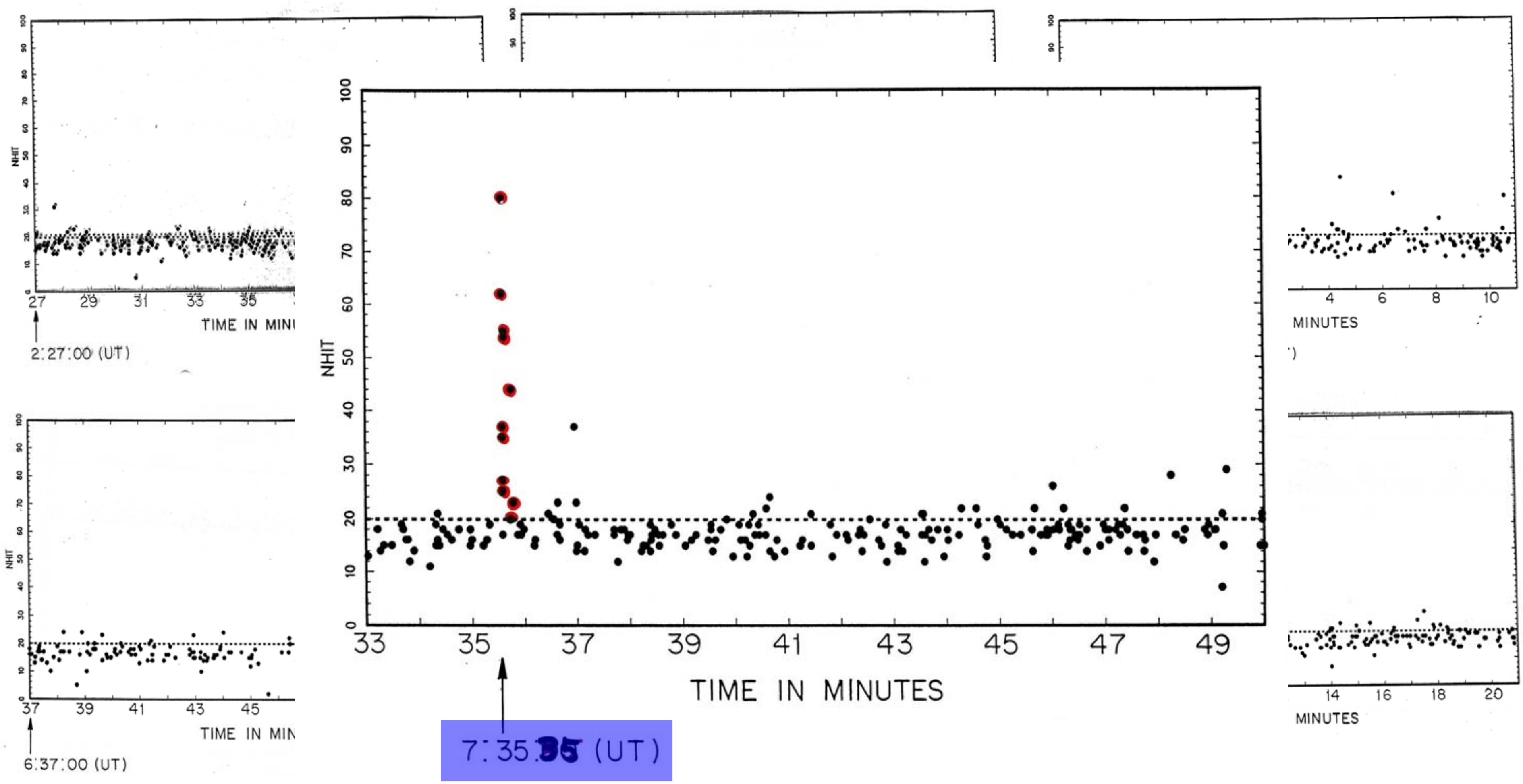
27 February 1987

Data MT arrived at U.T

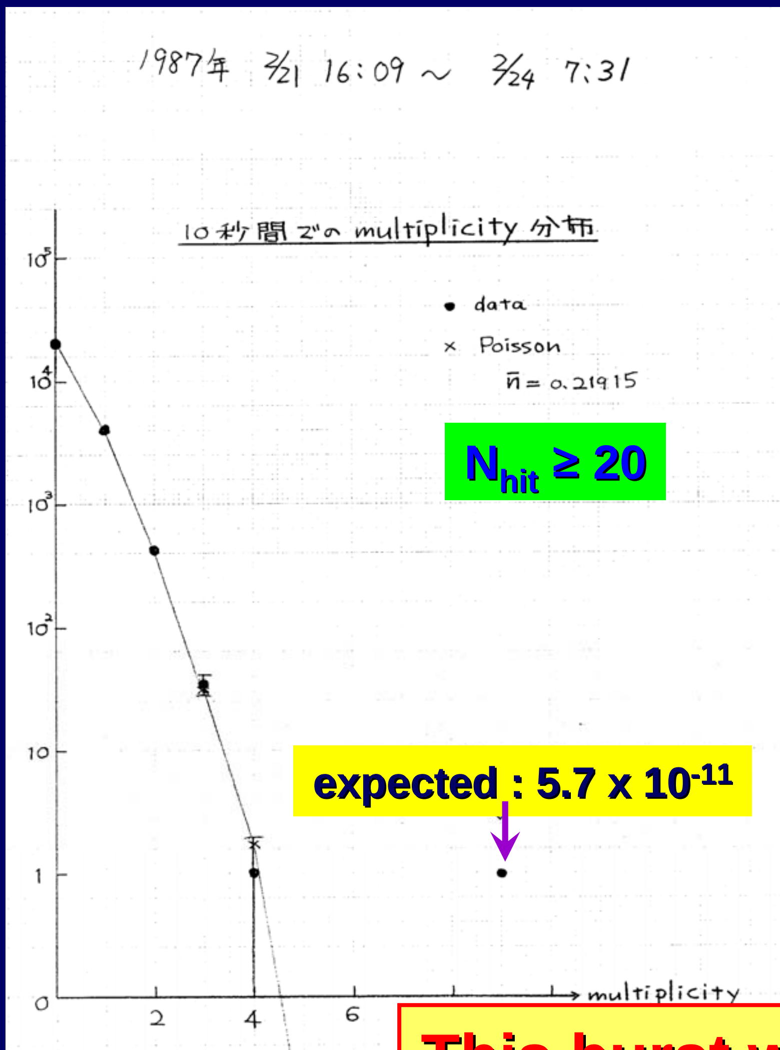
Normal event reduction procedure and SN burst search for data of 2/20 ～2/25

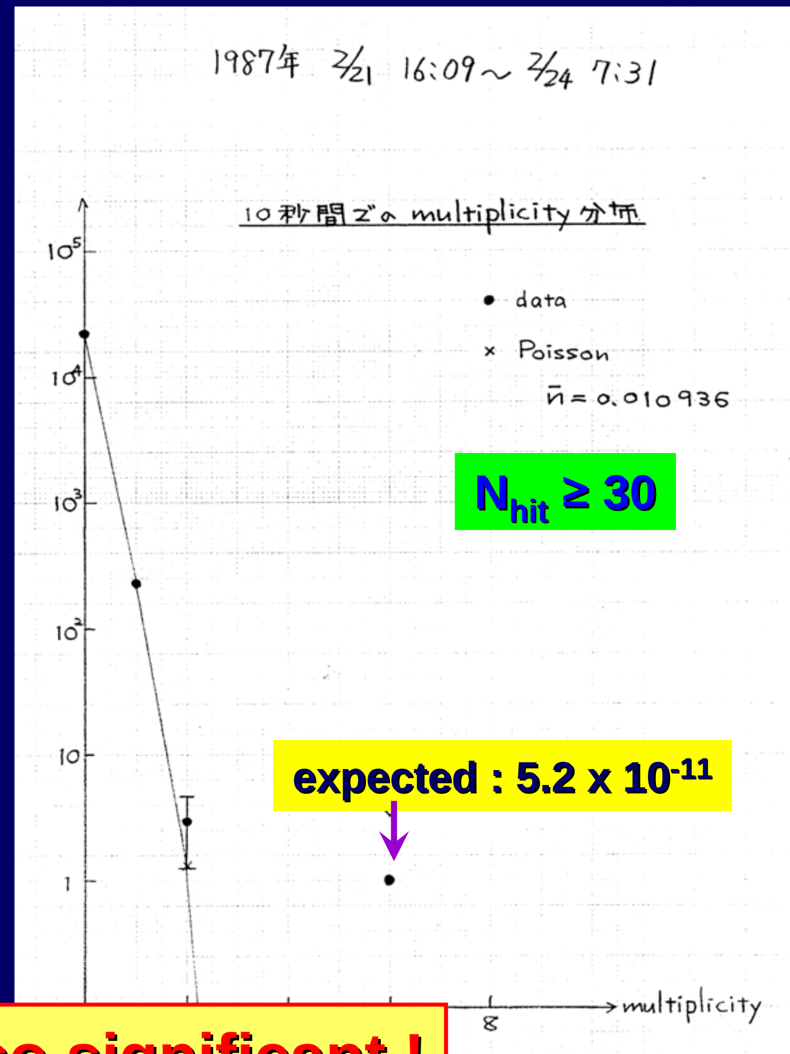
28 February 1987

[N_{hit} – Time] Plots



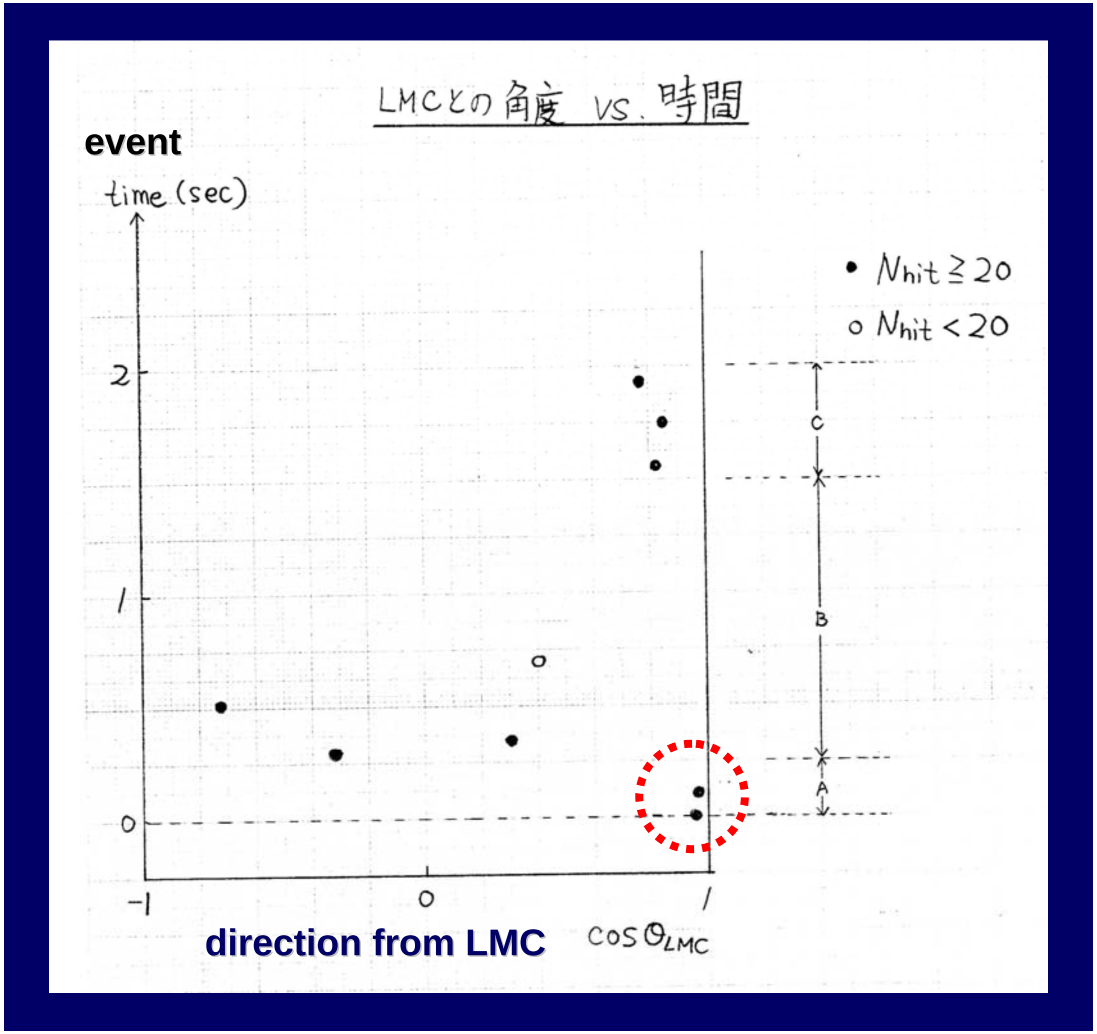
Faked Rate : Multiplicity Distribution for 10 sec. Window (~ burst duration)





This burst was so significant !

First 2 Events Pointed Back to LMC



1 March 1987

blank day : no analysis day

2 March 1987

explain : whole story of data analysis

expect : his smile like this

order : analyse more data (Jan. 1 ~ Feb. 25)

2 March 1987

News from LSD

5 events during 7 s.

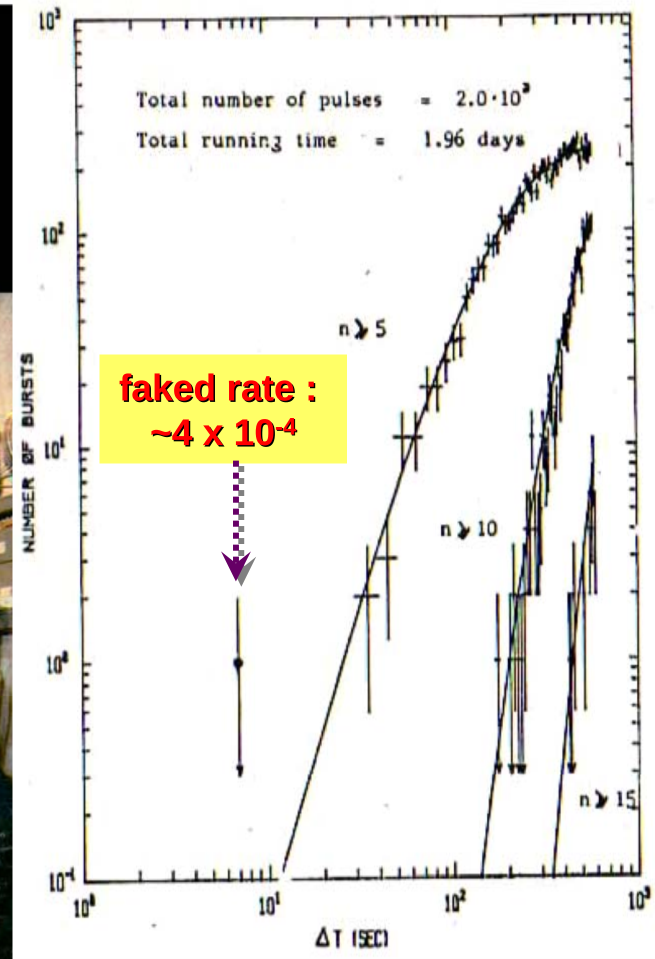
Feb. 23, 2 h 52 min 36s.

(4.5 hours before the Kamiokande time)

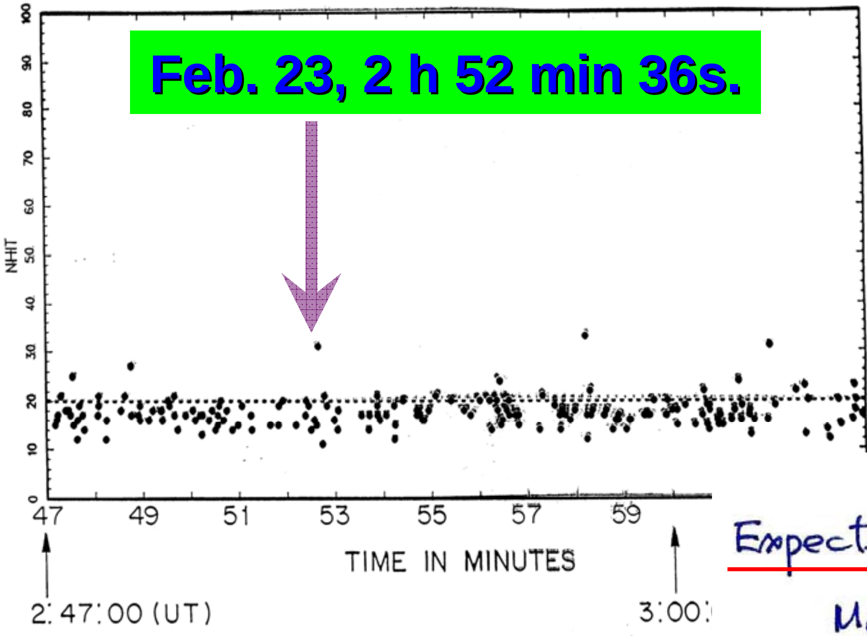
Events, detected by LSD

February,23, 1987 (SN 1987 A)

# of event	Time, UT±2ms	Energy, MeV
1	2:52:36,79	6,2 – 7
2	40,65	5,8 – 8
3	41,01	7,8 – 11
4	42,70	7,0 – 7
5	43,80	6,8 – 9
1	7:36:00,54	8
2	7:36:18,88	9



O. Saavedra (Hawaii, 2007)



Expected event number in Kamiokande

Mont Blanc data $7, 8, 11, 7, 9 = E_\nu$

$5.8, 6.8, 9.8, 5.8, 7.8 = E_{e^+}$

average KAMIOKANDE efficiency

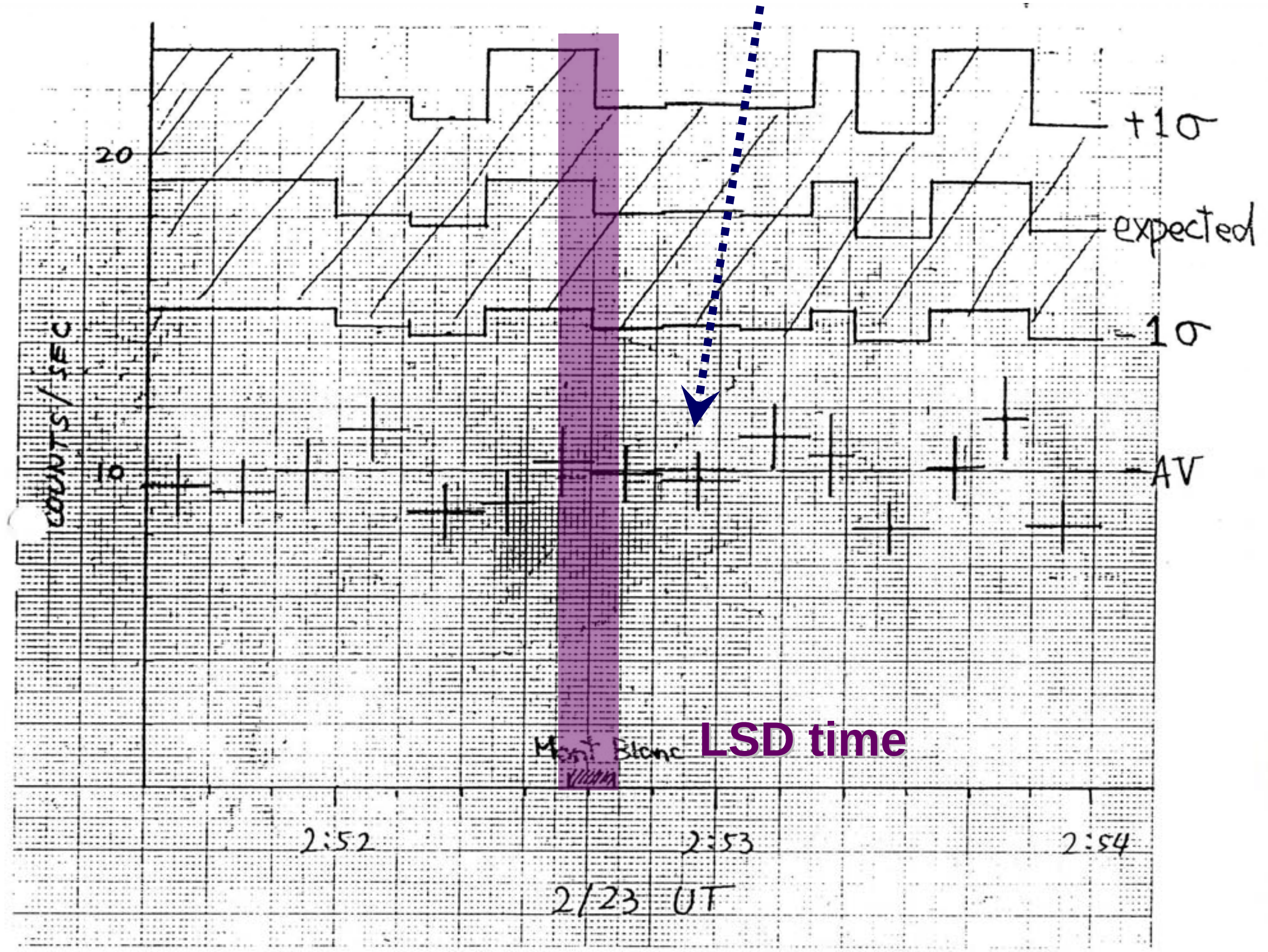
$E_{e^+} = 5.8$	0.1
6.8	0.25
9.8	0.7
5.8	0.1
7.8	0.4
	0.31

$$(5 \pm \sqrt{5}) \times \frac{2140\ \text{ton}}{90\ \text{ton}} \times \underbrace{\frac{2/18}{22/142}}_{C_{20}H_{22}} \times 0.31 = (27 \pm 12)$$

$\frac{1}{1.39}$

Kamiokande: low level trigger
E ≥ 6.5 MeV (50% detection efficiency)
:
only trigger rate

low level trigger rate



2 ~ 6 March 1987

UT-ICEPP-87-01
UPR-142E

Observation of a Neutrino Burst from the Supernova SN1987a

The KAMIOKANDE-II Collaboration

March 6. 1987
(Submitted for publication in Phys. Rev. Lett.)

Feb. 23, 7 h 35 min 35 s. (±1 min)

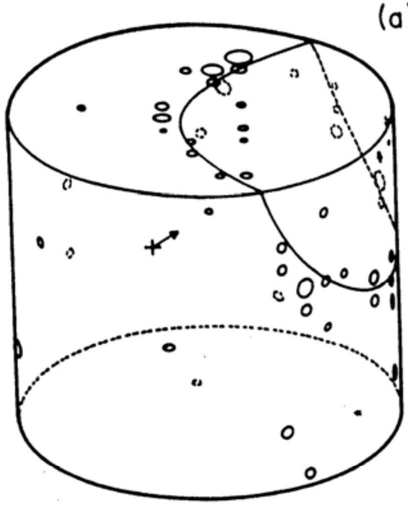
11 events during 13 s.
E ≥ 7.5 MeV

Event number	Event time (sec)	Number of PMT's (N_{hit})	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

time-adjust :
manually entering the phone company's recorded time into the control computer

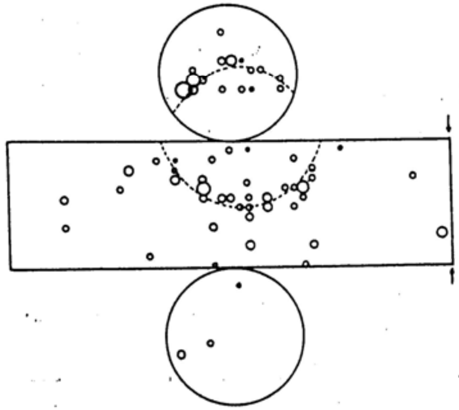
KAMIOKANDE 2-P

(a)



NUM	9
RUN	1892
EVENT	139372
TIME	2/23/87 16:35:37 JST

TOTAL ENERGY	19.8 MeV
TOTAL P.E.	51 (0)
MAX P.E.	4 (0)
THRES P.E.	0.2 (1.0)



KAMIOKANDE 2-P

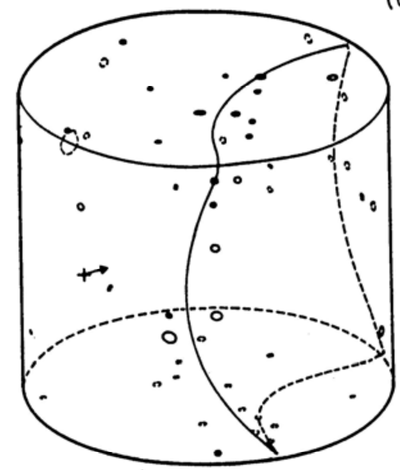
(b)

NUM	9
RUN	1892
EVENT	139372
TIME	2/23/87 16:35:37 JST

TOTAL ENERGY	19.8 MeV
TOTAL P.E.	51 (0)
MAX P.E.	4 (0)
THRES P.E.	0.2 (1.0)

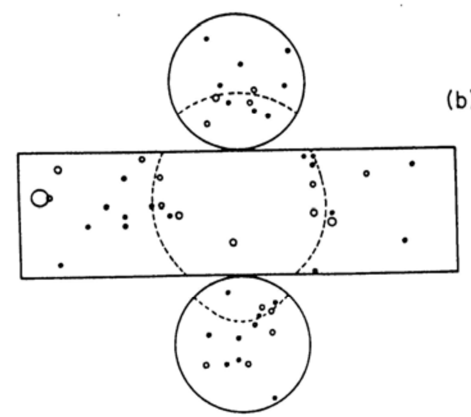
KAMIOKANDE 2-P

(a)



NUM	1
RUN	1892
EVENT	139364
TIME	2/23/87 16:35:35 JST

TOTAL ENERGY	20 MeV
TOTAL P.E.	72 (1)
MAX P.E.	13 (1)
THRES P.E.	0.2 (1.0)



KAMIOKANDE 2-P

(b)

NUM	1
RUN	1892
EVENT	139364
TIME	2/23/87 16:35:35 JST

TOTAL ENERGY	20 MeV
TOTAL P.E.	72 (1)
MAX P.E.	13 (1)
THRES P.E.	0.4 (1.0)

7 March 1987

- The paper submitted to PRL was posted.
- Everything was finished, we thought.
- A small party in a seminar room.
- One student came into the room and told us : our definition of the coordinate system (Right Ascension – Declination) was wrong.
- Soon after this, we found he was correct.
- Our analysis went back to the beginning.
- This mistake gave only sign-change and also we mistook two times • • • • • • (-)x(-) = (+)
- Fortunately modifying the paper was minimum.

8 March 1987

News from IMB

8 March 1987

To: IMB Collaboration

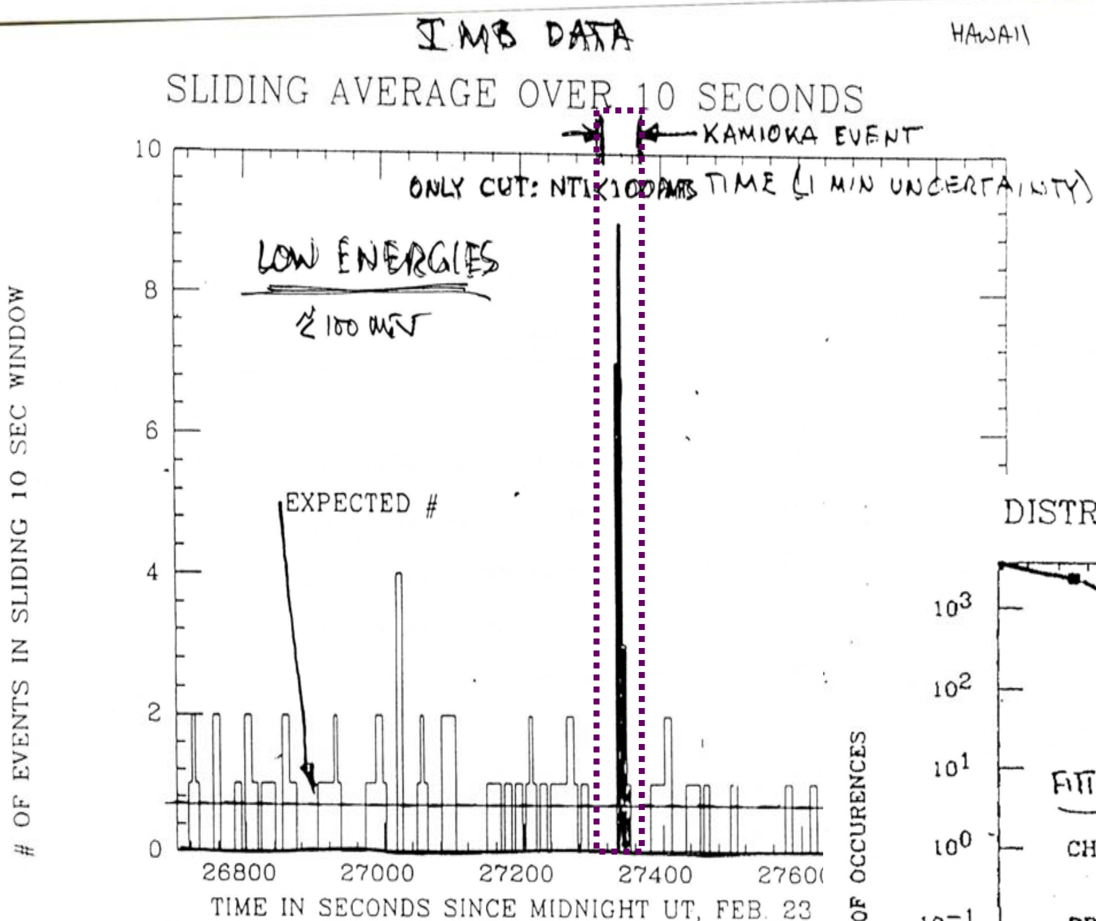
From: Steve Dye, John Learned, and friends in Hawaii

Subject: **Observation of SN1987A in IMB**

As everyone knows by now, we have good evidence for having seen the supernova in the Large Magellanic Clouds from the salty depths of Cleveland. The intention of this note is to summarize what we in Hawaii know at this time. It should be noted that much of this is work done in close contact with Bob Svoboda and Todd Haines at Irvine. We have also had help from many of the grad students here, in particular from Ralph Becker-Szendy, and also John Babson and Dan O'Connor (taking a few hours vacation from DUMAND).

Is it a real signal?

The first question is do we really have something? First of all we began by knowing the time that Kamiokande was reporting, namely that they had a neutrino burst on 2/23 at 7:35:35 UT (with a 1 minute absolute time uncertainty). Figure 1A shows the result of a scan of our data from Tape 2601 with a sliding time window of 10 seconds over a period of 20 minutes around the Kamiokande time. Note that the **only** data cut was to take events with NT1<100 PMTs. One sees a nice peak of 6 events in 2 seconds at just about the trial time, in fact starting within 6 seconds of the nominal Kamiokande time, as shown in Figure 2. This in itself is enough to be remarkable: we found 6 events when 0.67 were expected in 2 seconds. The number of trials might be taken as 60 (for the whole minute uncertainty quoted by Kamiokande, though we are infact within 6 seconds), so the probability of coincidence is something less than 4×10^{-3}. Figure 1B shows the data for a cut of NT1>100 PMTs, and has no evidence for a signal in the high energy events (> about 50 MeV). Figure 1C shows the effect of making a simple cut to eliminate garbage events (require average uncalibrated Q < 52). The chance probability of the 8 event peak is about 4×10^{-9}.



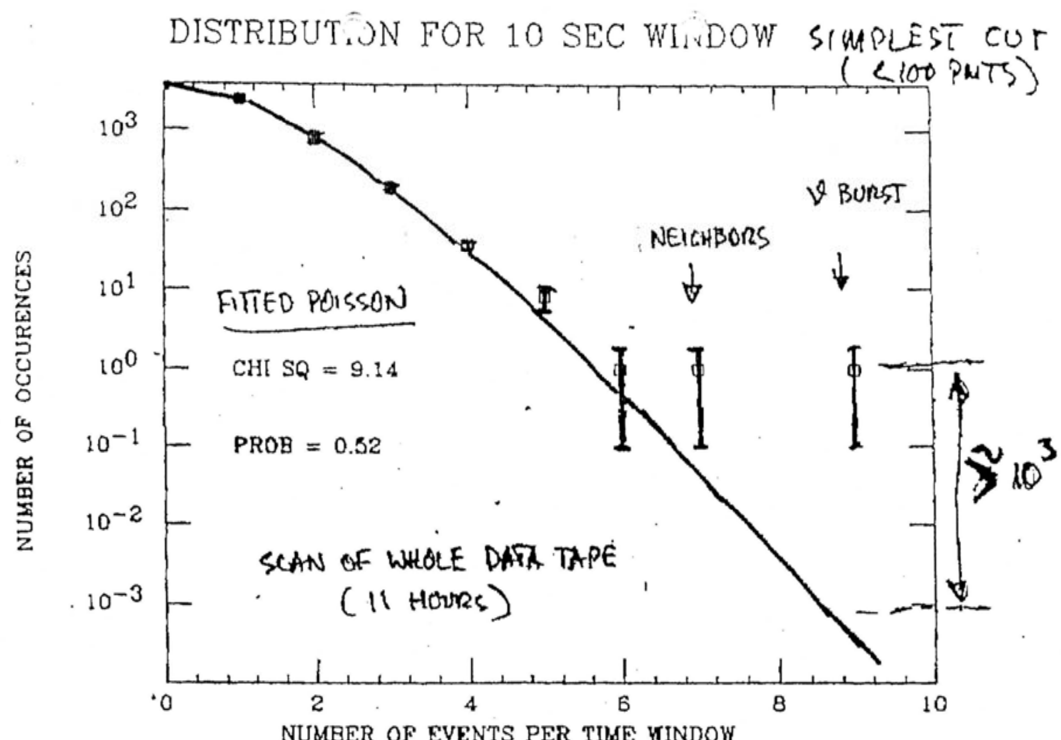


FIG 3

PROB OF SUCH A CLUSTER $< 10^{-3}$ IN WHOLE TAPE
$\lesssim 10^{-5}$ AT KAMIOKA TIME

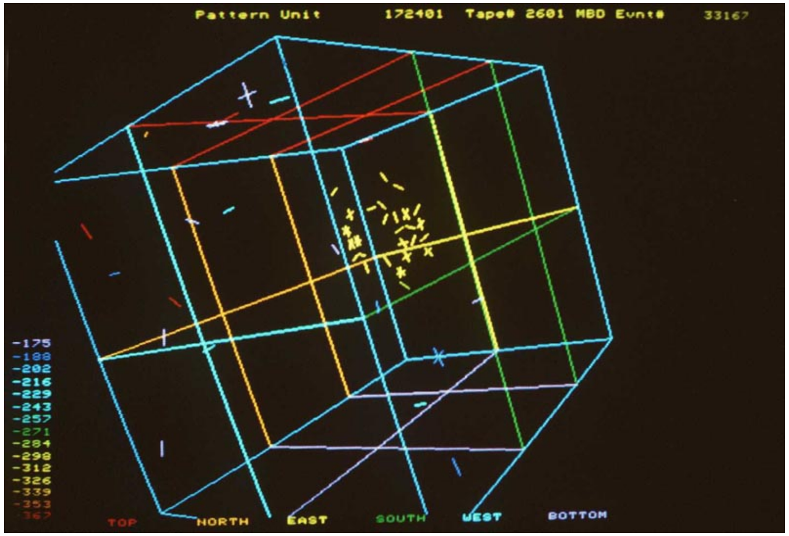
IMB

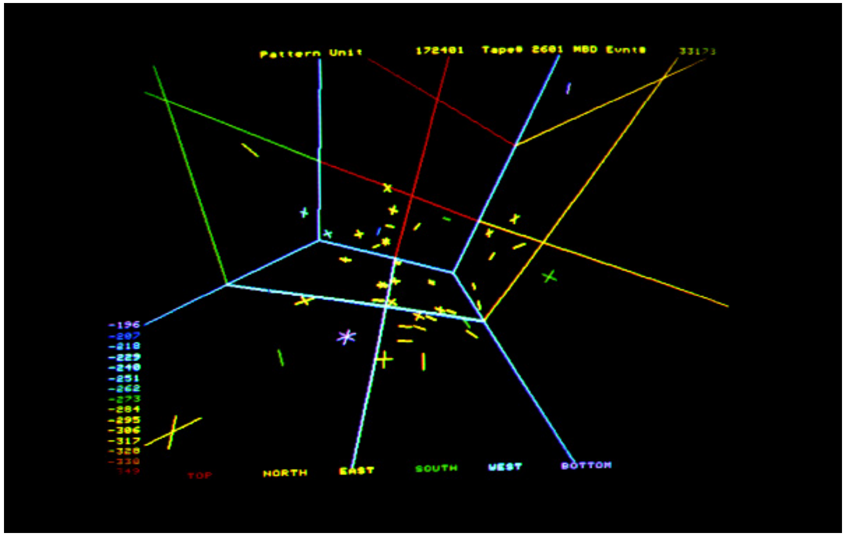
Feb. 23, 7 h 35 min 41.37 s. (±50 msec)

8 events during 6 s.

TABLE III. Characteristics of the contained neutrino events recorded on 23 February.

Event No.[a]	Time (UT)	No. of PMT's	Energy[b] (MeV)	Angular distribution[c] (degrees)
33162	7:35:41.37	47	38	74
33164	7:35:41.79	61	37	52
33167	7:35:42.02	49	40	56
33168	7:35:42.52	60	35	63
33170	7:35:42.94	52	29	40
33173	7:35:44.06	61	37	52
33179	7:35:46.38	44	20	39
33184	7:35:46.96	45	24	102





9 March 1987

Kamiokande and IMB
:
submitted their papers to *PRL*

press release at Ministry of Education

「超新星からのニュートリノ検出」を発表する小柴昌俊・東大教授（右端）。左は観測装置に使われたものと同じ光電子増倍管　＝文部省で

(Asahi newspaper)

6 April 1987

Kamiokande & IMB in *PRL*

VOLUME 58, NUMBER 14 PHYSICAL REVIEW LETTERS 6 APRIL 1987

Observation of a Neutrino Burst from the Supernova SN1987A

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E. W. Beier, L. R. Feldscher, S. B. Kim, A. K. Mann, F. M. Newcomer, R. Van Berg, and W. Zhang
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California Institute of Technology, Pasadena, California 91125
(Received 10 March 1987)

VOLUME 58, NUMBER 14 PHYSICAL REVIEW LETTERS 6 APRIL 1987

Observation of a Neutrino Burst in Coincidence with Supernova 1987A in the Large Magellanic Cloud

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M. Crouch,[9] S. T. Dye,[6] S. Errede,[10] G. W. Foster,[15] W. Gajewski,[1] K. S. Ganezer,[1]
M. Goldhaber,[3] T. J. Haines,[1] T. W. Jones,[7] D. Kielczewska,[1,8] W. R. Kropp,[1] J. G. Learned,[6]
J. M. LoSecco,[13] J. Matthews,[2] R. Miller,[1] M. S. Mudan,[7] H. S. Park,[11] L. R. Price,[1]
F. Reines,[1] J. Schultz,[1] S. Seidel,[2,14] E. Shumard,[16] D. Sinclair,[2] H. W. Sobel,[1] J. L. Stone,[14]
L. R. Sulak,[14] R. Svoboda,[1] G. Thornton,[2] J. C. van der Velde,[2] and C. Wuest[12]

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[3]*Brookhaven National Laboratory, Upton, New York 11973*
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[5]*Cleveland State University, Cleveland, Ohio 44115*
[6]*The University of Hawaii, Honolulu, Hawaii 96822*
[7]*University College, London WC1E 6BT, United Kingdom*
[8]*Warsaw University, Warsaw, Poland*
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[11]*The University of California, Berkeley, California 94720*
[12]*Lawrence Livermore National Laboratory, Livermore, California 94550*
[13]*The University of Notre Dame, Notre Dame, Indiana 46556*
[14]*Boston University, Boston, Massachusetts 02215*
[15]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[16]*AT&T Bell Laboratories, Summit, New Jersey 07910*
(Received 13 March 1987)

Baksan

DETECTION OF THE NEUTRINO SIGNAL FROM SN 1987A USING THE INR BAKSAN UNDERGROUND SCINTILLATION TELESCOPE

E.N.Alexeyev, L.N.Alexeyeva, I.V.Krivosheina, V.I.Volchenko

Institute for Nuclear Research of the USSR Academy of Sciences, 60th October Anniversary Prospect 7a, 117 312 Moscow, USSR

A signal of 5 events within 9.1 seconds was found in the fiducial mass of 200 tons of the Baksan scintillation telescope at the KAMIOKANDE - IMB time on February 23. We have performed analysis of temporal structure and energy estimates of the signal. The properties of the Baksan events are very close to the KAMIOKANDE - II signal.

Table 1. The Baksan events detected at $7:36:11.818^{+2\,sec}_{-54\,sec}$ on February 23, 1987.

	Time (UT)	Energy E_e (Mev)
1.	7:36:11.818	12 ± 2.4
2.	7:36:12.253	18 ± 3.6
3.	7:36:13.528	23.3 ± 4.7
4.	7:36:19.505	17 ± 3.4
5.	7:36:20.917	20.1 ± 4.0

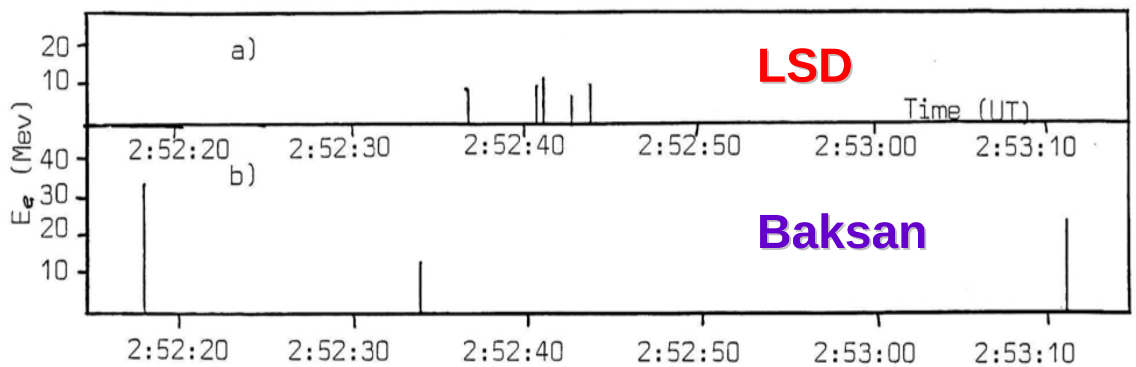
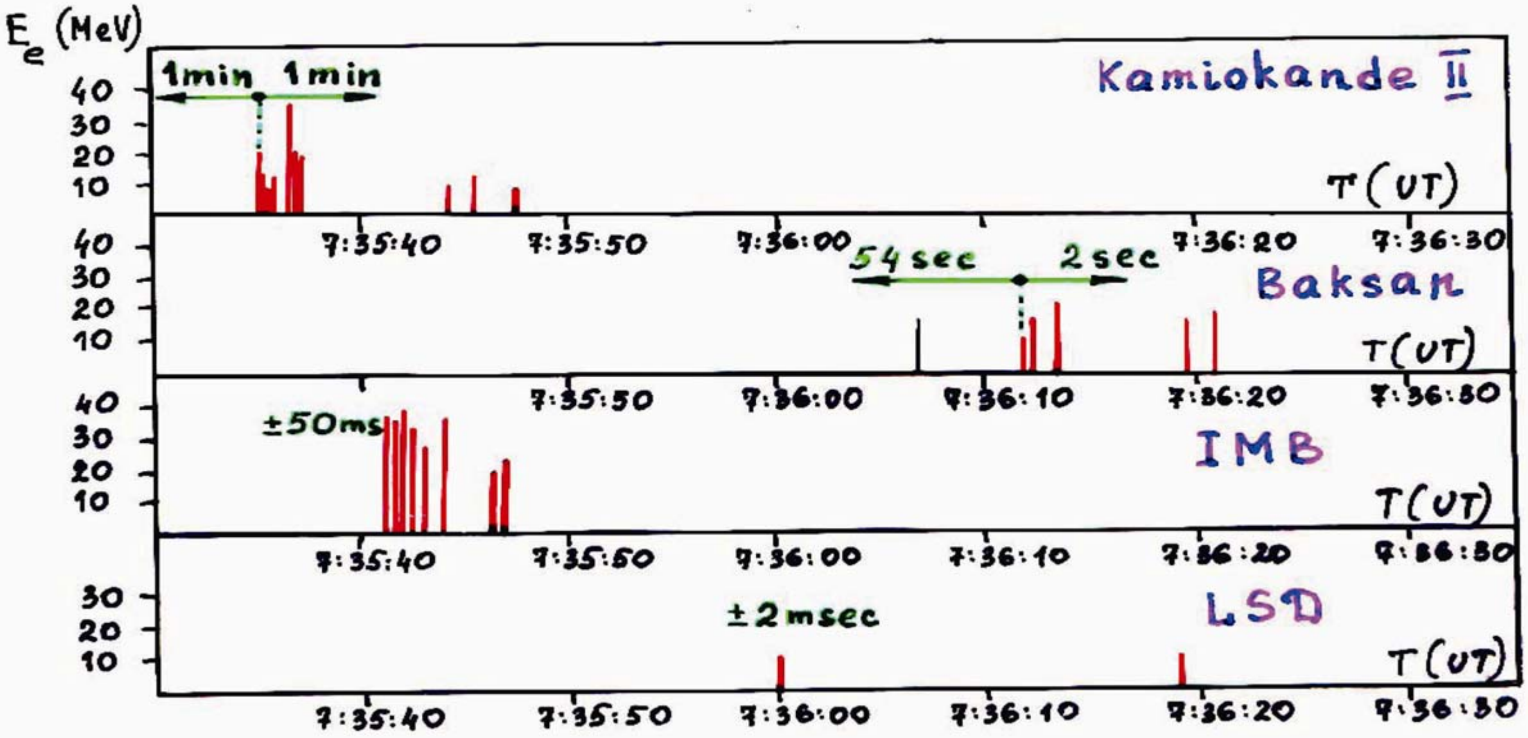


Fig.1 The time sequences of events detected by the LSD (a) and the Baksan telescope (b) at 2:52:36 UT on February 23, 1987.

E. N. Alexeyev (Hawaii, 2007)

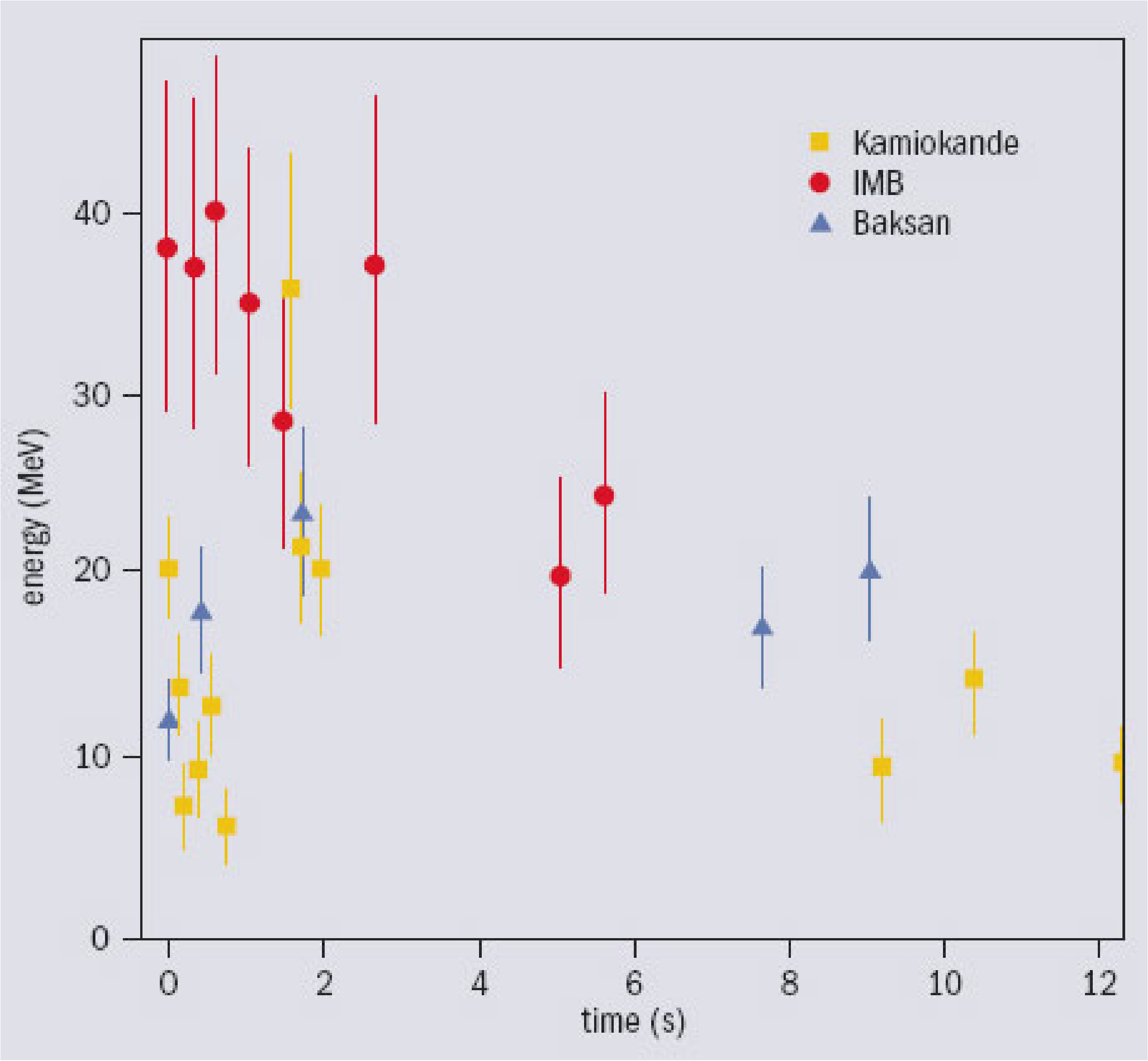
The time sequence of events detected by the Kamiokande II, the Baksan telescope, IMB and LSD at 7:35 UT



Baksan: 5 events during 9.1 seconds,

random background probability……….. 1.7 x 10 $^{-5}$

Scatter Plot of Energy and Time



M. Nakahata : CERN COURIER 47 (2007) 23-24 theory

What could we learn from SN1987A ?

(1) 10 neutrino events ---> exploded star mass (M)

11

$8 M_{\odot} < M < 15 M_{\odot}$

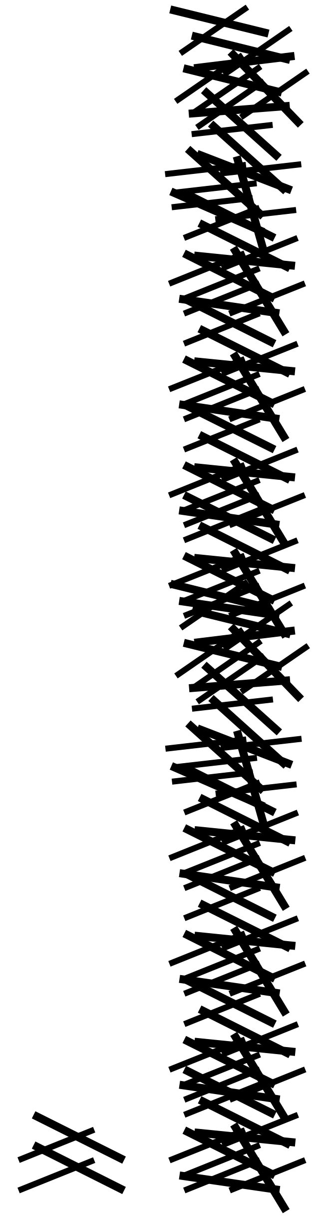
(2) Burst duration time ~ 12 second

---> [indirect evidence of neutron star formation]

(3) Observed neutrino energy

---> E_{ν} (total) ~ 10^{53} ergs ($100 \times E_{light}$)

(4) First Confirmation of Stellar Evolution Theory



experiment

Kamiokande & IMB were lucky !

In Kamiokande
a regular electronics
calibration sequence
finished several minutes
before the burst.

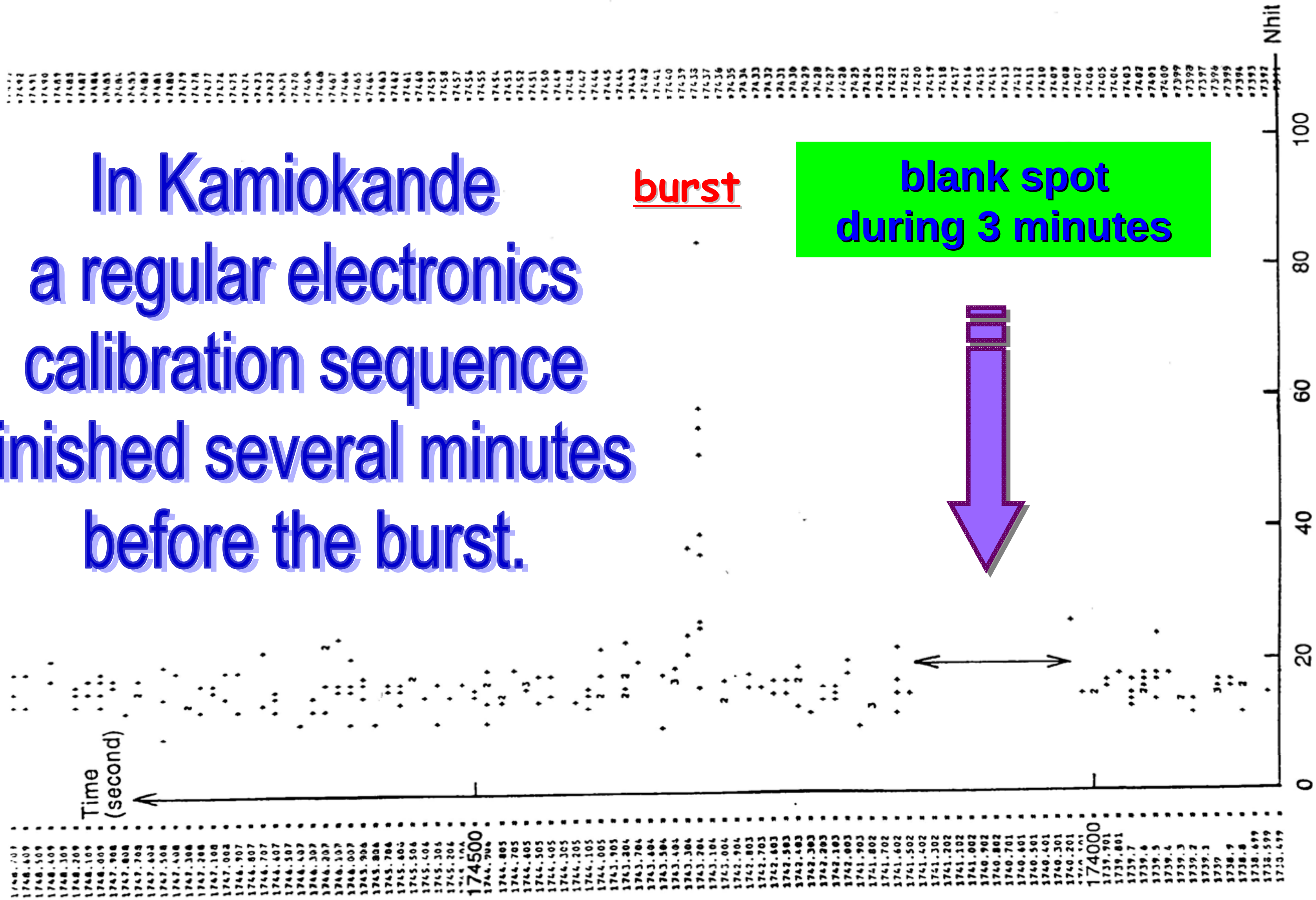


Fig. 5.1. The SN1987A neutrino "signal" in the computer print-out.

In IMB

J. van der Velde (Hawaii, 2007)

UT 05:00:00.001

One of four HV power supplies
shuts down at IMB.

On-line data analysis system shuts down.

Detector limps ahead with ¾ tubes
and raw data tapes only

Two hours later…….

Shooting luck

is

one of abilities

Conclusion

11 June 1988

In the summary talk of Neutrino '88
Prof. Lev Okun :

To predict the year of explosion of a supernova
is not harder than to predict the year of funding
a big accelerator or a big detector.

I expect that the date of the next supernova is
2003 ± 15 years

We have to be more serious to next supernovae

Observation of a Neutrino Burst from the Supernova SN1987A

The KAMIOKANDE-II Collaboration

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March 6, 1987

(Submitted for publication in Phys. Rev. Lett.)

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Kamiokande & IMB Data