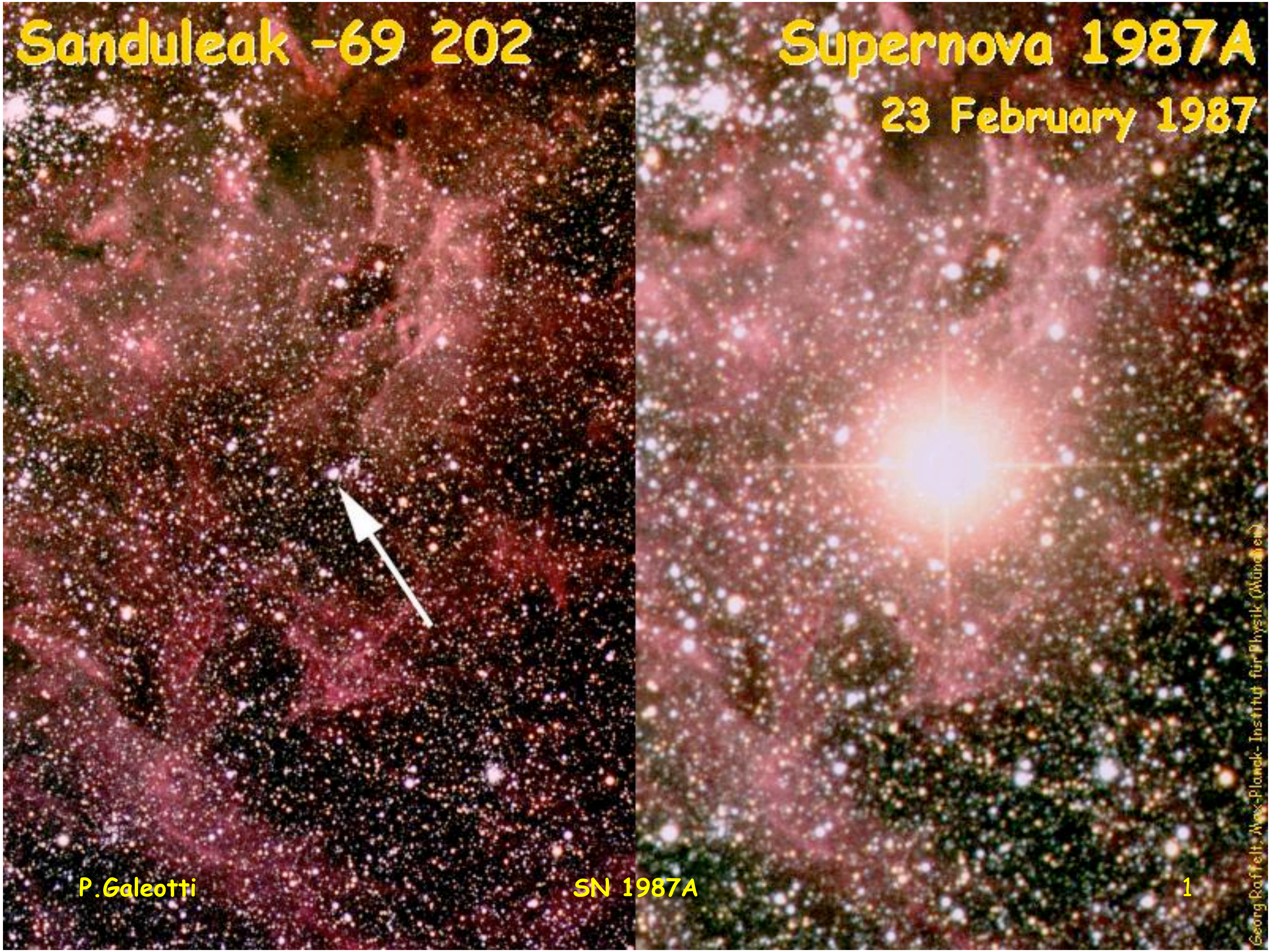
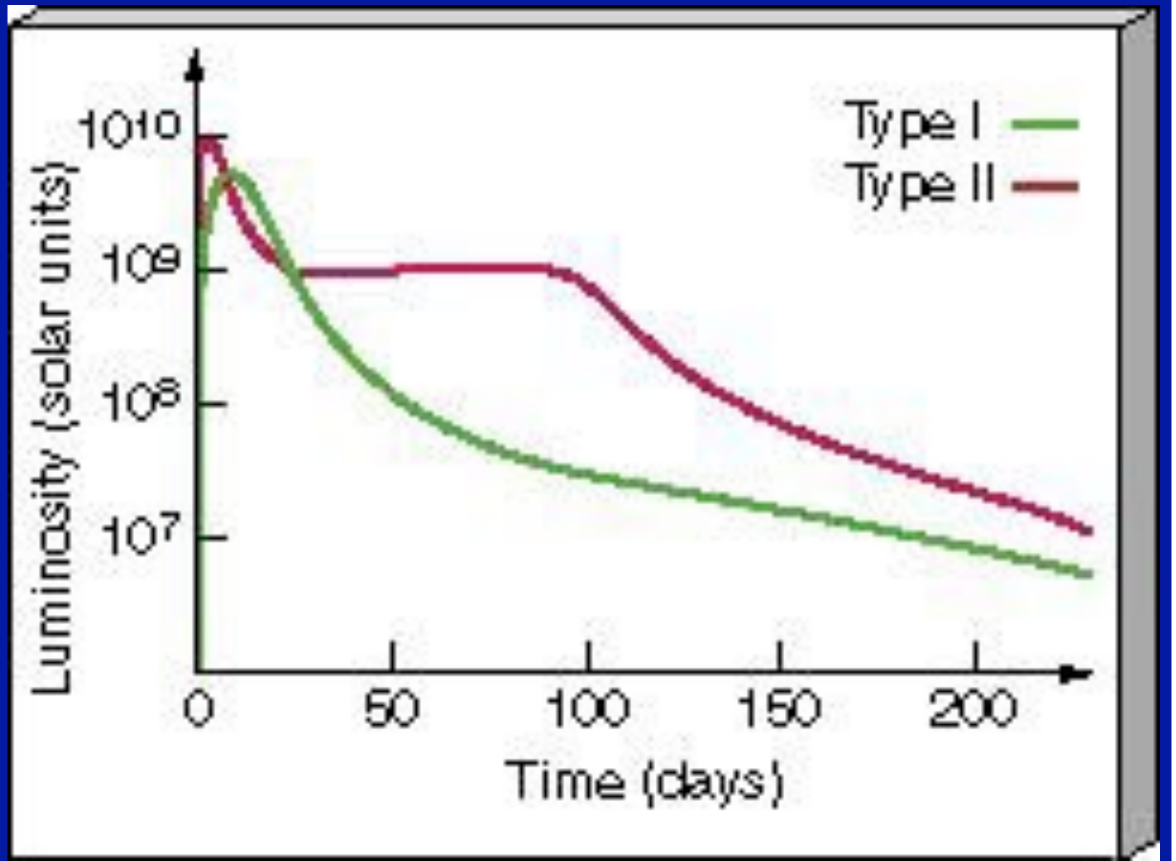

Sanduleak -69 202
Supernova 1987A
23 February 1987
Georg Raffelt, Max-Planck-Institut für Physik (München)

Supernovae

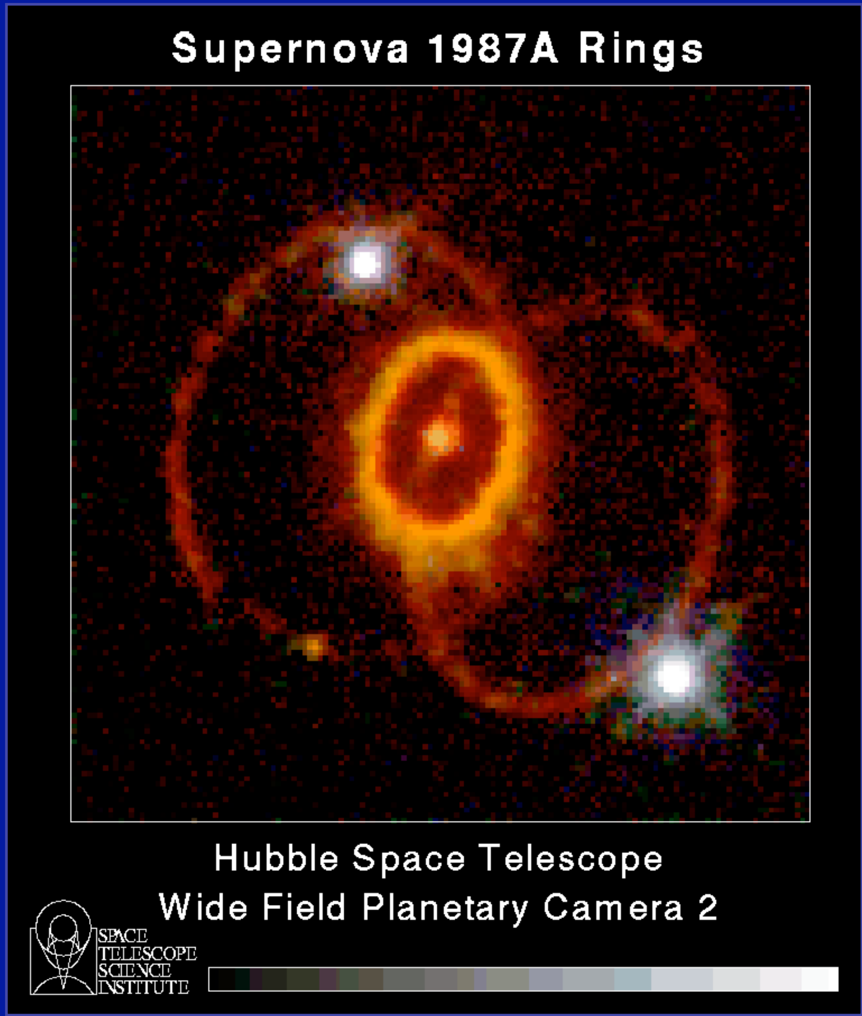
Supernovae are classified according to light curves and spectrum:

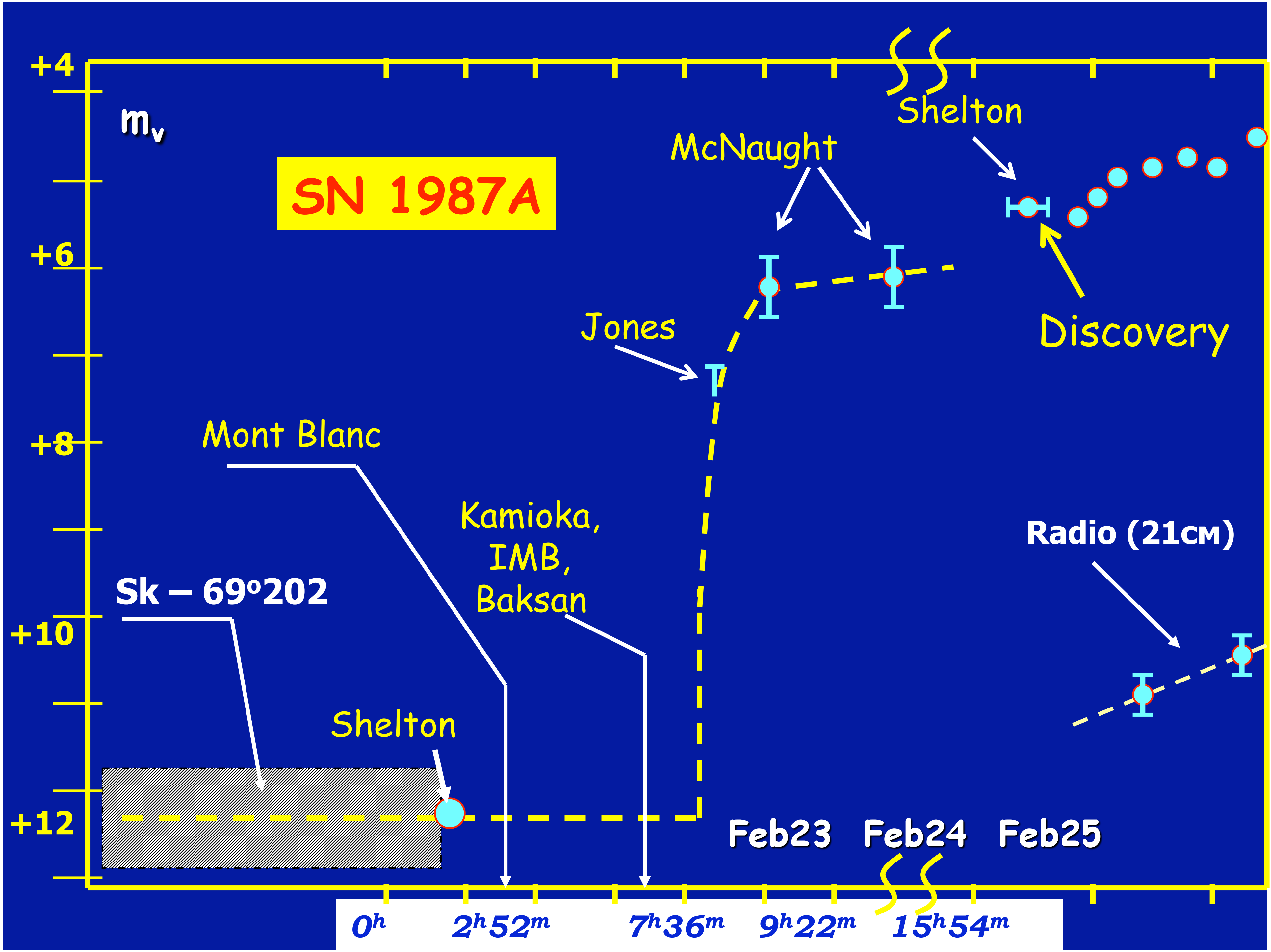


Large uniformity and Hydrogen poor in type I.
Large differences and Hydrogen rich in type II.
Light curves are consistent with heathing from decay of radioactive nuclei.

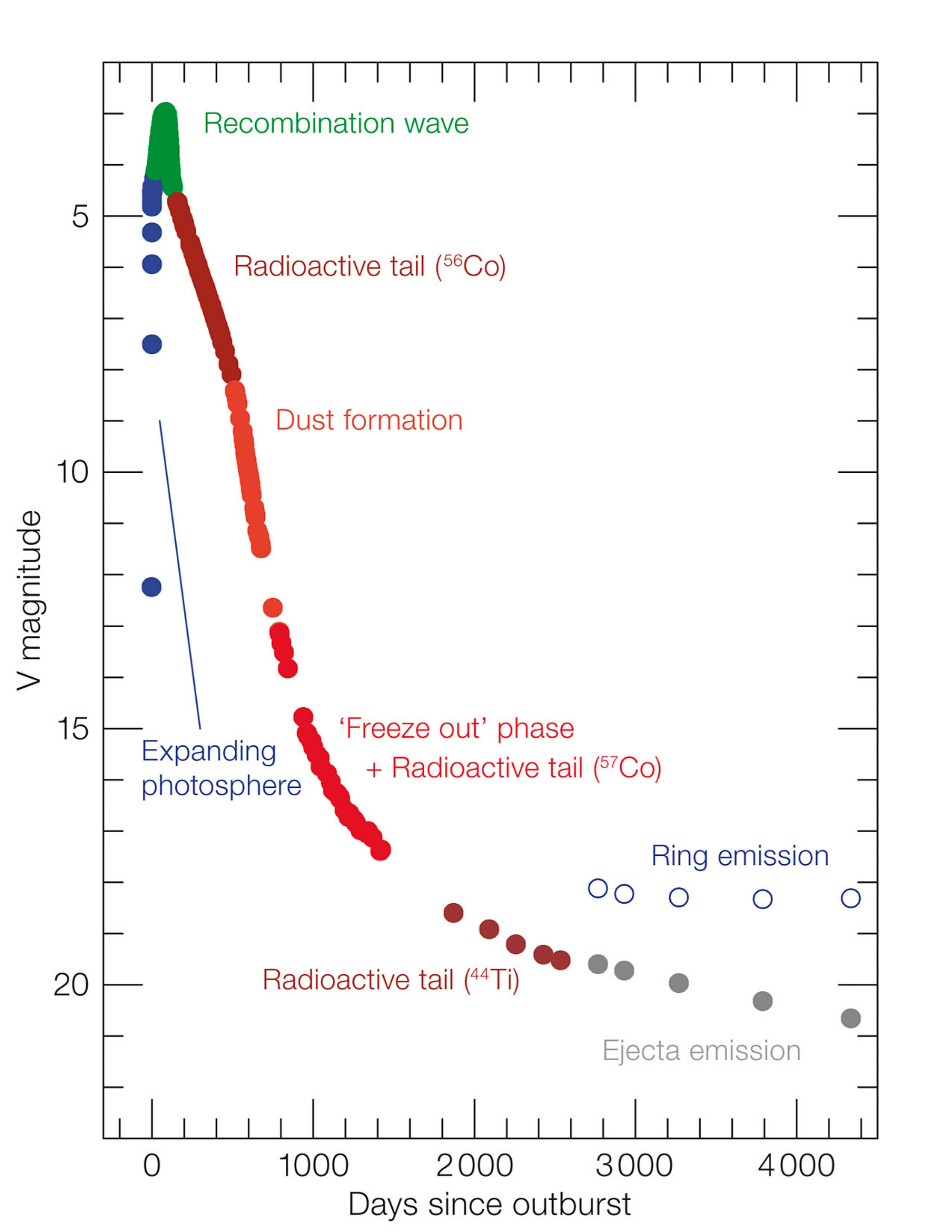
SN 1987A

- Large Magellanic Cloud
- Tipo II peculiar
- Progenitor: a blue massive supergiant
- Neutrinos detected a few hours before explosion
- Observation of X and γ rays from ^{56}Co decay.
- Light echos, produced by pre-explosion mass loss) require high rotation rate.





SN 1987A
m_v
+4
+6
+8
+10
+12
McNaught
Shelton
Jones
Discovery
Mont Blanc
Kamioka,
IMB,
Baksan
Sk – 69°202
Shelton
Radio (21cм)
Feb23
Feb24
Feb25
0h
2h52m
7h36m
9h22m
15h54m



SN 1987A: light curve in visual band

$$m_1 - m_2 = -2,5 \log \frac{L_1}{L_2}$$

letters to nature

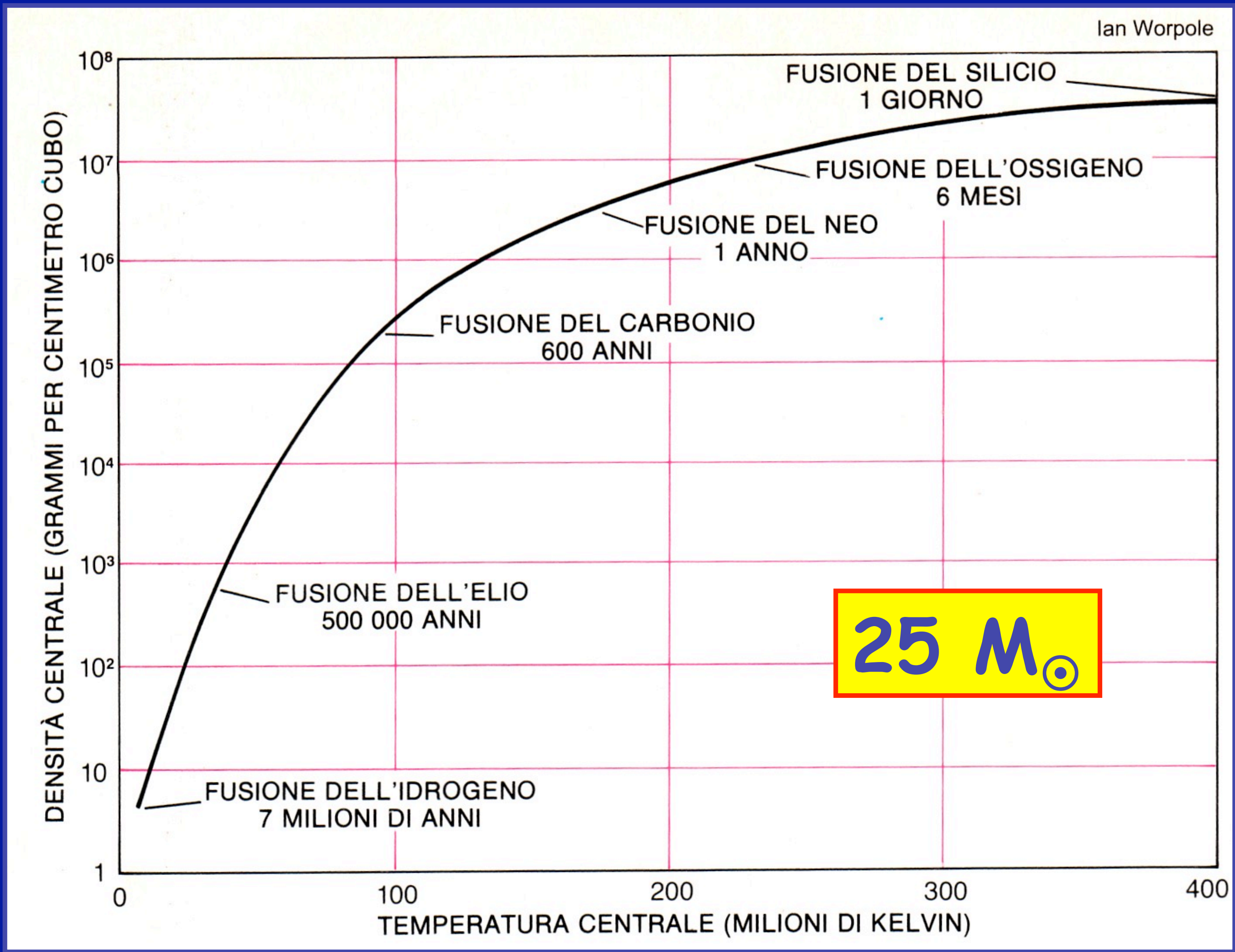
Nature 327, 597 - 600 (18 June 1987); doi:10.1038/327597a0

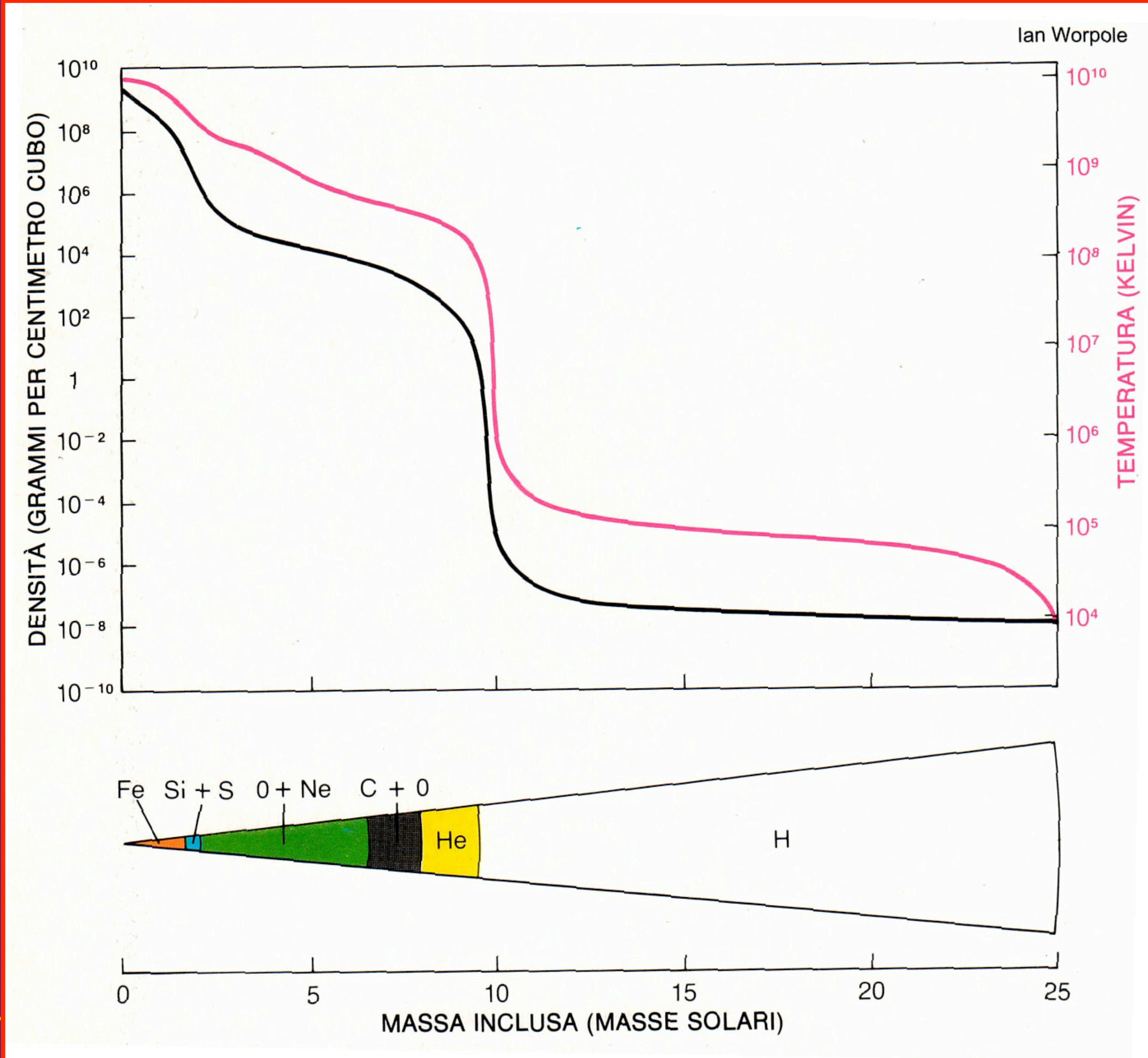
Explosion of a blue supergiant: a model for supernova SN1987A

W. HILLEBRANDT, P. HÖFLICH, J. W. TRURAN*† & A. WEISS

Max-Planck-Institut für Physik und Astrophysik, Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, 8046 Garching, FRG
*University of Illinois, Urbana, Illinois 61801, USA
†Present address: Max-Planck-Institut für Physik und Astrophysik, Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, 8046 Garching, FRG.

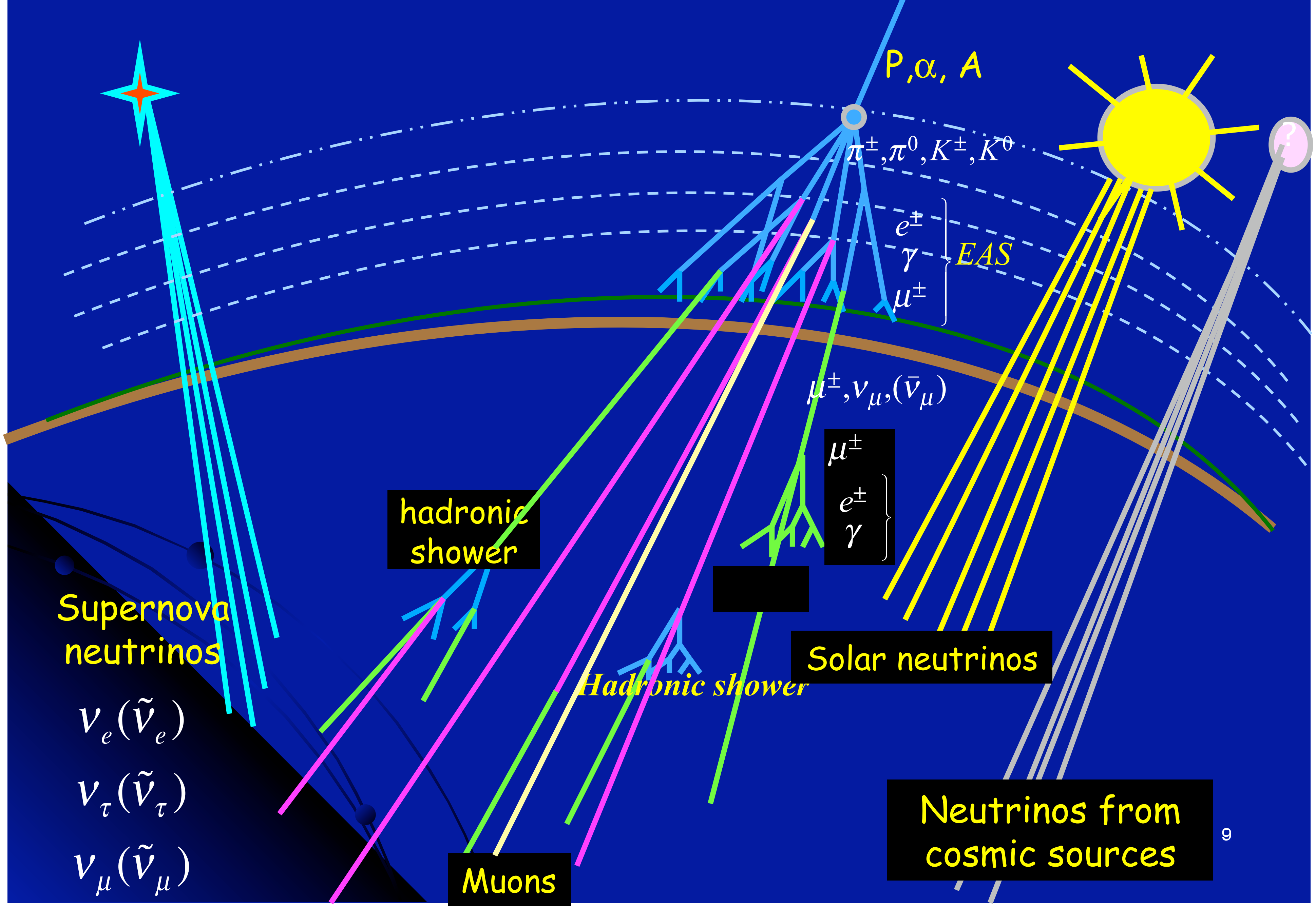
We present a model for the outburst of supernova SN1987A. This supernova was discovered in the Large Magellanic Cloud on 24 February, 1987. Astrometry[1,2] reveals the supernova to lie within 0.1 arcs of the B3 I supergiant Sanduleak (Sk) –69 202. The optical features indicate that the event was a type II supernova. Such supernovae are the expected consequence of the evolution of massive stars M >=10M⊙ and may be expected to leave behind a neutron star or black-hole remnant. Neutrinos released as a consequence of the anticipated core collapse to neutron star densities may indeed have been observed (ref. 3; Aglietta *et al*. preprint, 1987; Bionta *et al*. preprint, 1987). SN1987A certainly cannot be considered a prototype of a type II supernova, however, as it has proved to be unusual in several respects, including: (1) the progenitor of SN1987A appears to have been a blue supergiant rather than a red supergiant star; (2) SN1987A was found to be some 3 or 5 magnitudes dimmer at visual maximum than is known to be typical of supernovae of type II; and (3) SN1987A exhibited an extremely rapid spectral development, seemingly consistent with the very high expansion velocities inferred from studies of the hydrogen absorption features in the early spectra. Here we present a model for the outburst of SN1987A that permits a straightforward interpretation of the observed behaviour.

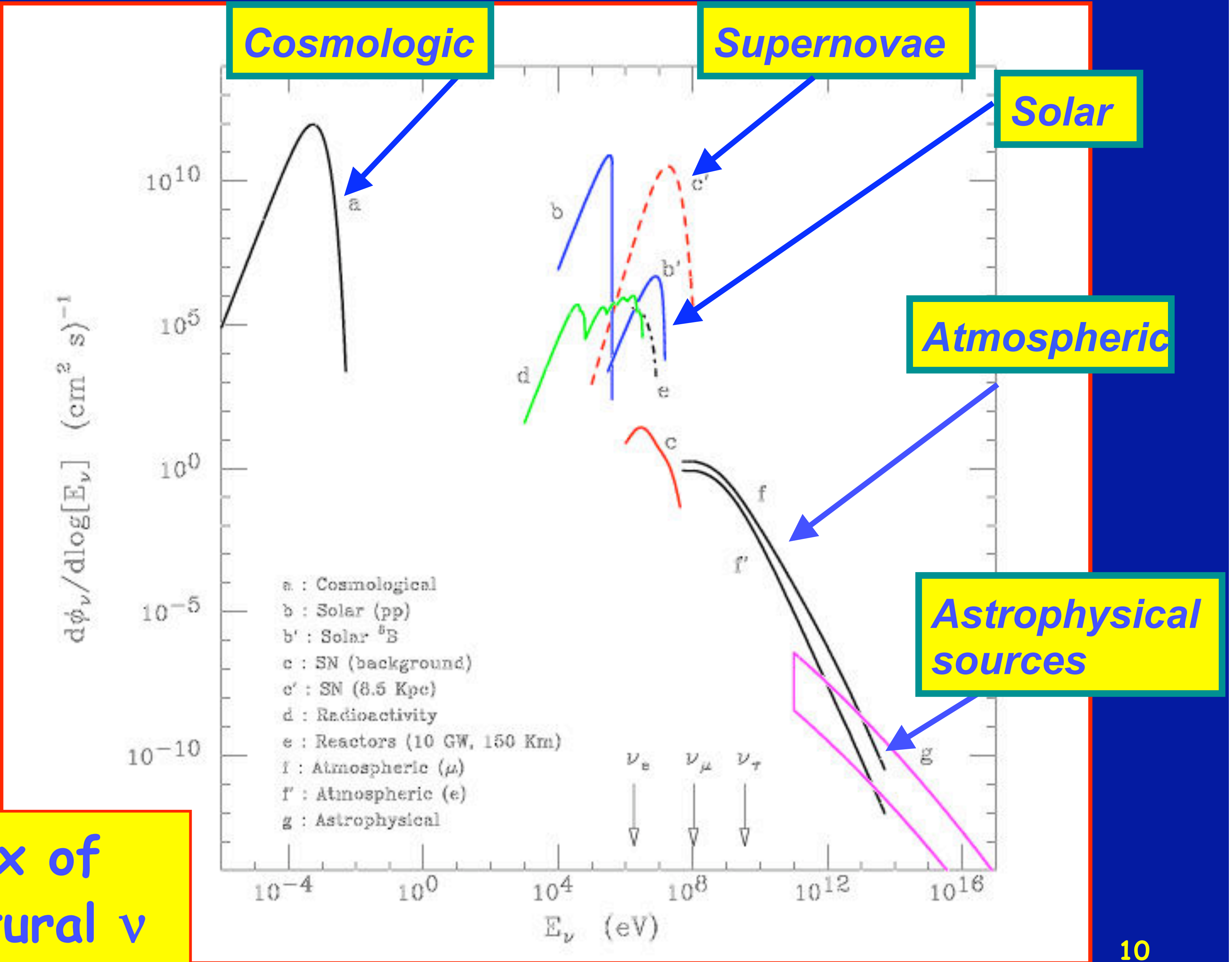

Ian Worpole
DENSITÀ CENTRALE (GRAMMI PER CENTIMETRO CUBO)
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10
1
0
100
200
300
400
TEMPERATURA CENTRALE (MILIONI DI KELVIN)
FUSIONE DEL SILICIO
1 GIORNO
FUSIONE DELL'OSSIGENO
6 MESI
FUSIONE DEL NEO
1 ANNO
FUSIONE DEL CARBONIO
600 ANNI
FUSIONE DELL'ELIO
500 000 ANNI
FUSIONE DELL'IDROGENO
7 MILIONI DI ANNI
25 M⊙



Ian Worpole
DENSITÀ (GRAMMI PER CENTIMETRO CUBO)
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
TEMPERATURA (KELVIN)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
Fe
Si + S
0 + Ne
C + 0
He
H
0
5
10
15
20
25
MASSA INCLUSA (MASSE SOLARI)

Neutrinos are detectable in underground laboratories





Flux of natural ν

The idea of neutrinos being massive was first suggested by Bruno Pontecorvo.
The prediction came from a proposal of
neutrino oscillations

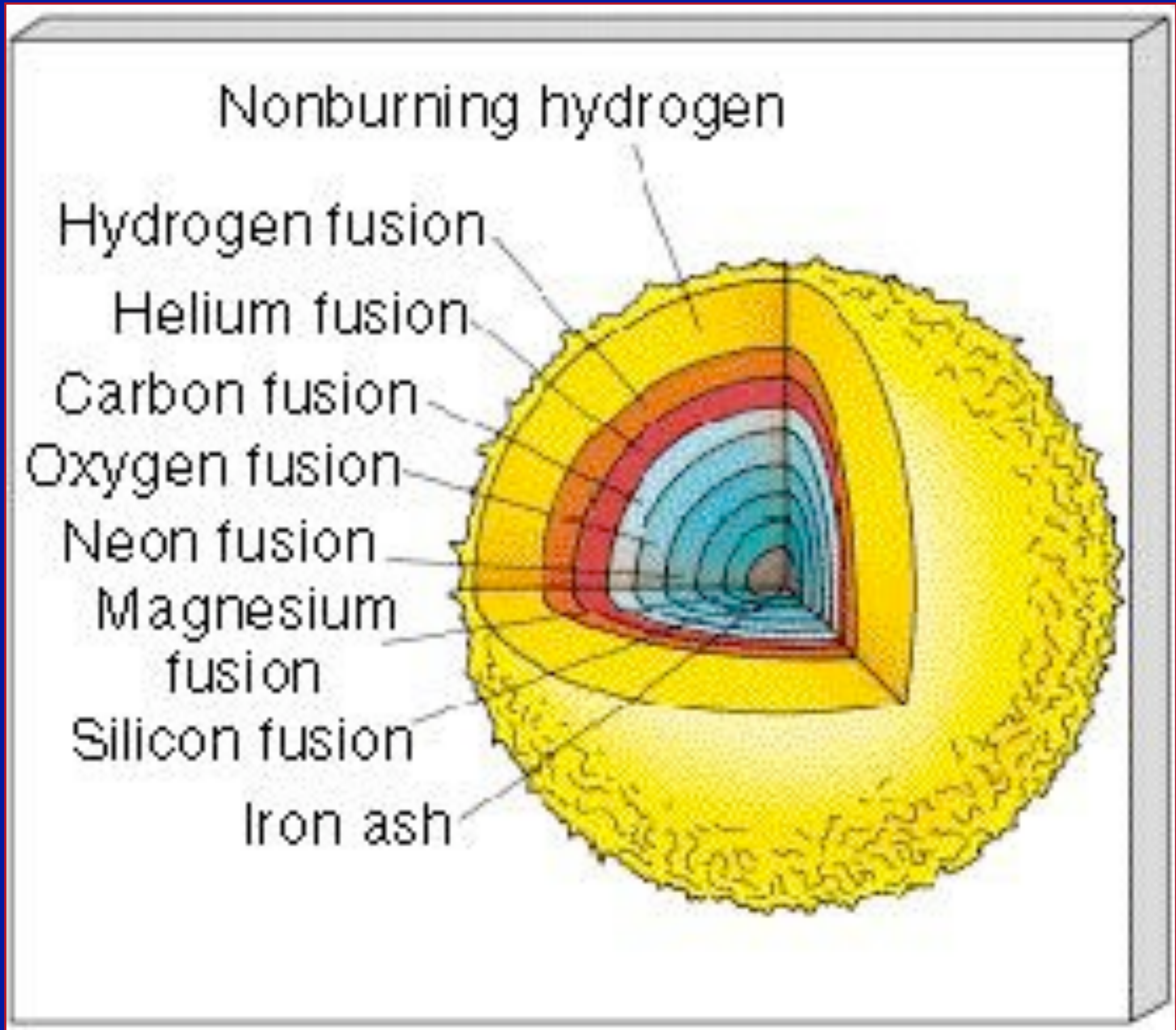
Neutrinos are created or annihilated as W.I. eigenstates

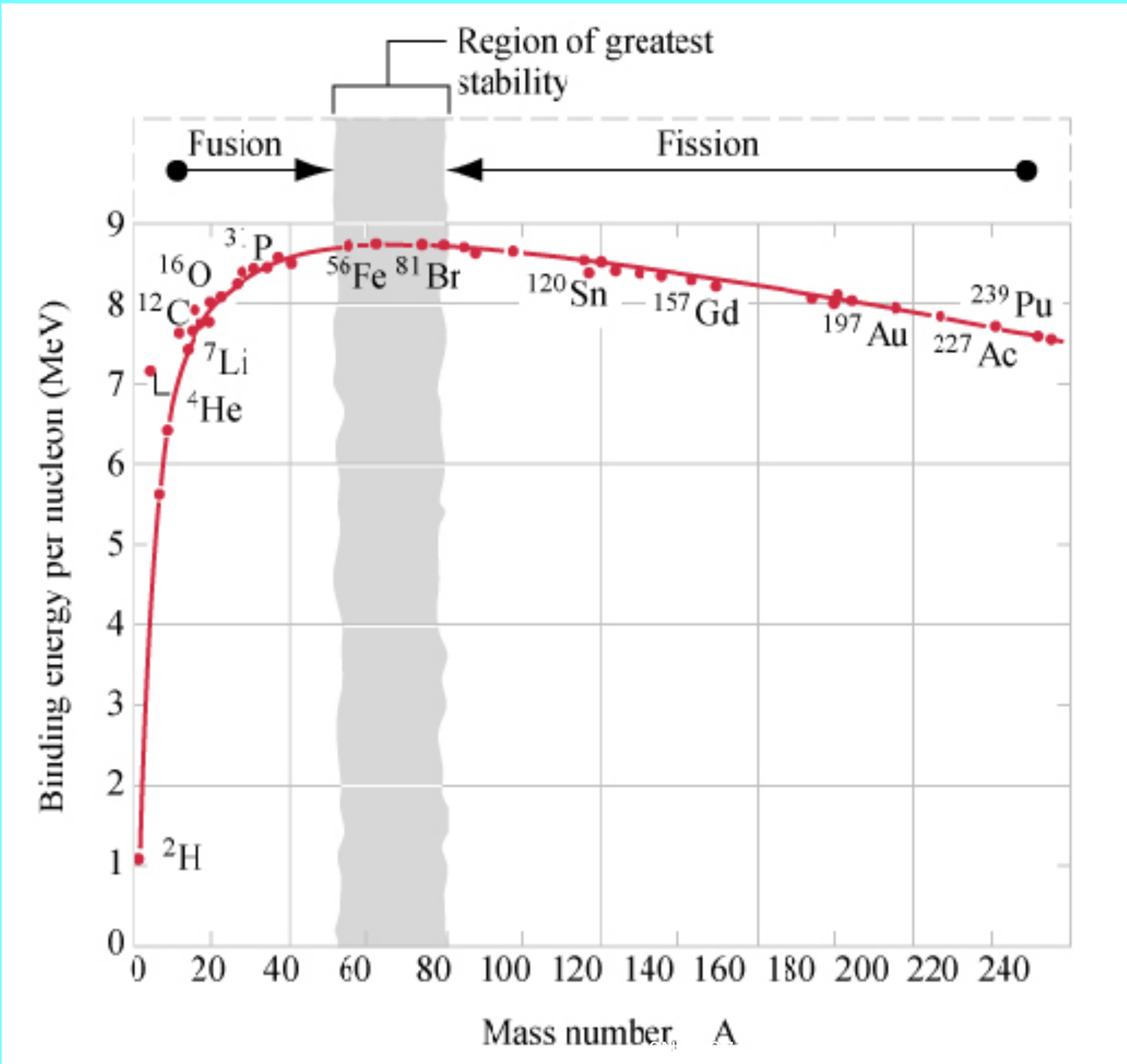
$|\nu_e\rangle$, $|\nu_\mu\rangle$, $|\nu_\tau\rangle$ = Weak Interactions eigenstates

$|\nu_1\rangle$, $|\nu_2\rangle$, $|\nu_3\rangle$ = Mass (Hamiltonian) eigenstates

Neutrinos propagate as a superposition of mass eigenstates

Structure of an evolved massive star





Region of greatest stability
Fusion
Fission
Binding energy per nucleon (MeV)
9
8
7
6
5
5
4
3
2
1
0
0 20 40 60 80 100 120 140 160 180 200 220 240
Mass number, A
56Fe
81Br
120Sn
157Gd
197Au
227Ac
239Pu
16O
12C
7Li
4He
2H
P

Type II supernovae

The stellar collapse of the iron core is induced by three cooling processes:

1. photodissociation of iron nuclei
2. neutronization of matter
3. neutrino emission from electron pair annihilation

$$T_c \approx 8\times10^9\ \mathrm{K} \quad \rho_c \approx 10^{10}\ \mathrm{g\ cm^{-3}}$$

$$\gamma + {}^{56}_{26}Fe \rightarrow 13\ {}^{4}_{2}He + 4n$$

$$\gamma + {}^{4}_{2}He \rightarrow 2p + 2n$$

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

$$\gamma\gamma \rightarrow e^+e^- \rightarrow \nu_x \bar{\nu}_x$$

Stellar Collapse

The core collapse is inevitable when its mass M_C exceeds the Chandrasekhar mass:

$$M_{Ch} = 5.76 \cdot Y_e^2 M_\odot \approx 1.44 M_\odot$$

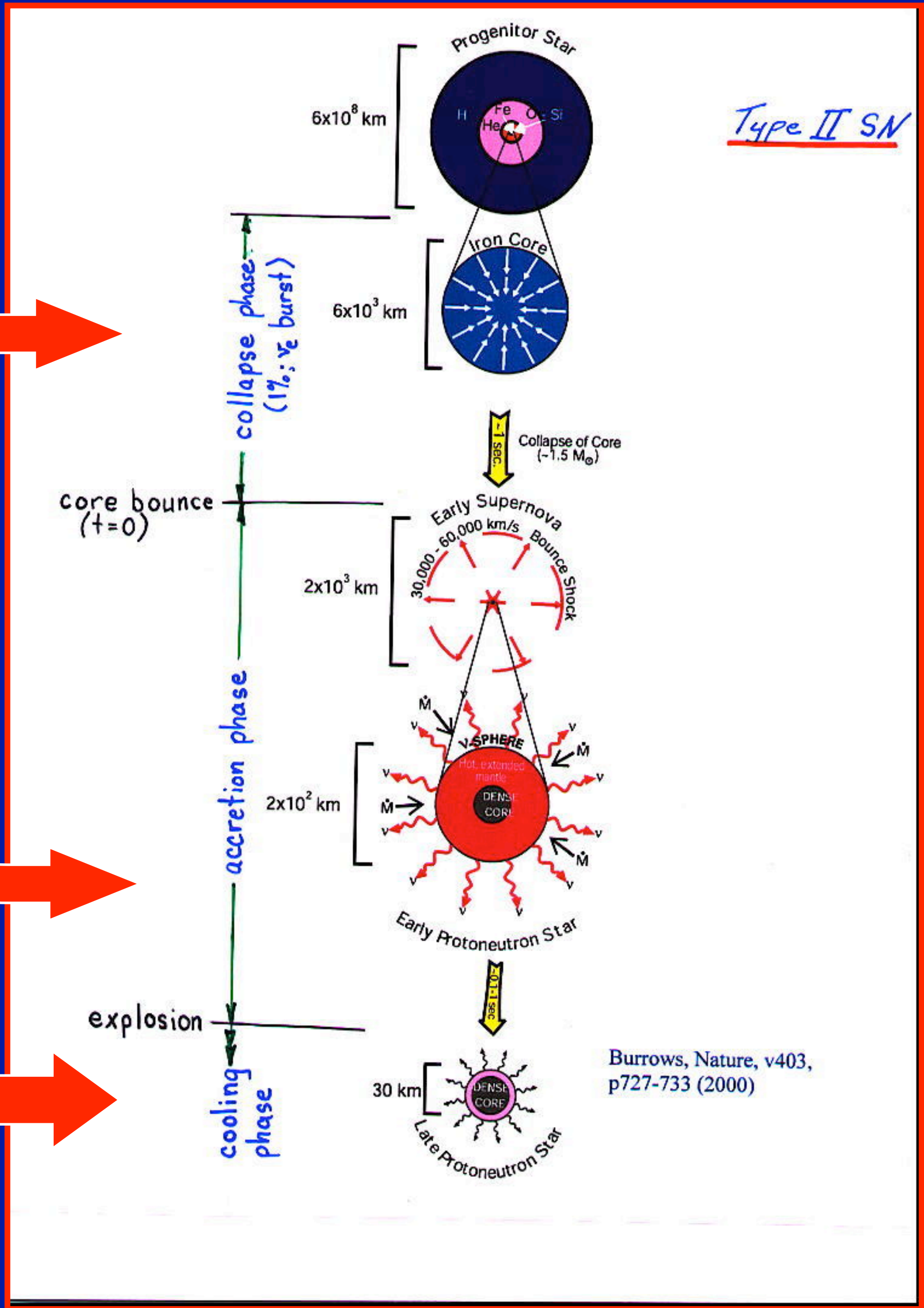
where Y_e is the leptons to barions ratio in the core. Note that M_C increases because of thermonuclear burning of the Si shell around the core, and M_{Ch} decreases because Ye decreases in the previously mentioned processes of neutronization of matter and annihilation processes.

$$M_C > M_{Ch} = 5.76\, Y_e^2\, M_\odot$$

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

$$\chi = \frac{1}{n\sigma}$$

$$\Delta E_B = \frac{GM^2}{R_{ns}} - \frac{GM^2}{R_c}$$



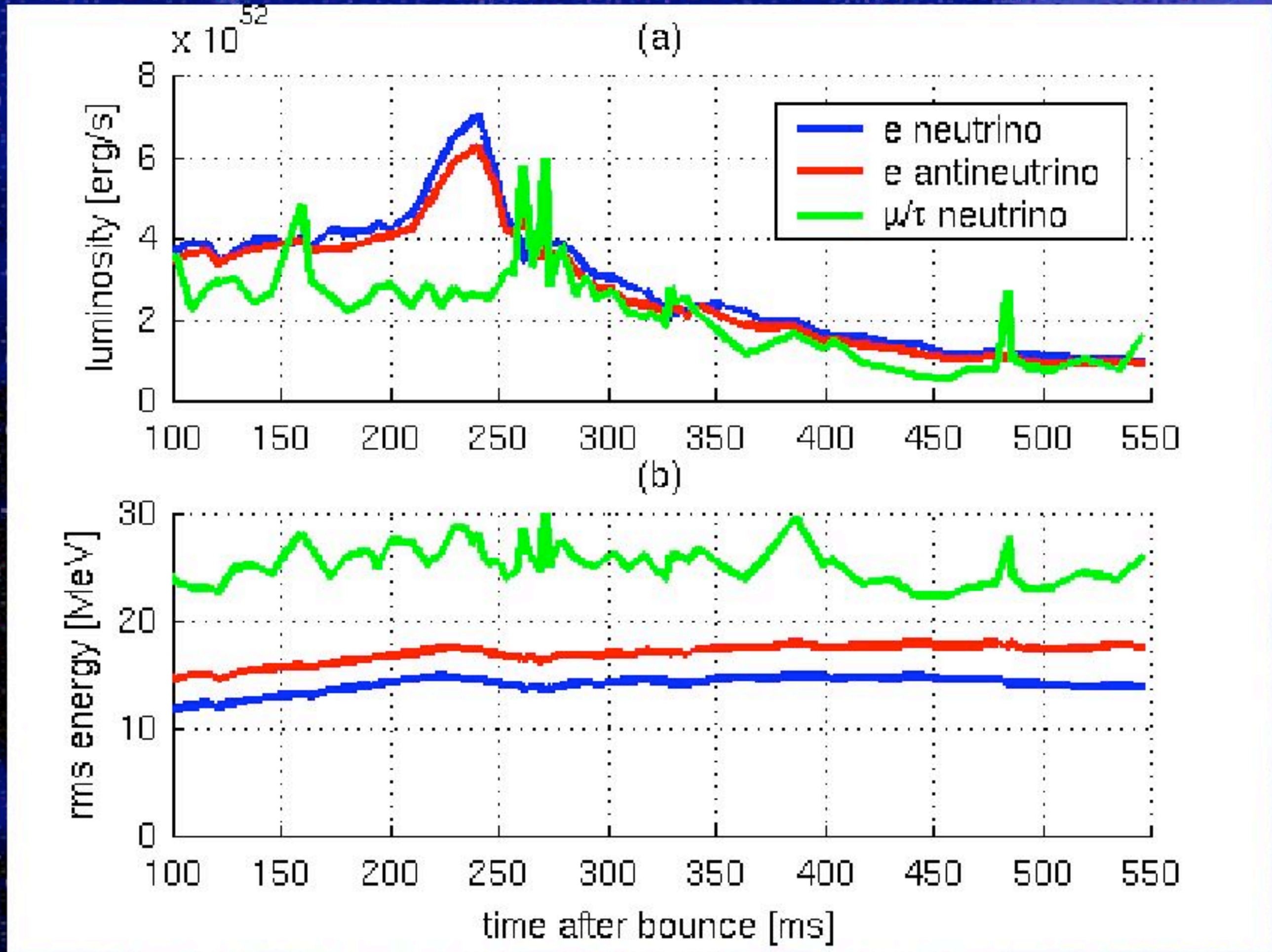
Neutrinos from stellar collapses

In a stellar core with $M_C = M_{Ch} \sim 1.5\ M_\odot$ there are $\sim 10^{57}$ protons, and the maximum number of neutronization neutrinos emitted during the collapse is of the same order of magnitude. Since their average energy is ~ 10 MeV = 10^{-12} J, the total energy emitted in this collapse phase is of the order of 10^{45} J, corresponding to $\sim 10^{-2}\ M_C \cdot c^2$. According to most models, the energy emitted in neutrinos during electron pairs annihilation processes is ~ 20-30 times bigger, namely of order of $3 \cdot 10^{46}$ J.
For a stellar collapse at the center of our Galaxy (d~8.5 kpc) the flux of electron neutrinos and antineutrinos is:

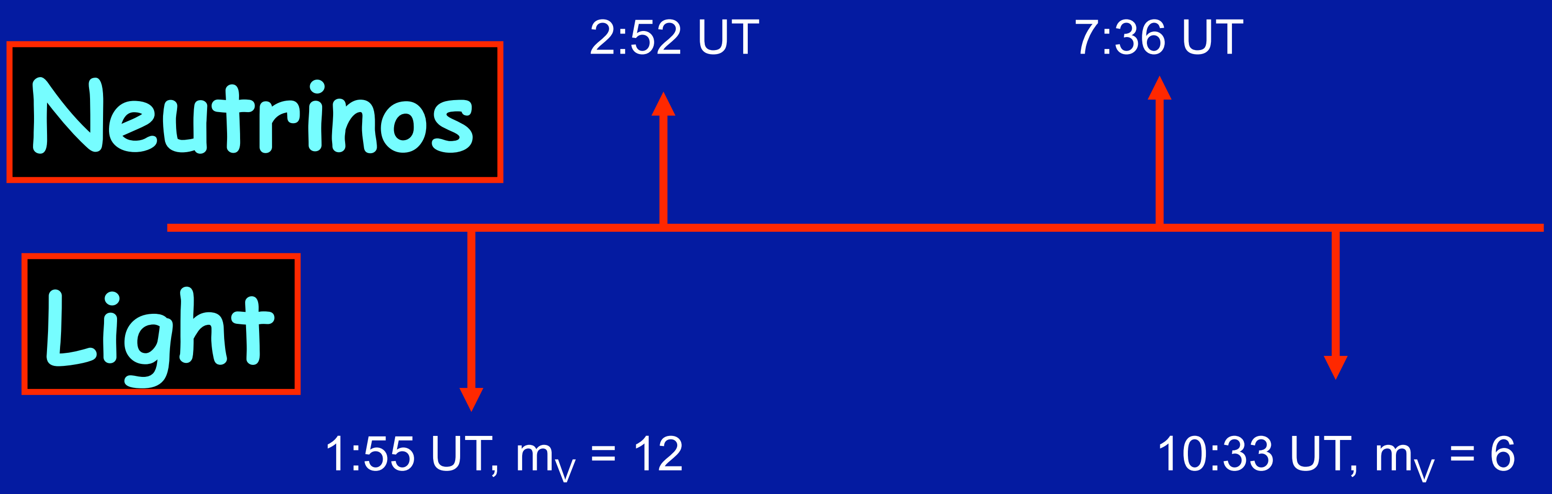
$$\boxed{\Phi(\nu_e,\bar{\nu}_e) = \frac{\Phi_0(\nu_e,\bar{\nu}_e)}{6 \cdot 4\pi d^2} \approx 10^{12}(\nu_e,\bar{\nu}_e)\ \mathrm{cm}^{-2}}$$

producing $n = N\Phi\sigma$ interactions in a detector

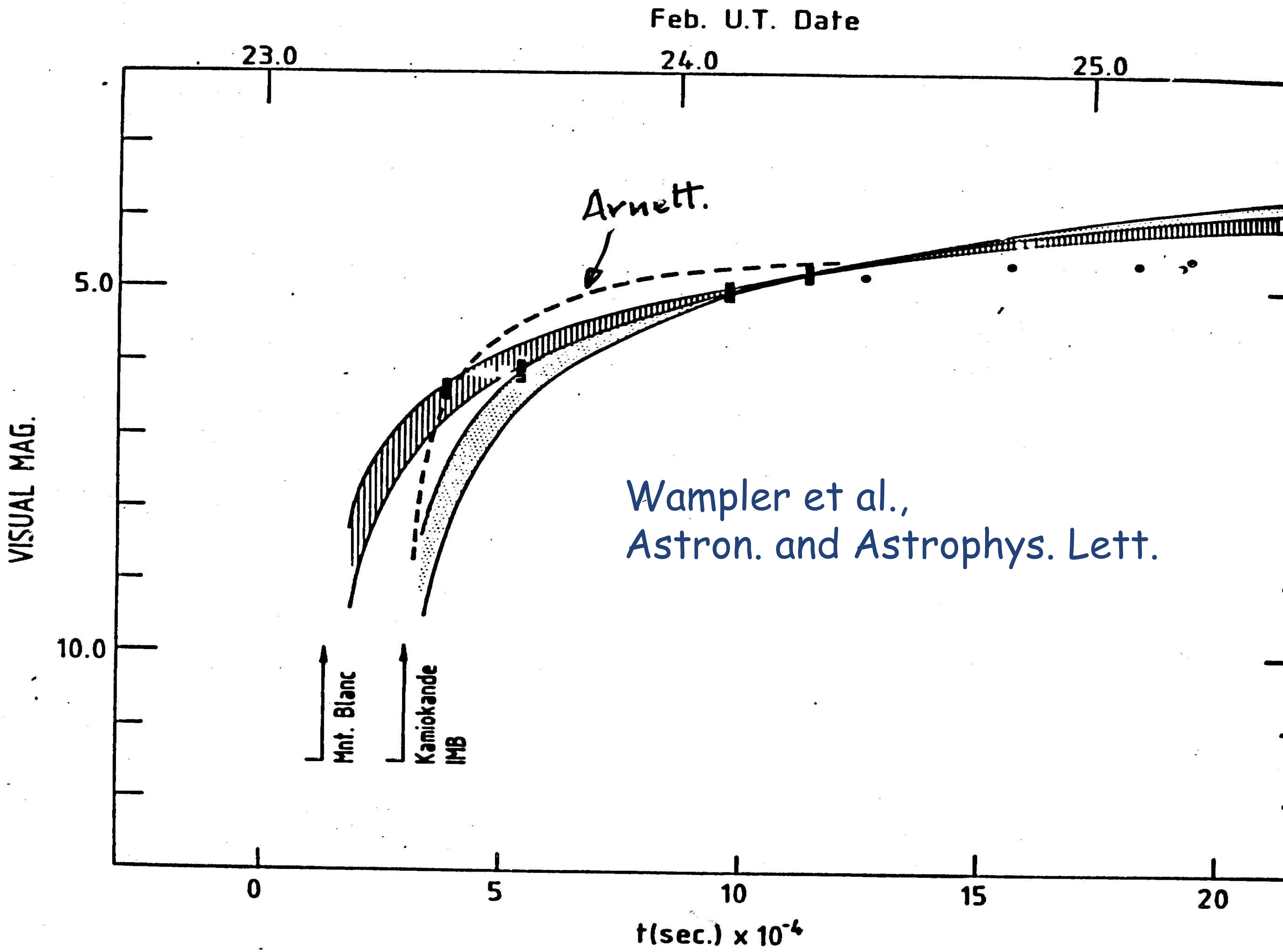
Luminosities RMS Energies



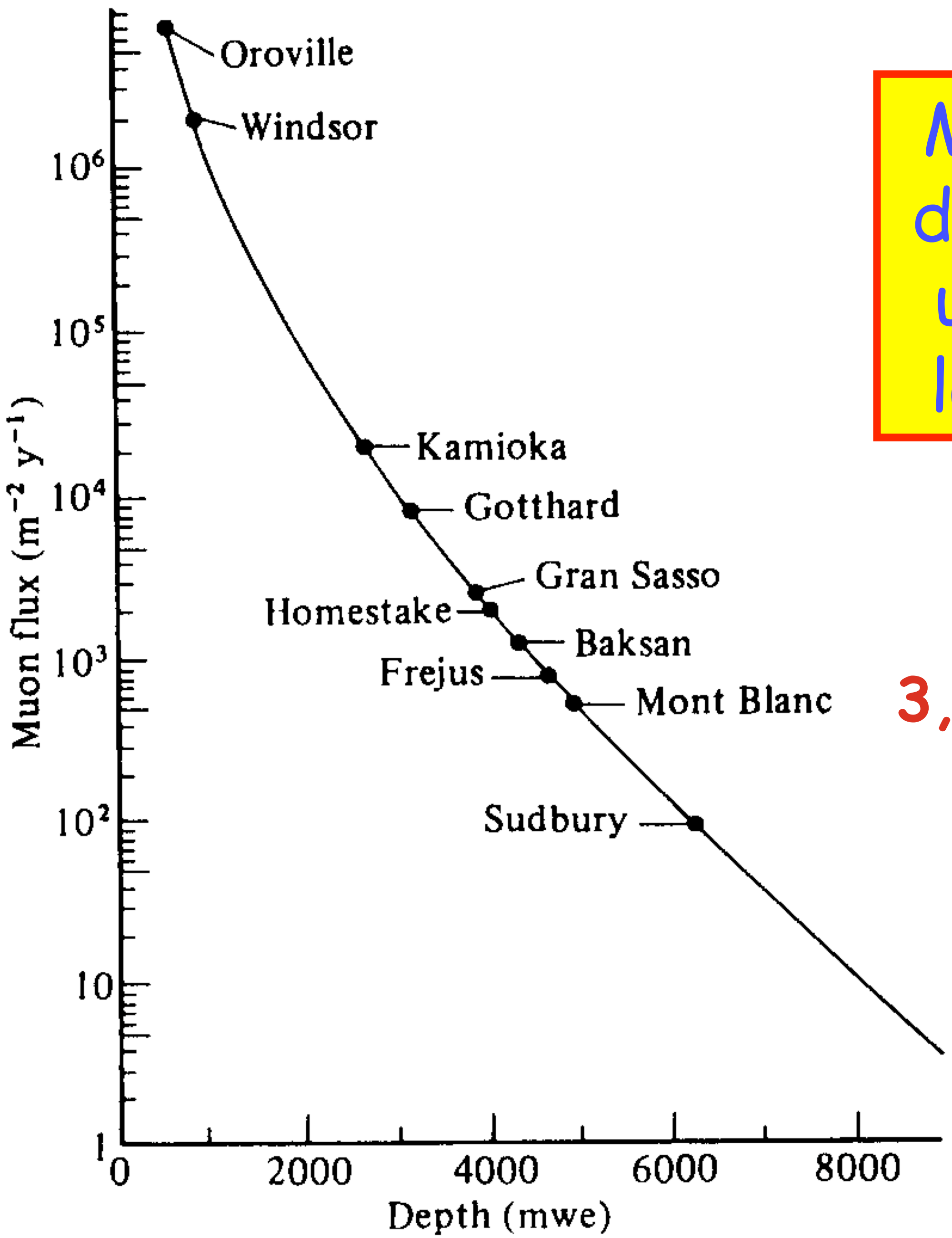
Neutrinos from SN 1987A



The progenitor star, Sanduleak -69.202, spectral type B3 Ia and mass 20-25 $M_{\odot}$, belonged to a binary (or even triple) system. Neutrinos (and gravitational waves?) were detected in all the experiments running at that time.



Wampler et al.,
Astron. and Astrophys. Lett.

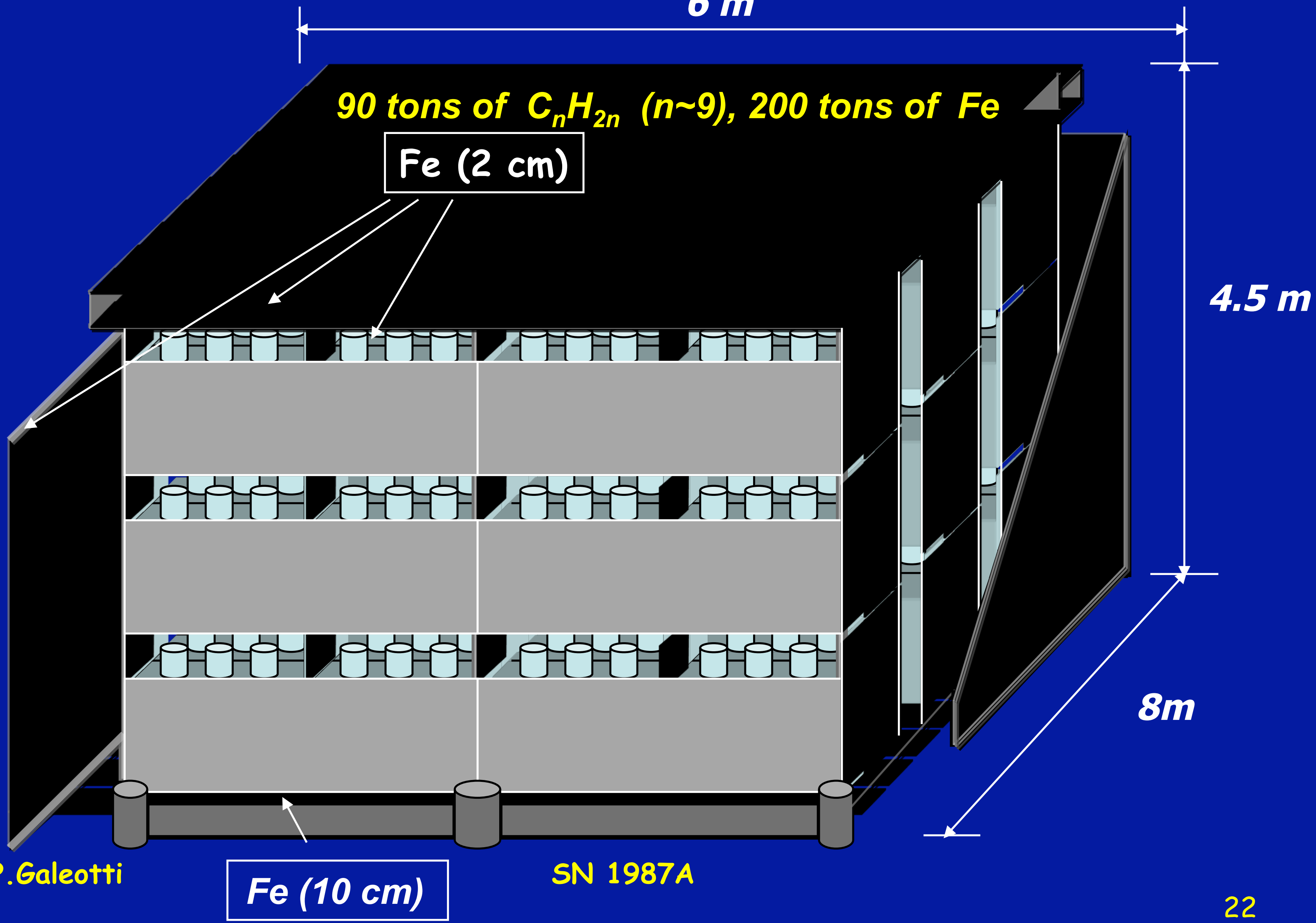


Muon flux vs. depth in some underground laboratories.

3,5 μ/h

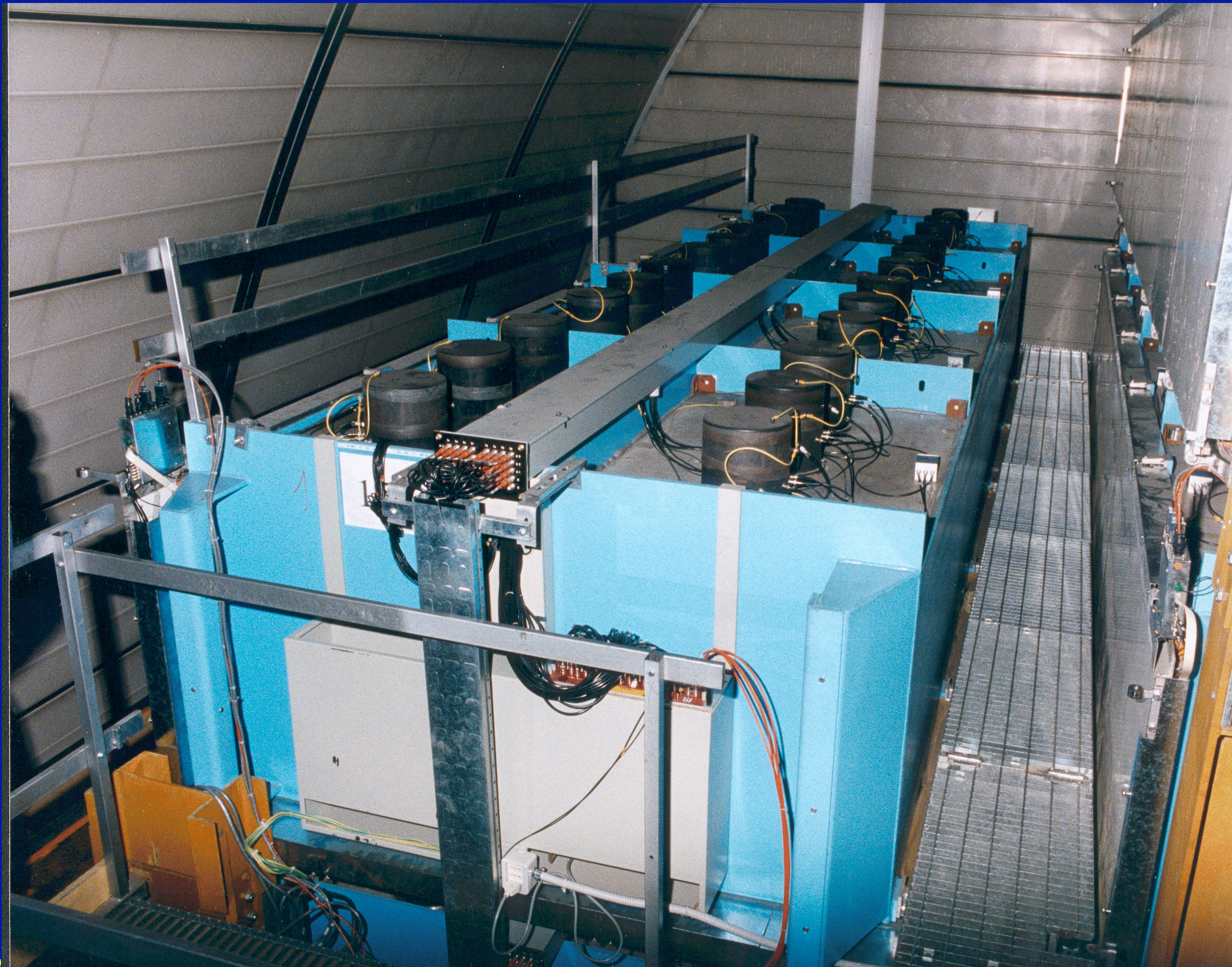
H=5200 m.w.e.
72 counters

Liquid Scintillator Detector (LSD)



P.Galeotti

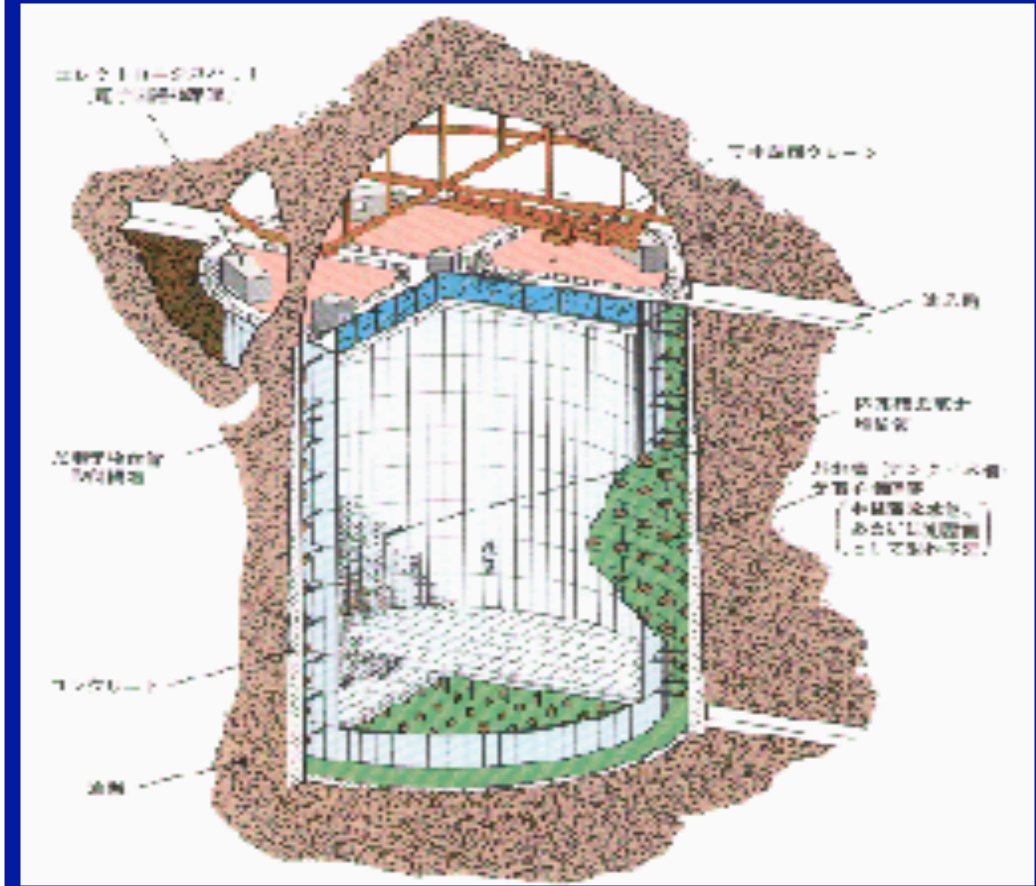
SN 1987A

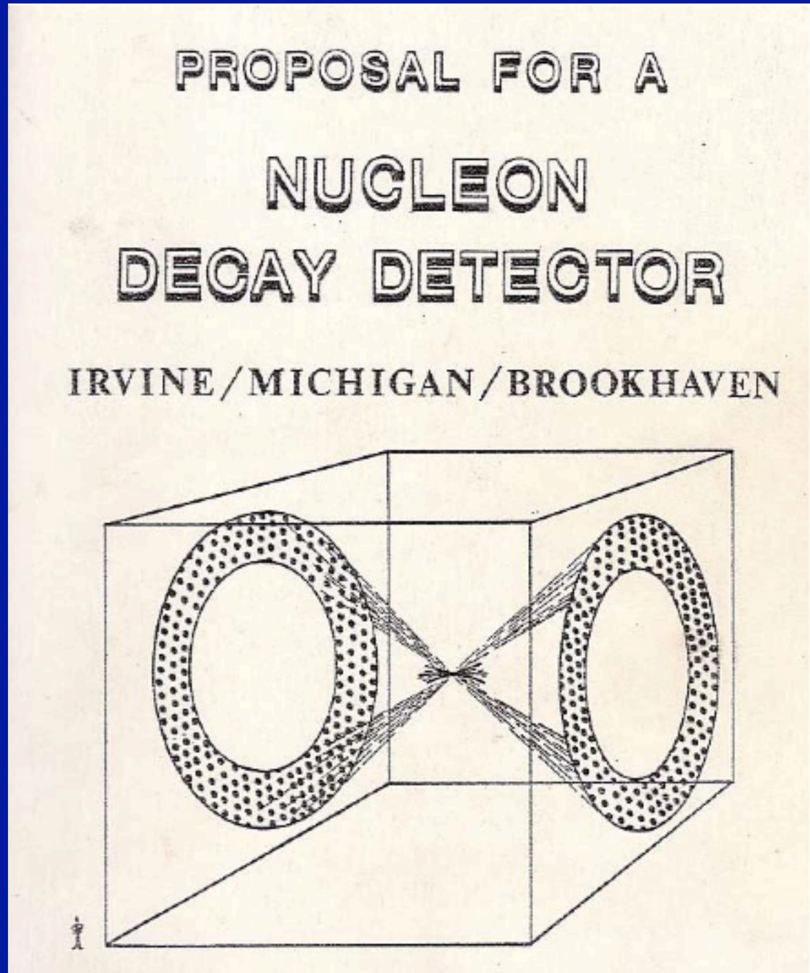


Atrium I

Baksan Underground Scintillation Telescope

KamiokaNDE





IMB

Main interactions in scintillator

- Inverse β decay:

  $$\bar{\nu}_e + p \rightarrow n + e^+$$

- Neutrino-elettron scattering:

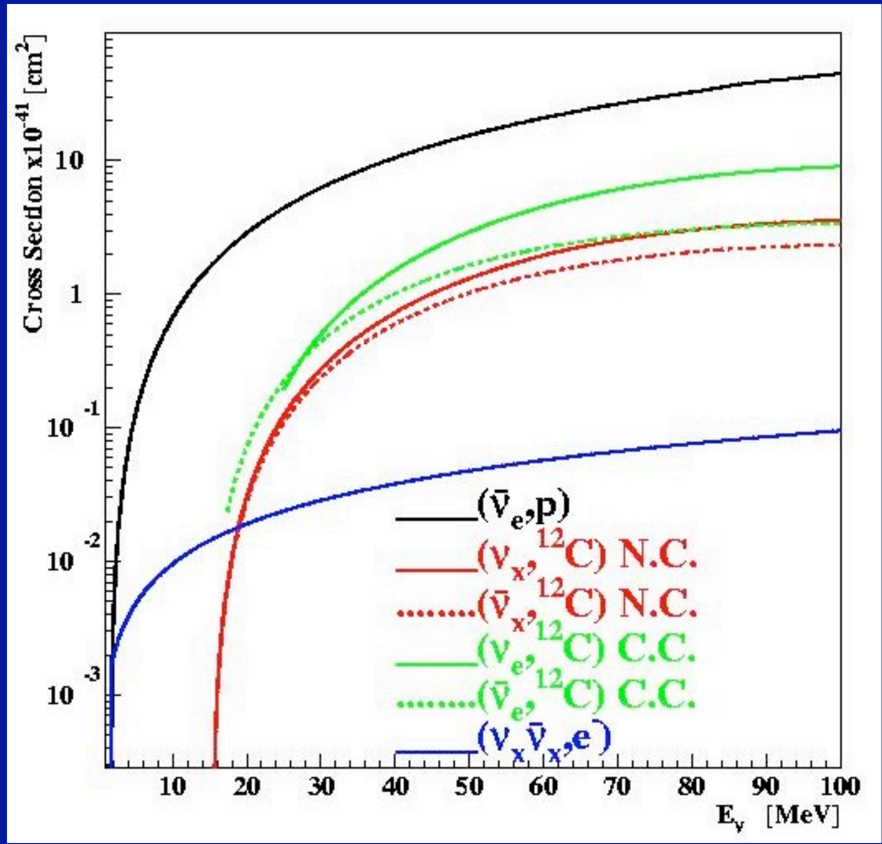
  $$\nu_{e,\mu,\tau} + e^- \rightarrow \nu_{e,\mu,\tau} + e^-$$

- Neutral currents interactions:

  $$\nu_{e,\mu,\tau}(\bar{\nu}_{e,\mu,\tau}) + {}^{12}C \rightarrow \nu_{e,\mu,\tau}(\bar{\nu}_{e,\mu,\tau}) + {}^{12}C^*$$

- Charged currents interactions:

  $$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$$
  $$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$$

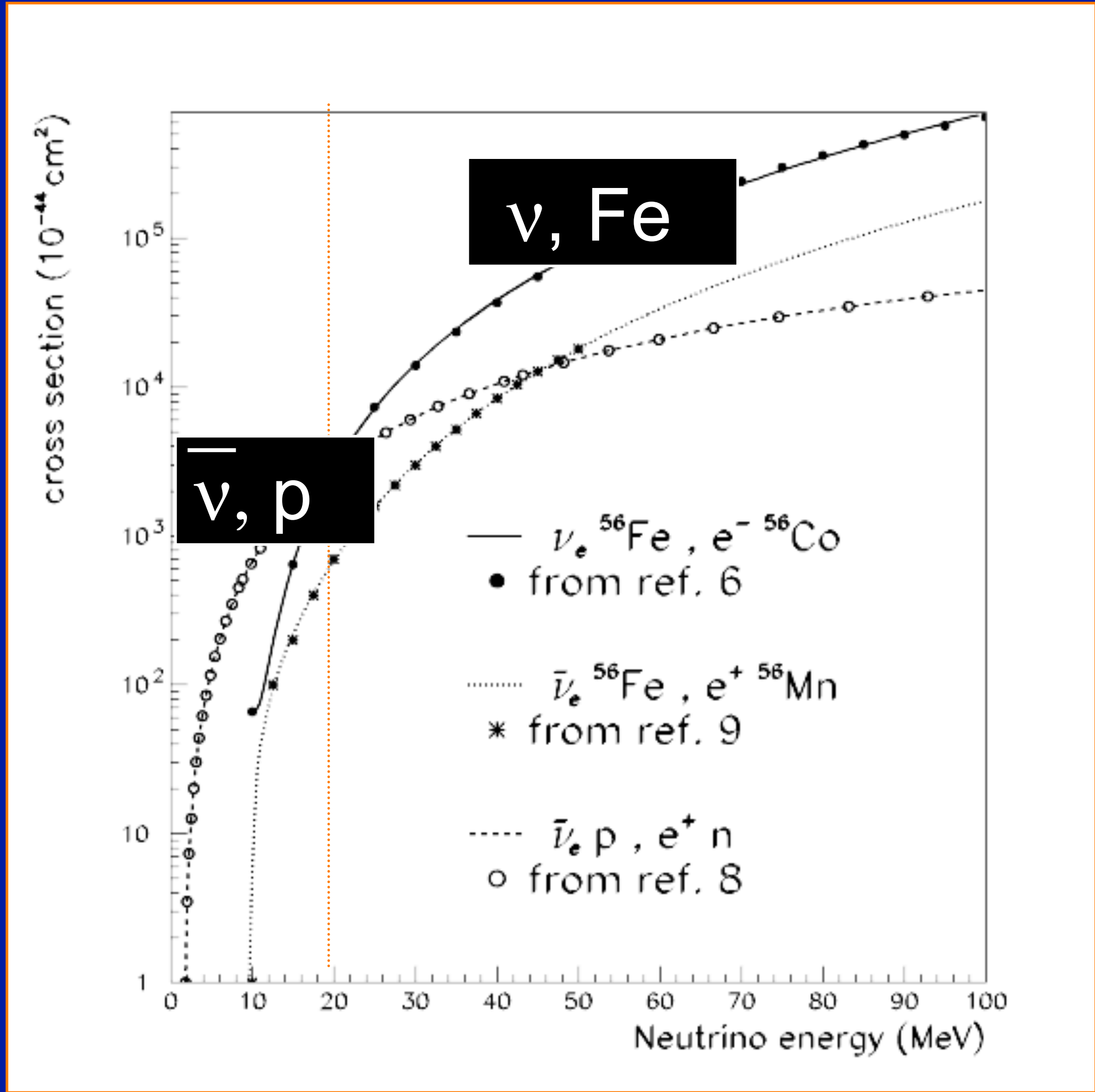


$$\sigma(\nu_e + e) = 10^{-44}\left(\frac{E_\nu}{\mathrm{MeV}}\right)\mathrm{cm}^2$$

$$\sigma(\nu_e + n) = \sigma(\bar{\nu}_e + p) = 9 \cdot 10^{-44}\left(\frac{E_\nu}{\mathrm{MeV}}\right)^2 \mathrm{cm}^2$$

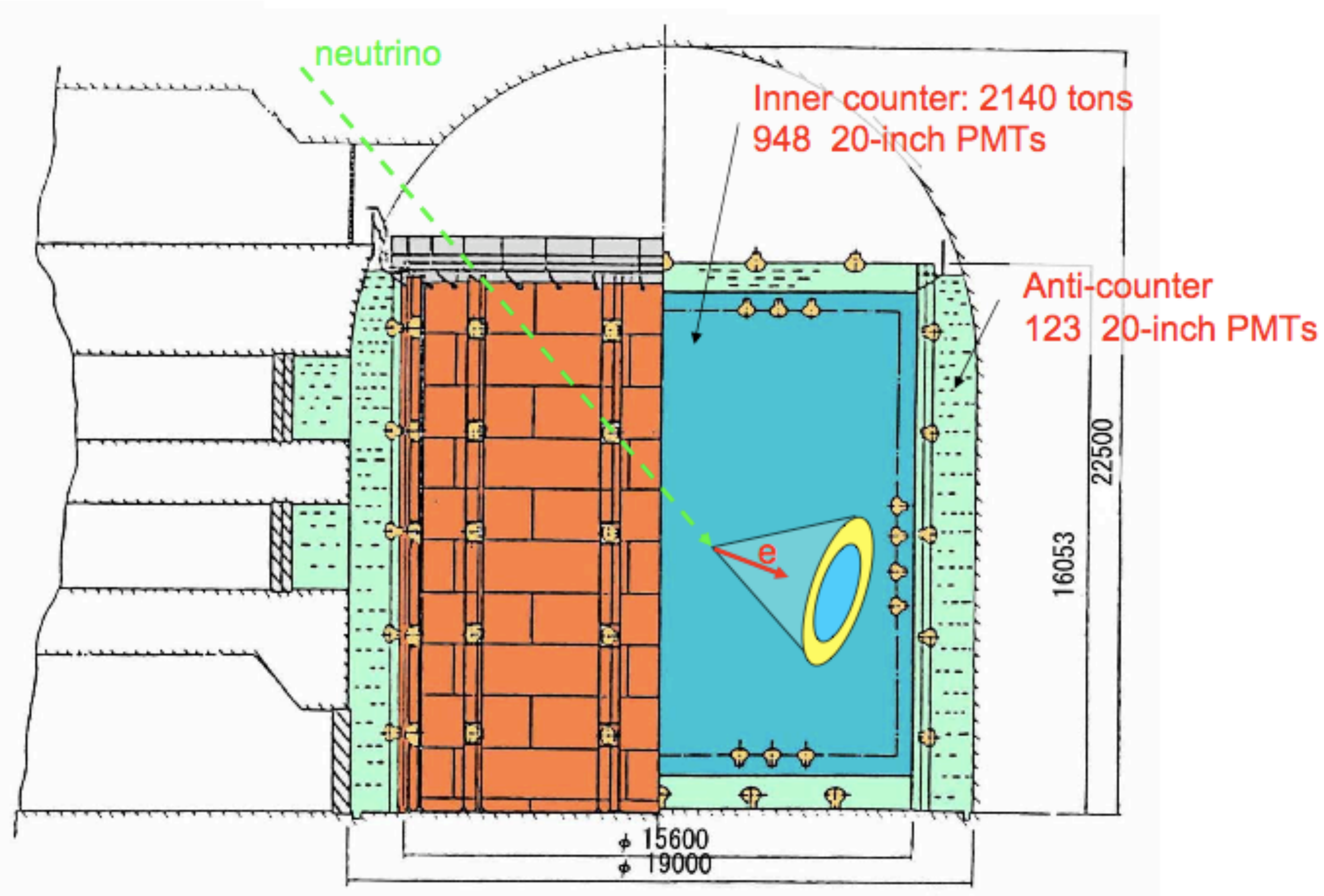
Neutrino interactions in iron

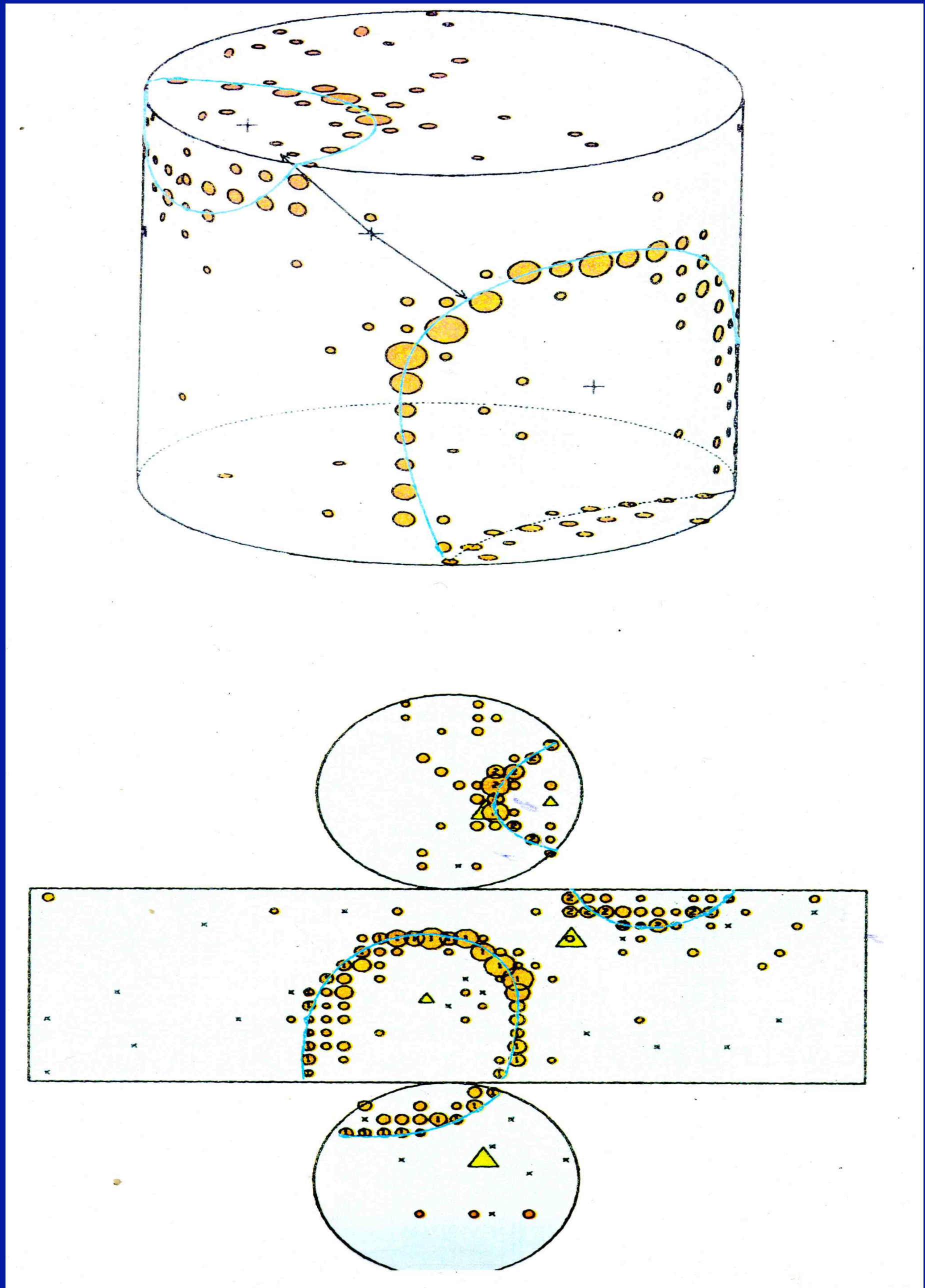
$$\nu_e + {}^{56}Fe \Rightarrow {}^{56}Co + e^-$$



P.Galeotti

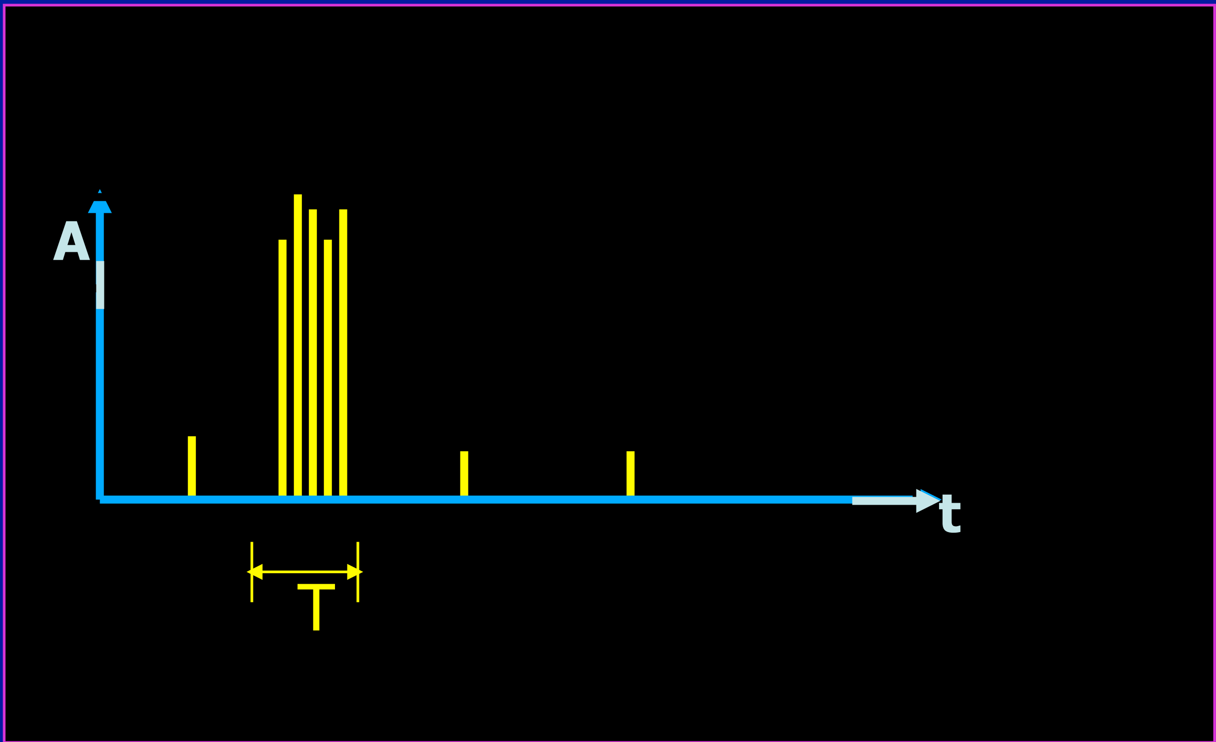
Kamiokande-II detector





Cherenkov light in water is emitted at angles of ≈ 43° from the parent particle. The direction of this particle can be easily reconstructed.

How can a neutrino burst be identified ?

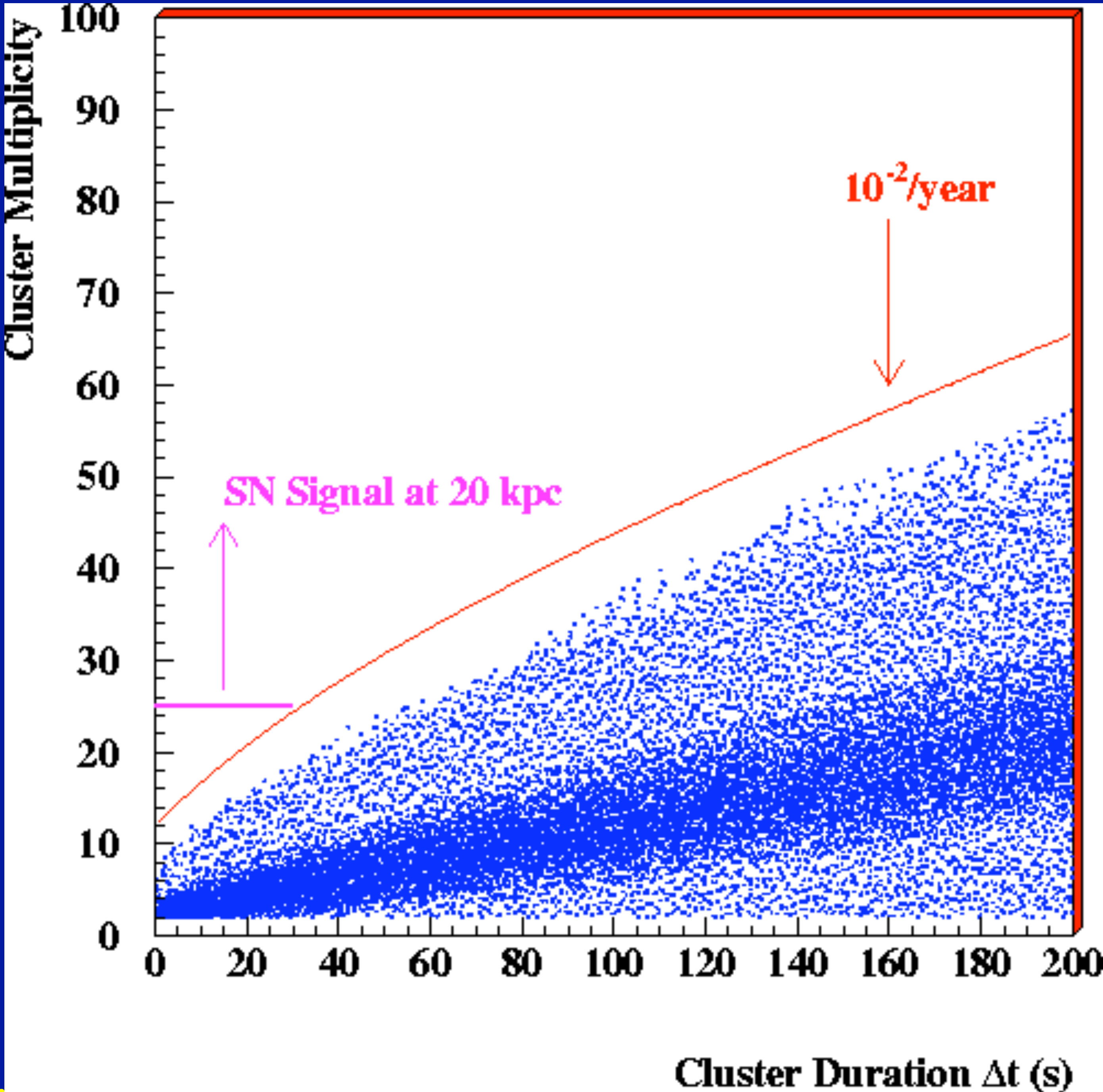


1: Statistics
(on line)

2: Check on run,
Spectrum,
Topology
(off line)

By detecting a statistical significative burst of N pulses in a short time interval

$$F_{imit} = f \sum_{n=N-1}^{\infty} P(n,\Delta t) = f \sum_{n=N-1}^{\infty} \frac{e^{-f\Delta t}(f\Delta t)^n}{n!}$$


Cluster Multiplicity
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
10^-2/year
SN Signal at 20 kpc
Cluster Duration Δt (s)

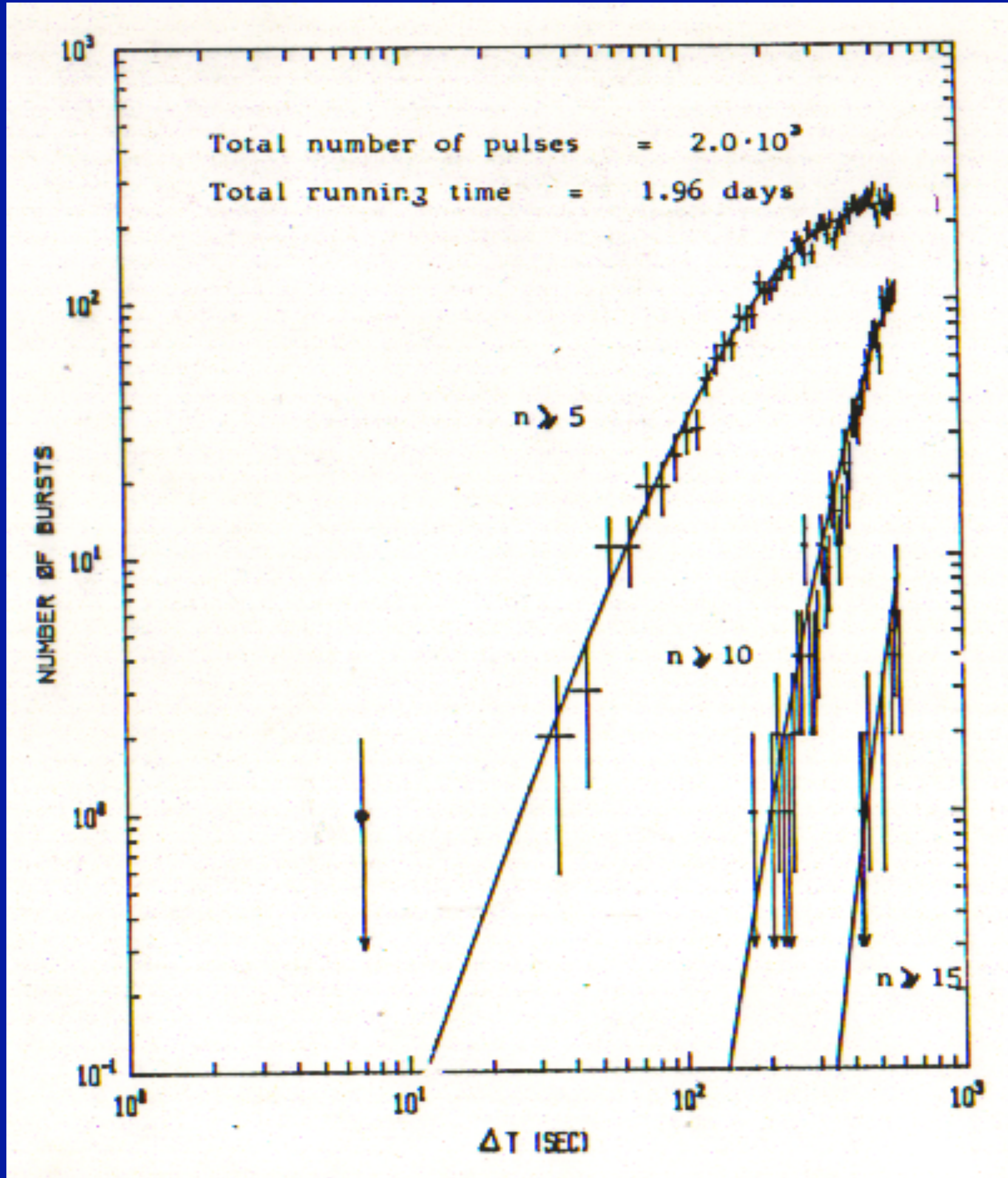
On line print of five pulses on Monday 23 febbrury 1987 at 3 hr, 52 min cet, detected at Mt. Blanc LSD experiment

```
              23 59 52.80/7 22 02 1987/CN 051 A 158/ SCR-0000240 REL 0128
 *** PDP-11 DATE/TIME WAS : 87/02/23    00:00:07:24
 *** INEGF CLOCK DATE/TIME IS  :         23    00:00:00:29 ( 591 MSEC  *** SOLAR TI
 CLOCK   --   STOP

 LSDMON   --   23-FEB-87 00:12:59 *** HIST.UPDATE AT EVENT 761 RUN 1328

 LSDM02   --   23-FEB-87 01:28:10 *** UPDATE HIST. FILE 2 ***

 LSDMON   --   23-FEB-87 01:33:52 *** HIST.UPDATE AT EVENT 861 RUN 1328

 LSDMON   --   23-FEB-87 02:12:48 *** EMPTY/ERRORED EVENT 900 RUN 1328

 LSDMON   --   23-FEB-87 03:17:08 *** HIST.UPDATE AT EVENT 962 RUN 1328

 LSDM02   --   23-FEB-87 03:37:47 *** UPDATE HIST. FILE 2 ***

 LSDM02   --   23-FEB-87 03:52:47 !!!!!!!! BURST OF   4 EVENTS   !!!!!!!!

  3:52:42.696 23- 2-87    TIME =      5.904 SEC.  EV.ATTESI =    0.07      FREQ.IMIT =    0.523E-01 /DAY
 EV   994   TANK 31   ADC   33 L.E.P.   0
 EV   995   TANK 14   ADC   37 L.E.P.   0
 EV   996   TANK 25   ADC   46 L.E.P.   1
 EV   997   TANK 35   ADC   32 L.E.P.   0
 LSDM02   --   23-FEB-87 03:52:56 !!!!!!!! BURST OF   4 EVENTS   !!!!!!!!

  3:52:43.800 23- 2-87    TIME =      3.151 SEC.  EV.ATTESI =    0.04      FREQ.IMIT =    0.811E-02 /DAY
 EV   995   TANK 14   ADC   37 L.E.P.   0
 EV   996   TANK 25   ADC   46 L.E.P.   1
 EV   997   TANK 35   ADC   32 L.E.P.   0
 EV   998   TANK 33   ADC   40 L.E.P.   0
 LSDM02   --   23-FEB-87 03:53:04 !!!!!!!! BURST OF   5 EVENTS   !!!!!!!!

  3:52:43.800 23- 2-87    TIME =      7.008 SEC.  EV.ATTESI =    0.08      FREQ.IMIT =    0.178E-02 /DAY
 EV   994   TANK 31   ADC   33 L.E.P.   0
 EV   995   TANK 14   ADC   37 L.E.P.   0
 EV   996   TANK 25   ADC   46 L.E.P.   1
 EV   997   TANK 35   ADC   32 L.E.P.   0
 EV   998   TANK 33   ADC   40 L.E.P.   0
 CLOSTR --
               04 52 52.90/1 23 02 1987/CN 052 A 158/ SCR 0000100 REL 0000
 LSDMON   --   23-FEB-87 04:53:22 *** HIST.UPDATE AT EVENT 1062 RUN 1328
 LSDM02   --   23-FEB-87 05:28:53 *** UPDATE HIST. FILE 2 ***
```

Number of bursts as a function of their duration ΔT (s) for multiplicities

$n \geq 5$, ≥ 10 and ≥ 15

Trigger rate
$f = 0.012/s$



Neutrino '84, 11th Int. Conference on Nutrino Physics and Astrophysics

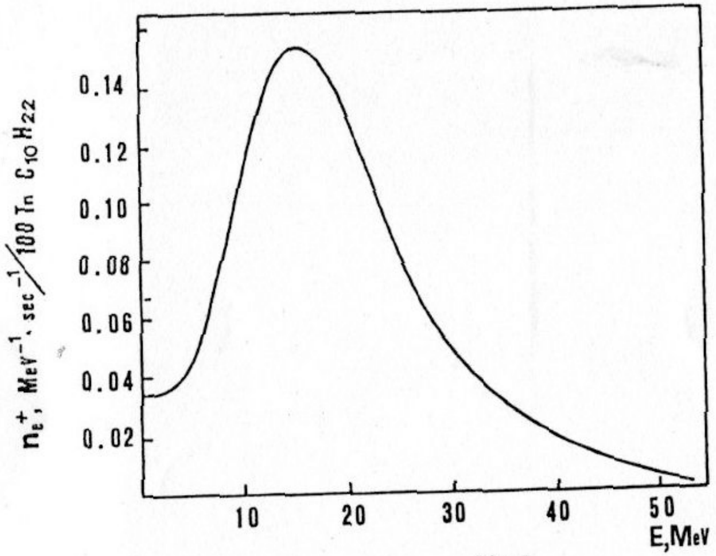


Fig.3

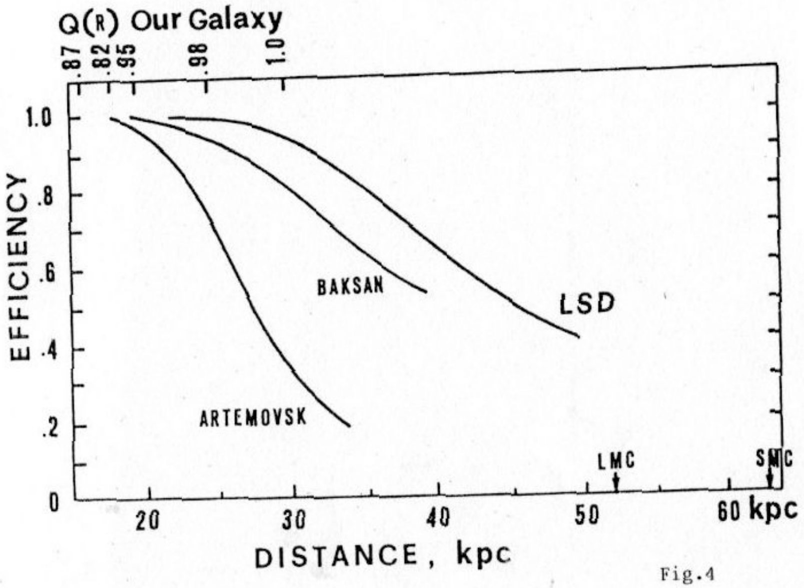


Fig.4

of information on the dynamics of the collapse and on the physical conditions inside the pre-supernova core can be obtained by observing not only the $\bar{\nu}_e$ through reaction (1), but also the ν_e through the elastic scattering reaction $\nu_e + e^- \rightarrow \nu_e + e^-$, which however produces a lower number of interactions in the detector. The signature of the electron neutrinos is given in LSD by pulses above the high energy threshold of 7 MeV, without any low energy delayed pulse. In this way, since ν_e are emitted as early as the neutronization stage of the collapse, the initial phases of the development of a collapsing star can be study.

4. Solar neutrinos

Since in our apparatus the local radioactivity background from the surrounding rock has been reduced to very low counting rates, we are checking the possibility to detect high energy solar neutrinos from the ^{10}B decay in the Sun, through the elastic scattering reaction with the electrons of our detector.

By using the present limit flux of solar neutrinos observed in the Brookhaven detector, and taking into account that the energy threshold in our apparatus can be set at 5 MeV, the number of detectable electrons from solar neutrinos is ~ 0.3/day.

5. Atmospheric neutrinos

At low energy range, $10 \lesssim E_\nu \lesssim 700$ MeV, no experimental information is at present available for the atmospheric neutrino spectrum; also the theoretical predictions are not well defined in this region, even if some calculations have been recently made for energies $\gg 200$ MeV to stimate the neutrino background in proton decay experiments in underground laboratories. However, new efforts are in progress, Gaisser[7], to predict the neutrino spectrum at low energies.

With our LSD experiment we intend to directly measure the $\bar{\nu}_e$ atmospheric neutrinos above an energy threshold of $\gtrsim 10$ MeV through reaction (1). By measuring inside the fiducial volume of LSD both the energy of the contained e^+ and the associate γ-pulse from neutron capture, we'll obtain a direct experimental measure of the $\bar{\nu}_e$ atmospheric spectrum, with a very clear signature that makes such events easily distinguishable from any other type of neutrino interactions. At a threshold of 10 MeV, the total number of atmospheric neutrino interactions has been estimated to be of the order of a few tens per year.

Circular No. 4323

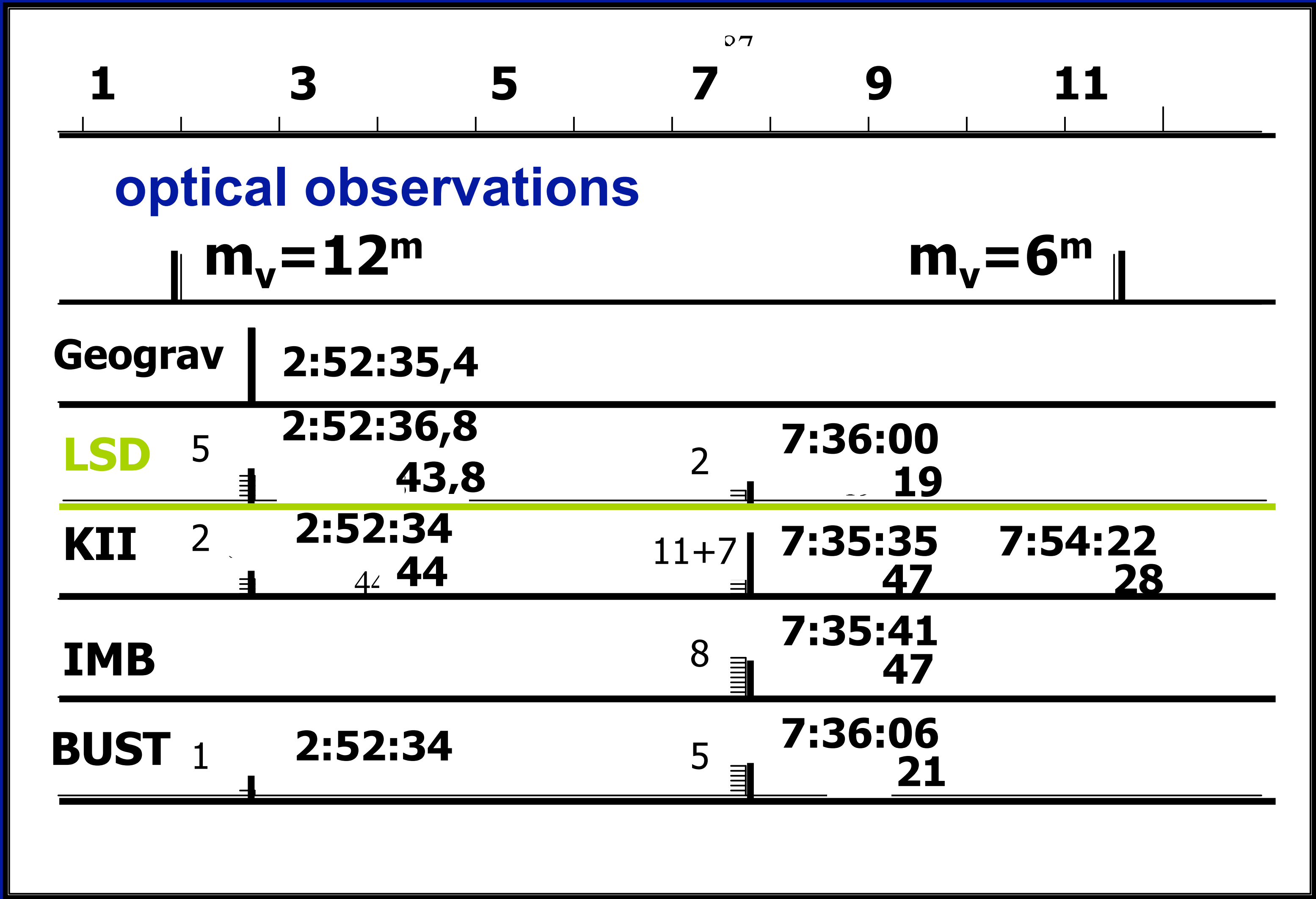
Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
Postal Address: Central Bureau for Astronomical Telegrams
Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.
TWX 710-320-6842 ASTROGRAM CAM Telephone 617-495-7244/7440/7444

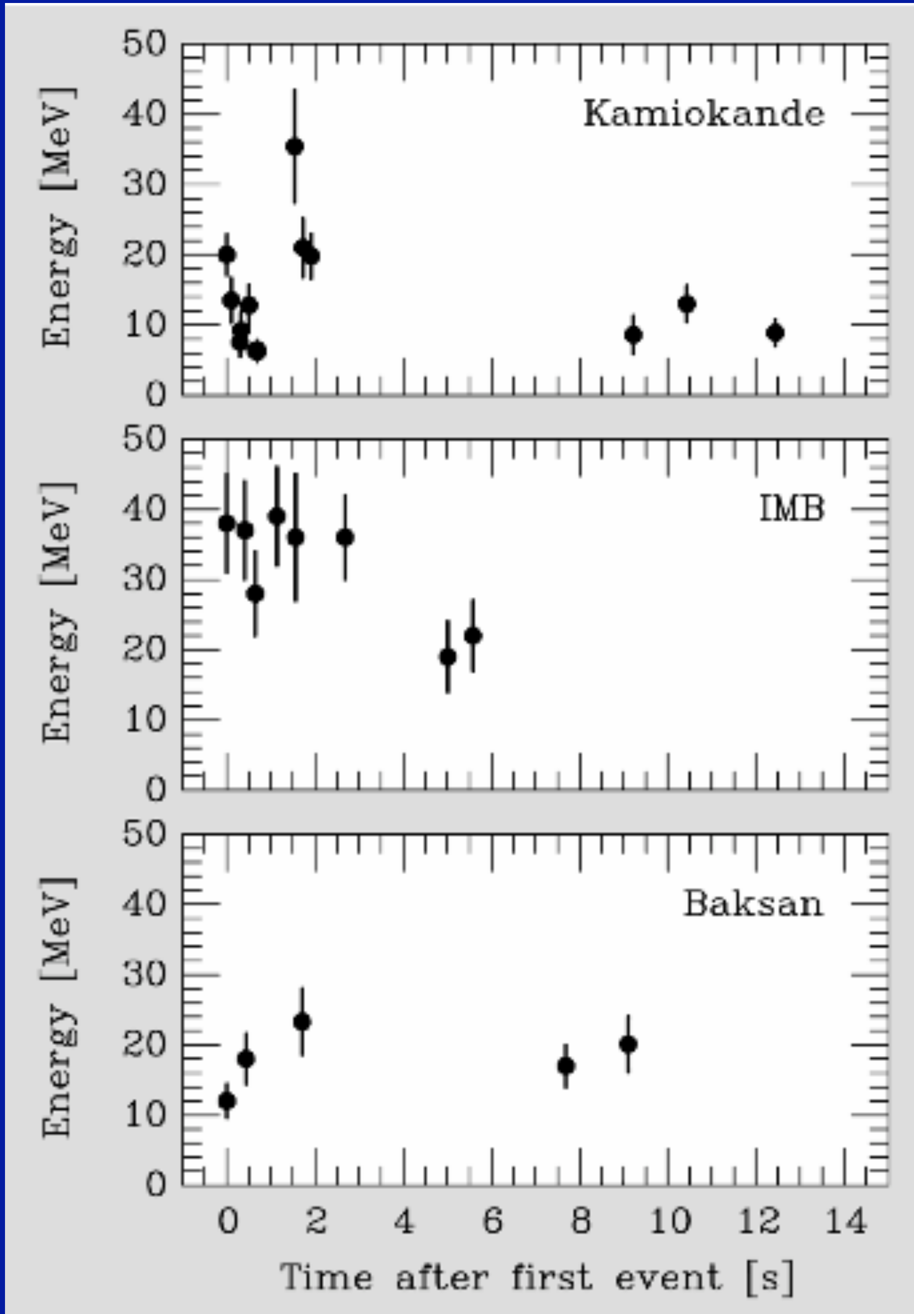
SUPERNOVA 1987A IN THE LARGE MAGELLANIC CLOUD

C. Castagnoli, Istituto di Cosmogeofisica, Turin, telexes: "A signal was detected on Feb. 23.124 UT at the Mont Blanc Neutrino Observatory. The signal consists of five pulses, above the 7-MeV energy threshold over an interval of 7 seconds. This is in agreement, both in energy and duration, with predictions of collapsing iron-core standard models at 50 kpc. The probability of a random occurrence with SN 1987A is 1 per 10**4 yr. The neutrino telescope, running since 1984 Oct. at 5000 meters water equivalent underground, in a collaboration between our Institute and G. Zatsepin's group at the Institute of Nuclear Studies in Moscow, consists of 90 tonnes of liquid scintillator in 72 counters shielded with 200 tonnes of iron slabs."

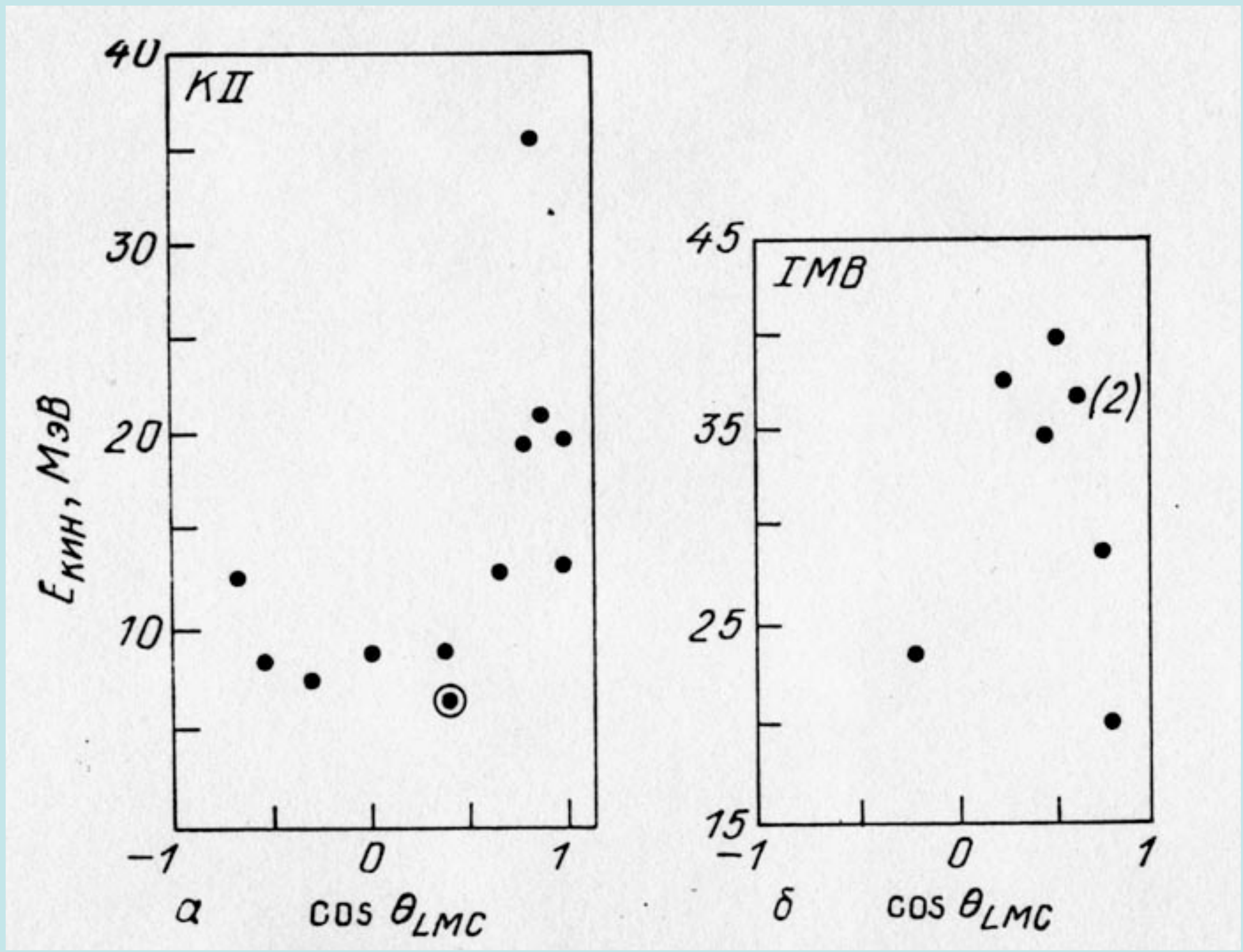
1987 February 28 (4323) Brian G. Marsden

February 23, 1987





Kamiokande
IMB
Baksan
Energy [MeV]
Time after first event [s]



KII
40
30
20
10
$E_{кин}$, МэВ
−1
0
1
a
cos θ_{LMC}
IMB
45
35
25
15
(2)
−1
0
1
б
cos θ_{LMC}

ELSEVIER

Physics Letters B

Volume 193, Issue 4, 23 July 1987, Pages 514–524

May a supernova bang twice?

A. De Rújula

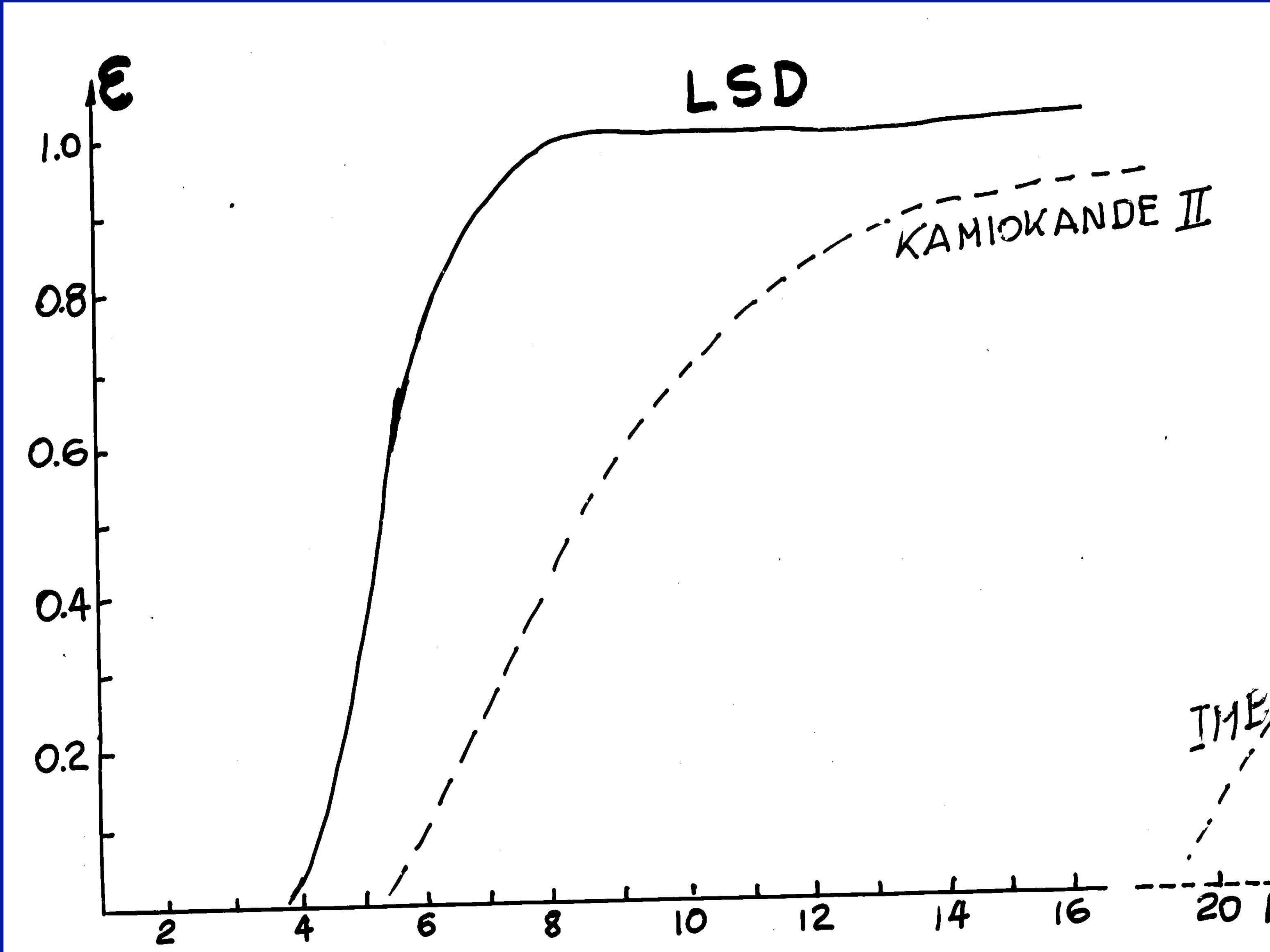
CERN, CH-1211 Geneva 23, Switzerland

Received 27 April 1987, Available online 28 October 2002

doi:10.1016/0370-2693(87)91709-6

Abstract

The Mont Blanc group reports a burst of neutrinos in the LSD detector occuring the day before the optical discovery of SN1987A. The Kamiokande (K2) and IMB experiments see neutrino bursts ~4 h 43 min after LSD. The K2 observations at LSD time here said to contradict LSD. I argue that the K2 results strongly support the LSD pulse(!). I critically analyse the data, and prove that all experiments are compatible at all times. I discuss the plausibility and predictive power of a two-neutrino-burst scenario, wherein the progenitor's core first became a neutron star, and subsequently recollapsed into a black hole (or strange star) as matter left behind by a partially failed shock wave accreted on and around the neutron star, with a calculated fall-back time of a few hours



ε
LSD
KAMIOKANDE II
IMB
1.0
0.8
0.6
0.4
0.2
2
4
6
8
10
12
14
16
20

DETECTED NEUTRINO SIGNALS

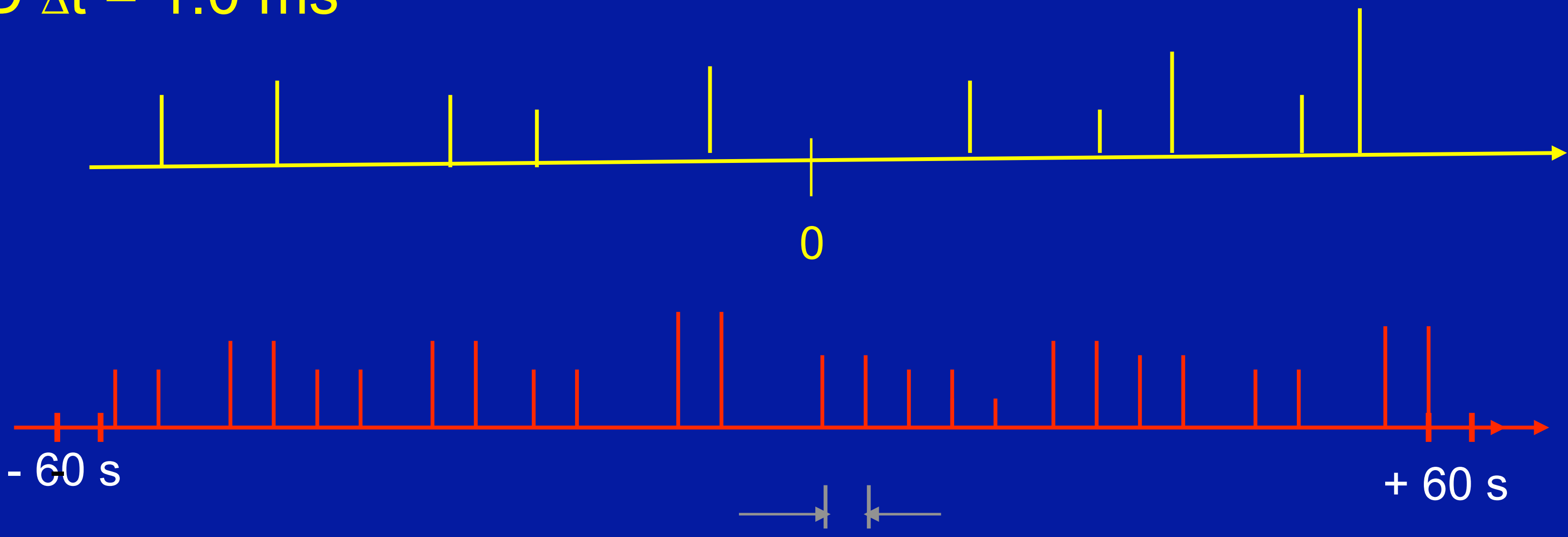
Mont Blanc	5 pulses	$E \geq 5$ MeV	UT 2:52:36.8 $\pm$ 2 ms
Kamioka	11 “	8	7:35:35 $\pm$ 1 min
IMB	8 “	25	7:35:41 $\pm$ 5 ms
BST	(2+5) “	10	2:52:34 and 7:36:06 (+ 2s-54s)

The main signal comes from electron antineutrinos: $\bar{\nu}_e p \rightarrow \nu e^+$ followed by e^+e^- annihilation producing 2 γ's, detectable in scintillator but not in water. The Mont Blanc signal ($5.8 \leq E_{vis} \leq 7.8$ MeV) corresponds to $4.6 \leq E_{vis} \leq 6.6$ MeV in water, at the limit to be detected in Kamioka.

Kamioka - Mont Blanc correlations

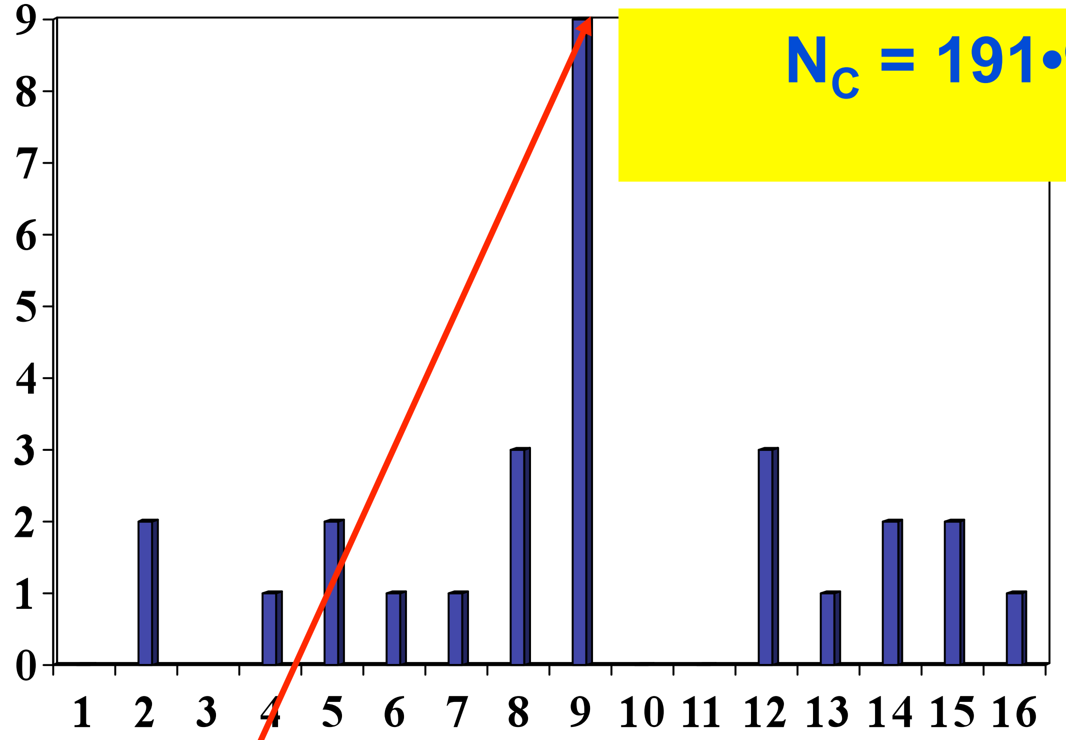
$$N_c = 2\frac{N_1 \cdot N_2}{T}\Delta\tau$$

LSD Δt = 1.0 ms



Kamioka Δt = 60 sec

Coincidences Mt.Blanc-Kamioka



N_C = 191•91•2•0.5/7200 = 2.4

N_O = 9

Mt. Blanc event time
1:45 – 3.45 U.T.

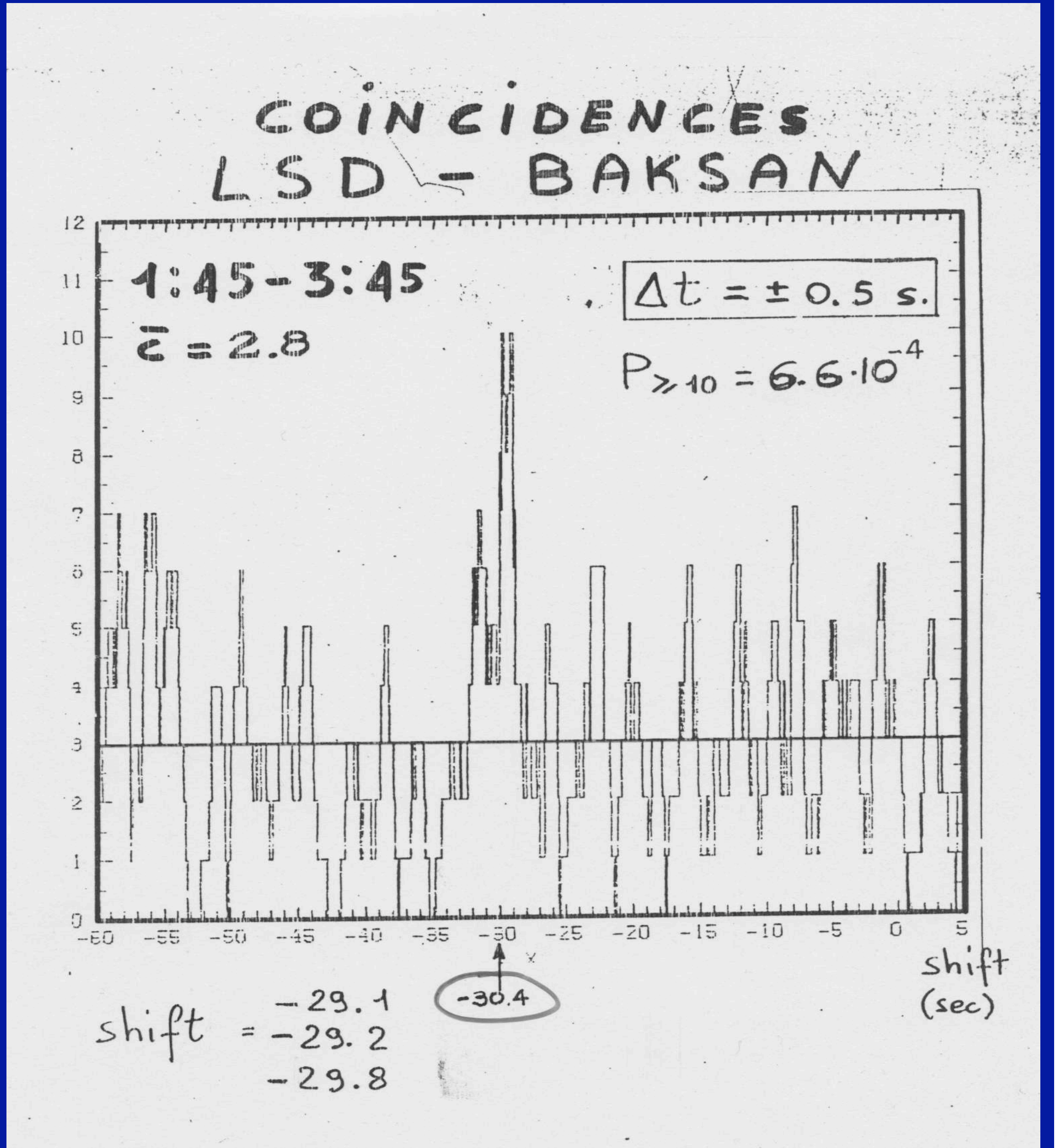
Coincidence window $\Delta t = \pm\ 0.5$ s
Bin width: 2 hours
Coincidence time: 34 hours
Kamioka time + 7 seconds

Table 4. Coincidences between LSD and Kamioka in the period from 1:45 to 3:45 UT on February 23, 1987[a]

LSD			Kamiokande				
Event number	Time	Energy (MeV)	Event number	Time	N hit	$\cos\theta$[b]	Time difference (s) 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
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	126905	3:12:32:57	21	−0.842	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	9.96

[a] The coincidence window is ±0.5 s.
[b] θ is the direction from SN 1987A.
The LSD event No 979 coincident with event No 125275 from K2 is also coincident with BST.

91 Mt. Blanc events
240 Baksan events



POSITIVE EVIDENCE NO. 1

Following reference 1, we have to choose several quantities for our correlation analysis:

(1) Δt = the time gate or correlation time,
(2) T = the time period in which coincidences are summarized,
(3) t = the position of the center of the T period on the U.T. scale,
(4) t_0 = a relative shift of the time scales of the two detectors; in our case, a correlation of the Baksan clock.

We first choose $\Delta t = \pm 1$ s. One second is exactly the time gate chosen in reference 1 and the plus-minus sign arrives from the assumed symmetry of the detectors. The choice of Δt by intention is not made as an optimal one (for $\Delta t = \pm 0.2$ s or $\Delta t = \pm 2$ s, the result could be made more impressive).

Next, $T = 1$ hour is in our opinion a good choice, both improving the significance of the result by a factor of four (as compared with $T = 2$ hours) and indicating the maximum of activity better.

The choice of $t = 2{:}15$ U.T. is illustrated in FIGURE 1.

The choice of $t_0 = -29.5$ s for the correction of the Baksan clock is shown in FIGURE 2.

FIGURE 1 shows the significance of the correlation both for the G.A.-LSD pair

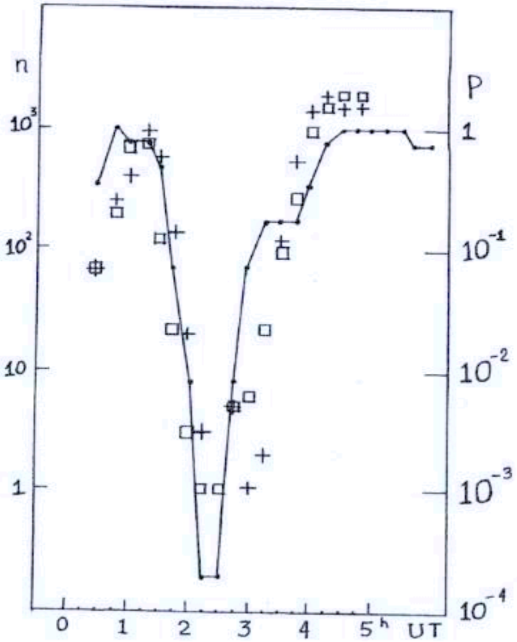


FIGURE 1. The significance of observed correlations for both G.A.-LSD (squares and crosses) and LSD-Baksan (dots and solid line) as a function of the position of the period T on the U.T. scale. Squares: $E_M \times E_R$ algorithm; crosses: $E_M + E_R$ algorithm (see reference 1).

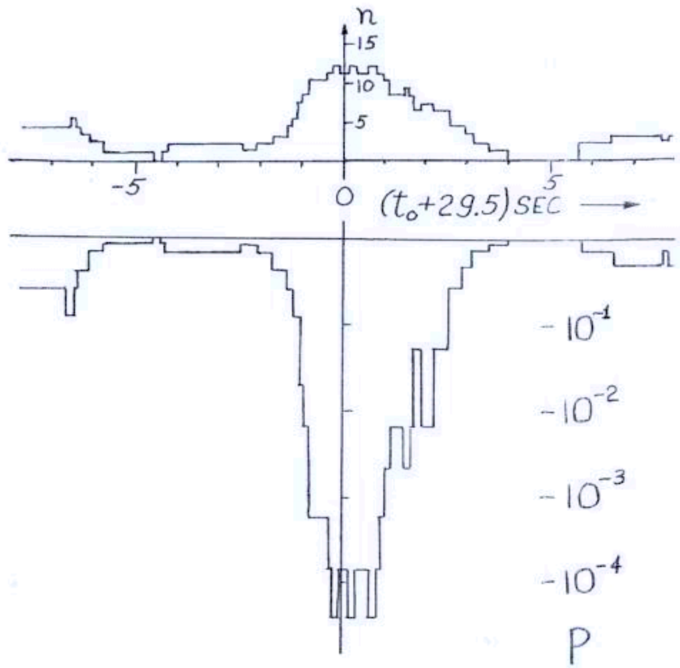
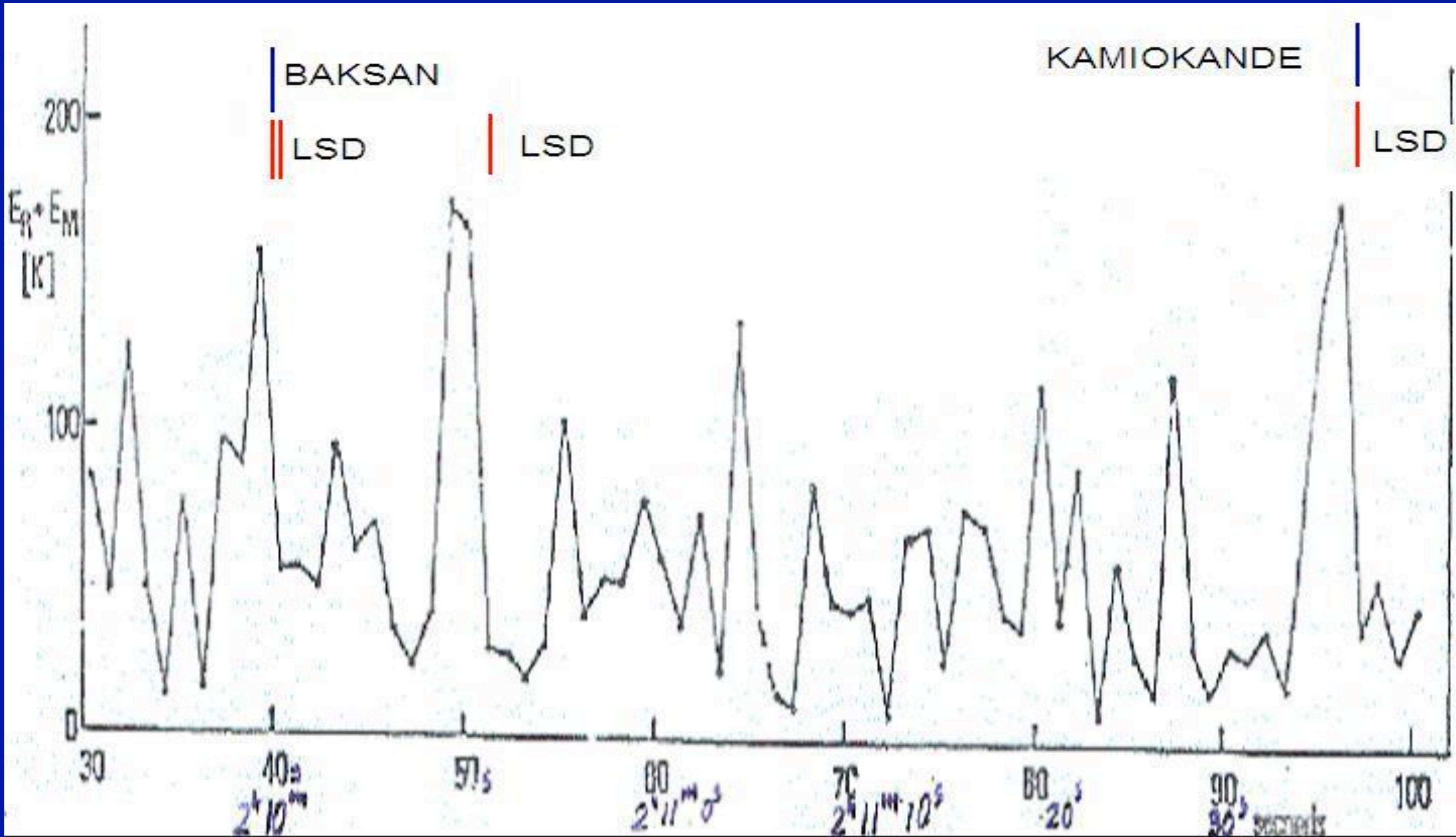


FIGURE 2. The number of LSD-Baksan coincidences as a function of the time shift, t_0 (top histogram). The Poisson probability to have the observed number or more (bottom histogram).

(crosses and squares) and the LSD-Baksan pair (solid line with dots). Note that data for the G.A.-LSD pair are taken from reference 1.

For both data, the time period of $t = 1$ hour is moved by steps of 15 min along the U.T. time scale. On the left vertical scale, the quantity, n, is plotted (see reference 1); $n = 2000$ roughly represents the chance probability to observe the recorded magnitude of the G.A.-LSD correlation. On the right vertical scale, the chance probability to observe the recorded number or a bigger number of LSD-Baksan coincidences, $\Delta t = \pm 1$ s, is plotted. Although this quantity strictly does not obey the Poisson distribution, the latter is quite a good approximation in our particular case. For $t = 2{:}15$, we have: $N(\text{LSD}) = 44$; $M(\text{Baksan}) = 116$; the mean (expected) value of coincidences is $\lambda = 2 \times 44 \times 116/3600 = 2.84$; the observed one is 11. The practical validity of the Poisson distribution of the number of coincidences for these particular figures was checked by 32,400 trials.

Looking at FIGURE 1, we see a striking similarity between the G.A.-LSD data and the LSD-Baksan data. The correlation arrives at the same time and, approximately, with the same strength. The probability of this to happen by chance is $P = 2 \times 10^{-4}$. However, the last figure should be corrected for the arbitrary choice of $t_0(\text{Baksan}) = -29.5$ s.


BAKSAN
LSD
LSD
KAMIOKANDE
LSD
200
100
0
[K]
30
40
50
60
70
80
90
100
seconds

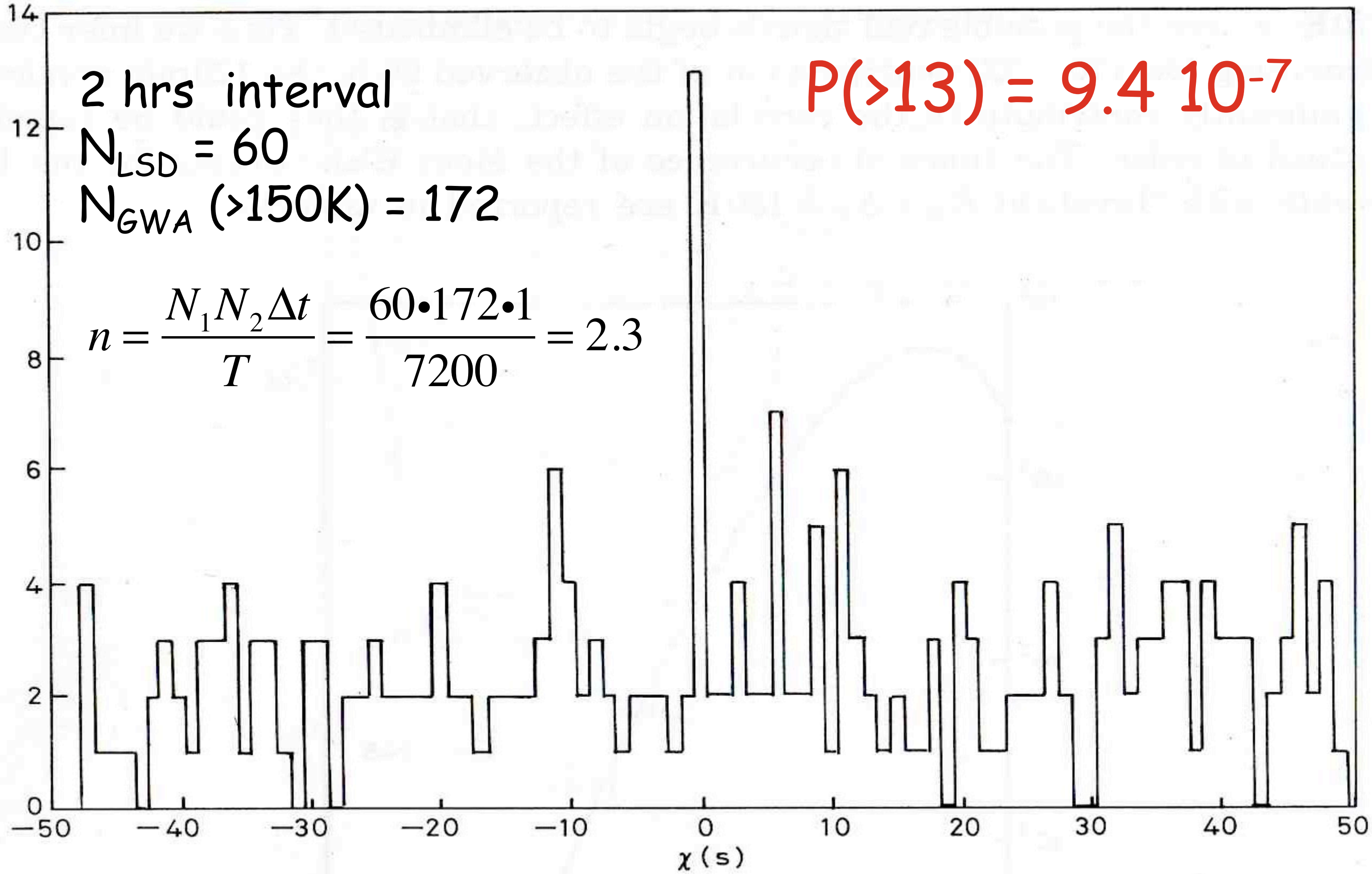
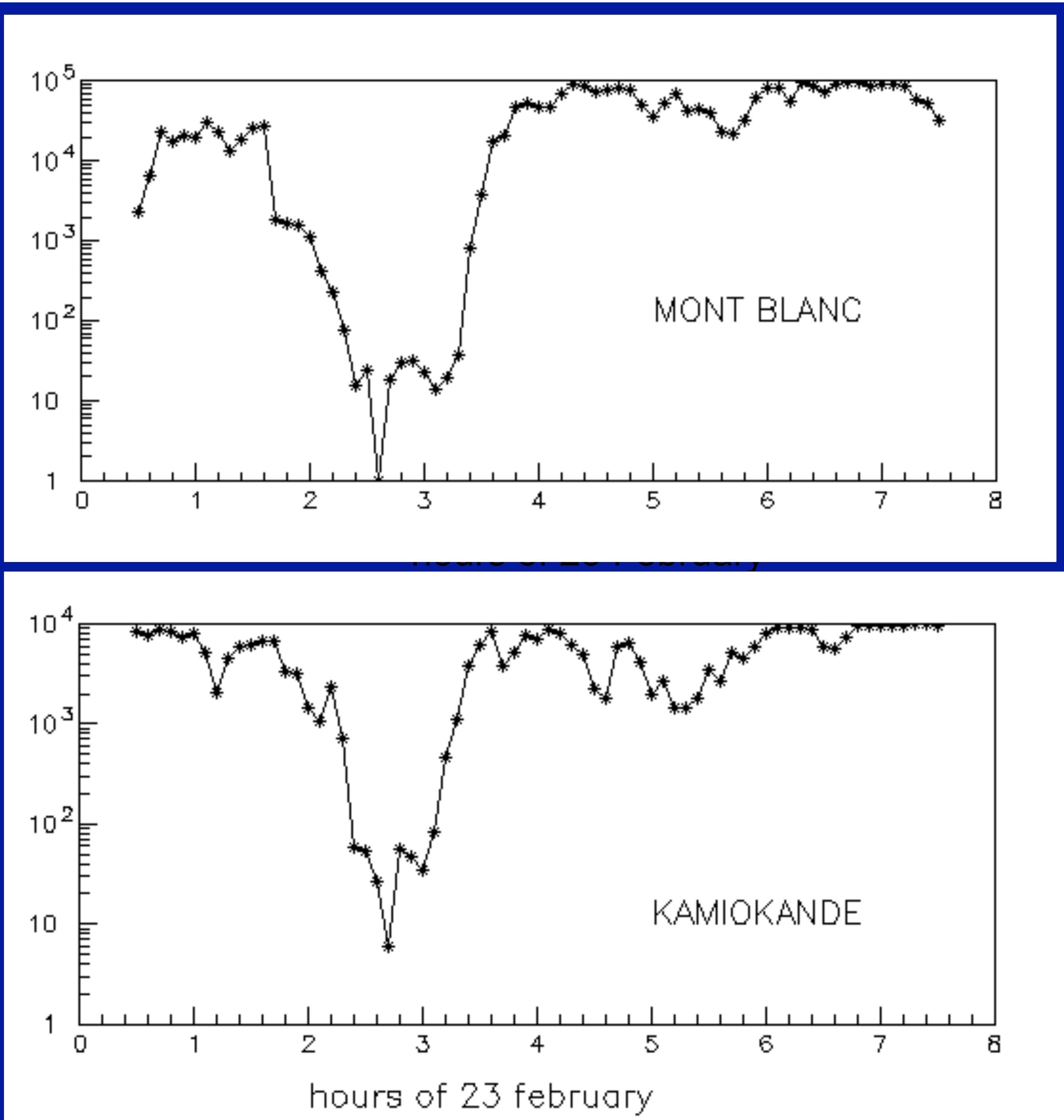


Fig. 14. – The coincidences for the period of fig. 12 between the neutrinos ($N_\nu = 96$) and the g.w. sum events above 150 K ($N_{\text{g.w.}} = 172$).



P.Galeotti

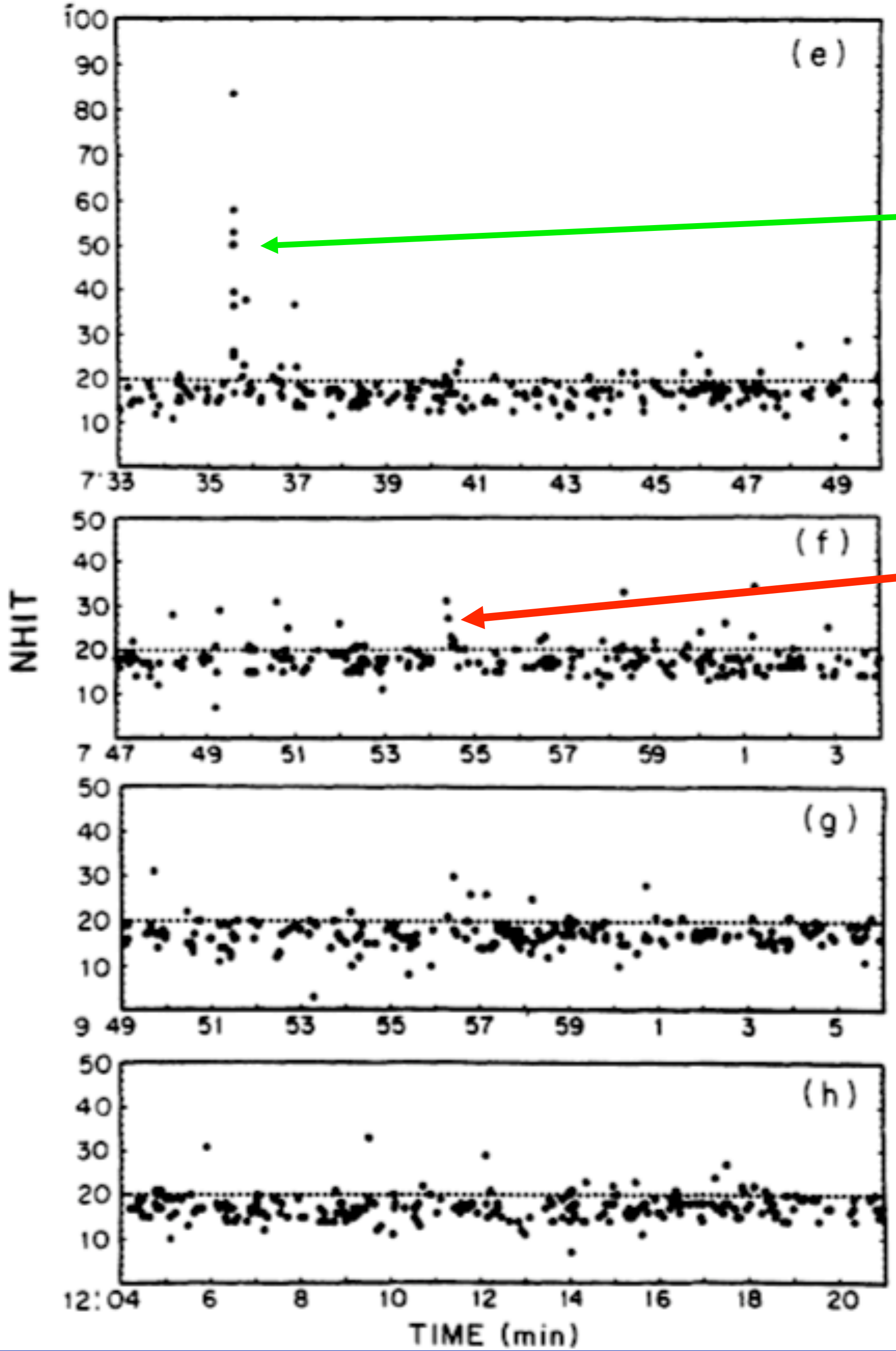
Springer Link

Find out how to access preview-only content
Look Inside Get Access
Il Nuovo Cimento C
Maggio–Giugno 1988, Volume 11, Issue 3, pp 287-303

On the possibility of a two-bang supernova collapse

Summary

The possibility of a two-bang stellar collapse originating SN 1987*a*, and having the characteristics of the events recorded in Mont Blanc and Kamiokande, is discussed here. According to the «standard» collapse models of nonrotating stars, which predict the formation of a neutrinosphere with a nondegenerate neutrino gas inside the star, the Mont Blanc and Kamiokande data for the first burst give a too large stellar mass. On the contrary, a degenerate neutrino gas with low temperature $T \approx 0.5$ MeV, and chemical potential $\mu \approx (12 \div 15)$, predicts a relatively low total energy outflow $W_\nu \approx (2 \div 6) \cdot 10^{54}$ erg, and a small number of expected interactions in Kamiokande. A possible scenario is suggested: a massive ($M \approx 20 M_\odot$) rotating star is fragmented into two pieces, one light and the other heavy, at the onset of the collapse. The massive component collapses to a black hole, and produces the first burst. Neutrinos are trapped inside the collapsing star because of elastic scattering in the outer core off heavy nuclei, with $A \gtrsim 300$. It is shown that neutrinos fill up the quantum states, producing a degenerate neutrino gas. The second burst is explained by coalescence of the light fragment ($M \approx (1 \div 3) M_\odot$) onto the massive black hole. The time delay between the two observed bursts (4.7 h) is mostly connected with gravitational braking, when the light fragment falls down onto the black hole, with an accompanying emission of gravitational waves for times of order of hours.



11 ν in 12 s

7 ν in 6 s

IMB
E > 15 MeV

hour	min	sec	nhit	number	duration [s]	prob [years]
7	35	33.67	58	11	12.4	$1.21\ 10^7$
7	35	33.78	36			
7	35	33.98	25			
7	35	34.00	26			
7	35	34.18	39			
7	35	35.21	83			
7	35	35.40	55			
7	35	35.59	51			
7	35	42.89	21			
7	35	44.11	37			
7	35	46.11	24			

No IMB
E < 15 MeV

7	54	22.26	33	7	6.2	669
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			

LVD results from 21 years of data taking at LNGS

The Astrophysical Journal, 802:47 (9pp), 2015 March 20
doi:10.1088/0004-637X/802/1/47

IMPLICATION FOR THE CORE-COLLAPSE SUPERNOVA RATE FROM 21 YEARS OF DATA OF THE LARGE VOLUME DETECTOR

N. Y. Agafonova[1], M. Aglietta[2], P. Antonioli[3], V. V. Ashikhmin[1], G. Badino[2,7], G. Bari[3], R. Bertoni[2], E. Bressan[4,5], G. Bruno[6], V. L. Dadykin[1], E. A. Dobrynina[1], R. I. Enikeev[1], W. Fulgione[2,6], P. Galeotti[2,7], M. Garbini[3], P. L. Ghia[8], P. Giusti[3], F. Gomez[2], E. Kemp[9], A. S. Malgin[1], A. Molinario[2,6], R. Persiani[3], I. A. Pless[10], A. Porta[2], V. G. Ryasny[1], O. G. Ryazhskaya[1], O. Saavedra[2,7], G. Sartorelli[3,4], I. R. Shakiryanova[1], M. Selvi[3], G. C. Trinchero[2], C. Vigorito[2,7], V. F. Yakushev[1], A. Zichichi[3,4,5,11]
(The LVD Collaboration)
[1] Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia
[2] INFN-Torino, OATo-Torino, I-10100 Torino, Italy; vigorito@to.infn.it, fulgione@to.infn.it
[3] INFN-Bologna, 40126 Bologna, Italy
[4] University of Bologna, I-40126 Bologna, Italy
[5] Centro Enrico Fermi, I-00184 Roma, Italy
[6] INFN-Laboratori Nazionali del Gran Sasso and Gran Sasso Science Institute, I-67100 LAquila, Italy
[7] Dep. of Physics, University of Torino, I-10125 Torino, Italy
[8] CNRS-IN2P3, Paris, Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE), Universités Paris 6 et Paris 7, France
[9] University of Campinas, 13083-859 Campinas, SP, Brazil
[10] Massachusetts Institute of Technology, Cambridge, MA 02139-4307, USA
[11] CERN, Geneva, Switzerland
Received 2014 October 30; accepted 2015 January 12; published 2015 March 20

ABSTRACT

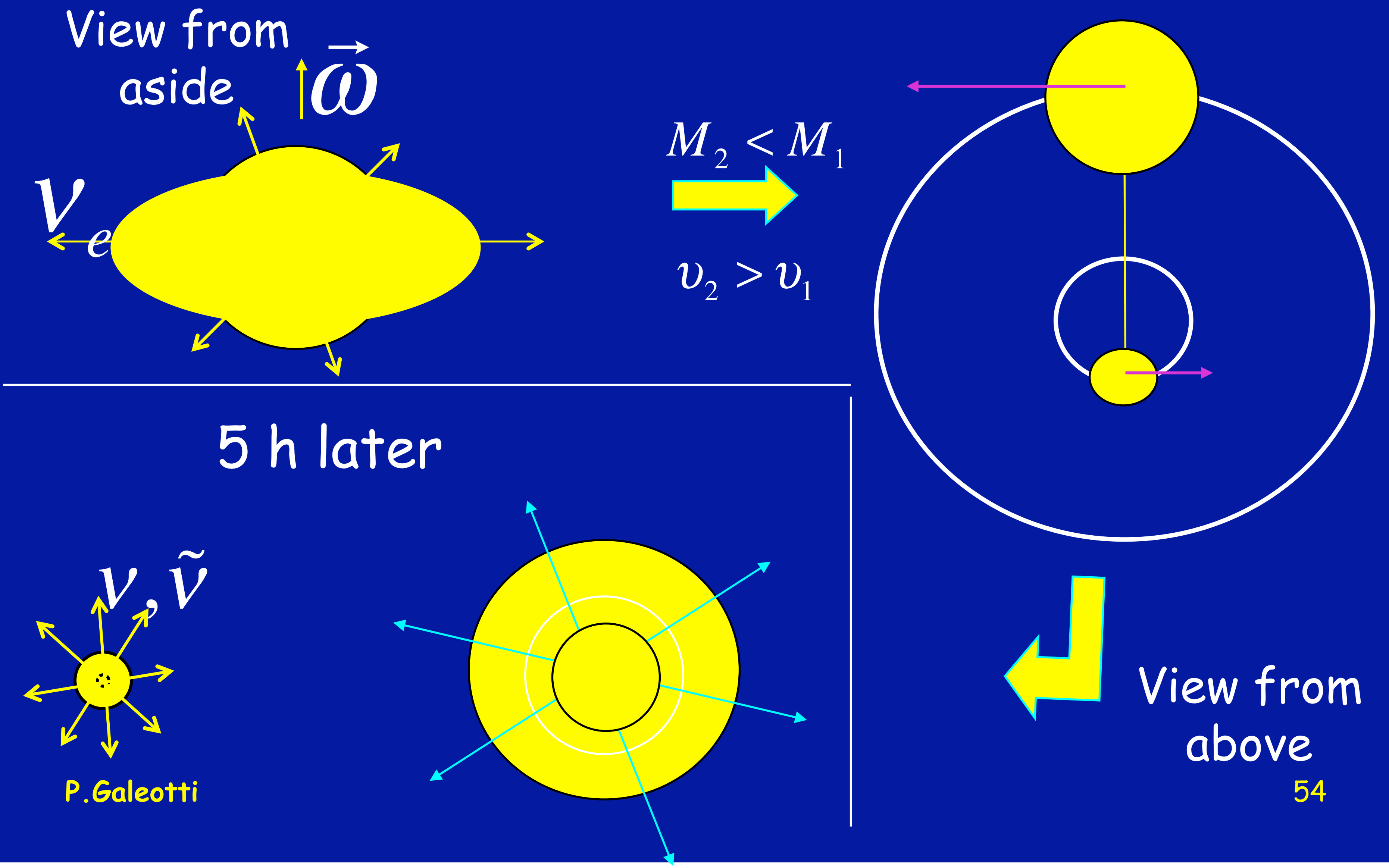
The Large Volume Detector (LVD) has been continuously taking data since 1992 at the INFN Gran Sasso National Laboratory. The LVD is sensitive to neutrino bursts from gravitational stellar collapses with full detection probability over the Galaxy. We have searched for neutrino bursts in LVD data taken over 7,335 days of operation. No evidence of neutrino signals has been found between 1992 June and 2013 December. The 90% C.L. upper limit on the rate of core collapse and failed supernova explosions out to distances of 25 kpc is found to be 0.114 yr^{-1}.

Key words: methods: observational – neutrinos – supernovae: general

A rotating collapsar

The Two-Stage Gravitational Collapse Model

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



P.Galeotti

ECRS 2014 Kiel

Neutrinos from SN 1987a
A Puzzle Revisited

Gerd Schatz
Universität Heidelberg *and* Karlsruhe Institute of Technology
bgschatz@t-online.de

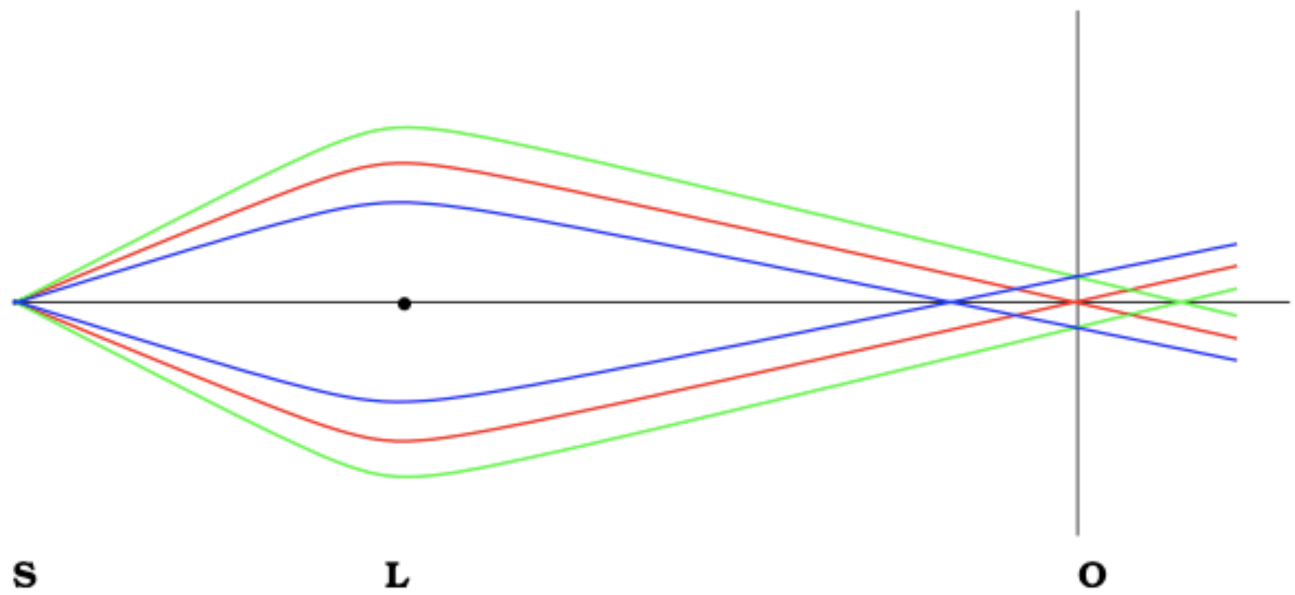


Figure 2: *Schematic representation of microlensing with source S, lens L and observer O.*

Conclusions

1. A signal has been detected in the Mont Blanc experiment a few hours before the optical detection of SN 1987A.
2. This signal is generally considered as a statistical fluctuation in the Mt Blanc data (a noise). This is the only significant "noise" detected in almost 30 years of data taking with LSD in Mont Blanc and LVD in Gran Sasso
3. This "noise" is self consistent and additionally supported by the data of **all** the experiments running at that time, at intercontinental distances, (rather strange for a noise). In addition, when a supernova (visible to naked eye) exploded near us.
4. The main problem of this "noise" is that it does not fit a collapse theory based on non rotation and no magnetic field of the stellar core.

WHAT HAVE WE LEARNED FROM SN 1987A?

- **Neutrinos:** One or two bursts? Feb. 23.12 and/or Feb 23.32, or a long activity during several hours as suggested by gravitational waves observations?
- Was it a 2 step collapse (first into a NS and 4.7 hours later into a BH or a SQM star)?
- **Light:** A week after the explosion $m_V = 4.5$ and $M_V = -14.5$ being 18.95 the distance module. Hence this SN wouldn't be visible to the naked eye if exploded in the disk of our Galaxy, unless closer than ~ 5 kpc (assuming an extinction parameter of ~ 1.5 mag/kpc). However the neutrino burst would have been 100 times stronger!!!
- **Hidden sources:** Are there sources visible only in neutrinos and not in light? Is the rate of stellar collapses higher than that of SN?