



THE CORE COLLAPSE SUPERNOVA RATE FROM 24 YEARS OF DATA OF THE LARGE VOLUME DETECTOR

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OUTLINE





THE LVD EXPERIMENT

1000 tons of liquid scintillator @ LNGS

- 840 counters
- Compact & Modular Geometry
- Member of the SNEWS network





- 1.2 ton per counter viewed by three 15" PMTs
- Trigger mode: three-fold coincidence of PMTs of a single counter (H0)
 - H0 Energy Threshold : E_H~4 MeV (E_L~0.5 MeV for 1 ms after H0)







NEUTRINO INTERACTION CHANNELS

1-5 on Scintillator (1000 t)

6-8 on Iron Structure (850 t)

	ν Interaction Channel	E_{ν} Threshold	%
1	$ar{ u_e} + p \ ightarrow \ e^+ + n$	(1.8 MeV)	(88%)
2	$ u_{ m e} + {}^{12}{ m C} \rightarrow {}^{12}{ m N} + { m e}^{-}$	(17.3 MeV)	(1.5%)
3	$\bar{\nu}_{e} + {}^{12} \mathrm{C} \rightarrow {}^{12} \mathrm{B} + \mathrm{e}^{+}$	(14.4 MeV)	(1.0%)
4	$ u_{\mathrm{i}} \ +^{12}\mathrm{C} ightarrow u_{\mathrm{i}} \ +^{12}\mathrm{C}^{st} + \gamma$	(15.1 MeV)	(2.0%)
5	$ u_{ m i}+{ m e}^- ightarrow u_{ m i}+{ m e}^-$	(-)	(3.0%)
6	$ u_{\rm e} + {}^{56} { m Fe} \rightarrow {}^{56} { m Co}^* + { m e}^-$	(10. MeV)	(3.0%)
7	$\bar{\nu_e} + {}^{56}$ Fe $\rightarrow {}^{56}$ Mn $+ e^+$	(12.5 MeV)	(0.5%)
8	$ u_{ m i} \ + {}^{56} \ { m Fe} ightarrow u_{ m i} \ + {}^{56} \ { m Fe}^{st} + \gamma$	(15. MeV)	(2.0%)

Trigger mode & Energy Thresholds optimized for IBD



DETECTOR FACTS

On line since 1992





TRIGGER RATES



- H0 Trigger ~ 5 billions
- H1 Trigger 15167155 -> Time Sequence

Time intervals normalized to the reference rate f=0.03 Hz



SEARCH FOR NEUTRINO BURSTS

• Two step process :

S1) Searching for clusters of events within a time window Δt S2) Selecting the candidates

Two methods

M1) On-line / Fixed Time Window ∆t=20 s <u>APh, 28, 516 (2008)</u>
 PROs: Fast & Reliable CONs: model dependent

M2) Off-line / Variable Time Window $\Delta t < 100$ s *NIMPA, 368, 512 (1996)* <u>ApJ, 802, 47 (2015)</u> PROs: less model dependent CONs: more complex procedure

THE OFF-LINE METHOD



- S1) Defining the cluster: m≥2 events initiated by each H1 trigger in the time sequence, with ∆t<100 s
 N_{cls}= 31169916 over 24 years
- S2) Selecting the bursts candidates by its imitation frequency, the statistical significance of the cluster
 See details in NIMPA, 368, 512 (1996)

See details in MIMPA, 368, 512 (1996

$$F_{im} = f_{bk}^{2} \cdot \Delta t_{\max} \cdot \sum_{k \ge m-2}^{\infty} P(k, f_{bk} \cdot \Delta t)$$

$$F_{im} < \frac{1}{100} year^{-1}$$

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MONITORING THE ALGORITHM



 Different value for F_{im} (< 1/day, 1/week, 1/month) allow to monitor the performances , full data set



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LVD EXPECTED SIGNAL



- Modelling the neutrino flux for core collapse SN (ccSN) Standard ccSN as in Pagliaroli et al. *Aph, 31, 163 (2009)* Failed ccSN as in Nakazato et al. *PhRvD, 78, 083014 (2008)*
- Oscillation effects
- Detector response function

Expected Signal @ 10 kpc & 1000 t

ccSN: 260 events in 10 s Failed ccSN: 500 events in 360 ms See details in ApJ, 802, 47 (2015)

LVD

LVD SENSITIVITY

Full efficiency in the Galaxy @ M>300 t



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RESULTS

1992-2016 (May) summary

Livetime: 8211 days @ M> 300 t

No burst canditates @ $F_{im} < 0.01 \text{ yr}^{-1}$: 6 clusters with $F_{im} < 1 \text{ yr}^{-1}$

	n.	UTC	$\mathbf{M}_{act}[t]$	$\mathbf{f}_{bk}[s^{-1}]$	$D_{90\%}[kpc]$	m	$\Delta t[s]$	$\mathbf{F}_{im}^{-1}[years]$	$\bar{E}_{signal}[MeV]$	N _L
1	1	1994 16 April 10:40:49.263	346	$1.08 \cdot 10^{-2}$	29.5	7	18.88	1.06	26.5	2
	2	1995 27 August 16:18:10.478	431	$1.85 \cdot 10^{-2}$	35.0	7	5.49	11.16	36.2	1
ApJ, 802, 47 (2015)	3	1998 7 October 15:41:41.775	552	$1.40 \cdot 10^{-2}$	30.6	12	90.05	1.76	32.2	3
(data set 1992-2013)	4	2009 18 July 7:39:20.517	976	$2.40 \cdot 10^{-2}$	40.4	12	42.71	4.02	14.6	1
	5	2014 25 May 3:54:14.555	959	$2.78 \cdot 10^{-2}$	36.8	14	61.56	1.49	22.6	4
ECRS Update:2014-2016	6	2014 18 December 20:21:28.787	937	$2.33\cdot10^{-2}$	45.9	8	9.98	3.22	18.8	3

Table 1: Characteristics of clusters with significance $F_{im} < 1 \cdot year^{-1}$.

Individually checked / Compatible with background fluctuation.





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CONCLUSIONS

- LVD on-line since 1992
- Full sensitivity to ccSN in the Galaxy in both on-line and offline mode
- Active member of the SNEWS network
- 1992-2016 data (8211 days) have been analized
- No evidence for a signal @ F_{im} < 1/100 yr⁻¹
- Most stringent upper limit ever achieved: 0.1 yr⁻¹@ 90% c.l.