Update on the search for supernova neutrino bursts with LVD

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Presenter

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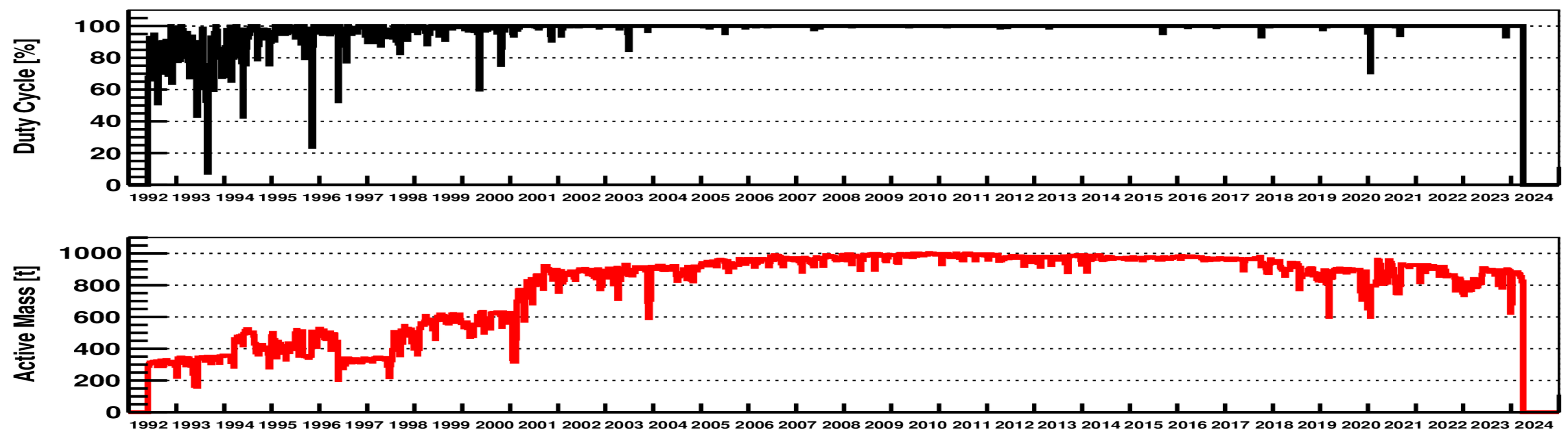
The Large Volume Detector (LVD)

LVD is a **1 kt liquid scintillator detector** located underground at INFN Laboratori Nazionali del Gran Sasso (Italy) [1]

Main goal of LVD is the detection of neutrino bursts from supernovae in the Galaxy



LVD is in **data taking since 1992** with variable active mass and high duty cycle

LVD Energy threshold ~4 MeV

Neutrino burst from supernova

Core-collapse of stars with mass $M>8\ M_{sun}$
ν and anti-ν of all flavours are produced

Duration of the burst is $O(10\ s)$

$\langle E\nu_e \rangle \sim 10\text{-}12$ MeV
$\langle E\bar{\nu}_e \rangle \sim 12\text{-}18$ MeV
$\langle E\nu_{\mu\tau} \rangle \sim 15\text{-}25$ MeV

ν oscillations in stellar matter have to be taken into account [2]

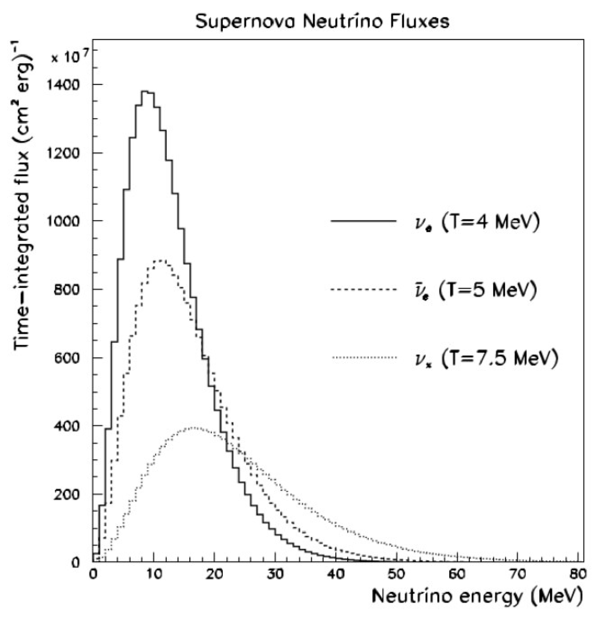


Figure from [2]

Expected signal in LVD

~300 events in 10 seconds in LVD for a supernova at 10 kpc

Table 1
The ν Interaction Channels in LVD

	ν Interaction Channel	E_ν Threshold	%
1	$\bar{\nu}_e + p \rightarrow e^+ + n$	(1.8 MeV)	(88%)
2	$\nu_e + ^{12}C \rightarrow ^{12}N + e^-$	(17.3 MeV)	(1.5%)
3	$\bar{\nu}_e + ^{12}C \rightarrow ^{12}B + e^+$	(14.4 MeV)	(1.0%)
4	$\nu_i + ^{12}C \rightarrow \nu_i + ^{12}C^* + \gamma$	(15.1 MeV)	(2.0%)
5	$\nu_i + e^- \rightarrow \nu_i + e^-$	(-)	(3.0%)
6	$\nu_e + ^{56}Fe \rightarrow ^{56}Co^* + e^-$	(10. MeV)	(3.0%)
7	$\bar{\nu}_e + ^{56}Fe \rightarrow ^{56}Mn + e^+$	(12.5 MeV)	(0.5%)
8	$\nu_i + ^{56}Fe \rightarrow \nu_i + ^{56}Fe^* + \gamma$	(15. MeV)	(2.0%)

Note. Cross sections of different interactions are obtained referring to Strumia & Vissani (2003) for interaction 1, Fukugita et al. (1988) for interactions 2–4, Bahcall et al. (1995) for interaction 5, and Kolbe & Langanke (2001) and Toivanen et al. (2001) for interactions 6–8.

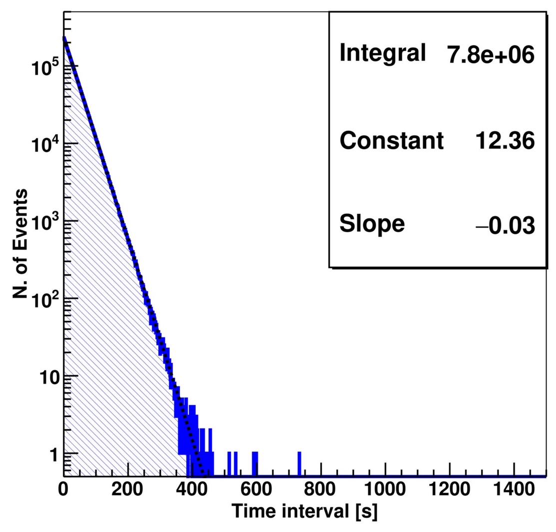
Table from [3]

Mainly Inverse Beta Decay (IBD), but other interaction channels are also contributing [2][3]

Detectable ν signal is expected also for *failed supernovae*, in which the core-collapse directly ends in a black hole

Data selection

All triggers with energy in **[10,100] MeV** are included in the dataset



After quality cuts are applied, **the background is well described by Poisson statistics** with event rate $f_{bk} = 3{\cdot}10^{-2}\ s^{-1}$

Search for neutrino bursts (method)

A cluster is a set of *m* events in a time window Δt (up to $\Delta t_{max} = 100$ s)

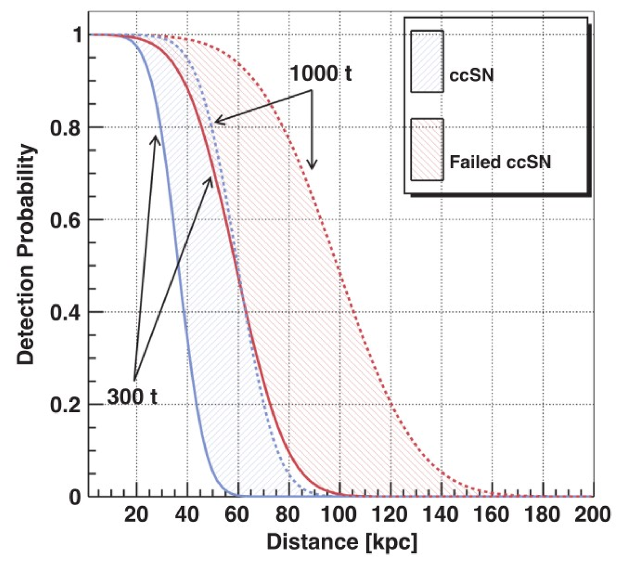
For each cluster *i* we calculate the frequency with which it can be produced by background fluctuations (Imitation Frequency) $F_{im,i}$ [3]

$$F_{im_i} = f_{bk}^2 \Delta t_{max} \sum_{k \geq m_i - 2} P(k, f_{bk} \Delta t_i)$$

Where f_{bk} is the event rate and *P* is the Poisson probability

Statistical selection
Any cluster with $F_{im} < 10^{-2}$ / year is a neutrino burst candidate

Sensitivity

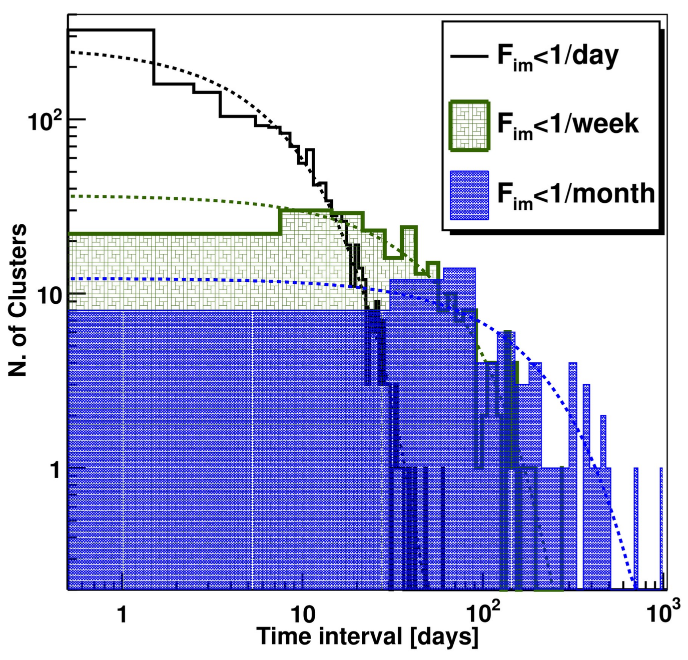


>95% efficiency for ν bursts from supernovae or failed supernovae **in the whole Galaxy** with **at least 300 t** active mass [3]

Search for neutrino bursts (results)

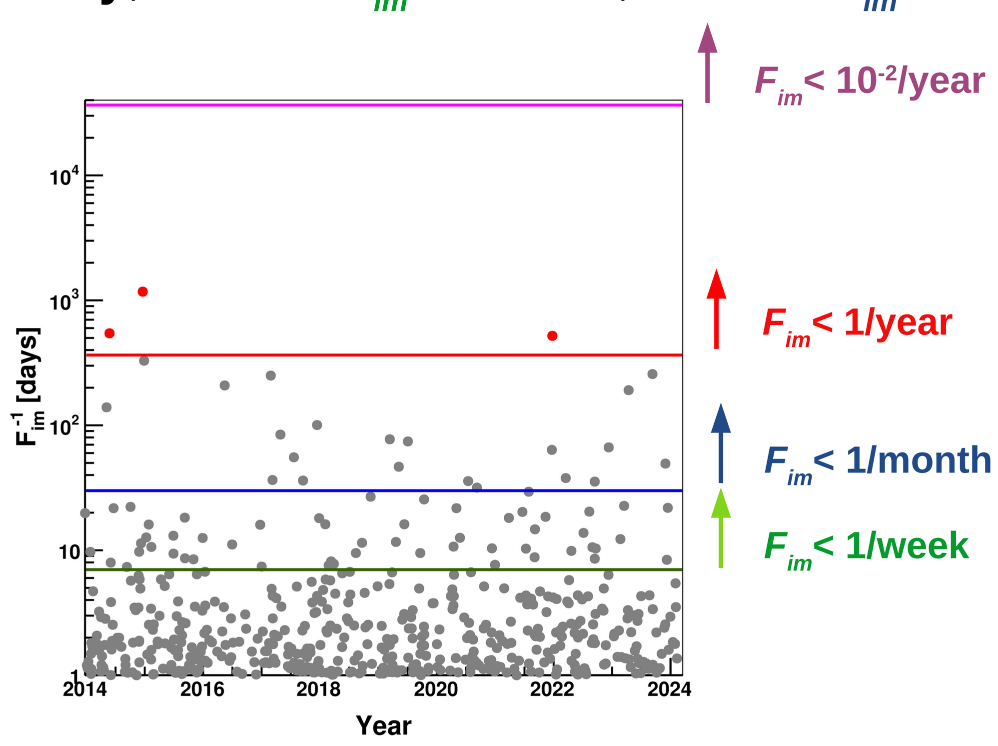
Analysis of the LVD data taking period from **January 1st, 2014 to March 10th, 2024**
The LVD active mass has been M > 300 t for **3711 days , exposure 8.86 kt*y , <M> = 871 t**

A total of **~17 M** clusters are found, of which: 497 with F_{im} **< 1/day**, 77 with F_{im} **< 1/week**, 24 with F_{im} **< 1/month**, 3 with F_{im} **< 1/year**



Left Figure: The time differences between consecutive clusters are following the expectations (all data since 1992)

Right Figure: Clusters with F_{im} < 1/day detected vs time (2014 – 2024). Red points for cluster with F_{im} **< 1/year**



Inspection of the 3 clusters with F_{im} **< 1/year**

Energy spectrum, temporal distribution of events and number of low energy signals following a trigger are compatible with background characteristics

No cluster with $F_{im} < 10^{-2}$/year, hence no neutrino burst candidate, is found

Conclusions

No evidence has been found for supernova neutrino burst in the last 3711 days of LVD data (*2014/1/1 – 2024/3/10*)

Considering all previous LVD data since 1992 for a total livetime of 30.26 years, an upper limit can be set on the supernova rate in the Galaxy
R_{SN} < 0.076 / year (90% C.L.)

This is the **most stringent limit** achieved to date by directly observing supernovae through neutrino emission in the whole Galaxy

References

[1] Aglietta et al. (LVD Collaboration), Il Nuovo Cimento A, 105, 1793 (1992)
[2] Agafonova et al. (LVD Collaboration), Astroparticle Physics 27, 4 (2007)
[3] Agafonova et al. (LVD Collaboration), The Astrophysical Journal, 802:47 (2015)