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Update to 2005 of the results of the search for ν bursts from gravitational stellar collapse with LVD

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The Large Volume Detector LVD (Gran Sasso National Laboratory, Italy) is a neutrino scintillator observatory monitoring the Galaxy since 1992, searching for low energy neutrino bursts from gravitational stellar collapses. We present the status of the detector that, after reaching its final active mass of 1000 t in 2001, has been recently upgraded to increase its sensitivity at lower energies. We update the search for neutrino bursts by including the last two years of data. No candidates have been detected over all the thirteen years of observation: the resulting 90% c.l. upper limit to the rate of Gravitational Stellar Collapse (GSC) in the Galaxy is 0.21 event $\cdot$ y^{-1}.

1. Introduction

The Large Volume Detector (LVD) in the Gran Sasso Underground Laboratory, Italy, consists of an array of 840 scintillator counters, 1.5 m^3 each, arranged in a compact and modular geometry (see [1] for a more detailed description), with an active scintillator mass M=1000 t.
The main purpose of the telescope is the detection of neutrinos from gravitational stellar collapses in the Galaxy, mainly through the absorption interaction $\bar{\nu}_{\rm e}{\rm p}, {\rm e}^{+}{\rm n}$. This reaction is observed in LVD counters through two detectable signals: the prompt signal due to the e$^+$ (detectable energy $E_{\rm d} \simeq E_{\bar{\nu}_{\rm e}} - 1.8$ MeV $+2{\rm m_e c^2}$), followed, with a mean delay $\Delta t \simeq 180$ μs, by the signal from the np, dγ capture ($E_\gamma = 2.2$ MeV).
Up to 2004, out of the 840 counters, the inner ones (57%), better shielded against rock radioactivity, were operated at energy threshold $\mathcal{E}_h \simeq 4$ MeV, while the external ones (43%) at $\mathcal{E}_h \simeq 7$ MeV. During 2004 we re-calibrated the whole array and set the threshold at the same value for both internal and external counters, namely $\mathcal{E}_h \simeq 5$ MeV. To tag the delayed γ pulse due to n-capture, all counters are equipped with an additional discrimination channel, set at a lower threshold, $\mathcal{E}_l \simeq 1$ MeV. As a result of the upgrade LVD accomplished a higher efficiency for neutron capture detection. LVD has been taking data since June 1992 with increasing mass configurations, its sensitive mass being always greater than $300\,t$, high enough to cover the whole Galaxy ($D < 20$ kpc) [2]. Moreover, since 1998 it has been participating to the SuperNova Early Warning System (SNEWS), an international collaboration connecting world-wide existing supernova neutrino detectors. We have reported results of the search for neutrino bursts for the period 1992-2003 with no detected candidates for a supernova signal [3][4] [5][6][7][8]. In the present paper we (i) present the analysis regarding 2003-2005 and update the global result up to February 4th, 2005, (ii) discuss the performances of LVD within the SNEWS network.

2. Search for neutrino bursts with 2003-2005 data

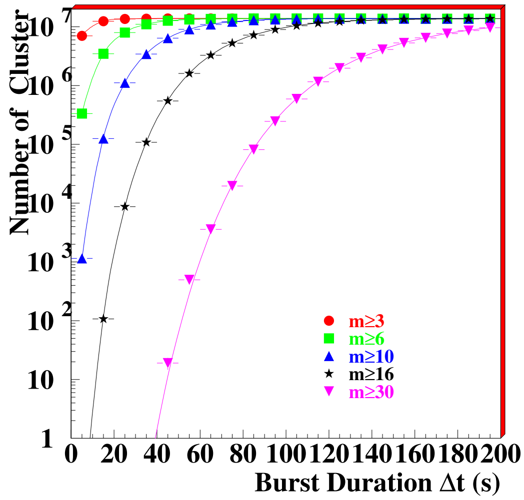

Figure 1. Distributions of the number of clusters, detected during 2003-2005, as a function of cluster duration (Δt), for different multiplicity (m).

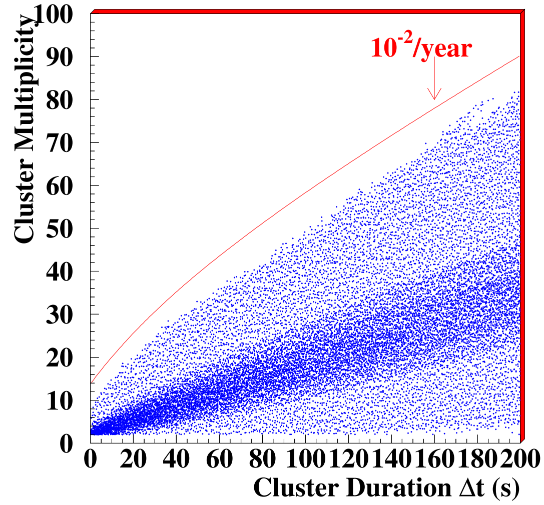

Figure 2. Clusters (Δt, m) detected during 2003-2005. The full line represents the LVD sensitivity in standalone mode ($F_{im} = 1 \cdot 10^{-2}$ y^{-1}).

The data used for the present analysis spans the period since March 25th, 2003 to February 4th, 2005, for a total live-time of 666 days.

The search for ν burst candidates is performed off-line by studying the temporal sequence of triggers and looking for signal clusterizations. The considered data set comprises 8732734 of such triggers. For each period of data acquisition, characterized by a fixed detector configuration (i.e. stable mass and counting rate), preliminary cuts are applied to reject signal contributions coming from non-optimal counters. To this purpose, informations contained in the general LVD Data Base, which is daily updated, are used. The pulse energy of the events is required to belong to 7-100 MeV range and the muon signals are rejected. The neutrino burst candidate selection, widely discussed in [9], processes all possible clusters up to 200 s of duration, initiated by each single pulse belonging to the trigger sequence. For each selected cluster with multiplicity m and duration Δt, the Imitation Frequency F_{im} is calculated as a function of the cluster parameters and of the rate f_{bk} of the background events, which for the period under analysis is $f_{bk} = 0.15$ Hz. After this pure statistical selection a complete analysis of each detected cluster with $F_{im} \leq 1$ y^{-1} tests its consistency with a ν burst through: *a)* the study of topological distribution of pulses inside the detector; *b)* the energy spectrum of the events in the cluster; *c)* the characteristics of the time distribution of delayed low energy pulses. The distributions of the number of clusters, detected between 2003-2005, as a function of cluster duration (Δt), for different multiplicity (m) are shown in figure 1 compared to the expectations from the Poissonian fluctuations of the background: quite good agreement is observed. For LVD in standalone mode, we choose $F_{im} = 1 \cdot 10^{-2} \cdot$y^{-1}, as a level above which to claim a detection. The sensitivity of the telescope at such a level is shown in fig. 2 as a full line, each dot representing a background cluster with a certain multiplicity (m) and duration (Δt).

LVD has been continuously monitoring the Galaxy since 1992 in the search for neutrino bursts from GSC. Its active mass has been progressively increased from 310 t in 1992 to the final 1000 t in 2001 (see tab.1.), always guaranteeing a sensitivity to GSC up to distances $D \sim 20$ kpc from the Earth, even for the lowest temperature of the ν-sphere. Also the telescope duty cycle has been continuously improving since 1992: in the last five years the average uptime has been $> 99\%$. The sensitive detector mass involved in the trigger generation (trigger mass) during this period is shown in figure 3.

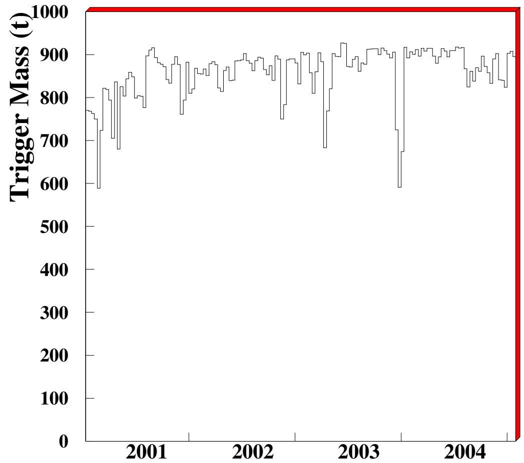

Figure 3. Detector trigger mass during 2001-2005.

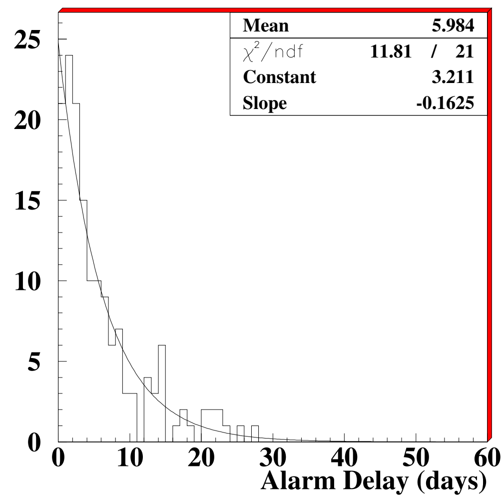

Figure 4. Time delay distribution of the alarms that LVD sent to the SNEWS network during the 3 years of test operation.

In the whole period of 4073 days of observation, since June 6th,1992 to February 4th, 2005 no candidate bursts have been detected with a $F_{im} \geq 1 \cdot 10^{-2}$ y^{-1}: the resulting upper limit to the rate of Gravitational Stellar Collapse at 90% c.l. is 0.21 event$\cdot$ y^{-1}.

Table 1.

Run	Start	End	Live Time	Uptime (%)	Mass (t)	Reference
1	Jun.6th 1992	May 31st 1993	285	60	310	[3]
2	Aug.4th 1993	Mar.11th 1995	397	74	390	[4]
3	Mar.11th 1995	Apr.30th 1997	627	90	400	[5]
4	Apr.30th 1997	Mar.15th 1999	685	94	415	[6]
5	Mar.16th 1999	Dec.11th 2000	592	95	580	[7]
6	Dec.12th 2000	Mar.24th 2003	821	98	842	[8]
7	Mar.25th 2003	Feb.4th 2005	666	> 99	881	this paper
Σ	Jun. 6th 1992	Feb. 4th 2005	4073	91		

3. SNEWS

The SNEWS (SuperNova Early Warning System)[11] is a collaboration among several neutrino-sensitive experiments. The primary goal of SNEWS is to provide the astronomical community with a prompt alert for a galactic supernova. An additional goal is to optimize global sensitivity to supernova neutrino physics, by such cooperative work such as experiment downtime-coordination.
The charter member experiments of SNEWS are LVD in Italy, Super-K in Japan and SNO in Canada. Representatives from Amanda and IceCube will eventually join the active members of the network.
There is currently a single coincidence server, hosted by Brookhaven National Laboratory. We expect that additional machines will be deployed in the future. The BNL computer continuously runs a coincidence server process, which waits for alarm datagrams from the experiments clients, and provides an alert if there is a coincidence within a specified time window (10 seconds for normal running). A scheme of “GOLD” and “SILVER” alerts has been implemented: GOLD alerts are intended for automated dissemination to the community; SILVER alerts will be disseminated among the experimenters, and require human checking. As of today, only SILVER alerts, between LVD and Super-K, are activated.
Up to now, no inter-experiment coincidence, real or accidental, has ever occurred (except during a special high rate test mode), nor any core collapse event has been detected within the lifetimes of the currently active experiments. With respect to LVD, since 2001 an on-line selection technique is operational where data are processed through a ”sliding window” of fixed duration $\delta t = 20$ s. In this case the chosen F_{im} is $\sim 1\cdot$ week^{-1} as requested by the SNEWS network. Figure 4 shows the time delay distribution between consecutive LVD alarms sent to the SNEWS network in 930 days of operation: it is well fitted by an exponential distribution with $\tau \sim 6$ days.

4. Conclusions

The Large Volume Detector has been monitoring the Galaxy over more than 12 years searching for neutrino signals from Gravitational Stellar Collapses. No burst candidate has been found over 4073 days of live-time observation and the upper limit at 90% c.l. 0.21 event $\cdot$ y^{-1} to the rate of GSC is obtained ($D \leq 20$ kpc). Since 2001 an on-line ν-burst monitor has been implemented to keep LVD connected to the SNEWS system.

In memory of Giuliana and Carlo Castagnoli, we would like to remember their outstanding contributions not only to the LVD experiment but also to the birth and development of underground physics in Italy.

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