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Search for neutrino bursts from gravitational stellar collapses with LVD: update to 2007

N.Y.AGAFONOVA[1], M.AGLIETTA[2], P.ANTONIOLI[3], G.BARI[3], A.BONARDI[2], V.V.BOYARKIN[1], G.BRUNO[2,4], W.FULGIONE[2], P.GALEOTTI[2], M.GARBINI[3,5], P.L.GHIA[2,4], P.GIUSTI[3], E.KEMP[6], V.V.KUZNETSOV[1],V.A.KUZNETSOV[1], A.S.MALGUIN[1], H.MENGHETTI[3], A.PESCI[3], R.PERSIANI[3], I.A.PLESS[7], A.PORTA[2], V.G.RYASNY[1], O.G.RYAZHSKAYA[1], O.SAAVEDRA[2], G.SARTORELLI[3], M.SELVI[3], C.VIGORITO[2], L.VOTANO[8], V.F.YAKUSHEV[1], G.T.ZATSEPIN[1], A.ZICHICHI[3]

[1] *Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia*
[2] *IFSI-Torino, INAF, University of Torino and INFN-Torino, Italy*
[3] *University of Bologna and INFN-Bologna, Italy*
[4] *INFN-LNGS, Assergi, Italy*
[5] *Museo Storico della Fisica, Centro Studi e Ricerche "E.Fermi", Rome, Italy*
[6] *University of Campinas, Campinas, Brazil*
[7] *Massachusetts Institute of Technology, Cambridge, USA*
[8] *INFN-LNF, Frascati, Italy*
Carlo.Vigorito@to.infn.it

Abstract: The Large Volume Detector (LVD), in the INFN Gran Sasso National Laboratory (Italy), at the depth of 3600 m w. e., is a 1 kt liquid scintillator detector whose major purpose is monitoring the Galaxy to study neutrino bursts from gravitational stellar collapses. The experiment has been taking data, under different larger configurations, since 1992, reaching in 2001 its present and final configuration. Its modularity and rock over-burden, together with the trigger strategy, make this detector particularly suited to on-line disentangle a cluster of neutrino signals from the background.
No candidates have been detected over fifteen years of observation: the resulting 90% c.l. upper limit to the rate of gravitational stellar collapses in the Galaxy is 0.18 events / year.

Introduction

LVD consists of an array of 840 scintillator counters, 1.5 m^3 each [1]. The whole array is divided in three identical "towers" with independent high voltage power supply, trigger and data acquisition. In turn, each tower consists of 35 "modules" hosting a cluster of 8 counters. Each counter is viewed from the top by three 15 cm photomultiplier tubes (PMTs) FEU49b or FEU125. The charge of the summed PMTs signals is digitized by a 12 bit dynamic range ADC (conversion time = 1 μs) and the arrival time is measured with a relative accuracy of 12.5 ns and an absolute one of 100 ns. The modularity of the array allows high duty cycle performance ($\geq$ 99%) as shown in figure 1.

The main neutrino reaction in LVD is $\bar{\nu}_{\rm e}{\rm p},{\rm e}^{+}{\rm n}$, which gives two detectable signals: the prompt one due to the ${\rm e}^{+}$ (visible energy $E_{\rm vis} \simeq E_{\bar{\nu}_{\rm e}} - 1.8$ MeV $+\ 2$ m$_{\rm e}$c^2) followed, with a mean delay $\Delta t \simeq 185\ \mu$s, by the signal from the ${\rm np},{\rm d}\gamma$ capture ($E_\gamma = 2.2$ MeV). The trigger logic is optimized for the detection of both products of the inverse beta decay and is based on the three-fold coincidence of the PMTs of a single counter. Indeed each PMT is discriminated at two different thresholds resulting in two possible levels of coincidence: H and L, corresponding to $\mathcal{E}_H \simeq 4$ MeV and $\mathcal{E}_L \simeq 1$ MeV. The H coincidence in any counter represents the trigger condition for the array. Once a trigger has been identified, the charge and time of the three summed PMTs signals are stored in a memory buffer. All the signals satisfying the L coincidences in the same module of the

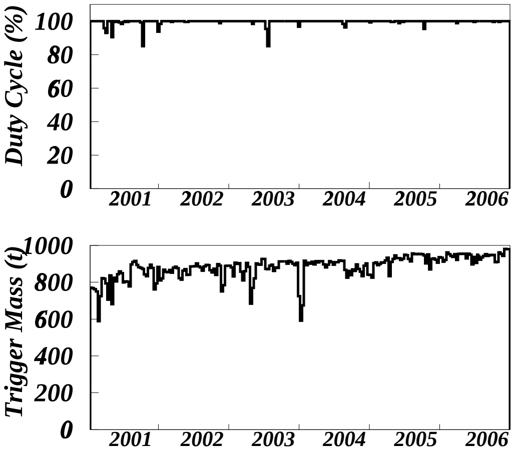

Figure 1: LVD duty cycle (top) and trigger mass (bottom) during years 2001-2006.

trigger counter are also stored, if they occur within 1 ms. The average neutron detection efficiency, $\epsilon_{\rm n}$, amounts to about 50% for neutrons detected in the same counter where the positron has been observed [2].

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) [3]. The LVD active mass during years 2001-2006 is shown in figure 1. The results of the search for neutrino bursts in the period 1992-2004 have been reported in [4][5][6][7][8][9][10].

In this communication we present the results of the analysis of the last run, since February 4th 2005 to December 31st 2006. Details on the LVD on-line search will be discussed in the last section.

Search for ν burst in 2005-2006 run

The data used for the present analysis spans the period since February 4th, 2005 to December 31st, 2006, for a total live-time of 695 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 includes 11523747 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 the 7-100 MeV range and the muon signals are rejected. The neutrino burst candidate selection, widely discussed in [11], 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 $f_{bk} = 0.19$ 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.

Two events have been selected in the last run: ($F_{im} = 0.46$ y^{-1}, 0.48 y^{-1}). They are statistically compatible with the number of candidates expected by chance during 695 days (in standalone mode, $F_{im} = 1 \cdot 10^{-2}$·y^{-1}, is the level above which to claim a detection). Moreover the energy distribution, the topological distribution and the time delay distribution of low energy pulses are in total agreement with the background behaviour.

The distributions of the number of clusters, detected between 2005-2006, as a function of cluster duration (Δt), for different multiplicities (m) are shown in figure 2 compared to the expectations from the Poissonian fluctuations of the background: a quite good agreement is observed. The sensitivity of the telescope is shown as a line in fig. 3 together with all the clusters detected during this period: each dot represents a cluster with a certain multiplicity (m) and duration (Δt).

Table 1: LVD data runs.

Run	Start	End	Live Time (days)	Uptime (%)	Mass (t)	Reference
1	Jun.6th 1992	May 31st 1993	285	60	310	[4]
2	Aug.4th 1993	Mar.11th 1995	397	74	390	[5]
3	Mar.11th 1995	Apr.30th 1997	627	90	400	[6]
4	Apr.30th 1997	Mar.15th 1999	685	94	415	[7]
5	Mar.16th 1999	Dec.11th 2000	592	95	580	[8]
6	Dec.12th 2000	Mar.24th 2003	821	98	842	[9]
7	Mar.25th 2003	Feb.4th 2005	666	> 99	881	[10]
8	Feb.4th 2005	Dec.31st 2006	695	> 99	934	this paper
Σ	Jun. 6th 1992	Dec. 31st 2006	4768	92		

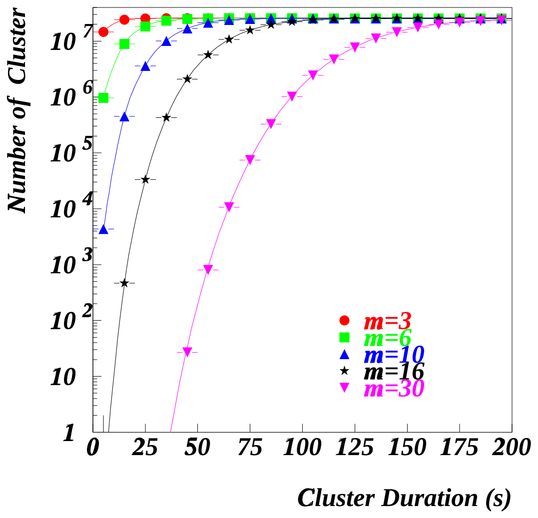

Figure 2: Distributions of the number of clusters, detected during 2005-2006, as a function of cluster duration (Δt), for different multiplicity (m).

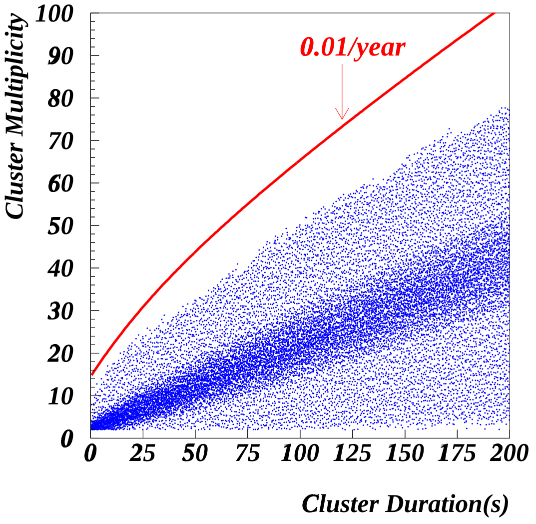

Figure 3: Clusters ($\Delta t, m$) detected during 2005-2006. The full line represents the LVD sensitivity in standalone mode ($F_{im} = 1 \cdot 10^{-2}$ y^{-1}).

The Supernova On-line Monitor

Since 2001 a fast and reliable on-line ν-burst monitor has been implemented to keep LVD connected to SNEWS[12], the network of world-wide neutrino detectors designed to provide a prompt alert to astronomical community in case of a coincidence. The algorithm for the on-line selection of candidate bursts is based on the search for clusters of high threshold signals within a fixed time window, Δt=20 s. The candidate is simply characterized by its multiplicity m, i.e., the number of pulses detected in Δt. All the other characteristics of the cluster, e.g., detailed time structure, energy spectra, ν flavor content and topological distribution of signals inside the detector are left to a subsequent independent analysis. Based on this principle, the LVD data are continuously analyzed by the on-line supernova monitor. In detail, the on-line data period T, is scanned through a "sliding window" with duration $\Delta t = 20$ s, that is, it is divided into $N = 2 \cdot \frac{T}{\Delta t} - 1$ intervals, each one starting in the middle of the previous one, so that the unbiased time window is 10 s. The frequency of clusters of duration 20 s and multiplicity $\geq m$, due to background, is:

$$F_{im}(m, f_{bk}) = 8640 \cdot \sum_{\mathrm{k} \geq \mathrm{m}}^{\infty} P(k; \frac{20 \cdot f_{bk}}{s^{-1}})\,\mathrm{ev}\cdot\mathrm{day}^{-1} \quad (1)$$

where f_{bk} is the background counting rate of the detector for $E \geq E_{\rm cut}$, $P(k; f_{bk}\Delta t)$ is the Poisson probability to have clusters of multiplicity k if $f_{bk}\Delta t$ is the average background multiplicity, and 8640 is the number of trials per day. In the on-line mode the search for burst candidates is performed for both energy cuts: $E_{cut} = 7$ MeV and $E_{cut} = 10$ MeV. The chosen Fim, below which the detected cluster will be an on-line candidate supernova event, is 1 per 100 year in standalone mode while it is relaxed to 1 per month when working in coincidence with other detectors, as in the SNEWS project.

In figure 4 we show the distributions of observed on-line delay between selected clusters at the imitation frequency $F_{im} = 1$/day and $F_{im} = 1$/month during 688 days and $E_{cut} = 7\ MeV$. The observed mean rates are respectively $F_{im}^{obs} = 1.24$ day^{-1} and $F_{im}^{obs} = 1.28$ month^{-1}, meaning that, within 25%, the time behaviour of the background is under control, even during long periods of data acquisition and with variable detector conditions.

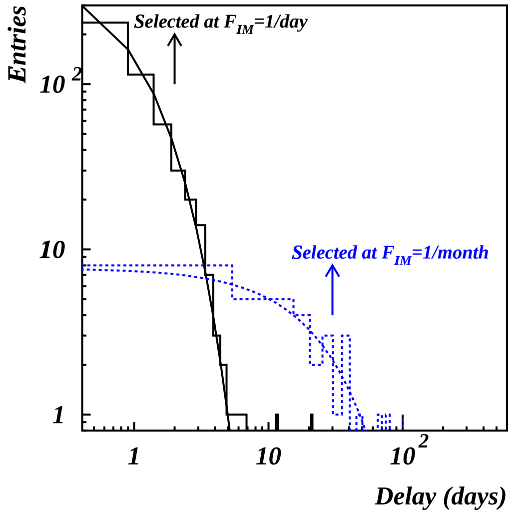

Figure 4: Distribution of the delay between clusters, due to background, observed by the on-line monitor at the $F_{\rm im} = 1$/day (solid histogram) and $F_{\rm im} = 1$/month (dashed histogram) during 688 days and $E_{cut} = 7\ MeV$.

Conclusions

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, always guaranteeing a sensitivity to GSC up to distances $D \sim 20$ kpc from the Earth. The telescope duty cycle, in the last six years, was $> 99\%$ (see tab.1).

No burst candidate has been found over 4768 days of live-time observation and the upper limit at 90% c.l. 0.18 event $\cdot$ y^{-1} to the rate of GSC is obtained ($D \leq 20$ kpc).

Since 2001 an on-line ν-burst monitor is in operation keeping LVD connected to the SNEWS inter-experiment system.

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