Search for Correlations between GW Detectors and the LVD Neutrino Telescope

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Abstract

We report the results of the search for low-energy ν bursts with the LVD neutrino telescope (Gran Sasso National Laboratory, Italy) in coincidence with an excess of 8 events found by the gravitational waves (GW) detectors EXPLORER and NAUTILUS during 2001. No evidence for any statistically relevant signal in LVD, over a wide range of time durations, has been found in coincidence with these events. Based on the reasonable hypothesis for ν emission processes, the analysis set severe constraints for the possible GW emission mechanism.

1. Introduction

An interesting result has been recently reported using data collected by the gravitational wave detectors EXPLORER and NAUTILUS during the year 2001 [3]. The cross-correlation, performed on 90 days of data, shows an excess (8 events against 2.6 expected) when the detectors are favorably oriented with respect to the galactic disc. This result suggested the search for possible correlated low-energy neutrino signals in the LVD detector. Two processes of the ν emission - the cooling and the accretion mechanisms - have been investigated including also the ν oscillation effect. This analysis sets constraints on the total amount of energy emitted in neutrinos in the first case and on the accretion mass in the second. Both these results have to be considered while attempting to model the source of the GW signals.

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2. Data Selection and Analysis

The Large Volume Detector (LVD) in the Gran Sasso Underground Laboratory, Italy, has been described elsewhere [1]. Raw data are firstly processed in order to reject muons; then ν-like events are grouped in 3 different classes, depending on the energy release of the prompt pulse and on the presence of delayed low energy signals (tagging the n-capture): **class A**, pulses with $E_{\rm d} \geq 7$ MeV; **class B**, pulses with $E_{\rm d} \geq 7$ MeV, followed by a delayed ($\Delta t \leq 1$ms) low energy pulse in the same counter; **class C**, pulses detected by core scintillators ($E_{\rm d} \geq 4$ MeV), followed by a delayed low energy pulse in the same counter. Classes B and C are therefore focussed in the search for $\bar{\nu}_{\rm e}$ candidates ($\bar{\nu}_{\rm e}{\rm p}, {\rm e}^{+}{\rm n}$), while class A includes, more generally, neutrino candidates. In LVD the scintillator counting rate is continuously monitored, in order to search for neutrino burst candidates. The on-line algorithm processes the events on the basis of their time sequence, in order to identify significant clusters of pulses having an imitation frequency less than a predefined threshold, representing the candidate alarms.* During 2001, no neutrino burst candidate has been found, concluding that no ν signal from gravitational stellar collapse in the Galaxy has been detected. However, the absence of candidates in the LVD detector taken alone does not preclude the possibility of positive effects, when combining it with another detector. Therefore we correlated our data stream with the 8 GW candidate events as here discussed.

Step 1. Check of the detector stability The LVD detector performance at the occurrence of the 8 GW events has been checked by studying the behavior of the counting rate in a 24 hours interval centered around the time t_0^{GW} of each event. The counting rate variations around the mean value are well fitted by zero mean and unit-width Gaussian. This sets a firm base for the following steps.

Step 2. Search in a sliding window The search for a possible ν burst has been performed over the selected period for each event. The 8 intervals have been scanned through a "sliding window" of variable duration. The multiplicity distributions of clusters (i.e., the number of events within each interval of duration δt) have then been studied for the 3 classes of data and for $\delta t = 1, 5, 10, 20, 50, 100$ s, and have been compared with the expectations from Poissonian fluctuations of the background.

Step 3. Search in a fixed window. A ν signal in coincidence with each GW event has been further searched using "fixed windows" of different durations δt centered on t_0^{GW}. In particular, we compare the number of recorded pulses $N_{\rm d}$, recorded during each window, with the average number of pulses expected from the background, $\bar{N_{\rm bk}}$ obtained over the whole 24 h interval but excluding the selected δt window to avoid the contamination due to the possible signal. All the differences between the number of detected pulses and the expectations from the

*see 10 Years Search for Neutrino Bursts with LVD, these Proceedings.

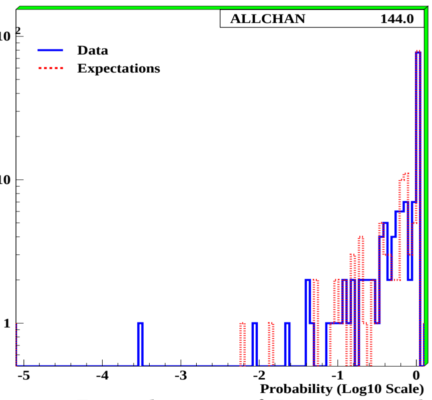

Fig. 1. Distribution of Poisson probabilities associated to each measured number of pulses (solid line), compared to the expectations (dashed line).

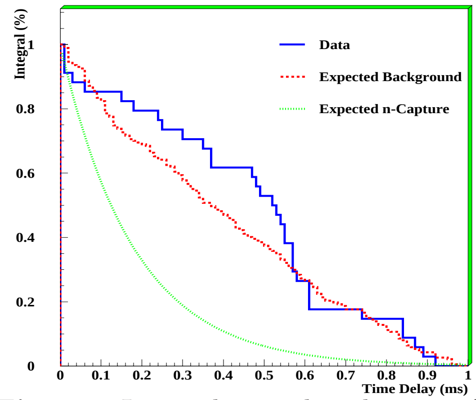

Fig. 2. Integral time distribution of secondary pulses with respect to the prompt ones (8 events and class C data) (solid line); the expected behavior in case of pure background (dashed line) and of n-capture (dotted line).

background are within the statistical fluctuations. Figure 1. shows the distribution of the Poissonian probabilities of every N_{d}, given the associated $\bar{N_{\mathrm{bk}}}$ (solid line) together with the expected one (dashed line).

Step 4. Time distribution of pulses To complete the coincidence analysis the time distribution of LVD pulses around each GW event has been studie: no particular time structure is observed. Finally, for class B and C data, we studied the time distribution of secondary pulses (i.e. those tagging the possible n-capture) with respect to the prompt triggers: there is no evidence for an exponential behavior that could be correlated to the presence of n-capture reactions (see fig.2.).

3. Conclusions and Remarks

Assuming a thermal spectrum, constant during the emission interval, as expected if the cooling mechanism is responsible of the neutrino emission, and using the ν interaction cross section from [5], upper limits to the $\bar{\nu}_{\mathrm{e}}$ flux as a function of the spectral temperature $T_{\bar{\nu}_{\mathrm{e}}}$ [MeV] at the detector are obtained. The limits are calculated for each event using the number of events recorded in the 10 seconds window after the GW signal and then considering the 8 events as due to a unique kind of source. Figure 3. shows the obtained results. Under the hypothesis of neutrino emission from the cooling phase of newly formed neutron stars located at a distance of 10 kpc, within the frame of 3-flavor ν oscillation and LMA-MSW solution for solar ν [2], we can express the results in term of limits to the total energy emitted in neutrinos in the first 10 s as a function of the $\bar{\nu}_{\mathrm{e}}$ temperature at the source. The results depend on different factors, related, on the one hand, to the source characteristics, namely, the ratio between the neutrinosphere temperatures $\frac{T_{\bar{\nu}_{\mathrm{e}}}}{T_{\bar{\nu}_{\mathrm{x}}}}$ and the energy fraction emitted in $\bar{\nu}_{\mathrm{e}}$ ($f_{\bar{\nu}_{\mathrm{e}}}$) and in $\bar{\nu}_{\mathrm{x}}$

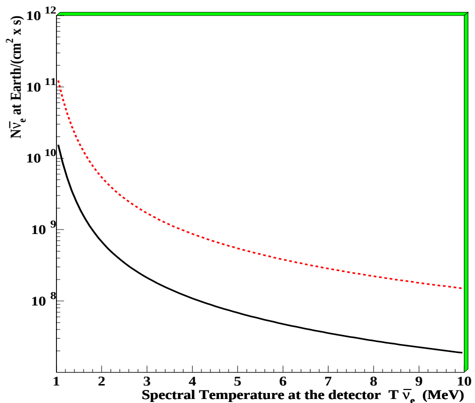

Fig. 3. Upper limits (90% c.l.) to the $\bar{\nu}_e$ flux at the detector, in the first 10 s for thermal $\bar{\nu}_e$ spectra: only one GW event considered (dashed line) and the 8 events as a whole (solid line).

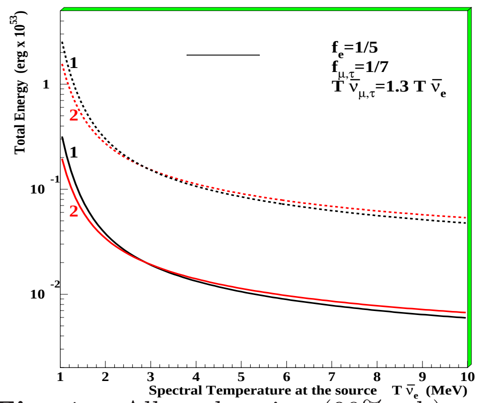

Fig. 4. Allowed region (90% c.l.) to the total energy emitted at the source in neutrinos, in the first 10 s for thermal $\bar{\nu}_e$ spectra: dashed curves are the limits obtained from one event; solid lines correspond to the limits obtained from the 8 events group. Curves #2 show the adiabatic case with inverse mass hierarchy and curves #1 show the adiabatic and non adiabatic cases with normal mass hierarchy and the non adiabatic case with inverse mass hierarchy.

($f_{\bar{\nu}_x}$), and, on the other, to neutrino properties, such as the adiabaticity or non adiabaticity of the conversion determined by the value of $|U_{e3}|^2$, and the mass hierarchy. Figure 4. shows the limits to the emitted energy, for a conservative choice of $\frac{T_{\bar{\nu}_x}}{T_{\bar{\nu}_e}} = 1.3$, $f_{\bar{\nu}_e} = 1/5$, $f_{\bar{\nu}_x} = 1/7$, in the case of either normal or inverse mass hierarchy and for adiabatic or non-adiabatic conversion, being $U_{e2} = 0.33$ and $U_{e3} = 10^{-2}$ in the adiabatic case or $U_{e3} = 10^{-6}$ in the non adiabatic one. These results can be compared with the expectatios when almost all the binding energy of the nascent n-star is emitted in neutrinos of every flavors during a time interval of about 10 seconds. We can then conclude that the considered GW events are not due to n-star formation, even assuming very soft ν energy spectra. For the sake of completeness, we show in the same figure the expected energy region for cooling neutrino emission (we conservatively assume that in the first 10 s $\frac{3}{4}$ of the total energy is emitted) (see e.g. Burrows, 1992).

References

[1] Aglietta M. et al. 1992, Il Nuovo Cimento A105, 1793.

[2] Aglietta M. et al. 2002, Nucl. Phys. B Proc. Sup. 110, 410 (astro-ph/0112312)

[3] Astone P. et al., 2002, Class.Quantum Gravity 19, 5449

[4] Burrows A., Klein D., Gandhi R. 1992, Phys.Rev. D45, 3361

[5] Strumia A. and Vissani F. 2002, astro-ph/0302055