Baksan GW-detector OGRAN
and
a search for neutrino-gravity events

(status report)

Popov S.M., Rudenko V.N., Samoilenko A.A., Yudin I.S
Sternberg Astronomical Institute MSU

L.B. Bezrukov, V.A. Krysanov
Nuclear Research Institute RAS
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• Summary.
Search for neutrino bursts from core collapse supernovae at the Baksan Underground Scintillation Telescope (BUST)

The Baksan Neutrino Observatory of Institute for Nuclear Research of RAS
BUST – the general view

(the effective depth 850 m of w.e.)

- **Dimensions**: $17 \times 17 \times 11 \text{ m}^3$
- **Number of tanks**: 3180.
- **Tank size**: $70 \times 70 \times 30 \text{ cm}^3$

- **Low-background concrete (70 cm)**

- **Scintillator**: $C_nH_{2n+2}$ ($n \approx 9$)

- **Dead time of BUST**: $\approx 1 \text{ ms}$

- **A clock**: 0.2 ms accuracy of determining the absolute time (signal of GPS)

- **Iron layer**: (0.8 cm)

- **Total mass of scintillator is 330 t** (3180 tanks)
- **Three lower horizontal layers**: -130 t (1200 tanks)
The information from each module is transferred through three channels concurrently:

1) **an anodic channel** provides measuring amplitude and time of a scintillator layer.
2) **a pulse channel** from $12^{th}$ dinode with the energy threshold of 8 MeV.
3) **a logarithmic channel** from $5^{th}$ dinode with the energy threshold 500 MeV.
Standard model of collapse

<table>
<thead>
<tr>
<th>$\varepsilon$, erg</th>
<th>$\bar{E}_{\bar{\nu}_e}$, MeV</th>
<th>$\bar{E}_{\nu_e}$, MeV</th>
<th>$\bar{E}<em>{\nu</em>\mu}$, MeV</th>
<th>$\tau$, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(3-5) \cdot 10^{53}$</td>
<td>10-12,6</td>
<td>8-10,5</td>
<td>25</td>
<td>5-20</td>
</tr>
</tbody>
</table>

G. G. Raffelt, “Stars as laboratories for fundamental physics”

From the theory of the Standard collapse it follows that the total energy, carried out by all flavors of neutrinos, is equally divided among these 6 components.

\[
\bar{\nu}_e + p \rightarrow n + \nu_e^+ \quad (1)
\]

\[
E_{\nu_e^+} = E_{\bar{\nu}_e} - 1.3\text{MeV}
\]

\[
\sigma(\bar{\nu}_e p) \approx 9.3E_{\nu_e^+}^2 \times 10^{-44} \text{cm}^2
\]
The Baksan experiment: the method

If the mean antineutrino energy is $12 - 15$ MeV, the range of $e^+$ will be included, as a rule, in the volume of one detector.

The search for a neutrino burst consists in recording a bunch of single events within time interval of $\tau = 20$ s.

$$E_{e^+} = E_{\bar{\nu}_e} - 1.3\text{MeV}$$
$$E_{e^+} \geq 8\text{ MeV}$$

The radiation length for our scintillator is $47 \text{ g/cm}^2$.
The collapse models with neutrino energy 30-50 MeV

• The registration of SN1987A has given rise to non-standard two-stage scenario of stellar collapse.
  The mean neutrino energy (during the first stage) in this model is $\bar{E}_{\nu_e} = 30-40\text{MeV}$.

• *V.Bajkov, V.M. Suslin, V.M. Chechetkin, V.Bychkov,L.Stenflo, Astronomicheskij jurnal, 2007, 84(4):308*
  **This model** has taken into account large-scale convection caused by nonequilibrium neutronization of matter in the central region of protoneutron star.
  The large-scale convection provides high yield of high energy neutrinos from the central region of presupernova.
  The average energy of neutrinos is 30-50 MeV which is more than in the case of diffusion.
Current results:

- Investigations of BUST response to neutrinos of 30 - 40MeV have been performed.

  The total livetime for the period of 30.06.1980 to 31.12.2010 is $T = 26.2$ years. No burst candidate for the core collapse in the Galaxy has been detected during this period.

- If $f_{\text{col}}$ will be the mean frequency of collapses. The probability of collapse absence during the time interval $T$ is $\exp(-f_{\text{col}}T)$.

An upper bound (at 90% CL) on the mean frequency of gravitational collapses in the Galaxy can be obtained with the help of the expression

$$\exp(-f_{\text{col}}T) = 0.1$$
II.

Opto-Acoustical Gravitational Antenna
(project OGRAN)

collaboration
INR RAS, ILP SB RAS, SAI MSU

$h \sim 10^{-18} \text{ Hz}^{-1/2}$, $f \sim 1 \text{ kHz}$, $\Delta f \sim 10 \text{ Hz}$

underground location in BNO INR RAS
Principal scheme of the OGRAN setup

Electronic driving device

PD

Polarisation cube

λ/4

Modulator

Faraday cell

Laser
General view of the big setup

OGRAN parameters: $M = 2.2$ t., $L = 2.3$ m, $f_0 = 1.33$ kHz

$P \approx (1 - 0.5) \, W$, $F = 30,000$
OGRAN bar (2.3 T) at the anti seismic suspension
process of mirrors mounting
Setup general view
Monitoring of the complete locking
Current sensitivity of the GW detector OGRA

Frequency (Hz)

$S_h(1/\sqrt{\text{Hz}})$

current $F=2000$ has to be changed for $F=30000$
ОГРАН chamber
III.

Coincidence and Correlation with non-GW detectors

The Universe is already observed by means of different kinds of radiations; some events may be accompanied by detectable GW emission, most likely:

1) Neutrinos from Supernovae Explosions in Coincidence with GW: **GW-Neutrino detectors Coincidences**

2) Pulsar ellipticity induces monochromatic GW emission: **GW-Radiotelescope Coincidences**

3) Gamma Ray Bursts can be accompanied by GW emission: **GW-GRB ground and space detectors coinc.**

Etc.................................

A.Giazotto, Elba 2004
Multi – Messages Astronomy argumentation

• Catastrophic events with superdense stars (*coalescence, collapse, SN explosion*) might be sources of GW bursts accompanied by other type of radiation such as neutrino fluxes, electromagnetic optical, X-ray and gamma ray pulses.

• This accompaniment (in the case of its registration by correspondent detectors) provides *time marks* for gravitational antennae around of which one might expect to find traces of GW excitation.

• Such manner of data analysis cuts off enormously a volume of stochastic data to be processed, increases a right detection probability and might point out coordinates of the source.
Multistage collapse


BH-progenitor $J \sim J_c$

Bar-instability

Remnants Coalescence

M. Rees; V. Imshenik, D. Nadezhin; M. Van Putten; etc.
General approach to AG-correlation searching

GOAL: TO FIND ANOMALIES IN GW-BACKGROUND IN VICINITY OF $t_j$- time marks
Research domains:

Three principal branches of investigation:

– development, classification and selection theoretical astrophysical models of multi channel radiators;

– development of the optimal data processing for filtration weak GW signals refering to the data of parallel non gravitational channels;

– development a procedure for effective accumulation weak GW signals of many transient sources;
knowledge of internal dynamics of radiation processes is desirable; The more important characteristics is an expected delay time between GW bursts and other type radiation pulses (registered astrophysical events)

\[ \tau_k = t_k + \Delta \tau_k \]

- \( \tau_k \) - GW burst arrival times.
- \( t_k \) - arrival time of astrophysical events,
- \( \Delta \tau_k \) - time shift estimates
General model of sources

- for the case when time shift $\Delta \tau_k = \Delta \tau$ is considered as unknown but deterministic parameter (neutrino-gravity correlation during the SN 1987A);
  the estimation of the shift is defined by the absolute maximum of likelihood function

$$\ln \Lambda = \sum_{k=1}^{N} \ln \Lambda_k , \quad \ln \Lambda (\Delta \tau) = \max_{\Delta \tau} \sum_{k=1}^{N} \ln \Lambda_k (\Delta \tau)$$
Literature

- **(ν-g) correlation** effect SN1987A
- **(ν-g) correlation** (BATSE, BeepoSAX etc.)

  *for bar-detectors*

- Modestino G., Moleti A. Phys Rev.D 65, 022005, 2002,

  *for interferometers*

- Abbott et al. gr-qc/0501068 v.2, 2004
SAI MSU group publications


IV. M. Aglieta et al. Nuovo Cimento Vol. 12C. N1 p75-102

LSD and Gravitational antennae
Mont Blanc (Rome and Maryland)

Event of \( (\nu - g) \) correlation during the SN1987A phenomenon
gg – coincidence
$P \approx 10^{-3}$

$\nu$ - coincidence
$\Delta \tau$ selection
$P \approx 10^{-6}$

C - statistic (average energy innovation)

$C_{\text{exp}} \approx 56 \text{ K}$

$C_{\text{event}} \approx 72 \text{ K}$
Figure: Time series data from February 22 to February 23. The y-axis represents E, in arbitrary units.
**LSD - Grav. Detectors**

1:45 – 3:45 UT

\[ N_{\text{LSD}} = 96 \text{ соб.} \]

\[ N = 172 \text{ соб.} \]

Грав. (E > 150 K)

\[ N = 13 \text{ эксп.} \]

\[ \bar{N} = 2.3 \]

Fig. 14. – The coincidences for the period of fig. 12 between the neutrinos (\( N = 96 \)) and the g.w. sum events above 150 K (\( N_{gw} = 172 \)).

**Table II.** – Times of occurrence of the Mont Blanc events for the 13 events of fig. 14 with threshold \( \geq 150 \text{ K} \). The g.w. and \( \nu \) energies and the delay of each \( \nu \)-event with respect to the corresponding g.w. event are also indicated.

<table>
<thead>
<tr>
<th>February 23, 1987</th>
<th>Delay (s)</th>
<th>( E_{\nu} + E_{gw} ) [K]</th>
<th>( E_{\nu} ) [K]</th>
<th>( E_{gw} ) [K]</th>
<th>( E_{\nu} ) [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td>min</td>
<td>s</td>
<td>1.50</td>
<td>261</td>
<td>192</td>
</tr>
<tr>
<td>1</td>
<td>47</td>
<td>48.80</td>
<td>0.80</td>
<td>156</td>
<td>113</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>40.10</td>
<td>1.01</td>
<td>156</td>
<td>113</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>40.31</td>
<td>1.11</td>
<td>166</td>
<td>57</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>37.04</td>
<td>0.74</td>
<td>178</td>
<td>172</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>5.05</td>
<td>0.75</td>
<td>201</td>
<td>166</td>
</tr>
<tr>
<td>2</td>
<td>38</td>
<td>24.89</td>
<td>1.59</td>
<td>170</td>
<td>128</td>
</tr>
<tr>
<td>2</td>
<td>43</td>
<td>38.50</td>
<td>1.20</td>
<td>181</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>38.84</td>
<td>1.04</td>
<td>209</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>36.79</td>
<td>1.49</td>
<td>196</td>
<td>135</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>7.30</td>
<td>1.00</td>
<td>199</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>42.08</td>
<td>0.78</td>
<td>228</td>
<td>202</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>44.04</td>
<td>0.74</td>
<td>168</td>
<td>126</td>
</tr>
</tbody>
</table>
\[ C(\tau) = \left\{ \sum_k \left[ E_R(t_k + \tau) + E_M(t_k + \tau) \right] \right\} n^{-1} \]

\[ k = \{1 \div n\} , \tau \Rightarrow C_{\text{max}} \]

Selection of \( \tau \) shifts a statistical distribution \( C \Rightarrow C_{\text{max}} \)

"chance probability" \( P \sim 10^{-6} \Rightarrow 10^{-2} \)
Reception frequency bandwidth of a gravitational resonant detector with optical readout

A V Gusev\textsuperscript{1}, V N Rudenko\textsuperscript{1}, S A Cheprasov\textsuperscript{1} and M Bassan\textsuperscript{2}

\textsuperscript{1} Sternberg Astronomical Institute of Moscow State University, Moscow, Russia
\textsuperscript{2} Dip. Fisica, Università Tor Vergata and INFN Roma, Italy

Received 11 July 2007, in final form 21 January 2008
Published 15 February 2008
Online at stacks.iop.org/CQG/25/055006

Abstract
A gravitational resonant bar detector with a large scale Fabry–Perot (FP) cavity as an optical readout and a mechanical displacement transformer is considered. We calculate, in a fully analytical way, the final receiver bandwidth in which the potential sensitivity, limited only by the bar thermal noise, is maintained despite the additional thermal noise of the transformer and the additive noise of the optical readout. We also discuss an application to the OGRAN project, where the bar is instrumented with a 2 m long FP cavity.

PACS numbers: 07.60.Ly, 07.07.Mp, 04.80.Nn, 95.55.Ym
\[ \mu = \frac{m}{M}, \ldots, \Omega_B = 0.5\sqrt{\mu} \cdot \omega_0, \ldots, (H_2/H_1) \approx \mu^{-1}(Q_1/Q_2) \]

\[ \mu \ll 1 \quad \text{thermal noise} \Rightarrow Q_2 \ll Q_1, \; \text{for} \cdot T = 300 \cdot K \]

\[ Q_2 \approx Q_1, \; \text{for} \cdot T = 0.01 \cdot K \]
FP parameters: \( P_0 = (0, 1\div 1) W, \quad <\Delta P_f^2> = P_0 \nu \eta/\eta \)

\[ F = 3 \cdot 10^3 \div 10^4, \quad A = (1-3) \text{ ppm} \]
Results

1. For OGRAN at $T=300$ K the best expectation is

$$h_{\text{min}}(f) \approx 1.5 \times 10^{-20} \text{ Hz}^{-1/2} \text{ in the bandwidth } \Delta f \approx 70 \text{ Hz}$$

$DT$ is not needed if

$$\left( \frac{Q_2}{Q_1} \right) \leq \left( \frac{\Omega_r}{\Omega_B} \right)^2$$

2. For a super cryogenic OGRAN at $T=0.01$ K

$$h_{\text{min}}(f) \approx 10^{-23} \text{ Hz}^{-1/2} \text{ in the bandwidth } \Delta f \approx 100 \text{ Hz}$$
Technological problem: to join “cooled mirrors” with “optical power”?

This is also the main problem to be solved for advanced GW interferometers of third generation.

LCGT project (Japan): $T=20 \text{ K}, P=100 \text{ W}$

Successful experiment: $T=4 \text{ K}, P=0.1 \text{ W}, A=1 \text{ ppm}$

“Grail” setup achieved $T=0.03 \text{ K}$

With current refrigerators (Nautilus $T=100 \text{ mK}$)

OGRAN could reach sensitivity $\sim 3 \cdot 10^{-23} \text{ Hz}^{-1/2}$
R&D research with “cryogenic mirrors”: cryostat for pilot model OGRAN.
Pilot model: $M \sim 8 \text{ kg}, f \sim 10 \text{ kHz}$

Preliminary result on the quality factor

$T=300 \text{ K}, \quad Q = 4500$

$T\sim 30 \text{ K}, \quad Q = 300 \, 000 \quad (!)$

Cooling is continuing…

Mirrors: $F=2000$ was not changed after cooling
Process of thermal screen mounting
Clean volume

5 class: 1 мкм, 1000 ч/м^3

Facilities for high quality mirrors F= 50 000
SUMMARY

• Neutrino Telescope BUST sensitive to low energy neutrino and Gravitational Wave Detector OGRAN are installed in the underground facilities of BNO INR RAS for a continuous monitoring rare events: relativistic collapsing catastrophes in the Galaxy and close environment ~ 100 kpc.

• Effective data processing algorithm for ν-g channels searching for has to be elaborated referring to known models of collapse.

• OGRAN sensitivity improvement up to ~ $10^{\{-23\}}$ 1/√Hz is foreseen with a cooling of the opto-acoustical bar below 1 K°

• Technological problem of operation with cryogenic mirrors illuminated by the light power ~ 1 W and more has to be addressed, especially in association with the ET project.