Search for neutrino bursts from core collapse supernovae at the Baksan Underground Scintillation Telescope

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BUST is located in the Northern Caucasus in the underground laboratory at the effective depth of 850 m of w.e. [1].
The facility has dimensions 17•17•11 m^3 and consists of four horizontal scintillation planes and four vertical ones. The total number of standard autonomic detectors is 3180.
Each standard detector is 70•70•30 cm^3 in size, and is filled with organic liquid scintillator (on the basis of white spirit C_nH_{2n+2}, n ≈9), viewed by one photomultiplier with a photocathode of 15sm in diameter.
The total mass of scintillator is 330 ton.
Three lower horizontal planes have 1200 standard detectors and 130 ton of scintillator.
The angular resolution of the facility is 2^o, time resolution is 5 ns.

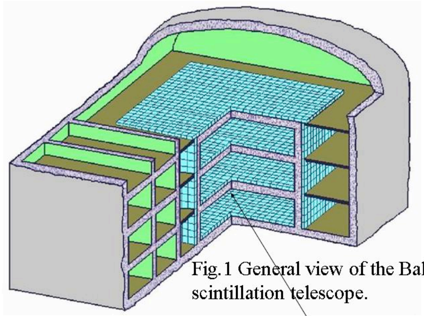


Fig.1 General view of the Baksan underground scintillation telescope.

1. The method of neutrino burst detection.

The neutrino signal from a supernova explosion is recorded with the help of the reaction

$$\bar{\nu}_e + p \rightarrow n + e^+ \quad (1)$$

If the mean antineutrino energy is 12 - 15 MeV the pass of e^+ (produced in reaction (1)) will be inside a single detector.

In such a case the signal from a supernova explosion will appear as a series of events from singly triggered detectors (one and only one detector from 3180).

2.Background events.

- radioactivity
- ghost signals from detectors
- cosmic ray muons, in the case of a single detector
- muon inelastic interaction of cosmic rays with the matter of the detector

The total count rate from background events is
n = 0.02 Hz in internal planes (three lower horizontal layers)
n= 1 Hz in external planes

Therefore three lower horizontal planes are used as the target (130 t).

Background events can imitate a bunch of k single events within the time interval τ with a count rate

$$p(k) = n \times \exp(-n\tau)\frac{(n\tau)^{k-1}}{(k-1)!} \qquad (P)$$

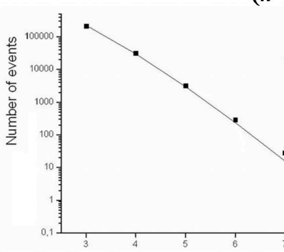


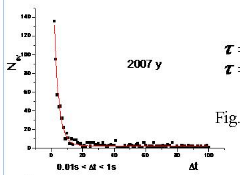
Fig2. The number of bunches with k single events within time interval of τ=20s. Squares - experimental data, the curve - the expected number according to the expression (P).
2001 – 2008 y;
T= 2459.65 days

2.1.Muon inelastic interaction of cosmic rays with the matter of the detector.

Some part of the background events can be connected with such interaction which can produce unstable nuclei whose disintegration brings into operation only one detector. To separate such events, afterpulses following large energy deposition (≥ 500 MeV) in this detector were studied.

The events were analyzed, which have on internal planes of the facility at least one detector with energy deposition E≥500 MeV (event of type "a"), then a single event was registered in the detector within interval Δt (event of type "b"). The afterpulses could be connected with ^{12}B.

^{12}B can appear in reactions $^{12}C + \pi^- \rightarrow {}^{12}B + \pi^0$,
$^{12}B \rightarrow {}^{12}C + e^- + \bar{\nu}_e$, $E_e = 13.37\,MeV$ (τ(^{12}B) = 20.4 ms)



$\exp(-\Delta t/\tau)$
$\tau = 29.7 \pm 0.9ms \quad (0.01 < \Delta t < 1s)$
$\tau = 21.8 \pm 1.0ms \quad (0.01 < \Delta t < 0.1s)$

Fig.3 Time spectrum of type "b" events

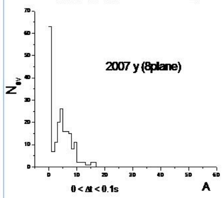


Fig.4. Amplitude spectrum of type "b" events .
The peak in the fourth channel corresponds to energy deposition 13.3 MeV that complies with typical energy of the decay electron from ^{12}B (E_e=13.37 MeV).

The contribution of background from nuclear decay ^{12}B does not exceed 0.013.

3. Search for neutrino bursts.

3.1.The standard delayed explosion scenario [2], [3]:

ε, erg	$\bar{E}_{\bar{\nu}_e}$, MeV	$\bar{E}_{\nu_e}$, MeV	$\bar{E}_{\nu_{\mu\tau}}$, MeV	T, sec
(3-5)•10^{53}	16	13	23	5 – 20

- 1)a distance from a star is 10 kpc
- 2) the total energy radiated in neutrinos is $\varepsilon_{tot} = 3 \bullet 10^{53} erg$,energy neutrino flavor $\frac{1}{6} * \varepsilon_{tot}$
- 3)the expected number of single events from reaction (1) will be

$$N^H_{(1)} \cong 38 * \eta_1$$

E_e(MeV)	η_1
10	0.7
20	0.9

- η_1 denotes the detection efficiency of e+ in reaction (1)

3.2 The scenario of 2-stage collapse [4]:
the mean electron neutrino energy during the first stage is (30 – 40) MeV [5]

$$\nu_i + {}^{12}C \rightarrow {}^{12}C^* + \nu_i, \quad E_{th} = 15{,}1\,MeV$$
$$i = e, \mu, \tau \qquad (2)$$
$$^{12}C^* \rightarrow {}^{12}C + \gamma, \qquad E_\gamma = 15{,}1\,MeV$$

$$N^C_{(2)} = 16 \times \eta_2, \ (E_\gamma = 15 MeV), \quad \eta_2 \approx 0.2$$

Reaction (2) allows us to measure the total neutrino flux with the energy $E\nu$ > 15,1 MeV.

$$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-, \ E_{th} = 17{,}34\,MeV$$
$$^{12}N \rightarrow {}^{12}C + e^+ + \nu_e, \quad \tau = 15{,}9\,ms \qquad (3)$$
$$N^C_{ev2} = 16 \times \eta_2 \ (E_\gamma = 15MeV) \qquad \eta_2 \approx 0.2$$
$$N^C_{ev3} = 30 \times \eta_3 \ (E_\nu = 30MeV) \qquad \eta_3 \approx 0.5 - 0.7$$

The low part of the overlap between horizontal scintillation planes is the 8 mm iron layer. This layer can be used as the target in the reaction

$$\nu_e + {}^{56}Fe \rightarrow {}^{56}Co^* + e^-, \ E_{th} = 4.056\,MeV \quad (4)$$

e^- could trigger two detectors. $N^{Fe}_{ev4} \cong 6{,}3 * \eta_4$

$\eta_4 \approx 0.4$ - the detection efficiency of e^- with 26 MeV.

- 2-stage collapse - the number of neutrino-induced events at the BUST has been increased by ≈ 50%.

4.Results.

- Study of temporary and energy distributions of events, registered on the telescope, can confirm or reject some models of the burst.
- The Baksan Underground Scintillation Telescope has been searching for collapse neutrinos since the mid-1980s [6,7].

The clean observational time (from 30.06.1980 to 31.12.2009) is
$T = 25.58$ years.

An upper bound on the mean frequency of gravitational collapse in our Galaxy at 90% CL on evidence derived from BUST

$$f_{col} < 0.090\,\mathrm{yr}^{-1}, \quad 90\%\,CL$$

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