Perspectives of DSNB neutrino researches in modern detectors

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Abstract. Studies of diffuse supernova neutrino background (DSNB) by modern underground detectors are reviewed. DSNB neutrino fluxes, their spectra and current experimental limits on their flux are discussed. Currently the best upper limit on DSNB neutrino flux is $2.9 \ cm^{-2}\ s^{-1}$. Also possibilities to improve upper limits on future detectors and perspectives of DSNB neutrino detection are discussed.

1. Diffuse Supernova Neutrinos
The Diffuse Supernova Neutrino Background (DSNB) is the flux of neutrinos and antineutrinos, which were emitted by all core-collapse supernovae in the Universe. Total rate and spectral shape of DSNB neutrinos could give new information about supernova core-collapse rate and neutrino emission from supernova.

1.1. Spectrum
The DSNB flux spectrum at the Earth can be written as[1]:

$$\frac{d\varphi}{dE_\nu} = \int_0^{z_{max}} \frac{N_{SN}(E(z+1))R_{SN}}{H_0\sqrt{(z+1)^3\Omega_m + \Omega_\Lambda}} \ dz$$

(1)

where $N_{SN}$ – neutrino emission spectrum from each individual supernova, $R_{SN}$ – cosmic supernova rate (it is a function of redshift and star formation rate), $H_0$ – Hubble constant, $\Omega_m = 0.3, \Omega_\Lambda = 0.7$ – the relative densities of the matter and dark matter in the Universe.

1.2. Astrophysical inputs
DSNB predictions are dependent from astrophysical inputs: the cosmic supernova rate, the star formation rate(SFR), the neutrino emission spectra from core-collapse supernova.

Star formation rate is defined by the mass of the formed star in a volume unit. The SFR function can be written in the form[2]:

$$R_{SN} = 10^{-4} yr^{-1}Mpc^{-3} \begin{cases} (1 + z)^{3.28}, & z < 1; \\ (1 + z)^{-0.26}, & 1 < z < 4.5; \\ (1 + z)^{-7.8}, & 4.5 < z; \end{cases}$$

(2)
The energy spectrum for neutrino of each flavour is expected to be thermal near the surface of the supernova and can be parametrized as:

$$N_{SN} \approx \frac{(1 + \beta_\nu)^{1+\beta_\nu} L_\nu}{\Gamma(1 + \beta_\nu) E_0^{\nu}} \frac{E}{E_0^{\nu}}^{2} \left(1 + \beta_\nu\right) E_{\nu},$$

(3)

where $E$ — neutrino energy, $L_\nu$ — expected luminosity of individual flavour of $\nu$, $E_0^{\nu}$ — average energy, $\beta_\nu$ — pinch factor $\sim 2 - 5$ describing the shape of the spectrum.

Currently, there are several MC calculations performed by different groups, predicting the neutrino spectral shape: Lawrence-Livermore National Laboratory group (LL)[3], Keil, Raffelt, Janka (KRJ) group[4] and Thompson, Burrows, Pinto (TBP) group[5]. General difference between models is in time of bursts simulation.

Neutrino energy spectrum is thermal and neutrinos average energy is $\sim 10 - 20$ MeV, $\nu_e$ and $\bar{\nu}_e$ will have colder spectra with respect to $\nu_\mu$ and $\nu_\tau$.

Studies of DSNB neutrinos were performed on several detectors but diffuse neutrinos from supernovae were not detected yet, nevertheless some upper limits for diffuse neutrino flux were obtained.

2. Super-Kamiokande

Super-Kamiokande detector is a 50 kton water Cherenkov detector located in the Kamioka mine in Japan. More information about the detector can be found in [6].

Super-Kamiokande detects electron antineutrinos via inverse beta decay reaction:

$$\bar{\nu}_e + p \rightarrow n + e^-$$

(4)

In 2012 upper limit for DSNB electron antineutrino was set on. Limit is $2.9 \bar{\nu}_e \text{ cm}^{-2} \text{s}^{-1}$ in $E > 16$ MeV ($17.3$ MeV $E_\nu$) energy range[6].

In the paper [7] SK collaboration lowered neutrino energy threshold from $17.3$ MeV to $13.3$ MeV by including neutron tagging. In further researches the collaboration expects that the energy threshold will be lowered to $10$ MeV.

3. KamLAND

The KamLAND is liquid scintillator detector located in underground laboratory Kamioka Observatory in Japan.

Results of searches for extraterrestrial electron antineutrino sources were published in 2012. As a result of these researches, limit for diffuse supernova electron antineutrino flux was obtained and its value is $139 \text{ cm}^{-2} \text{s}^{-1}$ in $8.3 < E < 31.8$ MeV energy range[8].

4. SNO

SNO is one kton the water-Cherenkov detector, which used heavy water as a target. It is located in the Inco, Ltd. Creighton nickel mine near Sudbury, Ontario, Canada at a depth of 6010 m water equivalent.

The diffuse supernova electron neutrinos and antineutrinos were detected in this detector through the reactions: $\nu + d \rightarrow \nu + n + p$, $\nu_e + d \rightarrow p + p + e^-$, $\bar{\nu}_e + d \rightarrow n + n + e^+$. Upper limit on the supernova neutrino flux was obtained in $22.9 < E < 36.9$ MeV energy range and this limit is $70 \text{ cm}^{-2} \text{s}^{-1}$ [9], $\bar{\nu}_e$ from unknown sources flux limit is $2 \cdot 10^6 \text{ cm}^{-2} \text{s}^{-1}$ for energy range $4 < E < 8$ MeV and for energies up to $14.8$ MeV limit is $3.4 \cdot 10^4 \text{ cm}^{-2} \text{s}^{-1}$[10].
5. Borexino

Borexino is a large volume liquid organic scintillator detector located in the underground national laboratory Gran-Sasso, Italy.

DSNB electron antineutrinos detect in Borexino via inverse beta decay reaction.

Borexino collaboration has published the limit for $\bar{\nu}_e$ from unknown sources in the energy range $1.8 < E < 17.8$ MeV [11]. This limit value is $760 \text{ cm}^{-2}\text{s}^{-1}$.

Summary of all detectors results for all antineutrino extraterrestrial sources are shown in figure 1.

![Figure 1. Model independent upper limits at 90% flux from different detectors](image)

![Figure 2. Predicted upper limit contour (90% C.L.) if JUNO finds for absence DSNB signal](image)

6. Prospects for future measurements

The Jiangmen Underground Neutrino Observatory (JUNO) will be a 20 kton liquid scintillator underground detector, being constructed in Guangdong, China.

Diffuse supernova neutrinos will be detected by inverse beta-decay reactions. Expected DSNB rate is 1.5 - 2.6 events per year. Expected upper limit for diffuse electron antineutrino flux in absence of signal is shown on the figure 2 together with Super-Kamiokande results for comparison.

The collaboration expects upper limit value will be $0.2 \text{ cm}^{-2}\text{s}^{-1}$ after 10 years in energy range above 17 MeV[12].

7. Conclusion

Modern results limit neutrino fluxes in energy range from 8.3 MeV to 40 MeV. Since Borexino detector has the least energy threshold, this low-background detector has an unique chance to set the upper limit for DSNB neutrinos in the low-energy area.

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References
[1] Beacom J F 2010 The diffuse supernova neutrino background Ann. Rev. Nucl. Part. Sci. 60 439-62
[2] Lunardini C 2010 Diffuse supernova neutrinos at underground laboratories arXiv:1007.3252 [astro-ph.CO]
[3] Ando S and Sato K 2004 Relic neutrino background from cosmological supernovae New J. Phys. 6 170
[4] Keil M Th, Raffelt G G and Janka H 2003 Monte Carlo study of supernova neutrino spectra formation Astrophys. J. 590 971-91
[5] Thompson T A, Burrows A and Pinto P A 2003 Astrophys. J. 592 434
[6] The Super-Kamiokande Collaboration 2012 Supernova relic neutrino search at super-Kamiokande Phys. Rev. D 85 052007
[7] The Super-Kamiokande Collaboration 2015 Supernova relic neutrino search with neutron tagging at Super-Kamiokande-IV Astropart. Phys. 60 41
[8] The KamLAND Collaboration 2012 Search for extraterrestrial antineutrino sources with the KamLAND detector Astrophys. J. 745 193
[9] The SNO Collaboration 2006 Search for neutrinos from the solar hep reaction and the diffuse supernova neutrino background with the Sudbury Neutrino Observatory Astrophys. J. 653 1545-51
[10] The SNO Collaboration 2004 Electron antineutrino search at the Sudbury Neutrino Observatory Phys. Rev. D 70 093014
[11] Borexino Collaboration 2011 Study of solar and other unknown anti-neutrino fluxes with Borexino at LNGS Phys. Lett. B 696 191-6
[12] Fengpeng An et al. 2015 Neutrino Physics with JUNO arXiv:1507.05613 [physics.ins-det]