Neutrino from stellar collapses

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Abstract In this paper the modern results and investigation prospects of neutrino from astrophysical sources by low-background neutrino detectors are reviewed. Also results of simultaneous analysis by neutrino and gravitational waves detector are presented.

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1. Introduction

Neutrinos produced during stellar collapses carry information about collapse process because they are not influenced by the interstellar medium. Beside neutrino emission the second possible source of data about supernova explosion and gamma ray bursts mechanisms are gravitational waves that also propagate without any changes. Therefore they could bring us information about distant phenomena such as Supernovae explosions and Gamma Ray Bursts, about their origins and about processes taking place inside them. Simultaneous analysis by neutrino and gravitational waves detectors could be one of the ways to get the whole picture of these processes.

2. Neutrinos from Supernovae

It is expected that stars with masses $M_* \geq 8M_\odot$ and $M_* \leq 65M_\odot$[1] could end their lives through the Supernova explosion. All stages of the star collapse are accompanied by neutrino emission. Neutrinos carry away about 99% of binding gravitational energy [2] and provide necessary energy for supernova explosion. Neutrinos are produced through the beta- and thermal processes inside the core and star medium. During the first collapse phase neutrinos can propagate freely. But increasing of core mass leads to the formation of neutrinosphere and neutrinos are trapped inside it . Trapped neutrinos provides necessary amount of energy for the explosion through the neutrino heating process [3].

Thanks to very low interaction cross-section neutrinos emitted from Supernova could provide us with information about new neutrino physical properties and expand our knowledge about stars structure and evolution. Also the presupernova neutrino signal that preceded the explosion could help astronomical community to detect early core-collapse stages. For this aim the SuperNova Early Warning System (SNEWS) was created [4]. The SNEWS system includes modern neutrino detectors such as Super-K (Japan), LVD (Italy), Ice Cube (South Pole), KamLAND (Japan), Borexino (Italy) Daya Bay (China) and HALO (Canada). The main idea of this project is to search coincidences among neutrino candidates from different detectors during 10 second window by central computer located in Brookhaven National Lab. The time of the neutrino registration signal could help astronomers find direction to the future Supernova.

2.1. Diffuse Supernova Neutrino Signal

Neutrino signal from the individual supernova explosion is not distinguishable from the background in modern detectors when supernova distance is more than few kiloparsecs. But the neutrino flux from all supernova collapses that occurred through the existence of the Universe could be detectable. The predicted flux of such neutrinos is about ~1 cm^{-2} s^{-1} [5]. Total spectrum of these neutrino depends on Supernova rate in Universe and relative densities of ordinary matter and dark energy [5] . Therefore Diffuse Supernova Background neutrinos could provide us an information not only about supernovae explosion mechanism but also it could be independent instrument to test our knowledge of star formation rate function and constrain modern cosmological models [6,7].

Several detectors such as Super-Kamiokande [8], SNO [9] and KamLAND [10] searched for the signal from DSNB neutrinos. Although there was no DSNB-signal observed, upper limits on the neutrino fluxes were established. For electron antineutrinos the best limit on DSNB flux in energy range 13.3-31.3 MeV belongs to Super-Kamiokande collaborations. In near future Super-Kamiokande and future detector JUNO [11] are expected to be able to detect DSNB neutrino signal.

2.2. Simultaneous analysis of neutrino and gravitational waves detectors

After registration of the gravitational wave signal from the black holes merging by LIGO detector [12] several neutrino detectors including Super-Kamiokande [13], KamLAND [14] and Borexino [15] tried to find time correlation between neutrino signal and gravitational wave events. The correlation was searched upon two neutrino detection channels: through scattering on electrons in all detectors and through inverse beta decay channel in KamLAND and Borexino. No correlation was found.

Also simultaneous analysis of neutrino detectors data and gravitational waves detectors data could be performed for the search of neutrinos from distant, so-called "dark", supernovae [16]. In order to enlarge the statistics, data from several neutrino detectors such as LVD , Borexino, KamLAND, and IceCUBE will be put to common database after estimation of background for each detector. In addition to detection of neutrinos from individual distant supernovae this method could also make possible the detection of neutrinos from so-called "dark" supernovae with explosions not accompanied by light emission.

3. Neutrinos from Gamma Ray Bursts (GRB)

Gamma Ray Bursts (GRBs) are non regular bursts of gamma rays in the Universe. Their origin is not fully understood, but because of most GRBs occurring in the star formation regions of Universe they could be produced by star collapses [17]. The GRBs could be divided in two groups by the their duration. The short GRBs are bursts with total duration less than 2 seconds. The long GRBs have duration longer than 2 seconds. Beside duration short and long gamma ray bursts differ by their supposed source. Long GRBs have supernova explosion as progenitor [17].

Low background neutrino detectors Borexino [18], KamLAND [19] and Super-Kamiokande [20] searched for neutrino signal correlated with GRBs. No correlation was found and the upper limits on neutrino fluences were established. The best limit in low-energy region 2-6 MeV belongs to Borexino detector. In the higher energy range 6-15 MeV the best upper limit is established by Super-Kamiokande .

4. Conclusion

Modern detectors sensitivity is not enough to detect neutrino fluxes from the rare sources like an individual distant Supernova. More statistics and higher volume neutrino detectors are required to obtain any significant signal. But it is expected that neutrino detectors of the next generation will reach required sensitivity level.

Also simultaneous analysis based on the common data from network of the neutrino and gravitational waves detectors could allow to measure the signal from neutrinos produced inside star collapses.

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