Pis'ma v ZhETF, vol. 108, iss. 12, pp. 803 – 804

Search for high-energy neutrinos from GW170817 with the Baikal-GVD neutrino telescope

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Submitted 23 October 2018
Resubmitted 1 November 2018

DOI: 10.1134/S0370274X18240037

A gravitational wave signal, GW170817, from a binary neutron star merger has been recorded by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) and Advanced Virgo observatories on August 17, 2017 [1]. A short gamma-ray burst (GRB) (GRB170817A), associated with GW170817, was detected by Fermi Gamma-ray Burst Monitor (Fermi-GBM) and International Gamma-Ray Astrophysics Laboratory (INTEGRAL). NGC 4993 was localized as the host galaxy of the merger by follow up optical observations. High-energy neutrino signals associated with the merger were searched for by the Astronomy with a Neutrino Telescope and Abyss environmental RESearch (ANTARES) and IceCube neutrino telescopes in muon and cascade modes and the Pierre Auger Observatory [2] and Super-Kamiokande [3]. Two different time windows were used for the searches. First, a ±500 s time window around the merger was used to search for neutrinos associated with prompt and extended gamma-ray emission [4, 5]. Second, a 14-day time window following the gravitational wave (GW) detection, to cover predictions of longer-lived emission processes [6, 7]. No significant neutrino signal was observed by the neutrino telescopes.

The deep underwater neutrino telescope Baikal Gigaton Volume Detector (Baikal-GVD) is currently under construction in Lake Baikal [8]. The telescope has a modular structure and consists of functionally independent sub-arrays (clusters) of optical modules (OMs). Since each GVD-cluster represents a multi-megaton scale Cherenkov detector, studies of neutrinos of different origin are allowed at early stages of construction.

During 2017 two GVD-clusters have been operated in Lake Baikal. A search for high-energy neutrinos associated with GW170817 in Baikal-GVD is based on the selection of cascade events generated by neutrino interactions in the sensitive volume of array. The procedure for reconstructing the parameters of high-energy showers – the shower energy, direction, and vertex – is performed in two steps. In the first step, the shower vertex coordinates are reconstructed by χ_t^2 minimization using the time information from the telescope's triggered photo-sensors. The reconstruction quality can be

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increased by applying additional event selection criteria based on the limitation of the admissible values for the specially chosen parameters characterizing the events. In the second step, the shower energy and direction are reconstructed by applying the maximum-likelihood and using the shower coordinates reconstructed in the first step.

The zenith angle of NGC 4993 at the detection time of GW170817 was 93.3° for Baikal-GVD. Since background events from atmospheric muons and neutrinos can be significantly suppressed by requiring time and space coincidence with the GW signal, relatively weak cuts can be used for neutrino selection. For the search for neutrino events within a ±500 s window around the GW event, 731 events were selected, which comprise > 5 hit OMs at > 2 hit strings. After applying cascade reconstruction procedures and dedicated quality cuts, two events were selected. The median angular error is 4.5° with this set of relaxed cuts and the expected number of atmospheric background events is about 5×10^{-2} during the coincident time window. Finally, requiring directional coincidence with NGC 4993 $\psi < 20°$ no neutrino candidates survived.

The absence of neutrino candidates in the ±500 s window associated with GW170817 allows to constrain the fluence of neutrinos from GW170817A. Assuming an E^{-2} spectrum single-flavor differential limits to the spectral fluence in bins of one decade in energy have been derived according to [9]. In the range from 5 TeV to 10 PeV a 90 % Confidence Level (CL) upper limit on an E^{-2} power-law spectral neutrino fluence is $5.2\times(E/GeV)^{-2}\,\mathrm{GeV}^{-1}\mathrm{cm}^{-2}$.

The search over 14 days used a more stringent cut on the number of hit OMs – $N_{\mathrm{hit}} > 7$. The zenith angle of the optical counterpart oscillates daily between 74° and 150°. No events spatially coincident with GRB170817A were found in this search. Given the non-detection of neutrino events associated with GW170817, differential upper limits have been derived. The corresponding upper limit to the spectral fluence is $9.0\times(E/GeV)^{-2}\,\mathrm{GeV}^{-1}\mathrm{cm}^{-2}$ over the same energy range as for the ±500 s time window. The ongoing analysis of GVD data using the muon detection mode will allow to improve these limits.

Full text of the paper is published in JETP Letters journal. DOI: 10.1134/S0021364018240025

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