The Baikal Neutrino Telescope: Results, Plans, Lessons

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Abstract

We review recent results on the search for high energy extraterrestrial neutrinos, neutrinos induced by WIMP annihilation and neutrinos coincident with Gamma Ray Bursts as obtained with the Baikal neutrino telescope NT-200. We describe the moderate upgrade of NT-200 towards a ∼10 Mton scale detector NT-200+. We finally draw a few lessons from our experience which may be of use for other underwater experiments.

I. INTRODUCTION

The Baikal Neutrino Telescope NT-200 is operated in Lake Baikal, Siberia, at a depth of 1.1 km. A description of the detector as well as physics results from data collected in 1996 and 1998 (70 and 234 live days, respectively) have been presented elsewhere [1][2]. Here we present new limits including data taken in 1999 (268 live days).

We note that the year 2003 marks the tenth anniversary of the deployment of NT-36, the pioneering first stationary underwater array [3][4]. Fig.1 shows a textbook neutrino event (an upward moving muon track) recorded with the early 4-string configuration of 1996 [5].

Figure 1: Upward going muon track with 19 fired channels, recorded in 1996. Hit channels are marked in color, with the size of the aura indicating the recorded amplitude.

II. SEARCH FOR EXTRATERRESTRIAL HIGH ENERGY NEUTRINOS

The survey for high energy neutrinos is focused to bright cascades produced at the neutrino interaction vertex in a large volume around the neutrino telescope. Lack of significant light scattering allows to monitor a volume exceeding the geometrical volume by an order of magnitude. This results in sensitivities of NT-200 comparable to those of the much larger Amanda-B10 detector. The background to this search are bright bremsstrahlung flashes along muons passing far outside the array (see 3 for details).

Candidate events do not show a statistically significant excess of hit multiplicities compared to the simulated background from atmospheric muons. Assuming an $E^{-2}$ shape of the neutrino spectrum and a flavor ratio $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$, the new, preliminary 90% c.l. upper limit with respect to the flux of all three flavors is $\Phi_{\nu_e + \nu_\mu + \nu_\tau} E^2 = 1.3 \times 10^{-6} \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}^{-1}$, about twice below previous results [6]. The preliminary limit on $\nu_\tau$ at the $W$-resonance energy is: $\Phi_{\nu_\tau} \leq 5.4 \times 10^{-20} \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}^{-1}$. Fig. 2 shows the experimental upper limits obtained by BAIKAL (this work), and
AMANDA [7], as well as the projected sensitivity for NT-200+ (see below). Limits are compared to SSDS [8] and MPR [9] predictions. The slanted lines at the left side represent the atmospheric neutrino fluxes (dashed for $\nu_\mu$, solid for $\nu_e$).

Figure 2: Experimental upper limits on neutrino fluxes (see text for explanation).

III. SEARCH FOR NEUTRINOS Coincident WITH GRBs

We have searched for high energy cascades coincident with 772 Gamma Ray Bursts (GRB) recorded between April 1998 and February 2000 by the BATSE detector and falling into online periods of NT-200 (386 triggered GRB, 336 non-triggered from Stern catalogue). After cuts for background reduction, we are left with one event within one of the $\pm 100$-second windows, where 0.47 events would have been expected from accidental coincidences. Precise limits on the fluence are being derived at present. With an effective volume in the Megaton range, NT-200 is the largest Northern detector for high energy neutrinos from GRBs.

IV. SEARCH FOR NEUTRINOS FROM WIMP ANNIHILATION

The search for WIMPs with the Baikal neutrino telescope is based on a possible signal of nearly vertically upward going muons, exceeding the flux of atmospheric neutrinos (see [10]). Note that the threshold of $\sim 10$ GeV for this analysis is lower than that of $\sim 15$ GeV for atmospheric neutrinos spread across the full lower hemisphere. Fig. 3 (top) demonstrates that the angular distribution of events passing a special filter for events close to the vertical is well described by simulations including the effect of neutrino oscillations (assuming $\Delta m^2 = 2.5 \cdot 10^{-3}$ eV$^2$).

With no significant excess observed, we derive improved upper limits on the flux of muons from the direction of the center of Earth related to WIMP annihilation. Fig. 3 (bottom) compares our new limits to those obtained by other experiments (see [10] for references).

Figure 3: Angular distribution of selected neutrino candidates compared to expected distributions including (full line) and excluding (dotted line) the effect of oscillations.

Figure 4: Flux limits from different experiments as a function of WIMP mass.

V. UPGRADE TO NT200+

NT-200+ is an upgrade of NT-200 by three sparsely instrumented distant outer strings (see Fig. 5). The fenced volume is a few dozen Mtons. A prototype string of 140 m length with 12 optical modules was deployed in March 2003, and electronics, data acquisition and calibration systems for NT-200+ have been tested. The 3 strings allow for dramatically better vertex reconstruction of high energy cascades than with NT-200 alone (see Fig. 6). This, in turn, allows a much better determination.
of the energy and makes NT-200+ a true discovery detector with respect to reactions within the mentioned fiducial volume. (This is in contrast to NT-200 which is an excellent exclusion experiment but would have certain difficulties to prove – for a single event outside its geometrical volume – that the signal is indeed due to a far high-energy event and not to a closer medium-energy event.) NT-200+ will be installed in 2004 and 2005.

Figure 5: Configuration of NT-200+.

Figure 6: Reconstructed vs. simulated coordinates of cascades in NT-200+ (black rectangles) and NT-200 (crosses).

VI. A GIGA-TON DETECTOR?

First discussions have started on an even larger detector of the order of a cubic kilometer in Lake Baikal. The configuration of such a detector will be consequently tailored to certain classes of events and should complement Mediterranean arrays. A possible design was sketched in [2]. Given the drawbacks of stronger absorption and shallower depth compared to Mediterranean sites, this idea rests on the proven, stable deployment procedures, lower-cost considerations and possible national funding strategies. However, even in the case of strong national funding, such a project would need international participation.

VII. SOME LESSONS

We finally summarize some lessons which may be of use for all underwater arrays.

A. Leakage

The early history of Baikal could have been written as a history of leaking feed-throughs, connectors and pressure housings. After having designed a special connector tailored to depths up to \( \sim 1.6 \) km (the maximum depth in Lake Baikal), this phase was overcome. NT-36 did not suffer from leaks. In the mean time, more than 1000 connectors and feed-throughs are in operation at 1.1 km depth, and the failure rate is less than 1 per year. Clearly, detectors much deeper, like the Mediterranean ones, have to make use of different technologies. Still, it seems now obvious that instruments with hundreds of pressure spheres and more than thousand connectors can work in deep water over many years, with tolerable leakage rates – a statement which ten years ago would have been questioned by many oceanographers.

B. Sedimentation

Sedimentation and bio-fouling are a concern in Lake Baikal. The performance of the up-down symmetric NT-36 detector, with the same number of optical modules facing upward and downward, was particularly affected by sedimentation [3]. The sensitivity of the upward looking modules with respect to atmospheric muons decreased to 35% after one year [11]. At present, only two of the 12 layers of NT-200 have upward facing modules. The glass spheres are dressed with a tapering hat of plastic foil. Much of the sediments glide along the foil and do not stick to the hat. The effect of sedimentation, i.e. a progressively decreasing sensitivity of the upward looking modules, is weakened, and an acceptable functionality may be kept by cleaning the hats once every two years. This is important since the outer strings of NT-200+ will be up-down symmetric. We conclude that symmetric configurations can be operated in Lake Baikal, but only if the optical modules can be easily hauled up, inspected and cleaned. The same limitation should hold for those Mediterranean sites with strong biological activity.

C. Reliability and repair

The possibility to haul up the array and to repair connectors was a key for NT-200’s operation. In the very beginning, about 40% of the optical modules turned non-operational after one year of operation due to failures in electronics. Clearly this was not tolerable, be it with or without the possibility to repair failed components. In the mean time the failure rate reduced to
less than 5% per year. This lower rate, combined with the possibility to repair failed components results in a tolerable regime of operation and maintenance. From our experience we would recommend designs which give a not too complicated access to deployed parts of the detector.

D. Electro-corrosion

With the reliability of the detector itself improving from year to year, we were faced by another, non-expected problem: we observed electro-corrosion along the cables to shore. Actually electro-corrosion was thought to be negligible since the fresh water of Lake Baikal is nearly free of minerals and salts and is a bad conductor of electricity. Much of the return current was thought to flow along the outer metal jacket of the shore cable (white arrows in figure 7) and not through the water.

During the last year it became clear that the cable arming showed damages at the points indicated in the figure. The reason seems to be that close to the shore the current leaks into ground and propagates there with a low resistance compared to the cable, and that also current flows through the water at the depth of the big metallic, umbrella-like support frame of NT-200 (black arrows). At these points, strong electro-corrosion is observed. It led to the loss of two of the four shore cables in the last year. The cables will be replaced by new cables in 2004, and the distance between the vertical part of the shore cable and NT-200 will be increased.

Electro-corrosion should be an even stronger issue for salt water detectors, as shown by the DUMAND history. The Baikal experience can certainly not be translated to different designs of power distribution and return current. Still it may suggest that one should be prepared to unpleasant surprises and necessary design changes.

E. Staged approach

A staged approach seems mandatory when building a large instrument in a new and challenging environment like deep water. The idea that one can already in the design phase account for all possible problems has been disqualified not only by the Baikal experience but also by DUMAND, NESTOR and ANTARES. The operation of prototype detectors and the readiness for technological modifications is of key importance.

F. Looking beyond the geometrical volume

Underwater detectors do not suffer from strong light scattering as does ice. Therefore the timing information from distant light sources is not strongly dispersed. This opens the possibility to monitor a huge volume around the detector. A few strings far outside, like those planned for NT-200+, can dramatically improve the sensitivity to PeV processes. Due to best background rejection, the most efficient region is that below the geometrical volume of the detector. Apart from stronger bottom water currents and slightly worse water quality close to ground, this may be another argument not to place the detector as deep as possible, but a few hundred meters above ground.

This work was supported by the Russian Ministry of Research, the German Ministry of Education and Research and the Russian Fund of Basic Research (grants 03-02-31004, 02-02-17031, 02-07-90293 and 01-02-17227), Grant of President of Russia NSh-1828.2003.2 and by the Russian Federal Program “Integration” (project no. E0248).

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