ANTARES - Baikal-GVD Alerts Analysis

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Abstract

ANTARES and Baikal-GVD are both Cherenkov neutrino telescopes located in the Northern Hemisphere. As a consequence, their fields of view overlap allowing for a combined study of the sky (Fig: 1). ANTARES sends alerts after a fast on-line analysis based on energy and reconstruction direction of track-like events. Baikal-GVD received 38 ANTARES alerts, and followed up a total of 32 as 6 alerts were sent during a period of detector maintenance. While no prompt coincidence was found, a cascade mode search revealed that for three alerts, named as A7, A15 and A16, a total of 3, 2 and 2 cascade events were detected respectively within an angular distance of less than 5° from the alert direction and in a time span of ±1 day of the alert time.

The 4.5° angular resolution of Baikal-GVD allows for the possibility of these events to be spatially correlated, which makes them of special interest. A dedicated offline analysis based on the full ANTARES data sample has been done to search for additional coincident tracks and cascades at a 3σ significance near A7, A15 and A16. With this contribution we present the final results on the analysis: limits on the astrophysical neutrino fluence as obtained by this analysis are reported.

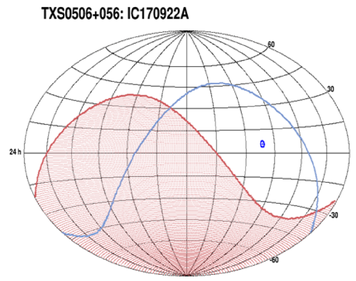

Fig. 1: Example of overlapping FoV in time of known neutrino alert IC170922A. Red for GVD and blue for ANTARES.

ANTARES Alerts

ANTARES is located in the Mediterranean sea, 40 km offshore of the coast of Toulon, France [1]. It is optimized for the detection of up-going neutrinos coming across the earth. It is able of real-time processing with delays below 10 seconds between detection and alert emission.

ANTARES sends alerts for **doublets of neutrinos**, neutrinos with $E > 1$ TeV and direction **close to local galaxies** (directional); and with **high energy** ($E > 7$ TeV) or **very high energy** ($E > 30$ TeV) neutrinos, HE and VHE respectively.

ID	Right Asc. [°]	Declination [°]	Trigger
Alert A7	151.1	-27.3	Dir.
Alert A15	280.4	1.0	HE
Alert A16	186.5	-4.2	HE

Baikal-GVD

The deep underwater neutrino telescope Baikal-GVD is under construction in Lake Baikal [2]. It is built in individual clusters, separated 300 m of each other. A cluster is composed of 288 optical modules divided in 8 strings. In season Apr 2018 - Feb 2019 three clusters were operational and were extended to five on Apr 2019, and to seven in Apr 2020. Detection is based on measuring the Cherenkov radiation emited by leptons produce in neutrino interactions.

Fig. 2: Pictures of the installation of cluster 7 in lake Baikal

Follow up of ANTARES neutrino alerts: 5° cone radius ± 1 day

Follow-up frame:

1. Search for events per cluster in different time windows of ±500 sec, ±1 hour and ±1 day around alerts inside a 5° cone radius.
2. Search for coincidence on two or more clusters within 6 μs for the first ±10 seconds and, in an extended interval, for the next ±1 hour around the trigger.

The next table summarizes the number of cascades detected, the detection time, expected background and pre-trial significance. Coordinates are shown in Figure 3, 4 and 5.

Alert	# cas.	$\Delta T_{trigger}$ [h]	Bkg/(clust.·day)	sig. [σ]
A7	3	+21.7, -3.2, -23.2	0.090	3.1*
A15	2	+20.3, -0.6	0.108	2.6
A16	2	-14.8, -18.6	0.090	2.7

*Only for 2 coincident events [4].

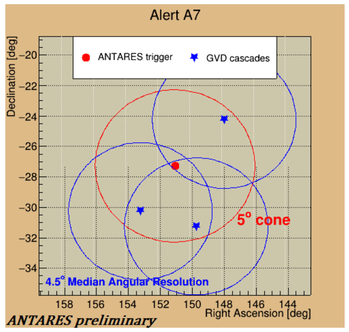

Fig. 3: Alert A7: A triplet of cascades was reconstructed around the ANTARES trigger in ±1 day time.

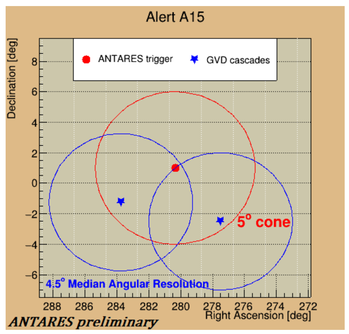

Fig. 4: Alert A15: Two cascades were reconstructed around the ANTARES trigger in ±1 day time.

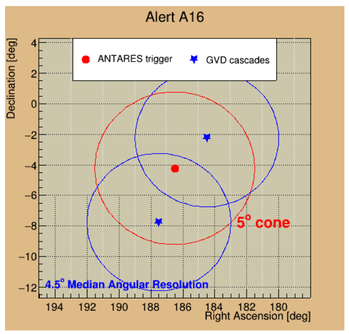

Fig. 5: Alert A16: Two cascades were reconstructed around the ANTARES trigger in ±1 day time.

ANTARES Upper Limits on the Neutrino Fluence

No additional track or shower was found coming from the same directions of the alerts within ±1 day. ANTARES upper limits on the neutrino fluence for an E^{-2} spectrum over the time search are presented.

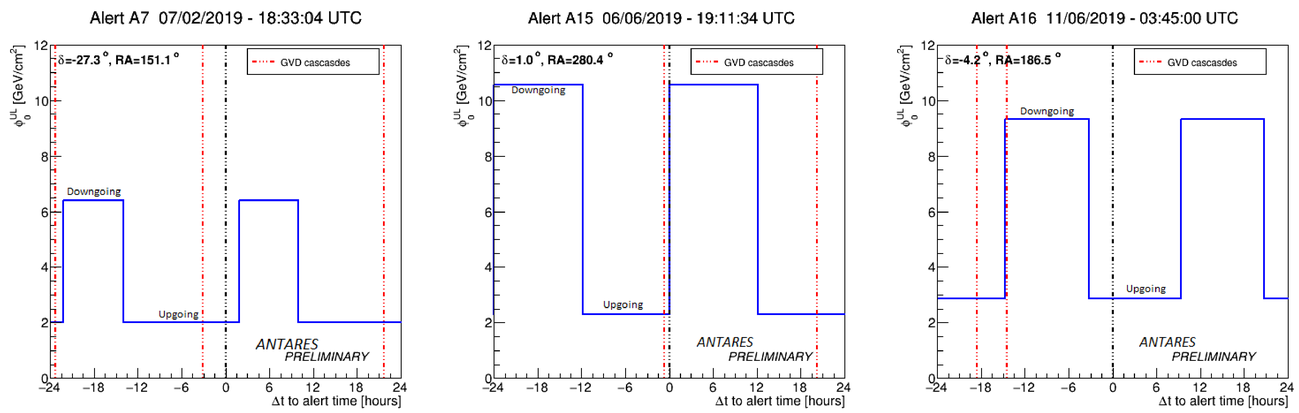

Fig. 6: Upper limits on the fluence for all the three alerts assuming a E^{-2} spectrum as a function of the tiem relative to the alert trigger. The red dotted lines represent the detection time of the GVD cascades. The expected uncertainty for this limits is around 30% and 40% for the up-going and down-going sky respectively [3].

Outlook: Despite no additional event was observed, the track events that triggered the alerts did manifest again during the offline analysis over the 3σ cuts. This means that these neutrino candidates are quite significant on their own when compared with the expected background. Together with the pre-trial significance close to 3σ of the GVD cascades an the extra track seen in Figure 5, these events are still quite interesting so further efforts are going to be made to compute the final post-trial joint significance of the detection as it could be close to the evidence threshold.

References:

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[2] Avrorin, A. D., et al. "The Baikal-GVD neutrino telescope: First results of multi-messenger studies." arXiv preprint arXiv:1908.05450 (2019).

[3] Albert, A., et al. "Search for neutrino counterparts of gravitational-wave events detected by LIGO and Virgo during run O2 with the ANTARES telescope." The European Physical Journal C 80 (2020): 1-9.

[4] VLVnT 2021 contribution by Olga Suvorova, INR RAS, Moscow. Baikal - GVD collaboration.

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