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ANTARES search for neutrino flares from the direction of radio-bright blazars

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In 2017, a high-energy muon neutrino detected by IceCube was found positionally coincident with the direction of a known blazar, TXS 0506+056, in a state of enhanced γ-ray emission. Soon after, IceCube reported a compelling evidence for an earlier neutrino flare from the same direction found in the archival data, this time not accompanied by any observed electromagnetic activity. The IceCube findings suggest searching for flaring neutrino emissions from astrophysical sources, not necessarily accompanied by flares detected in γ-rays. The analysis presented in this contribution scans the events collected by the ANTARES neutrino telescope in 13 years of data taking in a search for clustering in space and time. The analysis method is based on an unbinned maximum likelihood approach. Generic Gaussian and Box profiles are assumed for the signal time emission, with both the central time and duration of the flare being free parameters in the likelihood maximization. The time-dependent approach is applied to the catalog of radio-bright blazars for which a promising directional correlation with IceCube muon tracks was recently reported [ApJ 894 (2020) 101, ApJ 908 (2021) 157].

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1. Executive Summary

In these proceedings, a search for time and space clustering of ANTARES events from the direction of radio-selected blazars is presented. The blazar catalog employed in this work corresponds to the most up-to-date version of the catalog used in two recent searches for correlation between blazars and IceCube events, which resulted in a promising evidence of association [ApJ 894 (2020) 101, ApJ 908 (2021) 157]. The radio catalog is an all-sky sample of 3415 blazars, selected on the basis of their very-long-baseline interferometry (VLBI) radio flux, as those sources with a flux density integrated over VLBI images at 8 GHz of at least 150mJy. Only sources with a declination $\delta < 40°$ are employed in this analysis, for a total of 2774 investigated blazars. The ANTARES data set includes 10162 tracks and 225 showers recorded in ANTARES between January 29, 2007 and February 29, 2020 (3845 day livetime).

The search for neutrino flares relies on an unbinned time-dependent maximum likelihood method, in which the combined information of three parameters – direction, energy and detection time – is included in the likelihood probability density functions (PDFs). Regarding the signal time PDFs, two time profiles are tested for the signal emission, characterized by a Gaussian shape and a Box shape, with both the central time and duration of the flare being free parameters in the likelihood maximization, together with the number of signal events and the source energy spectral index. As for the time-dependent parameters, the central time can vary over the time range of the investigated ANTARES data, while the flare duration can take values between 1 day and 2000 days. The approach is similar to the one used by the IceCube Collaboration in the search for time clustering at the position of TXS 0506+056, which yielded a 3.5σ evidence for an excess of high-energy neutrino events between September 2014 and March 2015 [Science361(2018) 147–151].

No significant neutrino flare is found when applying the search method to the 2774 radio-bright blazars. The same source, J1500-2358, shows the lowest pre-trial p-value using both time profiles. The pre-trial significance of 3.3σ (3.4σ) obtained for the Gaussian-shape (Box-shape) assumption for J1500-2358 corresponds to a post-trial p-value of 56% (40%). The best-fit flare for J1500-2358 has a duration of 4 days (6 days) with the Gaussian-shape (Box-shape) assumption. A pre-trial significance of over 3σ for at least one of the tested time profile has been obtained for other six sources: J1517-4424, J1606+2717, J1418-3509, J0242+1101, J0732-0150, and J0641-3554.

As a follow-up study of the findings of this analysis, the obtained best-fit neutrino flares have been compared to the radio light-curves produced by the Owens Valley Radio Observatory. The most interesting case is the one of the blazar J0242+1101 with a typical parsec-scale core-jet structure. Its largest flare observed in radio shows a notable overlap in time with the best-fit neutrino flare found in this analysis for the same source. In view of this intriguing observation, the time distribution of the public data of the Fermi γ-ray telescope and of the IceCube neutrino telescope compatible with the source direction have also been studied. Remarkably, the most significant Fermi γ-ray flare for this source happened during the flaring emission observed in radio and the period highlighted by the present analysis of ANTARES neutrinos. As for the IceCube events, while there is not evidence of time clustering, a muon-neutrino-induced track with the notable high energy of 50 TeV was detected during the flare. A dedicated analysis will be soon performed to estimate the chance probability of the association between radio, γ-ray and neutrino observations.