Where neutrinos come from

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The Russian RATAN-600 telescope helps to understand the origin of cosmic neutrinos Credit: Daria Sokol/MIPT

Russian astrophysicists have come close to determining the origin of high-energy neutrinos from space. The team compared data on the elusive particles gathered by the Antarctic neutrino observatory IceCube and on long electromagnetic waves measured by radio telescopes. Cosmic neutrinos turned out to be linked to flares at the centers of distant active galaxies, which are believed to host supermassive black holes. As matter falls toward the black hole, some of it is accelerated and ejected into space, giving rise to neutrinos that then coast along through the universe at nearly the speed of light.

The study is published in the *Astrophysical Journal* and is also available from the arXiv preprint repository.

Neutrinos are mysterious particles so tiny that researchers do not even know their mass. They pass effortlessly through objects, people and even entire planets. High-energy neutrinos are created when protons accelerate to nearly the speed of light.

The Russian astrophysicists focused on the origins of ultra-high-energy neutrinos at 200 trillion electron volts or more. The team compared the measurements of the IceCube facility, buried in the Antarctic ice, with a large number of radio observations. The elusive particles were found to emerge during radio frequency flares at the centers of quasars.

Quasars are sources of radiation at the centers of some galaxies. They consist of a massive black hole that consumes matter floating in a disk around it and spews out extremely powerful jets of ultrahot gas.

"Our findings indicate that high-energy neutrinos are born in active galactic nuclei, particularly during radio flares. Since both the neutrinos and the radio waves travel at the speed of light, they reach the Earth simultaneously," said the study's first author Alexander Plavin.

Plavin is a Ph.D. student at Lebedev Physical Institute of the Russian Academy of Sciences (RAS) and the Moscow Institute of Physics and Technology. As such, he is one of the few young researchers to obtain results of that caliber at the outset of their scientific career.

Neutrinos come from where no one had expected

After analyzing around 50 neutrino events detected by IceCube, the team showed that these particles come from bright quasars seen by a network of radio telescopes around the planet. The network uses the most precise method of observing distant objects in the radio band: very long baseline interferometry. This method in essence creates a giant telescope by placing many antennas around the globe. Among the largest elements of this network is the 100-meter telescope of the Max Planck Society in Effelsberg.

Additionally, the team hypothesized that the neutrinos emerged during radio flares. To test this idea, the physicists studied the data of the Russian RATAN-600 radio telescope in the North Caucasus. The hypothesis proved highly plausible despite the common assumption that high-energy neutrinos are supposed to originate together with gamma rays.

"Previous research on high-energy neutrino origins had sought their source right 'under the spotlight." We thought we would test an unconventional idea, though with little hope of success. But we got lucky," says Yuri Kovalev from Lebedev Institute, MIPT, and the Max Planck Institute for Radio Astronomy. "The data from years of observations on international radio telescope arrays enabled that very exciting finding, and the radio band turned out to be crucial in pinning down neutrino origins."

"At first, the results seemed too good to be true, but after carefully reanalyzing the data, we confirmed that the neutrino events were clearly associated with the signals picked up by radio telescopes," Sergey Troitsky from the Institute for Nuclear Research of RAS added. "We checked that association based on the data of years-long observations of the RATAN telescope of the RAS Special Astrophysical Observatory, and the probability of the results being random is only 0.2%. This is quite a success for neutrino astrophysics, and our discovery now calls for theoretical explanations."

The team intends to recheck the findings and figure out the mechanism behind the neutrino origins in quasars using the data from Baikal-GVD, an underwater neutrino detector in Lake Baikal, which is in the final stages of construction and already partly operational. The so-called Cherenkov detectors, used to spot neutrinos—including IceCube and Baikal-GVD—rely on a large mass of water or ice as a means of both maximizing the number of neutrino events and preventing the sensors from accidental firing. Of course, continued observations of distant galaxies with radio telescopes are equally crucial to this task.

More information: Alexander Plavin et al. Observational Evidence for the Origin of High-energy Neutrinos in Parsec-scale Nuclei of Radio-bright Active Galaxies, *The Astrophysical Journal* (2020). DOI: 10.3847/1538-4357/ab86bd

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