



PRESS RELEASE

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Neutrino Factories in Deep Outer Space

An international research team reveals for the first time the origin of neutrinos, elementary particles that reach our planet from the depths of the Universe.

Highly energetic and difficult to detect, neutrinos travel billions of light years before reaching our planet. Although it is known that these elementary particles come from the depths of our Universe, their precise origin is still unknown. An international research team, led by the University of Würzburg and the University of Geneva (UNIGE), is shedding light on one aspect of this mystery: neutrinos are thought to be born in blazars, galactic nuclei fed by supermassive black holes. These results are published in the journal *Astrophysical Journal Letters*.

The Earth's atmosphere is continuously bombarded by cosmic rays. These consist of electrically charged particles of energies up to 1020 electron volts. That is a million times more than the energy achieved in the world's most powerful particle accelerator, the Large Hadron Collider near Geneva. The extremely energetic particles come from deep outer space, they have travelled billions of light years. Where do they originate, what shoots them through the Universe with such tremendous force? These questions are among the greatest challenges of astrophysics for over a century.

Cosmic rays' birthplaces produce neutrinos. Neutrinos are neutral particles difficult to detect. They have almost no mass and hardly interact with matter. They race through the Universe and can travel through galaxies, planets and the human body almost without a trace. "Astrophysical neutrinos are produced exclusively in processes involving cosmic ray acceleration," explains astrophysics Professor Sara Buson from Julius-Maximilians-Universität (JMU) Würzburg in Bavaria, Germany. This is precisely what makes these neutrinos unique messengers paving the way to pinpoint cosmic ray sources.

A step forward in a controversial debate

Despite the vast amount of data which astrophysicists have collected, the association of high-energy neutrinos with the astrophysical sources that originate them has been an unsolved problem for years. Sara Buson has always considered it a major challenge. It was in 2017 that the researcher and collaborators first brought a blazar (TXS 0506+056) into the discussion as a putative neutrino source in the journal *Science*. Blazars are active galactic nuclei powered by supermassive black holes that emit much more radiation than their entire galaxy. The publication sparked a scientific debate about whether there truly is a connection between blazars and high-energy neutrinos.

Following this first encouraging step, in June 2021 Prof. Buson's group began an ambitious multi-messenger research project with the



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An artistic illustration of a blazar accelerating cosmic rays, neutrinos and photons up to high energies, as observed in PeVatron blazars.

High resolution pictures

support of the European Research Council. This involves analysing various signals (“messengers”, e.g. neutrinos) from the Universe. The main goal is to shed light into the origin of astrophysical neutrinos, possibly establishing blazars as the first source of extragalactic high-energy neutrinos with high certainty.

The project is now showing its first success: In the journal *Astrophysical Journal Letters*, Sara Buson, along with her group, the former postdoc Raniere de Menezes (JMU) and with Andrea Tramacere from the University of Geneva, reports that blazars can be confidently associated with astrophysical neutrinos at an unprecedented degree of certainty.

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ArXiv: <https://iopscience.iop.org/article/10.3847/2041-8213/ac7d5b>

Revealing the role of blazars

Andrea Tramacere is one of the experts in numerical modelling of acceleration processes and radiation mechanisms acting in relativistic jets - outflows of accelerated matter, approaching the speed of the light - in particular blazar jets. “The accretion process and the rotation of the black hole lead to the formation of relativistic jets, where particles are accelerated and emit radiation up to energies of a thousand billion of that of visible light! The discovery of the connection between these objects and the cosmic rays may be the ‘Rosetta stone’ of high-energy astrophysics!”

To arrive at these results, the research team utilized neutrino data from the IceCube Neutrino Observatory in Antarctica - the most sensitive neutrino detector currently in operation - and BZCat, one of the most accurate catalogues of blazars. “With this data, we had to prove that the blazars whose directional positions coincided with those of the neutrinos were not there by chance.” To do this, the UNIGE researcher developed a software capable of estimating how much the distributions of these objects in the sky look like the same. “After rolling the dice several times, we discovered that the random association can only exceed that of the real data once in a million trials! This is strong evidence that our associations are correct.”

Despite this success, the research team believes that this first sample of objects is only the ‘tip of the iceberg’. This work has enabled them to gather “new observational evidence”, which is the most important ingredient for building more realistic models of astrophysical accelerators. “What we need to do now is to understand what the main difference is between objects that emit neutrinos and those that do not. This will help us to understand the extent to which the environment and the accelerator ‘talk’ to each other. We will then be able to rule out some models, improve the predictive power of others and, finally, add more pieces to the eternal puzzle of cosmic ray acceleration!”

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