Press release

Max-Planck-Institut für Radioastronomie
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The Highest Energy Neutrino Ever Observed

From the abyss of the Mediterranean Sea, scientists including astronomers from the Max Planck Institute for Radio Astronomy in Bonn, Germany, used the KM3NeT neutrino telescope to detect a cosmic neutrino with a record-breaking energy of about 220 PeV. The ARCA detector, part of the KM3NeT deep-sea observatory, captured this extraordinary event, named KM3-230213A, which is the most energetic neutrino ever observed. This discovery provides the first evidence that neutrinos of such extreme energies are produced in the universe.

After meticulous analysis and interpretation of the experimental data, the international scientific collaboration working with the kilometre-cubic KM3NeT neutrino telescope—including astronomers from the Max Planck Institute for Radio Astronomy (MPIfR)—has identified a signal on 13 February 2023 with an energy 16,000 times greater than the most powerful particle collisions that can be produced by CERN's Large Hadron Collider.

The detector picked up a single muon that crossed the entire detector, triggering signals in more than a third of the active sensors. The direction in which it travelled and its strength suggest that the muon came from a cosmic neutrino close to the detector. Neutrinos are the second most abundant particles in the Universe after photons (light). Because they interact very weakly with matter, detecting them requires huge instruments.

The KM3NeT telescope, which is currently being built, is a huge deep-sea structure made up of two parts, ARCA and ORCA. When it is finished, KM3NeT will be more than one cubic kilometre in size. KM3NeT relies on seawater as both a detection medium and a shield against background noise. Its high-tech optical modules detect the Cherenkov light, a bluish glow that is generated during the movement of the extremely fast particles produced in interactions of neutrinos through the water.

"By combining multi-messenger observations, we seek to connect the acceleration of cosmic rays, the production of neutrinos, and the role of supermassive black holes in shaping these energetic phenomena," says Yuri Kovalev, leader of the ERC-funded MuSES project at the MPIfR and a collaborator on this work. "Through the ERC MuSES project, we aim to unravel the intricate processes powering Active Galactic Nuclei, which are among the most extreme particle accelerators in the universe."

The high-energy universe is full of dramatic events—supermassive black holes, supernova explosions, and gamma-ray bursts—whose inner workings remain largely mysterious. These powerful cosmic accelerators produce streams of cosmic rays, some of which interact with surrounding matter or photons to generate neutrinos and high-energy photons. Others may collide with photons from the cosmic microwave background, creating extremely energetic cosmogenic neutrinos.

KM3NeT is now detecting neutrinos from extreme astrophysical events, exploring previously uncharted energy ranges. "This first detection of a neutrino in the hundreds of PeV range opens a new chapter in neutrino astronomy," says Paschal Coyle, KM3NeT spokesperson at the time of the detection and a researcher at IN2P3/CNRS in France. One petaelectronvolt (PeV) corresponds to 10^15 or one quadrillion electronvolts. Neutrinos are among the most mysterious elementary particles - they have no electric charge, almost no mass, and interact only weakly with matter. "They are special cosmic messengers that reveal the secrets of the most energetic phenomena in the universe," adds Rosa Coniglione, deputy spokesperson for KM3NeT at the time of the discovery and a researcher at INFN in Italy.

Determining the direction and energy of this neutrino required precise calibration of the telescope and advanced track reconstruction algorithms. "This remarkable detection was achieved with only a tenth of the final detector configuration, demonstrating the great potential of our experiment," comments Aart Heijboer, KM3NeT physics and software manager at the time of the detection and a researcher at the National Institute for Subatomic Physics (Nikhef) in the Netherlands.

This high-energy neutrino could have come directly from a powerful cosmic accelerator, or it could be the first detection of a cosmogenic neutrino. However, with only one event, its origin remains uncertain. To learn more, astronomers and physicists need to detect more such events. The KM3NeT project is expanding with additional detection units and more data, improving its ability to capture cosmic neutrinos and cementing its role as a key tool in multimessenger astronomy. To put the energies involved in a macroscopic perspective, KM3-230213A's energy is about 30 times that required to press a key on a computer keyboard.

"By combining data from instruments like KM3NeT, the Global mm-VLBI Array, and the Effelsberg 100-m radio telescope, we can identify the sources of high-energy neutrinos," says Eduardo Ros, astronomer at the MPIfR and also collaborator of the discovery team. "Multi-messenger astronomy is key to solving the puzzle of these hard-to-find particles, helping us trace where they come from and discover the most extreme processes in the universe."

"The KM3NeT project is an enormous undertaking, covering about one cubic kilometre and using around 200,000 photomultipliers," says Miles Lindsey Clark, KM3NeT Technical Project Manager at the time of detection and research engineer at IN2P3/CNRS in France. "This achievement reflects the tremendous collaborative effort of engineers, technicians, and scientists working in one of the most challenging environments for neutrino research."

The detection of KM3-230213A marks a major step forward in multimessenger astrophysics, a field that combines observations across the electromagnetic spectrum and beyond - including cosmic rays and neutrinos - to study the most energetic events in the universe.

"The great mystery remains as to how and where in our universe neutrinos - almost massless, electrically neutral particles - reach such enormous energies. We can only solve it if astroparticle researchers, theorists and observatories from different areas of the electromagnetic spectrum work together closely and in a coordinated manner. I am sure that astronomy is currently experiencing an extremely exciting time," concludes Anton Zensus, director at MPIfR.

Additional Information

The KM3NeT Collaboration brings together more than 360 scientists, engineers, technicians, and students of 68 institutions from 22 countries all over the world.

KM3NeT has two detectors: ARCA near Sicily and ORCA near Toulon in France. The ARCA detector has 230 units, while the ORCA detector has 115. ARCA units are 700 m high and 100 m apart, while ORCA units are 200 m high with 20 m separations. Each unit contains 18 optical modules with 31 photomultipliers. The data are sent to the shore stations at the INFN Laboratori Nazionali del Sud in Portopalo di Capo Passero and the Laboratoire Sous-marin Provence Méditerranée in La Seyne-sur-Mer via submarine cable.

Following institutions in Germany were involved in the published study: Friedrich-Alexander-Universität Erlangen-Nürnberg with scientists M. Chadolias, Y. Darras, A. Domi, T. Eberl, T. Gal, N. Geißelbrecht, R. Gracia, K. Graf, C. Haack, L. Hennig, O. Kalekin, U.F. Katz, C. Kopper, R. Lahmann, J. Schnabel, J. Schumann, B. Setter, H. Warnofer, and S. Weissbrod; Max-Planck-Institut für Radioastronomie with Y.Y. Kovalev, A. Plavin, and E. Ros; and Julius-Maximilian-Universität Würzburg with S. Buson (also Deutsches Elektronen-Synchrotron DESY), M. Lincetto, and L. Pfeiffer.

MuSES, which stands for Multi-messenger Studies of Energetic Sources, is a pioneering initiative in astrophysics. It is dedicated to the study of Active Galactic Nuclei (AGN), which are among the most powerful particle accelerators known in the cosmos. The MuSES project has received funding from the European Research Council (ERC) under the European Union's Horizon Europe research and innovation programme (grant agreement No 101142396). It is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or ERC. Neither the European Union nor the ERC can be held responsible for them.

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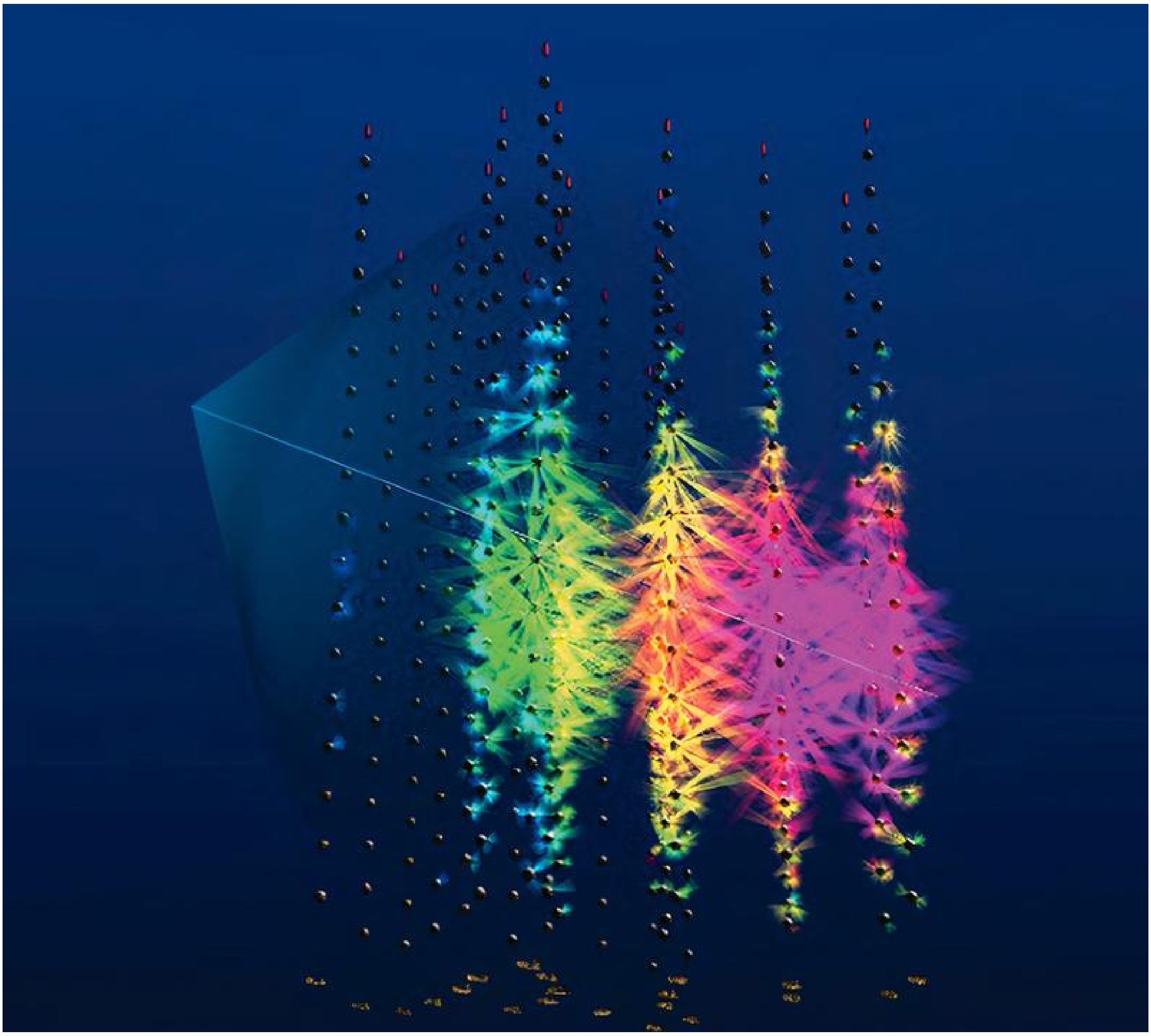

Visual impression of the ultra-high energy neutrino event observed in KM3NeT/ARCA. The different colours represent different observing times. The almost horizontally reconstructed track of the particle is shown as a line from left to right.
The KM3NeT Collaboration

An assembly of digital optical modules which later become a part of the KM3Net neutrino telescope in the Mediterranean Sea.
The KM3NeT Collaboration