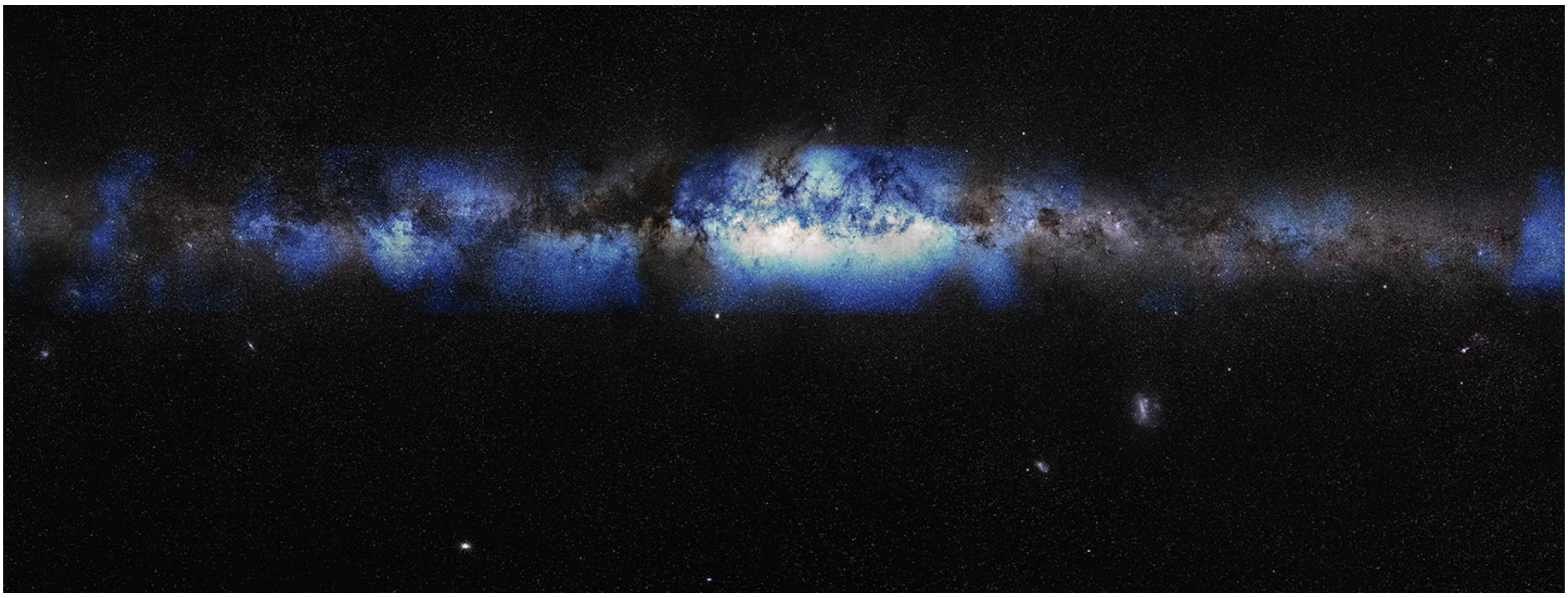

News

Our galaxy seen through a new lens

IceCube Observatory produces first image of the Milky Way using neutrinos

29 June 2023

Our Milky Way galaxy is an awe-inspiring feature of the night sky, viewable with the naked eye as a horizon-to-horizon hazy band of stars. Now, for the first time, the IceCube Neutrino Observatory has produced an image of the Milky Way using neutrinos — tiny, ghostlike astronomical messengers that are extremely difficult to detect because they rarely interact with matter. In an article published online today (June 29), in the journal *Science*, the IceCube Collaboration, an international group of over 350 scientists, including Penn State researchers, presents evidence of high-energy neutrino emission from the Milky Way.

“Most of what we know about our universe and our host galaxy we have learned by observing electromagnetic radiation — this includes visible light but stretches in energy from radio waves to x-rays and gamma rays,” said Doug Cowen, professor of physics in the Penn State Eberly College of Science and a member of the IceCube Collaboration. “This new image of the Milky Way using neutrinos is completely different and allows us to explore questions about the origins and workings of our galaxy in new ways.”

The high-energy neutrinos, with energies millions to billions of times higher than those produced by the fusion reactions that power stars, were detected by the IceCube Neutrino Observatory, a gigaton detector operating at the Amundsen-Scott South Pole Station. It was built and is operated with National Science Foundation (NSF) funding and additional support from the 14 countries that host institutional members of the IceCube Collaboration. This one-of-a-kind detector encompasses a cubic kilometer of deep Antarctic ice instrumented with over 5,000 light sensors. IceCube searches for signs of high-energy neutrinos originating from our galaxy and beyond, out to the farthest reaches of the universe.

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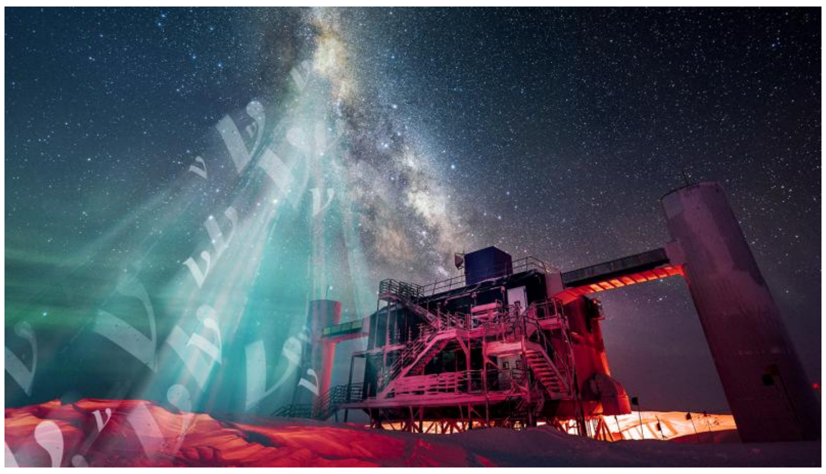


An artist's impression of neutrino emission from the Galactic plane above the IceCube lab. Credit: IceCube/NSF. Original photo taken by Martin Wolf

"As is so often the case, significant breakthroughs in science are enabled by advances in technology," said Denise Caldwell, director of NSF's Physics Division. "The capabilities by the highly sensitive IceCube detector, coupled with new data analysis tools, have given us an entirely new view of our galaxy — one that had only been hinted at before. As these capabilities continue to be refined, we can look forward to watching this picture emerge with ever-increasing resolution, potentially revealing hidden features of our galaxy never before seen by humanity."

Interactions between cosmic rays — high-energy protons and heavier nuclei, also produced in our galaxy–and galactic gas and dust inevitably produce both gamma rays and neutrinos. Given the observation of gamma rays from the galactic plane, the Milky Way was expected to be a source of high-energy neutrinos, according to the research team.

IceCube has previously detected energetic neutrinos from astrophysical sources at much greater remove than our own Milky Way galaxy, but those sources were situated in the northern sky, allowing analyzers to use the Earth as a filter to remove everything but neutrinos. Due to the orientation of the Earth in the Milky Way, many potential galactic sources of neutrinos are located in the southern sky.

"That means that analyzers had to devise other methods to reduce the background from particles raining down on the detector from cosmic-ray interactions in the atmosphere in the vicinity of the South Pole," said Cowen. "Those particles would otherwise completely obscure the galactic neutrino signal."

To overcome this background, IceCube collaborators at Drexel University developed analyses that select for "cascade" events, or neutrino interactions in the ice that result in localized, roughly spherical showers of light. Because the deposited energy from cascade events starts within the instrumented volume, contamination of atmospheric muons and neutrinos is reduced. Ultimately, the higher purity of the cascade events gave a better sensitivity to astrophysical neutrinos from the southern sky.

An artist's composition of the Milky Way seen with a neutrino lens (blue). Credit: IceCube Collaboration/U.S. National Science Foundation (Lily Le & Shawn Johnson)/ESO (S. Brunier)

However, the final breakthrough came from the implementation of machine learning methods, developed by IceCube collaborators at TU Dortmund University, that improve the identification of cascades produced by neutrinos as well as their direction and energy reconstruction. The observation of neutrinos from the Milky Way is a hallmark of the emerging critical value that machine learning provides in data analysis and event reconstruction in IceCube.

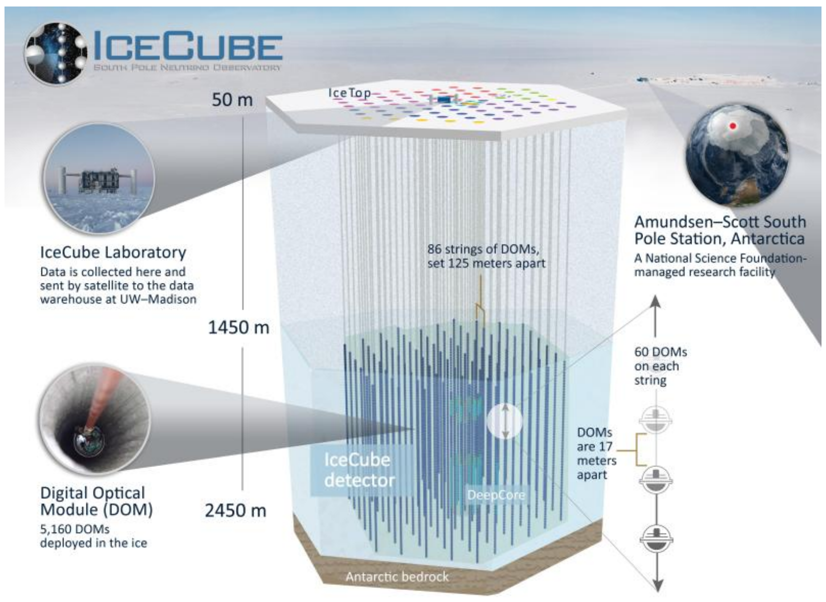
"The improved methods allowed us to retain over an order of magnitude more neutrino events with better angular reconstruction, resulting in an analysis that is three times more sensitive than the previous search," said IceCube member, TU Dortmund physics doctoral student and co-lead analyzer Mirco Hünnefeld.

The dataset used in the study included 60,000 neutrinos spanning 10 years of IceCube data, 30 times as many events as the selection used in a previous analysis of the galactic plane using cascade events. These neutrinos were compared to previously published prediction maps of locations in the sky where the galaxy was expected to shine in neutrinos.

The maps included one made from extrapolating Fermi Large Area Telescope gamma-ray observations of the Milky Way and two alternative maps identified as KRA-gamma by the group of theorists who produced them.

“This long-awaited detection of cosmic ray-interactions in the galaxy is also a wonderful example of what can be achieved when modern methods of knowledge discovery in machine learning are consistently applied,” said Wolfgang Rhode, professor of physics at TU Dortmund University, IceCube member and Hünnefeld’s adviser.

The power of machine learning offers great future potential, bringing other observations closer within reach.



The IceCube Neutrino Observatory instruments a volume of roughly one cubic kilometer of clear Antarctic ice at the South Pole. Over 5,000 digital optical modules (DOMs) are frozen at depths between 1,450 and 2,450 meters. The observatory includes a densely instrumented subdetector, DeepCore, and a surface air-shower array, IceTop. Credit: IceCube/NSF

“The strong evidence for the Milky Way as a source of high-energy neutrinos has survived rigorous tests by the collaboration,” said Ignacio Taboada, a professor of physics at the Georgia Institute of Technology and IceCube spokesperson. “Now the next step is to identify specific sources within the galaxy.”

These and other questions will be addressed in planned follow-up analyses by IceCube.

“Observing our own galaxy for the first time using particles instead of light is a huge step,” said Naoko Kurahashi Neilson, professor of physics at Drexel University and IceCube member.

“A neutrino counterpart has now been measured, thus confirming what we know about our galaxy and cosmic ray sources,” said Steve Sclafani, Kurahashi Neilson’s physics doctoral student and co-lead analyzer.

The IceCube Neutrino Observatory is funded and operated primarily through an award from the National Science Foundation to the University of Wisconsin–Madison. The IceCube Collaboration, with over 350 scientists in **58 institutions from around the world**, runs an extensive scientific program that has established the foundations of neutrino astronomy.

IceCube’s research efforts, including critical contributions to the detector operation, are funded by agencies in Australia, Belgium, Canada, Denmark, Germany, Italy, Japan, New Zealand, Republic of Korea, Sweden, Switzerland, Taiwan, the United Kingdom, and the United States, including NSF. IceCube construction was also funded with significant contributions from the National Fund for Scientific Research (FNRS and FWO) in Belgium; the Federal Ministry of Education and Research (BMBF) and the German Research Foundation (DFG) in Germany; the Knut and Alice Wallenberg Foundation, the Swedish Polar Research Secretariat, and the Swedish Research Council in Sweden; and the Wisconsin Alumni Research Fund.

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