IceCube-Gen2

THE WINDOW TO THE EXTREME UNIVERSE

Incredible advances in science allow us to see beyond what is visible with our eyes. From gamma rays to radio waves, the full spectrum of light is revealing a hidden universe and making unimaginable discoveries possible. We now know, however, that the very highest energy gamma rays can be seen only from within our galaxy, leaving most of the high-energy universe unexplored. Fortunately, there is a particle that can reveal the far reaches of the cosmos: the **neutrino.**

Neutrinos are called "ghost particles" because they move through matter like spirits, making them notoriously difficult to observe. But the National Science Foundation-funded **IceCube Neutrino Observatory** can do it.

An enormous detector with a clever design and robust technology located at the South Pole, IceCube utilizes a cubic kilometer of glacial ice as a natural detection medium. When a neutrino collides with a proton or neutron in an ice molecule, the interaction produces high-energy, electrically charged particles that emit light. Over 5,000 sensors arranged in a three-dimensional grid deep in the ice capture these faint light signals, and these signals are converted to patterns of data that tell us about the neutrino. In this way, IceCube indirectly detects neutrinos, the way tracks in the snow reveal a passing animal without the animal itself having been seen.

From IceCube to IceCube-Gen2

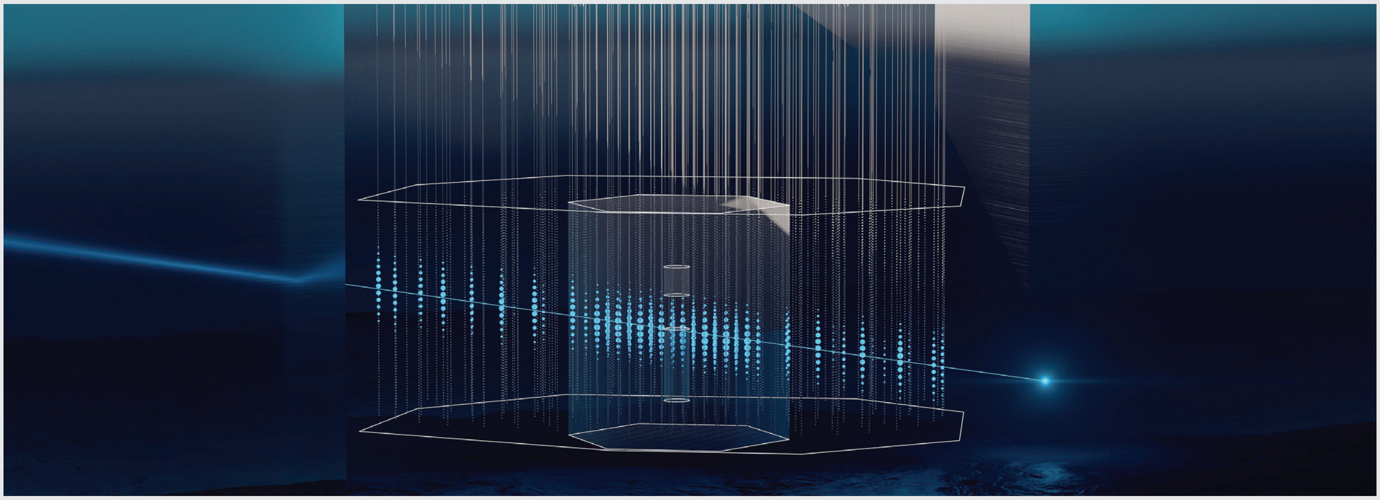
Since its completion in 2010, IceCube has exceeded expectations, enabling us to reach the milestone of using neutrinos in **multimessenger astronomy** as well as making real progress on the century-old question concerning the origin of the highest energy cosmic rays. IceCube has graced the covers of *Science* and *Nature Astronomy*, was named the Breakthrough of the Year by *Physics World* in 2013, and has been presented with numerous other awards, including the 2021 Bruno Rossi Prize.

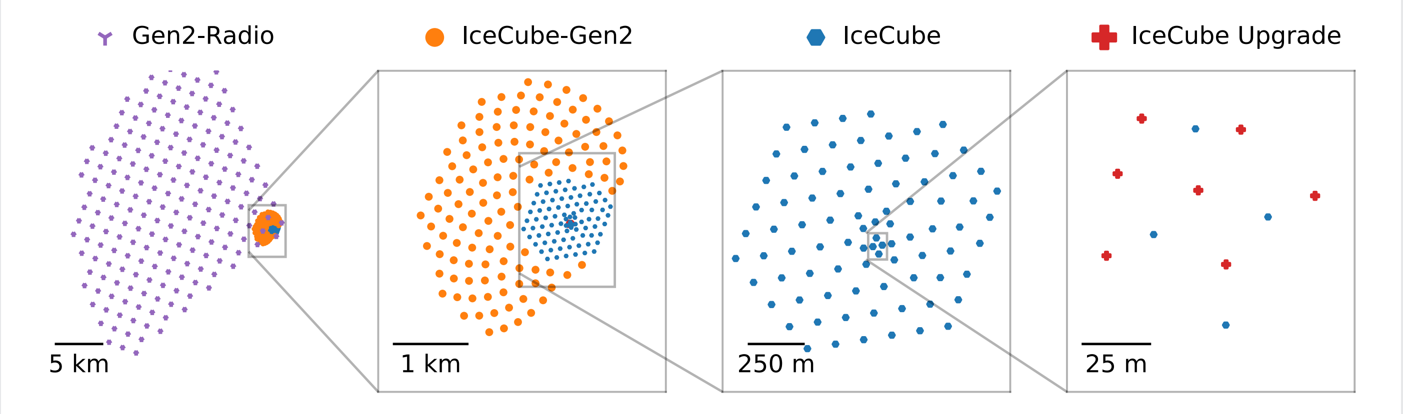
But to make more discoveries and collect enough data to probe the mysteries of the universe, a bigger and more capable observatory is needed. That's where IceCube-Gen2 comes in.

A 10-times-larger expansion of IceCube, IceCube-Gen2 will have new optical modules that will detect nearly three times as many photons as current sensors. A new radio component will cover an area 50 times larger, with antennas spaced a kilometer apart to search for the as yet undetected, extremely high-energy neutrinos.

The first step toward IceCube-Gen2 is already underway as NSF has funded the IceCube Upgrade with significant contributions from other national and international partners, which will improve the science capabilities of the current IceCube Neutrino Observatory. It will also be the most precise experiment to study the oscillation from a muon to a tau neutrino, an aspect of neutrinos not currently well understood. The new light sensors and calibration devices installed near the densely instrumented center will also improve measurements of the optical properties of the ice, resulting in better fidelity for all past and future IceCube data.

Visualization of neutrino event triggering a light signal in the IceCube-Gen2 detector.
Credit: DESY, Science Communication Lab





Top view of the envisioned IceCube-Gen2 facility at the South Pole. From left to right: The radio component, the optical component, the current IceCube array, the IceCube Upgrade layout. Credit: IceCube Collaboration

The benefit of experience

Constructing and operating IceCube has taught us a great deal about the Antarctic ice, knowledge that we can apply directly to IceCube-Gen2. Likewise, the discovery and characterization of cosmic neutrinos has allowed us to optimize the design of the next-generation detector. We have established methods for construction, reliable operation, and the production of high-quality science data at a much-reduced cost compared to alternative approaches covering the same scientific opportunities. All of this presents an extraordinary opportunity to construct IceCube-Gen2—a roughly 10-times-larger instrument—on a budget and schedule similar to those of the original IceCube.

What will IceCube-Gen2 deliver?

The groundbreaking successes of IceCube have already demonstrated the enormous discovery potential of neutrino astronomy. With an even larger footprint and improved technology, IceCube-Gen2 will pave the way for future scientific breakthroughs.

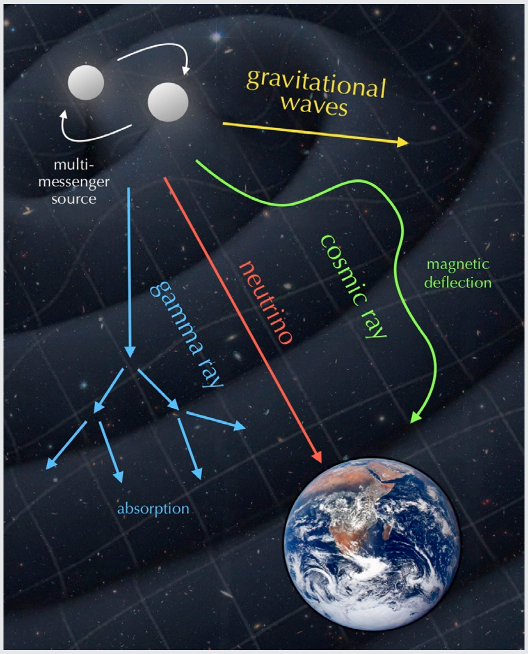
As envisioned, IceCube-Gen2 will…

- resolve the high-energy sky well above energies accessible with photons.
- probe extremely high energy cosmic particle acceleration.
- reveal the sources and propagation of the highest energy particles in the universe.
- probe fundamental physics with neutrinos at energies well beyond those achievable with particle accelerators on Earth.
- increase the capability to search for mysterious elementary particles, like hypothetical magnetic monopoles and dark-matter particles.

MULTIMESSENGER ASTRONOMY

Multimessenger astronomy is the simultaneous observation of cosmic phenomena using various "messengers," such as neutrinos, gravitational waves, and different wavelengths of light.

IceCube-Gen2 is designed to address some of the mysteries that persist in multimessenger astronomy by identifying many more potential neutrino sources. In addition, artificial intelligence methods will be used to evaluate the data from each IceCube-Gen2 neutrino detection, enabling faster and more precise neutrino alerts that will guide other astronomical telescopes to examine potential sources. These advancements will shape the next era of multimessenger astronomy and revolutionize our understanding of the high-energy universe.



An artistic impression of different messengers traveling through space from a multimessenger source to reach Earth.
Credit: Markus Ahlers, IceCube