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Nature’s Most Elusive Particle: What Can Neutrinos Tell Us About Our Universe?

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What Can Neutrinos Tell Us About Our Universe?

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Did you feel that? Every second, you are being bombarded by millions of particles. And yet, you can't feel a thing. They pass right through you with virtually no interaction. Forget the stories about ghosts from your childhood; these ghosts are real. They are also incredibly old, serving as fossils from older periods in the universe and providing clues to what those periods in the universe were like. These are the particles known as neutrinos.

Neutrinos are relativistic (always traveling at a large fraction of the speed of light), high-energy particles that are almost massless. For many decades they were believed to have no mass at all, requiring that they must always travel at the speed of light. It wasn't until the beginning of the 21st century that it was established that neutrinos oscillate. This process "mixes" the various mass and flavor states of the neutrino, giving it mass. Even with this tiny amount of mass, these particles are constantly travelling at 99.9999 percent the speed of light. Because the difference between these speeds is so miniscule, even the most rigorous experiments still measure speeds at or faster than light within their margins of error.

Produced mainly in high energy interactions, such as nuclear fusion in the sun or in the collapse of a star going supernova, neutrinos rarely interact with their surroundings, and many travel halfway across the universe without interacting with anything. The best neutrino detectors in the world are built more than a kilometer underground to prevent them from interacting with particles other than neutrinos. These massive underground detectors are considered a success if they can detect around 10 or 20 neutrinos per month. In the rare event that a neutrino does strike a detector, what we measure isn't the neutrino itself, but rather the particles that result from the neutrino's decay. As of right now, this decay chain is as close as we can get to inferring their existence, but the reactions are explained so well that it is very easy to infer.

Despite this particle's elusiveness, we are able to use it to predict, observe, and better understand a variety of important astrophysical phenomena. A particularly significant example of this took place in 1987, when three neutrino detectors detected the signals from more than 20 neutrinos in a span of about 10 seconds. About two hours later, telescopes observed a massive supernova that was determined to be in the same location on the sky from which the neutrinos originated. The neutrinos had allowed us to predict an impending supernova hours before its light had reached us.

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If you're following along, that last sentence might seem strange, or even counterintuitive. The light from the supernova was detected after the neutrinos were. Light travels at the cosmic speed limit because its particles have no intrinsic rest mass; however, neutrinos do have mass (however little it may be), so they clearly must travel slower than the photons. What's going on here?

Surprisingly, there are no physical laws being broken. The photons and neutrinos are still travelling at their own speeds, but neutrinos have an advantage that allows them to beat the photons to our detectors: they hardly interact with anything. When a star initially collapses, it acts like a massive particle accelerator, smashing together billions of trillions of particles and spewing them out into space. Among these particles, flurries of neutrinos are created and are able to escape the star virtually uninhibited. The photons, however, interact with so many particles that they take long, random walks within the star before they are able to escape. If you imagine a large traffic jam, the photons would be cars trying to get through the backup and make it onto the open highway. The neutrinos are like scooters that can maneuver around the other cars and make it onto the highway without much incident.

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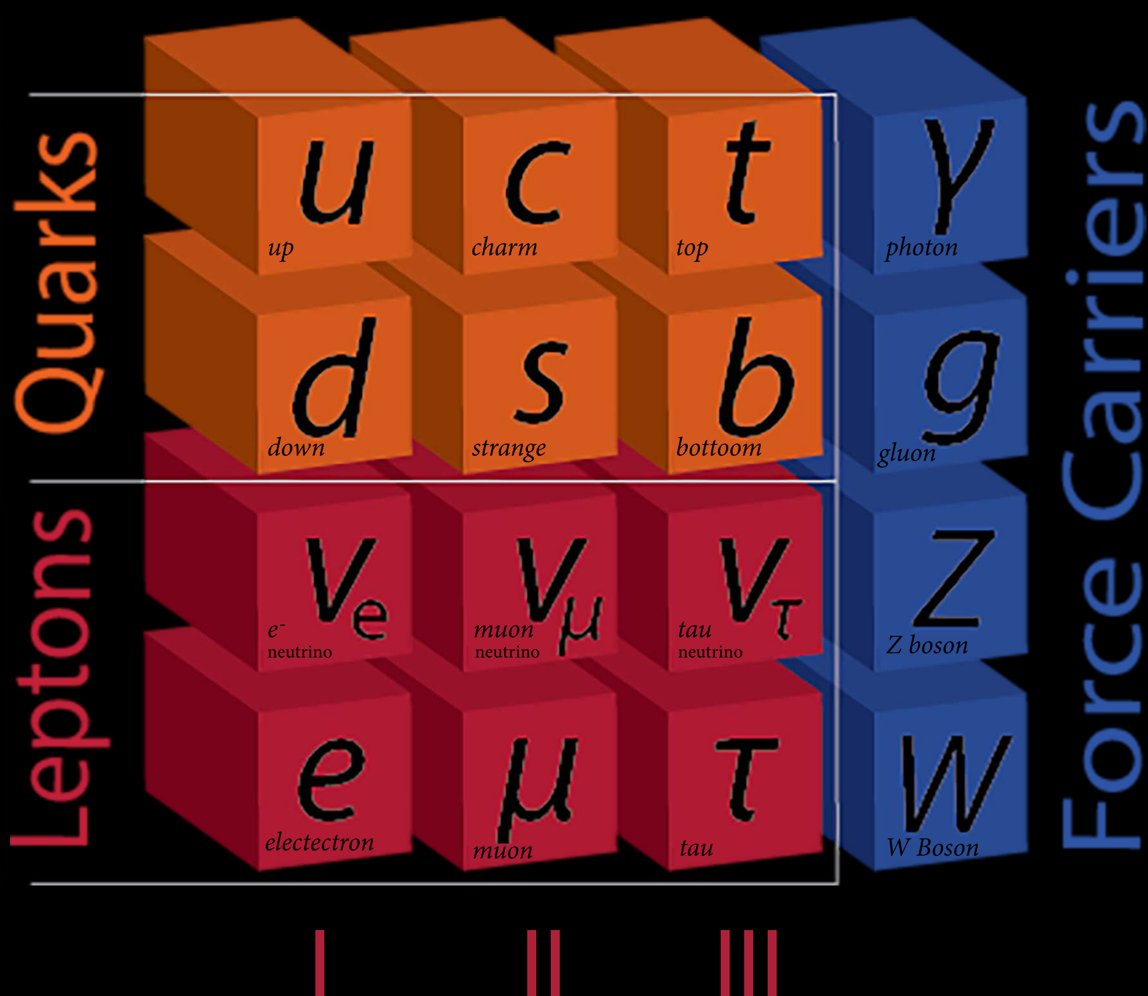
Another, more recent application of neutrino detection came about in the past 10 years. Researchers using detectors deep under Antarctic ice have been able to detect signals from cosmic neutrinos with origins far outside the reaches of our galaxy. These neutrinos form in high energy events, such as the collapse of stars going supernova or black holes drawing in mass. Many of these events happen hundreds of millions of light years away, which would indicate that they happened back in the early universe. Since we believe the universe was originally compressed into a point smaller than the width of a proton, the early universe was much smaller than it is today. This meant that everything was more densely packed, meaning that violent events would occur at a higher frequency. The neutrinos produced in these events have energies that may be hundreds to thousands times those of particles produced in CERN's Large Hadron Collider, and their negligible interactions have allowed them to maintain almost all of this energy, even by the time they reach us hundreds of millions of years after their birth. As a result, these particle fossils can provide clues about the nature of the early universe, such as properties of particle physics or the origins of dark matter. In the end, it may be that nature's most elusive particle will open the largest doors into our understanding of the universe.



The three types of neutrinos show in relation to the other known elementary particles