Searching for supernova neutrinos with Deep Underground Neutrino Experiment

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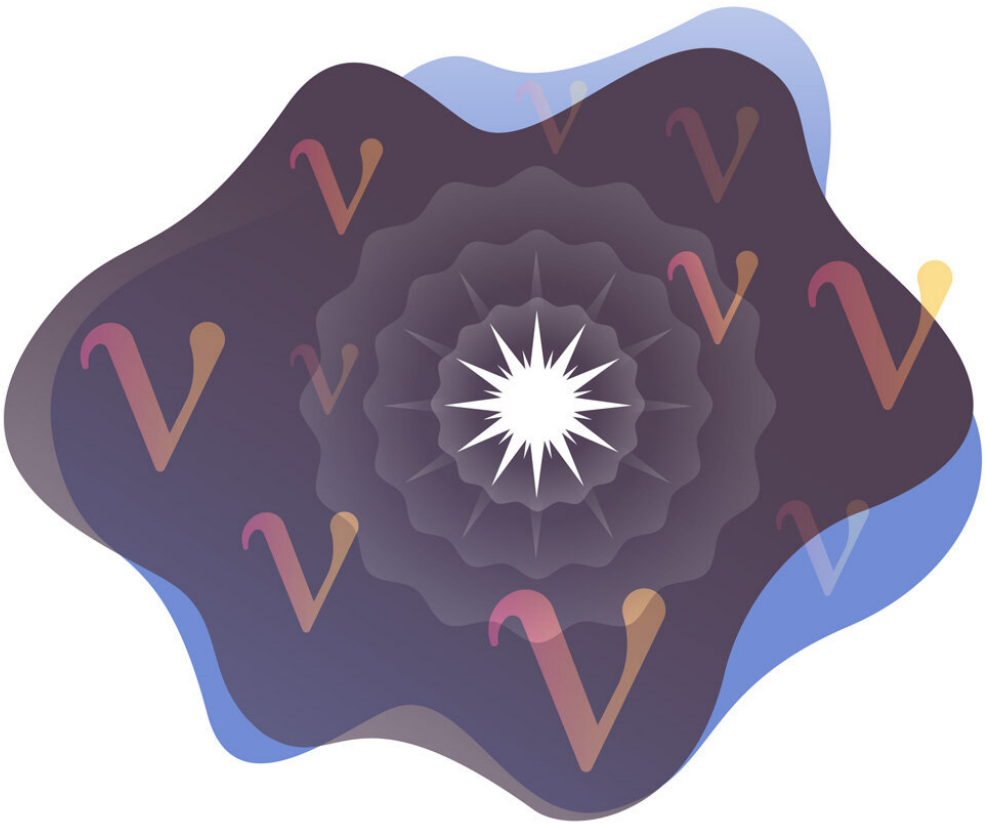

DUNE scientists will study streams of neutrinos emitted by exploding stars. DUNE's unique strength is its sensitivity to a particular type of neutrino called the electron neutrino, which will provide scientists with supernova data not

available from any other experiment. Credit: Fermilab

When a massive star reaches the end of its life, it can explode in a process known as a supernova. The massive star—much more massive than our sun—runs out of fuel in its core. Gravity forces the core to collapse on itself, causing a shockwave to form and spew stellar material into space. Metals, along with heavy elements such as carbon, are expelled into the universe.

Ninety-nine percent of the star's energy, however, is released in the form of neutrinos, small chargeless particles that barely interact with the matter surrounding them. When some of them arrive on Earth, they arrive in three flavors—electron, muon and tau—in a burst a few tens of seconds long. Along with the fact they rarely interact with matter, each of these neutrinos contains only a relatively small amount of energy, which makes them even harder to observe on Earth.

Scientists have observed supernova neutrinos one time, in 1987. About two dozen neutrinos interacted in several particle detectors located across the globe, and those neutrinos gave us insight into the life cycle of massive stars and how they die. However, two dozen neutrinos aren't enough to tell us everything about how supernovae occur. Dozens of different theories and models exist to describe the supernova explosion process. To fully describe it, we need to observe more neutrinos from core-collapse supernovae.

Enter the international Deep Underground Neutrino Experiment, hosted by Fermilab. DUNE will study neutrino properties and look for new physics, along with waiting for supernova neutrinos to arrive. The experiment will comprise two particle detectors—a "near detector" at Fermilab and a "far detector" located 1,300 kilometers away at the

Sanford Underground Research Facility in South Dakota. The far detector is where most of the supernova neutrinos would be detected. The detector's massive size—70,000 tons of liquid argon—along with its impressive sensitivity means that thousands of neutrinos could be observed during the next supernova in our galaxy.

The DUNE collaboration has published a paper about DUNE's capability for performing supernova physics. The paper discusses what kind of activity DUNE scientists expect to see in their detectors during a supernova burst, how DUNE will know once a supernova occurs, and what results DUNE will be able to extract from the supernova neutrinos.

DUNE will be sensitive primarily to the electron flavor component of the neutrinos—a new type to add to our collection of supernova neutrino data, which so far is made up only of 1987's sample of antielectron neutrinos. This sensitivity to electron neutrinos sets DUNE apart from other experiments; it is the only experiment in the world that will provide a precise measurement of the electron flavor.

When the supernova neutrinos and argon atoms interact, the protons and neutrons making up the argon atom can be elevated to a higher-energy state. The argon atom then de-excites, and a variety of particles can be emitted as a result. These include gamma rays, neutrons and protons, all of which could leave signals in the DUNE detector. The primary signatures DUNE will look for come from electrons emitted in the interaction. Both the short electron tracks and secondary particles (even shorter "blips") make up the dominant supernova signals in DUNE.

The neutrinos will leave the exploding star as the core collapse is ongoing. DUNE should be able to distinguish between different stages of the supernova burst because of the different interactions and signals it leaves behind. This can help place constraints on the supernova flux—the number of neutrinos leaving the supernova per second—and

the explosion mechanism.

Different supernova flux models will produce different numbers of neutrino interactions and signals in the DUNE detector. For one particular flux model, called the pinched-thermal model, several parameters control the neutrino energies and number of interactions expected. The paper describes the development of a method that measures the flux model parameters from the expected DUNE supernova signal. DUNE's signal can be affected by the detector's particular characteristics, detector thresholds and input models. Those uncertainties must be taken into account for the most accurate measure of the flux parameters.

The DUNE collaboration will investigate neutrino properties and why stars die for as long as neutrinos arrive at the detector. As physicists continue to refine and improve the DUNE design, they'll continue to study neutrinos to unlock the mysteries behind a core-collapse supernova burst.

More information: Abi et al., Supernova Neutrino Burst Detection with the Deep Underground Neutrino Experiment. arXiv:2008.06647 [hep-ex]. arxiv.org/abs/2008.06647

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