Neutrinos Rising from the Floor

A neutrino background that could confound dark matter searches is now becoming an opportunity for probing new physics.

By **Michael Schirber**

The "neutrino floor" has been looming under dark matter searches for years. This neutrino background is still below the sensitivity of dark matter detectors, but as such detectors continue to become more sensitive, it's only a matter of time before neutrino events will begin to dominate the signal. Reaching this floor might sound like bad news, but some researchers see it as an opportunity for gaining new information about neutrinos, as well as for potentially uncovering particles and interactions beyond the standard model of particle physics.

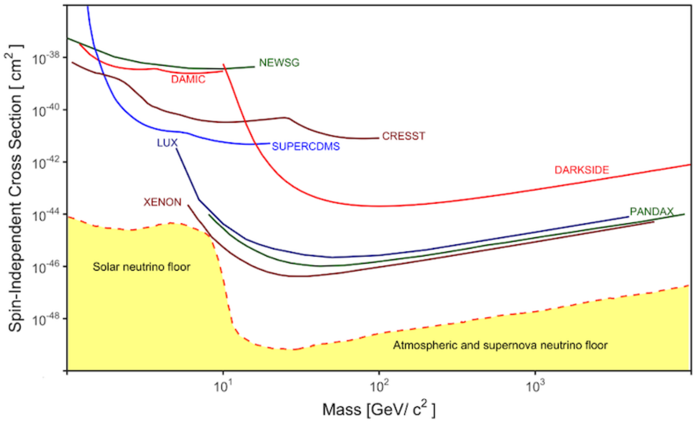
The XENON1T detector shown from below. The bottom array of photomultiplier tubes is designed to capture light produced from dark matter interactions. Soon, however, detectors like this will have to contend with a background from neutrinos.
Credit: XENON Collaboration

The neutrino floor is the result of a particular neutrino interaction called coherent elastic neutrino nucleus scattering, or CEνNS (pronounced "sevens"). "If you're searching for dark matter, CEνNS is a background. If you're searching for neutrinos, it's a signal," says Louis Strigari from Texas A&M University. The first observation of CEνNS happened just four years ago in an accelerator-based experiment. Now, a dozen other experiments are aiming to retrieve a CEνNS signal. At the **Weak Interactions and Neutrinos 2021** conference earlier this month, Strigari gave an overview of what CEνNS holds in store for researchers.

First postulated in the 1970s, CEνNS occurs when a neutrino "bumps" into a nucleus and gives it a kick. Compared to other neutrino-nucleus interactions in which the neutrino interacts with a single neutron or proton, CEνNS is a coherent interaction between the neutrino and all the neutrons and protons in the nucleus. This larger target (or "cross section") makes CEνNS much more likely than other neutrino interactions with individual nucleons or electrons. On the flip side, the kick, or recoil, that the nucleus receives is tiny, making CEνNS very difficult to observe.

Despite this difficulty, proposals for detecting CEνNS go back 40 years. The early designs for CEνNS detectors were based on scintillators in which the nuclear recoil produces an observable light flash. Researchers later adopted this scintillator technology to search for dark matter particles called WIMPs. "It's actually kind of funny that we're coming back full circle," Strigari says, as researchers are looking to use dark matter detection technology for studying CEνNS.

The XENON Collaboration, which operates a large dark matter experiment at the Gran Sasso National Laboratory in Italy, recently performed **a dedicated search** for CEνNS. The team



The neutrino floor (red dashed line) is shown in comparison with the sensitivity limits of several dark matter experiments. The peak at around 6 GeV/c^2 corresponds to the CEνNS signal expected from boron-8 solar neutrinos.
Credit: L. Strigari/Texas A&M University

focused on a specific source of neutrinos—those coming from boron-8 nuclear reactions in the Sun. In the XENON detector, these neutrinos are expected to produce a CEνNS signal that is indistinguishable from a WIMP with a mass of 6 GeV/c^2. This indistinguishability is what makes CEνNS neutrinos anathema to dark matter scientists. “It’s a background that you can’t discriminate from your signal,” says XENON team member Joseph Howlett, a graduate student at Columbia University, New York. He and his colleagues estimated that CEνNS neutrinos may already be identifiable in XENON observations. To test this possibility, they reanalyzed some archived data—relaxing certain selection criteria and eliminating some other backgrounds—but in the end they didn’t uncover a CEνNS signal. The situation may change with upgraded detectors at XENON and other dark matter facilities. “There’s a good chance that in the next few years, we will begin to see these events,” Howlett says.

The only experiment that has captured a CEνNS signal so far is COHERENT—a dedicated CEνNS project at the Spallation Neutron Source in Tennessee. The experiment takes advantage of a high-energy neutrino beam, generated as a by-product from an accelerator experiment. In 2017, the COHERENT Collaboration reported the first observations of CEνNS events in a cesium iodide scintillator. And earlier this year, the team released evidence of CEνNS in a different type of detector, one based on argon. The reason for changing the type of detector is that the CEνNS interaction should depend on the size of the target nucleus, explains Kate Scholberg from Duke University in North Carolina, who is the spokesperson for COHERENT. In particular, the CEνNS rate is predicted to be proportional to N^2, where N is the number of neutrons. “We would like to probe different values of N to test this dependence,” Scholberg says.

COHERENT is planning to measure CEνNS with other types of detectors, such as those based on germanium and sodium iodide. At the same time, several other experiments, such as **TEXONO** in Taiwan and **CONNIE** in Brazil, have installed detectors next to nuclear reactors, allowing them to study CEνNS with reactor neutrinos. Some of these projects, Strigari says, have spontaneously sprung up in physics departments that had some extra dark matter detector equipment and a nearby neutrino source. “It’s a really experimentally favorable field, where it doesn’t take huge detectors or huge collaborations,” Strigari says.

One of the reasons to study CEνNS is to look for new physics. “Because the nucleus just looks like a single, structureless particle to a neutrino that kicks it via CEνNS, there are few uncertainties in the process due to internal nuclear structure,” Scholberg says. If neutrinos do exhibit nonstandard interactions with neutrons, for example, then the coherent aspect of the CEνNS interaction could boost that effect. “In some sense, you amplify a new physics signal,” Strigari says.

There are other questions that CEνNS research might tackle, such as whether or not the so-called sterile neutrino exists (see **Viewpoint: Sterile Neutrino Down but Not Completely Out**). Some neutrino experiments have observed a deficit in neutrino counts, which might be explained by the three standard-flavor neutrinos transforming into undetectable sterile neutrinos. As CEνNS is a flavor-independent interaction, it might offer a new way to test this sterile neutrino hypothesis.

Of course, the more sensitive that detectors become to CEνNS neutrinos, the harder it will be for them to spot other particles. “Mitigating this background is one of the biggest challenges to dark matter experiments in the coming decade,” Howlett says. Some mitigation strategies are being proposed, such as making detectors with direction sensitivity or including spin dependent effects (see **Synopsis: Discriminating Dark Matter from Neutrinos**). But meeting the CEνNS-detection challenge could offer the chance to learn new and perhaps unexpected things about neutrinos. “That’s an opportunity that dark matter detectors can fulfil,” Howlett says.

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