Measuring elusive neutrinos flowing through the Earth, physicists learn more about the sun

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Using one of the most sensitive neutrino detectors on the planet, an international team including physicists Laura Cadonati and Andrea Pocar at the University of Massachusetts Amherst are now measuring the flow of solar neutrinos reaching earth more precisely than ever before. The detector probes matter at the most fundamental level and provides a powerful tool for directly observing the sun's composition.

Pocar, Cadonati and colleagues report in the current issue of Physical Review Letters that the Borexino instrument has now measured with high precision the flux of the beryllium seven (7Be) solar neutrino, abundant, low-energy particles once below the observable threshold. With this advance, they can now precisely study the behavior of solar neutrinos with kinetic energy below 1 megaelectron volt (MeV). Borexino scientists also recently reported the first observation of neutrinos produced in a little-studied solar nuclear process known as proton-electron-proton, or pep, and set of stringent limit on reactions involving carbon, nitrogen and oxygen (the CNO cycle) in the sun.

Cadonati says, "Borexino is the only detector capable of observing the entire spectrum of solar neutrinos at once. Our results, the culmination of 20 years of research, greatly narrow the observation precision. The data confirm the neutrino oscillations, flavor changes and flow predicted by models of the sun and particle physics."

Of particular interest, Pocar and Cadonati note, is the Borexino instrument's ability to more thoroughly test neutrino oscillation parameters, allowing an exploration of their characteristic non-zero mass, which does not fit the Standard Model of particle physics. "Our data can tell us about fundamental micro physics at the particle level," says Cadonati. "Borexino is using neutrinos to explore the interior of the sun, looking for new, exciting clues to the mysteries of the universe we cannot see." Pocar adds, "Our detector provides stringent tests of the three-neutrino oscillations model."

Solar neutrinos are produced in nuclear processes and radioactive decays of several elements during fusion reactions at the sun's core. As many as 65 billion of them stream out of the sun and hit every square centimeter of the earth's surface [or 420 billion every square inch] every second. But because they only interact through the nuclear weak force they pass through matter unaffected, making them very difficult to detect and to distinguish from the trace nuclear decays of ordinary materials. The weak force is one of the four fundamental forces of nature, with gravity, electromagnetism and the strong force. It is responsible for the radioactive decay of unstable subatomic particles, with a short range of influence, about 1 percent of the diameter of a typical atomic nucleus.

The Borexino instrument, housed far beneath Italy's Apennine Mountains, detects neutrinos as they interact with an ultra-pure organic liquid scintillator at the center of a large sphere surrounded by 2,000 tons of water. Its great depth and many onion-like protective layers maintain the core as the most radiation-free medium on the planet.

There are three neutrino types, or "flavors": electron, muon and tau. Those produced in the sun are the electron type. As they travel away from their birthplace, they oscillate, or change from one flavor to another. A detector like Borexino can observe all three types in real time and measures each one's energy, but it cannot distinguish between them. It's more sensitive to the electron type so they are more likely to be seen.

The 7Be neutrino flux now being detected by Borexino is predicted by the standard solar model to make up about 10 percent of solar flow, Cadonati says. Earlier instruments in Canada and Japan designed to detect higher-energy neutrinos had already observed evidence of their flavor oscillations, probing 1/10,000 of the solar neutrino flux and their oscillations as they travel through solar matter. However, without data in the low-energy range as scanned by Borexino, physicists were not able to confirm the specific energy-dependent effect of solar neutrino oscillations. Borexino has now filled this gap and for the first time observed evidence of neutrino oscillation in vacuum, as they travel between the sun and Earth.

Pocar says that from the astrophysics angle, Borexino's ability to conduct "precision physics" experiments and collect a large number of observations, with concomitant higher statistical power, is yielding data that show how our sun works. As for the possibility of discovering a new kind of neutrino coming from the sun, which is allowed by some theoretical extensions to the Standard Model of particle physics, he adds, "You always have the hope of seeing surprises, some small deviation from the expectations. And this you can only have if your accuracy and precision are good enough to see very small variations."

In a companion paper, the Borexino team says their 7Be solar neutrino flux measurements show no flow differences between day and night. Some had hypothesized that one might exist because neutrinos pass through the earth's bulk at night. But Pocar says, "The traverse through the earth seems not to change neutrinos' flavor."

In the future, the researchers hope to identify the origin of every neutrino type coming from the sun, particularly to assess the relative levels of carbon, nitrogen and oxygen there, to deepen understanding of how the sun evolved and how its workings are related to that of larger stars.

Provided by University of Massachusetts at Amherst

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