Neutrinos yield first experimental evidence of catalyzed fusion dominant in many stars

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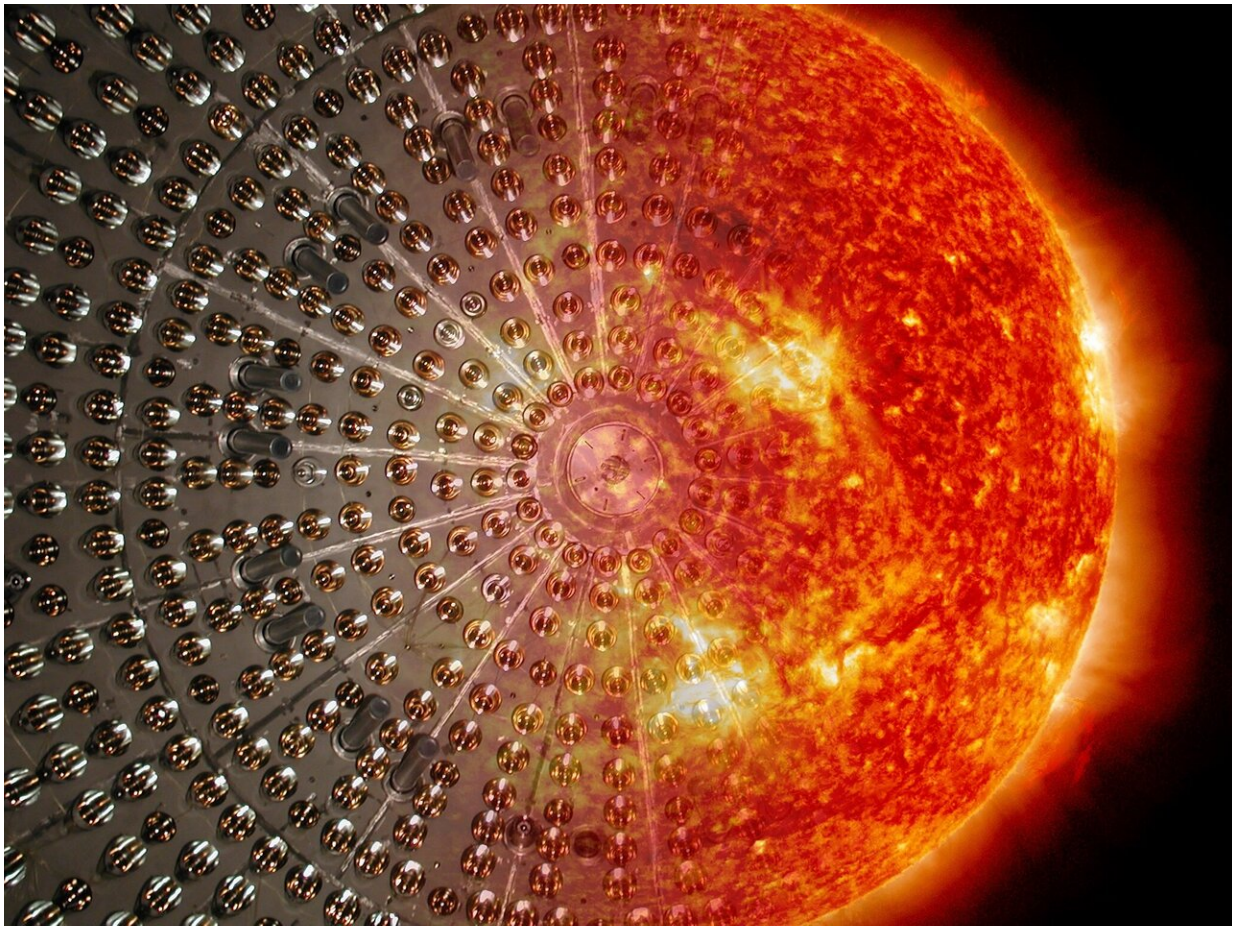


The Borexino detector in combination with the Sun. Credit: Borexino Collaboration/Maxim Gromov

An international team of about 100 scientists of the Borexino Collaboration, including particle physicist Andrea Pocar at the University of Massachusetts Amherst, report in *Nature* this week detection of neutrinos from the sun, directly revealing for the first time that the carbon-nitrogen-oxygen (CNO) fusion-cycle is at work in our sun.

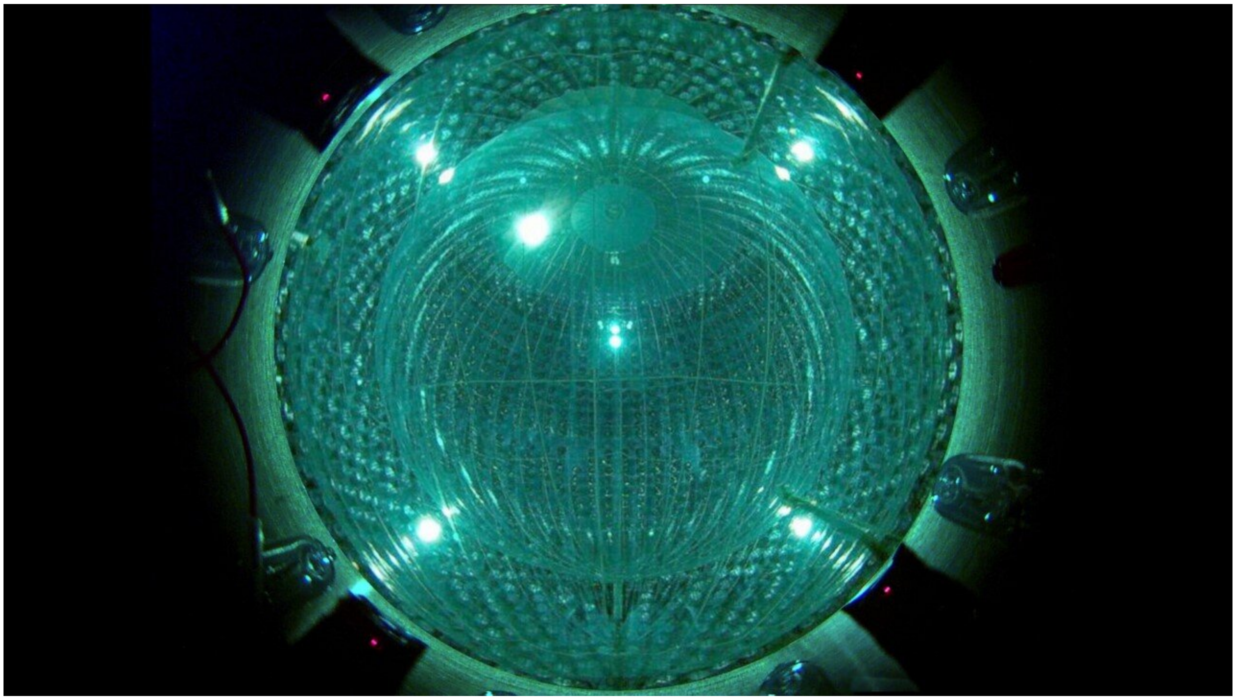
The CNO cycle is the dominant energy source powering stars heavier than the sun, but it had so far never been directly detected in any star, Pocar explains.

For much of their life, stars get energy by fusing hydrogen into helium, he adds. In stars like our sun or lighter, this mostly happens through the 'proton-proton' chains. However, many stars are heavier and hotter than our sun, and include elements heavier than helium in their composition, a quality known as metallicity. The prediction since the 1930's is that the CNO-cycle will be dominant in heavy stars.

Neutrinos emitted as part of these processes provide a spectral signature allowing scientists to distinguish those from the 'proton-proton chain' from those from the 'CNO-cycle.' Pocar points out, "Confirmation of CNO burning in our sun, where it operates at only one percent, reinforces our confidence that we understand how stars work."

Beyond this, CNO neutrinos can help resolve an important open question in stellar physics, he adds. That is, how the sun's central metallicity, as can only be determined by the CNO neutrino rate from the core, is related to metallicity elsewhere in a star. Traditional models have run into a difficulty—surface metallicity measures by spectroscopy do not agree with the sub-surface metallicity measurements inferred from a different method, helioseismology observations.

Pocar says neutrinos are really the only direct probe science has for the core of stars, including the sun, but they are exceedingly difficult to measure. As many as 420 billion of them hit every square inch of the earth's surface per second, yet virtually all pass through without interacting. Scientists can only detect them using very large detectors with exceptionally low background radiation levels.



The Borexino detector lies deep under the Apennine Mountains in central Italy at the INFN's Laboratori Nazionali del Gran Sasso. It detects neutrinos as flashes of light produced when neutrinos collide with electrons in 300-tons of ultra-pure organic scintillator. Credit: Borexino Collaboration

The Borexino detector lies deep under the Apennine Mountains in central Italy at the INFN's Laboratori Nazionali del Gran Sasso. It detects neutrinos as flashes of light produced when neutrinos collide with electrons in 300-tons of ultra-pure organic scintillator. Its great depth, size and purity make Borexino a unique detector for this type of science, alone in its class for low-background radiation, Pocar says. The project was initiated in the early 1990s by a group of physicists led by Gianpaolo Bellini at the University of Milan, Frank Calaprice at Princeton and the late Raju Raghavan at Bell Labs.

Until its latest detections, the Borexino collaboration had successfully measured components of the 'proton-proton' solar neutrino fluxes, helped refine neutrino flavor-oscillation parameters, and most impressively, even measured the first step in the cycle: the very low-energy 'pp' neutrinos, Pocar recalls.

Its researchers dreamed of expanding the science scope to also look for the CNO neutrinos—in a narrow spectral region with particularly low background—but that prize seemed out of reach. However, research groups at Princeton, Virginia Tech and UMass Amherst believed CNO neutrinos might yet be revealed using the additional purification steps and methods they had developed to realize the exquisite detector stability required.

Over the years and thanks to a sequence of moves to identify and stabilize the backgrounds, the U.S. scientists and the entire collaboration were successful. "Beyond revealing the CNO neutrinos which is the subject of this week's Nature article, there is now even a potential to help resolve the metallicity problem as well," Pocar says.

Before the CNO neutrino discovery, the lab had scheduled Borexino to end operations at the close of 2020. But because the data used in the analysis for the Nature paper was frozen, scientists have continued collecting data, as the central purity has continued to improve, making a new result focused on the metallicity a real possibility, Pocar says. Data collection could extend into 2021 since the logistics and permitting required, while underway, are non-trivial and time-consuming. "Every extra day helps," he remarks.

Pocar has been with the project since his graduate school days at Princeton in the group led by Frank Calaprice, where he worked on the design, construction of the nylon vessel and the commissioning of the fluid handling system. He later worked with his students at UMass Amherst on data analysis and, most recently, on techniques to characterize the backgrounds for the CNO neutrino measurement.

More information: Experimental evidence of neutrinos produced in the CNO fusion cycle in the Sun, *Nature* (2020). DOI: 10.1038/s41586-020-2934-0 , www.nature.com/articles/s41586-020-2934-0

Provided by University of Massachusetts Amherst

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