Detecting neutrinos, physicists look into the heart of the Sun

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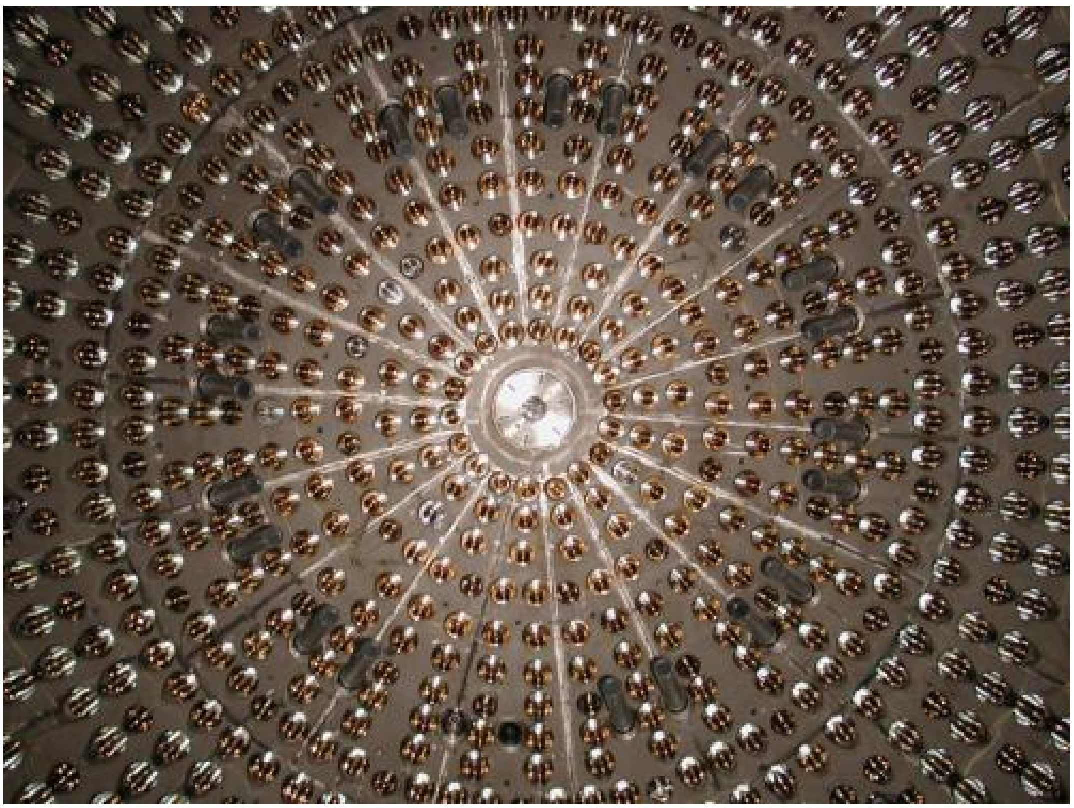


Inside view of the Borexino stainless steel sphere, prior to nylon vessel installation and fluid filling. The sphere is 13.7 meters in diameter; the picture was taken from the bottom looking upwards. There are 2212 installed photomultipliers (PMTs) to detect light from neutrino interactions, most of which equipped with aluminium light concentrators to focus their view on the central volume of the detector. The central flange is where the nylon vessels and fluid piping was anchored. Nylon vessel installation was in 2004, final fluid filling in 2007. Credit: Borexino Collaboration

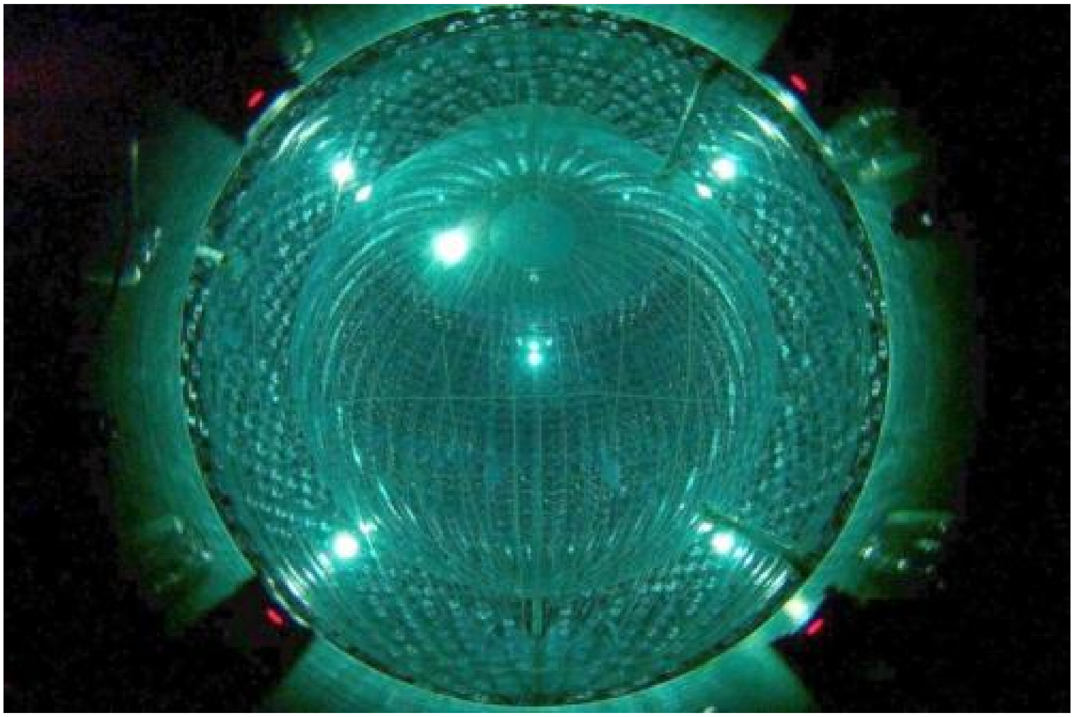
Using one of the most sensitive neutrino detectors on the planet, an international team of physicists including Andrea Pocar, Laura Cadonati and doctoral student Keith Otis at the University of Massachusetts Amherst report in the current issue of *Nature* that for the first time they have directly detected neutrinos created by the "keystone" proton-proton (pp) fusion process going on at the sun's core.

The pp reaction is the first step of a reaction sequence responsible for about 99 percent of the Sun's power, Pocar explains. Solar neutrinos are produced in nuclear processes and radioactive decays of different elements during fusion reactions at the Sun's core. These particles stream out of the star at nearly the speed of light, as many as 420 billion hitting every square inch of the Earth's surface per second.

Because they only interact through the nuclear weak force, they pass through matter virtually unaffected, which makes them very difficult to detect and distinguish from trace nuclear decays of ordinary materials, he adds.

The UMass Amherst physicist, one principal investigator on a team of more than 100 scientists, says, "With these latest neutrino data, we are directly looking at the originator of the sun's biggest energy producing process, or chain of reactions, going on in its extremely hot, dense core. While the light we see from the Sun in our daily life reaches us in about eight minutes, it takes tens of thousands of years for energy radiating from the sun's center to be emitted as light."

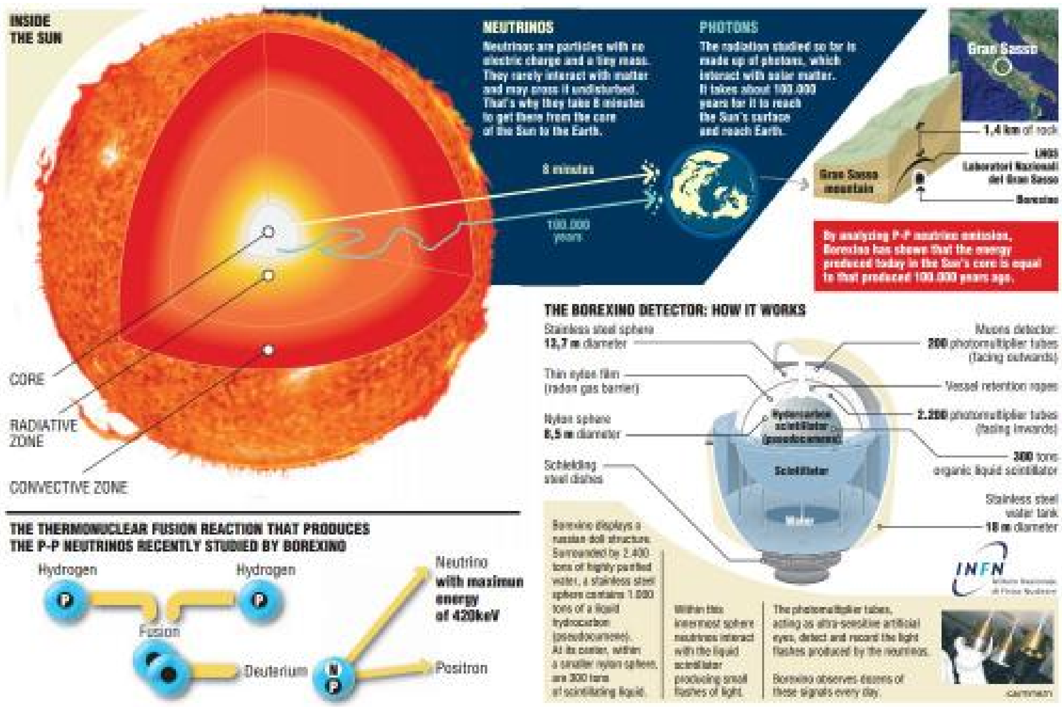
"By comparing the two different types of solar energy radiated, as neutrinos and as surface light, we obtain experimental information about the Sun's thermodynamic equilibrium over about a 100,000-year timescale," Pocar adds. "If the eyes are the mirror of the soul, with these neutrinos, we are looking not just at its face, but directly into its core. We have glimpsed the sun's soul."



The Borexino detector first filled with ultra-pure water in 2007. The thin nylon spherical "inner vessel" (8.5 meters diameter) is surrounded by a second nylon vessel and by ~2,000 photomultiplier tubes. A second, concentrical nylon vessel (11.5 meters diameter) prevents radioactive contamination from reaching the innermost volume of the detector. Both nylon membranes are 125 micron thick, were assembled as a nested package in a radon-suppressed clean room, and installed inside the detector in 2004. The nylon vessels are restrained with ultra-high molecular polyethylene ropes. The water was later displaced by the organic liquid scintillator, a benzene-like transparent liquid that produces flashes of light when neutrinos (and other ionising radiation) interacts with its electrons and nuclei. Credit: Borexino Collaboration

"As far as we know, neutrinos are the only way we have of looking into the Sun's interior. These pp neutrinos, emitted when two protons fuse forming a deuteron, are particularly hard to study. This is because they are low energy, in the range where natural radioactivity is very abundant and masks the signal from their interaction."

The Borexino instrument, located deep beneath Italy's Apennine Mountains, detects neutrinos as they interact with the electrons of an ultra-pure organic liquid scintillator at the center of a large sphere surrounded by 1,000 tons of water. Its great depth and many onion-like protective layers maintain the core as the most radiation-free medium on the planet.



Indeed, it is the only detector on Earth capable of observing the entire spectrum of solar neutrino simultaneously. Neutrinos come in three types, or "flavors." Those from the Sun's core are of the "electron" flavor, and as they travel away from their birthplace, they oscillate or change between two other flavors, "muon" to "tau." With this and previous solar neutrino measurements, the Borexino experiment has strongly confirmed this behavior of the elusive particles, Pocar says.

The Borexino prototype, CTF (Counting Test Facility), displaying a 4 tonne spherical scintillator target inside a nylon vessel (0.5 mm thick, 2 meters diameter), surrounded by ultra-ure water and 100 photomultiplier tuber (PMTs) to detect flashes of light from ionising radiation (including neutrinos) occurring in the scintillating volume. A thin (125 micron) nylon "shroud" prevents adioactive contamination from entering the centre-most volume of the detector. CTF demonstrated that the required scintillator purity from long-lived radioactivity for Borexino (mainly Uranium-238 and Thorium-232 and their daughters) could be achieved at the tonne scale. Credit: Borexino Collaboration

One of the crucial challenges in using Borexino is the need to control and precisely quantify all background radiation. Pocar says the organic scintillator at Borexino's center is filled with a benzene-like liquid derived from "really, really old, millions-of-years-old petroleum," among the oldest they could find on Earth.

"We needed this because we want all the Carbon-14 to have decayed, or as much of it as possible, because carbon-14 beta decays cover the neutrino signals we want to detect. We know there is only three atoms of C14 for each billion, billion atoms in the scintillator, which shows how ridiculously clean it is."

Inside view of the Borexino stainless steel sphere before nylon vessel installation and fluid filling. The sphere is 13.7 meters in diameter. The curvature and the tightly packed photomultiplier tubes (PMTs) can be seen. There are 2212 installed PMTs, most of which equipped with aluminium light concentrators to focus their view on the central volume of the detector. Optical fibres used for

PMT timing calibration can be seen. Nylon vessel installation was in 2004, final fluid filling in 2007. Credit: Borexino Collaboration

A related problem the physicists discuss in their new paper is that when two C14 atoms in the scintillator decay simultaneously, an event they call a "pileup," its signature is similar to that of a pp solar neutrino interaction. In a great advance for the analysis, Pocar says, "Keith Otis figured out a way to solve the problem of statistically identifying and subtracting these pileup events from the data, which basically makes this new pp neutrino analysis process possible."

Though detecting pp neutrinos was not part of the original National Science Foundation-sponsored Borexino experiment, "it's a little bit of a coup that we could do it," the astrophysicist says. "We pushed the detector sensitivity to a limit that has never been achieved before."

More information: Neutrinos from the primary proton–proton fusion process in the Sun, *Nature*, dx.doi.org/10.1038/nature13702

Provided by University of Massachusetts Amherst

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