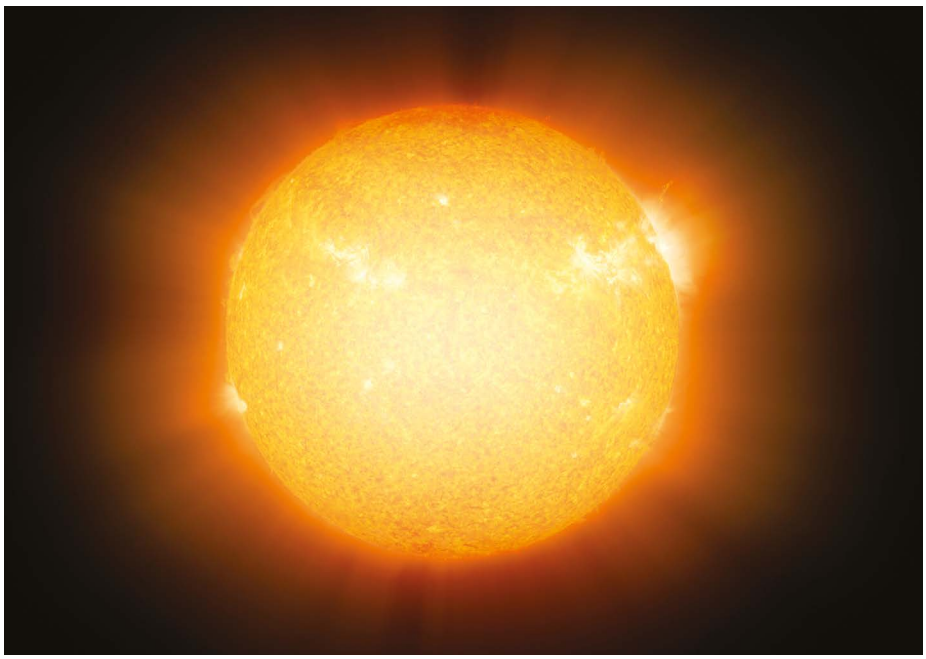


DETLEV VAN RAVENSWAAY/SPL

Neutrinos are released during nuclear-fusion reactions in the Sun's centre.

NEUTRINOS REVEAL FINAL SECRET OF SUN'S NUCLEAR FUSION

Detection of particles produced in the core supports long-held theory about how our star is powered.

By Davide Castelvecchi

By catching neutrinos emanating from the Sun's core, physicists have filled in the last missing detail of how nuclear fusion powers the star.

The detection confirms decades-old theoretical predictions that some of the Sun's energy is made by a chain of reactions involving carbon and nitrogen nuclei. This process fuses four protons to form a helium nucleus, which releases two neutrinos — the lightest known elementary particles of matter — as well as other subatomic particles and copious amounts of energy. This carbon–nitrogen (CN) reaction is not the Sun's only fusion pathway: it produces less than 1% of the Sun's energy. But it is thought to be the dominant energy source in larger stars. The results mark the first direct detection of neutrinos from this process.

"It's intellectually beautiful to actually confirm one of the fundamental predictions of stellar structure theory," says Marc Pinsonneault, an astrophysicist at Ohio State University in Columbus.

The findings, which have not yet been peer reviewed, were reported on 23 June by the Borexino underground experiment in central Italy, at the virtual Neutrino 2020 conference.

The facility was the first to directly detect neutrinos from three distinct steps of a separate reaction, called the proton–proton chain, which accounts for most of the Sun's fusion[1–3]. "With this outcome, Borexino has completely unravelled the two processes powering the Sun," said Borexino co-spokesperson Gioacchino Ranucci, a physicist at the University of Milan, Italy, who presented the results.

"It's intellectually beautiful to actually confirm one of the fundamental predictions of stellar structure theory."

The findings are a final milestone for Borexino, which might now shut down within a year. "We ended with a bang," says the experiment's other co-spokesperson, Marco Pallavicini, a physicist at the University of Genoa, Italy.

Balloon detector

The Borexino solar-neutrino experiment occupies a hall under more than one kilometre of rock in the Gran Sasso National Laboratories near L'Aquila, Italy, where it has been in operation since 2007. The detector is a giant nylon balloon filled with 278 tonnes of liquid hydrocarbons and immersed in water. Almost all neutrinos from the Sun zip through Earth — and Borexino — in a straight line, but a tiny number bounce off electrons in the hydrocarbons, producing flashes of light that are picked up by photon sensors in the water tank.

Because the CN reaction chain is responsible for only a small fraction of solar fusion, neutrinos from it are relatively rare. Moreover, the CN neutrinos are easy to confuse with those produced by the radioactive decay of bismuth-210, an isotope that leaks from the balloon's nylon into the hydrocarbon mixture.

Although the contamination is extremely low — at most, a few dozen bismuth nuclei decay per day inside Borexino — separating the solar signal from bismuth noise required a painstaking effort that began in 2014. The bismuth-210 couldn't be prevented from leaking out of the balloon, so the goal was to slow the rate at which the element seeped into the middle of the fluid, while ignoring signals from the outer edge. To do this, the team had to control any temperature imbalances across the tank, which would produce convection and mix its contents faster. "The liquid must be extraordinarily still, moving at most at a few tenths of centimetres per month," Pallavicini says.

To keep the hydrocarbons at a constant, uniform temperature, the researchers wrapped the entire tank in an insulating blanket and installed heat exchangers to automatically balance the temperature throughout. Then, they waited. It was only in 2019 that the bismuth noise became quiet enough for the neutrino signal to stand out. By early 2020, the researchers had gathered enough of the particles to definitively claim they had detected neutrinos from the CN nuclear-fusion chain.

"It is the first really direct evidence that hydrogen burning through CN operates in stars," says Aldo Serenelli, an astrophysicist at the Institute of Space Sciences in Barcelona, Spain. "So this is really amazing."

Sun-surface speculation

As well as confirming theoretical predictions about what powers the Sun, the detection of CN neutrinos could shed light on the structure of its core — specifically, the concentrations of elements astrophysicists call metals (anything heavier than hydrogen and helium).

The amounts of neutrinos seen by Borexino seem consistent with the standard models in which the 'metallicity' of the Sun's core is similar to that of its surface. But more up-to-date studies have begun to question that assumption, Serenelli says.

These studies suggest that the metallicity is lower. And because these elements regulate how fast heat diffuses from the Sun's core, it implies that the core is slightly cooler than

previously estimated. Neutrino production is extremely sensitive to temperature and, taken together, the various amounts of neutrinos seen by Borexino seem to be consistent with the older metallicity values — not with the new ones, Serenelli says.

As a possible explanation, he and other astrophysicists have suggested that the core has higher metallicity than have the outer layers. Its composition could reveal more about early stages of the Sun's life, before the formation of the planets removed some of the metals that were accreting onto the young star.

1. Bellini, G. *et al. Phys. Rev. Lett.* **107**, 141302 (2011).
2. Bellini, G. *et al. Phys. Rev. Lett.* **108**, 051302 (2012).
3. Bellini, G. *et al. Nature* **512**, 383–386 (2014).

NIH SEXUAL-HARASSMENT RULES ARE STILL TOO WEAK, SAY CRITICS

US biomedical research agency has a new policy, but relies on universities to report bad behaviour.

By Nidhi Subbaraman

The US National Institutes of Health (NIH) last week published new guidelines for tracking sexual-harassment complaints involving scientists funded by the agency. On 24 June, it described the actions it will take when alerted to reports of unsafe behaviour, including restricting scientists from peer-review panels, holding back pending grants and refusing university requests to transfer funding to other institutions in cases where a harasser changes jobs.

Advocates who have campaigned for changes at the US$41-billion biomedical-research agency say the adjustments are necessary, but are still weaker than rules issued by other funding agencies, such as the National Science Foundation (NSF).

Measures introduced on 11 June say that universities must inform the NIH when major changes are made to a grant owing to an investigation about scientists creating an unsafe work environment. "We have specifically defined that as including harassment, bullying, sexual harassment and other inappropriate behaviour," says Carrie Wolinetz, NIH associate director for science policy.

The NIH began collecting information about sexual-harassment investigations at the institutions it funds in 2019. But until the June announcement, disclosures had been voluntary. According to NIH officials, the new measures put harassment on the same level as research misconduct, fraud, issues of foreign influence and violations of peer-review integrity.

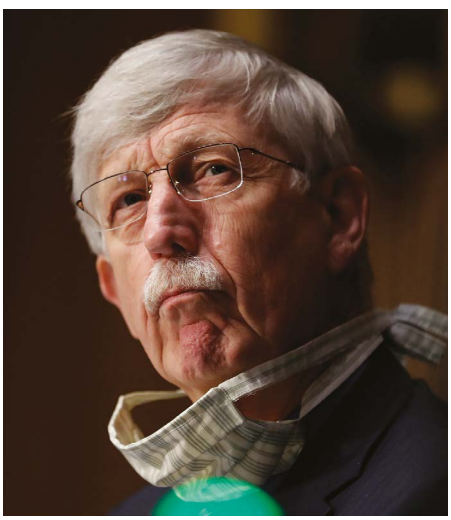
Critics say that the policy still relies too heavily on universities, which might be disinclined to report bad behaviour to the agency that funds them, and that a raft of steps must follow to change the status quo.

It "assumes good faith on the part of the institutions", says BethAnn McLaughlin, a neuroscientist and founder of the non-profit group MeTooSTEM. "What an absurd and insulting notion."

Others are awaiting the agency's next move. "This guidance is a good start, but there is much more that needs to be done," says Angela Rasmussen, a virologist at Columbia University in New York City, who was part of a working group convened by the NIH to examine its policies and suggest ways the agency could improve.

Changes and challenges

Agencies and institutions in the United States have begun making changes after acknowledging the scope and harm of sexual harassment in science. A 2018 report by the US National Academies of Sciences, Engineering, and Medicine in Washington DC found that incidents of harassment are rampant, that such behaviour pushes talented researchers out of science, and that university and federal policies for keeping it in check are lacking.



ANDREW HARNIK/GETTY

NIH director Francis Collins has been criticized for not moving faster to strengthen the agency's policies against harassment.

In a June presentation to a panel of advisers to the NIH director, Wolinetz said that as of 8 June, the NIH had received information about 115 cases of sexual harassment in 2019 and 27 cases in 2020, from 71 institutions. So far this year, it has removed 24 people from peer-review committees. In 2019, it removed 64.

According to the information provided to the NIH, only 14 principal investigators have been removed from grants so far, in part because investigations at their institutions are ongoing. But even in cases in which there have been findings of harassment, some institutions have pushed back against removing the harassers, arguing to keep the funding in place after the offender has been disciplined. "We are starting to see people, upsettingly, try to game the system a little bit," Wolinetz says.

Alysha Dicke, a member of the NIH's working group, is concerned that this pattern will continue if the NIH is not more transparent about affected universities and grants, and about what constitutes reportable behaviour. "I think it's important for NIH to point out how institutions are not responding as intended/desired, as it will likely be even more difficult to change some of the undesirable institutional behaviour if it's never called out," she wrote in an e-mail to *Nature*.

The new guidance won't provide a comprehensive view of harassment at funded institutions. The NIH requests that universities report "concerns" about scientists that have led to changes in grants — including pending investigations. But lawyer Kristina Larsen is sceptical that many institutions will report anything other than the findings of completed investigations — which only rarely occur. Larsen was an administrator at the University of California, San Diego, before she began representing people who filed sexual-harassment complaints. "I don't think it's realistic," she says.

Other funding agencies in the United States have stronger rules. In 2018, the NSF began requiring universities that find that an agency-funded scientist has committed sexual harassment to report this to the NSF within ten business days. NASA adopted similar rules this March. But the NIH rules require reporting only when the status of a grant changes. Wolinetz says that's because the NIH does not have the authority to ask institutions to report investigations or their results outside the grant-update cycle.

"The NSF has direct oversight of civil-rights violations at NSF-funded organizations, and NIH does not," Wolinetz says. "It does present some legal limitations in what we're able to do."