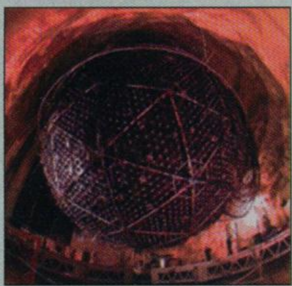
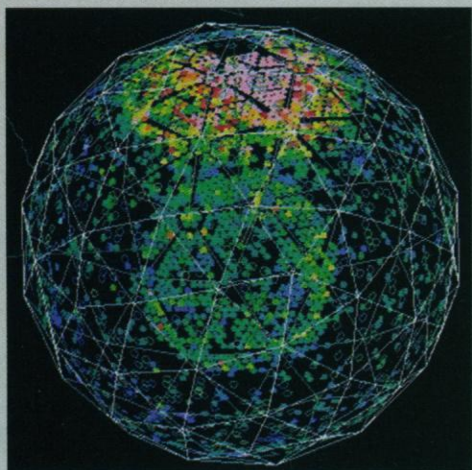
SNO Closes In on Solar Neutrino Riddle

The first neutrinos have been spotted colliding with heavy water molecules in a giant tank at the bottom of an Ontario nickel mine. Announced last week, the events mark the inauguration of the Sudbury Neutrino Observatory (SNO), a new facility that physicists hope will finally solve the solar neutrino problem, which has been haunting the field for decades.





Tracks in the SNO. A neutrino colliding with heavy water in SNO's giant tank *(top)* generated secondary particles that cast a glow on photodetectors *(above)*.

Generated by the sun's nuclear processes, nearly a billion solar neutrinos—ghostly subatomic particles that can easily pass through Earth without hitting anything—shower down on each square centimeter of the planet's surface every second. Although neutrinos come in three "flavors," electron, muon, and tau, existing detectors can only see the electron variety, and they only see half as many coming from the sun as theorists had predicted. To resolve this discrepancy, physicists have proposed that half of the neutrinos switch flavors, or "oscillate," on their way from the sun's center to Earth. Other neutrino experiments have been gathering indirect evidence for oscillations by comparing the number of neutrinos from a known source with the number observed in a detector, and a new project in Japan called KamLAND could firm up the case (see main text). But SNO should provide the most direct test yet of the theory.

The key is its ability to see several varieties of solar neutrinos at once. SNO contains 1000 tons of ultrapure heavy water, water in which the hydrogen atoms have been replaced with deuterons, whose nuclei have a proton and a neutron. When an electron neutrino collides with a heavy water molecule, it can split apart the neutron and the proton and eject an electron. Other neutrino flavors split the nuclei but don't scatter electrons. By counting both neutrons and electrons, SNO should be able to measure both the total number of incoming neutrinos and the fraction of electron neutrinos, says physicist and SNO spokesperson David Wark of Oxford University in the United Kingdom. If SNO finds that the shortfall of electron neutrinos is made up in other flavors, it will provide strong support for oscillations.

"It is an extremely important experiment," agrees physicist Paul Langacker of the University of Pennsylvania, Philadelphia. "They will very likely ascertain definitively whether neutrino oscillations are taking place." Unfortunately, physicists will have to be patient: Neutrinos collide with matter so rarely that SNO will detect only some 20 neutrinos every day. As a result, says Wark, "it will be at least a year" before SNO has an answer.

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in the observed versus expected number of neutrinos from the sun. As a bonus, KamLAND could also yield clues to the distribution of radioactive elements in Earth's crust and how their decay contributes to the heat generated within the planet.

"KamLAND is a great experiment," says John Bahcall, a neutrino expert at the Institute for Advanced Study in Princeton, New Jersey. He is particularly excited about the ability to investigate the solar neutrino anomaly under what amounts to laboratory conditions, that is, knowing the conditions under which the neutrinos were created: "I never expected to live to see a laboratory test of a solar neutrino explanation."

KamLAND is a collaboration of three Japanese and 10 U.S. institutions, led by the Research Center for Neutrino Science of Tohoku University in Sendai. It uses a mine cavern occupied by Kamiokande, an earlier neutrino detector that has been succeeded by Super-Kamiokande, now running in a separate cavern in the same mine. The detectors made worldwide headlines last year by offering evidence of mass for at least one of the three flavors, or types, of neutrinos. Both of these detectors consisted of huge tanks of water outfitted with photomultiplier tubes, which pick up the flash of light generated when an occasional high-energy neutrino interacts with a proton in the water.

In contrast, KamLAND will use 1200 cubic meters of a liquid scintillator, a chemical soup that luminesces in response to neutrinos at lower energies. The liquid is confined in a 13-meter-diameter spherical balloon surrounded by layers of inert oil and water intended to cut background noise. With 1280 photomultiplier tubes to pick up the luminescence, KamLAND will cost an estimated $20 million, all coming from Japan's Ministry of Education, Science, Sports, and Culture (Monbusho). U.S. collaborators have asked the Department of Energy for $7.8 million to provide another 650 photomultiplier tubes, which would increase the sensitivity of the detector.

After it starts taking data in 2 years, KamLAND could bolster the neutrino mass claims from Super-Kamiokande. Those claims were based on signs that muon neutrinos made by cosmic rays colliding with air molecules were "oscillating," or changing into another type, on their way to the detector—something the laws of quantum mechanics forbid if both particles are massless. But Super-Kamiokande's case for oscillations had a weak point, because it relied in part on calculations of how efficiently cosmic rays should produce neutrinos in the atmosphere.

A number of so-called long-baseline experiments are attempting to remove the uncertainty by sending streams of neutrinos generated in accelerators through a near detector to a far detector so the neutrinos can be counted at both ends of their trip. These experiments, however, are aimed at the muon neutrino and energy ranges associated with atmospheric neutrino oscillation. KamLAND will focus on electron antineutrinos and the solar neutrino anomaly.

Atsuto Suzuki, a professor of physics at Tohoku University and head of the collaboration, says there's no need to place a detector at the source because the neutrino-producing reactions of commercial nuclear reactors are well understood. Instead, Suzuki and his colleagues will simply compare the number of electron antineutrinos detected at KamLAND with the number made by the

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