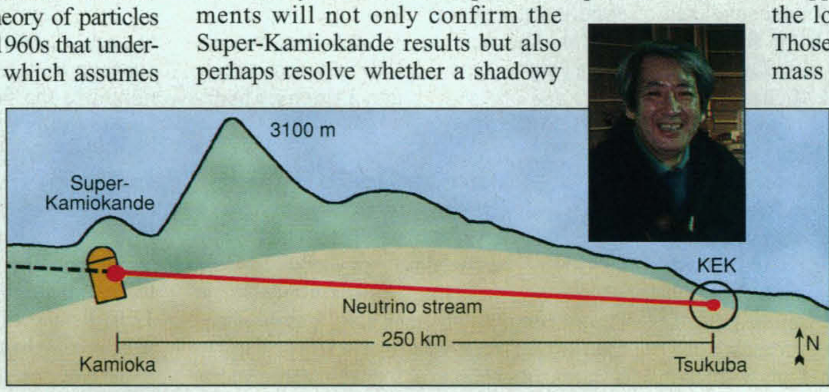
PARTICLE PHYSICS

# Search for Neutrino Mass Is Big Stretch for Three Labs

**A Japanese experiment kicks off novel attempts to optimize conditions and learn more about an elusive particle**

**TSUKUBA, JAPAN**—Physicists around the world got a jolt last June when an international team unveiled evidence that neutrinos have some mass. The finding pointed to interesting science beyond physicists' beloved but incomplete Standard Model, the theory of particles and forces developed in the 1960s that underlies modern physics—and which assumes neutrinos have zero mass. But for some researchers, the evidence, like the elusive particles themselves, was a bit insubstantial.

It came from glimpses, recorded in an underground detector called Super-Kamiokande, of so-called atmospheric neutrinos, generated when cosmic rays slam into Earth's upper atmosphere. Researchers would be more comfortable with results from an experiment in which they control the variables. "Important segments of the particle physics community want to see direct laboratory confirmation of the Super-Kamiokande result," says Wick Haxton, a theorist at the University of Washington, Seattle. Last month, scientists in Japan started tuning up an experiment to provide exactly that type of evidence.




**Ground truth.** The K2K experiment, says spokesperson Koichiro Nishikawa, will send neutrinos underground from KEK to Super-Kamiokande.

The research, scheduled to begin this spring, will generate a stream of neutrinos at the High-Energy Accelerator Research Organization (KEK) in Tsukuba and shoot the particles 250 kilometers through Earth's crust to the Super-Kamiokande detector. This K2K experiment, combined with similar so-called long-baseline neutrino experiments planned in the United States and Europe (see table), will permit scientists "to do everything with neutrino beams that one normally associates with a laboratory experiment," says John Bahcall, a physicist at the Institute for Advanced Study in Princeton, New Jersey. Researchers hope these experiments will not only confirm the Super-Kamiokande results but also perhaps resolve whether a shadowy "sterile" neutrino also exists.

Physicists first began to doubt the Standard Model's picture of the massless neutrino in the 1970s, when they set up detectors to look for neutrinos streaming from the sun. They found fewer than theory predicts. Because the detectors can typically "see" only one or two of the three neutrino flavors (electron, muon, and tau), physicists speculated that the particles were changing, or oscillating, from a flavor the detectors could see to one they couldn't. And the laws of quantum mechanics require oscillating particles to have mass.

The case for a neutrino with mass received a tremendous boost last June when findings from Super-Kamiokande were presented (*Science*, 12 June 1998, p. 1689). Theory suggests that atmospheric neutrinos should bombard Earth in equal numbers from all directions. But Super-Kamiokande, by far the largest neutrino detector ever built, recorded far more muon neutrinos coming from directly overhead than from the far side of Earth. Scientists posited that the longer trip through Earth gave the neutrinos more time to oscillate into an undetectable flavor.

**LONG-BASELINE NEUTRINO EXPERIMENTS**

| Name | K2K | MINOS | NGS |
|---|---|---|---|
| Sites used | KEK, Kamioka mine | Fermilab, Soudan mine | CERN, Grand Sasso |
| Cost (millions) | $50 | $130 | $51 +detectors |
| Distance (km) | 250 | 730 | 732 |
| Start date | Spring 1999 | Late 2002 | 2004 |

The Super-Kamiokande finding was generally regarded as compelling but not definitive. "Even those already convinced understand the importance of controlled laboratory verification," says Haxton. But weighing neutrinos in the lab can be a complicated business. Researchers have to know exactly how many they are manufacturing, and they must carefully sift out the few they detect from the downpour of neutrinos from the sun, other stars, the atmosphere, and elsewhere. They also need the right combination of neutrino energy and distance between source and detector.

In fact, last year's findings from Super-Kamiokande appeared to pose problems for the long-baseline experiments. Those early results indicated the mass difference between muon neutrinos and the flavor they oscillate into could be as small as 0.07 electron volts. (Oscillation data can only provide estimates of mass difference, not absolute mass.) The laws of quantum mechanics say that the chances of observing oscillations vary proportionately with the distance between source and detector and inversely with the energy of the neutrinos. Because the experimental distances are fixed, the only option is to lower the energy of the neutrino beams. But at lower energies the beam scatters like a floodlight, and too few particles may hit the detector to create a significant signal. Based on those early findings, Harvard University physicist Sheldon Glashow gave the long-baseline experiments only a 50-50 chance of observing neutrino oscillations.

But for once, neutrinos appear to be playing easy to get. Additional data from Super-Kamiokande have significantly narrowed the range of the possible mass difference and raised the floor, providing a better fit for K2K. "The allowed region … now seems to be accessible to long-baseline experiments," Glashow says.

If the experiments are looking for neutrinos in the right range, K2K is likely to be the first to spot them when it starts to collect data this spring. "If we will ever see a signal, I think the first few runs should be enough to get a feel for what will happen," predicts Koichiro Nishikawa, spokesperson for the 90-member international K2K collaboration. But he says the team intends to collect 2 years' worth of data before publishing its results.

Even if K2K confirms Super-Kamiokande's findings of oscillation, many questions will remain. "There will still be plenty of goals left

CREDITS (CLOCKWISE FROM TOP LEFT) KEK; D. NORMILE; SOURCE: K2K, MINOS, NGS for us," says Stanley Wojcicki, a Stanford University physicist and spokesperson for the MINOS collaboration, an experiment based at the Fermi National Accelerator Laboratory in Illinois. For example, K2K probably won't be able to determine which neutrino flavor the missing muon neutrinos assume. Super-Kamiokande can observe both muon and electron neutrinos, so it has been able to rule out a transformation into electron neutrinos. That would seem to make tau neutrinos the only candidate. But recent theoretical work has pointed to the possibility of an even more elusive variety of neutrino, the sterile neutrino (*Science*, 11 September 1998, p. 1594).

MINOS may eventually settle the matter. It will include a detector capable of observing tau neutrinos directly, and the wider range of data it can capture may enable it to tell whether muon neutrinos are oscillating into tau neutrinos or sterile neutrinos. "That is where we are somewhat unique," Wojcicki says. The European experiment at CERN in Geneva also expects to detect tau neutrinos.

Bahcall notes that ruling out a significant role for sterile neutrinos would make it easier for scientists to construct theoretical explanations of neutrino interactions. But, he adds, "none of these experiments can rule out the existence of sterile neutrinos" entirely. That would leave the door open for future neutrino experiments by teams around the world.

–DENNIS NORMILE

ARCHAEOLOGY

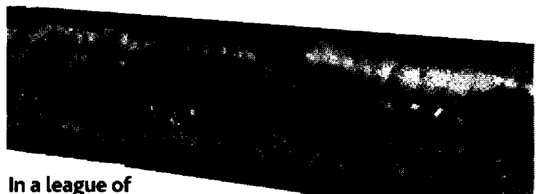
# Researchers Ready for the Plunge Into Deep Water

**Archaeologists are hoping that new technologies will help them beat salvagers to hidden treasures on the unplumbed ocean floor**

**CAMBRIDGE, MASSACHUSETTS**—A watershed moment in Anna McCann's career came as she was sprawled on the floor of a Navy submarine in the Mediterranean Sea, gazing through a porthole at a jumble of amphoras and timber from a Roman ship that sank off Sicily some 2000 years ago. Captured in floodlights 850 meters below the surface was evidence of a deep-sea trade route between Rome and ancient Carthage, in North Africa. "It was one of the thrills of a lifetime," says McCann, an archaeologist at Boston University who helped excavate the Skerki Bank site in 1997. "We were looking at untrespassed space," a site that no salvager in the well-plundered Mediterranean had ever found, she says.

Skerki's terra-cotta amphoras, which hauled everything from olive oil to wine, and other artifacts will keep scientists busy painting a more detailed picture of ancient Roman life. But the expedition also marked the beginning of a new era of collaboration among archaeologists, oceanographers, and engineers to search for treasures in the deep sea, at depths below 400 meters. "Underwater archaeology is poised to make a great leap forward," says archaeologist Robert Grenier of Parks Canada at a small symposium* here on how archaeologists might use crewed submersibles and autonomous underwater vehicles (AUVs) to access the 90% of the world's oceans they haven't yet laid eyes on.

Archaeologists go starry-eyed over what they hope to discover in this mare incognita. "We'd like to find shipwrecks from periods or cultures for which we know *nada*," says Shelley Wachsmann of Texas A&M University's Institute of Nautical Archaeology in College Station. One example is the mysterious Minoans, who came to the Greek isle of Crete about 3000 B.C. and were apparently conquered 1500 years later. "Finding a Minoan shipwreck would rewrite an entire chapter of history," he says. Other sites might lie along a trade route in the Black Sea or off Alexandria's port. Before the ocean bottom is sounded for historical gems, however, archaeologists must overcome several obstacles—from pricey voyages to vague laws guiding open-ocean finds. And they must act fast, as private salvagers are gearing up for their own treasure hunts. "The genie is out of the bottle" now that new deep-sea submersibles are coming on line every month, says Johns Hopkins University underwater engineer Louis Whitcomb. "We are in a race against time."



**In a league of its own.** This 2nd century B.C. Roman shipwreck at Skerki Bank hints at a new era for archaeology.

CREDIT: WHOI/IFE, H. SINGH, J. ADAMS, B. FOLEY, D. MINDELL, L. WHITCOMB, D. YOERGER

Archaeologists have donned wet suits and undertaken dozens of near-shore excavations since the 1960s. Now they would like to move to depths where crushing pressures render scuba gear useless—a realm already probed routinely by oceanographers and geologists. "The introduction of archaeologists into this world can be either bumpy or smooth," depending on how well they forge alliances with those who control the submersibles, says *Titanic* discoverer Robert Ballard, director of the Institute for Exploration (IFE) at Mystic Aquarium in Connecticut. One hurdle is money: "One million dollars for a month at sea is standard for our community," Ballard says. IFE has amassed a $50 million war chest from donations, which enables it to support Skerki Bank, as well as upcoming work in the Black Sea and at what may be an Iron Age ship at the Ashkelon site in Israel. Other researchers on tighter budgets may have to set up a system for sharing submersibles, similar to how astronomers divvy up telescope time.

Archaeologists will also have to develop new tools for digging in the deep sea. Although the clayey sediments at these depths lack oxygen and help preserve artifacts, "they're incredibly cohesive" and hard to work in, says Ballard. The muck also makes it tough to find wrecks in the first place. "We need tools to see into the sediment," says Wachsmann. Such tools—everything from souped-up side-scan sonar to modified squeegees for skimming sediment off objects—could be attached to AUVs, which Gordon Watts of East Carolina University in Greenville, North Carolina, predicts will become "the trowels of the next century."

Perhaps the prickliest issue is how to thwart private salvagers, because in the open ocean it's finders-keepers. So far no salvagers have beat archaeologists to any good stuff in deep waters, although Greg Stemm of Odyssey Marine Exploration in Tampa, Florida, says his company this summer will mount a $3 million excavation of a Punic War–era shipwreck in the Western Mediterranean. Odyssey has a staff archaeologist to ensure artifacts are recovered properly, Stemm says. But in fact current laws say little about how to treat deep-water relics. According to James Goold of the law firm Covington & Burling, "there's nothing to stop the finder of a Minoan ship from sending down the biggest trawl net they can find" and hauling up booty. This issue is likely to explode if a Minoan or other scientifically priceless ship is found. For now, says Ballard, the deep sea's value to social sciences is as murky as the water itself: "Promise is one thing, proven reality is another." But no one thinks it will stay that way for long.

–RICHARD STONE

* Technology and Archaeology in the Deep Sea: Toward a New Synthesis, Massachusetts Institute of Technology, 29–31 January.