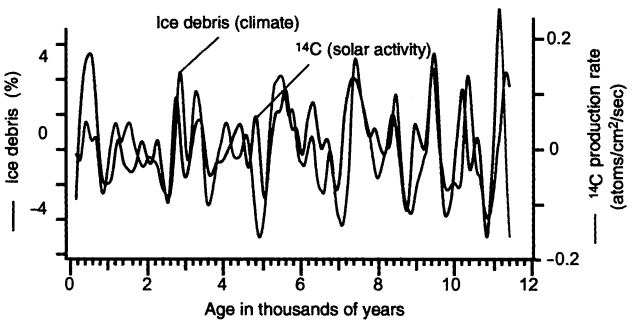
highly detailed records of both changing climate and solar activity. The climate record is a newly enhanced version of Bond's laborious accounting of microscopic rocky debris dropped on the floor of the northern North Atlantic during cold periods (*Science*, 25 June 1999, p. 2069). Ice on or around Canada, Greenland, and Iceland picked up these bits of rock and then floated into the North Atlantic, where the ice melted and dropped its load of debris. Bond and colleagues had found that the debris jumped in abundance every 1500 years (give or take half a millennium) as the ice surged farther out into a temporarily colder Atlantic. During spells of exceptional cold in the last ice age, huge amounts of ice crossed the Atlantic as far as Ireland, but even during the current warm interglacial interval a weaker millennial climate pulse continued across the Atlantic.



Well-matched wiggles. The synchroneity of fluctuations in ice-borne debris (black) and carbon-14 (blue) suggests that a varying sun can cause millennial climate change.

Records of solar activity are found in both carbon-14 in tree rings and beryllium-10 in cores of Greenland ice. Both isotopes are the products of cosmic rays striking the upper atmosphere. The solar wind of a brighter and more active sun would magnetically fend off more cosmic rays, decreasing production of carbon-14 and beryllium-10. Trees take up the carbon-14 to add new growth rings, and the beryllium-10 falls on Greenland snow that then forms annual ice layers.

The test for a sun-climate connection comes when the two types of records are put together for comparison. The more in synch the sun and climate are, the more it looks like the sun is driving climate change. "It's a strong result," says Bond. "You can do statistics on it," but what really persuades him is "what you see" in a plot of the two records: the close match between the peaks and troughs of the climate record and those of the solar record. Simple analysis gives correlation coefficients between 0.4 and 0.6. "That's a very high correlation" for separate geologic records, says geophysicist Jeffrey Park of Yale University. "It's not on the margin. It shows that the connection is real." Time series analyst David Thomson, soon to be at Queen's University in Kingston, Ontario, agrees that the statistics are good, "but their experiment may be good enough even without statistics. I think they've got a fairly convincing case."

As warm as the reception for a sun–millennial climate link may be, researchers caution that much is left to be sorted out. "It remains a little hard to figure out exactly how the sun has mattered to [recent] climate," says Alley, "and why it has mattered so much." The dimming and brightening was too small to alter the climate directly with changes as dramatic as the Little Ice Age, especially in the high-latitude North Atlantic, where the chill seems to have been greatest.

Alley points to growing evidence that solar variations can gain leverage on the atmosphere by altering the circulation in the stratosphere, which in turn changes the circulation below in the lower atmosphere (*Science*, 19 October, p. 494). Once near the surface, the solar influence might induce a change in ocean circulation. A self-sustained oscillation in the rate at which far northern North Atlantic waters sink into the deep sea had been the leading alternative to a solar influence. Given the cooling pattern they find across the Atlantic during the last few cycles, Bond and his colleagues suggest that deep-water formation does in fact oscillate, but the timing of the oscillation would be influenced by the now seemingly inconstant sun. **–RICHARD A. KERR**

CREDITS: (LEFT TO RIGHT) G. BOND *ET AL.*; ICRR/UNIVERSITY OF TOKYO

HIGH-ENERGY PHYSICS

Neutrino Oddity Sends News of the Weak

Physicists are excited, once again, about a potential conflict with the Standard Model of Particle Physics. Measurements of the behavior of neutrinos, made by a team at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, suggest that the Standard Model may misgauge the strength of one of the fundamental forces of nature. Although not conclusive, the results might signify an undiscovered particle—or an experimental fluke.

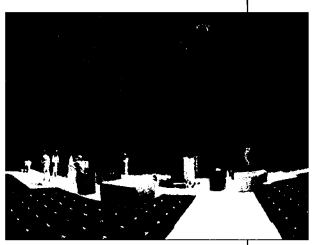
The Fermilab experiment measured θ_W ("theta-sub-w"), a quantity called the weak mixing angle. Although not an angle in the ordinary sense, θ_W smells like one to a mathematician. Roughly speaking, it measures the relation between the electromagnetic and weak forces: Different values of θ_W yield different pictures about the relative strengths of the forces at different energies.

ScienceScope

In the Dark In a major setback for neutrino observations, the Super-Kamiokande neutrino detector in central Japan has been knocked out of commission during repairs to the $100 million facility.

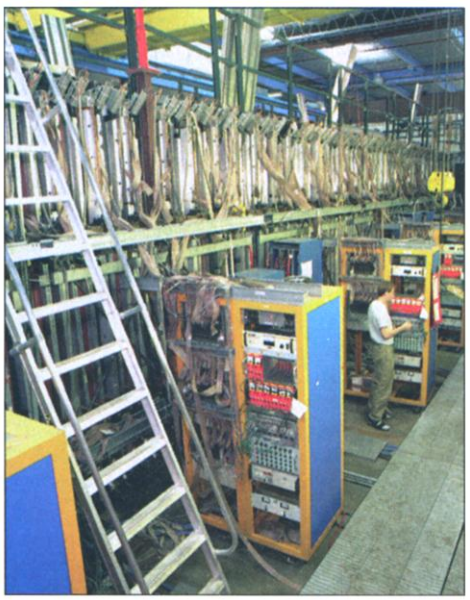
Buried a kilometer underground in a mine, Super-Kamiokande is a 39-meter-by-41-meter tank of water lined with 11,146 photomultiplier tubes that watch for a characteristic glow, known as Cerenkov radiation, from the statistically rare interaction of ephemeral neutrinos and atomic particles in the water. In 1998, it provided researchers with the first convincing evidence that neutrinos have mass.

The tank was emptied in August to replace 100 burned-out tubes and was being refilled on Monday when more than half of the tubes suddenly shattered in an apparent chain reaction. Yoji Totsuka, director of the University of Tokyo's Institute for Cosmic Ray Research, which heads an international collaboration operating Super-Kamiokande, says he has no idea what caused the accident or how soon the facility can be put back online. One scientist estimated that it could cost $10 million just to replace the tubes.



Deep Decision The underground science movement is still kicking. Congress last week included $10 million in a housing appropriations bill to prevent an abandoned gold mine from flooding. The money, for a skeletal crew and equipment to keep the mine dry, keeps alive scientists' hopes of transforming the Homestake gold mine in Lead, South Dakota, into the world's deepest underground laboratory (*Science*, 15 June, p. 1979). Scientists studying certain phenomena, such as neutrino signatures, need such sites to shield experiments from cosmic radiation.

Senator Tom Daschle (D–SD) and mine owners last month worked out environmental and liability issues that threatened to scuttle the plan. Ironically, Daschle aides were hammering out the final deal in the senator's Washington, D.C., office when they learned that a staffer had just opened the anthrax-bearing letter, according to *The Wall Street Journal*. While members of Daschle's staff wait to return to their shuttered building, researchers await word from the National Science Foundation on a $281 million proposal to build the underground lab.



Particle trap. This giant detector at Fermilab gathered puzzling data on neutrinos.

Unlike a similar-sounding quantity called the neutrino mixing angle, which determines the properties of neutrinos (*Science*, 2 November, p. 987), θ_W measures a fundamental force of nature, something that is fully accounted for in the Standard Model.

So when the Fermilab researchers measured θ_W using neutrinos produced by the Tevatron accelerator, they didn't expect to see anything unusual. The Tevatron produced powerful protons, then slammed them into a beryllium-oxide target, producing kaons and pions with various charges. Using magnets, the scientists sifted these particles, picking out varieties that would decay and produce either neutrinos or antineutrinos. They then compared how the resulting neutrinos and antineutrinos interacted with a 700-ton steel detector. The neutrinos and antineutrinos have different spin states and thus are affected differently by the weak force—and θ_W. By comparing the neutrinos' behavior with that of the antineutrinos, the team figured out the size of θ_W.

The result surprised them. The measured value of θ_W disagreed with what the Standard Model predicts by three standard deviations—"three sigma." "A three-sigma result is interesting; it gets people's attention," says Kevin McFarland, a physicist at the University of Rochester in New York state and member of the Fermilab team. In particle physics, such a result is usually considered provocative but not ironclad. But McFarland is sanguine. "I spent the last 8 years of my career making one measurement," he says, and after thorough checking and rechecking, the conflict with the Standard Model remained.

If real, the anomaly might be caused by an undiscovered particle such as a hypothetical new carrier of the weak force called Z′ ("Z-prime"), says Jens Erler, a physicist at the University of Pennsylvania in Philadelphia. "The [Fermilab] experiment is not explained by Z′ , but helped," he says. When combined with another recent intriguing but inconclusive result in atomic physics, says Erler, it is "almost crying out for Z′."

But doubts will remain until new experiments can shed more light on the situation. "Three sigma can easily be a fluke," says Erler. "But we take it seriously enough to have a really close look." **–CHARLES SEIFE**

ANIMAL BEHAVIOR

Single Gene Dictates Ant Society

Genes regulating behavior are very hard to pinpoint; even basic behaviors are thought to be influenced by many genes interacting in mysterious ways. But fire ant researchers at the University of Georgia say they've characterized a gene that may singlehandedly determine a complex social behavior: whether a colony will have one or many queens. The gene in question seems to work by controlling how ants perceive pheromones that tell them who's a queen and who isn't.

The research "opens up for the first time the study of genes influencing social behavior across the whole span of the biological hierarchy," says Andrew Bourke of the Zoological Society of London, "from the most basic, molecular level, through the level of individual behavior, right up to the social level." The findings, by biologists Michael Krieger and Kenneth Ross of the University of Georgia in Athens, are published online this week by *Science* (www.sciencexpress.org).

Fire ants have two basic kinds of social organization. A so-called monogyne queen establishes an independent colony after going off on her mating flight, nourishing her eggs with her own fat reserves without worker help until they hatch and become workers themselves. Polygyne queens, in contrast, are not as robust, fat, and "queenly" as monogynes, says Krieger, and they need worker aid to set up new colonies. They spread by "budding" from one primary nest into a high-density network of interacting colonies. Monogyne communities permit only a single queen, and those with a resident royal kill off any intruding would-be queen. Polygyne colonies can contain anywhere from two to 200 queens and accept new queens from nearby nests.

All these differences, the scientists suggest, depend on which version of a gene known as *Gp-9* ants possess. It encodes a pheromone-binding protein that may be crucial for recognizing fellow fire ants. All ants in a monogyne colony have two copies of the *B* allele, but among the polygynes, at least 10% are heterozygous, carrying a mutant allele, *b*. Polygyne communities kill off any potential *BB* queens, but the *Bb* proportion of the colony somehow "persuades" the rest to accept *Bb* queens, says Krieger. They apparently escape attack because the *Bb* workers aren't very good at recognizing *Bb* queens. The *b* allele appears to code for a faulty protein, he says. He theorizes that this prevents the polygyne workers from detecting as many pheromones as the monogyne workers do, and this leads them to allow many young heterozygous queens to survive, whereas the more queenly *BB*s are easy to target.

This is the first time scientists have nailed down the identity of "a single gene of major effect in complex social behavior," the researchers claim in their paper. Until now, about the closest anyone has come to a social behavior gene is one that determines whether nematodes, a kind of parasitic worm, clump together when food is plentiful, says Krieger. But nematodes don't really count because they're not "social animals," like bees or ants or primates, he claims.

Some researchers already suspected that this gene was pivotal in determining the shape of fire ant society, but the notion was "so unexpected as to arouse skepticism," says entomologist Ross Crozier of James Cook University in Townsville, Australia. Crozier says many scientists cling to the view that "genetic details are not important in studying evolutionary changes, because changes are due to many genes of small effect." The fire ant story is "a significant new example" to the contrary. **–CONSTANCE HOLDEN**

Full pheromone power. Monogyne workers tending their queen possibly have more sensitive pheromone receptors than do some polygynes.

CREDITS: (TOP TO BOTTOM) FNAL; K. ROSS