Solar Neutrino Deficit Confirmed?

The long-awaited first results from a new breed of solar neutrino detectors have finally arrived—and they're more striking than anyone imagined. According to collaborators on the Soviet-American Gallium Experiment (SAGE), who reported on their initial 4 months of data at a recent neutrino conference in Geneva,* the apparatus saw no solar neutrinos whatsoever.

If borne out—and the SAGE physicists are still very cautious about that—the results would confirm what astrophysicists have suspected, but have been unable to prove: that the neutrinos created by fusion reactions in the core of the sun are somehow getting lost on their journey to Earth.

"This is the most exciting news I've ever heard in science," exults astrophysicist John Bahcall of the Institute for Advanced Study in Princeton, who has long been one of the leading theorists on solar neutrinos. "If it's true, [these experiments] are telling us something about fundamental physics that we never expected to learn."

Bahcall's enthusiasm is understandable: astronomers and physicists have been awaiting results like these for two decades now, ever since University of Pennsylvania radiochemist Raymond Davis put his pioneering solar neutrino detector down in South Dakota's Homestake gold mine and discovered that the neutrino flux from the sun was only about one-third to one-fourth the flux predicted by standard astrophysical theory. Over the years, researchers have concocted dozens of theories purporting to explain that deficit. But until now, none of those theories could either be proved or disproved, because no one could be sure if the deficit was real. Since Davis' detector is sensitive only to the highest energy solar neutrinos, which are produced by a very rare fusion reaction involving the isotope boron-8, there was always a chance that the theorists had simply been wrong.

Enter SAGE, which has been under construction since the mid-1980s in a mine near the Soviet town of Baksan, and which has the participation of Davis and a number of other U.S. experimenters. Unlike Davis' original detector, which looks for radioactive argon-37 nuclei produced by neutrinos from the sun hitting chlorine-37 nuclei inside a huge tank of chlorine-rich cleaning fluid, SAGE looks for radioactive germanium-71 nuclei produced inside 30 tons of gallium-71.

The difference is that the gallium reaction can be triggered by relatively low-energy neutrinos from the fusion of protons with protons. And since the proton-proton reaction produces the vast majority of the sun's energy, there is no way the calculated neutrino production rate can be off by a factor of 3 or 4; theorists can obtain the flux simply by knowing how bright the sun is. Thus, a low neutrino rate from SAGE would be strong evidence that neutrinos are indeed being waylaid on the way out.

And low it is—although no one really expected to find a rate of *zero*. The SAGE experimenters themselves urge people not to take that number too literally, however. "This is still a fairly fresh experiment," notes SAGE team member Kenneth Lande of the University of Pennsylvania. First, he says, background noise from cosmic rays and such makes it impossible to say that the neutrino flux is really zero. The correct statement is that the signal most probably lies between zero and 70 solar neutrino units (SNUs)—the SNU being a convenient measure of the solar neutrino flux invented by Davis. But that is still well below the rate predicted by standard astrophysical theory, which is 132 SNUs, corresponding to about one germanium-71 nucleus being produced per day.

Second, says Lande, the SAGE result has yet to be confirmed. If similar numbers come out of Gallex, a gallium experiment that should be ready to begin taking data later this year in Italy's Gran Sasso tunnel, then physicists could feel more certain.

Bahcall, however, is already a believer. During his own talk at the Geneva meeting, he presented his own preliminary calculations suggesting that both results are consistent with the "MSW" model, which was already the most popular explanation for the solar neutrino deficit. The MSW model starts by postulating that neutrinos actually have a very tiny mass, in contrast to conventional particle theories that assume they are massless. Then the model shows how certain subtle interactions with ordinary matter in the sun can cause the original neutrinos to "oscillate" and occasionally transform themselves into other types of neutrino that would be invisible to SAGE as well as to Davis' original detector. Knowing the experimental results, says Bahcall, the model then allows you to make a rough prediction: that the mass of the original neutrino—or, more technically, the electron neutrino— is about 0.001 electron volt.

"My attitude is that the Baksan result must be right because it's so pretty," laughs Bahcall. ■ M. MITCHELL WALDROP

*The meeting "Neutrino '90," was held on 11 to 15 June in Geneva, Switzerland.

Glasnost, Greenhouses, and Ice Ages

Glasnost has come to the study of ancient climate. U.S. scientists are finally getting their hands on glacial ice that lay as much as 2 kilometers down in the Antarctic ice cap until Soviet researchers drilled it out in the early 1980s.

For almost a decade, the French were the only foreign researchers with access to those ice samples and the 160,000-year climate records they contain. But at the recent American Geophysical Union meeting in Baltimore, a group from the University of Rhode Island (URI) presented some of the first U.S. analyses of ice from Vostok, the Soviet drill site in central East Antarctica. The new U.S. results add support to the theory that natural greenhouse gases helped the planet break out of the penultimate ice age about 140,000 years ago.

The work was greatly helped by a novel method developed by the URI group for measuring the total volume of glacial ice in the world simply by analyzing a bit of ice that formed at the time. In the past, oceanographers had to go to deep-sea sediments to infer ice volume, but they could get a reading on greenhouse gases only from ice cores. That was a problem for researchers who wanted see whether an increase in greenhouse gases had preceded the first melting of glacial ice. If it did, the enhanced greenhouse could have helped cause the end of the ice age. But the comparison has been tricky because deep-sea and ice records have no common time scale.

Now the ice volume technique developed by marine geochemists Todd Sowers and Michael Bender of URI, in collaboration with colleagues at the University of Grenoble, France, and in the Soviet Union, avoids having to make any ice–deep-sea comparisons. The trick was to find a record in ice that responds to changing ice volume much the way deep-sea sediments do.

The URI group's tie between ice core and sediment core comes in seawater. The isotopic composition of seawater's lighter oxygen—the proportions of oxygen-18 and oxygen-16—varies along with ice volume. That happens because seawater becomes enriched in oxygen-18 when water containing only oxygen-16 preferentially evaporates from the ocean and falls as snow on the ice caps. Microfossils that form sediments pick up these variations in seawater's isotopic composition.

Sowers and Bender monitor the same isotopic variations of seawater in the Vostok ice. These variations were recorded in the air bubbles trapped when snow was squeezed into ice. The air's oxygen had in turn been released from seawater by photosynthesis.

Sowers and his colleagues found that the ice did not begin to melt until roughly 3000 to 5000 years after carbon dioxide and methane began to increase and temperatures began to rise at the end of the penultimate ice age. Subtleties in the link between seawater and atmospheric oxygen create some uncertainties in the timing of the greenhouse and melting, but Bender believes that there is an 80 or 90% chance they have the right order of events. If so, it that the greenhouse warming is a cause, and not an effect, of the end of an ice age.

This finding from the Vostok core supports earlier work by Nicholas Shackleton of the University of Cambridge and Nicklas Pisias of Oregon State University. Analyzing sediments, they found that an indirect measure of atmospheric carbon dioxide increased before ice melting began, and that it followed a change in the shape of Earth's orbit. Many researchers consider such orbital variations, the so-called Milankovitch mechanism, to be the ultimate trigger for ice age initiation and termination.

Much work remains to be done on ice from Vostok drilling, which is now being analyzed at three U.S. institutions. For example, something else must have helped end the penultimate ice age, because an enhanced greenhouse can account for only about half of the observed warming.

■ RICHARD A. KERR

Big Number Breakdown

Armed with a powerful new method of factoring and assisted by hundreds of mathematicians and computer scientists around the world, two researchers have found the factors of a 155-digit number. This number, which is by far and away the largest ever factored, had spent the last several years at the top of a list of "most wanted" numbers that have not yet been factored but are known not to be primes.

Aside from its intellectual satisfactions, this feat has some significant implications for much more worldly matters—such as protecting bank accounts. Some of the most sophisticated current schemes for ensuring the accuracy of electronic fund transfers, for example, rely on the difficulty of factoring very large numbers. A truly efficient factoring method, such as an improved version of the one used to factor the 155-digit number, could cause commercial headaches.

That feat was accomplished on 15 June, after about 2 months of effort, by Mark Manasse of Digital Equipment Corporation and Arjen Lenstra of Bellcore. The big number, which can be written as $2^{512} + 1$ is known as F_9. When the dust settled, F_9 appeared on Manasse's computer screen as the product of a previously known seven-digit prime and two new primes having 49 and 99 digits, respectively.

F_9 derives its monicker from the 17th-century mathematician Pierre Fermat. Sometime around 1640 Fermat conjectured that numbers of the form $2n + 1$ were prime whenever n was a power of 2. And indeed, the first four such numbers—5, 17, 257, and 65,537—are primes. But after that Fermat was mistaken: the next four (make that five, now) have been factored and many more are known to be composite (nonprime).

The new algorithm that Mannasse and Lenstra used for factoring F_9 is called the number field sieve. The sieve is a child of the fertile brain of British mathematician John Pollard, who introduced two other factoring algorithms for large numbers during the 1970s. It is closely related to a method called the quadratic sieve, which Manasse and Lenstra have used in previous factoring work.

Both sieves break the task of factoring a large number into a huge set of smaller factoring problems. These can then be farmed out—hence the large number of collaborators in the F_9 work. When enough results are in, the master computer stitches them together to form a candidate factorization. If the first try fails, the computer simply tries another combination of factors.

In case of F_9, the stitching was itself a major computational operation. Manasse and Lenstra estimated that one key step would have taken 6 weeks of computing time on a VAX 11/780. They were ultimately able to do it in 3 hours on a Connection Machine supercomputer at the Supercomputer-Computational Research Institute at Florida State University.

Successful as it was in this case, the number field sieve is not yet practical for use on all the large numbers that are currently of interest. The key new feature of the number field sieve is that the smaller factoring problems are done not with ordinary integers but with a number system that includes the root of a carefully chosen algebraic expression called a polynomial. The advantage of working with such "algebraic integers" is that it makes the smaller factoring problems even smaller, increasing their yield through the sieve.

This speeds up the algorithm for numbers of the form $an + b$, such as F_9, where the algebra is relatively easy. A theoretical generalization of the method is known, but it doesn't outperform the quadratic sieve until the numbers get up into the 200-digit range—where neither algorithm is currently practical.

That's good news for at least one group: cryptographers who make a living using big numbers to protect things like transfers between Swiss bank accounts. Schemes for encoding data based on number theory are just coming into commercial use, and a generalized, efficient factoring algorithm could bring the robbers up to speed with the cops.

But that hasn't happened yet. So far the cryptographers have been able to stay out ahead of the factoring community. In fact, the advances that make it possible to factor 100-digit numbers also make it possible to use codes based on 200-digit numbers. "We have hardware technology on our side," says Burt Kaliski, a cryptographic systems scientist at RSA Data Security, Inc., in Redwood City, California. The factoring of F_9 "doesn't threaten our business," he adds. "It only confirms that our estimates of the difficulty of factoring are accurate."

And what is Manasse and Lenstra's next big-number target? The obvious successor at the top of the most wanted list is F_{10}. But that's out of the question for now. Manasse estimates that factoring F_{10} with existing methods would require half a million times the resources that went into breaking down F_9 into its components.

It might be possible to manage a tenfold increase in resources, Manasse says, but that still leaves a factor of 50,000 to be accounted for. And when you multiply 50,000 by the 2 months that it took to pick apart F_9, Manasse says, you're starting to "talk about some serious computing time."

■ BARRY CIPRA