Solar Neutrino-Sunspot Connection Found

Already low, the solar neutrino rate drops when the sunspots increase and rises only when they fall again; what is going on?

SOLAR NEUTRINOS keep getting weirder and weirder.

First there was the original "solar neutrino problem," now almost 20 years old: the neutrinos being produced by fusion reactions in the core of the sun seem to be getting lost on the way out. More precisely, the one apparatus in the world capable of detecting those neutrinos, a huge tank of chlorine-rich bleach installed in 1968 in South Dakota's Homestake gold mine, has consistently found on average only one-third to one-fourth of the neutrinos predicted by standard astrophysical theory. And despite the extreme difficulty of detecting the ghostly particles, no one has ever been able to find a significant flaw in the experiment.

Now neutrino researchers have still another mystery to deal with. The Homestake group, led by University of Pennsylvania radiochemist Raymond Davis, has confirmed what was previously only suspected: the neutrino flux reaching Earth is heavily influenced by the 11-year sunspot cycle.

Sunspots? It does seem peculiar, admits Pennsylvania's Kenneth Lande, a senior collaborator on the Homestake experiment and the one who presented the new findings at a recent meeting of the American Physical Society.* After all, he says, the fusion reactions that generate the neutrinos take place only in the sun's central core, whereas the turbulent magnetic fields that produce the solar activity cycle seem to occur throughout the sun. And while the neutrinos obviously have to pass through those upper layers on their way out, standard particle theory says that they interact very weakly with ordinary matter and even more weakly with magnetic fields. So it's hard to see how the solar cycle could have any effect.

Except that somehow it does, says Lande. In 1980, at the peak of the previous solar cycle, the neutrino flux fell nearly to zero. Then it slowly rose again until 1986, when the sunspots were near a minimum. At that point, the flux reached a peak of about 4.2 "Solar Neutrino Units" or SNUs—the SNU being a convenient measure of neutrino reaction rate defined by Davis. But then in the summer of 1988, as the number of sunspots began to climb again toward the current sunspot maximum, the neutrino flux fell precipitously to 1 SNU and remained there for another year.

More recent data is still being analyzed, says Lande. But with nearly 20 years of data now in hand, the conclusion seems inescapable: "The solar cycle and the solar neutrino flux are anticorrelated."

How could this be? Although no one knows for sure, says Lande, neutrino watchers now favor a hybrid model proposed independently in 1988 by Soviet physicist E. Kh. Akhmedov, and by William J. Marciano and C. S. Lim at the Brookhaven National Laboratory.

The first half of the hybrid is the Mikheyev-Smirnov-Wolfenstein (MSW) model, which was first proposed in 1986 to explain why the average solar neutrino flux is so low. This model is based on the fact that there are actually three types of neutrinos in nature: the electron, tau, and muon neutrinos. The sun produces electron neutrinos—and that is the only type detectable at Homestake. According to some of the grand unified particle theories, however, certain subtle interactions with ordinary matter on the way out of the sun could cause the original electron neutrinos to "oscillate," occasionally transforming themselves into either of the other two types—which the Homestake detector would never see.

The second half of the hybrid is known as the anomalous magnetic moment model, which starts from the fact that each of the three known types of neutrinos also spins like a gyroscope. According to standard particle theories, moreover, they always spin counterclockwise around their direction of motion—a property that physicists refer to as being "left-handed." Right-handed neutrinos aren't allowed because standard theories offer them no way to interact with ordinary matter, which means they can never be produced or detected.

According to the anomalous magnetic moment model, however, this prohibition is sometimes lifted. In particular, the model stipulates that neutrinos of all types should interact with magnetic fields about ten times more strongly than standard theory allows. So if a neutrino exiting the sun were to encounter a particularly intense magnetic field—the kind that might prevail during times of high solar activity—the interaction might actually be able to flip the particle's spin and transform it into a right-handed neutrino. And since these flipped particles would be undetectable at Homestake or anywhere else, the falloff at the peak of the solar cycle would be explained.

These two half-theories become unified, Lande explains, when the energy of a neutrino's oscillation produces the energy needed to flip its spin. Both the neutrino deficit and the solar cycle connection can thus be explained by a single mechanism.

Unfortunately, says Lande, none of the model possibilities can be verified by the Homestake experiment, which even leaves some slight room for doubt about the existence of the solar neutrino deficit. It detects the conversion of chlorine-37 to argon-37,

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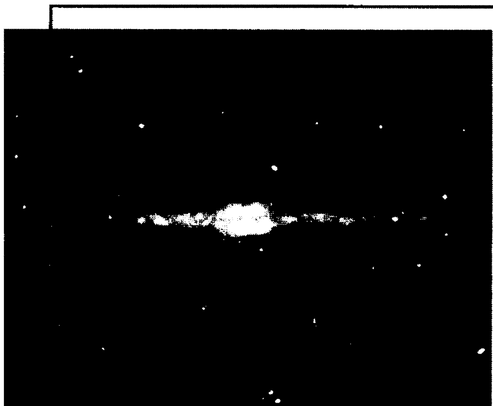

Family portrait. No, this isn't an image of some far-distant galaxy taken through a telescope, although that is certainly what it looks like. In fact, it's the clearest view ever of our own cosmic home town—an edge-on view of the Milky Way galaxy as seen by the infrared eyes of NASA's Cosmic Background Explorer satellite (COBE).

"Wonderful stuff!" exclaims COBE scientist David Wilkinson of Princeton University. Indeed, this view far surpasses a similar galactic center image made by the Infrared Astronomy Satellite in 1983.

The COBE image, which was presented at the American Physical Society meeting by Michael Hauser of Goddard Space Flight Center, is a composite of three produced by the Diffuse Infrared Background Experiment (DIRBE). When astronomers look at the sky in visible light, they find the center of the Milky Way obscured by foreground stars, gas, and galactic dust. But infrared radiation cuts through all that and allows a view all the way in. The DIRBE image shows the individual stars as distinct points of light. In the distance, 28,000 light-years away from Earth, is the bulge of stars and gas at the galaxy's center. And stretching to either side, like a phonograph record seen on edge, is the flat disk of gas and stars that forms the Milky Way's spiral arms.

■ SARAH WILLIAMS

which can be triggered only by relatively high-energy neutrinos produced by a rare side reaction in the sun. Skeptics can always argue that the "deficit" is really just some omission from the calculations by which theorists extrapolate from the side reaction to the whole sun.

By the end of this year, however, that situation should be clarified. The first results should be in from two new detectors in Europe and the Soviet Union, both of which look for the interaction of solar neutrinos with gallium. (*Science*, 16 March, p. 1291). This reaction is sensitive to the lower energy neutrinos produced by the fusion of protons into helium—the process that produces the vast majority of the sun's energy. Calculations made directly from the sun's known energy output show that proton-proton fusion should produce at least 70 SNUs in the gallium detectors. "If the gallium experiments see a lower rate," says Lande, "then something is definitely happening to the neutrinos."

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Who Will Win the El Niño Sweepstakes This Time?

Who makes the best forecasts of El Niño, man or machine? So far the machines—the computer models—have the upper hand. They won the first and only round 4 years ago when they correctly predicted the last El Niño, the occasional extreme warming of the tropical Pacific Ocean. Human forecasters at the time failed to see it coming. But now another test is under way and the positions are reversed. Will the models win again? Or will the human observers come out on top, reversing their decade-long string of embarrassing oversights and false alarms?

Much of the world's weather is riding on the answer. El Niño has been linked to a slew of weather extremes around the globe. It can bring unusually wet winter weather to the U.S. Gulf Coast, warm winters to Alaska and western Canada, heavy rains to Peru, and failure of the Indian monsoon rains.

Such crazy weather in the next year would not surprise human El Niño watchers. For a couple of months now, they have been saying it looks as if an El Niño will be here by winter. The tropical Pacific Ocean is already warming, they note, and wind shifts overhead should be sending in even more warm water. These same researchers failed to predict both El Niños of the 1980s, but the strength of the ongoing changes in the Pacific has brought them as close to making a forecast as they ever get. "The larger-scale pattern, to me, is clearly moving into a warm phase," says veteran El Niño watcher Eugene Rasmusson of the University of Maryland. "It looks like we're well into the transition" to a full-blown El Niño.

It may *look* that way, say researchers who use mathematical models to predict El Niños, but the humans may have been fooled by an ephemeral warming. Three of the four forecast models call for near normal conditions the rest of this year, not an El Niño. "My subjective feeling is that everything is going along [toward an El Niño]," says modeler Mark Cane of Columbia University's Lamont-Doherty Geological Observatory, "but [subjective judgments] have been wrong in the past. It's possible that, despite all the signs and portents, there won't be an [El Niño] event" and the three models, including Cane's, will be right after all. The other two are those of Tim P. Barnett at Scripps Institution of Oceanography and Jingsong Xu and Hans von Storch of the Max Planck Institute for Meteorology in Hamburg. The fourth model, run at Florida State University by James O'Brien, has come down on the side of the humans, however.

The last time the humans and the models went eyeball to eyeball over El Niño, the humans blinked first. In December 1985, Cane and Stephen Zebiak of Lamont went public with their model's prediction of an El Niño warming in the Pacific by the fall of 1986. The Lamont forecast was eventually confirmed by the Florida State and Scripps models. By February of 1986, most of the humans were also concluding that a warming then under way showed every sign of becoming an El Niño.

Then, in the face of what appeared to be imminent success for both subjective and objective forecasting, the tropical Pacific reversed itself and marched right back to normal conditions by late spring. The humans, blown by every changing wind, now saw little hope of an event by fall and in essence withdrew their El Niño prediction, while the modelers, stuck with their forecasts, wondered what might have gone wrong with their new toys. But, just when things looked bleakest for the model forecasts, the Pacific did another about-face and headed into a bona fide El Niño (*Science*, 13 February 1987, p. 744). The models had won after all.

Much rides on the outcome of the latest round of opposing El Niño forecasts. If the human forecasters prove to be wrong, they will have to confront the likelihood that their intensified monitoring of the Pacific in the 1980s has revealed unsuspected complexities in the canonical picture of El Niño originally developed in the 1970s.

If the models prove to be wrong, it would be a doubly severe blow because two types of computer models are being used to predict El Niños—and both would have failed. One type, as exemplified by the Lamont model, uses a crude simulation of the winds and currents of the tropical Pacific to predict sea-surface temperatures and sea levels several seasons into the future. The other objective forecast method, typified by the Scripps model, uses statistical techniques to look beyond the month-to-month variability in the tropical Pacific that has confused human observers in the past. Instead, these methods allow a search for patterns of long-term change that are harbingers of El Niño.

The current forecast confrontation also offers a newcomer to the model forecasting business a chance to win converts. Last November, before any signs of a Pacific warming had appeared, the Max Planck group announced—via the electronic mail network favored by El Niño researchers—that their statistical model was calling for a warming that would become evident during the coming winter. Other researchers initially paid little attention to the forecast from this newest of the models, but they have become intrigued after the recent warming in the tropical Pacific.

The Max Planck model could soon look even better. In an interview at press time, von Storch told *Science* that based on February's observations, their model has produced a new forecast. The current warming, according to the model, "will not fully develop. It will be an aborted El Niño similar to that of 1974," says von Storch. Ironically, it was February observations that finally drove the Florida State simulation model to call for an El Niño.

When will we know whether man or machine has won the El Niño sweepstakes? Not until fall, so don't make plans for a western Canada ski trip just yet. ■ RICHARD A. KERR