# 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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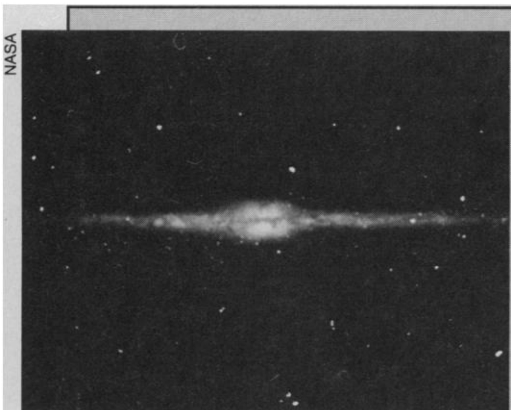

**Family portrait.** No, this isn't an image of some far-distant galaxy taken through a telescope, although that is certainly what it looks like. In fact, it's the clearest view ever of our own cosmic home town—an edge-on view of the Milky Way galaxy as seen by the infrared eyes of NASA's Cosmic Background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