Underground astronomer
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UNDERGROUND ASTRONOMER

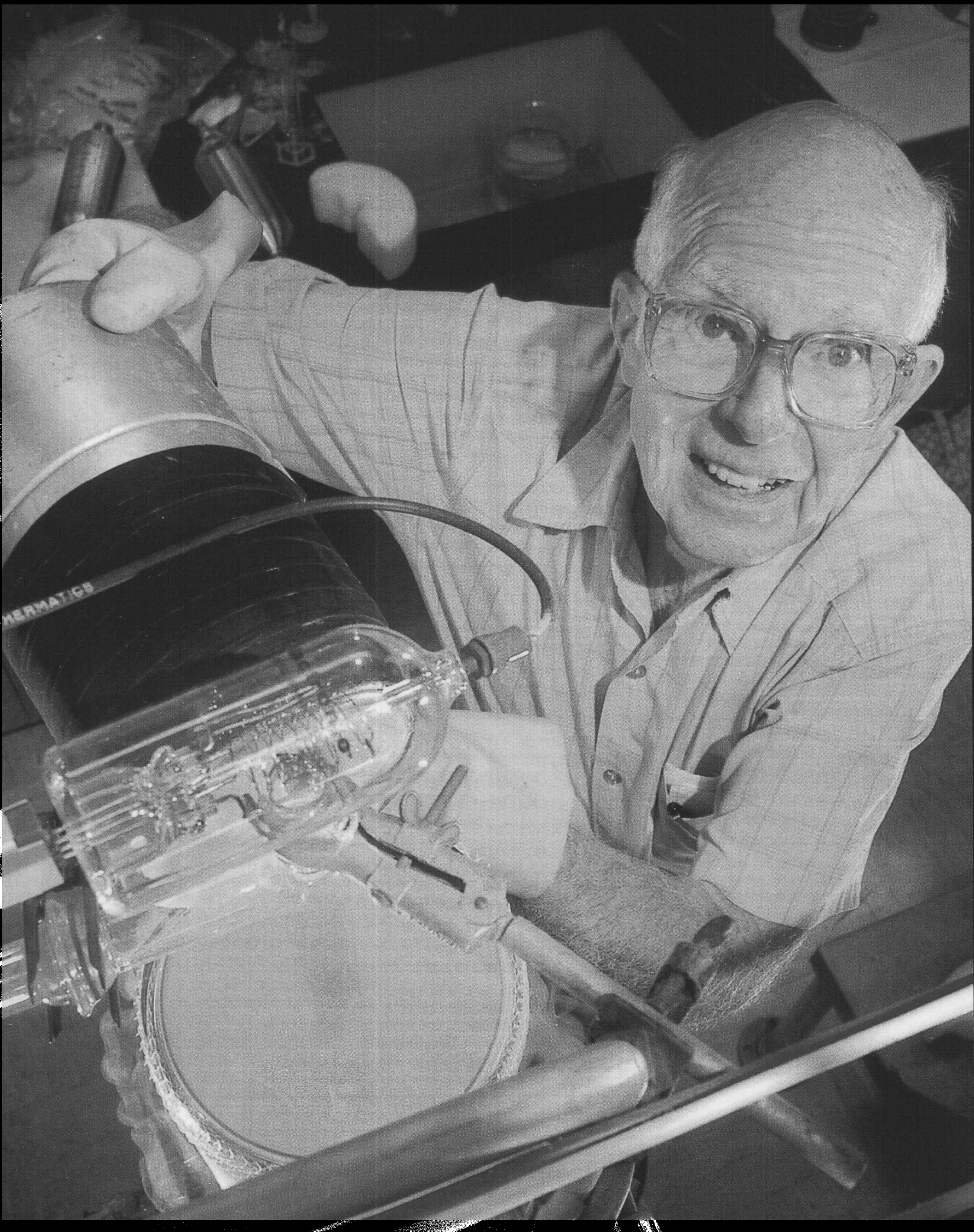
Ray Davis gave an active gold mine a second job — as a neutrino telescope.

by Marcia Bartusiak

Raymond Davis is famous for originating "underground astronomy." To examine the very heart of the sun, he went to the Black Hills of South Dakota in the 1960s and set up a detector nearly a mile below the surface. It operates to this day.

This solar telescope looks like no other on Earth. It resembles a huge, gray oil tank with rounded ends. Its construction crew affectionately called it "the horizontal blimp." Forty-eight feet long and 32 feet in diameter, this container is filled with 100,000 gallons of dry-cleaning fluid (perchloroethylene). Davis uses this chemical reservoir to trap neutrinos, the most ghostly particles in nature's arsenal. He's been gathering them, as they shoot through Earth, to understand the furnace powering the sun. His results have rattled solar physics for three decades, spawned even bigger subterranean neutrino observatories around the world, and forced particle physicists to rethink their notions about the lowly neutrino.

Roger Stoutenburgh/Brookhaven National Laboratory


HERMATICS

Sheer curiosity led Davis into his job as a solar-neutrino hunter. Trained as a chemist, Davis obtained his doctorate at Yale University, where he investigated the chemistry of soda water. World War II brought him to Dugway Proving Ground as an army liaison officer to the Air Chemical Office. After the war, he worked for Monsanto Chemical Company as a radiochemist, a job that deals with radioactive elements. By 1948, at the age of 34, he started what would become a lifetime career as a research scientist at the Brookhaven National Laboratory on New York's Long Island.

"It was the type of lab where you could choose your own problem," says Davis. He happened to read a journal article on neutrinos and was inspired to try to catch one directly. They were as yet unseen. The Viennese physicist Wolfgang Pauli first proposed the particle's existence in 1930 to explain an energy that is mysteriously lost during radioactive decay. As then conceived, the neutrino had no mass, no charge. It was merely an energetic mote, akin to a photon of light.

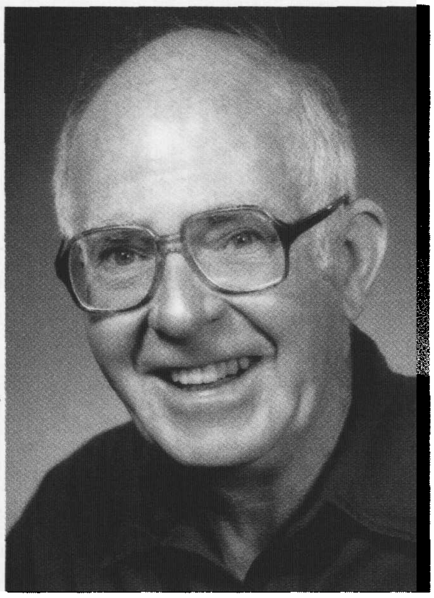
Davis's detectors were tanks filled with hundreds of gallons of carbon tetrachloride, set up first at Brookhaven then at the Savannah River nuclear power plant in South Carolina. A theorist had pointed out that when a neutrino bumps into a nucleus of chlorine, the chlorine would turn into traceable radioactive argon. It was the perfect strategy for Davis, given his background in radiochemistry. Normally, a neutrino is so elusive that it would take a stack of lead, hundreds of light-years in length, to stop one in its tracks. But Davis knew that the odds would be increased if a flood of neutrinos, such as one that might spew from an atomic reactor, is coming at you. He was in friendly competition with physicists Frederick Reines and Clyde Cowan, who were also at the plant looking for neutrinos but using a different method. In 1956, they won the competition and were awarded a Nobel Prize as well. However, Davis wasn't discouraged. He turned his chlorine-filled tank into a solar telescope.

The sun, it turns out, is the best source of neutrinos for Davis's chemical method of detection. A preliminary search in an Ohio limestone mine turned up nothing. But by the 1960s, theorists at the California Institute of Technology were tinkering with their solar models and concluding that the sun should be emitting enough high-energy neutrinos for Davis to detect — if his tank were bigger. "Everyone was stirred up by the possibility," says Davis. Here was the chance to look directly into the heart of the sun. He decided on a 100,000-gallon tank, bigger than the theorists suggested. He didn't want to take the chance that they had overestimated the flux of neutrinos. He placed his tank 4,800 feet underground, far from disruptive cosmic rays, in South Dakota's Homestake Gold Mine. Miners carved out a special niche for it. The Atomic Energy Commission paid the bill for the ambitious enterprise.

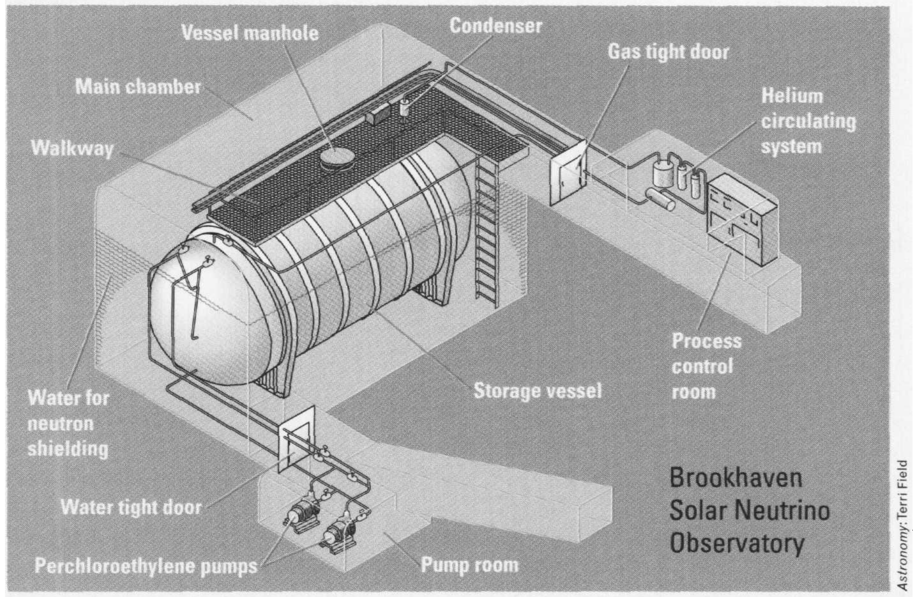
"It cost about 60 Cadillacs," says Davis, around $600,000. Ten railroad tanker cars were brought in to fill the tank, this time with less toxic perchloroethylene as his source of chlorine, roughly the amount of stain remover American consumers use in 24 hours. Davis is proud to say "it has never leaked." One percent of Earth's atmosphere is argon, so a leak would have ruined the experiment. With the

Previous page: Raymond Davis continues his work at Brookhaven National Laboratory. Below: In the 1960s, the Homestake Mining Company gave Davis's neutrino telescope a home in its active South Dakota gold mine.

Brookhaven National Laboratory



Raymond Davis is currently working on equipment that he hopes will count antineutrinos.



Original plans for the Davis solar neutrino telescope were drawn in the early 1960s. An early version was built at Brookhaven, then another at the Savannah River Nuclear Power Plant.

tank filled and the valves closed starting in 1967, Davis's team waited for the neutrinos to do their work.

Deep in the core of the sun, where temperatures reach up to 15,000,000° K, hydrogen nuclei — protons — collide and merge. During one second, half a billion tons of hydrogen are converted into helium, releasing a flood of neutrinos in the process. They escape with nary a fight, and each second 66 billion of them rain down on every square inch of Earth's surface and pass right on through. Occasionally, however, one will turn a chlorine atom into argon within Davis's tank. About every two months, the argon gets extracted by bubbling helium gas through the cleaning fluid. Sent through a cold trap, the argon freezes out of the gas.

By 1971, Davis had enough data to issue his first report. The results were surprising: The Homestake "telescope" was capturing about one neutrino every other day, between a third and a half of what solar physicists were expecting. Holding fast to their models of nuclear burning, theorists blamed either Davis's equipment or his chemistry. But after running numerous checks, Davis was sure his results were right. Solar physicists couldn't completely explain how the sun shined.

Over the next three decades, the Homestake result stood firm. Later, bigger and more sophisticated neutrino observatories were built in Japan, Russia, Italy, and Canada. They confirmed Davis's initial findings.

Although the controversy is far from settled, the most popular explanation for the shortfall arrives, not from solar physics, but from particle physics. Neutrinos come in three "flavors" (as theorists like to put it): the electron neutrino, the muon neutrino, and the tau neutrino. As the sun releases its storm of electron neutrinos, some might be changing their identity before they get to Earth, into the other flavors that the Homestake tank can't detect. And, to do that, the neutrinos must have a tiny bit of mass, a revolutionary finding. The cosmos released hordes of neutrinos at its birth. Given a little mass, this cosmic ocean of shadowy particles could be affecting the universe's evolution and destiny. And, to think, this revelation first arrived within a bit of cleaning fluid. Forced to retire from Brookhaven at the age of 70 in 1984, Davis has been carrying on his experiment as a research professor at the University of Pennsylvania. Now in his 80s, he can recall with vivid clarity the smallest technical detail of his instrument, as well as the names of every colleague who came to his aid. It has been his life for four decades. And it continues to be. From the home on Long Island he shares with his wife of 52 years, Anna, he commutes a few days a week to Brookhaven to work on equipment that may allow the Homestake telescope to count antineutrinos as well. (They turn chlorine into sulfur.)

The experiment was temporarily suspended for three years, due to a lack of money. But the University of Pennsylvania just received a grant to resume the operation for three more years, under the direction of Kenneth Lande. "I have a personal reason to continue it," says Davis. He is convinced that he is seeing the neutrino signal vary with the eleven-year solar cycle, and in an intriguing way. When the sun is most active — the number of its sunspots at its highest — he sees fewer neutrinos. The effect reverses when solar activity is on the wane. "It's a fairly good conclusion, but not everyone buys it," he says in his generous, self-deprecating manner. Moreover, he has also registered higher neutrino counts when solar flares pop off. His highest count occurred during a run in the 1970s when the sun emitted a particularly powerful solar flare. At the time, his tank registered double its normal count of neutrinos. But no other neutrino observatory is seeing either of these effects, although they are quite capable of doing so. Davis is determined to keep the Homestake telescope going to gather more data.

"Solar models are not perfect. We don't know what's happening in the core of the sun," he notes. "There's still a surprise there." Is he ready to go out to South Dakota again? "As soon as they give me an airplane ticket," he replies readily.

Contributing Editor Marcia Bartusiak is writing a book on gravitational-wave astronomy.