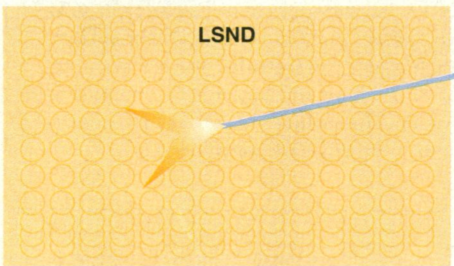
Found: Candidate for Missing Mass?

A Los Alamos team reports that the phantomlike particles called neutrinos may have a trace of mass. If so, physics and cosmology may both need amending

If a discovery announced by researchers at the Los Alamos National Laboratory holds up, poetic justice will have prevailed. Ten years ago, Hywel White, co-spokesperson for the experiment, was responsible for experimental programs at the ISABELLE Accelerator when the $200 million project at Brookhaven National Laboratory was aborted before completion. Three years ago, as White and his colleagues geared up for their experiment at the Los Alamos Meson Physics Facility (LAMPF), their plans were almost thwarted when LAMPF had a narrow brush with bureaucratic death. Last week, however, they reported evidence that could revolutionize physics and cosmology.

A handful of flashes in an oil-filled tank at the end of a LAMPF beamline imply that the chargeless—and supposedly massless—parti-



SOURCE: LSND

Wiggle room. Neutrinos generated at the end of a proton beam *(right)* may "oscillate" to a new variety on their way to a detector *(above)*.

cles called neutrinos may indeed have a small mass, between one millionth and one hundred thousandth the mass of an electron. That smidgen of mass, if real, would be the first sign of physics beyond the "Standard Model," the theoretical framework that explains the basic particles and forces of nature. Little neutrinos, as physicists are already calling them, could also provide at least part of the answer to the enigma of dark matter that bedevils cosmologists (see box on p. 790). Bernard Sadoulet, who hunts dark matter at the Institute for Particle Astrophysics at the University of California (UC), Berkeley, calls the result "fantastic." Then he adds, "If it is correct."

The caveat isn't trivial. Over the years, the quest for neutrino mass has proved to be among the most difficult in high-energy physics. Because neutrinos barely interact with matter at all, it is an experimental feat just to detect them, let alone weigh them. As a result, the history of the quest is littered with erroneous claims (*Science*, 8 May 1992, p. 731). Other researchers say the Los Alamos team has detected a particularly strong signal, in an experiment that one physicist describes as "remarkably simple." But the claim already seems to conflict with results from two other experiments, one at Brookhaven and the other at the U.K.'s Rutherford Appleton Laboratory, which saw nothing in the mass range probed by the Los Alamos group.

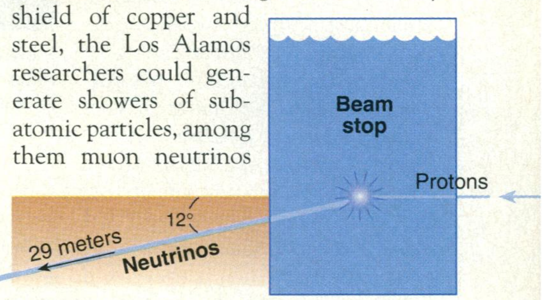
Adding to the caution voiced by Sadoulet and others, the discovery was first reported on page one of the *New York Times*—before a paper had been written or a preprint distributed, and even before the group was scheduled to present its latest data to colleagues at Los Alamos. Other physicists and cosmologists found themselves confronting what could be the discovery of a lifetime with nothing more to go on than newspaper reports and rumor. "All we have is what we read on the front page of the *New York Times*," says Mel Schwartz, a Nobel Prize–winning physicist at Columbia University.

Physicists and cosmologists have long been haunted by the possibility that neutrinos have mass. In the 1970s physicists trying to replace the Standard Model with more encompassing Grand Unified Theories (GUTs) found that GUTs predicted a small neutrino mass. But the theories lost favor when this prediction and others failed to pan out. Around 1980 cosmologists began talking about massive neutrinos as a likely component of the invisible dark matter that theory and observations suggest pervades the universe. Lately, support for neutrino mass has come from experiments that detect fewer neutrinos streaming from the sun and from cosmic rays bombarding the upper atmosphere than theory predicts.

These experiments are sensitive only to particular kinds of neutrinos, which come in three "flavors" (electron, muon, and tau). Theorists proposed that the deficits could be explained if neutrinos change in midflight from one flavor that is detectable to another that is not. According to theory, such "oscillations" would require that the two flavors of neutrinos have different masses—implying a nonzero mass for at least one.

The Los Alamos experiment was set up in 1988 to search for neutrino oscillations. The idea, says White, was to create a neutrino source in which one neutrino flavor would be conspicuously absent and then, some distance away, set up a detector capable of recognizing the signature of that particular flavor. Barring artifacts, any signals above the expected background might be a sign that neutrinos had oscillated from one flavor to another.

By directing the proton beam from LAMPF into a water target surrounded by a shield of copper and steel, the Los Alamos researchers could generate showers of subatomic particles, among them muon neutrinos



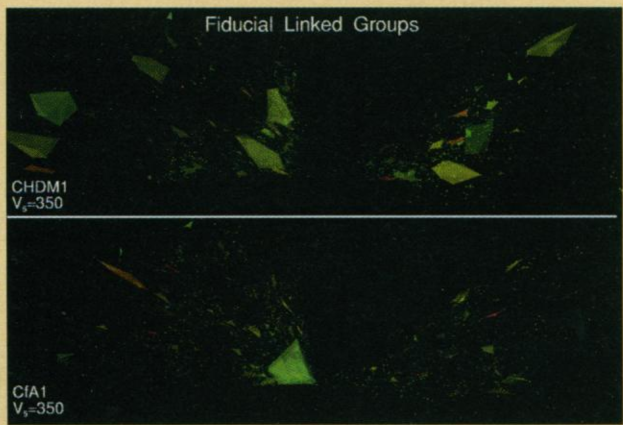
and their antimatter counterparts, muon antineutrinos. Thirty meters away, they set about building the Liquid Scintillator Neutrino Detector (LSND), a 51,000-gallon tank filled with a mixture of baby oil and a liquid scintillator—a compound that emits a flash in response to a high-energy particle—and lined with 1220 light-detecting photomultiplier tubes. LSND was designed to detect one neutrino flavor not generated by the source: electron antineutrinos. Any that impinged on the detector would interact with protons in the oil, generating a glimmer of scintillation, a flash of what's known as Cherenkov light, and a gamma ray of exactly 2.2 million electron volts.

The project was almost shut down in 1992 when the Department of Energy (DOE) announced the termination of LAMPF. But DOE's Nuclear Science Advisory Committee urged a reprieve, and in August 1993, the LSND finally got a chance to take data, albeit only for a month. Over the next year, the LSND researchers tantalized their colleagues at conferences with a view graph of the results. It showed a signal of eight electron antineutrino events, seven more than expected from background events such as cosmic ray interactions. It was, says University of Chicago cosmologist Michael Turner, "the kind of view graph you take to Stockholm."

But that was as far as it went. "We had very low [numbers]," explains William Louis, the LSND's other spokesperson. "We were nervous and didn't want to say more." Last August through November, the team got a

Cosmologists Hail the Little Neutrino That Could

If neutrinos do have a trace of mass, as recent results from Los Alamos National Laboratory suggest (see main text), they will still be among the wispiest of subatomic particles. But because the universe is aswarm with neutrinos, that tiny mass could have had a mighty effect on its formation and evolution. A neutrino weighing a few electron volts may be exactly what is needed to explain some of the mysterious dark matter whose gravitational influence may have sculpted the universe.



SOURCE: PRIMACK ET AL.

Pleasing resemblance. In computer images made at the IBM Almaden Research Center, a combination of cold dark matter and neutrinos (CHDM1) produces a distribution of galaxies *(points)* and galaxy groups *(boxes)* similar to those observed (CfA1).

Theory and observation hint that this invisible matter may outweigh the visible matter of stars and galaxies by a factor of 10 or more, and cosmologists have struggled for years to come up with a substance that could explain it. Many have favored "cold dark matter"—hypothetical particles that move much slower than the speed of light. Computer simulations of such a universe do generate the kind of galaxy clusters and superclusters that astronomers have mapped—but also form too many smaller structures, such as galaxies. "Cold dark matter looks pretty good," says University of Chicago cosmologist Michael Turner, "but it's not perfect. There are a number of ways of patching it up; one is to add a little bit of hot dark matter"—particles moving near light speed—"in the form of neutrinos."

But that model, advocated by physicists including Joel Primack of the University of California (UC), Santa Cruz, can work only if neutrinos carry some mass. Last fall, after early hints that they do, David Caldwell, a UC Santa Barbara physicist and a member of the Los Alamos experiment, teamed up with Primack to test the cold-plus-hot recipe. With John Holtzmann of the Lowell Observatory and Anatoly Klypin of New Mexico State University, they created a huge supercomputer simulation that followed 50 million particles of visible and dark matter—80% cold, 20% hot—from the birth of the universe through the formation of structure.

When they put in the number from Los Alamos—a neutrino mass of about 2.5 electron volts—they hit the jackpot, says Klypin. "You guess and guess and guess, and nothing works, but we plug in [the Los Alamos result], and, gasp, it produces good results"—a universe much like our own. As Caldwell puts it, the result "comes out in such a miraculous way, I tend to believe that it can't be by chance."

Other cosmologists are less confident that a 2.5-electron-volt neutrino is the answer to the dark matter puzzle. "Mixed dark matter solves some problems very gracefully," says Princeton University's Jim Peebles, "but there are apparent dilemmas it leaves unsolved." In particular, he points out, galaxy formation seems to take place too late in mixed dark matter models.

–G.T.

chance to triple their running time, accumulating 80 possible observations of electron antineutrinos, which was 40 more than could be accounted for by any conceivable background process. "Now we say we have evidence for neutrino oscillations," says Louis.

That evidence implies that the masses of the muon and electron neutrinos must differ by about 2.4 electron volts, and both masses must lie somewhere between 0.5 and 5 electron volts, says UC Santa Barbara physicist David Caldwell, a member of the LSND team. (An electron volt is a measure of mass as well as energy.) Those masses are just in the range predicted by cosmologists pondering dark matter. "If it's real—and that's still a bit of a stretch at this point—it really does solve a riddle in cosmology," says Turner. Less encouraging is the apparent conflict with the experiments at Brookhaven and in the United Kingdom, and the fact that the mass difference implies an oscillation rate 100 times too large to resolve the solar neutrino problem and 10 times too large for the atmospheric neutrino deficit.

Physicists trying to make sense of it all were hampered by what Jim Peebles, a Princeton University cosmologist, calls the Los Alamos experiment's "sorry history of disclosure." As many saw it, instead of cooperating with the community to help assure that the results were correct, the LSND researchers had cooperated with the *New York Times* to garner publicity—"with the only apparent purpose being the keeping of that laboratory open," said one physicist. LSND co-spokesperson Louis says he can't deny the importance of the favorable publicity. "I think this did strike a chord here. This has been a very difficult time for the laboratory and the DOE."

Nevertheless, two days after the *Times* article appeared, Louis gave a colloquium on the work at Los Alamos, and physicists present said the LSND team seemed to have done an impressive job—but only time would tell whether they really do understand all possible background phenomena. "They have a list of 30 backgrounds they've considered," says Los Alamos physicist Cy Hoffman. "They all appear quite small, but there's always the possibility that there's something no one has thought of yet."

The LSND researchers, meanwhile, are taking heart from some additional clues, which they have not yet discussed. "There are in effect two simultaneous experiments going on," explains Caldwell. "One is the potential conversion of muon antineutrinos to electron antineutrinos, and the other … is the possible conversion of muon neutrinos to electron neutrinos." Although the team is still working on the analysis of the electron neutrino signals, Caldwell says they seem to be above background as well.

Over the next few years the LSND researchers hope to get 10 more months of data and solidify their results. It won't be easy, however: LSND will take data in August and September, at which point DOE's Defense Programs Office will take control of LAMPF, putting it to work on defense-related research such as accelerator production of tritium. After that, the LSND researchers will have to piggyback on this defense work.

The real test of the LSND results will come when experiments based on different techniques—and presumably not prey to the same artifacts—search for the effect. Confirmation will probably take years, White notes, and meanwhile the group will be fielding questions and, perhaps, criticisms of their results. As White says, "The discovery was a lot of fun. This part of it is going to be less so."

–Gary Taubes