Physicists Close in on a Weighty Quarry

After a year of sightings, the Great (Heavy) Neutrino Hunt seems about to capture the beast—or prove it a chimera

NEUTRINOS ARE AMONG THE SLIPPERIEST creatures in the bestiary of particle physics, passing through the earth without nudging another particle. But this year they hit physicists with a jolt. A series of experiments hinted that one of the three known neutrino species might be far more massive than most physicists cared to contemplate—massive enough, in fact, to shake the foundations of particle physics and cosmology. Now several groups of physicists have set out to hunt down the unruly beast...or prove it a particle physics unicorn. If it does exist and they do find it, says neutrino tracker Wolfgang Stoeffl of Lawrence Livermore National Laboratory, "it would be the biggest discovery in 20 years."

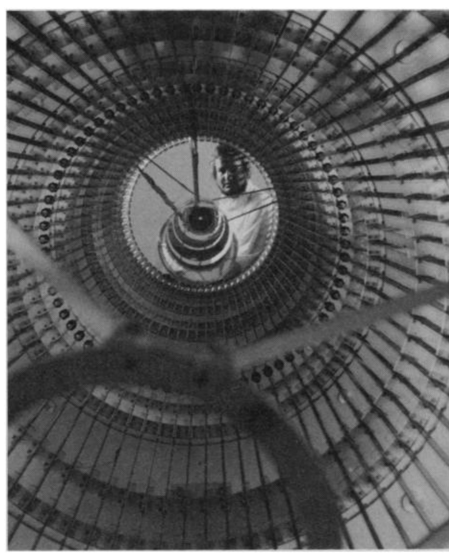
The reason: No theory predicts such a particle—on the contrary, all accepted models in cosmology and particle physics assume that neutrinos are massless, or nearly so (see box). While the heaviest neutrinos predicted by theorists ranged from 1 to maybe 10 electron volts, this woolly mammoth allegedly carries a mass of 17,000 electron volts (kev). Not surprisingly, other physicists thought this neutrino about as believable as an abominable snowman back when John Simpson, a physicist at Canada's University of Guelph, made the first heavy-nutrino sighting in 1985.

But early this year, Simpson got precious support from his former student Andrew Hime, working with Nick Jelly at Oxford University, Igor Zliman at Ruder Boskovic Institute in Prague, and Eric Norman and colleagues at Lawrence Berkeley Laboratory (see *Science*, 22 March, p. 1426). Their groups announced that they had come across tracks of this physics Yeti, and suddenly the world was listening.

Not with universal approbation, of course. The neutrino-spotters immediately found themselves under assault by another camp, led by Felix Boehm of Caltech, who had looked for the monster neutrino using a different experimental technique and found nothing. Indeed, the argument between the two groups is largely a dispute about the relative merits of their competing instrument types.

Both groups of neutrino-hunters seek their prey by observing the outcome of radioactive beta decay—a process in which an unstable nucleus in a radioactive isotope emits both an electron and a neutrino. The energy of the decay is divided between the electron and the neutrino; by gauging the electron's energy, researchers can infer the energy—which to physicists is equivalent to mass—of the neutrino.

The solid-state detectors Norman and his colleagues favor record the energies of the decay electrons by sending them into a crystal, where they knock other electrons loose, creating a current that provides a measure of energy. In the spectrum of electron energies recorded with these detectors a big, 17 kev bite regularly appears taken from the energy of a few electrons. The only explanation Simpson, Norman, and their colleagues can offer so far: The energy is going into a 17 kev neutrino.


LLNL

"Many people say if we see it, it's true, and if we don't, they are in trouble."

—Wolfgang Stoeffl

Boehm and the other nay-sayers gauge the energies of the electrons from beta decay by sending them into a magnetic field, which deflects them into circular paths. The radii of the circles indicates the electron energy, and measurements made in this way suggest that neutrinos aren't stealing any detectable share. In keeping with physics orthodoxy, the neutrino must be massless, or nearly so, say Boehm and his colleagues.

Members of each camp staunchly defend their choice of detector—and maintain that their opponents have been misled. Norman believes the agreement of his results with those reported by the Prague, Guelph, and Oxford groups argues that they are all seeing a real phenomenon. Not only do the energy spectra all show a kink at the same place (17 kev), but the kink always has exactly the same size (indicating that about 1% of the emitted neutrinos belong to the heavy species) and shape. "Personally, I find it hard to believe that each of these experimenters is doing something wrong—a different something wrong in each case and yet they are all getting the same answer. Nature would really have to be conspiring against us to do that," says Norman.

But the neutrino nay-sayers maintain that there wouldn't have to be a conspiracy—just some systematic effect that occurs in solid-state devices. After all, not much is known about how electrons behave in crystals, says Livermore's Stoeffl. "You have all kinds of effects"—vibrations of the crystal lattice called phonons and electron oscillations called plasmons—that could put spurious kinks in the solid-state signal, he says.

Norman and his solid-state colleagues think the magnetic-spectrometer camp is in no position to criticize their technique. He charges that Boehm's instruments record a distorted electron-energy spectrum, because the efficiency with which they capture electrons varies with electron energy. What's more, he says, even though the spectrometers evade some solid-state effects by snaring the electrons in a magnetic field instead of a crystal, the electrons are still generated by radioactive decay in a solid sample, where unknown solid-state effects could skew their energies, perhaps masking the signature of a heavy neutrino.

Hoping to resolve the bickering, several groups, including Stoeffl's at Livermore, have been sorting out the factors that might account for the conflict. The result: They've devised a new series of tests that nearly everyone in the field thinks will settle the question once and for all, when taken together. "If you do good experiments and you don't see it," Norman concedes, "then it's not a neutrino."

This new round of experiments will rely on magnetic spectrometers, just as Boehm's did, but they are designed to skirt the drawbacks of Boehm's setup well enough to win over

Cosmologists: "The Neutrino From Hell"

For cosmologists, evidence for a heavy neutrino should have come as a godsend. Extra mass was just what they needed to help them solve a key puzzle in their field—how matter coalesced into galaxies and the clusters of galaxies now being mapped (see *Science*, 22 November, p. 1106). "A massive neutrino is what we used to pray for," concedes Fermilab theorist Michael Turner. Maybe so, but not a beast the size of the one neutrino-hunters are now trying to corner (see main text). Turner and his colleagues call it "the neutrino from hell."

A neutrino this heavy, says University of Washington physicist Wick Haxton, conflicts with a host of measurements from astronomy and particle physics: the neutrinos detected from Supernova 1987A, observations of radioactive processes on Earth, measurements of neutrinos from the sun, and the amount of helium in the cosmos. Theorists grappling with the implications of a 17 kev neutrino have found that they can reconcile it to individual observations—but only by making different, and conflicting, assumptions in each case.

Take the 10-second pulse of neutrinos that was detected on Earth just as Supernova 1987A erupted. If it had included neutrinos as heavy as 17 kev, Turner has calculated, the pulse would have lasted just a second: Interactions among heavy neutrinos and antineutrinos would have "pulled the plug" on the star, says Haxton, letting them drain out faster. Unless, that is, the neutrinos belonged to a theoretical category called Majorana neutrinos. But Majorana neutrinos would also open the way to a radioactive process called neutrinoless double beta decay, says Turner; which has never been observed.

To reconcile that conflict, cosmologists have tried out "theories so ugly only their parents could love them," as Fermilab cosmologist Edward Kolb puts it. Beyond being ungainly, these notions also lack physical evidence: One assumes the existence of not one but two types of 17 kev neutrinos, and another would add an even heavier neutrino, of 250 kev or so. And on top of all their other handicaps, proposals for multiplying the number of heavy neutrinos run into constraints from observations.

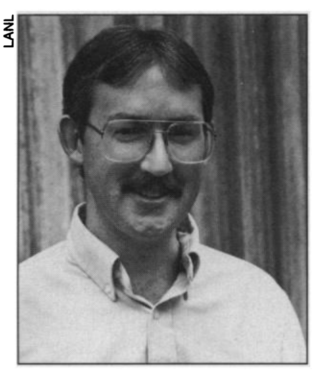
One constraint is the gap between the expected and observed neutrino output from the sun, which suggests to many theorists that one kind of light neutrino changes into a second kind of light one on its way to Earth, thereby escaping detection. Add one kind of heavy neutrino, and you've got three neutrino species. And that's all there can be, according to observations of the universe's helium abundance, which suggest that only three kinds of neutrino could have existed when the element was forged.

Still, there is a positive side to this mass of quandaries, says cosmologist Richard Bond of the University of Toronto. "You can do some interesting things with this neutrino cosmologically," he says, "as long as you give it some very specific properties." One thing you have to give it, he says, is a short lifetime. Otherwise, at the abundance experiments suggest, the 17 kev neutrino would add so much mass to the universe that it would collapse.

Suitably tamed, though, the 17 kev neutrino could help solve the problem of cosmic structure formation. Bond found that the gravitational influence of a massive neutrino could cause individual galaxies to take shape early in the history of the universe, followed by larger clusters of galaxies—the sequence supported by observations. The lighter neutrinos cosmologists had contemplated in the past couldn't do that.

Even so, Bond admits, a 17 kev neutrino would be an unruly beast. But he's confident that if the new round of experiments confirms its existence, his colleagues will find ways to cope. "I'm a believer in the cleverness of cosmologists to make a theory to fit this after the fact. ■ F.F.

even Norman. Stoeffl, for example, will measure a whole electron-energy spectrum at once—a technique that Norman concedes will minimize the distortions that plague existing spectrometers. And to rule out any solid-state effects in the electron source, the beta decay in Stoeffl's instrument will take place not in a radioactive solid but in a gas—in this case radioactive tritium (a hydrogen containing two neutrons). He adds that the detector is also designed to screen out electrons from stray beta decays in the solid walls of the sample container.


LANL

The result of these precautions, say many physicists, should be an instrument at least 10 times more sensitive than existing magnetic spectrometers—sensitive enough to capture the massive neutrino, if it exists. Stoeffl himself thinks the results should break the current impasse by the end of next year: "Many people in the community, including Norman and Simpson, say that if we see it, it's true, and if we don't, they are in trouble."

> ***"There is definitely something interesting going on that is still unexplained."***
>
> —Thomas Bowles

The neutrino community won't have to rely on Stoeffl alone to settle the issue: Frank Calprice at Princeton University and Thomas Bowles at Los Alamos National Laboratory also think they have the problems that bedevil magnetic spectrometers under control. Bowles, for example, is coping with the possibility that he might be misled by some solid-state effect in the electron source by running neutrino tests with a variety of different electron sources: nickel-63, sulfur-35, and carbon-14. "No one has yet done this search in a systematic way," he says. If the kink effect shows up with one source and not others, the effect can't be caused by a neutrino. "If it really is a 17 kev neutrino it should show up in a variety of sources," he says.

Even a "no" answer will be more interesting than it sounds, Bowles says. The solid-state researchers must be seeing something; even if it's not a neutrino but just some interesting solid-state effect, Bowles would like to get to the bottom of it. "We have discussed [the original] measurements, and we agree there is definitely something interesting going on that is still unexplained. We want to know what it is that's causing this effect."

And if the verdict on the heavy neutrino is yes? Even if a series of positive answers convinces both camps of neutrino hunters, Stoeffl says, it may take other physicists a while to swallow it. "Most physicists are skeptical because it doesn't fit into the standard model of particle physics," he says. "If we had expected it everyone would believe it now." ■ FAYE FLAM