# Neutrino Watchers Go to Extremes

**From polar cold to ocean depths, new detectors scan for flashes from massless particles. The flashes could reveal secrets from far-flung galaxies–if the detectors work**

At 7:00 AM on 9 December, the *Thomas G. Thompson*, a research vessel operated by the University of Washington, left the island of Hawaii with 150 tons of gear, 30 crew members, and another 30 passengers, all physicists, engineers, and technicians. Five days later, after testing equipment and practicing, those passengers began lowering a 400-meter-long cable over the side and into the ocean. Attached to the cable were 24 light sensitive photomultiplier tubes, five hydrophones, and two laser calibrators, part of an array designed to capture the ethereal flashes of neutrinos—massless, chargeless particles—crashing into water molecules 5000 meters beneath the sea.

Eleven days later, at 9:00 AM on the South Pole, another group of astrophysicists finished drilling a 20-inch-wide hole 1050 meters into the ice of Antarctica. By 7:00 PM that same day, the physicists had successfully lowered their own string of 20 photomultiplier tubes to the bottom of the hole, which then began to refreeze. These physicists, too, were embarking on a neutrino hunt, in which they will search for the telltale flashes deep in the ice.

These small-game hunts come with the possibility of a huge payoff. Neutrinos are so elusive that they can usually pass through the entire bulk of the Earth with the ease of sunlight through a pane of glass. Unlike light or any other wavelength of electromagnetic radiation, they can carry information straight from the hearts of mysterious, energetic objects such as neutron stars, supernovae, or active galactic nuclei (AGNs), whose secrets have long been veiled from observers by curtains of gas and dust.

The possibility of capturing this information for the first time has made extraterrestrial neutrinos so coveted that two other telescopes are being built in addition to the Hawaiian and Antarctic projects. Another team of physicists is working on a detector that will lie beneath the Aegean Sea, a few kilometers off the island of Pylos. And Russian and German physicists are submerging similar equipment in the depths of Lake Baikal. The worldwide activity, notes Michael Salamon, a University of Utah astrophysicist, marks the birth of "an entire new field of astronomy." All other telescopes—light, radio, gamma-ray, and others—detect some variety of photons. "That makes these detectors very potent," he says, "because in the past, any time you turned on a new instrument looking in a new bandwidth, you learned something new about the universe." (See other articles on high-energy astrophysics, starting on p. 40.)

These instruments, however, are working prototypes more so than final products, designed to illustrate the feasibility—or unfeasibility—of these methods. And the first lessons learned by these physicists have not been astronomical but practical: Circuits have died, rendering detectors inoperable, and photomultiplier tubes have malfunctioned in the cold, leaving the instruments with impaired vision. "With something like this," says John Learned, a University of Hawaii physicist who is spokesman for the Hawaiian project, the Deep Undersea Muon and Neutrino Detector (DUMAND), "we're often floundering around, or winging it, and hoping the [funding agents] in Washington understand. In my bad moments, I wish I was doing table top experiments with foreseeable conclusions." One astrophysicist, who is not involved in these experiments and whose career is not hanging on their success, described the enterprise of neutrino astronomy at the bottom of the ocean as "meshuga."


NESTOR

**Eyes in the Aegean.** Workers lower one stage of NESTOR, a neutrino detector, into the water off the island of Pylos.

Crazy may be a harsh description for the projects; "challenging" certainly is not, because the task of neutrino astronomy is to extract information from elementary particles that, in almost every case, give no sign of their passing. To catch solar neutrinos, researchers have set up huge tanks of liquid surrounded by photomultiplier tubes, located in deep underground mines. In 1987, similar projects searching for a phenomenon known as proton decay detected instead neutrinos coming from the Supernova 1987A, and researchers began thinking of neutrino astronomy as a real possibility.

### Bigger (and deeper) is better

To make it more than a possibility, astronomers have taken the concepts of the proton decay experiments and magnified them. All four neutrino observatories watch for neutrinos within the largest possible volume of very clear water or ice. There's not a lot to see. Of the million or so neutrinos that might be passing each second through an area of 20,000 square meters—roughly 5 acres, or the area of the DUMAND detector—only one every hour might zip close enough to a water molecule and the nuclei of its constituent atoms, says Learned, to "snatch a charge out of the nucleus and become a muon." A muon is a charged particle similar to an electron, albeit 207 times heavier. This muon continues to travel in the original direction of the neutrino, trailing behind it a cone of light, known as Cherenkov radiation, like a bow wave spreading out behind a speed boat. With suitably sensitive light detectors, physicists could observe both the Cherenkov radiation and its direction, and use that information to calculate where the original neutrino came from.

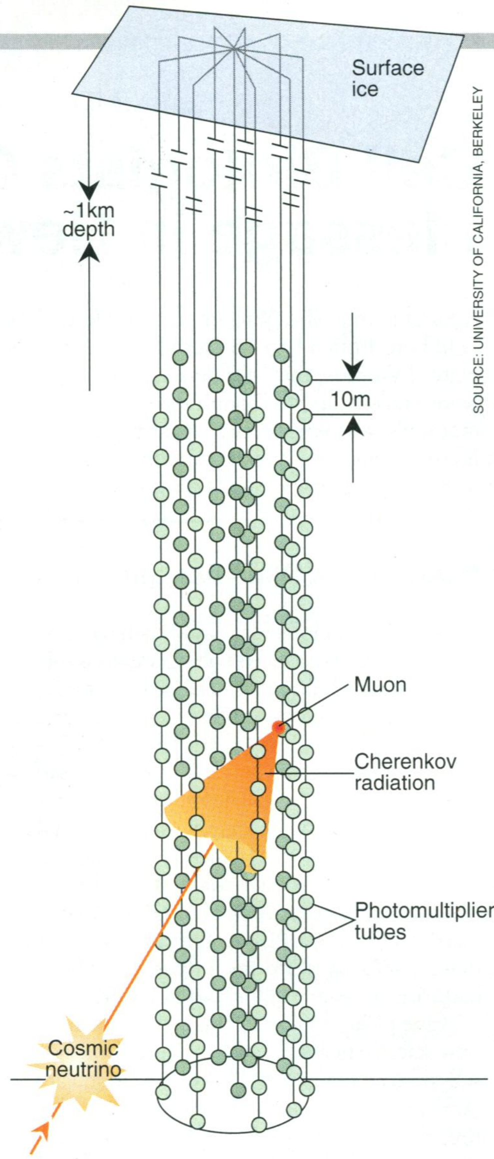
In order to do this, however, researchers have to isolate the rare neutrino-water molecule interactions from the background barrage of cosmic rays, which would create similar flashes in any experizment near the Earth's surface. So the second requisite of a neutrino observatory is that it be placed deep beneath the ocean (or ice) where miles of seawater would shield the equipment from most of the cosmic rays heading downward, and the bulk of Earth would shield it from all the cosmic rays heading upward. "The Earth is a filter," Learned says, "and nothing else but neutrinos comes through." Clusters of neutrinos coming from specific sources should stand out like a bright star.

In the early 1980s, Learned and his colleagues suggested that one good site for a neutrino observatory might be the deep waters of the Pacific Ocean. They ascertained that the water was clear enough to allow detection of Cherenkov radiation, and that their submerged detectors would remain free of biological growth that might impede their performance. The scientists then set about designing photomultiplier tubes and electronics that would survive in the ocean depths, and in July 1988, they submitted a proposal for $10 million to build DUMAND. A year later, the experiment was approved, with half the support coming from the Department of Energy, some from the National Science Foundation (NSF), and the rest, in the form of tubes and optical modules, from collaborators at the University of Tokyo and Tohoku University and in Switzerland and Germany.

Final plans call for eight strings of 24 photomultiplier tubes arranged in an octagon with a ninth string in the center. The strings, which float vertically, are held to the bottom by anchors and will be connected by a remotely piloted submarine to an 18-mile cable leading to shore. Learned says they hope to deploy four strings by next April, and if those work, the researchers will go back to the Department of Energy for money to build and deploy the other five strings.

While DUMAND was taking shape, a rival project appeared on the scene in 1988. Called AMANDA, for Antarctic Muon and Neutrino Detector Array, the instrument has a DUMAND-like configuration, but it is deployed in the ice at the South Pole. Ice is transparent enough to allow detection of the Cherenkov radiation, explains Salamon. At 1000 meters down, he says, the ice has "remarkable transparency properties—beautifully transparent. It has no bubbles; it's the perfect medium." The original idea was floated in 1988 by Learned and University of Wisconsin physicist Francis Holtzen, and AMANDA got the go-ahead in 1992 from the NSF for $1 million. That may sound like a bargain next to DUMAND's $10 million, but Learned points out that the figure does not include the cost of polar facilities, transportation to and from the pole, and even drilling, all of which are covered by the NSF's polar research program and other agencies.

The AMANDA researchers plan to sink nine strings of photomultiplier tubes in a circle, each 30 meters from a tenth central string, to a maximum depth of a little over 1000 meters. The trick is to do it without creating bubbles in the ice or cracks that would ruin the transparency. They begin by shoveling snow into heating tanks, which Steve Barwick, a physicist from the University of California, Irvine, and an AMANDA




**Hot flash in the cold.** AMANDA, at the South Pole, will try to spot the radiation of muons derived from neutrinos.

collaborator, calls "outdoor rubberized swimming pools." Heaters then melt the snow and heat the meltwater to just below boiling, at which point it jets out through a nozzle at the rate of 40 gallons per minute and melts a hole into the ice. When the hole reaches the needed depth, the pre-equipped string is lowered. Then the ice refreezes from the outside in and the bottom up, squeezing most of the air bubbles out of the hole as it does so.

AMANDA and DUMAND participants are quick to argue about the merits of neutrino astronomy in water or ice. In their original paper, Learned and Holtzen pointed out that one advantage of polar ice is that it's made from rain and snow, which are free of the radioactive potassium isotopes found in seawater. When these isotopes decay they can fake a neutrino signal. Polar ice also gives physicists a solid surface on which to mount delicate monitoring electronics, where they are easy to repair, unlike the submerged electronics needed for DUMAND. On the other hand, DUMAND partisans (Learned among them) point out that working in ice means AMANDA is only one-fifth as deep as DUMAND, subjecting AMANDA to 400 times the cosmic-ray bombardment. And though all the DUMAND gear has to be sunk, at least it can be retrieved if it breaks, notes Learned, which is not the case with the ice-bound strings of AMANDA.

### Working in extremes

Other physicists, in the meantime, have sidestepped the water-versus-ice debate and are pursuing the best of both worlds. The Lake Baikal experiment, which began a testing phase last winter, is something of a cross between AMANDA and DUMAND: The equipment is deployed deep in the water of Lake Baikal but is done in winter when researchers can cut a hole in the lake's frozen surface and drop strings of detectors through the ice like ice fisherman. Last winter, says Barwick, the Baikal collaboration deployed three dozen sensors, and they are now working at understanding their equipment and calculating their background noise.

The most advanced detector, which has not yet been deployed, is NESTOR, named after the legendary king of Pylos and run by a Russian-European-American collaboration led by Leo Resvanis, a University of Athens physicist. NESTOR will begin as a tower composed of 12 identical hexagonal floors, made out of titanium tubing and joined together by kevlar rope. Each hexagon will be 32 meters across with two photomultiplier tubes at the end of each arm, one looking down and one looking up.

The NESTOR physicists hope to place their first tower 3500 meters down in the Aegean in the spring of 1995. After that, says Resvanis, they intend to expand 2 years later with a hexagon of towers around the first tower—increasing the detection volume by a factor of 10—and then a few years later, to add yet another hexagon outside that, putting the total detection area at 1 square kilometer. The first tower will cost $2.5 million, and the next six might cost $12 million as a package. "Once the first tower is successful," says Resvanis, "I think we're in business in a big way."

Just getting a prototype to work may not be easy, however, as the DUMAND and AMANDA groups discovered last month. The first string of photomultiplier tubes laid by the DUMAND physicists worked fine for 10 hours after deployment, at which time the communication laser for the string quit, and the equipment, as Learned says, "went incommunicado." Now, says Learned, they'll have to bring the string back to shore, which they should be able to do with either a helicopter or a small fishing boat, and then set it down again in April with the other three strings. "We're disappointed," he said. "The whole team was so anxious to see everything working, and be in the business of counting neutrinos, which we clearly are not going to be able to do until April."

Nor has AMANDA's ice-bound strategy been immune to problems. All of the 20 photomultiplier tube modules on the first string were working and recording the detection of Cherenkov radiation when the string was lowered into the hole in December. Three days later, the hole had successfully frozen around the equipment. But one photomultiplier tube broke and was lost for good while one more, said Bob Morse, a University of Wisconsin physicist who had just returned from the Antarctic, "was coaxed to come alive" and another was still doubtful.

Once the physicists have multiple strings in place, they will be able to start looking in the slowly accumulating data for evidence of point sources of neutrinos, perhaps from astrophysical sources. They're expecting discoveries to be hard to come by, however. When physicists started writing papers on neutrino observatories two decades ago, says Holtzen, they assumed that to observe enough neutrinos to detect anything of interest they would need a detector at least 10 times the size of DUMAND if not 100 times larger. "Unless we get lucky," says Holtzen, "these [first] detectors are too small."

What he and his colleagues hope to show with the first round of detectors is that they can distinguish neutrinos from the various background sources and record the directions from which the particles came. If the first detectors provide this proof-of-principle for neutrino astronomy, he says, "it's no big deal to build one 10 or 100 times bigger for on the order of $50 million, which is something the world should be able to afford."

If the world decides it can indeed afford such a detector, physicists will then turn their attention to potential neutrino sources such as AGNs. Astrophysicists believe that at the heart of these objects are massive black holes. Because of neutrinos' ability to pass through matter, says Salamon, detecting neutrinos from AGNs "is probably the only way to get direct information about what's happening at the very central engine of these objects. We're talking about getting practically to the edge of the black hole itself." Researchers are also interested in identifying neutrinos from binary pulsars and from the center of the galaxy, which might also be home to a massive black hole.

The bottom line, however, says Learned, is that "we're groping into terra incognito. We really don't know what the hell we're going to see." Or how hard it will really be to see it.

–Gary Taubes

Additional Reading

Learned, J.G. "Neutrino Astronomy with Large Cherenkov Detectors," *Annals of the New York Academy of Sciences* **647**, Dec. (1991).

MEETING BRIEFS

# Cell Biologists Get the Message in New Orleans

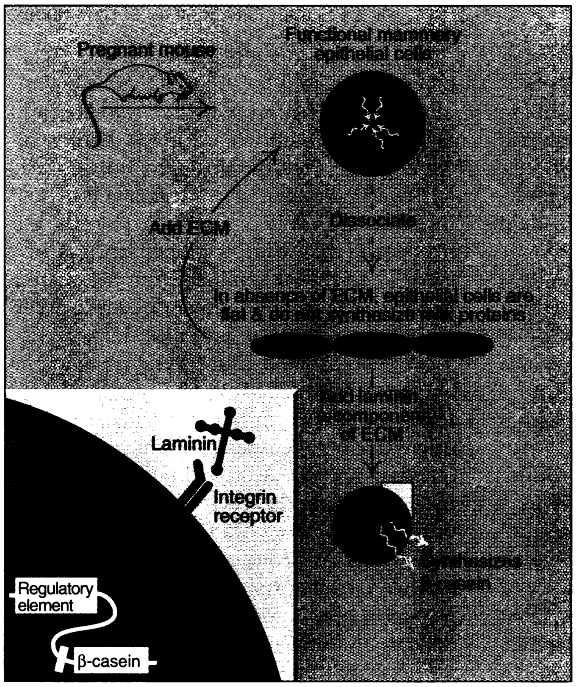
New Orleans–The 33rd Annual Meeting of the American Society for Cell Biology (ASCB), held here from 11 to 15 December, began on a triumphant note: In his opening address, Harold Varmus, the new director of the National Institutes of Health, proclaimed "that the scientific rabble [the bench scientists] has politely taken over the director's office." And he made clear, in what was his first policy speech since taking office, that he intended to fight for recognition for basic research. That message went down well with his ASCB audience–all keen supporters of basic research, as the samplings of the meeting below attest.

## Matrix Work Wins Acclaim

Back in the premolecular days of cell biology, textbook writers assigned an unglamorous role to the extracellular matrix (ECM), the messy mix of giant fibrous proteins and globular glycoproteins that surrounds the cells. According to that early type-casting, the cells did all the interesting work, determining, for example, what shape an organ—or an animal—would take. The ECM merely provided an inert scaffold upon which the cells could grow. More recently, a small band of cell biologists has shown that the ECM, far from being a bit player, actually performs a dynamic role in dictating a tissue's shape and function.

One prime shaker in the up-and-coming new science of the ECM has been Mina Bissell of the Lawrence Berkeley Laboratory (LBL) in California. And at the ASCB meeting, Bissell described her group's recent results, which help explain just how the ECM exerts its effects on cells. The LBL workers have directly demonstrated that the ECM can trip switches deep within the nucleus and spur the genes themselves into action. "It's really exciting," says Donald Ingber of Harvard Medical School, who's also studying the ECM. "[Bissell] has brought regulation of gene transcription into the realm of the ECM."

Bissell's research is grounded in a decades-old observation that specialized cells grown in lab culture in the absence of ECM molecules beget throwbacks. For example, mammary gland epithelial cells from a pregnant mouse growing in an ECM-free brew yield uncharacteristically flat cells that do not produce milk. Add ECM molecules, and the cells differentiate again, becoming plump and well-rounded and organizing themselves into sacs of cells that secrete milk into their interior and bear a remarkable resemblance to the milk-secreting alveoli of the breast. And researchers have evidence that the ECM is equally as important to cell growth and differentiation in living animals.




**Outside in.** Laminin, an extracellular matrix protein, activates gene regulatory elements.

SOURCE: C. ROSKELLEY/LAWRENCE BERKELEY LAB ILLUSTRATION: K. SUTLIFF

But although it's become clear that the ECM is vitally important for cells to function, until recently researchers had little inkling of the ECM's modus operandi. And that's where the LBL group's recent work comes in.

ECM proteins such as fibronectin and laminin provide structural support for cells by interlocking with cell surface receptors called integrins. What Bissell and her colleagues have now shown is that when these proteins bind to the integrin receptors, they also activate specific regulatory elements in the nucleus and in so doing incite gene activity.

The LBL group did this by attaching a bacterial "reporter" gene to a regulatory sequence needed to turn on the gene for the milk protein β-casein. After inserting this hybrid gene into cultured