Deep-Sea Km^3 Neutrino Detector Gets Thumbs Up

> To realize a humongous underwater neutrino detector, scientists from the various smaller deep-sea detectors should start laying the groundwork for an international collaboration, says a panel of experts.

Crazy people go into mineshafts to see stars during the day, says University of Athens physicist Leonidas Resvanis, quoting the first-century Roman naturalist Pliny the Elder. As Resvanis sees it, overcoming background light by peering at the sky from a hole in the ground was the forerunner to projects like the one he heads, the Neutrino Extended Submarine Telescope with Oceanographic Research. NESTOR is a detector designed to sit near the bottom of the Mediterranean Sea and monitor the heavens for neutrinos. In a report released this summer, the High Energy Neutrino Astrophysics Panel (HENAP), which was set up by the International Union of Pure and Applied Physics, gives its stamp of approval to stepping up such research and, specifically, to building a cubic-kilometer-scale neutrino detector deep under water in the Northern Hemisphere.

A km^3 detector would be an order of magnitude more sensitive than NESTOR and similar projects, thanks to a cross-sectional area about 10 times bigger. It would be the counterpart to the US-led IceCube—the planned expansion of the Antarctic Muon and Neutrino Detector Array (AMANDA), which has been collecting data since 1997 (see PHYSICS TODAY, March 1999, page 19). As a preliminary estimate, HENAP puts the price of a next-generation deep-sea neutrino detector at \$250–300 million. "These projects cost a few hundred million dollars," says former Fermilab boss John Peoples, a HENAP member. "It's not cheap, but it's not a linear collider, and Europe could do it on their own if they decide to."

Expecting signals

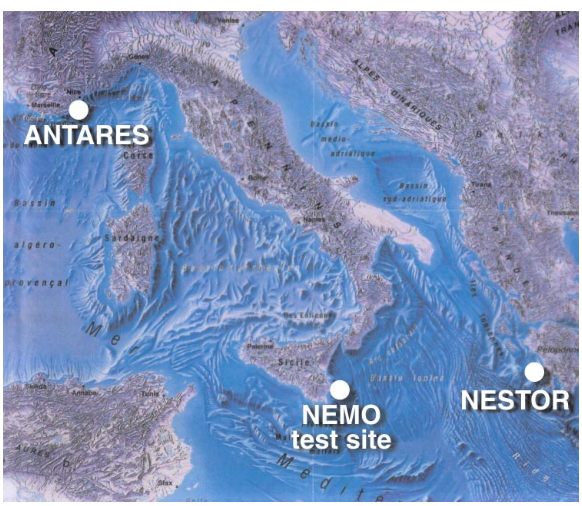
By spotting neutrinos with energies in the neighborhood of 1–1000 TeV, the km^3 detectors are expected to open a window to the universe's most violent and energetic phenomena. "The main thing is to learn about the astrophysics associated with extreme objects, suspected to be the most powerful natural accelerators," says Eli Waxman of the Weizmann Institute of Science in Rehovot, Israel, who was one of two theorists on HENAP. "We believe high-energy neutrinos are out there because we see other types of high-energy particles. Clues are coming from high-energy gamma rays and cosmic rays that are almost certainly produced by extragalactic sources. We can estimate the power output, from that the neutrino flux, and from that the size of the detector we need," he says. The effective detector size is energy dependent. What the detectors record is Čerenkov light emitted by muons that are created when a neutrino interacts with matter. The higher the incident neutrino's energy, the farther the muon travels and the greater the effective volume of a given detector.

Neutrino events are scarce—Waxman and others estimate that a km^3 detector will see 100 or so a year—but, because neutrinos are not deflected by electromagnetic fields and are extremely penetrating, they can be traced back to their sources. Researchers hope to learn about active galactic nuclei, gamma ray bursts, microquasars—and to discover new phenomena. Says HENAP chair Enrique Fernandez, director of Barcelona's Institute for High Energy Physics, "We debated the physics. The main danger was that we build a kilometer-cubed [detector] and don't find anything. We don't believe this will happen. You need this size, and with this size you can expect signals."

Assuming that IceCube will go ahead, HENAP makes the case for a second high-energy neutrino detector in the Northern Hemisphere. The southern one would detect neutrinos impinging from the Northern Hemisphere, and vice versa. The detectors look Earthward, with water or ice shielding them from the more or less homogeneous cosmic ray shower that engulfs Earth. Together, the two detectors would monitor most of the sky, which is especially desirable given that point sources are unlikely to be uniformly distributed. Moreover, from the Northern Hemisphere, a km^3 deep-sea detector would stare at the center of our galaxy, a hotbed of high-energy events that is not accessible from the Southern Hemisphere.

While the two km^3 detectors would be after the same science, there are differences. Ice scatters light more than water does, which results in poorer resolution. "Water is homogeneous and pure, so a detector would be much better if you can make it work in the sea," says John Carr, the spokesman for ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental Research), a French-led detector that, like its rival, the Greek-led NESTOR, is just getting under way in the Mediterranean. Seawater's downsides are that it is less transparent than ice and has more background noise from radioactive potassium-40 and bioluminescent marine animals. In any case, the HENAP report finds the Mediterranean to be a promising site—deep, clean, and clear.

As a practical matter, the technology for working in ice is in the lead. For AMANDA, workers melted ice and installed strings of photomultiplier tubes, which then froze into place. Looming in the minds of the water



THREE MEDITERRANEAN PROJECTS have an eye on developing a cubic-kilometer underwater neutrino detector.

detector teams are the technical failures of the Deep Underwater Muon and Neutrino Detector, a US-led experiment off the coast of Hawaii that was cancelled in 1996. Since then, the NT-200 experiment in Siberia's Lake Baikal has seen success, but even there the phototubes were lowered into the water from an ice platform—the lake's frozen surface in springtime. The ANTARES and NESTOR teams say they have learned much from DUMAND and that advances, pioneered largely for off-shore oil drilling, will help them overcome the extreme challenges of working in and on the sea. For example, says Carr, "the oil industry is making fiber-optic connections that mate in the sea. They have to be glass touching glass with micron precision. We now have to put [the advances] into practice in what's not an oil industry use." One potential advantage of water is that components could be taken out for repairs or be reorganized.

The jury is still out as to whether ice or water is better, in terms of optical properties and technical ease, for high-energy neutrino detectors. No ice detector has been proposed in the Northern Hemisphere, where, for the most part, the ice is neither thick enough nor clean enough. So scientists weren't forced to pick between ice and water, and they're just as glad. "Water has some advantages," says Fernandez. "But, so far, they are advantages only in principle—they haven't been proven yet. One thing we realized quickly is that it's good to have two detectors, in two hemispheres, using two different techniques."

Strings and towers

Also yet to be tested are different techniques for working in water. ANTARES, which is being installed some 50 km east of Marseille at a depth of 2500 meters, follows the string strategy. The detector will consist of 10 tethered strings, each carrying 90 photomultiplier tubes, with data transmitted to shore by fiber optics. The phototubes will be spaced vertically at 12-meter intervals, with the strings separated by about 60 meters and forming a hexagonal pattern.

NESTOR takes a different tack. The plan here is to stack floors—six-pointed stars with phototubes on the tips—into towers. The floors are 32 meters across, with 12 stories, each 20 meters high, per tower. Seven towers, spaced 150–200 meters apart, would make up 15–20% of a km^3 detector, says Resvanis. The advantage of the towers, he adds, is that they can be assembled at the sea surface and then lowered into the water. "All electrical connections are made in the air. There is no need for submersibles—they are expensive and complicate operations." NESTOR will go 4100 meters under the sea, off the west coast of Peloponnese.

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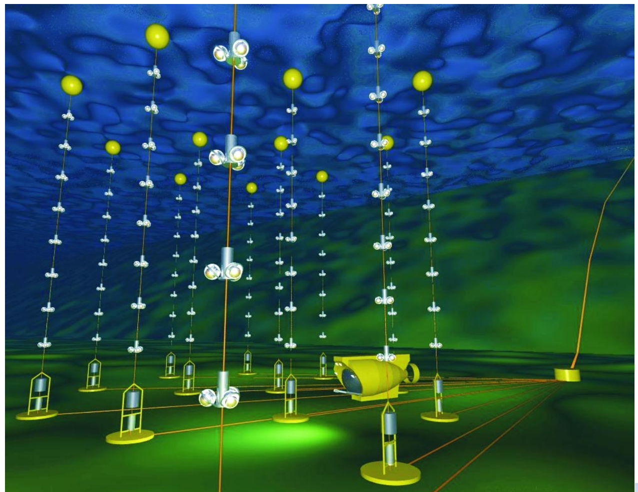

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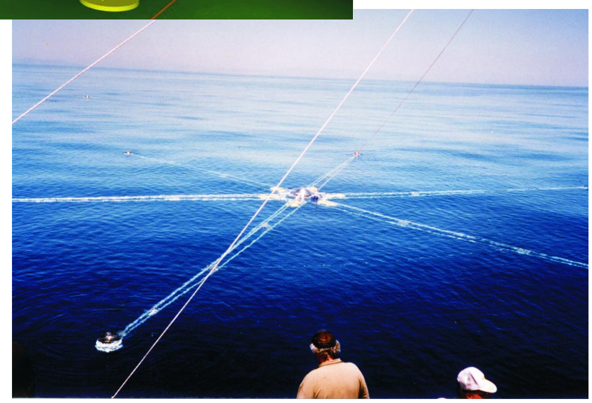

Strings of phototubes make up the ANTARES high-energy neutrino detector (schematic diagram, top). In NESTOR, the phototubes are mounted on stackable, rigid platforms (bottom). Both detectors are getting under way deep in the Mediterranean Sea.

A third underwater neutrino project, the Italian Neutrino Mediterranean Observatory (NEMO), coordinates with ANTARES to look ahead to a km^3-scale detector. "The optimal characteristics for . . . optical, sedimentation, and oceanographical properties of water were found in Capo Passero," says NEMO spokesman Emilio Migneco, who is director of the Italian National Institute for Nuclear Physics' Laboratori Nazionali del Sud in Catania, Sicily. Accordingly, the NEMO team has its sights set on a 3350-meter-deep site some 80 km off the shore of Siracusa, Sicily.

ANTARES and a seven-tower NESTOR would have comparable detection capabilities and would cost around $20 million apiece. ANTARES has the edge in terms of funding, but both teams say they will deploy phototube modules this month, start collecting data next year, and be ready to consider how to proceed to a km^3-scale detector by 2004.

"What they really have to do is demonstrate the techniques, show that they are able to deploy an array of phototubes, and that they see cosmic rays of neutrinolike origin. They have to show they can analyze the data," says Peoples. "It's important that R&D go on for a year or two—to see which design is better, or whether a combination would be best."

International planning

While ANTARES and NESTOR are testing their mettle, scientists should choose a single site and map out plans for an international collaboration, the HENAP report says. The ANTARES and NESTOR teams have a rocky relationship, and no one doubts that getting them to work together will be tricky. "We need the scientists to talk among themselves in a constructive way. And one needs that all those involved really understand that it is essential to cooperate on a single project to make it a reality," says Fernandez. "I believe that in HENAP we managed to advance on those two aspects."

"We have to find a way to work together if we want to do the physics," says Resvanis. "I will definitely follow the physics independent of the geography." But, he adds, "I would be very surprised if a better location than NESTOR is found."

If technical, political, and financial progress is smooth, a neutrino detector deep in the Mediterranean could come on line as early as the end of this decade.

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