PARTICLE PHYSICS

# China Builds Mammoth Detector To Probe Mysteries of Neutrino Mass

**BEIJING**—It isn't easy to weigh a ghost. After neutrinos were hypothesized in 1930, it took physicists 67 years to prove that these elusive particles—which zip through our bodies by the trillions each second—have mass at all. Now, a Chinese-led team is planning a mammoth neutrino detector, meant to capture enough neutrinos from nearby nuclear reactors to determine which of the three known types, or flavors, of neutrinos are heavier or lighter. That mass hierarchy could be key to explaining how neutrinos get their mass, and measuring it would be a coup for China's particle physicists.

Last month, scientists gathered in Jiangmen, in China's southern Guangdong province, to review plans for the Jiangmen Underground Neutrino Observatory (JUNO). Groundbreaking is slated for later this year on the $300 million facility, which China aims to complete by 2019. The facility, which backers say will be twice as sensitive as existing detectors, should not only pin down key properties of neutrinos themselves but also detect telltale neutrinos from nuclear reactions in the sun, Earth, and supernovas.

Other planned facilities aim to reveal the mass hierarchy (see table), but China could be the first to arrive at an ironclad result. If China can pull it off, says William McDonough, a geologist at the University of Maryland, College Park, JUNO "will not only lead to breakthroughs in neutrino physics, but revolutionize the field of geology and astrophysics." A successful project would also mark another triumph for China's neutrino research, 2 years after the Daya Bay Reactor Neutrino Experiment in Guangdong nailed a key parameter describing how different types of neutrinos morph into one another (*Science*, 16 March 2012, p. 1287).

In 1998, physicists working with the subterranean particle detector Super-Kamiokande in Japan showed that neutrinos of one flavor, muon neutrinos generated by cosmic rays in the atmosphere, can change flavor as they zip through Earth. In 2001, researchers at the Sudbury Neutrino Observatory in Canada proved that electron neutrinos from the sun do the same. Such neutrino "oscillations" prove that neutrinos have mass: Without it, the particles would move at light speed and—according to relativity—time would stand still for them, making change impossible.

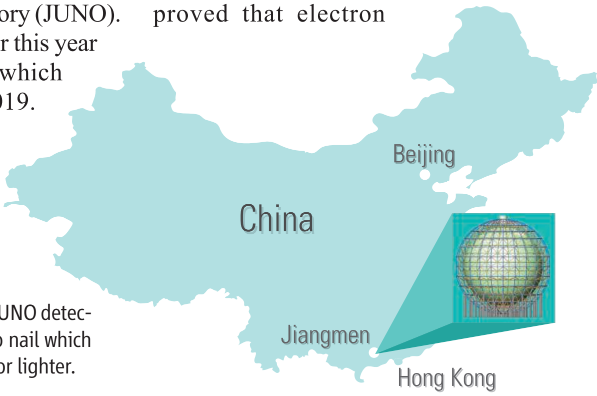
Knowing a neutrino has mass isn't the same as knowing what it weighs. In the simplest model, neutrino oscillations depend on just six parameters—the three mass differences among the neutrinos and three abstract "mixing angles." Physicists have measured all six—including the last mixing angle, which was measured by Daya Bay. They know that two of the neutrinos are close in mass and one is further off. But they don't know whether there are two lighter neutrinos and one heavier one—the so-called normal hierarchy—or an inverse hierarchy of two heavier ones and one light one.

How the masses shake out "is fundamental for a whole series of questions," says Wang Yifang, director of the Institute of High Energy Physics (IHEP) here, including whether neutrinos, like other particles, get mass from tangling with Higgs bosons or from a more exotic mechanism. The answer depends on whether the neutrino is, oddly, its own antiparticle. Physicists may be able to tell that by searching for a weird new type of radioactive decay. But, if it even exists, that decay would occur at an observable rate only if neutrinos follow an inverse hierarchy.

To explore this frontier, an international team led by Wang will build a detector 700 meters beneath a granite hill near Jiangmen, equidistant from two nuclear power plant complexes. A sphere about 38 meters in diameter will contain 20,000 tons of a material known as a liquid scintillator. About 60 times a day, one of the sextillion or so electron neutrinos spraying from the reactors every second should bump into an atomic nucleus, sparking a flash of scintillation light that the detector can measure and analyze. In the 53 kilometers that the neutrinos will traverse from reactor to detector, about 70% will change flavor, says Cao Jun, a particle physicist at IHEP. By studying the energy spectrum of the neutrinos, physicists should be able to tease out the mass hierarchy. "But it's not going to be easy because the amount of energy to be measured is minuscule," Cao says. He estimates the measurement will require 6 years of data-taking.

The key to JUNO's success will be its energy resolution. The largest liquid scintillation detector to date—KamLAND in Japan, which has 1000 tons of detector fluid—can only make out energy differences of greater than 6%. JUNO needs to double the resolution to 3%—no mean feat, especially as the larger volume of scintillator itself absorbs more light.

If it works, JUNO should also make finer measurements of the known mixing angles and mass differences. "This is particularly important for the search for a possible fourth form of neutrinos," says Lothar Oberauer




**Heavy hitter.** China hopes its planned JUNO detector, 38 meters across, will be the first to nail which of the three neutrino flavors is heavier or lighter.

**The Race to Establish the Neutrino Mass Hierarchy**

| Project | Location | Source of neutrinos | Projected startup | Resolving power (in multiples of experimental uncertainty σ) |
|---|---|---|---|---|
| NoVA and T2K | USA and Japan | Accelerator | Running | 1–3 σ |
| INO | India | Atmospheric | 2017 | 2.2–2.8 σ |
| JUNO | China | Reactor | 2019 | 3.2–4.4 σ |
| PINGU | South Pole | Atmospheric | 2019 | 4.2–6.9 σ |
| LBNE | USA | Accelerator | 2023 | 3–7 σ |

CREDIT: (INSET) IHEP; (SOURCE) M. BLENNOW ET AL. ARXIV 1311.1822 (2013)





Published by AAAS

of the Technical University of Munich in Germany. If the sum of all oscillations doesn't add up to 100%, then the data would point to a fourth flavor (*Science*, 21 October 2011, p. 304)—a possibility that could topple the standard model of particle physics and help explain a host of astronomical puzzles.

Another mission for JUNO is to observe geoneutrinos emitted during radioactive decay in Earth's deep interior, which generates heat that helps drive plate tectonics and power our planet's magnetic field. Detecting geoneutrinos "is the only way to get a glimpse of Earth's internal heat budget and distribution," McDonough says. The three facilities now detecting geoneutrinos, including the revamped Sudbury detector, record about 45 a year in total. JUNO should spot about 500 a year, enough to test various models of Earth's composition and heat flow, McDonough says. And that would score China another triumph in neutrino physics.

**–JANE QIU**

Jane Qiu is a writer in Beijing.

MARINE ECOLOGY

# As Lionfish Invade, Divers Defend Threatened Ecosystems

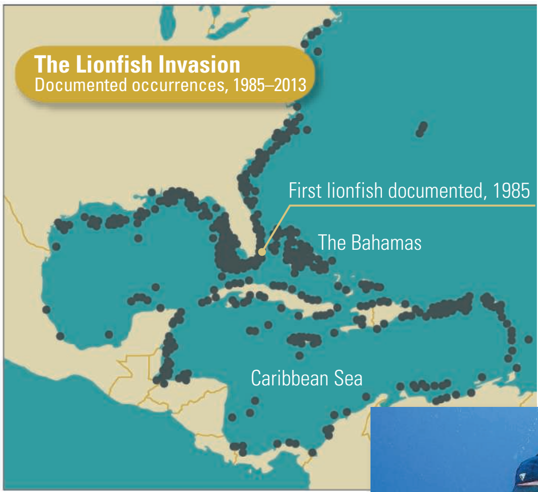
**NASSAU**—The red lionfish, with its striking stripes and huge outrigger fins, wasn't hard to spot. Nor to spear: It simply studied me, utterly fearless until I killed it. Within a half-hour, my group of divers had caught four of the gorgeous fish along a coral reef here; they made excellent eating that night.

For ecosystems in the southwestern Atlantic Ocean, however, the lionfish is a curse. Marine scientists say that the voracious predator, a Pacific native believed to have been released into the Atlantic by aquarium lovers in the mid-1980s, is spreading rapidly and wiping out native fish, especially on vulnerable Caribbean coral reefs. "They'll eat just about anything they can swallow and almost nothing eats them," says ecologist Stephanie Green of Oregon State University, Corvallis.

In the Bahamas, where *Pterois volitans* was first spotted in 1985, "they're everywhere," says Pericles Maillis, a Bahamian conservationist who has led local efforts to battle the invader. "It's a doomsday scenario."

Late last year, however, Maillis and other lionfish opponents got some good news. Using ecological models to plan a surgical 18-month offensive, divers killed enough lionfish for native fish populations to rebound at 24 coral reefs near the Bahamian island of Eleuthera, researchers reported online on 2 December in *Ecological Applications*. Removing 75% to 95% of lionfish at the sites allowed prey populations to increase by 50% to 70%—with up to one-third less effort than it would have taken to totally exterminate the invaders. The study shows that "we don't have to catch every lionfish" to allow native species to recover, says Green, the lead author, although the culling must be repeated regularly.

Such targeted tactics could help beat back an invasion that has spread to some 3.3 million square kilometers of the Atlantic, ranging from Rhode Island to the Panama Canal, according to Pam Schofield of the U.S. Geological Survey in Gainesville, Florida. Population densities are often many times greater than in the lionfish's native Pacific range, but the fish's phenomenal success is a mystery. Mark Hixon of the University of Hawaii, Manoa, guesses that a predator that keeps Pacific populations in check by eating baby lionfish is "absent in the Atlantic … but we have no idea what it is."




**Gotcha.** A diver bags a lionfish in the British West Indies as part of an effort to protect native fish from the invader, which has spread rapidly since it was first spotted off Florida in 1985 (map).

CREDITS (TOP TO BOTTOM): U.S. GEOLOGICAL SURVEY; OREGON STATE UNIVERSITY

Lionfish invaders can snap up one-half of resident fish within just a year after arriving on a reef, recent research shows. So far, they have taken their most visible toll on small reef fish. But researchers say they also eliminate the young of large predators such as snappers and groupers, an absence that might not be noticed for years.

Recent studies have found clues as to why the invader is so lethal. For example, some common Pacific reef fish inexplicably don't recognize lionfish as a threat, although they dart for cover when other predators appear, an Australian research team reported in *PLOS ONE* this past October. That's a worrying sign that Caribbean fish aren't likely to learn to avoid lionfish either. "That scares me even more," says lionfish specialist Isabelle Côté of Simon Fraser University, Burnaby, in Canada.

To reduce lionfish numbers, policymakers in the Bahamas and elsewhere have tried to promote commercial fishing of the tasty species. You need to "eat it to beat it," says Frederick Arnett II of the Bahamas' Department of Marine Resources. One problem facing any fishery, however, is that handling lionfish requires special care: Their venomous spines can make the slightest puncture extremely painful. And their unusual appearance can make consumers skittish.

Still, in Florida, the commercial catch quintupled from 1.1 tons in 2011 to 6.1 tons in 2012, according the U.S. National Marine Fisheries Service. "But we don't know yet if it's putting a dent in the population," says Lad Akins, founder of the Reef Environmental Education Foundation in Key Largo, Florida.

In the recent Eleuthera island study, researchers examined the effectiveness of a more targeted approach by killing virtually all lionfish on one set of reefs, fewer at two other sets, and none in a fourth control group. The surprises were how fast the lionfish decimated the local fish in the control, and that the native species quickly rebounded on other reefs even when 25% of the lionfish remained. That suggests focused lionfish culls aimed at protecting juvenile fish could be useful. "If we can get divers to take the lionfish out of the shallow reefs and the mangroves where the juveniles are," Green says, "we may be able to keep some reefs relatively intact."

**–CHRISTOPHER PALA**