Muons Meet the Maya

Betsy Mason

At its most glamorous, the life of an experimental high-energy physicist consists of smashing obscure subatomic particles with futuristic-sounding names into each other to uncover truths about the universe—using science's biggest, most expensive toys in exciting locations such as Switzerland or Illinois. But it takes a decade or two to plan and build multibillion-dollar atom smashers. While waiting, what's a thrill-seeking physicist to do?

SUBATOMIC ARCHAEOLOGY. Physicists plan to use muons generated by cosmic rays to probe the interior of the Pyramid of the Sun at Teotihuacán.
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How about using some of the perfectly good, and completely free, subatomic particles that rain down on Earth from space every day to peek inside something really big and mysterious, like, say, a Mayan pyramid? That's exactly what physicist Roy Schwitters of the University of Texas at Austin is preparing to do.

High-energy particles known as muons, which are born of cosmic radiation, have ideal features for creating images of very large or dense objects. Muons easily handle situations that hinder other imaging techniques. Ground-penetrating radar, for instance, can reach only 30 meters below the surface under ideal conditions. And seismic reflection, another method, doesn't fare well in a complex medium. With muons, all you need is a way to capture them and analyze their trajectories.

Besides probing pyramids in Belize and Mexico, physicists are applying the muon method to studying active volcanoes and detecting nuclear materials. The concept sounds out of this world, but it's really quite simple. When cosmic rays hit the Earth's atmosphere, collisions with the nuclei of air atoms spawn subatomic particles called pions that quickly decay into muons that continue along the same path. Many of the muons survive long enough to penetrate the Earth's surface. Because of their high energy, the particles can easily pass through great volumes of rock or metal or whatever else they encounter. However, they are deflected from their path by atoms in the material, and the denser the material, the greater the deflection.

Schwitters wants to exploit this deflection to see if there are any rooms or chambers inside a Mayan pyramid in Belize, he told science journalists in Spokane, Wash., at a recent meeting sponsored by the Council for the Advancement of Science Writing. His team is building several muon detectors that would be buried in shallow holes around the base of the pyramid to create an image of what's inside by measuring the trajectories of the muons that pass through it.

"What you see is very much like an X ray," he says. "If you see a spot with more muons, it means there's a space there. If you see fewer muons, it means there's something extra-dense there."

Schwitters won't be the first to marry physics and archaeology in this way. In 1967, Nobel prize–winning physicist Luis Alvarez of the University of California, Berkeley placed a muon detector in a chamber beneath the pyramid of Khafra in Egypt to see if it was hiding any burial chambers like those discovered in the larger pyramid of Khufu. He found none, but the experiment showed that the method worked.

From physics to archaeology

As the director of the Superconducting Supercollider laboratory in Texas until 1993, when Congress gave the project the axe, Schwitters is no stranger to waiting for the next big thing. And he has always been intrigued by the possibility of applying the tools of the high-energy physics trade elsewhere, so a chance conversation with one of Alvarez' former colleagues, combined with a little spare time, got Schwitters wondering what other enigmatic ancient structures were waiting to be probed.

Archaeologist Fred Valdez, director of the Mesoamerican Archaeological Research Laboratory at UT Austin, had the answer: an enormous pyramid in the third-largest Mayan city in Belize. The city is in an area in northwestern Belize known as La Milpa, which was home to one of the densest populations of Maya from as early as 1000 B.C. until around A.D. 850. The area was packed with four large cities, each with 20,000 or more residents, that were only around 8 to 12 kilometers apart with 60 or more towns, villages, and hamlets in between. Valdez believes there is much to be learned from the society that existed there.

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"The amazing part is how close how many of these large cities are to each other," he said. "The Maya were clearly expert at adapting to their environment and exploiting their environment, clearly making better use of things than we are today, just to support the populations that were there."

Because there isn't a chamber below the La Milpa pyramid, Schwitters plans to harness muons with four or five smaller detectors spaced around the structure to get a three-dimensional view inside. Each detector will be a cylinder wrapped with strips of polystyrene, which emits light when hit by a muon. The bursts of light as each particle passes through both sides of the detector will be recorded by photo detectors at the end of the cylinder and used to reconstruct the muon trajectories.

Dense matter will deflect muons away from their paths, so fewer muons will hit the detectors from that area while more particles will pass through empty spaces to reach the detectors. A computer program will translate the information into an image that can be read like a CT scan or an X ray with bright spots indicating voids and dark areas correlating to more dense matter. Because muons hit the Earth at the rate of about 1 per square centimeter per minute, it will take several months to get a good image of the guts of the pyramid. Schwitters hopes he'll be able to resolve chambers as small as a cubic meter.

20/20 hindsight

Knowing exactly where to dig to find potential tombs or other chambers could save precious time when dealing with very large structures like the pyramid in Belize. It could also save artifacts that need special treatment, sometimes within hours, to keep them from deteriorating from exposure. Dust in a tomb that is normally trampled during excavation could contain valuable information about diseases that affected the Maya, or about the plants and herbs they used.

"Ideally, the results would give us a look into the building without having to do the destructive process of excavation," Valdez said.

He envisions being able to drill a small auger hole into a chamber and send a fiber-optic camera down to take a look. That way he can study the chambers exactly as they were left, and the appropriate experts and equipment can be on hand to deal with the contents as they are exposed by coating them with resin, immersing them in water, or sealing them in an airtight case.

"That's tremendous information," he said. "It's almost like 20/20 hindsight."

With funding from Sandia National Laboratory in Albuquerque, N.M., and support from UT and National Instruments, Schwitters' team has already built and successfully tested one detector at UT that weighs in around a ton, at 4.5 m long with a 1.5 m diameter. The detectors that will go to Belize will be much smaller, around the size of water heaters and weighing about 200 pounds. Depending on funding, the detectors could be ready for showtime in 2009.

Another team of scientists may be just months away from using muons to image the Pyramid of the Sun in Teotihuacán, Mexico, in a quest to learn why the pyramid was built. And if burial chambers such as those found in the nearby Pyramid of the Moon are discovered, they could reveal whether the society was ruled by a single person or a government of several leaders.

Led by physicist Arturo Menchaca-Rocha of the National Autonomous University of Mexico, the team is currently working out some kinks in its detector having to do with wires cracking from temperature changes. Once that hurdle is cleared, which will likely be sometime after January, their single detector will be placed in a tunnel discovered under the pyramid in 1971, much like Alvarez' experiment in Egypt.

"We are quite delayed," Menchaca-Rocha said in an e-mail from a meeting in Veracruz. "But the pyramid has been sitting there for 2,000 years, so it can wait for us to be perfectly happy about the detector."

Nuclear security

In the meantime, physicists at Los Alamos National Laboratory in New Mexico are looking to muons to help detect special nuclear materials such as plutonium and uranium at the country's borders. Current nuclear-detection capability relies on identifying the gamma-ray radiation emitted by the materials, but that doesn't always work.

"If someone wants to bring in nuclear material to build a bomb, they need to shield it with something dense like lead to stop the gamma rays," says Los Alamos physicist Chris Morris.

So Morris is working on a detector that would use muons to root out both nuclear materials and shielding. Lead is dense enough to perturb a muon's path, and it is even easier to spot the muon fingerprint of things like plutonium and uranium because their high density and big atomic charge scatter the particles more than anything else.

Los Alamos lab has partnered with Decision Sciences Corporation of San Diego to build a prototype four-sided muon detector that resembles a carport before the end of the year. Vehicles would drive into the device like entering a car wash and wait while detectors on all four sides of the tunnel record muon trajectories. A single muon would be recorded by multiple detectors, revealing any changes in its path.

"It measures the track of every muon going through the vehicle," Morris says. "In 20 seconds you can detect whether or not they have a chunk of metal that's 4 inches by 4 inches by 4 inches. If you went a little longer, you can see something smaller."

Volcanic insight

But the real strength of muon imaging is tackling very large structures, such as volcanoes, that defy other methods. Scientists led by Hiroyuki Tanaka of the University of Tokyo installed a single muon detector 1 kilometer from the summit of Mount Asama on the main island of Japan. By measuring muons traveling nearly horizontally through the volcano, the detector successfully imaged a lava mound that was created a few hundred meters below the crater floor during a 2004 eruption and a conduit below it.

"The cosmic-ray muon imaging technique has much higher resolving power than conventional geophysical techniques, with resolutions up to several meters allowing it to see smaller objects and greater detail in volcanoes," Tanaka wrote in a report on the results of the Mount Asama study in the Nov. 15 *Earth and Planetary Science Letters*.

Tanaka's team has also used muon detection to image a lava dome that has been smoking since 1945 on the flank of Usu volcano in Hokkaido, Japan. Both of Tanaka's current studies involved single detectors. But adding more detectors would give a three-dimensional view and help untangle the effect of higher-density materials on the muons from that of a longer distance traveled through somewhat less-dense material.

"This technique might provide a way to forecast a volcanic eruption by monitoring changes in the density of the magma channel inside the summit region of a volcano," Tanaka writes in a study on the lava dome in the Nov. 16 *Geophysical Research Letters*.

Even more promising is a real-time digital muon camera that Tanaka is working on that could capture real-time images of an active volcano. He hopes to have one installed with a view of Mt. Asama from 1.5 km away by May 2008, and a second one sometime thereafter that could provide a 3-D picture of Asama's next eruption.

"With this device, I think that the technique would be more practical for use in forecasting eruptions," he wrote in an e-mail from Japan.

Schwitters envisions other geologic studies that could benefit from muon detection, such as gauging the size and location of underground aquifers or assessing the stability of the geology around nuclear-waste depositories. But for now he is content to focus on the pyramids buried under dirt, trees, and vines in the forest in Belize.

"There is good reason to believe they contain rooms and chambers that have not been disturbed since the Maya left, and that's what makes them so exciting," he says.

References and sources for this article

References:

Tanaka, H.K.M., *et al*. 2007. Imaging the conduit size of the dome with cosmic-ray muons: The structure beneath Showa-Shinzan Lava Dome, Japan. *Geophysical Research Letters* 34(November):L22311. Abstract available at http://dx.doi.org/10.1029/2007GL031389.

Tanaka, H.K.M., *et al*. 2007. High resolution imaging in the inhomogeneous crust with cosmic-ray muon radiography: The density structure below the volcanic crater floor of Mt. Asama, Japan. *Earth and Planetary Science Letters* 263(Nov. 15):104-113. Abstract available at http://dx.doi.org/10.1016/j.epsl.2007.09.001.

Sources:

Arturo Menchaca-Rocha
Departamento de Fisica Experimenta
Universidad Nacional Autonoma de Mexico
Mexico City, D.F. C.P. 04510
Mexico

Chris Morris
P.O. Box 1663
Los Alamos, NM 87545

Roy Schwitters
University of Texas, Austin
1 University Station C1600
Austin, TX 78712-0264

Hiroyuki Tanaka
Earthquake Research Institute
University of Tokyo
1-1-1 Yayoi
Bunkyo, Tokyo 113-0032
Japan

Fred Valdez
University of Texas, Austin
Mesoamerican Archaeological Research Laboratory/TARL

1 University Station R7500
Austin, TX 78712-0714

From *Science News*, Vol. 172, No. 23, Dec. 8, 2007, p. 360.