uncovered evidence of the centuries-long battle that ancient engineers waged against both gradual and sudden subsidence. He says the subsidence was brought on by a lethal combination of earthquakes, tsunamis, and the slow but relentless sinking of heavy foundations into unstable soil, which defeated even savvy Roman engineers. Although several wharves appear to have been reconstructed over centuries, no amount of piling could long hold up heavy stone foundations and buildings, he says. "[Adding] on all that material was asking for trouble," Stanley says. "The additional weight of a wave surge could be powerful enough" to submerge part of Alexandria's shore.

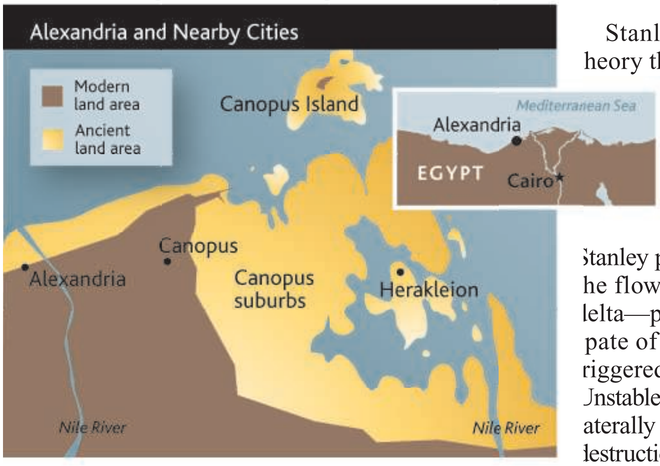
The historical record also shows an unusually active period of tremors from the 4th to the 6th centuries C.E. Quakes and tsunamis could have transformed sediment into a more fluid state, says Stanley. Sixty-five cores taken from the western harbor show signs of ancient liquefaction, he said, and numerous pieces of red coral not native to the harbor suggest that a tsunami washed them into the basin. But he says it is too early to reconstruct details of ancient collapse and rebuilding. "We need better 3D images of harbor substrate" to understand what repairs were done and when, he said.

The impact of these geological forces extended beyond Alexandria—and with even more dramatic consequences. Stanley and Goddio also are excavating three submerged cities in nearby Aboukir Bay: Herakleion, Canopus, and Menouthis. The first was an important entrance point to the mouth of the Nile, and the others were well-known pilgrimage sites. The area received huge amounts of sediment from the Nile, which compacted and sank over time. This process, combined with a slow rise in world sea levels, pushed the water at least 2 meters higher between the 6th century B.C.E. and the 7th century C.E. "Arabic texts show a huge Nile flood in 741 and 742 A.D.," notes Clauss. And by the 8th century—the same time Alexandria slips into obscurity—the historical record on these sites goes silent.

Stanley's research supports a heory that combines catastrophe and gradual sinking to explain the disappearance. Submergence alone cannot explain why much of the area is now a full 6 meters under water, and Stanley posits that sudden shifts in he flow of Nile branches on the delta—perhaps brought on by the pate of earthquakes—may have riggered more dramatic changes. Unstable sediment would have been aterally displaced, causing sudden destruction as the Nile moved into a new bed. Goddio's team has found evidence of human remains underneath toppled walls at the three sunken cities, backing up this theory.

In an era of climate change and fast urban growth along coasts, this research may have implications today. Stanley notes that modern cities such as Venice, Bangkok, and New Orleans sit on unstable delta soils. "This is becoming a world problem," he says. "Understanding the subsidence threat might help such cities avoid the fate of Herakleion, Canopus, and Menouthis." Alexandria, at least, escaped with only a flooded harbor—a sign that Homer perhaps was as canny a geologist as he was a storyteller.

—ANDREW LAWLER



SOURCE: ADAPTED FROM FRANCK GODDIO/HILTI FOUNDATION

Radio Astronomy

Bristling With Promise

By substituting software for massive signal-gathering dishes, arrays of simple FM antennas offer astronomers a cheap, versatile alternative to traditional radio telescopes

In a remote Chinese valley sit 25 neat clusters of antennas, each tipped slightly askew. They are testing the airwaves, listening for interference from TV signals. If reception is clear enough and other things go well, within the next year or two the fields of the Ulastai Valley will fill with tilted antennas, like a Christmas tree farm pummeled by wind.

The valley will become a huge array of 2-meter-long antennas, 10,000 strong, covering 30,000 square meters. The array, dubbed the Primeval Structure Telescope (PaST), is the brainchild of a group of Canadian, Chinese, and American scientists pursuing a low-frequency portrait of the early universe. And they hope to find it out in the vast, quiet stretches of western China, one of the last places on Earth out of the reach of jabbering TV and FM radio broadcasts.

Though just 25 pods of 127 antennas each right now, PaST is a herald of what's to come. Thanks to recent advances in theory and computing power, radio astronomers can now build telescopes consisting of huge arrays of antennas capable of viewing the universe in a novel palette of low frequencies hitherto rarely used for astronomical observations. "What's most exciting to me [is] that we don't know what we're going to see," says PaST collaborator Jeffrey Peterson of Carnegie Mellon University in Pittsburgh, Pennsylvania.

Peterson isn't alone in his enthusiasm. Several other array telescope projects are under way in the Netherlands, Western Australia, and the American Southwest. Their scientific goals include finding radio equivalents of gamma ray bursts and detecting the faint traces of the first stars.

The arrays will take radio astronomy back to its roots in the 1930s, when Karl Jansky, an engineer at Bell Telephone Laboratories in Holmdel, New Jersey, noticed radio waves emanating from the center of the Milky Way galaxy at 20 MHz. The field took off after radar operators during World War II discovered a technique called interferometry, which enabled astronomers to string together several small antennas to get the same resolution as that of one huge antenna. But researchers soon realized that low frequencies were wrinkled and warped into indecipherability by Earth's ionosphere. Frustrated, they switched their attention toward frequencies above 1 GHz. And that's where radio astronomy stayed until recently, when new calibration techniques opened a window into the low-frequency range.

The breakthrough came in 1991, when astronomers using computer algorithms to correct for the effects of ionospheric interference jiggered the Very Large Array (VLA), a Y-shaped assemblage of 27 dish antennas in western New Mexico, into receiving at a record low frequency of 74 MHz. Their success blasted open opportunities for large low-frequency arrays. "The old low-frequency telescopes were like a nearsighted person trying to read from far away without his glasses," says Namir Kassim, a radio astronomer at the Naval Research Laboratory in Washington,

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D.C. "When we learned how to put glasses on these telescopes, all hell broke loose, and now everyone's trying to build them."

VLA and its kin, however, suffer from a major disadvantage: Dish antennas are not good at picking up low frequencies. If the length of the wave is close to the diameter of the dish or longer, the dish can't see it at all. By contrast, arrays of wire antennas—either simple FM dipoles or log-periodic antennas made of multiple dipoles—can be designed to pick up any wavelength astronomers might fancy. All it takes is the right arrangement, enough land, and a supercomputer programmed to convert the jumbles of waves sweeping across the arrays into useful images. Somewhere between 200 MHz and 100 MHz, the efficiency advantage switches over from dishes to dipoles.

In the early 1990s, inspired by the new calibration techniques, scientists from the United States, the Netherlands, and Australia started investigating designs and locations for the Low Frequency Array. LOFAR was conceived as a cheap, quick instrument to get a first look at the low-frequency universe, says Kassim, who was LOFAR's international project scientist. But ballooning costs and disagreements over siting and scientific goals crippled the project, and the collaboration disintegrated.

Today, Germany and the Netherlands are working to build a 25,000-antenna LOFAR array spread over an area 350 kilometers in diameter on both sides of their border; researchers hope to develop sophisticated new techniques to filter out radio and television signals. Other erstwhile LOFAR partners, meanwhile, have hatched projects that rely on geography to solve the problem of interference. Kassim and colleagues at the Naval Research Lab are now collaborators in the Southwest Consortium, a low-frequency radio astronomy project based in the American Southwest, a popular site for traditional radio telescopes. The telescope, known as the Long Wavelength Array (LWA), will examine ultralow frequencies from 20 MHz to 80 MHz with 10,000 dipoles strung along 400 kilometers.

Other former LOFAR participants—astronomers at the Massachusetts Institute of Technology (MIT), the University of Melbourne, and the Australia National Telescope Facility—have joined with the Harvard-Smithsonian Center for Astrophysics to plan a 3000-antenna low-frequency array in the outback of western Australia. If all goes well, the Mileura telescope will look at large-scale structure in the universe. The United States and Australia are negotiating joint funding for the $10 million project.

Location is key. FM radio and television signals are as damaging to radio astronomy as light pollution is to optical astronomy and are far more pervasive. "The best place for this would be the far side of the moon," says Jacqueline Hewitt, an astronomer at MIT involved in the planning of the Mileura project. "But if we can't go to the moon, we'll go to western Australia." PaST scientists say that if they could afford to, they would build their array at the South Pole, 2000 km from the nearest TV transmitter and with a 6-month polar night to increase the transparency of the ionosphere.


Array of hope. Peterson predicts a bright future for PaST.

CREDIT: COURTESY OF J. PETERSON

Remote real estate aside, antenna arrays offer several advantages over traditional radio telescopes. For one, their cost—a fraction of the $3.5 million price tag of a single VLA dish—puts them within reach of even small astronomical partnerships. In the spring of 2003, for example, PaST was just an idea Carnegie Mellon's Peterson was batting around with Ue-Li Pen of the University of Toronto. Within a year, Xiang-Ping Wu of the National Astronomical Observatory of China had joined the project, and they had gotten $600,000 of funding from the Chinese government, found a site, and set up test antenna. The current funding will support an array of 2500 antennas. The researchers expect that support from the National Astronomical Observatory will enable them to install another 7500 antennas by 2006.

Antenna arrays boast technical advantages as well. Existing radio dish telescopes, such as Arecibo in Puerto Rico, just aren't up to the task of seeing in the ultralow frequencies, the researchers say. Big dish telescopes with just one, huge antenna have too narrow a field of view. They can sweep the sky over a period of time, but sweeping complicates the delicate calibration needed to compensate for the ionosphere. Dish arrays have the same drawback. Dipole arrays, by contrast, can effectively look in any direction or all directions at once, as long as computers are available to crunch the data. Log-periodic arrays are similar but have narrower fields of reception.

The 180-degree view of a dipole array means that transient phenomena may be noticeable. For example, researchers say, a very high-resolution array might pick up bursts of ultralow-frequency radio waves from gas-giant planets circling other stars—something a dish telescope could spot only if it were looking in exactly the right direction at the right time. Arrays might also pick up long-theorized radio counterparts to the cosmic energy blasts known as gamma ray bursts. By studying how such radio bursts distort as they cross space, astrophysicists could test cosmological models that predict there should be lots of ionized gas between galaxies.

The most mouthwatering possibility is that sensitive array telescopes will catch whispers of reionization, the moment early in cosmic history when the first stars flickered on. At that time the universe was filled with neutral hydrogen gas. Ultraviolet light from newly ignited stars blew electrons off hydrogen atoms, creating ions that don't radiate at certain wavelengths. The result, if radio astronomers can spot it, should be big patches of silence between 100 and 150 MHz amid an otherwise steady hum of neutral hydrogen. PaST, Mileura, and LOFAR all hope to detect reionization, although researchers acknowledge that it's a long shot.

At least astronomers won't have to wait long for the arrays themselves. PaST spotted galaxies at redshifts of 0.3 last year with just two protopods, and it is scheduled to start collecting data seriously this spring. The Southwest Consortium could have the core of the LWA up and running by 2008. The Mileura project hopes to erect its first test antennas by the end of the month. And more ambitious arrays may be in the works. From now on, when the universe rumbles in the ultralow, we'll be listening.

–KIM KRIEGER

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