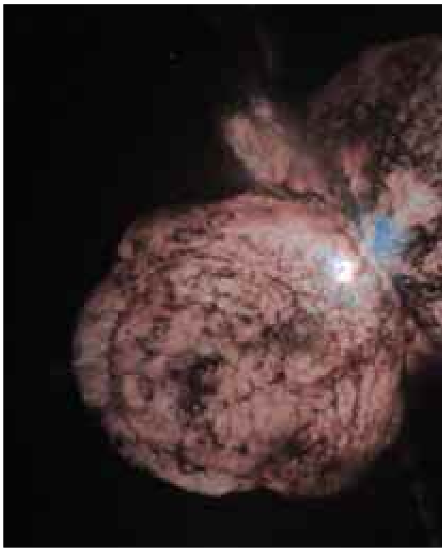
Seven Wonders of Modern Astronomy

by George Musser



View of the ultramassive star Eta Carinae

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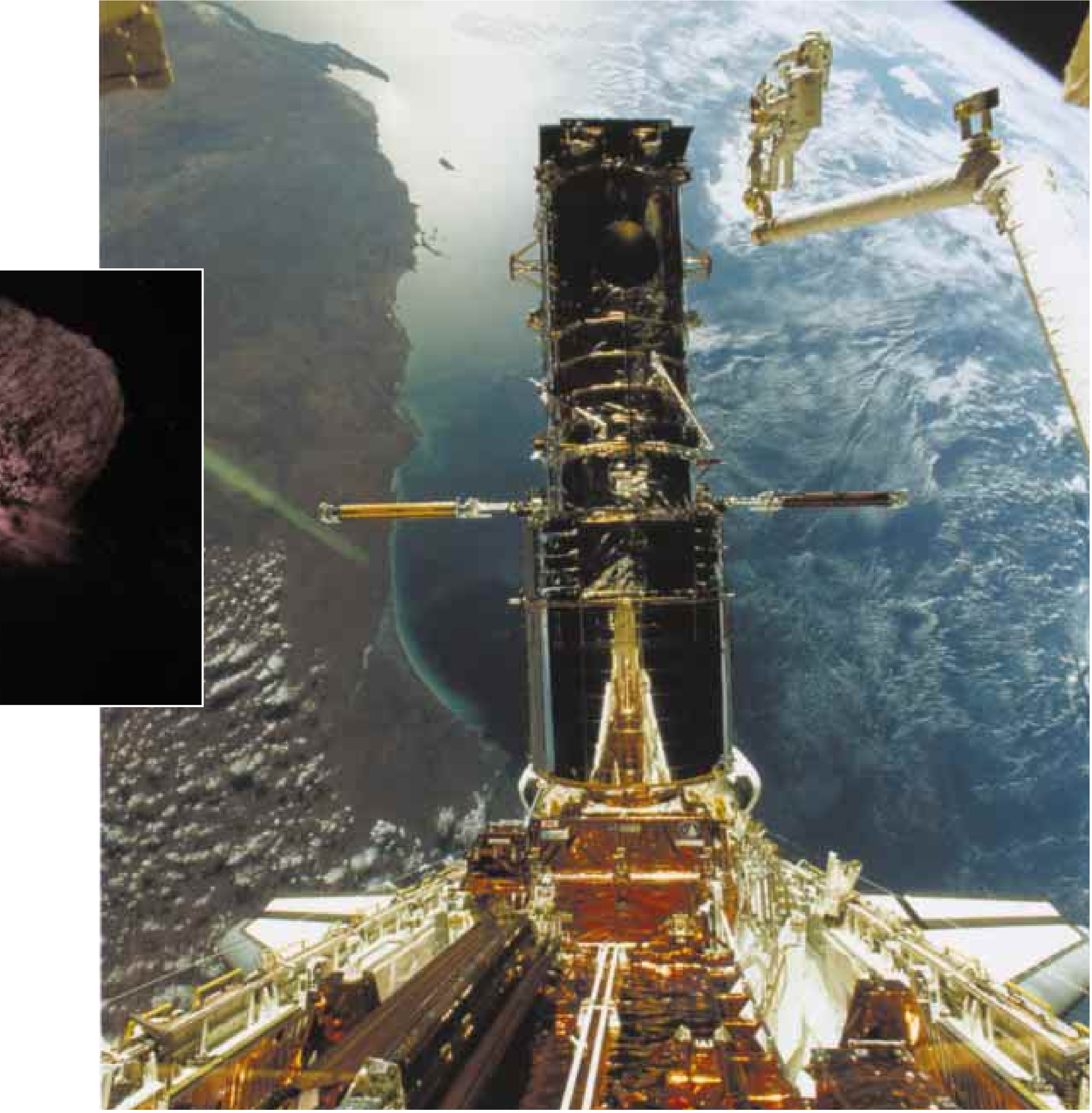
Choosing only seven wonders out of the myriad accomplishments of modern astronomy is an impossible task—just the sort I like. The mere attempt encourages a tour of the golden age of astronomy in which we are now living, a time of big questions and proportionately big efforts to answer them.

For many people, astronomy sounds like a quaint science—they imagine a recluse perched on a mountain, quietly pondering the inky skies. To a large extent it is indeed a battle of the solitary mind with the almighty heavens. But sky-watching was also the first Big Science. Nineteenth-century astronomers wielded huge budgets, commanded armies of peons and reigned over megafacilities at a time when physicists' labs were simple affairs, just some magnets and oil droplets. And the tradition extends even further back: consider the great observatories of Jaipur and Delhi, the sky temples of the Maya, Stonehenge.

Nowadays the term "Big Science" is generally reserved for particle accelerators and genome projects. Yet astronomy still qualifies, even if you leave aside planetary exploration, a subject perhaps better thought of as an offshoot of geology. A major observatory is like a factory, filled with pallets of equipment, DANGER signs, gangways, metal ladders, bustling workers and the buzzing of great machinery—all to catch a sliver of light from the dawn of time.

The wonders are many; any big adventure is really a succession of small victories. Another list might focus on the cosmic marvels themselves, but those already tend to get the attention. Some lists concentrate on the technological breakthroughs, whose size is often in inverse proportion to their importance: for instance, charge-coupled-device (CCD) microchips, the exquisitely sensitive detectors that have supplanted photographic film in observatories big and small over the past decade. Or a list might preview the mindblowers soon to come: the plans to detect new forms of radiation, say, or to see the continents and oceans of a distant planet. But here I present my own idiosyncratic selection of seven noteworthy telescopes now in operation or just gearing up.

GEORGE MUSSER is an editor at Scientific American. *He hopes one day to become chief of the magazine's Mars bureau.*



NASA JOHNSON SPACE CENTER; JON MORSE *University of Colorado* AND NASA (*inset*)

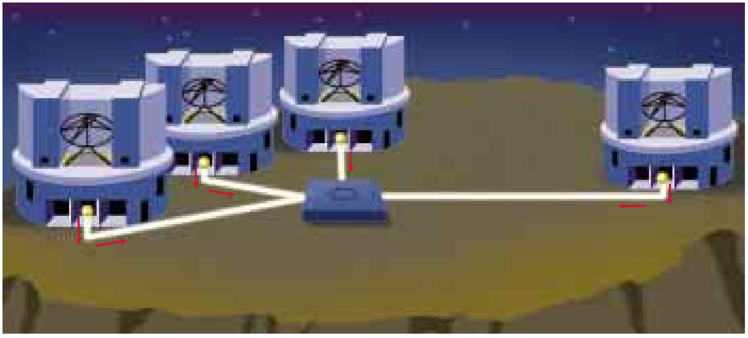
Refurbishing the Hubble Space Telescope high above the western coast of Australia

THE SHARPEST What would a list of astronomical wonders be without Hubble? The space telescope, after all, has broken all kinds of records, including probably the most newspaper headlines produced by any single astronomical project. Although its 2.4-meter (94-inch) mirror is a runt by today's standards, Hubble and its ilk are still the most complex robotic spacecraft ever built. One reason is the tracking mechanism. Above the madding clouds and turbulent distortion of Earth's atmosphere, the optics can attain its theoretical limit of resolution, but only so long as the spacecraft remains rock-steady despite the orbital motion and various buffeting forces. Hubble effects this stability using an interlinked system of mini-telescopes and flywheels.

Nine years ago, however, Hubble would have been placed on the list of projects that never made it—a victim of bureaucratic mismanagement, space program politics and technical snafus. Most infamously, the space telescope became a $1.6-billion example of the difference between accuracy and precision: because of a faulty measuring device, its mirror had been sculpted with utmost care to the wrong shape. But since astronauts fixed it in a dramatic series of space walks six years ago, even seasoned researchers have seen the universe in a new light. The gleam of comet crashes, the dainty arcs of gravitational lenses, the stellar corpses that look uncannily like eyeballs or sperm—Hubble is the Ansel Adams of our age.

EUROPEAN SOUTHERN OBSERVATORY

The summit of Cerro Paranal



LAURIE GRACE

Four telescopes act as one when their light is merged

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THE BIGGEST The nicest thing about the Very Large Telescope (VLT) is the charm of its lyrical names. Its four constituent telescopes were recently rechristened Antu, Kueyen, Melipal and Yepun—which mean the sun, moon, Southern Cross and Sirius in the indigenous Mapuche language of Chile. It is something of an improvement on Unit 1, Unit 2, Unit 3 and Unit 4.

Each of those 8.2-meter instruments is itself a very large telescope. Ten years ago such devices were impossible, but since then engineers have developed various ways to fabricate and support their huge, unwieldy mirrors. The European Southern Observatory—the consortium that built the VLT in northern Chile for $500 million—decided on single pieces of glass just 18 centimeters (seven inches) thick. Too thin to maintain their shape on their own, they are each propped up by 150 pistons, which are readjusted whenever the telescope shifts to a new position.

What justifies the "V" in VLT, however, is the way the individual scopes will work in unison to achieve the resolving power of a whopping 200-meter device. Beginning in 2002, their light will be funneled into a central lab and merged in a technique known as interferometry. Although the technique has long been used in radio astronomy [*see opposite page*], its arrival in optical astronomy awaited two recent developments. First, laser rangers can now gauge distances to one part in a billion, the precision needed to align and merge the shorter wavelengths of visible light. Second, new adaptive optics—in the VLT's case, a small extra mirror fine-tuned 100 times a second—can correct for atmospheric distortion so that the interferometer won't merely take a sharper picture of a blurred star. Similar interferometers should even be able to detect minute disturbances in the fabric of space itself, such as might occur during the birth of a black hole.

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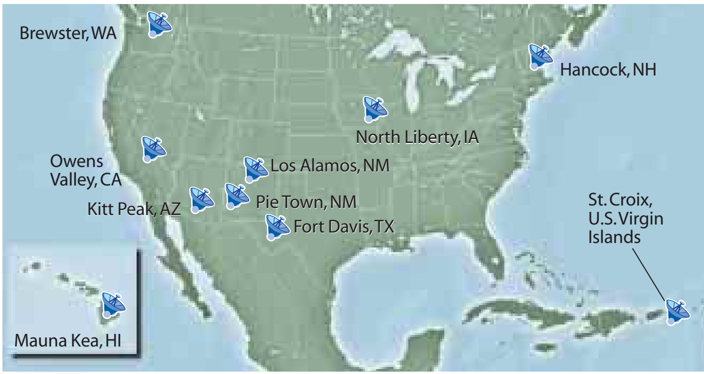
THE FARTHEST FLUNG In high school physics, my favorite lab exercise—to be honest, the only thing I remember at all—was the wave tank. For one of the experiments, we had to send a wave of water toward a barrier with two gaps. Two pieces of the wave squeezed through the gaps and then blended into a distinctive pattern. Little did I know at the time that such patterns would make possible a radio telescope bigger than planet Earth.

A telescope, too, is a gap in a barrier. It only lets through part of a wave of light; the rest gets chopped off at the edge. An observer notices this chopping as a slight smearing of the image. The larger the scope is relative to the wavelength, the less the smearing. Because radio astronomers deal with wavelengths measured in centimeters or meters, rather than in millionths or billionths of a meter, they suffer from such smearing more than their optical colleagues do.

So in the late 1940s they decided to punch another hole in the barrier. That is, they built two dishes and blended their outputs—two pieces of the same wave from a cosmic source. From the resulting pattern, they could calculate what the unsmeared light must look like. It was as though they had constructed two segments of a single telescope equal in size to the separation between the dishes.

Researchers have now taken this technique of interferometry to an extreme. Six years ago the National Radio Astronomy Observatory opened the $85-million Very Long Baseline Array: 10 radio dishes scattered from Hawaii to the U.S. Virgin Islands. Collectively they act as a single telescope more than 8,000 kilometers across. Astronomers record the signals—along with the exact time as measured by an atomic clock—and later merge them computationally. When they also mix in signals from a new Japanese radio satellite, the effective size swells to over 20,000 kilometers. For short radio wavelengths, the system produces sharper images than even the Hubble does. In fact, it is so sensitive that continental drift shows up in some of its observations.

Ten radio dishes equal one enormous telescope



Radio dish, 25 meters (82 feet) across, in Owens Valley, Calif.

NRAO/AUI; LAURIE GRACE (*map*)

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THE MOST EXTENSIVE Here's a subversive thought: Instead of observing the cosmos piecemeal, pointing your telescope at this galaxy today and that one tomorrow, what if you just took one big picture of the whole sky? Crudely speaking, that is the goal of astronomical sky surveys, such as the Palomar Observatory sky survey in the mid-1950s. Such surveys have not replaced observations of individual celestial bodies; rather they offer a macro view of the heavens, revealing the broad patterns.

Recently astronomers embarked on the most ambitious effort yet: the Sloan Digital Sky Survey. Over the next five years, this $77-million American-Japanese collaboration will scan a quarter of the sky (avoiding the crowded Milky Way) out to a distance of 1.5 billion light-years from Earth. The researchers expect to tabulate 100 million stars, one million galaxies and 100,000 quasars. They say that if the completed data set were to be printed and bound in books by someone who had little concern for the world's trees, it would nearly fill the Library of Congress.

The survey utilizes a 2.5-meter telescope on Apache Point in southern New Mexico, specially designed to capture as much of the sky as possible at a time. The light alternately feeds one of two instruments. The first is said to be the most complex camera ever built: 54 CCDs that take images in green and red light as well as in ultraviolet and near-infrared. The second is a pair of spectrographs, fed by a forest of optical fibers so that they can analyze the light of more than 600 objects in one go.

Sloan is expected to answer a key question in cosmology: How far do you need to zoom out before the matter in the universe, which on smaller scales is blatantly clumped into planets, stars and galaxies, begins to arrange itself uniformly? By determining where this transition occurs, Sloan could help resolve the age-old debate over the fate of the universe: Will it end in fire or ice, or something else?

FERMILAB VISUAL MEDIA SERVICES; THOMAS NASH *Fermi National Accelerator Laboratory (inset)*

Apache Point Observatory

Fiber optics feeding the Sloan spectrograph

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ROTSE-1

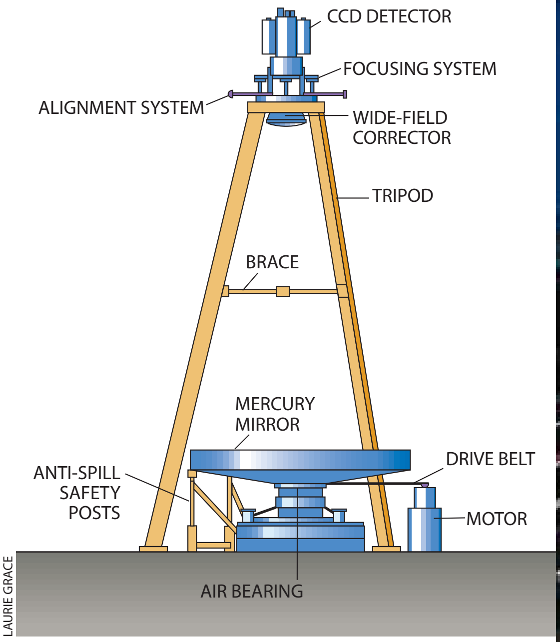
ROTSE-2

W. CARL AKERLOF *University of Michigan*

THE SWIFTEST Once upon a time pagers were only for doctors. And astronomers. As eternal and unchanging as the night sky might sometimes seem, it is actually filled with flickers and flashes, explosions and eruptions that flare up and fade out in a matter of seconds or hours. To catch these flighty phenomena, scientists have to be standing by at all hours, ready to reposition satellites and swivel telescopes at a moment's notice. In fact, this is one of the areas of astronomy where amateur astronomers, by virtue of their wide fields of view and sheer numbers, have made crucial discoveries.

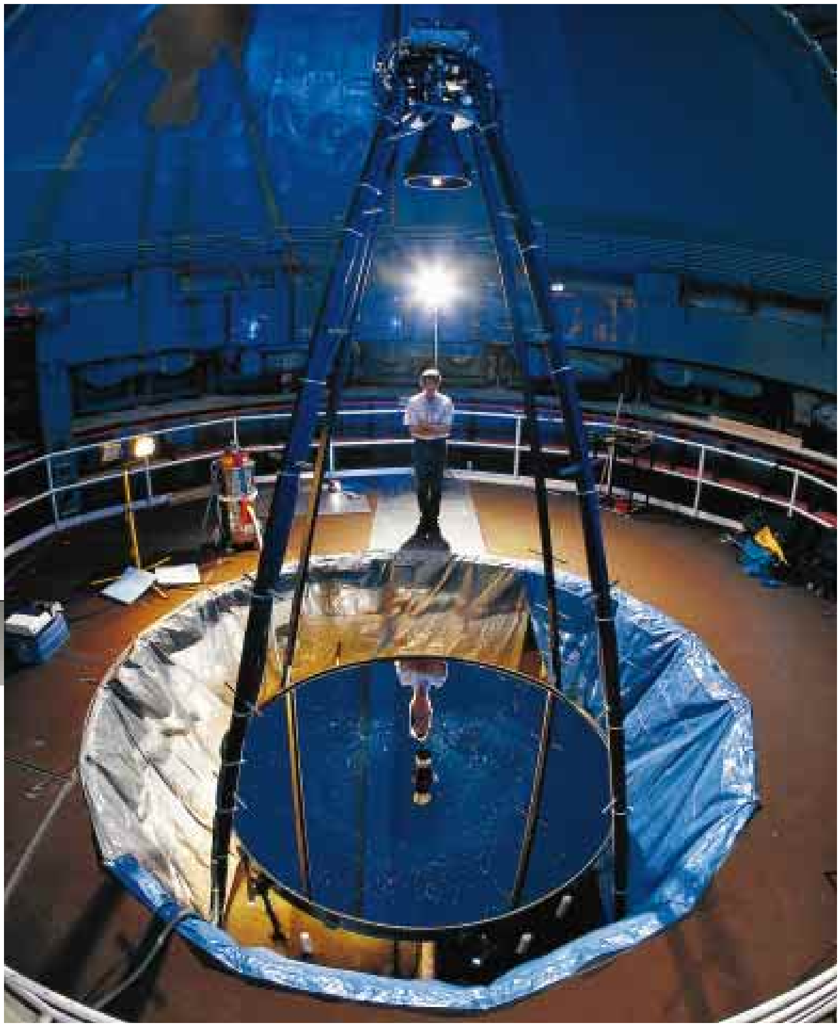
The latest entrant in the fast lane is ROTSE, the Robotic Optical Transient Search Experiment, in Los Alamos, N.M. Its first incarnation, ROTSE-1, looks like something from the camera bags of the paparazzi: a set of four 200-millimeter telephoto lenses cobbled together on a high-speed mount. The recently installed ROTSE-2 is a pair of half-meter telescopes. Whereas the standard telescope drive relies on precision gears, like a clock, ROTSE-2 uses position encoders and a feedback control loop, like a robot.

As does a sky survey [*see opposite page*], ROTSE sacrifices sensitivity and incisiveness for speed and sweep. It can capture 1 percent of the sky in a single exposure; during normal operation, it photographs the entire sky twice a night. Whenever an event of interest occurs, ROTSE suspends surveying, swings around and snaps away. In January the instrument proved its mettle. Satellites saw a gamma-ray burst—an intense but ephemeral blast of high-energy radiation—and sent out rough position information via the Internet. Within 10 seconds ROTSE had pinpointed the burst. Never before had astronomers caught such an event in visible light while it was still flaring in gammas.



LAURIE GRACE

Layout of earlier, 2.7-meter liquid-mirror telescope



CHIP SIMONS PHOTOGRAPHY

Taming quicksilver in the cause of astronomy

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THE DEADLIEST It is enveloped in poisonous vapors that can cause progressive kidney and brain damage. It can look only straight up; slewing would create an instant toxic waste dump. In short, a mercury mirror is not for everyone. But how else could you build a six-meter telescope for $500,000?

Any swirling liquid naturally assumes a parabolic form, whereas glass requires expensive grinding and hefty supports even to approximate that shape. Over the past two decades astronomers have built several bargain-basement telescopes using mercury, the shiniest element known.

The largest will soon be the Large Zenith Telescope (LZT) near Vancouver. A collaboration among Canadian and French astronomers, the LZT contains 28 liters (30 quarts) of mercury in a large pan that spins at the rate of one rotation every 8.5 seconds. The only real hassle has been the bearing. A mechanical bearing would have been too jerky, and no air bearings of the required size were available commercially, so the team had to design its own. Still, the observatory has cost a hundredth as much as one with a glass mirror.

The restriction on pointing straight up might seem a bit of a disadvantage. But it works just fine for studying representative samples of stars, galaxies and even space junk in Earth orbit. By synchronizing the CCD output rate to Earth's rotation, the telescope can electronically track objects as they move through its field of view. Even the mercury isn't as much trouble as you might think. It oxidizes on contact with air, partially trapping the noxious vapors. To be sure, no one will go near the mirror during normal operation, and the building is sealed to contain any spill.

UNIVERSITY OF WISCONSIN

Lowering detectors into the ice cap

THE WEIRDEST Most telescopes look up. This one looks down. Most capture some sort of light. This one seeks an invisible subatomic particle. Most telescopes are in remote locations, but this one goes to extremes: it is buried under more than a mile of ice at the South Pole.

The Antarctic Muon and Neutrino Detector Array (AMANDA) is the world's largest detector of the mysterious neutrino—and the first that can claim to be an astronomical instrument rather than a physics experiment. It trades sensitivity for the sheer size needed to catch a meaningful number of high-energy neutrinos from distant objects, which include many of the violent felons on astronomers' most wanted list: the swirling gas around black holes, the innards of stellar explosions, the decomposition of the unidentified matter that dominates our cosmos.

So far the observatory, a $7-million collaboration among U.S., Belgian, Swedish and German universities, consists of 424 glass orbs, each the size of a basketball. They watch for the eerie blue glow indirectly emitted when neutrinos collide with atomic nuclei in the ice or underlying rock. The orbs point downward so that Earth will screen out extraneous particles. To deploy them, workers first used pressurized hot water to melt a column of ice half a meter across and 2,400 meters deep. Then they lowered in the orbs, strung on a cable like beads on a necklace, and let them freeze in place. Ultimately, scientists want 5,000 orbs on 80 cables throughout a cubic kilometer of ice.

It turns out that ice is a friendly place for neutrino detectors. At depth it is crystal-clear, so the orbs can spot flashes of light hundreds of meters away. AMANDA exemplifies a new breed of telescope that has redefined what it means to "see." SA

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Inside the hole

THE AMANDA COLLABORATION