6,500 MILE WIDE TELESCOPE

BY MARCIA BARTUSIAK

A global network of radio telescopes allows us to probe the hearts of quasars and witness the birth of stars.

For almost half a century, BL Lacertae was known as a variable star in the obscure northern constellation Lacerta, the Lizard. Only in the past 10 years have the profound cosmic mysteries that BL Lac represents become apparent. As astronomers focused on its dim, irregular light, they found that BL Lac was not a part of our celestial backyard but rather the core of a giant elliptical galaxy 1.2 billion light-years away. Nothing unusual here. BL Lac's distinction lies in the fact that its swirling masses of stars, dust and gas vary in brightness as though they were one object.

The fluctuations sometimes occur within a matter of days. Since it would take considerable time for brightness to change over a large area, astronomers surmised that BL Lac's power source must be relatively small, perhaps only the diameter of several solar systems. But what kind of cataclysms could possibly be occurring deep within a galactic core to create such rapid changes in luminosity?

Author Marcia Bartusiak is featured on page 8.

That was the question on the minds of astronomers Bob Phillips, of the University of Kansas, and Robert Mutel, of the University of Iowa, when they aimed one of the giant dishes of the National Radio Astronomy Observatory (NRAO) skyward from the rolling hills of Green Bank, West Virginia, last June. But the West Virginia antenna was not alone.

On that very same day, in perfect step with Green Bank, radio telescopes in Texas, California and West Germany also locked on to BL Lac and listened for many hours to its distinctive radio voice. With such a unified network, Phillips and Mutel had at their disposal, in a sense, a single gigantic radio antenna that stretched across the United States and the Atlantic Ocean.

The development of such intercontinental arrays over the past 15 years has opened an exciting new window on the Universe, enabling man to peer into the hearts of mysterious celestial objects at the very edge of the cosmos and at the dawn of time. With this technique, which astronomers call Very Long Baseline In-

Illustration by Robert Pasternak

terferometry (VLBI for short), they can also probe the tenuous seas of gas that continue to give birth to new stars in our own Milky Way.

VLBI is an extraordinary tool; it can achieve resolution of detail 1,000 to 10,000 times better than ground-based optical telescopes when it is trained on very bright sources. Phillips and Mutel, for example, were able to cross over the enormous distance to BL Lac and discern details in the core only three light-years in width, a separation smaller than those between most stars in our own galaxy. Notes Phillips, "That's like standing in Kansas and being able to count the shirt buttons on someone in Hawaii."

Under such close inspection, BL Lac appears as a maelstrom of matter, putting out as much radio energy as 100 billion suns crammed into a space only a few light-years across. A December 1980 radio picture showed an elongated core, somewhat like a peanut. By last June, the core had quadrupled in size. "It's just like a Roman candle," says Phillips, who now works at the Haystack Observatory in Westford, Massachusetts. "The nucleus is blowing off blobs of matter at extremely high speeds. It's as if a billion nuclear warheads were being detonated each second within its very heart."

The structure of these active galactic nuclei and the nature of the physical processes that could release such enormous amounts of energy are the most fundamental problems in extragalactic astronomy today. As we observe such a nucleus, we may be seeing the last climactic gasp of one stage in the life of a galaxy. It is a perplexing view of the Universe, one that was unheard of only 50 years ago.

HISSING NOISES

Before 1931, the cosmos visible to our eyes was a rather serene place, filled with well-ordered stars and graceful spiral galaxies. Only an occasional supernova (a star exploding as it uses up the last of its fuel) hinted at some violent tendencies. Then Karl Jansky, a researcher for Bell Telephone Laboratories who was looking for the source of strange noises disrupting transatlantic phone communications, found that certain hissing noises were coming not from Earth but from the core of the Milky Way. Nature, it seemed, was showering the earth with low-frequency electromagnetic radiation, and it could be picked up by what came to be called a radio telescope.

Unlike visible light, radio waves can easily pass through the dust and debris that fill our galaxy. Astronomers could receive signals from sections of the Universe long hidden from view. After World War II, the new kind of telescope began to scan the sky on a regular basis; it used a large dishlike antenna tuned to radio frequencies instead of visible light. Astronomers found radio sources all over the heavens, but the view of the cosmos provided by radio telescopes was fuzzy. A typical optical telescope, which focuses on extremely short wavelengths, can discern details in the sky that have angular widths as small as three ten-thousandths (0.0003) of a degree (by comparison the sun and moon each span about half a degree). But because radio waves are roughly a million times longer than light waves, a radio telescope would have to be several miles wide to match optical resolution. Astronomers thus turned to an old, but very useful, technique called interferometry to obtain much sharper radio maps.

"The very first radio interferometers were developed in Great Britain and Australia during the late 1940s and early 1950s," notes Marshall Cohen, a professor of radio astronomy at the California Institute of Technology and a longtime expert in interferometry. "In fact, they had a monopoly on the technique for a number of years." The process goes like this: two telescopes a mile or more apart are connected by cable (later, microwave links stretched that distance to 80 miles). Because of the separation, as radio waves from some celestial object rain down upon the two antennas, each sees a different portion of the wave front.

> Six antennas, operating for 72 hours, record up to 10 trillion bits of data that are processed into a single image.

The waves received by each telescope go to a central "mixer," where they are combined. If the two waves are in step, they add up to a bright, strong signal, but if they're not in step, they cancel each other. As the earth rotates and the antennas wheel slowly to stay on their targets, an interference pattern of peaks and troughs emerges. These squiggles become a sort of fingerprint that can then be processed by a computer to yield an image of the source, an image almost as detailed as the one you would get if you had a single antenna many miles wide collecting that picture from space.

Early interferometers allowed researchers to pinpoint the locations of those enigmatic radio squeals that filled the heavens. In 1953, for example, the Cygnus A source, one of the "brightest" objects in the radio sky, turned out to be a galaxy 1 billion light-years away. Its radio emission alone is six times greater than the total energy radiated by the Milky Way at *all* wavelengths.

Other sources of radio energy could not even be linked with visible galaxies; through optical telescopes they appeared as starlike objects that, from the red shifts in their optical spectra, seemed to be receding from the earth at speeds approaching the velocity of light. That meant they were billions of light-years away. Astronomers christened them *quas*i-stell*ar* objects, or quasars. They may be the bright nuclei of abnormally violent galaxies that are too far away to be seen in their entirety.

RADIO-LOBE MYSTERY

The detection of bewildering titans like these suggested a whole new class of objects: radio galaxies. "Radio galaxies have turned out to be the most powerful objects in the Universe," says Caltech radio astronomer Anthony Readhead. "Thousands have now been found, and on the whole their radio structures are rather similar." Typically, they have two large regions, or lobes, of radio emission, one on each side of the visible galaxy. The lobes stretch out for hundreds of thousands, even millions, of light-years, and dwarf the visible portion of the galaxy. In fact, one giant radio source known as DA240 has two puffs of radio emission as large as an entire cluster of galaxies. "Immediately, astronomers began to ask how those radio lobes could form," says Readhead. "What was producing this tremendous energy, and how was it being transferred out to intergalactic space?"

In order to delve into the hearts of these tumultuous galactic centers, astronomers realized they had to have radio interferometers separated by *thousands* of miles. As Cohen stresses, "The smaller the source, the wider apart the antennas have to be to resolve the celestial object." Cables and microwave links were certainly out of the question over such distances; longer baselines appeared to be beyond the wildest dreams of radio astronomers. But by the late 1960s, advances in atomic clocks provided an answer to the distance problem.

Independently, groups in the United States and Canada realized they could eliminate the direct connection between radio telescopes by recording the signals at each telescope separately on magnetic tape and later combining the two recordings at a central computer. An extremely accurate atomic clock at each antenna was a guarantee that the recordings were synchronized to within a tenth of a microsecond. Any greater error would lead to a garbled picture. A label for the new technique came almost spontaneously. "If a

Diagram by Robert Pasternak

hundred miles is long, what do you call six thousand miles? Six thousand is *very* long," smiles Cohen, one of the many founding fathers of VLBI.

Although it resolved details better than a single radio telescope or an optical scope, Very Long Baseline Interferometry appeared at first to be a limited method, according to Readhead. When astronomers attempted to get angular resolutions to 300-billionths of a degree, the earth's atmosphere caused the interference pattern to jitter around. But, by the mid-1970s, they found that combining the signals from three or more telescopes produced a clearer image. Today, VLBI investigators regularly use intercontinental arrays of six or seven telescopes that, in effect, produce an antenna that stretches from Europe to North America and from South America to Australia.

With so many astronomers anxious to use so few telescopes, coordination becomes a problem. In the United States, an informal committee reviews each VLBI proposal and arranges for the telescope time. The work itself is so streamlined now that, once each observatory in the network receives the schedule, staff members can take complete care of the tracking, timing and taping. BL Lac investigator Phillips, in fact, was cooking dinner in Kansas while his observations were being made around the globe.

After a VLBI experiment is completed, the tapes from each radio observatory are sent to one of four processing facilities: NRAO in West Virginia, Caltech, the Haystack Observatory or the Max Planck Institutes in West Germany. Each has the equipment to analyze three to five tapes at one time, a formidable task. "Typically, we observe an object for twelve hours," explains Readhead, "and if six stations are recording, that's seventy-two hours of data—one to ten trillion digital bits to be processed into an image." Readhead's colleague Stephen Unwin once remarked that his job as an astronomer was now "10 percent observing and 90 percent computing."

For the entire VLBI community, such arduous computations have paid off in the new vistas they have revealed. "VLBI has enabled astronomers to take three quantum leaps into the very cores of these bright extragalactic radio sources," says Readhead. "There is no other technique, currently used or even envisioned, that can match its resolution." What the images reveal inside many of these quasars and active galaxies is one very narrow beam of matter being shot out from the nucleus. VLBI has confirmed what noted British astrophysicist Martin Rees had long suspected: this "jet" is the channel by which energy was being transferred to those enormous radio lobes found in most radio galaxies and radio-wave-emitting quasars.

Why only one jet? Why not one going to each lobe? There may be. A jet aimed in the general direction of the earth will stand out, while, says Readhead, "The stuff going away from us will have its energy shifted downward and, in effect, become invisible."

Astronomers are used to dealing with gargantuan numbers; they come with the territory. But even the most hardened expert seems awed by the energy these jets represent. Says Readhead, "What we are seeing in these objects is the luminosity of a trillion suns coming out of something not much bigger than our own solar system. You have to have some kind of extraordinary beast to generate that power." Such a central engine must be stable, it must be able to eject stupendous amounts of energy at nearly the speed of light, and it must channel that energetic matter into a narrow beam. So far, astrophysicists know of only one sort of cosmic dynamo that would satisfy all those requirements: a spinning, supermassive black hole that formed from the collapse of one billion suns, an object so dense that not even light can escape its awesome gravitational field.

In one scenario, stars and gas are pulled by the black hole's enormously powerful gravitational field and form a disk of matter that rotates around—and in the same direction as—the spinning hole. Enormous amounts of energy are released as the stellar material spirals toward the abyss and is ripped apart by tidal forces.

BIRTH OF RADIO JETS

To picture this, imagine that you are looking straight down at a spinning phonograph record. The hole in the center is the black hole; the rest of the record is the swirling disk. In a way not yet fully understood, the disk works like a generator and continuously channels the energy along the black hole's spin axis. As you stare down at the record, one beam of energy is coming straight at your face; the other is going in the opposite direction. Perhaps this is the way the powerful jets seen so clearly in VLBI images are born.

The strange machine hidden deep within the bowels of those brilliant cores may also be linked to one of the most dramatic phenomena discovered in the past decade: superluminal motion, motion that is apparently faster than the speed of light.

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EXOTIC EARS & EYES

The eyes of astronomy are continuously getting bigger, more varied and more exotic.

- **Radio telescopes** scrutinize various cosmic radio sources, such as Jupiter, the sun, radio galaxies and quasars. Yet the signals we pick up from these sources are so weak that the total energy received by all radio telescopes in the world over the past 50 years is equal to the energy expended when a mosquito takes off.

The world's largest radio-radar telescope lies in a natural depression in the earth near Arecibo, Puerto Rico. Its 1,000-foot dish is immobile, but its receiving and transmitting equipment, weighing 600 tons and hanging 50 stories above the dish, can be steered by remote control. The Very Large Array (VLA) in New Mexico is even more powerful, though its 27 antennas are only 82 feet in diameter each. Moving along 37 miles of railroad track, the VLA's antennas perform as if they were a single telescope 21 miles across.

- **X-ray telescopes** probe the behavior of matter at extreme densities and temperatures, such as those near a black hole. NASA's Einstein Observatory, the best X-ray detector of its day, orbited 300 miles up and could have detected a doctor's X-ray machine 100 miles away in space.

- **Infrared detectors** look at cosmic dust, the raw material out of which stars and planets are formed. The United Kingdom Infrared Telescope, the largest of its kind, is so sensitive that under ideal conditions it could detect infrared radiation from a mouse as far away as the moon.

- **Optical observations** still remain the hub around which astronomy revolves. Russia's new 236-inch reflector in the Caucasus Mountains has taken the title of largest optical telescope from the 200-inch on Mount Palomar.

The Multiple Mirror Telescope, at the Fred Whipple Observatory in Arizona, uses six 71-inch mirrors to achieve the same light-gathering power as a single 176-inch mirror—and it costs far less. The 94-inch space telescope, scheduled for launch aboard the space shuttle in 1985, will orbit above the atmosphere. It should be able to detect objects 50 times fainter than those discernible from Earth.

–Wallace Tucker

AMARANTH

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self with its own pollen, making it unlikely that important new genetic combinations will appear.

Some of the first offspring of Kauffman's project have been encouraging. A cross between a Mexican amaranth and an African amaranth, for example, produced the desired short variety with white seeds and resistance to insect pests. And a cross between Mexican and Nepalese varieties produced amaranth with a single massive seed head.

WHEAT STILL TOPS

Even if Kauffman and other researchers create a superior strain of amaranth, it will be very difficult to introduce it into the food system. Wheat reigns with a scepter over American agriculture, and every part of the system, from farmer to food company, has an enormous investment in it. Critics point to the dismal performance of triticale, one of the most promising new crops of recent years, as an augury of amaranth's future. A laboratory cross between wheat and rye, triticale has competed unsuccessfully against wheat despite its attractive characteristics.

For now, one of the biggest problems with amaranth is that so little is known of the plant's economics. "There's enough risk in agriculture without compounding it with a crop nobody knows about," says Gary Laidig, a research specialist with Soil and Land Use Technology, Inc., a consulting company in Columbia, Maryland. Researchers do not know how much it will cost to grow and process amaranth, whose small seed may require specialized machinery, or what price it will fetch in the marketplace. "Unless these factors look favorable, amaranth doesn't have a chance," says Robin Saunders, who directs the cereal-grains research unit at the U.S. Department of Agriculture station in Albany, California.

Before large food companies show serious interest, amaranth may have to prove itself in the specialty health-food market. At least one amaranth cereal is already in the stores, promoted as "the mystical food of the Aztecs." The food companies may also need assurance of a large and reliable supply of the grain before they move forward, so amaranth may have to go into widespread cultivation first as a feed grain for livestock.

Amaranth researchers know that they are trying to reverse the course of a powerful river. Of the 3,000 plant species that mankind has used for food over the centuries, only 150 have been commercially grown. Today, only about 20 plants out of that 150 feed most of the world. To buck this trend and place amaranth on the list of staple crops is a considerable challenge. "We started in 1978," says Kauffman, "but this is lifetime work." ■

CHALLENGE

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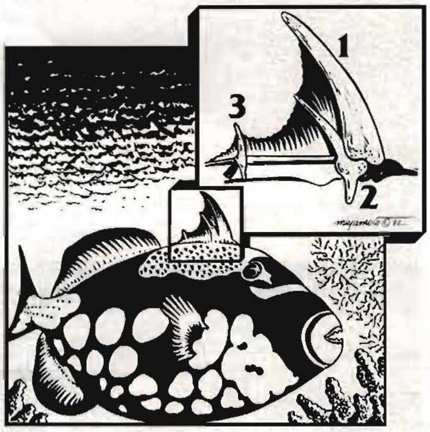
TRIGGER-HAPPY

The clown triggerfish on page 112, ordinarily a slow swimmer, dashes off at great speed when pursued by a hungry predator or enthusiastic diver. It heads for the nearest crack or crevice in the coral, wedges itself in, then pops up its dorsal fin and locks it. Nothing can pull the fish out of its hiding place now.

If it is pursued farther, this foot-long fish can inflict a serious wound with its surprisingly sharp, ratlike teeth and powerful jaws. These chisel-shaped teeth are adapted for crunching right through the hard shells of oysters, clams and crabs.

It is called a "clown" triggerfish because of its round shape and polka-dotted body, but according to Guido Dingerkus, of the American Museum of Natural History, its humorous markings are quite



When the triggerfish raises its top fin, spine 2 moves forward into a notch at the base of spine 1, locking the fin in place. The fin lies flat after spine 3 pulls spine 2 out of its notch, thus releasing spine 1.

practical: they help it blend into the colorful coral reefs it inhabits in the tropical Indo-Pacific ocean.

The name *triggerfish* comes from a mechanism, which works like the trigger of a gun, that it uses to lock and unlock its dorsal fin. Even though this fish had been using its trigger for hundreds of thousands of years before man appeared on Earth, it could not get its name until man invented the trigger for himself.

Why do the names we give to animals so often reflect our own inventions? According to Dr. Jonathan Miller, author of *The Body in Question*, the machines we invent not only help us master the world but also give us a way of seeing it. One way we try to understand the workings of living organisms such as triggerfish is by likening them to man-made mechanisms. "Analogy is the method by which science advances," says Miller. "It is much easier for us to understand a machine than the growing of a tree." ■

TELESCOPES

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Scientists stumbled on the effect while looking for something else. In October 1970, a group of investigators simultaneously trained a telescope in Massachusetts and another in California on the most luminous object currently known in the cosmos, quasar 3C279. They hoped to see the quasar's signal bend as it skimmed the sun's gravitational field. But the test took an interesting detour. "We had been assuming all along that 3C279 was a point source," says MIT physicist Irwin Shapiro, head of the observing team. "But to our surprise, we discovered that the quasar looked like *two* point sources." A few months later, another look showed that the two blobs had moved apart at an apparent speed of about 10 times the speed of light.

Throughout the 1970s, other superluminal sources were sighted in quasars and in galactic cores such as BL Lac. But how could this be? Einstein's special theory of relativity contains a speed limit for the Universe. Nothing, he said, can move faster than a speeding photon (186,000 miles a second). Journals were soon filled with dozens of attempts to explain away this apparent speeding violation. Some said quasars must be closer to the earth than previously believed; others suggested that several parts of the quasar might be flashing in sequence, like lights on a Christmas tree, giving the appearance of faster-than-light movement.

But recently Caltech astronomers, led by Timothy Pearson, were able to produce what they called "the first direct and unambiguous evidence" for superluminal motion. For three years, they intermittently used a VLBI network to probe the nucleus of quasar 3C273. They saw a bright knot breaking away from the quasar's central core and moving along its jet at many times the speed of light.

VIOLENT QUASARS

Caltech astronomers are not giving up on Einstein, however. They support the suggestion that the violent quasars are occasionally ejecting—but at only nearly the speed of light—streams of matter almost directly toward the earth. However, such geometry, coupled with the effects of the speed, they say, would create an optical illusion that makes the speed of the blobs *appear* much greater than it really is. But as George Field, director of the Harvard-Smithsonian Center for Astrophysics, cautions, "Why do so many happen to be pointed straight toward us? The final story may not be in."

VLBI's keen eyesight is not limited to the far shores of the Universe. Intercontinental arrays of telescopes are scrutinizing some amazing radio sources right here in our own galaxy. They are seeing beacons of pure microwave energy ema-

Illustration by Lance Miyamoto

nating from the dusty and turbulent regions surrounding new and very massive blue stars, the hottest and brightest in our galaxy. Astronomers have dubbed these beacons cosmic masers, after the laserlike process that produces them. They are clouds of molecules that are constantly absorbing the new star's energy and then reradiating it as intense, coherent microwave beams.

Each maser is about the size of the diameter of the earth's orbit, and a hundred can surround the newly born star at any one time. Since their strong radio voices can pierce the dusty veil that hides the infant star for tens of thousands of years, these hot spots are often the first announcement of the star's birth. "There's one in the Orion nebula that would be the equivalent of a hundred-trillion-trillion-watt radio station," says Mark Reid of the Harvard-Smithsonian Center.

THINGS TO COME

Despite the provocative findings that have come out of Very Long Baseline Interferometry over the past decade, all VLBI investigators agree that they are merely at the "chewing-gum-and-bits-of-string" stage compared to what they could do with a properly designed system. "At the moment, we're merely borrowing time on a handful of antennas in the United States that were built, in most cases, over twenty years ago," points out Reid. "They were not designed for VLBI use, and most do not work well at high frequencies. The greatest handicap is that they're in random locations, which doesn't produce the best imaging."

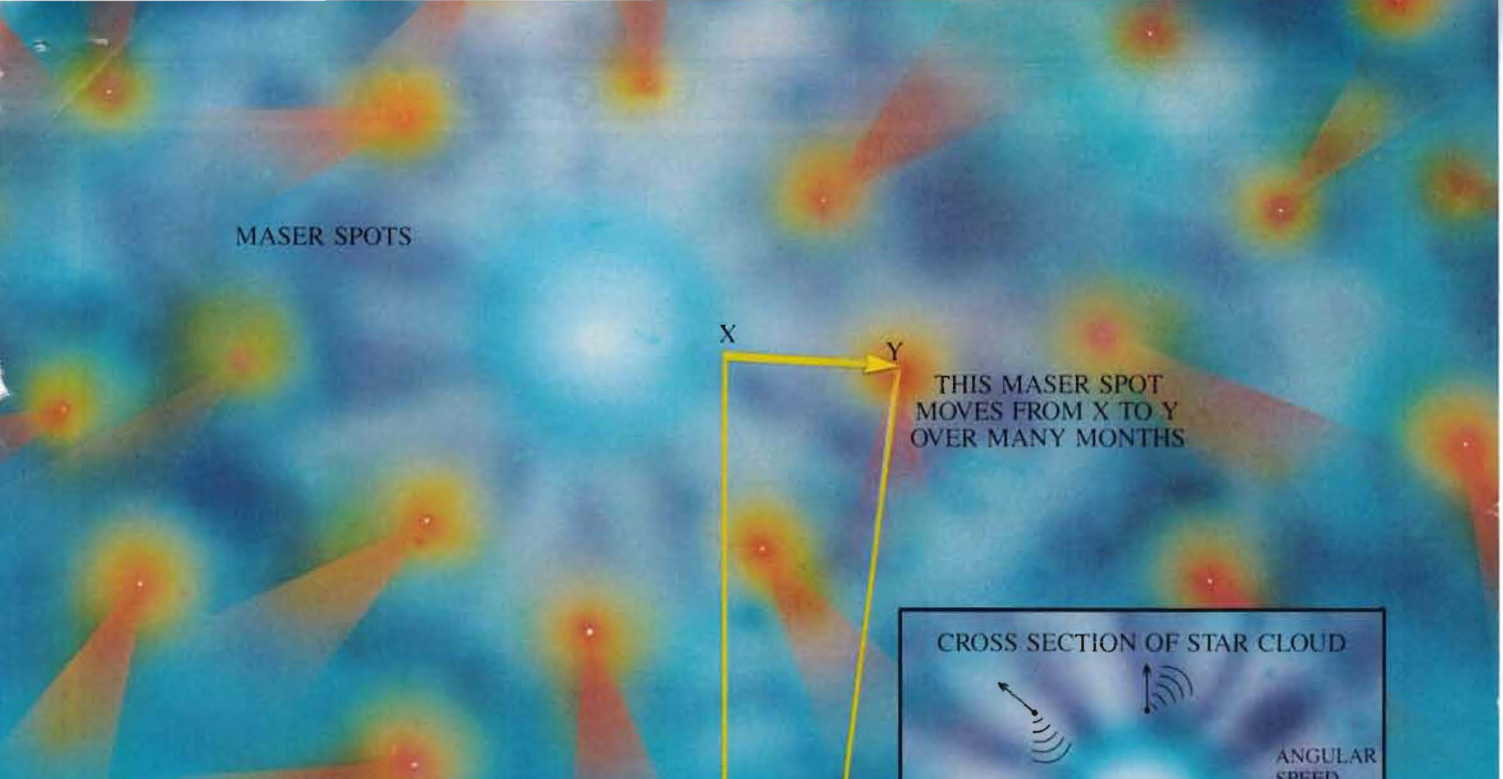
Because of these limitations, both American and Canadian astronomers have called for special very long baseline arrays to be set up across each of their countries. The U.S. proposal (called the Transcontinental Radio Telescope, or TRT) envisions a network of 10 telescopes: one in Hawaii, one in Alaska and eight scattered across the continental United States.

Each dish antenna in the network would be 25 meters across and could pick up radio waves as short as 7 millimeters. Provision would be made to tie in with other antennas around the globe. Operation of the entire array would take place from one control center, where the latest in data-processing equipment would synchronize and correlate up to 14 tapes at one time. The price tag: $40 to $50 million. While the prospect for Federal funds is poor these days, the proposal recently received a boost when a National Academy of Sciences committee, charged with developing priorities for U.S. astronomical research in the 1980s, gave the TRT a top recommendation.

A TRT array would take extragalactic specialists like Readhead 10 times closer to the fire within those explosive fountains of energy. "This would probably tell us whether the central object is indeed a black hole or some other beast as yet undreamed of," he says. Other astronomers are excited by the possibility of better exploration of our own galactic core. Perhaps it, too, harbors a black hole.

Of course, terrestrial real estate can only be stretched so far to create longer and longer baselines. Astronomers are confident, however, that eventually VLBI will take to space. "Space antennas will complement and extend the ground-based arrays," says MIT astrophysicist Bernard Burke. "Though some have raised an eyebrow at the possibility, we are technically ready to do it now." Burke points out that NASA has a project on the drawing board called the Antenna Test Flight Facility. If funded, it would squeeze a 150-foot antenna into a canister, place it on the space shuttle and unfold it right from the cargo bay. While the project is primarily a test for deploying large structures in space, Burke expects the antenna could be hooked into the ground-based network while it was out. Another NASA proposal suggests putting an antenna on an orbiting space platform.

In the meantime, VLBI experts are working to improve the instrumentation that is available to them now. The Naval Research Laboratory is looking into the possibility of synchronizing the telescopes by satellites instead of clocks. Others are attempting to tune into shorter and shorter wavelengths (which would greatly enhance resolution). "VLBI is still in its infancy," stresses Caltech radio astronomer Unwin. "So anything we do at this time is sure to turn up a few surprises." ■



NEW COSMIC YARDSTICK

Radio astronomers are now measuring distances to stars and galaxies more directly than ever before. Their new technique makes use of masers—beams of pure microwave energy that emanate from as many as 100 spots around newborn stars.

Calculating distances is one of astronomy's shakiest enterprises. Astronomers measure distances to nearby stars—up to about 300 light-years away—by using conventional trigonometric calculations that have a probable error of 15 percent. But to extend outward and keep the amount of error to a minimum, they must use a succession of steps, each relying on the initial measurements. "One mistake in that sequence can throw off all measurements to the edge of the Universe," says Matthew Schneps, a radio astronomer with the Harvard-Smithsonian Center for Astrophysics.

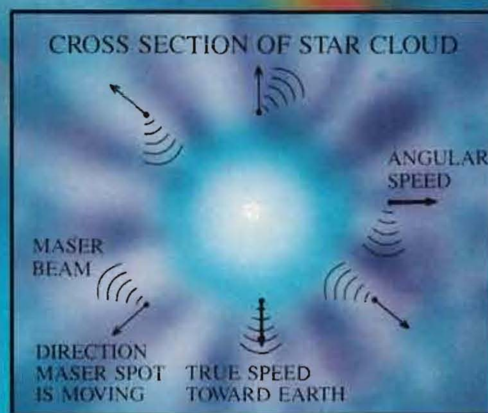
But by using the maser method, developed by Berkeley astronomer Reinhard Genzel, Schneps and his colleagues, Dr. Mark Reid and Dr. James Moran, can bypass several links in the traditional chain and measure out to perhaps a few million light-years in one giant leap.

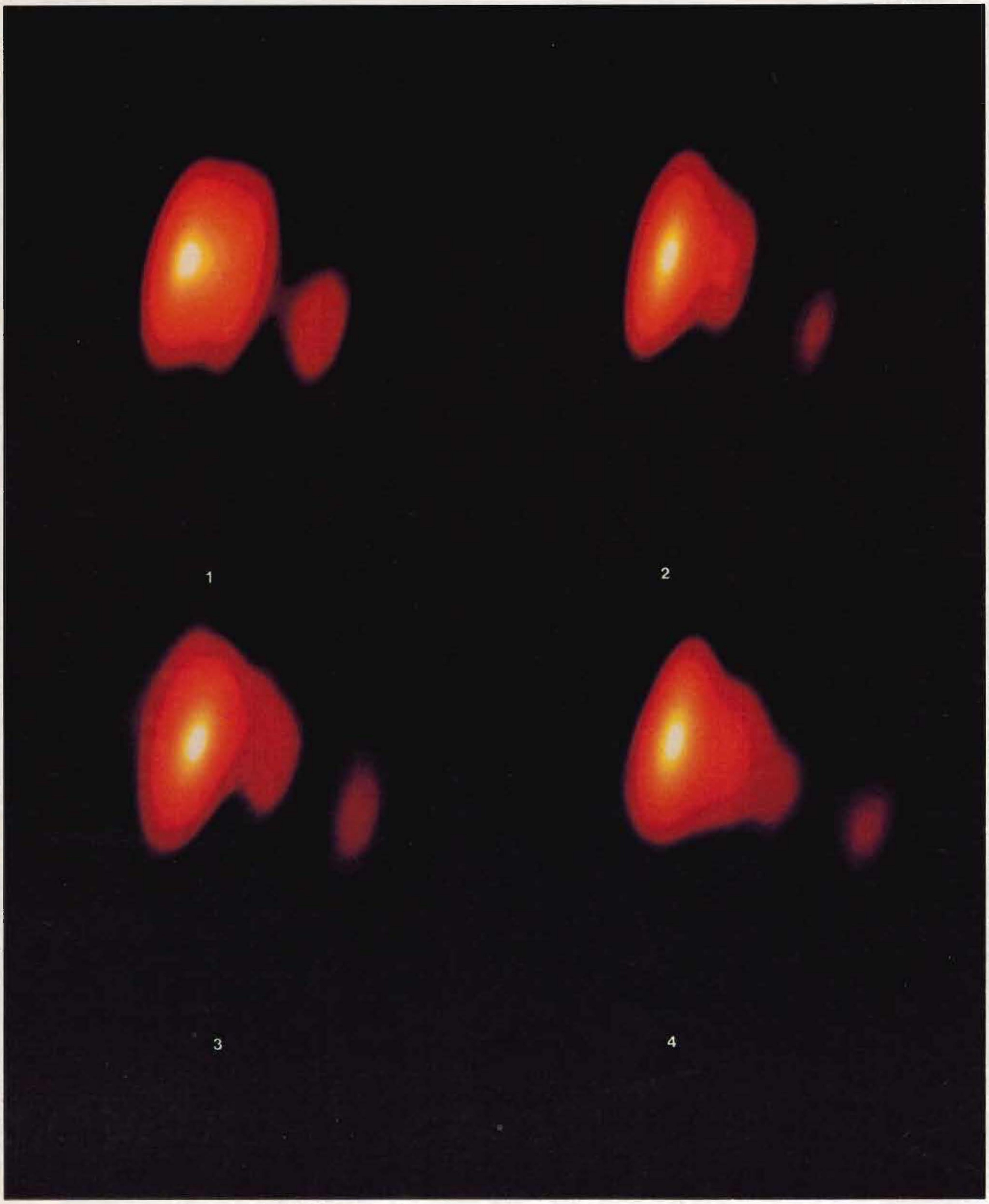
First they need to calculate a maser spot's speed. In the diagram above, the powerful wind from a newly formed star blows maser spots in all directions at the same speed. These spots, formed out of either hydroxyl, methanol, silicon monoxide or water, emit microwave beams in various directions. If a spot is moving toward Earth, the observed wavelength of its microwave beam will be shorter than if there were no relative movement. This effect is known as the Doppler shift: the microwaves are shifting toward higher frequencies. Knowing the maser's observed wavelength and its true wavelength (molecules emit microwaves in a certain frequency range), astronomers can calculate the speed at which the maser spot moves toward Earth. The masers with the greatest Doppler shifts are moving directly toward Earth, and these are used to determine the *true speed* of the spots (see inset).

Next, the astronomers spend months observing the maser beams coming from spots that move sideways and have little or no Doppler shift (on diagram, the spot moving from point X to point Y). From this they determine a maser spot's *angular speed,* which is calculated by dividing the very small angle A (which is converted into a special dimensional unit that represents a fraction of the circle) by the time it took the maser spot to sweep through angle A. Finally, they simply divide the speed at which the spot is moving toward Earth by the angular speed, thus arriving at the distance from Earth.

This new cosmic yardstick has already been successful in matching previous (and more complicated) distance calculations to the Orion nebula, about 1,600 light-years away, and to an active star-forming region called W51 halfway across the galaxy (23,000 light-years away).

Testing the technique, the maser team is pushing out farther—out to the nearby galaxy M33. They began observing maser spots traveling across the sky last year and will follow them for a few more months. If their finding is different from the current estimate of 2 million light-years for M33's distance, it could change astronomers' view of the size of the Universe.





SUPERLUMINAL MOTION: IS IT REAL OR MERELY AN ILLUSION?

Events occurring at the nucleus of quasar 3C273 seem to indicate motion that is faster than the speed of light, something Albert Einstein claimed was impossible. The photo series above, taken by Caltech astronomers, shows that (1) by July 1977, a bright knot that had broken away from 3C273's central core (white) had moved a calculated 62 light-years toward the right. (2) By March 1978, the knot was about 68 light-years away; (3) by June 1979, 77 light-years away and (4) by July 1980, 87 light-years away. The knot seems to have traveled 25 light-years in just 3 years, but astronomers firmly believe this is only an optical illusion.

Photographs courtesy of California Institute of Technology