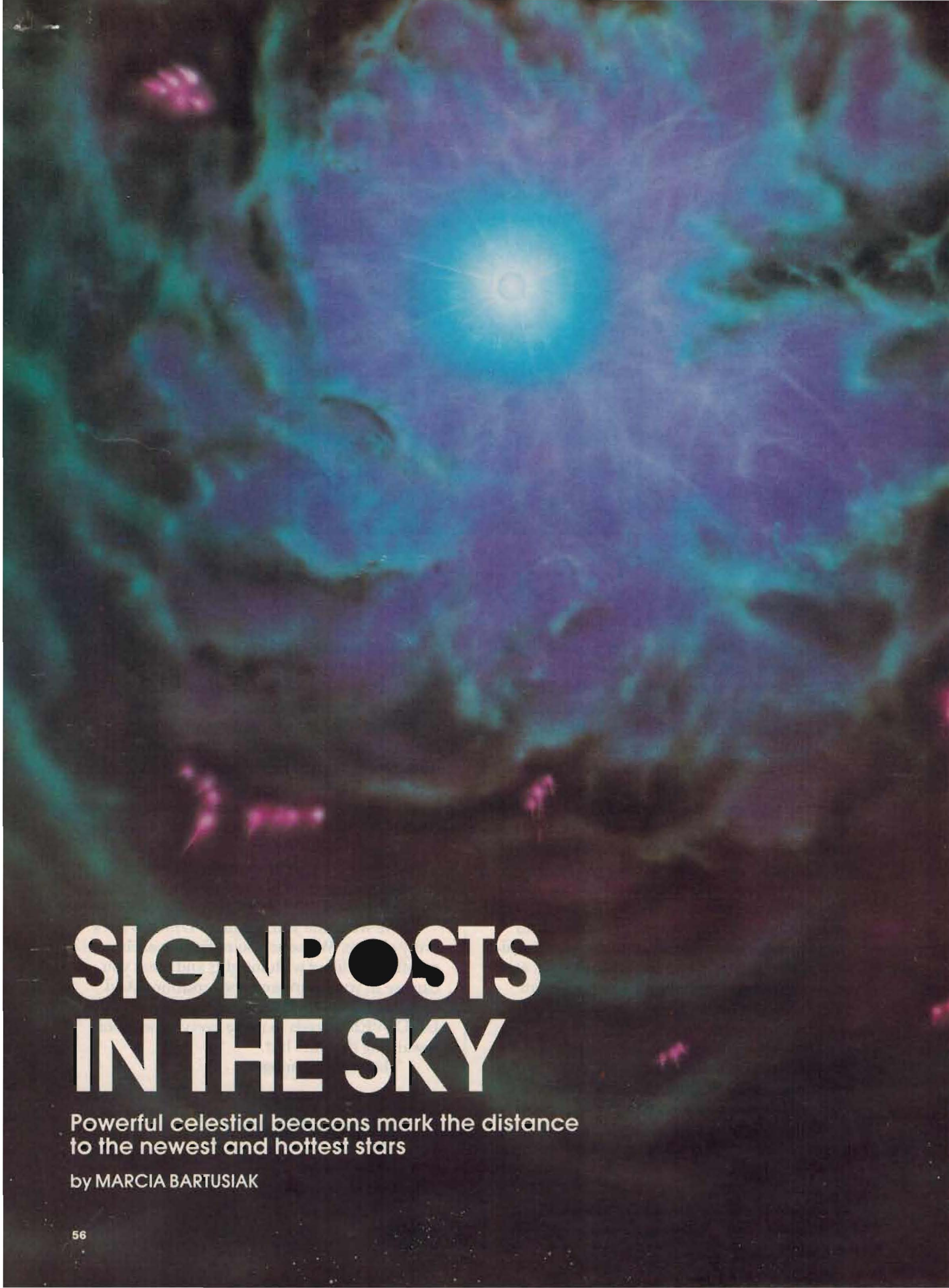


SIGNPOSTS IN THE SKY

Powerful celestial beacons mark the distance to the newest and hottest stars

by MARCIA BARTUSIAK

The howls come from deep in the gassy, dust-streaked clouds of space, where stars are born—clear radio tones amid the dissonant chatter and squeals of the cosmos. Puzzled by the immense power and pure frequencies of these beams, astronomers once dubbed their unknown source "mysterium." The mystery has since been solved, and the beams have become known as cosmic masers, after the exotic laserlike process that produces them. Each beam is, in fact, a kind of microwave radio voice of a cloud of interstellar molecules excited by the intense radiation from bright young stars.

Astronomers have just begun to use the masers to solve another kind of puzzle, as an accurate new yardstick to gauge celestial distances. Next winter astronomers from the Harvard-Smithsonian Center for Astrophysics, in Cambridge, Massachusetts, will simultaneously train a bevy of radio telescopes—some in the United States, others in Europe—on the cosmic masers of the galaxy M33 in the constellation Triangulum. Their goal: to measure the distance of that galaxy from earth in just one step; the present estimate of 2 million light-years was determined by a sequence of complex methods. If the new finding is different, it could change astronomers' view of the size of the universe. The new yardstick has already been used successfully in confirming distances to several regions of the Milky Way, the solar system's home galaxy.

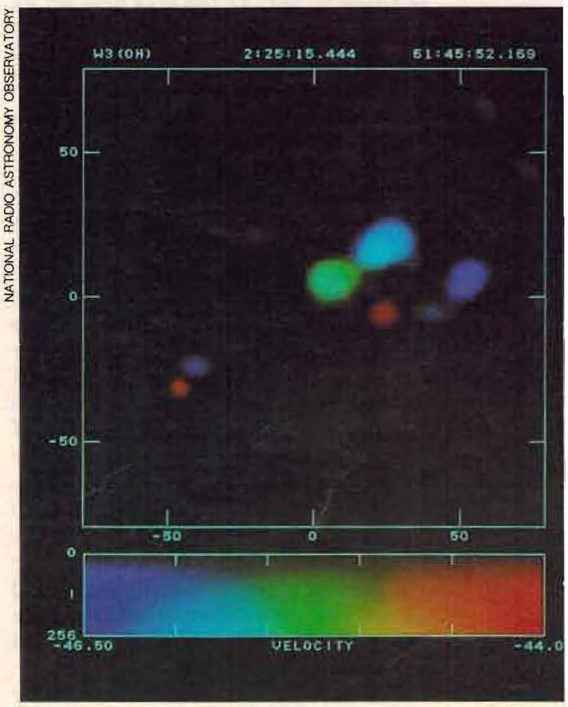
Like pulsars and other exotic members of the celestial zoo, cosmic masers were discovered by accident. In 1965 Harold Weaver and his colleagues at the University of California at Berkeley were using a radio telescope to survey the emissions given off by vast clouds of gas and dust concentrated in the spiral arms of the Milky Way. While tuning in the distinctive radio frequency emitted by hydroxyl molecules (one hydrogen atom bound to one oxygen atom), the Berkeley group picked up one of the most pure and intense radio signals ever recorded. It was as if some advanced extraterrestrial civilization were pointing a powerful beacon straight at the earth.

Soon the astronomers discovered similar beams emanating from all over the Milky Way—in the Orion Nebula, in a dusty cloud near the constellation Cassiopeia, and in diffuse gaseous regions near Aquila and Cygnus. What could cause such powerful outbursts? In a report to the journal *Nature*, Weaver and his colleagues wrote, "to emphasize the surprising nature of the observation . . . we shall speak of this unidentified line [of radio energy] as arising from 'mysterium.' "

In this artist's conception, cosmic masers dot the dusty and turbulent region around a newly born star

Within a year of this discovery astronomers had figured out that mysterium was nothing more mysterious than a cloud of hydroxyl molecules, but one that had coalesced to form a gigantic maser. Other microwave beacons have since been found operating at frequencies belonging to methanol, silicon monoxide, and water vapor in more than 500 regions of the Milky Way and even in nearby galaxies. In all of these

NATIONAL RADIO ASTRONOMY OBSERVATORY



Masers in the constellation Cassiopeia, revealed in a computer-generated picture; velocity is indicated by color

the energy source is basically the same. By a process not completely understood, molecules (of, say, water vapor) absorb energy from the surrounding dust cloud in such a way that many of them eventually wind up at the same energy level, like birds sitting on a telephone wire. There they sit until a chance event—a stray photon or the sudden decay of one of these pumped-up molecules—triggers an avalanche. The molecules dump their energy simultaneously, producing an intense beam of single-frequency radio waves, all precisely in phase and reinforcing each other. (A similar process produces the intense light of lasers.) Because the cos-

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mic versions produce microwaves, they are called masers.

"The water masers are especially impressive," says James Moran, a radio astronomer with the Center for Astrophysics, who has been studying them for more than a decade. "It's as if the total luminosity of the sun over the entire electromagnetic spectrum were pouring out in a small band of frequencies the width of a television channel." Besides marking off distances in the sky, the masers are also handy pointers to regions of the galaxy where new stars are forming.

The process starts with the birth of massive blue stars that are 100,000 times as bright as the sun and dozens of times as big. As the star fires up its thermonuclear furnace for the first time and its surface temperature reaches 50,000 degrees Fahrenheit, atomic particles are driven off the star into space, becoming an intense stellar "wind" that drives away the surrounding dust and gas left over from the star's birth. This placental cloud speeds outward at hundreds of miles a second, but not smoothly. Some of the gaseous molecules in that violent flow begin to form clumps. It is those clumps, each of them bigger than the earth's orbit around the sun, that absorb the star's energy and re-radiate it as intense microwave beams. At any one time, a hundred of these giant masers can surround the newly born star, like fireworks heralding its birth. Moran compares them to "fireflies that flicker on and off." Because it takes up to a million years for the dust to blow completely away and reveal the stellar glow itself, a cosmic maser is often the first announcement of a newborn star.

The lifetime of a water maser is only one to two years, but the first-discovered hydroxyl masers last much longer, and the maser phenomenon can go on for tens of thousands of years around the young star. The two types of maser seem to appear at different times in the stellar cycle. "The water masers form during the very energetic phase of the star's evolution," says Moran's colleague Mark Reid. "We seem to be seeing the hydroxyl masers during a quieter stage, when the expanding gas has slowed down and reached a tenth of a light-year [nearly 600 billion miles] across."

Using intercontinental arrays of radio telescopes and months of computer analysis, the Harvard-Smithsonian team has been able to measure the almost imperceptible movements across the sky of individual masers as they are blown away from the parent star. It was Reinhard Genzel, now at Berkeley, who first realized that those measurements could be put to cosmological use, to determine distances to stars and galaxies more directly and perhaps more accurately than ever before.

RICHARD HOWARD

Moran, Schneps, and Reid at the Harvard-Smithsonian computer center

Distance determinations are the Achilles' heel of modern cosmology, because estimating the distances of faraway stars and galaxies depends on a lengthy chain of inferences and assumptions. It begins with the stars closest to the sun: their distances are measured trigonometrically by noting how much they have changed position against the celestial background when they are observed first from one point in the earth's orbit around the sun and then, six months later, from the other side of the orbit. Using those results as a calibration, the distance of stars and galaxies further out is estimated by a complex sequence of steps, often involving luminosity. "One mistake in that chain can throw off all measurements to the edge of the universe," says Matthew Schneps, a radio astronomer with the Harvard-Smithsonian group.

But by using Genzel's method, the Harvard-Smithsonian astronomers can bypass that long, involved chain, measuring distances—possibly as far as a few million light-years—in one step. Observing masers in the cloud expanding around a newly born star, they determine, by measuring the Doppler shift in the frequency of the microwave beams, how fast these bright spots are moving toward the earth. They also measure, over many months, how the masers move across the sky at right angles to a line between the earth and the cloud. From these two pieces of information plus a bit of geometry, they can determine the distance of the cloud from the earth. "It's an old astronomical technique used with star clusters that is now recast using masers," says Reid.

The Harvard-Smithsonian group has just applied the new yardstick to several groups of masers in relatively nearby regions of the Milky Way. Some are in the Orion Nebula, which astronomers have determined by other techniques to be 1,600 light-years away. The results agree, good evidence for the accuracy of the new method. Now the astronomers are gearing up to measure the distances to maser groups in the galaxy M33 and throughout the Milky Way. Says Schneps, "By mapping enough sources in the Milky Way, we may get the first direct measurement of our galaxy's size."

Like celestial physicians, masers attend not only the birth of certain stars, but also their death. Astronomers have found that masers can form in the cloud of material emanating from giant red stars during the twilight of their existence. In 1964, physicist Charles Townes was awarded the Nobel Prize for constructing the first maser. The Nobel committee did not realize then that nature had preceded Townes by billions of years.