COMING HOME

Not long ago many astronomers all but ignored the Milky Way. Now they are turning to our own galaxy for answers to cosmic conundrums.

BY MARCIA BARTUSIAK

When darkness falls on an isolated mountaintop or a rural plain, a creamy ribbon of light, laced with patches of the deepest black, stretches across the heavens. To the ancient Egyptians and Greeks, whose view of the evening sky was never obscured by pollution and city lights, this starry canopy looked like a river of milk, and so it came to be known as the Milky Way. The word *galaxy,* in fact, is derived from *gala,* the Greek word for milk. The Milky Way is our home galaxy. For centuries its borders defined the known universe—and the limits of astronomy.

In the early part of this century, however, our universe ballooned: astronomers realized that many of the fuzzy nebulas they had seen in their telescopes and had taken for gas clouds in the Milky Way were actually far-off galaxies. And gradually, over the ensuing decades, the study of the Milky Way itself came to seem a bit passé. The glamour lay on the frontier, in watching galaxies collide and quasars explode in the far reaches of the cosmos. "There was more to be learned, it seemed, from observations of other galaxies than from observations of our own," says Leo Blitz of the University of Maryland. "The far edge of the universe is a very sexy place to be."

But now the scientific fashion is changing; the Milky Way is shaking its stodgy image. Astronomers are coming to realize that answers to some of their most profound questions—from the nature of the dark matter that is thought to pervade the universe to the source of power in quasars and other active galaxies—may be found right here in our own backyard. And so, like seasoned explorers returning from far-flung adventures, many of them are coming home. Armed with new telescopes and electronic detectors, they are uncovering a starscape that would have astounded their predecessors 20 years ago.

The "new" Milky Way, like the old one, is a disk of comparatively young, bluish stars surrounding a central bulge of old, red stars; but the disk is now much bigger, and it has kinks in it. The new Milky Way still has spiral arms, but the arms are studded with giant clouds of molecular gas, inside of which astronomers can at last see massive stars being born. In the core of the galaxy there may well be a black hole, as has long been thought, but there is also a cluster of hot objects that no one has been able to identify. And shooting out from a region near the core are glowing filaments that look like flares on the surface of the sun.

In short, our home galaxy is far from ho-hum. "Galaxies are like people," says Virginia Trimble of the University of California at Irvine. "When you get to know them they're never normal."

Yet most spiral galaxies, including the Milky Way, are believed to have formed in much the same way. Between 10 and 18 billion years ago—precisely when is a matter of ongoing debate—billions of galaxies condensed out of the primordial stuff spewed from the Big Bang. Thus the Milky Way started off as a spinning sphere of gas, primarily hydrogen and helium, spread over hundreds of thousands of light-years. Ultimately this cloud collapsed under its own gravity, and because it was spinning it flattened into a disk, leaving behind a residual halo of individual stars and dense star groups known as globular clusters. Today the bulk of the Milky Way's mass is tied up in some 100 billion stars held together by their mutual gravitational attraction; 5 to 10 percent of that mass remains as a tenuous gas. Dust grains—microscopic specks of ice-coated silicate and graphite—make up a fraction of a percent.

The idea that the solar system is immersed in a flattened disk of stars was first conceived in the eighteenth century. But for a long time people assumed the sun was at the center of the disk. In 1917 noted American astronomer Harlow Shapley dispelled that myth. By measuring the distances to a number of globular clusters in the galaxy's halo, Shapley determined that the solar system is actually situated in the galactic suburbs. "The solar system is off-center," he remarked many years later, "and consequently man is too."

Yet we may be closer to the action than Shapley and his successors ever figured. An international team of radio astronomers recently measured the distance to certain radio-wave emitting objects near the Milky Way's nucleus. They concluded

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The Milky Way is shaped like a phonograph record with a tennis ball stuck in the center.

that the distance to the nucleus is not 30,000 light-years, as astronomers had thought, but closer to 23,000 light-years. This puts the sun about halfway out in the disk of stars, in a lazy, 250-million-year orbit about the galactic hub.

Meanwhile other astronomers discovered that a disk of atomic hydrogen gas extends far beyond the disk of stars, perhaps as far as 80,000 light-years from the center of the galaxy. The Milky Way is thus significantly larger than textbooks of a decade or two ago described it. "There was a time when the Milky Way candy bar had a wrapper that said 'Milky Way—now thirty-five percent bigger,' " recalls Blitz, whose radio maps of the hydrogen disk have helped push the galaxy's boundaries outward. "But they took it off the market before I could get one and frame it."

Although the galactic disk is large, it is surprisingly thin. It has the proportions of a phonograph record; a tennis ball stuck in the center would represent the galaxy's central bulge. What's more, the record is warped. Australian astronomers first noticed this phenomenon in the 1950s, but Blitz and his colleagues have only recently succeeded in clearly mapping the warps. The disk flips up on one side by about 6,000 light-years, and down by a similar amount on the opposite side ("like a fedora that's been run over by a bus," says Blitz). All around its edge the disk also exhibits a subtle scalloping, like (to switch metaphors) the undulating folds of a seashell. There are about ten folds in all. Blitz speculates that they may be formed by the gravitational pull of two small galaxies—the Large Magellanic Cloud and the Small Magellanic Cloud—caught in orbit around the Milky Way.

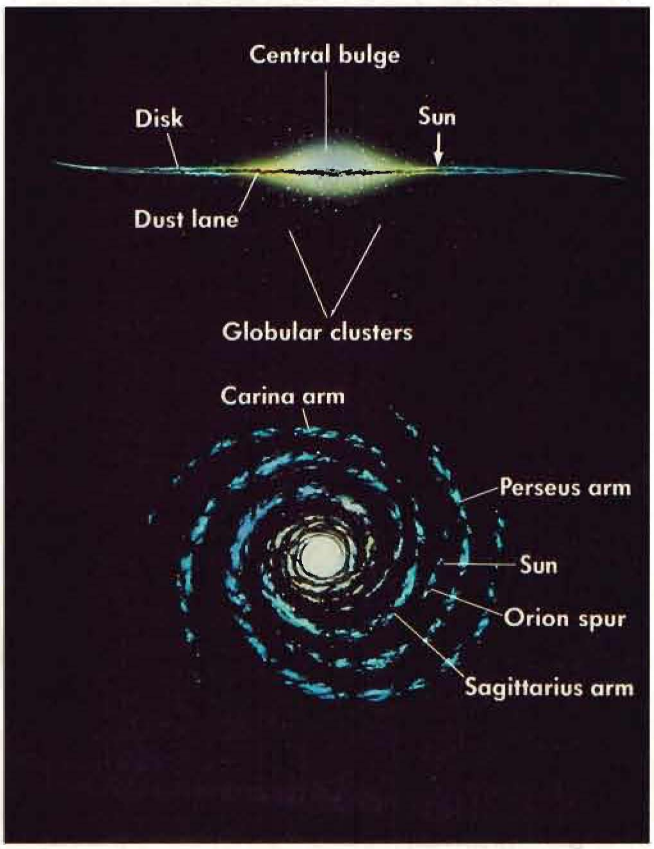
Mapping our galaxy's spiral structure is even harder than defining its boundaries. Considerable cleverness is needed to deduce, from our position inside, what the Milky Way looks like from the outside. Visible-light astronomers have had limited success; they can't see much farther than 20,000 light-years through the dust-and gas-filled plane of the galaxy. Radio astronomers, tuned to the 1.4-gigahertz signal of atomic hydrogen, have had better luck, but after nearly 40 years of such observations, the observers still can't agree on any one map. However, a clearer picture is now coming in from a different radio source: interstellar molecules.

Around two decades ago most investigators thought that molecules would be exceedingly rare in space, breaking apart quickly if they ever formed at all. This conventional wisdom was wrong. Starting in the 1960s, astronomers discovered that the Milky Way is actually a vast chemical stockroom, whose inventory of more than 60 chemical species includes such molecules as ammonia, the welding fuel acetylene, and the preservative formaldehyde. Each type of molecule is identified by the unique set of radio or infrared waves it emits.

Each, that is, except hydrogen, which accounts for the bulk of the molecular gas in space. While individual hydrogen atoms emit radio waves profusely, hydrogen molecules—which consist of two atoms joined together—are virtually silent. Fortunately, carbon monoxide (the stuff of car exhaust) is invariably mixed in with the hydrogen, and *it* is noisy. By tuning in to carbon monoxide's distinctive signal (its frequency of 115 gigahertz is a bit higher than the one used in microwave cooking), Milky Way researchers can map the distribution of interstellar molecules, much the way neuroanatomists use chemical stains to map regions of the brain.

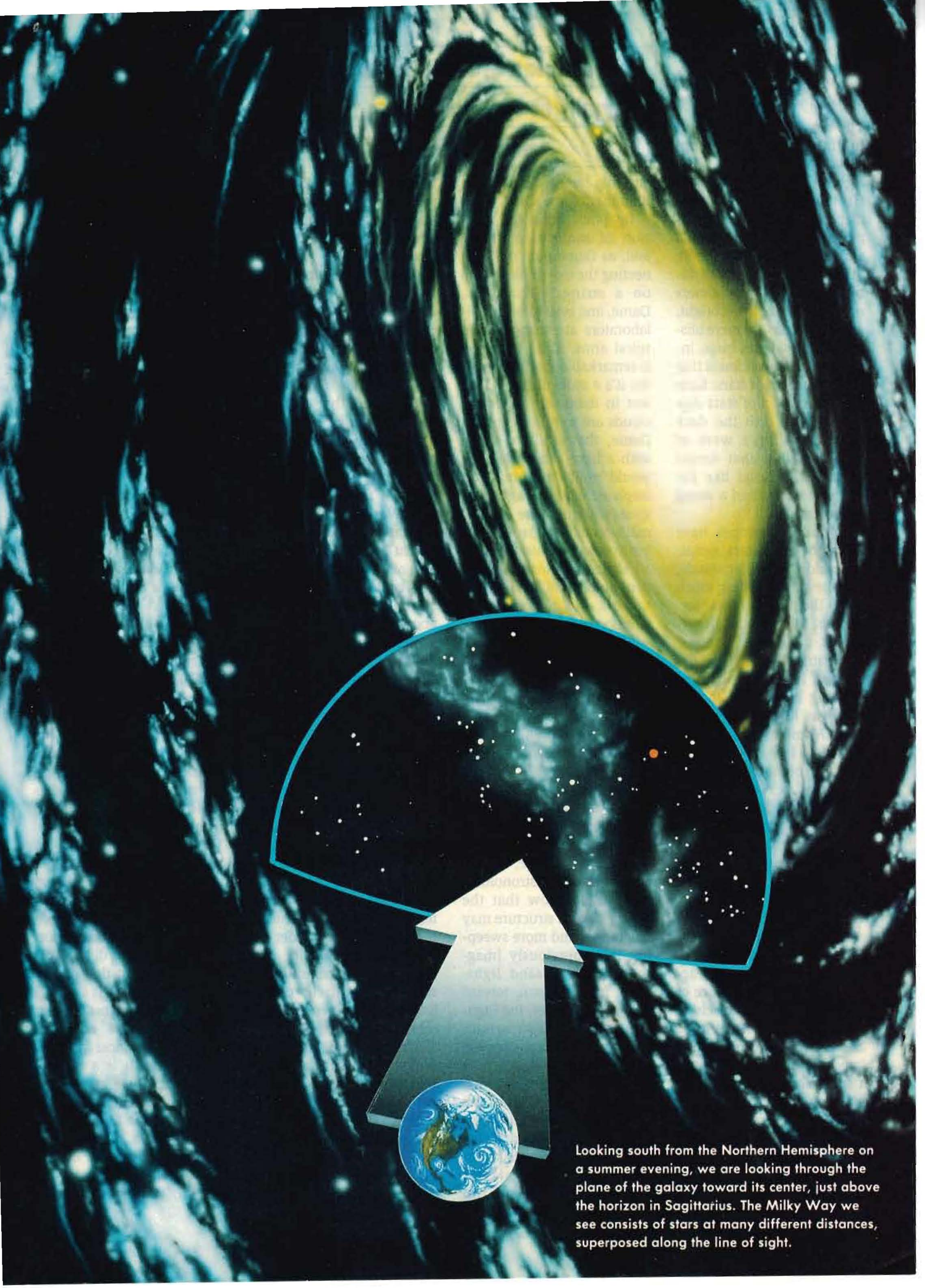
With this method astronomers have discovered a whole new class of celestial objects: molecular clouds. The Great Rift, a dark lane of dust and gas silhouetted against the mistlike Milky Way, is a chain of small, nearby molecular clouds; each cloud is a couple of hundred light-years across. Other molecular clouds are as much as a thousand light-years across and contain more gas than a million suns. These giant clouds, of which several hundred are known, are the most massive objects in the galaxy. "In the inner Milky Way, that part within the sun's orbit," notes Thomas Dame of the Harvard-Smithsonian Center for Astrophysics in Massachusetts, "about half of the interstellar gas is contained in molecular clouds."

More important, the giant clouds are the galaxy's most prolific stellar incubators.



Seen edge-on (top), the Milky Way would be a thin disk with a bulge of stars at the center. A warped disk of hydrogen would extend beyond the stars. An observer above the galaxy could view much of the galaxy's spiral structure (bottom).

ILLUSTRATIONS BY DENNIS DAVIDSON; INFORMATION SUPPLIED BY THOMAS DAME AND PATRICK THADDEUS, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS



Looking south from the Northern Hemisphere on a summer evening, we are looking through the plane of the galaxy toward its center, just above the horizon in Sagittarius. The Milky Way we see consists of stars at many different distances, superposed along the line of sight.

"Galaxies are like people: when you get to know them they're never normal."

The idea that stars form in interstellar clouds is not new; as long ago as the eighteenth century, William Herschel, private astronomer to King George III, suggested that the Orion nebula and other bright clouds were "the chaotic material of future suns." But astronomers now realize that the bright, visible nebulas are mere blisters on the sides of huge, invisible molecular clouds that spawn clusters of stars. Each new generation of stars digs ever deeper into the dark cloud, kindling a wave of star formation that surges through the cloud like the successive bursts of a string of firecrackers.

Infrared telescopes have spied the protostars gestating inside molecular clouds, and they are revealing much about the process of star formation. ("Before the discovery of molecular clouds," says Patrick Thaddeus of the Center for Astrophysics, "talking about star formation was like trying to discuss *Hamlet* without the Prince.") But as far as the structure of the Milky Way is concerned, it is the distribution of the clouds that counts: the giant ones tend to line up like streetlamps along the galaxy's spiral arms.

Why the clouds should do that is not yet clear, because astronomers do not fully understand what accounts for the persistence of the spiral arms themselves. One theory is that the arms are essentially cosmic traffic jams, the luminous result of a spiral-shaped compression wave moving through the Milky Way's smooth disk of matter. According to this theory, gas gets squeezed by the wave; huge molecular clouds form; and, eventually, big new stars turn on, illuminating the spiral.

By pinpointing the location of molecular clouds and, as Dame puts it, "connecting the clouds like beads on a string," Thaddeus, Dame, and several other collaborators are mapping the spiral arms. Their telescope is remarkable for its simplicity: it's a radio dish just four feet in diameter. Molecular clouds are so huge, explains Dame, that studying them with a large radio telescope would be like examining an elephant with a magnifying glass: you might see the animal's toenail in great detail, but you would miss its overall structure. Nor do Thaddeus and his colleagues have to work on a remote mountaintop. Indeed, until 1986, when Thaddeus moved his operation to Harvard, the telescope was set up in Manhattan, on a Columbia University rooftop. Neither pollution nor city lights can block the radio signal of carbon monoxide.

"To us, the spiral structure is unmistakable," says Thaddeus. "The major arms are seen quite beautifully." The maps that he, Dame, and other radio astronomers have made show that the galaxy's spiral structure may be grander and more sweeping than previously imagined. Six thousand light-years from the sun, toward the galactic center, the Sagittarius and Carina arms, once thought of as separate, are now seen to link up in a long, starry lane that swirls more than two thirds of the way around the Milky Way's disk. Six thousand light-years in the opposite direction, toward the galaxy's outer edge, the Perseus arm is clearly defined. Our solar system lies between Perseus and Sagittarius-Carina on a small loose branch. This branch is called the Orion spur, since the Orion nebula is a fellow resident.

Some astronomers think that yet another arm, called Cygnus, sweeps majestically around the side of the galaxy, opposite Sagittarius-Carina, and that a similar arm lies hidden behind the galactic core. It is too early to say whether they are right. The maps of the Milky Way, like the first charts of the New World, are still crude.

That crudeness is most apparent in the crowded territory of the inner Milky Way. The center of the galaxy is surrounded at a distance of about 15,000 light-years by a broad ring of molecular gas; the ring may or may not consist of several inner spiral segments seen edge-on. Farther in is still another arm that seems to be moving rapidly. Some investigators speculate that this arm is being pushed outward at 200,000 miles per hour by an explosive event, perhaps a tremendous burst of star formation, that occurred between 10 and 20 million years ago in the galactic center. Others argue that the gas is simply flowing under the gravitational influence of a bar-shaped concentration of stars in the galactic center, like the bars seen in some other spiral galaxies.

The innermost core of the Milky Way, a region about ten light-years in diameter, is unlike any other sector of the galaxy. A visitor there would see the sky ablaze with millions of stars separated by light-days instead of light-years. (By comparison, the same volume of space near the solar system would contain only a handful of stars.) We can't see this remarkable spectacle because its visible light is blocked by dust and gas floating between us and it. But radio, infrared, and high-energy photons (X-rays and gamma rays) can slice through the dust with ease. These photons reveal that the central region of our galaxy is as energetic as 10 million suns.

Astronomers who study this region have essentially the opposite needs of astronomers who study the galaxy's spiral structure. They want to see the toenail of the elephant: a lot of detail in a narrow field of view. For that purpose many of them travel to a desolate plain in southern New Mexico, where a set of 27 radio dishes, lined up for miles in the shape of a Y, mimics the resolving power of a single dish larger than Washington, D.C. When this Very Large Array is aimed at the Milky Way's heart, astronomers see a maelstrom of energized gas a few light-years wide, spiraling around a bright, tiny radio source. With an even larger array—a network of radio telescopes scattered across the United States—K.-Y. Lo of the University of Illinois measured the size of the central source. He found that its diameter is no greater than that of Saturn's orbit, which is a couple of light-hours across.

What is this compact source? The most popular view is that it is a stupendous black hole as massive as a million suns, and that the core of the Milky Way is essentially a mini-quasar. Quasars are starlike objects that are thought to be billions of light-years away;

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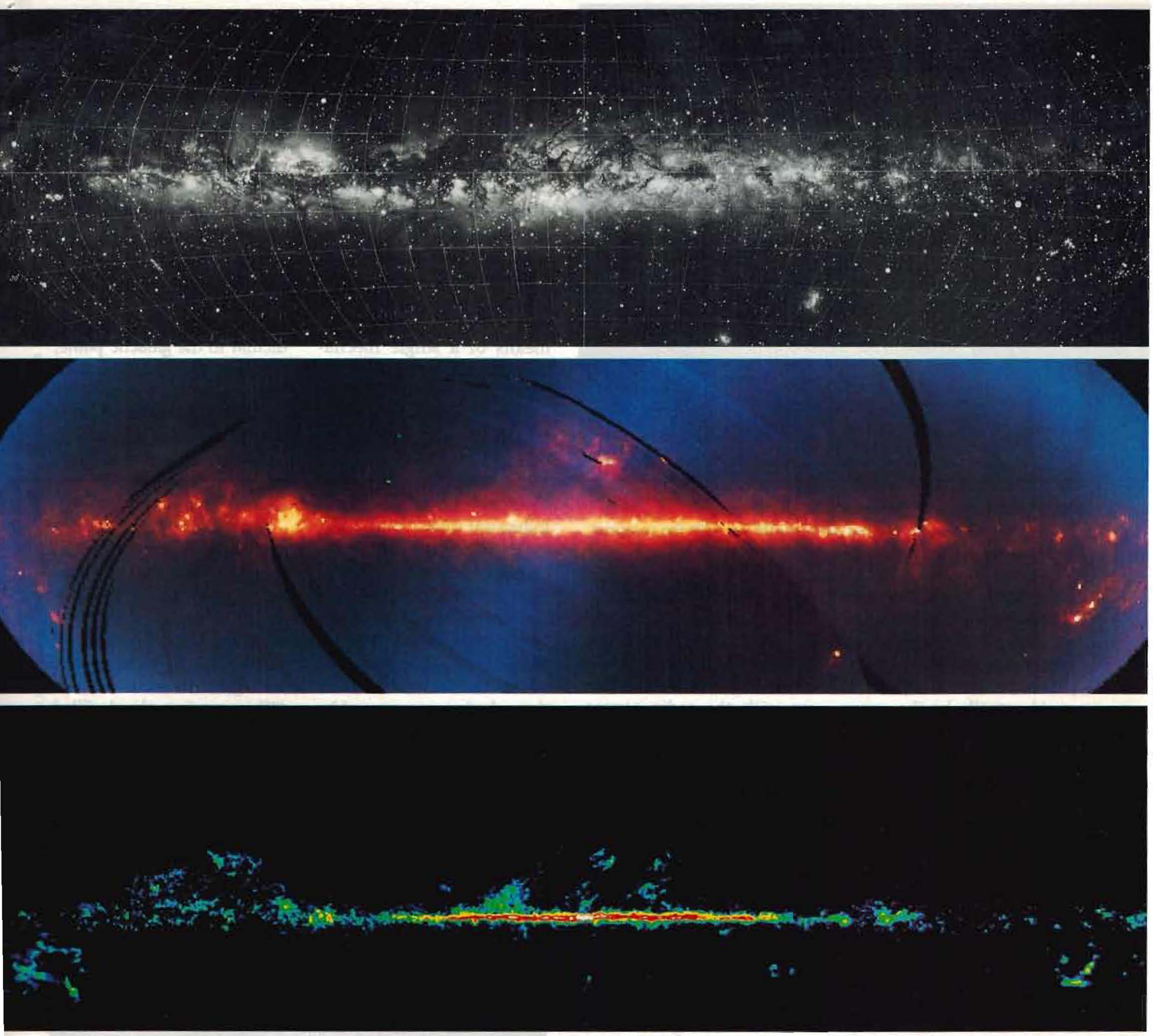
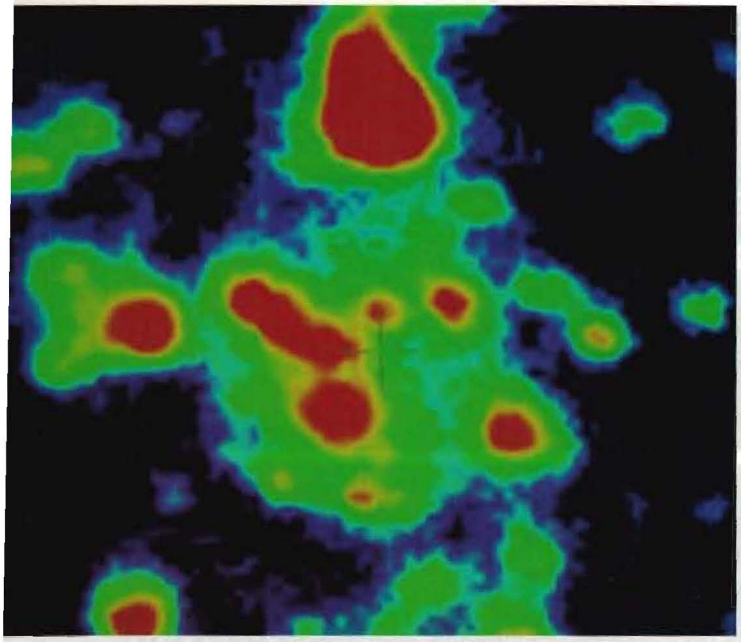


The Milky Way looks different at different wavelengths. In visible light (top) we see thousands of stars, but much of our view through the galactic plane is blocked by scattered dust. In the infrared (middle) we see primarily the heat radiation from this dust. The radio image (bottom) shows the distribution of carbon monoxide gas, which is found in the dense molecular clouds where stars are born. (The images are 360-degree views of the entire sky, centered roughly on the galactic center.)

most astronomers believe they are not individual stars at all but whole galactic nuclei, and tremendously energetic ones at that. The source of energy, according to this conventional theory, is a supermassive black hole that spins like a turbine in the galaxy's core. As matter is drawn into the hole, it heats up to an extreme radiance; in the process excess gas may be deflected outward in a powerful beam known as a cosmic jet.

Australian and U.S. radio astronomers have seen what looks like a very faint jet directed southward out of the Milky Way's center. Other evidence also suggests the presence of a huge black hole. For instance, gas near the galactic center is being whipped around at speeds of some 200 miles per second. At such speeds a lot of the gas should have flown off long ago, but it hasn't. That implies that the gas is being held by the gravity of 2 million or more solar masses packed into the innermost light-year of the galaxy. Such a mass concentration, some theorists say, cannot be accounted for by stars alone. Even if it could, others argue, a large concentration of stars at the center of a galaxy must inevitably collapse into a supermassive black hole.

Martin Rees of Cambridge University thinks the Milky Way has a hole that feeds sporadically, gobbling up a



An infrared image of the central few light-years of the galaxy shows several hot objects, but none match up with the compact radio source (indicated by cross hairs) detected earlier.

passing star and flaring into action every 10,000 years or so. The gas that appears to be spiraling toward the compact radio source, says Rees, could actually be the vapor trails left by material flung outward during the last feeding. Today the core is relatively quiet—the radio source is emitting only ten times the power of our sun—but in the future it could well erupt again.

The radio source, though, is not alone at the center of the galaxy—and that has become a problem for Rees and other devotees of the supermassive-black-hole theory. Much of the energy emanating from the central region comes from a cluster of infrared sources, including one known as IRS 16. Until recently it looked like IRS 16 overlapped the compact radio source, and so it was assumed that infrared energy was also somehow coming from the black hole.

But over the last few years a number of infrared astronomers, including Marcia and George Rieke of the University of Arizona, have been making sharper pictures of the galactic center with advanced infrared detectors. IRS 16, it turns out, has several distinct components—and not one matches up with the radio source. "The closest is about a quarter of a light-year away," says George Rieke. "Close, but no cigar."

The enigmatic infrared objects do not resemble individual stars; one looks like it might be a particularly dense and energetic cluster of stars. Whatever they are, their combined power could account for much of the hubbub in the galactic center. If so, then there is no need for a supermassive black hole in the Milky Way; the tiny yet powerful radio source could be a black hole of more moderate size, say, several hundred solar masses. "We had been looking for one object to explain all the center's energy," says Rieke, "and now we've found two or three."

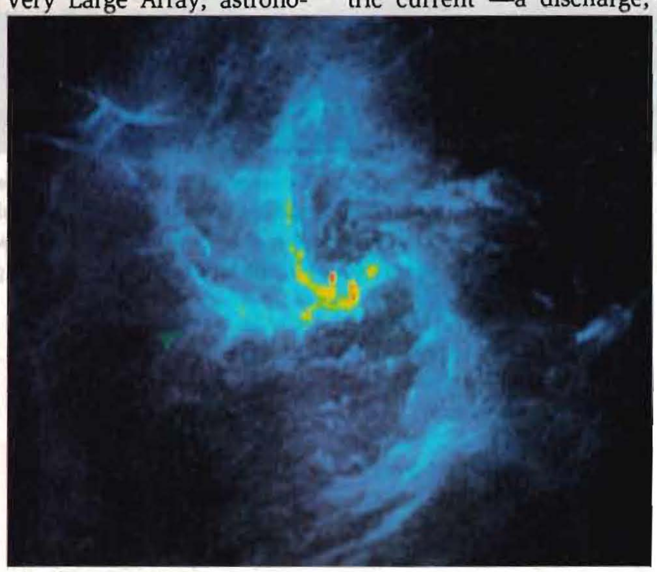
Rees acknowledges that the case for a supermassive black hole in the Milky Way is hardly airtight. "But the evidence is much stronger that nearby galaxies, such as the Andromeda galaxy, have big black holes in their centers," he points out. "One almost feels that our galaxy would be a bit underprivileged if it didn't have a massive black hole as well." The strategy of explaining all energetic galaxies, from the Milky Way to quasars, by means of a single mechanism exerts a seductive attraction on astronomers.

Yet it may have to be amended in light of the recent evidence from the Milky Way. As Rieke puts it, "No one said nature has to follow our rules." Monstrous black holes may well be the source of power behind quasars and their dazzling jets; nobody has come up with a better idea so far. But the Milky Way could be telling us that the centers of less active galaxies are powered by processes not quite so exotic.

Astronomers already realize that an altogether ordinary force, electromagnetism, is sculpting some magnificent structures near the Milky Way's center. Several years ago, using the Very Large Array, astronomers from Columbia University and UCLA observed an enormous arc of hot, radio-emitting gas in the central region. The arc has two components: several arched filaments meet up with a bundle of linear strands. The strands are almost certainly stretched along magnetic field lines that run perpendicular to the galactic plane, the way Earth's field lines run perpendicular to the equator. The galactic field was found to be far weaker than that of a toy magnet; but even that strength was more than expected.

One of the arc's discoverers, Mark Morris of UCLA, now suspects that the filaments, each about 100 light-years long, are "galactic lightning bolts." The arc, it turns out, is in the same spot as a giant molecular cloud. "This moving cloud, filled with partially ionized [electrically conducting] gas, could be careening into the magnetic field, causing the fireworks that we see," explains Morris. "If you push a conductor through a magnetic field, you get an electric current"—a discharge,

PHOTOGRAPHS: TOP, BY M. J. RIEKE, G. H. RIEKE, AND A. E. PAUL, UNIVERSITY OF ARIZONA; BOTTOM, COURTESY K.-Y. LO, UNIVERSITY OF ILLINOIS



The bright radio source at the galactic center may be a black hole—in which case the spiral structures seen in this image may be gas that is being sucked down the hole.

in this case, that courses for dozens of light-years through the tenuous cloud. The voltage is small by terrestrial standards (.0001 volt per centimeter), but over an entire filament that adds up to 10,000 trillion volts. Once out of the cloud, the electrons may simply continue down the magnetic field lines, eventually completing the electric circuit.

The arc may not be the only manifestation of the Milky Way's magnetic field. Japanese astronomers observing the galactic center have discovered a horseshoe-shaped plume of radio emission, vastly larger than the arc, rising several hundred light-years above the galactic plane. To many observers this structure closely resembles the giant loops of plasma, called solar prominences, that often erupt from the sun's surface. Like them, the plume too may be a magnetic phenomenon.

With each new technological advance in their instrumentation, astronomers have discovered unexpected vistas in the Milky Way. Yet they are disconcerted by their inability to see something they feel sure must be there: the so-called missing mass. Stars and gas in our galaxy's outer regions—as well as in other galaxies—circulate appreciably faster than Newton's law of gravity allows. Not wanting to give up on Newton, theorists figure that the Milky Way must have a vast amount of "dark," or unseen, matter that keeps the speeding stars from flying out into intergalactic space. "It's an embarrassing fact," says Rees. "Ninety percent of our galaxy is unaccounted for." Indeed, if dark matter exists, it could make up 90 percent or more of the entire universe and help explain how galaxies formed.

One popular idea is that dark matter consists of exotic, as-yet-undiscovered subatomic particles. Yet it could also be something comparatively mundane: a lot of small black holes, for instance, or stars with so little mass we can't see them, or Jupiter-size gasballs that are too small even to ignite nuclear fusion and become stars. The advantage of such objects—"the dull man's dark matter," as Rees puts it—is that astronomers studying the Milky Way have some hope of detecting them. In fact, infrared astronomers have recently been spotting caches of low-mass stars and objects that look like solar systems in the making. "The Milky Way," says Rieke, " will allow us to find some answers to the missing mass that can't be done elsewhere."

Whether or not the hunt for dark matter proves successful, the Milky Way surely has more secrets to reveal. Today's "new" Milky Way—so much less stately, so much more tempestuous than the one of a few decades ago—will probably be labeled "new and improved" in the near future. "In visible light we were only seeing the tip of the iceberg," says Mark Morris. "Over the last twenty years we've seen a lot more of the ice. But the final word is hardly in. There are so many areas still unexplored. The more we know about the Milky Way, the more complicated it becomes." Morris pauses. "But then, the Milky Way today is also much more interesting." ❑

Marcia Bartusiak wrote in May about the use of supercomputers in astronomical modeling.