The Mysterious Middle of the Milky Way

Astronomers used to dismiss our own galaxy as boring--until they found that its center is a storm of exploding stars and roiling gas, all circling a hungry black hole and adorned by a fountain of antimatter.

By David H. Freedman

DISCOVER Vol. 19 No. 11 | November 1998 | Astronomy & Physics

After journeying across light-years of empty space and on through the black, still skies above Mauna Kea, the faint blush of energy is now gently washing over the twin mirrors of the Keck telescope. For Mark Morris, who is here in Hawaii to aim and fine-tune the telescope for one precious night of data, the barely detectable glow is relatively vivid. He usually has to settle for the whisper of hydrogen and ammonia molecules, picked up by radio towers scattered across the world.

Considering their subtlety, the message these wispy signals bring is one of surprising violence. Taken together, they form a picture of billion-degree temperatures, cataclysmic winds, searing radiation, tentacled magnetic fields that roil and squeeze atoms until they shine, vast fountains of hot gas in which matter is instantly annihilated, and gravitational tides that can cleave a giant star in two. And you thought the freeway was hell.

Of course, astronomers are constantly scoping out spectacular fireworks--most often in the cores of galaxies scattered across the remote reaches of the visible universe. What makes this particular cosmic tumult a surprise is that it isn't in a distant galaxy. It's in the heart of our galaxy--virtually in Earth's backyard, astronomically speaking. Though long considered the Milk Dud of galactic cores, the center of the Milky Way is gradually revealing itself to be one happening place.

And that's not even the really exciting news. One reason Morris and a growing number of astronomers are mesmerized by the maelstrom at the core of our galaxy is that it doesn't fit neatly into any of the models that scientists have painstakingly assembled over the decades to describe the various types of "active" galaxies they observe. Instead our galactic center appears to be a sort of hybrid, combining elements of at least three distinct types.

That means the Milky Way could well turn out to be the missing link in a long quest to answer one of science's biggest questions: Are there fundamentally different types of galaxies, as it appears, or do most galaxies merely look different because we're catching them at different stages of a single, common life cycle? That the answer may have been in our own galaxy all along is akin to searching all day for your glasses only to find they've been on top of your head.

What's more, the fire at the heart of the Milky Way is already providing important insights into other key astronomical puzzles, including black holes and the birth of stars. "Every time I go there," says Morris--speaking metaphorically, of course--"I find something new and unexpected."

There are many ways to categorize galaxies. By shape, for example: The Milky Way, like most galaxies that can be clearly observed, appears as a spiral; other galaxies can be somewhat spherical or elliptical. Or size: At about 200 billion stars, the Milky Way is strictly an average player. Large galaxies contain a trillion or more stars.

A more interesting way to categorize galaxies, though, is by the activity they display at their core. By this measure, quasars rule supreme. These extremely young, extremely distant galaxies blast out as much light as the entire Milky Way, all from a core that is a millionth the Milky Way's diameter. "Seyfert" galaxies, which are all around us, are sort of miniquasars, producing a torrent of radiation from their core that, though it's far less than a quasar's, is spectacular by ordinary galactic standards. And then there are equally common "starburst" galaxies, in which a brilliant stream of light is produced by the rapid burning and eventual explosive death of millions of massive young stars created together at each galaxy's core.

Compared with such cosmic jewels, the Milky Way has long seemed deserving of only one label: ordinary. No known massively radiating core. No known swarm of superheated stellar studs crammed into the center. Just a swirly smear of stars and dust that produce their relatively meager light the old-fashioned way.

But in truth, astronomers couldn't be sure. Granted, the Milky Way's core is plenty close enough for a good look--a mere 25,000 light-years away, as opposed to the millions typical of other galaxies, and a distance (at about 6 trillion miles to the light-year) at which even run-of-the-mill telescopes ordinarily have no trouble making out detail. The problem is that vast, dense clouds of dust and hundreds of millions of stars lie huddled in and around the core, obscuring the view. Of every trillion photons of visible light that leave the core aimed toward a telescope here on Earth, only one makes it. If our own sun had to push its light to us through that sort of filter, even at its normal distance it would be all but invisible to the naked eye.

But photons of much lower frequency aren't as easily dissuaded by dust. As early as the 1930s, astronomers were picking up the hiss and cackle of what appeared to be dense stores of hydrogen and other elements at the Milky Way's center. And in the 1950s they distinguished a particularly powerful source of radio noise there. It became known as Sagittarius A (abbreviated Sgr A) because it comes from the direction of the eponymous constellation, and astronomers speculated that it was the remains of a massive supernova--an exploded star. Even more intriguing, much of the energy was later determined to come from an even narrower region within Sgr A, and this compact radio source was dubbed Sgr A* (pronounced "A star").

In 1968 astronomers aimed a new tool at the galactic center: the infrared detector, capable of picking up the faint heat thrown off by even lukewarm matter. They soon discovered that a central region about 300 light-years across was jammed with dust lit up by impressive amounts of radiation. But from what? Sgr A*? Massive, dense clusters of stars?

Over the next several years, new infrared measurements showed that much of the gas and clouds and even entire stars nearest the center weren't simply rotating with the rest of the galaxy. Instead, they were screaming along at much higher speeds. In 1979, ucla astronomer Eric Becklin discovered a ring of dust around the center a mere 10 light-years or so across. There was little dust inside the ring. Something had consumed the innards of what must once have been a complete disk, leaving behind only a hollow skin.

Meanwhile, scientists were becoming convinced that quasars and Seyfert galaxies were powered by supermassive black holes constituting, respectively, the mass of billions and tens of millions of suns. Could Sgr A* be a black hole? Morris, a younger member of what was shaping up to be a ucla galactic center mafia, joined the hunt for explanations of the strange goings-on. "It was natural to suppose every galaxy, including ours, had a chance to harbor a black hole," he says. "Maybe some black holes were just more impressive than others."

It wasn't until last year that astronomers reached a consensus on the identity of Sgr A*, thanks to the work of two independent groups of investigators. One of those groups was led by Andrea Ghez, an up-and-coming member of the ucla clutch. For five years Ghez, an energetic, athletic young woman, trekked annually to Mauna Kea for a Keck check on the movement of the hundred stars closest to the center of Sgr A*. To get the needed resolution--20 times that of other ground-based telescopes and 3 times that of even the Hubble Space Telescope--Ghez helped develop a technique that involved taking a rapid series of snapshots that could be "averaged" to cancel out the distorting effects of our atmosphere.

The resulting sharp observations clearly showed that the closer the stars were to the very center of the galaxy, the faster they orbited; and the innermost stars were moving as fast as .5 percent the speed of light, or about 900 miles per second. Whatever entity was keeping stars in that fast an orbit, it had to have a mass of about 2.5 million suns. And the tight orbits of the nearest stars meant that all that mass was packed into a relatively tiny space--tiny enough to imply a density in the galactic middle at least a trillion times that of the galactic suburbs. Only one entity fits those specs and the laws of physics: a black hole. "We considered the possibility that the nucleus contained a million smaller black holes formed from dead stars," says Ghez. "But in that little a space they would have collapsed into a single hole. Any configuration of matter other than a single black hole would be unstable."

By the time Ghez was starting to pin down the size and identity of Sgr A*, probing the mysteries of the Milky Way's core had become a hot field. The growing ucla group, as well as groups at a dozen other universities around the world, was now routinely winning coveted time on top-notch telescopes and detectors, yielding a treasure trove of data. The results confirmed what these researchers had been arguing all along. As Don Figer, yet another ucla researcher, puts it: "The galactic center is a lab for astronomy unlike any other."

Mark Morris loves to give tours. Not of his office, which is notable only for a 15-foot-wide window that frames mostly pure sky, with just enough mountain at the bottom for a nice compositional balance; nor of ucla's mathematics building, where the astronomy department is rather drably ensconced. Rather, Morris enjoys taking visitors for a spin around the galactic center.

Why shouldn't he? Morris has done as much as anyone to uncover and at least plausibly explain the core's many secrets. "The ingredients of every spectacular phenomenon that can be observed elsewhere in the universe can be studied right here in the galactic center," he says. "Except much closer up."

A good place to begin the tour is the center of the center: the Milky Way's black hole, also known as the Great Annihilator, Sgr A*. As with any black hole, the beast at the heart of our galaxy packs all its multimillion-star mass into a space smaller than an atom--infinitely small, in fact, according to Einstein's general theory of relativity. First off, you'll note that black holes aren't black, strictly speaking. Rather, they produce the most luminous objects in the universe--quasars--thanks to a phenomenon known as accretion. As matter is sent whirling into a black hole, tugged ever harder by the hole's irresistible gravity, the material heats up, and along its wild ride it radiates that heat away as light, until it disappears past the black hole's "event horizon"--the border beyond which nothing, not even light, can escape the hole's violent gravitational pull. Thanks to accretion, Sgr A* glows with the radiation of about a thousand suns. "It's a pip-squeak compared with quasars," admits Morris. "But you still have to have a lot of respect for our black hole."

You don't have to be sucked into our black hole to be pulverized by it. Even outside the event horizon, the hole's gravity increases so fiercely with proximity that the tug on the near side of a passing object can be vastly stronger than the pull on the far side. As a result, a gravitational "tidal force" tries to stretch the object out in the direction of the hole. It's a force to be reckoned with--enough to rip a close-passing star in half, sending the near half plunging into the hole, while the other half, like a sudden winner in a tug of war, goes careering backward. That's exactly what happens to some unfortunate star near our black hole about every 10,000 years, on average, says Morris. The half-star snack provides a big accretion boost to the hole, he adds, resulting in a 100-year-or-so-long light show. (No predictions on the next performance.)

Most stars near the center manage to stay out of the clutches of the hole, though, simply by virtue of being in ultrafast orbits around it. And there are stars galore. If you were to divide the galaxy into cubes of space 3 light-years to a side, the average cube would hold a single star. Here, near the center, a cube might hold a million of them. What's more, nearest the center there are lots of unusually massive stars--as much as 100 times as massive as our sun, throwing off some 10 million times as much light. The resulting blue-hot torrents of photons create vicious stellar winds capable of hurling dust and gas light-years away, whipping up clouds, and even peeling back the outer layer of other stars into cometlike tails.

Dust and gas are scattered throughout our galaxy, but there are far denser concentrations near the core--about 100 times denser, on average. The gas, mostly hydrogen, is a mere 5 degrees or so above absolute zero at the edge of the core, some 1,500 light-years from the black hole. Get within 300 light-years, though, and the temperature climbs to about 10,000 degrees. It gets up above 10 billion around the black hole. The dust is mostly silicate and graphite and is a bit like chalk dust, only finer. In general, the dust is moving in toward the black hole, much of it accumulating onto a rotating outer ring or shell some 300 light-years outside the hole. The rotation slows the matter's inexorable dance toward the black hole, but eventually--perhaps over the course of a few hundred million years, estimates Morris--the stuff we see on the shell today will end up as hole food. Closer to the hole, at about 15 light-years, as Becklin discovered two decades ago, is a second ring of dust. This rapidly spinning inner ring is clumpy and has streamers of matter jutting out of it toward the black hole, as if it is being devoured strand by strand.

Farther out from the hole are any number of wandering clouds of dust. Not that these clouds escape the fireworks: intense magnetic fields cause the electrically charged surfaces of some of the clouds to radiate as they push through the fields, like a dragging car bumper throwing off sparks as it scrapes along the asphalt. The effects of the magnetic fields can also be seen rippling through large clouds like a gust through a cornfield. "Astronomers tend to ignore magnetic fields," says Morris. "But here, you just can't. They're too strong."

The most recent addition to the tour, discovered just last year, involves what appears to be a giant plume of antimatter--a fountain of particles identical to ordinary matter except that they have the opposite electric charge--shooting up from the core and straight out of the disk of the galaxy as far as 5,000 light-years, where the antimatter jet meets clouds of ordinary matter, and both are annihilated in a burst of energy.

Come back next year, suggests Morris, and the tour will probably include new attractions.

Now that we know there's a big black hole sucking in matter and belching radiation at the core of our galaxy, can the Milky Way be upgraded to a more respectable Seyfert galaxy? Not quite. Sure, there are similarities, concedes Boston University astronomer John Mattox. But there's also one major discrepancy: our black hole just isn't shining nearly as brightly as it should, given its mass. "You don't see the exotic radiation that you see with Seyferts," he says. In fact, the radiation shortfall is huge: it should be 100,000 times as bright.

Okay, fine. Given the massive concentrations of giant, hot stars clustered around the center, could we at least call ourselves a starburst galaxy? Well, yes and no, says astronomer Charles Dermer of the Naval Research Laboratory. On the negative side, we simply don't see the sort of star formation and brilliant supernova activity typical of starburst galaxies. On the positive side, it appears there probably were periods of such activity in the past--and that, given the current crop of fast-burning stars huddled at the center, there probably will be again. "There are indications that there have been intense episodes of star formation in our galactic center," says Dermer. So maybe we're a past and future starburst galaxy, for what that's worth.

In recent years, however, there's been a growing suspicion among astronomers that they may be able to fit these slightly disappointing pieces together in a way that will score a major scientific coup--not only in understanding where the Milky Way fits in the galactic hierarchy but also in understanding the nature of virtually all galaxies. To see how, it helps to understand star formation.

Normally, stars form when a cloud of dust and gas starts to contract under its own gravity, heating up as the pressure rises. When some part of the cloud becomes dense and hot enough, nuclear fires ignite, and the resulting radiation blows off most of the surrounding cloud, leaving behind a newborn star. Generally, then, the required ingredients are a cloud, time, and plenty of peace and quiet to let gravity do its work.

Clouds are no problem at the galactic core. Peace and quiet are another story. The tidal forces, winds, magnetic fields, and general pushing and shoving would vastly overwhelm and ultimately break up the slow, gentle process of gravitational collapse. And yet stars can be observed forming furiously in at least a dozen different major clouds near the center. It's a bit like finding a nursery in a war zone. "Nature looks to still, cold places for star formation," says Morris. "How do you make stars form in this hostile environment?"

The answer, says Morris, who often answers his own questions, is that though the violence destroys the normal process of star formation, it also makes possible another means. If a cloud gets gravitationally, magnetically, or radiationally whacked hard enough, that shock can compress some section of the cloud enough to allow it to skip straight to the final stages of star formation. That is, the compressed section might be dense enough, and hence gravitationally powerful enough, to ignore the ruckus going on around it and finish the job.

A radiationally raging black hole would be a handy provider indeed of the required star-forming shocks, notes Morris. And that's the key to the theory he's proposed. Imagine, he says, that our center was a Seyfert-like galaxy with an active black hole, fed by a surrounding disk of dust, that seeded the violent creation of several nests of big, hot stars. Within a few million years, the black hole would exhaust its supply of dust in the surrounding disk, leaving behind a surrounding ring. By this time the stars would be shining at their peaks, creating an intense stellar wind that would blow gas and dust back toward the black hole, slowly replenishing the ring. This would be a relatively quiet period for the center. But within a few million years the stars would start to go supernova, at which point the center would be that of a starburst galaxy. A few million years later yet, when the supernovas had burned out, the black hole would again begin to consume the dust disk, and the center would go back to its Seyfert stage.

In other words, according to Morris's theory, a temporarily active black hole would help create stars, and the stars would repay the favor by sending the black hole new dust before explosively burning themselves out. The result would be alternating Seyfert and starburst periods, separated by a period of relative quiet. If this were the case, then we'd expect to see a mixture of Seyfert, starburst, and quiet galaxies as we looked around the cosmos--exactly as we do.

The theory also implies that our own galactic center is in the quiet period. If so, we'd expect to see clusters of active young stars around the core blowing material into the center, and a rather dim black hole surrounded by a hollow ring. Exactly as we do.

Dermer, like many others, finds the proposed model appealing. "It's possible that galaxies evolve temporally, and we're just seeing snapshots in time," he says. "It would be nice to find a way to link the classes together in one process."

Just one annoying problem: How does the black hole manage to essentially turn off during the quiet period? Even having exhausted the disk of dust that fuels the Seyfert period, conventional theory insists there's more than enough matter flowing in even now to create many times as much radiation as we see.

The answer may have come recently from Harvard astrophysicist Ramesh Narayan. Narayan's theory is based on the idea that matter pulled toward a black hole radiates away its heat only when the particles that make up the matter have a chance to interact with one another, and radiating photons are more or less coaxed from particles by other particles. If the particles don't come close enough to one another, they won't entice one another to cough up photons. Thus, says Narayan, if the matter coming into the black hole is sparse enough, its particles won't interact much and won't radiate much, and thus the matter will retain most of its heat. If the matter retains its heat, then it will expand, becoming even sparser, and thus continue not to radiate much despite its growing temperature.

For a black hole of a given mass, Narayan says, there is a "switch"**--**a rate of matter flow above which the matter will be dense enough to radiate in the intense way conventional theory says it should, and below which it will radiate at a tiny fraction of that level. "When the switch is on, the black hole is bright," he says. "When it's off, the black hole is dim." In the case of our black hole, he adds, calculations confirm that the switch would indeed be off.

Morris, for one, thinks Narayan's theory may fit the bill. "Not everyone accepts it yet," says Morris. "But it is a very attractive model, and it makes theoretical sense."

Clearly, solving the riddle of the ordinary galaxy isn't quite a done deal. Both Morris's and Narayan's models face a bevy of calculational and observational trials. Morris himself points out that even if his theory was unabashedly embraced by all comers, there would be nothing like the satisfaction he'd get from actually seeing his predictions come to life. "It would be really wonderful if the black hole were cataclysmic now," he sighs. "Oh, well. Maybe we'll have a nice catastrophe in a million years."

Hey, a scientist can only hope.