MONSTER BLACK HOLES

Searching for the hidden engine at the heart of galaxies

By RON COWEN

Armed with ultrasensitive light detectors and state-of-the-art telescopes, astronomers during the past decade have peered deeper than ever before into the center of galaxies. And there they've found more than just stars. Some galaxy cores rank among the most brilliant and energetic entities in the universe. Spewing out jets of radiation that extend for thousands of light-years, the cores of active galaxies can accelerate particles to energies dwarfing those of the biggest accelerator on Earth.

Powerful cores require powerful energy sources. Many astronomers now believe that compact, supermassive black holes may fuel the fireworks at the center of some galaxies. Supermassive black holes are dense, collapsed objects — millions to billions of times the mass of the sun — with a gravitational tug so strong that not even light can escape their clutches. "The only way we know how to put such a big mass in a very small region is to make it a black hole," says Alan Dressler of the Observatories of the Carnegie Institution in Pasadena, Calif.

But while black holes have captured the imagination of scientists and the public alike, hunting them remains a challenge. By definition, a black hole can't be seen. This means its presence must be detected through indirect evidence. So, like an invisible houseguest who makes his presence known by the amount of food he eats, a black hole reveals its existence by the way it influences its surroundings.

Yet the mounting flurry of supporting evidence for galactic black holes can leave the average astronomy buff bewildered. Reports earlier this year about black hole candidates — many based on observations with the Hubble Space Telescope — beg some fundamental questions: What are the criteria for finding a supermassive black hole, and what constitutes the nearest thing to absolute proof?

Just the place for a snark,
I have said it twice,
That alone should encourage the crew.
Just the place for a snark,
I have said it thrice,
And what I tell you three times is true.
— "The Hunting of the Snark"

Just as the hunters of Lewis Carroll's mythical beast had their own standards for deciding when they had found the creature, astronomers have developed some basic rules for determining when they have snared the black hole they seek. To house a giant black hole, a galactic core must meet two requirements. It must exhibit a telltale increase in the intensity of starlight from its edge to its center. And the stars surrounding the core must orbit so rapidly that the tug from visible matter alone can't account for their speed.

While searching for bright nuclei may appear easier than measuring star velocities, the tests must go hand in hand to prove the existence of a galactic black hole, says John Kormendy of the University of Hawaii in Honolulu. Adds Dressler: "Most astronomers I know are not saying any black hole is absolutely proven until the kinematic data — the motions of stars — complement studies of light intensity."

Astronomers often trace the hunt for galactic black holes to 1978, when the late astronomer Peter Young and his colleague Wallace L. W. Sargent of the California Institute of Technology in Pasadena published two seminal papers on the giant elliptical galaxy M87. The researchers suggested that an unexpected increase in the intensity of light toward the galaxy's center might signify a collection of densely packed stars orbiting a black hole. They also asserted that as higher-resolution telescopes became available, these instruments would find that the concentration of starlight closer and closer to the galaxy's center would continue to rise steeply, according to a formula that describes the density of stars surrounding a black hole.

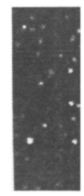
The research articles, recalls Kormendy, drew criticism from many astronomers. But the studies also sparked fresh interest in the black hole scenario.

In their analysis, Young and Sargent had assumed that near the core of M87, located some 52 million light-years from Earth, stars move with about the same average velocity in all directions. Astronomers later found that this so-called isotropic distribution of stars is not correct for most giant elliptical galaxies and probably does not describe the motions of stars in M87. Researchers pointed out that if stars near the center of M87 had a less isotropic distribution, moving nearly straight in and straight back out from the core, then their light profile and velocities would mimic the star movement and light intensity expected if a black hole were present.

Last January, researchers announced that the Hubble Space Telescope had examined the core of M87 at a resolution greater than that of ground-based telescopes. The Hubble study confirmed that the intensity of starlight increased toward the center, as Sargent and Young had predicted (SN: 1/25/92, p.52). Sandra M. Faber of the University of California, Santa Cruz, a Hubble team member, says her group's study makes the case for a billion-solar-mass black hole in M87 more compelling, but not airtight. Alternative explanations for the light intensity don't require a black hole, but she notes that these models do require an asymmetric distribution of stars so unusual that she regards them as "hokey."

Dressler agrees that such models often seem contrived. And given the fiery glow of starlight from M87, as well as a bright jet of material spewing out from its center,

Hunting in the

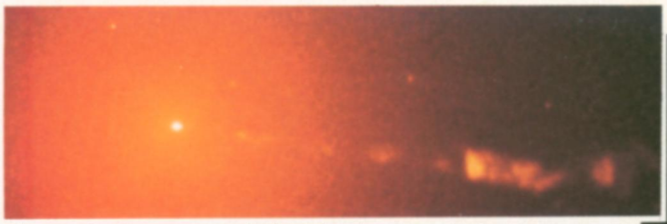


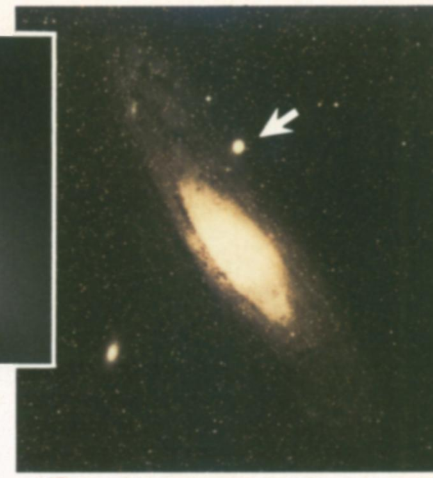
If evidence for black holes lurking in distant galaxies remains uncertain, a casual observer might assume the case would be more clear-cut in our own galaxy. Certainly at a mere 28,000 light-years from the center of the Milky Way, high-resolution studies of stars and gas at the core are possible.

Alas, there's a major obstacle. Like a pervasive fog, a shroud of light-absorbing dust within the disk of our galaxy prevents a clear view of the center in either visible or ultraviolet light. Instead, most astronomers rely on observations in the infrared or at radio wavelengths to glimpse activity at the core. Indeed, the tiny but powerful radio source Sagittarius A*, located at the very center of the galaxy, first prompted many astronomers to speculate that the Milky Way might contain a black hole.

In the infrared, scientists use two techniques to "weigh" the mass of material that lies within a few light-years of the Milky Way's heart. Some monitor the motion of stars; others look at gas.

Kristen Sellgren of Ohio State University in Columbus and her co-workers examine the rapid motion of stars near the center of the galaxy by studying a particular infrared fingerprint: the absorption of carbon monoxide in the atmospheres of cool, puffed-up stars





Four galaxies suspected of harboring a central, supermassive black hole: top, the giant elliptical M87; right, the disk-shaped NGC 3115; far right, our nearest spiral neighbor, Andromeda, and its tiny companion M32 (arrow).

NASA/Kormendy/JPL

he says a black hole probably does lurk at M87's core. But Dressler adds that without further evidence, models that don't invoke a black hole can't be dismissed just because they seem unlikely. "Extraordinary claims require extraordinary proof," he says.

To find a supermassive black hole, notes Kormendy, astronomers must "weigh" the center of a galaxy. Measuring light intensity doesn't accomplish the task directly. Instead, Kormendy, Dressler, and their colleagues rely on kinematic evidence.

Using spectroscopy, they measure the velocity of stars whipping around a galactic nucleus. Applying Newton's law of gravitation, the scientists then estimate the amount of mass that must be present to account for such rapid motion. By recording the intensity of starlight at the center, the researchers can calculate how much of the required mass is associated with visible stars. If the mass contained in visible stars isn't enough, then there must be additional, invisible material concentrated in a tiny region: precisely the criteria for a galactic black hole.

Following this relatively straightforward recipe, Kormendy, Dressler, Faber, and their colleagues had hoped to use Hubble to pin down the galaxies most likely to harbor black holes. But Hubble's blurry optics have – at least temporarily – dashed that hope. In its present condition, the telescope can record the intensity of starlight, but it can't perform the high-resolution spectroscopy required to measure the motion of stars at the core of galaxies.

Ground-based studies, however, have made the black hole scenario a compelling model for several galaxies, Kormendy contends. Ironically, all of them have relatively quiescent cores, exhibiting none of the fireworks associated with an active quasar or other powerhouse that might require a black hole.

Two of the galaxies – our nearest spiral neighbor, Andromeda, and its satellite galaxy M32 – lie close enough to the Milky Way for ground-based spectroscopic studies. Telescopes on Earth

Continued on p.300

Milky Way

Marcia Rieke et al., U. of Ariz.

Infrared image of stars clustered near the center of our galaxy.

called red giants.

Sellgren and her team have detected an increase in the velocity of these stars within 2 to 12 light-years of the center, as indicated by a broadening of the carbon monoxide absorption line. The velocities she measures suggest that the core contains several times the amount of visible mass in hidden matter – evidence that a million-solar-mass black hole might reside there, Sellgren and her colleagues reported in the Aug. 10, 1990 ASTROPHYSICAL JOURNAL.

Using the NASA Infrared Telescope Facility atop Mauna Kea in Hawaii, John H. Lacy of the University of Texas at Austin and his colleagues have found similar results by monitoring the velocity of ionized gas. He notes that gas has a more organized, collective motion than the random orbits of stars, providing a stronger signal to measure velocities. But unlike stars, he adds, forces other than gravity, including magnetic fields, can push gas around and fool astronomers into thinking they have found evidence of a black hole.

Moreover, Sellgren herself cautions that the evidence gathered so far hasn't eliminated the possibility that the only things lurking at the center of our galaxy are stars. She notes that several observational puzzles have stymied efforts to reliably estimate the amount of visible mass at our galaxy's core, a calculation critical for determining the likelihood of a central black hole. Among the unsettling findings, her team has found that carbon monoxide absorption appears to vanish within about 2 light-years from the center. This may indicate that something strips away the infrared-absorbing atmosphere of red giants at the heart of our galaxy – or that the giant stars simply don't exist there.

The second possibility suggests that the inner core of the Milky Way contains a different mix of stars, hotter and possibly younger, than do regions even a few tens of light-years farther away, she says. This means that a given amount of starlight observed at the center may signify a different mass of visible stars than the same amount of starlight detected elsewhere, hampering efforts to pin down the visible mass at our galaxy's core, Sellgren adds.

But the carbon monoxide problem may actually argue in favor of black holes, says Mark Morris of the University of California, Los Angeles. He speculates that collisions between the red giants and a cluster of small black holes could rob the stars of their atmospheres. And as the black holes accumulate atmospheric material around them, the stolen matter may emit a glow resembling that of hot, young stars.

Morris says the scenario of black holes masquerading as young stars may also solve a mystery. Many astronomers have wondered how large numbers of young stars could exist at the Milky Way's center, since the hot, turbulent conditions there don't seem to permit starbirth. He reviewed his theory in mid-October at the annual University of Maryland astronomy conference in College Park.

Morris and other astronomers agree that if our galaxy does contain a supermassive black hole, the hidden body is now eating lightly. If the proposed hole were devouring huge amounts of gas and stars, the center of our galaxy would appear far more luminous. They suggest that the black hole goes through periods of feast and famine and that, at present, infalling gas and stars are replenishing a disk of material around it, creating a new supply of food for the insatiable monster. *– R. Cowen* contraceptives designed to mimic a first pregnancy.

The Los Angeles researchers have a long way to go before they can answer the scientific, practical, and ethical questions raised by their speculations, warns Robert N. Hoover of the National Cancer Institute in Bethesda, Md.

That caution is echoed by Helene Smith of the Geraldine Brush Cancer Research Institute in San Francisco.

She especially takes issue with the concept of a hormonally induced pseudopregnancy for teenage women. "Nobody is real comfortable with the idea of taking healthy young women and doing something drastic to them," she says. Such an approach might trigger morning sickness and other unpleasant side effects associated with pregnancy, she notes. "I wouldn't be willing to do that to my 13-year-old daughter, would you?"

For the high-risk adult woman, however, the risk-benefit equation might look quite different, Smith acknowledges. Pike's cancer-protection method might appeal to such women, who have very few means of reducing their chances of developing this deadly disease, she says.

Other scientists doubt the approach will ever win widespread acceptance. Women are unlikely to put up with such a complex regimen, says Gabriel Bialy, chief of the contraceptive development branch of the National Institute of Child Health and Human Development in Bethesda, Md. Doctors often have trouble getting their patients to follow relatively simple drug regimens, yet Pike's method involves a once-a-month injection as well as several different types of pills taken at various times, he says. Indeed, Pike plans to simplify the regimen, perhaps by delivering all the drugs together in a single injection.

Furthermore, Bialy says, the birth control method would rack up quite a bill. The complexity of the method, together with its cost, would make large-scale clinical trials difficult, if not impossible, he says. "The hypothesis, while reasonable on the surface, is terribly difficult to support with actual data," he contends.

Everyone agrees that women will have to wait a long time for research findings to catch up with the theory. Even if the researchers can generate enough support to kick off a large clinical trial, it will take at least a decade to gather enough information to evaluate the regimen's prowess against breast cancer.

No doubt about it: The approach is radical. Yet breast cancer is too important a disease for scientists to ignore this intriguing lead, says Willett.

"The problem is so serious," he argues, "that we should pursue anything that is at all promising." □

Continued from p.297

can also monitor the motion of stars at the core of certain more distant neighbors, such as NGC 3115, because the black holes believed to reside there rank among the biggest of the current candidates.

In the mid-1980s, while studying the far more luminous core of another galaxy, NGC 1068, Dressler stumbled onto evidence that nondescript Andromeda might harbor a black hole. Although NGC 1068 seemed like a prime candidate for containing a compact object, Dressler's observations turned the tables on his prediction.

"I took the spectrum of [Andromeda] merely as a calibration, to make sure I knew what the center of a galaxy looks like where there *wasn't* a black hole," recalls Dressler. "I didn't see anything special in NGC 1068, but I saw this amazingly rapid rotation of stars [at the core of Andromeda]." In a separate study, Kormendy also found evidence that a supermassive black hole could best explain the motion of stars at Andromeda's core. Dressler and Kormendy say they consider the core of Andromeda the most likely candidate for a black hole.

According to Kormendy, the galaxy NGC 3115 ranks second in the black hole sweepstakes. Located some 30 million light-years from Earth, this neighboring galaxy has a dense cluster of stars – within a few hundred light-years of the center – that rotates rapidly about the core. Observations with the Canada-France-Hawaii telescope atop Mauna Kea show that the motion is so fast that the mass of the visible stars can't explain it – not by a long shot.

Although the apparent runner-up as far as kinematic evidence goes, NGC 3115 appears to be the heavyweight champ among the leading black hole contenders, with a mass more than a billion times that of the sun. Kormendy and Douglas O. Richstone of the University of Michigan at Ann Arbor reported their work in the July 10 ASTROPHYSICAL JOURNAL.

Andromeda's tiny satellite M32 garners third place among galaxies most likely to contain a black hole, Kormendy suggests. Again, the discovery was made by serendipity. John L. Tonry of the Massachusetts Institute of Technology examined the general character of this small spherical galaxy, believed to be the remnant of a larger galaxy that was stripped of material by the gravitational tug of Andromeda.

His 1987 study revealed stars moving so rapidly that the mass of visible stars estimated to lie at the galaxy's core couldn't explain their motion. In addition to the spectroscopic evidence, recent Hubble images have revealed that the core of M32 emits an unusually high intensity of starlight, indicating that the tiny galaxy may harbor a black hole about 3 million times the mass of the sun (SN: 4/18/92, p.245).

Dressler notes that, aside from Andromeda's large central bulge, the galaxy appears "kind of common, kind of dull." Thus, "if Andromeda, the closest spiral galaxy to us . . . has a black hole, then it does imply that a black hole is probably in every galaxy with a big spheroidal bulge," including the Milky Way (see sidebar, p.296).

Dressler suggests that some of these bulging galaxies – those with the most massive cores – once shone with the blinding light of quasars, the most brilliant objects observed. Other galaxies, such as Andromeda, lacked the extraordinary brilliance associated with quasars but did possess highly luminous cores. In either case, when the central fireworks burned out, they left behind the superdense bodies that gave them their energy. He estimates that up to half the galaxies in the universe may harbor supermassive black holes.

Ironically, he adds, researchers shy away from galaxies with highly energetic cores, some of the most likely places to look for supermassive black holes. Instead, they prefer to hunt their quarry among some of the *least* active galaxies – provided the galaxies have a central bulge. Galaxies with quiet cores, notes Dressler, don't spew out jets of material that can outshine starlight and confound measurements of stellar motion.

If Andromeda, its satellite, and NGC 3115 rank among the likeliest candidates for housing black holes, what would it take for astronomers to obtain compelling proof?

Because the radius of a supermassive black hole is no bigger than the solar system, the ability to watch stars begin to fall toward such an object – even in a nearby galaxy – would require a telescope a million times sharper than now exists, Kormendy notes. Lacking such an instrument, astronomers had looked to Hubble to gather more convincing proof. Indeed, Dressler notes, Andromeda and its satellite were prime targets for spectroscopic studies with Hubble.

"We thought we'd actually go in and nail them [as having central black holes], getting that extra factor of 10 in resolution that would eliminate any other contrived explanation," Dressler says.

Such studies will probably have to wait until astronauts correct Hubble's optics late next year. But over the next several years, Kormendy says, ground-based telescopes atop such choice viewing sites as Hawaii's Mauna Kea may nearly match a repaired Hubble.

Until then, contends Alexei V. Filippenko of the University of California, Berkeley, "extragalactic black holes will remain like Darth Vader, cloaked in a shroud of circumstantial evidence." □