A New Look at Black Holes

Dim monsters in the spotlight

BY RON COWEN

Exerting a gravitational tug so strong that not even light can escape their grasp, black holes are among the strangest objects in the universe. The monster believed to lurk at the center of our galaxy poses a particular puzzle.

According to the standard theory of black hole dynamics, gas ripped from surrounding stars emits a last gasp as it spirals into the black hole. As a result of this swan song, a brilliant burst of ultraviolet light and X rays, the region around a galactic black hole should shine like the blazes.

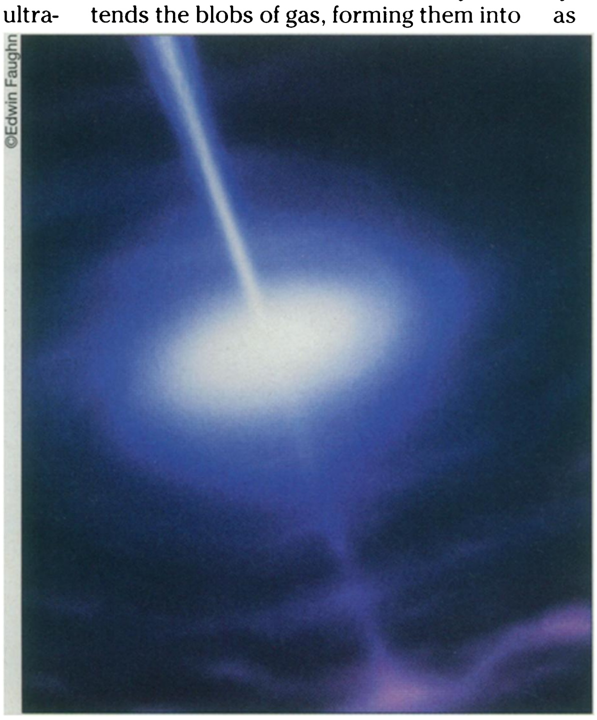
Many galaxies believed to contain central black holes display such fireworks. Numerous observations of the heart of the Milky Way, however, do not bolster the traditional story line. Even after accounting for the dust that cloaks the center of the galaxy, the galactic core appears only about one-thousandth as bright as expected. "It's much too dim," notes theorist Ramesh Narayan of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass.

Not only is the radiation muted, its spectrum does not match the pattern predicted by the standard theory.

"Awareness of this problem has been growing steadily," notes observational astronomer Mark Morris of the University of California, Los Angeles. "There may have been people who faced it a decade ago, but their measurements weren't that good then, so there was always a way out." Over the past 5 years, he says, newer studies with higher-resolution telescopes have forced astronomers to come face to face with the discrepancy.

All of which has led Narayan and his colleagues to reconsider what may happen when black holes devour matter. According to Narayan, when the rate at which black holes accumulate material falls below a certain limit, the trapped material grows hot but does not radiate. Instead of cooling off by lighting up, the matter retains its heat energy even as it passes through the point of no return—the boundary between the hole and the outside world. The hot gas is swallowed by the black hole, and the energy simply vanishes.

The gas does not spiral directly into the black hole. Because the matter has some rotational motion, or angular momentum, it is first drawn into an orbit around the hole. Gravity distends the blobs of gas, forming them into a disk. Friction within the disk, the result of adjacent layers rubbing against each other, heats the gas to temperatures far hotter than the surface of the stars from which they came.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Artist's depiction of a black hole and its surroundings.

If the black hole dines voraciously, then the disk remains thin and compact. In such a disk, frequent collisions between gas ions and electrons distribute the energy evenly among all the particles. Because the electrons readily turn their energy into light, the disk radiates away nearly all of its heat before the gas disappears into the black hole. Such is the case with quasars, the brilliant beacons fueled by black holes at the centers of active galaxies.

It's a different world, says Narayan, if the black hole accumulates matter at a slower rate. Then the disk becomes tenuous and bloated. Collisions are few and far between, and protons and ions are unlikely to encounter and transfer much energy to electrons. Because protons and ions do not easily radiate the energy they absorb, they reach staggeringly high temperatures in the disk, as great as 1 trillion kelvins. According to Narayan, virtually all of this heat energy disappears into the black hole through a process known as advection.

"We are saying that the [Milky Way's black hole] is dim because it's advecting," says Narayan. He adds that the spectrum of radiation, ranging from X rays to radio waves, emitted at the galactic center matches that predicted by the advection model. Narayan and his colleagues at the astrophysics center, including Rohan Mahadevan, detail their model in a study to be published in the ASTROPHYSICAL JOURNAL.

"It's a wonderful solution for that problem," says Andrew C. Fabian of the University of Cambridge in England.

Another team has used the advection model to account for the small amount of radiation associated with a black hole candidate at the center of the giant elliptical galaxy M87. Christopher S. Reynolds, now at the University of Colorado at Boulder, and his colleagues, including Fabian, described their results in the Dec. 15, 1996 MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY.

Narayan, Jeffrey E. McClintock, and Ann A. Esin, also of the Harvard-Smithsonian Center, have also applied advection to explain the behavior of certain X-ray binaries, pairs of stars in which the visible member is locked in the embrace of an unseen, dense companion. Some of these binaries—those in which the companion is presumed to be a black hole—radiate less energy than others, and advection may account for their lack of fireworks (SN: 1/18/97, p. 39).

Several researchers have recently invoked the advection model to explain the origin of a ubiquitous X-ray background that bathes the universe. Known sources, such as quasars, can't account for this background because they emit too many low-energy X rays and too few high-energy ones.

Although advecting black holes don't emit much radiation, their feeble spectra do match the overall intensity pattern of the background radiation. If enough of these black holes exist, they could produce the observed X-ray emission, Tiziana Di Matteo and Fabian reported in the April 1 MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY. Insu Yi of the Institute for Advanced Study in Princeton, N.J., and Stephen P. Boughn of Haverford (Pa.) College present a similar argument in an unpublished article posted on the Internet.

The concept of advection dates back 2 decades. Setsui Ichimaru of the University of Tokyo proposed such a model in 1977. Cambridge astrophysicist Martin J. Rees independently described advection 5 years later.

"These solutions have been around for a long time, but I would say there has been a revolution [recently]," says Fabian. "[Advection] has gone from being a curiosity, sometimes a curiosity that was viewed with hostility, to becoming fairly mainstream."

Narayan notes a key consequence of the advection model: Because many black holes dine on matter with little visible fanfare, they are likely to have a bigger appetite than their low luminosity would indicate. In fact, the Milky Way's black hole may be devouring matter 10,000 times more rapidly than could be inferred from the luminosity, he says.

Black holes heavier than the one at the center of the Milky Way, which is as massive as 2.7 million suns, can suck in matter at a higher rate yet still qualify as advection systems. Indeed, giant black holes, like the ones believed to power quasars, don't have to change their eating habits very much to make the transition from the traditional thin-disk, high-luminosity model to the dim, advection model. The ease of such a transformation could explain why quasars were much more common in the early universe than they are today, Yi argued in the Dec. 20, 1996 ASTROPHYSICAL JOURNAL.

The abundance of newborn galaxies in the early universe would have provided black holes with plenty of gas to feed on—enough to generate the light of a quasar, notes Fabian. As galaxies matured, they converted gas into stars, limiting the fuel available to central black holes. With black holes now on a diet, advection takes over and the flame begins to flicker. The same galaxy whose core was once ablaze with quasar light today finds itself in the Dark Ages. The present-day universe may be rife with dead quasars.

There's another reason, says Fabian, to believe that quasars are doomed to die and that perhaps all black holes will eventually switch over to advection. A black hole that swallows matter at a fixed rate may initially generate intense radiation. As it accumulates matter and grows more massive, however, that fixed feeding rate eventually becomes insufficient to keep the system from flipping into a dim, advecting state.

Fabian notes that if a black hole were drawing in material at the maximum rate, it could double its mass every 100 million years, a short time compared with the age of the universe. Advection may thus be the rule rather than the exception.

Astronomers have identified many likely black holes at the center of bright galaxies precisely because of the fireworks at the core of these galaxies. "The few bright guys are easy to see, but the majority of black holes that do exist may be in this dim state," Narayan suggests.

Beware! Even puny, quiescent galaxies may harbor a monster. □

Ecology

Patchy forests and greenhouse gases

Since 1980, researchers have been studying a cut-up piece of tropical rain forest north of Manaus, Brazil. Not surprisingly, the pockets of remaining forest surrounded by logged land contain fewer plant and animal species than equivalent-size plots in intact forest. With the decline in diversity, many of the important interactions among species, such as pollination, have been thrown off as well.

An unanticipated, further attrition has also occurred.

In the 10 to 17 years after the logging, the remnant pockets of forest lost significant amounts of their plant matter, or biomass. It had dropped as much as 36 percent in some plots. A group of researchers, including William F. Laurance of the National Institute for Research in the Amazon in Manaus and Thomas E. Lovejoy of the Smithsonian Institution in Washington, D.C., reports the finding in the Nov. 7 SCIENCE.

To calculate the change, the researchers repeatedly measured the diameter of some 56,000 trees. Other studies had shown that without the surrounding forest to serve as buffer and support, many large trees at the edges of the plots are blown down. They are replaced in large part by climbing woody vines known as lianas, which constitute only a fraction of the biomass provided by the trees.

"Whether [the change in forest structure] will be a long-term effect remains to be seen," says tropical ecologist Stephen P. Hubbell of Princeton University.

In the meantime, the loss of biomass in the fragments is noteworthy for a global reason, the researchers say. Given that large areas of tropical forests are cleared annually, the decay of fallen large trees in the remaining fragments may be adding significant amounts of carbon dioxide to the atmosphere. This biomass loss may therefore represent an unrecognized contribution to atmospheric greenhouse gases.

Hubbell cautions that the burning of forests accounts for "a vastly more important component of global warming." —*C.M.*

Island plants let down their defenses

Give a hungry sheep the choice of a leafy island shrub or a mainland version and the sheep will almost always graze on the island greenery. That's what biologists Lizabeth Bowen and Dirk Van Vuren of the University of California, Davis found in a study comparing how well six shrubs from Santa Cruz Island and their California counterparts 30 kilometers away defend themselves against predators.

There's good reason for the sheep's fondness for the island flora, the researchers report in the October CONSERVATION BIOLOGY. In analyzing the specific defenses in the plants' arsenals, they found that island plants have significantly fewer and shorter spines per leaf area. The island subspecies of the bush poppy (*Dendromecon rigida*) lacks spines completely.

Less striking were the differences in chemical defenses, represented by amounts of phenols and tannins. One of the island shrubs (*Ceanothus*) has significantly lower concentrations of the compounds than the mainland version, while the island Christmas berry (*Heteromeles*) actually has more tannin for part of the year.

The difference may be explained by the island's evolutionary history. Santa Cruz Island has thousands of insect species, including many plant feeders, but lacks native mammalian grazers. The plants have largely maintained their insect-deterring chemical defenses but have lost the spines and other features that ward off animals like sheep.

Consequently, the researchers say, such island communities are susceptible to high rates of extinction when new plant-eating animals arrive. On Santa Cruz, introduced sheep that were culled in the 1980s chewed up the plant community. With their habitat destroyed, ground-nesting birds died out. —*C.M.*