Where Are the Dead Quasars?

Two recent observations suggest that many "ordinary" galaxies—including our own—contain ultramassive black holes

The standard model of a quasar—that its power comes from an enormous black hole at the center of an otherwise normal galaxy—has a corollary: that many of the nearby galaxies, among them perhaps our own Milky Way, are dead quasars still harboring black holes millions or billions of times as massive as the sun.

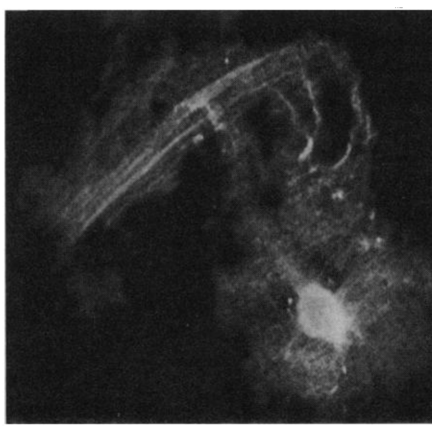
Although it has been very difficult to get direct confirmation of this idea, two recent observations now give it additional weight. In the first, Alexei V. Filippenko of the University of California, Berkeley, and Wallace L. W. Sargent of the California Institute of Technology find that a surprisingly large number of nearby galaxies still exhibit a flicker of quasar-like emissions in their depths (*1*).

In the second, radio astronomers Kwok-Yung Lo of Caltech, Donald C. Backer of Berkeley, Ronald D. Ekers and Kenneth I. Kellermann of the National Radio Astronomy Observatory, and Mark J. Reid and James M. Moran of the Harvard-Smithsonian Center for Astrophysics have examined the compact energy source at the center of our own galaxy using very long baseline interferometry, and have placed the most stringent limit yet on its size: less than 3 billion kilometers (20 astronomical units), considerably smaller than our own solar system—which makes it very difficult to interpret the source as anything other than a massive black hole (*2*).

The massive black hole model was first proposed in the late 1960's by Edwin Salpeter of Cornell University and Donald Lynden-Bell of Cambridge University. The idea is that gas, dust, and stars from the galaxy's central regions would spiral toward the hole, grow hot through compression, and convert much of their mass into radiant energy before finally falling in. Given a sufficiently large black hole—say a billion solar masses—and an infall of some 10 solar masses of matter per year, this one relatively tiny region of space could become as luminous as a thousand ordinary galaxies put together.

The black-hole-in-a-galaxy model is bolstered by the fact that long-exposure images of relatively nearby quasars (those with a redshift $z < 0.5$) almost invariably show them embedded in galaxy-shaped "fuzz"; indeed, the spectrum of fuzz, when available often shows the characteristic signature of starlight. Conversely, and much closer to home, there are "active" galaxies such as the rare class of spirals first described by American astronomer Carl K. Seyfert in 1943. The Seyferts are characterized by very bright nuclei, some of which are as bright as low-luminosity quasars and are spectroscopically indistinguishable from them; most astronomers now believe that the Seyferts and other active galaxies, such as the BL Lacertae objects, are miniature quasars powered by the same black hole mechanism.

The model also suggests that quasars would tend to fade over time, as each black hole finished sweeping up everything in its vicinity. And this is in fact what is observed: the closer a quasar is (which means the older it is when we see it), the less likely it is to be highly luminous.



National Radio Astronomy Observatory

The monster in the middle

This radio image of the galactic center, made at the Very Large Array near Socorro, New Mexico, reveals some of the complexity there. At upper left is a filamentary structure known as the continuum arc; it is roughly 150 light years long, and probably represents some kind of large-scale magnetic field. The compact source discussed in the text lies within the bright region at lower right.

On the other hand, the model suggests that one ought to see low-level quasar- or Seyfert-like activity among many of the nearby galaxies. Some of them would have to be dormant quasars still hiding their billion-solar-mass black holes. Others might only have a modest specimen of, say, a million solar masses. But even they ought to show some signs.

However, this low-level activity has been very hard to detect against the glare of normal starlight in the galaxies. What Filippenko and Sargent have done is to take a well-known method for screening out the glare and apply it to brand-new data. Using the 5-meter Hale telescope at Palomar Observatory, they scanned 75 bright nearby galaxies lying 10 million to 100 million light-years from Earth and digitally recorded the spectrum of each galaxy's nucleus with a charge-coupled device (CCD) sensor. (The high-precision spectrograph they employed was developed by Caltech's J. Beverley Oke and Princeton University's James Gunn.) Using a computer, they then subtracted out the background starlight, either by using spectra of similar, although definitely less active, galaxies as a standard or by subtracting the spectrum of the same galaxy measured away from the nucleus. What they were looking for in the remainder were the telltale spikes of emission characteristic of quasars, as well as a broadening of the lines due to the turbulence of gas falling into a black hole.

"The result was that, in 19 to 28 of the cases, the emission lines became evident," says Filippenko. "The reason for the range is that we are still analyzing the data, and since these emissions are only a few percent above the background, they're extremely hard to detect."

In fact, he says, the new CCD detectors were the key to the whole process. "They're wonderful things. We're subtracting two large quantities, which means that to get a meaningful result, you need a very linear response over a very large range, which the CCD's have. A project like this really couldn't have been done until a few years ago."

The 75 galaxies surveyed were "best-case" galaxies, with bright centers that Filippenko and Sargent felt would most likely yield detectable quasar-like activity. During the next few years the astronomers plan to extend their survey to a more representative sample of some 500 galaxies.

The one place that Filippenko and Sargent cannot look is the center of our own galaxy, which is obscured by gas and dust lying in the spiral disk. However, this material is relatively transparent to radio and infrared radiation, and astronomers working at those wavelengths have compiled a good bit of indirect evidence that something very strange is going on there.

The galactic nucleus turns out to be an exceedingly complex place; features include a series of looping magnetic field lines that resemble nothing so much as a solar flare expanded to the scale of a galaxy; a fragmented structure that looks like a spiral but is probably a disk some 5 light-years out from the center; an abundance of red supergiant stars; and a compact radio source, first observed in 1974, right at the galactic center.

In the midst of all these other fireworks the compact source itself is relatively faint and difficult to study. Even with very long baseline interferometry, which produces ultrahigh resolution images by combining the signals from widely spaced radio telescopes, nothing much can be seen except a circular blob. For years, observers could only set an upper size limit.

Now, however, Lo and his colleagues have used more sensitive receivers and higher frequencies to cut the previous size limits by a factor of 7, to 20 astronomical units. Moreover, they have found the first suggestions of structure in the source: it seems to be slightly elongated in a direction about 8 degrees from the galaxy's axis of rotation.

This new upper limit on the size makes it harder than ever to imagine a plausible alternative to the black hole model. In principle the source might be, say, a cluster of hot young stars. But 20 astronomical units is about the size of the orbit of Saturn; how could enough stars be crammed into such a small space? On the other hand, 20 astronomical units is also about the size of the emission region one would expect from gas and dust falling into a modest-sized black hole. (Other evidence suggests that the Milky Way's black hole, if it exists at all, is only about 5 million solar masses.) Moreover, the elongation is reminiscent of the jet structures seen in other active galaxies, where rotating holes seem to be squirting out material along their axes.

The possibility of a central black hole in the Milky Way thus seems stronger than ever. However, the researchers are careful to point out that they do not yet have detailed maps of the source, and in particular, that the observed elongation is very slight and needs to be confirmed. The real proof will probably have to await the Very Long Baseline Array of radio telescopes now under construction by the National Science Foundation.

—**M. MITCHELL WALDROP**

References

1. A. V. Filippenko and W. L. W. Sargent, *Astrophys. J. Suppl.* **57**, 503 (1985).
2. K. Y. Lo *et al.*, *Nature (London)* **315**, 124 (1985).

Chaotic Zone Yields Meteorites

For 200 years, astronomers have known that meteorites found on the ground had fallen from the sky. But from where in the sky? The asteroid belt between Mars and Jupiter has seemed a likely source, but theorists could find no likely mechanism that would drive enough asteroid fragments as far inward as the orbit of Earth. Now it appears that the gravity of Jupiter can so disturb the asteroids in one part of the belt that their orbital behavior becomes chaotic and carries them as far as Earth. The mechanism seems to throw material into orbits characteristic of ordinary chondrites, the most common type of meteorite.

The exact spot in the asteroid belt now shown to be a likely meteorite source has long been under close scrutiny. At two and one-half times Earth's distance from the sun, there is an empty gap in the asteroid belt. Particles orbiting at that distance repeatedly feel the tug of Jupiter's gravity at the same point in their orbit when three of their revolutions bring them abreast of Jupiter after one revolution along its larger orbit. The coincidence between the gap and this so-called 3:1 orbital resonance has remained unexplained for more than a century. George Wetherill of the Carnegie Institution of Washington, after studying the orbits of ordinary chondrites that fell to Earth, suggested that the chondrites probably came from a gap, but the only apparent mechanism at the 3:1 resonance, even with an assist from Mars, required 100 million years for the trip. In that time, the smaller asteroids would be smashed to smithereens in the segment of their orbits still in the asteroid belt and the orbits of the survivors would not match those of ordinary chondrites.

Jack Wisdom of the Massachusetts Institute of Technology recently found that chaos can quickly transport material from the 3:1 gap to Earth without help from Mars. Asteroid behavior would be chaotic if an eventual orbit depends sensitively on initial conditions. Under chaotic conditions, two asteroids starting out in nearly identical orbits can end up in wildly different orbits. They obey Newton's laws of motion, but their sensitivity to initial conditions is so great that prediction is impractical.

Wisdom found that Jupiter does indeed induce a relatively broad chaotic zone that coincides with the gap at the 3:1 resonance (*1*). A fragment of any size scattered into this zone might orbit for a million years in apparent placidity only to have its nearly circular orbit suddenly stretched into a long ellipse whose innermost point extends inside the orbit of Mars. Mars could then remove it and any other objects from the gap. But Wisdom had used a computational shortcut that raised doubts in the minds of others. So he did straightforward, brute force numerical integrations to show that the chaotic zone at the 3:1 resonance exists and that rapid shifts in orbital shape do occur there. He also found that in one of five cases a chaotic jump stretched the orbit all the way to the vicinity of Earth (*2*). Thus, chaotic behavior could also deliver meteorites to Earth.

Getting a rock to Earth's orbit once does not ensure that it will become a meteorite. Wetherill (*3*) used a Monte Carlo simulation to evaluate the effect of several other processes, such as close encounters with planets and fragmentation, on the eventual fate of a rock supplied by the chaotic zone. Two-thirds of the resulting meteorites would have orbits that would cause them to fall to Earth during the afternoon, as is the case with ordinary chondrites, and the amount predicted to fall fits the observed amount within the errors. In a preliminary search, Wetherill cannot find any other resonances that would work the way the 3:1 resonance does.

The case for the 3:1 resonance is strong, but Wisdom must now show that not just one but all chaotic orbits become Earth-crossing within a few million years. There is also the problem that many spectroscopists do not find asteroids near the gap that resemble chondrites. That matter may be resolved if, as hoped, the Galileo spacecraft passes the asteroid Amphitrite near the 3:1 resonance on its way to Jupiter.—**RICHARD A. KERR**

References

1. J. Wisdom, *Icarus* **56**, 51 (1983); *Astron. J.* **87**, 577 (1982).
2. ———, *Bull. Am. Phys. Soc.* **30**, 739 (1985); *Nature (London)*, in press.
3. G. Wetherill, *Meteoritics* **20**, 1 (1985).