NGC 4151: The Monster in the Middle

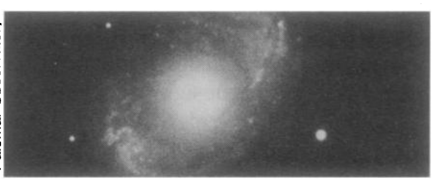
The core of this Seyfert galaxy is extremely luminous: new satellite data suggest that it may contain a gargantuan black hole

Through an elegant analysis of data from the International Ultraviolet Explorer satellite (IUE), a multinational team of European astronomers has obtained the best evidence yet that quasars and other active galaxies are powered by stars and gas falling into enormous black holes. Specifically, they find that NGC 4151, a barred spiral galaxy in the constellation Canes Venatici, has a condensed object in its core with a mass some 100 million times the mass of the sun.

NGC 4151 has been a prime target of the 11-member European Extragalactic Collaboration ever since the IUE was launched in 1978. The choice was a natural one. NGC 4151 is one of the brightest of the Seyfert galaxies, a rare species first identified by the American astronomer Carl K. Seyfert in 1943. These objects are now thought to be miniature quasars: ordinary enough in most respects, they have extraordinarily bright nuclei; moreover, the optical spectra of their nuclei are almost identical to quasar spectra. So despite the fact that quasars are further away and much more luminous, most astronomers now believe that the Seyferts (and certain other active galaxies, such as the BL Lacertae objects) work by the same mechanism.

The idea that this common mechanism might involve an enormous black hole was first put forward in the late 1960's by Donald Lynden-Bell of Cambridge University and Edwin Salpeter of Cornell University. Such an object in the center of a galaxy would tend to swallow all the stars, gas, and dust in its immediate neighborhood. But the infalling matter would not just disappear into the hole without a wimper. As the doomed material crowded to the center it would be swirled into a flat "accretion disk," piling up on itself and growing hot from compression, turbulence, and viscosity. Temperatures would soar, and so would the output of radiant energy. Given a sufficiently gargantuan black hole—say a billion solar masses—and a sufficiently rapid infall of matter, the result would be a cosmic torch as luminous as several thousand galaxies put together. Seen from distances of a billion light years or so, it would look very much like a quasar. If it were somewhat dimmer and closer, it would look very much like a Seyfert.

Unfortunately, even a quasar-class black hole would still be smaller than our own solar system, so direct imagery of the accretion disk is impossible. What the European group did instead is to rely on IUE's spectroscopic abilities in the ultraviolet. They found that the spectrum of NGC 4151's active nucleus contains emission lines of ionized carbon and magnesium. Moreover, these emission lines are broadened, smeared out in wavelength by the Doppler shift as the ions move about. Thus, under the assumption that the ions are in gas clouds orbiting about the center, the researchers were able to convert the line widths into orbital velocities. Specifically, doubly ionized carbon (carbon III) orbits at 4000 kilometers per second; singly ionized magnesium (magnesium II) orbits at 11,000 kilometers per second; and triply ionized carbon (carbon IV) orbits at 14,000 kilometers per second. For comparison, the space shuttle orbits the earth at some 8 kilometers per second.



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NGC 4151

Next, the researchers exploited a stroke of good fortune. NGC 4151 is the most variable of the known Seyfert's, and during an observing run in 1979 its core flared up sharply. Thirteen days later the carbon IV line flared up in response, indicating that the fastest moving clouds are 13 light-days (roughly 340 billion kilometers) out from the center. Thirty days later the magnesium II brightened, somewhat less strongly, indicating a distance of 30 light-days from the center. But the carbon III never brightened, indicating that these slowest moving clouds are at least 1 light-year from the center.

This gave the researchers both the distance and the velocities of the clouds, which meant that they could use simple Newtonian mechanics to calculate the mass of the object in the middle. Their answer, give or take a factor of 2, was 100 million solar masses. As an independent check, the far ultraviolet end of their spectra showed hints of thermal emission at some 30,000 K, which is roughly what theoretical models predict for an accretion disk of a 100-million solar mass black hole.

All the earlier estimates of the black hole mass have been indirect, notes Richard Mushotzsky of the Goddard Space Flight Center, who has done a good bit of work on NGC 4151 himself. "That's why this work is very nice," he says. "The technique has been used before to examine clouds around novas and supernovas, but so far as I know, this is the first time that the data have been sufficiently good to be applied in another galaxy."

There are caveats, of course. In particular, the European researchers suspect that much of the emission line broadening comes from turbulence in the nuclear gas clouds, instead of from simple orbital motion. That would mean that they have overestimated the central mass somewhat. On the other hand, NGC 4151 is almost face on to us in the sky (the inclination angle is 70 degrees). That means that the actual orbital motions could be considerably larger than observed, which in turn could mean that the researchers have *under*estimated the central mass. It is not at all clear which effect predominates.

Finally, the researchers still have not proved that the central mass is a black hole. Conceivably it could consist of a dense-packed swarm of thousands of more or less ordinary objects—although it is difficult to see how such a cluster could have formed, or how the objects could have avoided coalescing into a black hole once the cluster did form.

Although few astronomers have been able to review the team's work (their paper has been accepted for publication in the *Monthly Notices of the Royal Astronomical Society*), the early returns have beeen good; Scotland's Astronomer Royal, Malcolm S. Longair, has called it "the benchmark against which we should measure all other observations of active nuclei." As Princeton University's Edwin L. Turner says, "Black holes are a central idea in the theory of active galaxies, and for the empirically minded, direct observation is essential. If we assume for the moment that they've absolutely nailed it, then this work is very important."

—M. MITCHELL WALDROP