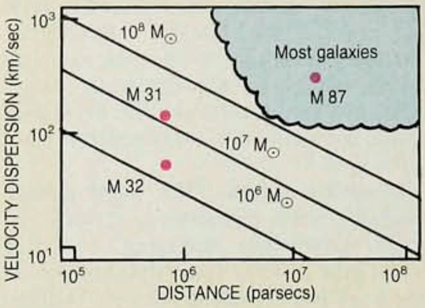
Massive objects in galactic nuclei may be black holes

New evidence indicates that there is much hidden matter in galactic nuclei. Quasars are thought to be galaxies with active nuclei, often characterized by nonthermal radio emission and oppositely directed colinear jets. About 1970 Donald Lynden-Bell and Martin Rees (both Institute of Astronomy, Cambridge, UK) proposed the paradigmatic quasar model: a supermassive black hole surrounded by an accretion disk.[1] In this model a disk overloaded with infalling matter spurts out oppositely directed jets perpendicular to the plane of the disk. "The new work is exciting evidence for how long the quasar phenomenon lasts," Rees tells us.

Is it possible to detect these hypothetical supermassive black holes in galaxies? Both a compact radio source and a 0.511 MeV γ-ray line (attributed to e^+e^- annihilation) indicate an unusual energy source at the Galactic center—probably a black hole.[2] Dead quasars should be common if each galaxy in its evolution has a short-lived active quasar stage. If this stage were long-lived, supermassive black holes would be more massive but rarer. Nonthermal (synchrotron) emission provides circumstantial evidence of black holes and motivation for making further observations of a source, but dead quasars will not reveal themselves in this way. Hidden mass in other galactic nuclei could be detected indirectly by observations indicating both less light and more rapid motion of stars in the core than otherwise expected.

Messier 87, a giant elliptical galaxy, is a strong radio source—Virgo A—and has a jet. About 10 years ago from a spectroscopic and photometric study of stars in the core region of M 87 Wallace Sargent (Caltech), Peter Young (Caltech) and their coworkers[3] concluded that a supermassive black hole with 5×10^9 solar masses lurked at the center of M 87. Among others, Douglas Richstone (University of Michigan) and Scott Tremaine (Canadian Institute for Theoretical Astrophysics) questioned their assumption of an isotropic stellar velocity dispersion. Later high-quality velocity observations by Alan Dressler (Mount Wilson and Las Campanas Observatories) and recent photometric observations by William Bagnuolo (Georgia State) and Richard Chambers (Aerospace Corporation) are consistent with a smaller black hole.[4] Alternatively, the mass-to-light ratio in M 87's core could be accounted for by a compact cluster of low-luminosity stars—white dwarfs or neutron stars (see Adam Burrows's article in PHYSICS TODAY, September, page 28).



Minimum black hole masses detectable with 1-arcsecond angular resolution are shown as a function of galaxy velocity dispersion and distance. The universe could be filled with unobserved 10^6 solar mass black holes. Only a few galaxies are near enough to detect $10^8 M_\odot$ black holes. (Courtesy of Douglas Richstone, University of Michigan, from *Supermassive Black Holes*, M. Kafatos, ed., Cambridge U. P., New York, in press.)

Because of poorly-known velocity anisotropies in giant ellipticals, John Kormendy (Dominion Astrophysical Observatory) has been searching for black holes mainly in the cores of disk galaxies. From observations of rotation and velocity dispersion, Kormendy infers the presence of 10^8–$10^9 M_\odot$ black holes in three galaxies (NGC 3115, NGC 4594, NGC 3377).

The Hubble Space Telescope will improve angular resolution, but the evidence for supermassive black holes will continue to be circumstantial for most galaxies—the Schwarzschild radius of a $10^9 M_\odot$ black hole in M 87 would subtend an angle of only 1.4×10^{-6} arcseconds as seen from Earth. For comparison, a ground-based angular resolution of one arcsecond corresponds to a distance of 75 parsecs at the 15-Mpc distance of M 87, but only 3 pc at M 31, the Andromeda spiral.

Nearby galaxies. New observations indicate rapid core rotation in both M 31 and M 32. This is an argument for a high mass-to-light ratio, but does not rule out a cluster of dark objects. John Tonry (MIT) prefers[5] a single $10^7 M_\odot$ black hole in M 32, a small elliptical companion of M 31. "The orbital signature can't be simulated by anisotropic orbits," says Tonry. And observing the core of M 31 with the Canada–France–Hawaii Telescope on Mauna Kea, Kormendy suggests that about 10^7–$10^8 M_\odot$ is contained in a supermassive black hole.[6] For significant rotation, the observed flattening of a galaxy can be explained without recourse to anisotropy in velocity dispersion, according to Kormendy, but generally detailed models including anisotropy are needed.

Under excellent seeing with the 5-m Hale telescope equipped with a high-resolution spectrograph that includes a charged-coupled device, Dressler has observed the core regions of both M 31 and M 32. Dressler and Richstone have constructed three-dimensional models allowing for anisotropic velocity dispersion to yield synthetic spectra to compare with Dressler's observations.[7] They conclude that all constant mass-to-light models can systematically be ruled out regardless of velocity dispersion anisotropy. The time-averaged assumed mass distribution of stars in galactic orbits must yield the observed galactic radial light distribution, but one cannot construct a galaxy from *any* combination of stellar orbits: "Presumably stars with negative stellar masses are rare," Richstone says. Various computational techniques can be used for the summing procedure, for example, linear programming (as first applied in this astrophysical context by Martin Schwarzschild about a decade ago) or maximum entropy as in Dressler and Richstone's analysis. Richstone is currently examining mass limits for a small but massive cluster of stars in the core, not excluded by their analysis.

To them the most straightforward interpretation is that M 31 has a central black hole with mass about $7\times10^7 M_\odot$ and that M 32 has one with about $8\times10^6 M_\odot$—see the figure.

Tremaine stresses, "M 31 and M 32 are the *only* two galaxies near enough that black holes could be detected with high-resolution observations—so maybe *every* galaxy has a 10^7–$10^8 M_\odot$ black hole!"

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References

1. M. C. Begelman, R. D. Blandford, M. J. Rees, Rev. Mod. Phys. **56**, 255 (1984).
2. K. Y. Lo, Science **233**, 1394 (1986).
3. W. L. W. Sargent, P. J. Young, A. Boksenberg, K. Shortridge, C. R. Lynds, F. D. A. Hartwick, Astrophys. J. **221**, 731 (1978). P. J. Young, J. A. Westphal, J. Kristian, C. P. Wilson, F. P. Landauer, Astrophys. J. **221**, 721 (1978). W. L. W. Sargent, in *The Galactic Center*, D. C. Backer, ed., AIP, New York (1987).
4. W. Bagnuolo, R. Chambers, Nature **326**, 681 (1987).
5. J. L. Tonry, Astrophys. J. **283**, L27 (1984). J. L. Tonry, Astrophys. J. **322** in press (1987).
6. J. Kormendy, Astrophys. J. **325** in press (1988).
7. A. Dressler, D. O. Richstone, Astrophys. J. **324** in press (1988). □