Monster at the Centers of Galaxies

In the mid-60s, a class of objects (Quasi-Stellar Objects or Quasars) was found that looks stellar but which have large redshifts.

Two possibilities were debated

1. If the redshifts are due to the expansion of the universe then the “Quasars” are tremendously distant, hence intrinsically very luminous
2. Alternatively, if the objects are nearby then the energy budget is relatively modest but the physics of the redshift needs to be understood
By the mid-70s, it was clear that the first of these explanations was correct. The redshifts are a consequence of great distances, which means tremendous energies are involved.

The Quasar phenomenon is a huge release of energy at the centers of galaxies. The light output from the central point is so intense that it obliterates our view of the rest of the galaxy unless we look very hard.
Black Hole Monster

No Escape

\[ \frac{1}{2} mv^2 = G \frac{Mm}{r} \]

\[ v^2 = 2G \frac{M}{r} \]

\[ v_{esc} = \sqrt{\frac{2GM}{r}} \]

Nothing can escape from within the event horizon because nothing can go faster than the speed of light.

No escape means there is no more contact with something that falls in. It increases the hole mass, changes the spin or charge, but otherwise loses its identity.
Just as the spacetime is stretched by the large mass, so is the wavelength of light!
$v_{esc} = \sqrt{\frac{2GM}{r}}$; $c = \sqrt{\frac{2GM}{r}}$

$c^2 = \frac{2GM}{r} \Rightarrow r = \frac{2GM}{c^2}$

$r_{sch} = \frac{2GM}{c^2}$

The Schwarzschild radius defines

**the Event Horizon**

the point at which nothing can escape!
- It is now generally accepted that we are witnessing the results of matter falling into a massive black hole.
- Probably most, if not all, big galaxies host a massive black hole at the center: in the range of millions to a billion time the mass of the sun.
  - Our own Galaxy seems to have a black hole nucleus of 4 million suns.

[Image: www.mpe.mpg.de/ir/GC/index.php]
Gas cloud falling into Galactic Center
Gas cloud falling into Galactic Center – with stars

A gas cloud on its way into the supermassive black hole in the Galactic Centre

S. Gillessen, R. Genzel, T. Fritz, E. Quataert, C. Alig, A. Burkert, J. Cuadra, F. Eisenhauer, O. Pfuhl, K. Dodds-Eden, C. Gammie, T. Ott

Simulation by: M. Schartmann, A. Burkert, C. Alig, S. Gillessen, R. Genzel
using PLUTO 3.1.1 (Mignone et al. 2007)
Feeding the Monster

Sometimes mass will fall into the monster black hole, making it more massive. The infalling mass might be in stars, or interstellar gas clouds, or another black hole!

If it is stars or gas, the infalling material will be sheared by the huge tidal field and form an accretion disk about the black hole.
Black Hole in the center of M84

Galaxy M84 Nucleus
Hubble Space Telescope • WFPC2 • STIS

PRC97-12 • ST ScI OPO • May 12, 1997 • B. Woodgate (GSFC), G. Bower (NOAO) and NASA
Black Hole in the Center of M87

Spectrum of Gas Disk in Active Galaxy M87

Hubble Space Telescope • Faint Object Spectrograph
Jets from M87 Black Hole

Gas Disk in Nucleus of Active Galaxy M87

Hubble Space Telescope
Wide Field Planetary Camera 2
As matter falls inward it spins up because of conservation of angular momentum

⇒ magnetic field gets squeezed and compressed to high values.

⇒ While much of the matter will fall into the black hole, some of it will squirt out the poles of the accretion disk as an ionized plasma, be accelerated in the intense magnetic fields, and carry off much of the angular momentum.
Often, the Quasar phenomenon is accompanied by the ejection of plasma in collimated pairs of jets that are most easily visible at radio wavelengths. Plasma orbits about magnetic field lines produce synchrotron radiation. Jets can extend for 1-3 million light years.
• If most or all big galaxies have a nuclear monster, than at one time or other they were probably active
• At early times, there was probably a lot of material in the vicinity of the central black hole; material that was sucked into the black hole over time
  – There was a peak of Quasar activity at a redshift of z~2 when the universe was between 3 and 4 billion years old
Nuclei become active when things get stirred up. An effective way for this to happen is to have a close passage or collision with another galaxy. Then stars and gas get perturbed out of their safe orbits at large distances from the monster and can get close enough to be eaten.
Collisions can be spectacular

Colliding Galaxies NGC 4038 and NGC 4039
The Mice
The Mice movie
Stephan’s Quintet
Seyfert’s Sextet
Bars can perturb gas toward the nucleus
• Quasars are colossal energetic events, but a wide range of activity possible.
• Intermediate-energy events are classified as “Seyfert” active nuclei (after discoverer Carl Seyfert) or “radio galaxies”.
• “LINERs” (low intensity nuclear emission regions) are galactic nuclei with only traces of recent activity.