Mystery at the Centers of (Most?) Galaxies

A bizarre jet from M87

(HST image of this Giant Elliptical Galaxy in the nearby Virgo Cluster)

Bright Nucleus of the galaxy

A highly collimated jet
Could stars produce this huge galactic blowtorch? (they can’t! It takes one huge engine!)

1) the M87 jet produces the most powerful radio waves in Virgo
2) its energetic radio lobes are enormous, extending far beyond the galaxy

- Each zoom step is roughly factor of 10X magnification
- Maps from a global radio interferometer give light-year resolution
M87’s jet is not the only one: More Blasts from the past

- 1960-70’s Radio-astronomers discovered hundreds of such galaxies —completely unexpected
- The huge radio lobes contain a prodigious amount of high-energy particles (e.g. electrons), which could only have been accelerated by a remarkably powerful, long-lived (Myrs) machine, with a gyroscopic axis
- By now many of them have escaped the galaxy, but they are still radiating energy by the synchrotron mechanism (when electrons spiral in a magnetic field at nearly the speed of light)
Most Powerful Radio Sources in Fornax and Cygnus

Center of galaxy

"What kind of monster…?"
(Even Billions of) supernovae couldn’t possibly have done this!

Visible stars;
Radio lobes
Where did these blasts originate?

- The giant radio lobes are the “smoke” of colossal explosions. Since the lobes always point back to well-collimated jets which start out in the galactic nucleus, that must be where all the power originated.

- Caught in the act: radio astronomers detect repeated (unpredictable) ejection of new radio blobs of high-energy particles start out at speeds of 0.95c.
Even if you don’t see a flashy radio jet, there are many more “active” galactic nuclei shining by non-stellar light.

The famous radio jets are just the tip of the iceberg: Far more power emerges from the Active Galactic Nucleus (AGN) at high energies, including visible light, UV, X-rays and Gamma-rays; total can exceed output of all the stars—trillions of solar luminosities!

Jet from powerful “Quasar” 3C 273
• AGN produces its power in a very compact region, since: \( R < c \Delta T \) i.e. only light-hours across, smaller than our Solar System!

• The *massive* central engine of AGN is the (bi-polar) high-energy particle accelerator

In this “quasar”, Gamma-ray flare erupts in 8 hours, 1000X more powerful than the entire Milky Way galaxy
Quasars

• In the 1960s, Maarten Schmidt identified the radio source 3C 273 with a faint, blue star.
  • the “star’s” spectrum displayed emission lines, plus lots of UV, X-ray, infrared radiation:
  • NOT a normal galaxy, which would have a spectrum of starlight (absorption lines), and mostly just visible light
  • they were called quasi-stellar radio sources or quasars for short
• He realized that the emission lines belonged to Hydrogen, but they were highly redshifted. ➔ extremely luminous:
  • $10^{40}$ watts ➔ 1,000 brighter than the entire Milky Way Galaxy!
• are extremely variable:
  • luminosity changes < 8 hours
  • implies they have a very small size
Quasars…

- Many quasars are very (> $10^{10}$ light years) far away.
- Quasars exist mainly in the *early* Universe!
- have absorption lines at lower redshifts.
  - from gas clouds & galaxies between us and the quasar
What is the AGN’s Compact Central Engine? The **Black Hole** Theory

- Best jet model is energy release from matter in close (disk) orbits around a *giant black hole*, the same as we see in little accretion disks in X-ray binary black holes like Cygnus X-1 (highly fuel efficient, **30 times more energy per kilogram than nuclear fusion**, ie almost pure conversion of matter into energy)

- Spinning disk of gas defines north and south polar directions—quasar is a long-lived *gyroscope*

- Huge luminosity → huge “radiation pressure” would make the object explode → only a huge gravity can hold it together → $M_{\text{engine}} > 1 \text{ Sun (L}/10^{31} \text{ Watts)}$
• The 4 Million-solar mass black hole in the center of our galaxy is usually starved for fuel, but…
• It bursts in X-rays (and infrared) about 3 times per week (unpredictably)
• This discovery was made at UCLA, and by former UCLA grad student

Matt Malkan, UCLA, Astronomy 4
X-ray power from the center of our galaxy

Oct 27 05:42 UT
45x, 4 hr


(Baganoff et al. 2001)
PROOF of Giant Black Holes in the Centers of (Many) Galaxies

• UCLA Galactic Center Group measures motions of stars around our Galactic Center—>
• They are going VERY FAST (up to 1000 kilometers per second!)—>
• Huge accelerations can only be explained by a central point 4 Million times the mass of the Sun
• WARNING: Do NOT confuse this dark mass with the Dark Matter HALOES of galaxies!