Astronomy 218

Loud Galaxies
A significant fraction of galaxies show marked differences in luminosity from their normal counterparts.

The differences vary from galaxy to galaxy, but they are collectively called active galaxies.

Most often, active galaxies show significant departures from the thermal stellar spectrum.

This generally includes excess radio and X-ray emission.

Even at ultraviolet, visible and infrared wavelengths, active galaxies are unusual with strong emission lines.
One class of active galaxy are extremely luminous galaxies experiencing an outburst of star formation.

Such galaxies, called starburst galaxies, likely result from interactions with a neighbor.

NGC 7742 has both a ring of hyperactive star-formation and an abnormally luminous core.

Such over-luminous cores are the most frequent signature of active galaxies.
These central bright regions, called Active Galactic Nuclei (AGN), are responsible for much of the light of the active galaxy, particularly the radio and X-ray radiation.

Rapid variations in the luminosity at radio and X-ray wavelengths, on timescales as rapid as minutes to hours, indicate that the core must be extremely compact.

This suggests the source is a supermassive black hole.
Radio Quiet or Loud

The most significant **taxonomic distinction** for active galaxies is the relative importance of their radio emission.

Those with low radio luminosity are termed **radio-quiet**.

Those with high radio luminosity are termed **radio-loud**.

This galaxy exhibits both a **starburst component** and signatures of two separate AGN.
Seyfert Galaxy

Nearby radio-quiet active galaxies are generally Seyfert galaxies, named for Carl Seyfert who first identified them as a class in the 1940s.

They resemble normal spiral galaxies, but their nuclei have luminosities, \( L \sim 10^8 \text{--} 10^{12} L_\odot \), much greater than that of the Milky Way \( \sim 10^3 L_\odot \).

Over 10,000 Seyferts have been cataloged, perhaps 5% of all spirals.

A class of similar but weaker nuclei are called Low-ionization nuclear emission-line regions (LINERs).
The visible emission of Seyfert galaxies is dominated by bright emission lines from hydrogen, helium, nitrogen, oxygen, etc. Seyfert 2 galaxies exhibit narrow lines, both forbidden and permitted, implying velocities $\sim 300\text{ km s}^{-1}$. Seyfert 1 galaxies exhibit similar narrow lines, forbidden and permitted, as well as an additional component of very broad permitted lines, whose doppler widths require velocities $\sim 5000-10000\text{ km s}^{-1}$.
Seyfert X-rays

While most Seyferts (95%) are radio-quiet, their excess luminosity extends to X-ray wavelengths.

The X-rays in this image of the Circinus Galaxy are color coded by energy, from red (low energy) to blue (high energy).

The X-rays are well correlated with the optical emission line producing region.

The harder spectrum, and asymmetry are ascribed to absorption by the galactic disk from the lobe below it.
Among radio-loud objects \( (L_{\text{radio}} > 10^{33} \, \text{W} \sim 10^7 \, L_\odot) \), the most common classification is simply radio galaxy.

Virtually all radio-loud AGN are hosted in elliptical galaxies.

Some radio galaxies show strong radio emission \( (L_{\text{radio}} \lesssim 10^{38} \, \text{W} \sim 10^{12} \, L_\odot) \) from a central bright source, with only a weak extended halo. These are termed compact or core-dominated radio galaxies.
Other radio galaxies have enormous radio emitting lobes, invisible to optical telescopes.

For Centaurs A (NGC 5128), the 5th brightest galaxy in the sky ($d \sim 3\text{–}5\ \text{Mpc}$), the radio lobes (shown here at $\lambda \sim 6 \text{ cm}$) stretch more than 600 kpc.

The host galaxy is peculiar, exhibiting a strong dust band and star formation in an otherwise typical elliptical galaxy.
Some radio galaxies show very little additional visible light beyond what you’d expect for a similar normal galaxy.

Others exhibit only narrow lines like a Seyfert 2. These are classified as Narrow Line Radio Galaxies (NLRG).

Some radio galaxies, classified as Broad Line Radio Galaxies (BLRG) also show broad lines.
An X-ray image of Centaurus A highlights a jet on the upper side leading to the radio lobe. A jet is not seen on the lower side, though X-ray emission highlights the lower lobe.

Kinematics in the galaxy interior reveal a black hole of $2 \times 10^8 \, M_\odot$.

This is moderately larger than would have been predicted from the observed velocity dispersion $\sigma \sim 140 \, \text{km s}^{-1}$ but consistent with a “bulge” mass of $3 \times 10^{11} \, M_\odot$. 
Even compact radio galaxies show evidence for jets, albeit smaller and obscured by the galaxy’s light.

A short optical exposure reveals the jet hidden in the core.

Observing in the IR reveals more.
Observations of the M87 jet spanning a wide range in wavelength highlight the same physical features.

In the core, HST provides evidence for a gaseous disk and a $6 \times 10^9 \, M_\odot$ black hole.
Blazars

While the radio emission of most AGNs typically varies quite slowly, for **Blazars** variations over a few days or less is typical.

Blazars are also radio bright with a **very flat radio spectrum**. The short-term variability extends to optical wavelengths. The optical signal is also highly polarized.

Blazars emit radiation across the entire electromagnetic spectrum, even **producing γ-rays** above 100 MeV. Fermi γ-Ray Space Telescope has found ~ 700, half Flat Spectrum Radio Quasars & half BL Lac objects.
Before the advent of radio astronomy, Blazars were classified as **irregular variable stars** with no discernible periods.

In 1968, the strong radio source VRO 42.22.01 was found to coincide with one of these "variable star", **BL Lacertae**.

BL Lac objects are characterized by their very **featureless optical spectra**, which make it hard to determine their redshift.

In contrast, FSR quasars, also called optically violent variable (OVV) quasars, show **broad lines** and tend to be radio-loud.
Markarian 421 is a BL Lac galaxy at a distance of 444 Mpc. Like many AGN, it shows a $\gamma$-ray bump, thought to be the result of photons scattered to higher energy via interaction with relativistic electrons.
The classification of Active Galaxies is *inexact* with any given member of a class *lacking a specific attribute*, but in general the following characteristics are *shared*. 

<table>
<thead>
<tr>
<th>Galaxy Type</th>
<th>Active Nucleus</th>
<th>Emission lines</th>
<th>Excess</th>
<th>Jets</th>
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<tr>
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<td>Broad</td>
<td>γ-rays</td>
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<tr>
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Key: Y= Yes, N= No, S=Some, W=Weak
Next Time

Monday, Supermassive Black Holes with Dr. Leah Huk