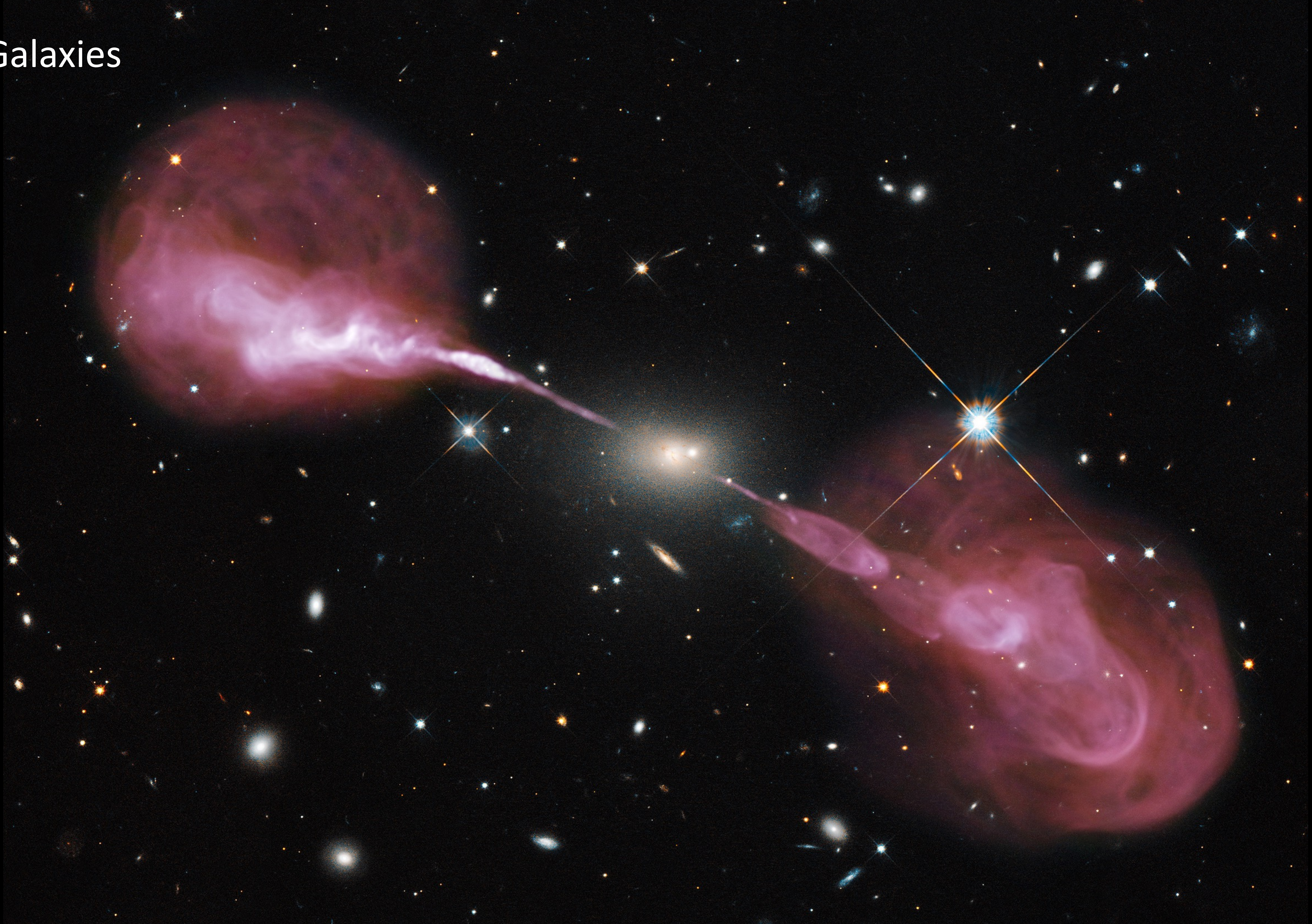
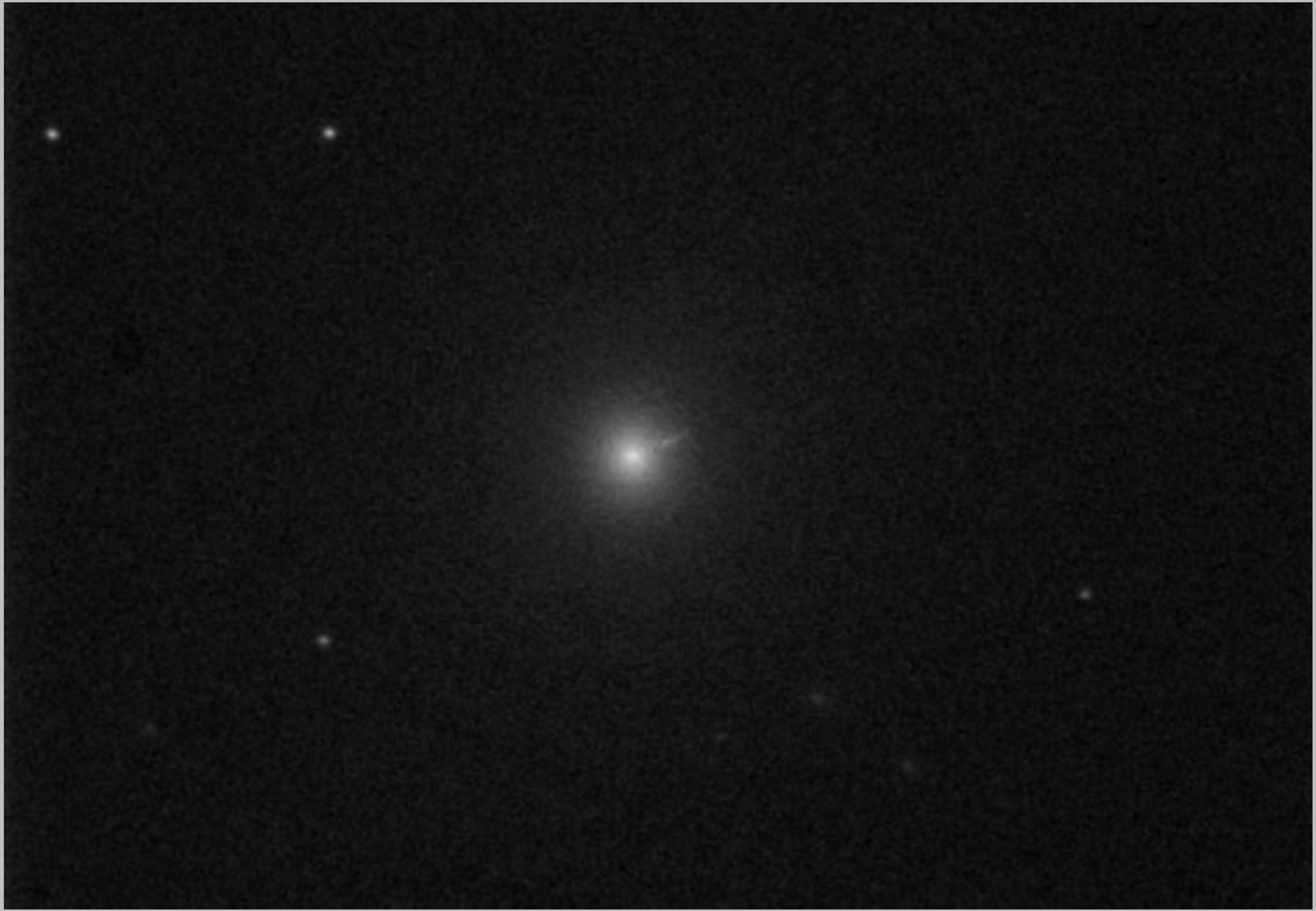
Active Galaxies



The Discovery of Active Galaxies: M87

1918: Heber Curtis notices a “curious straight ray” emanating from the center of the Virgo elliptical “nebula” M87.

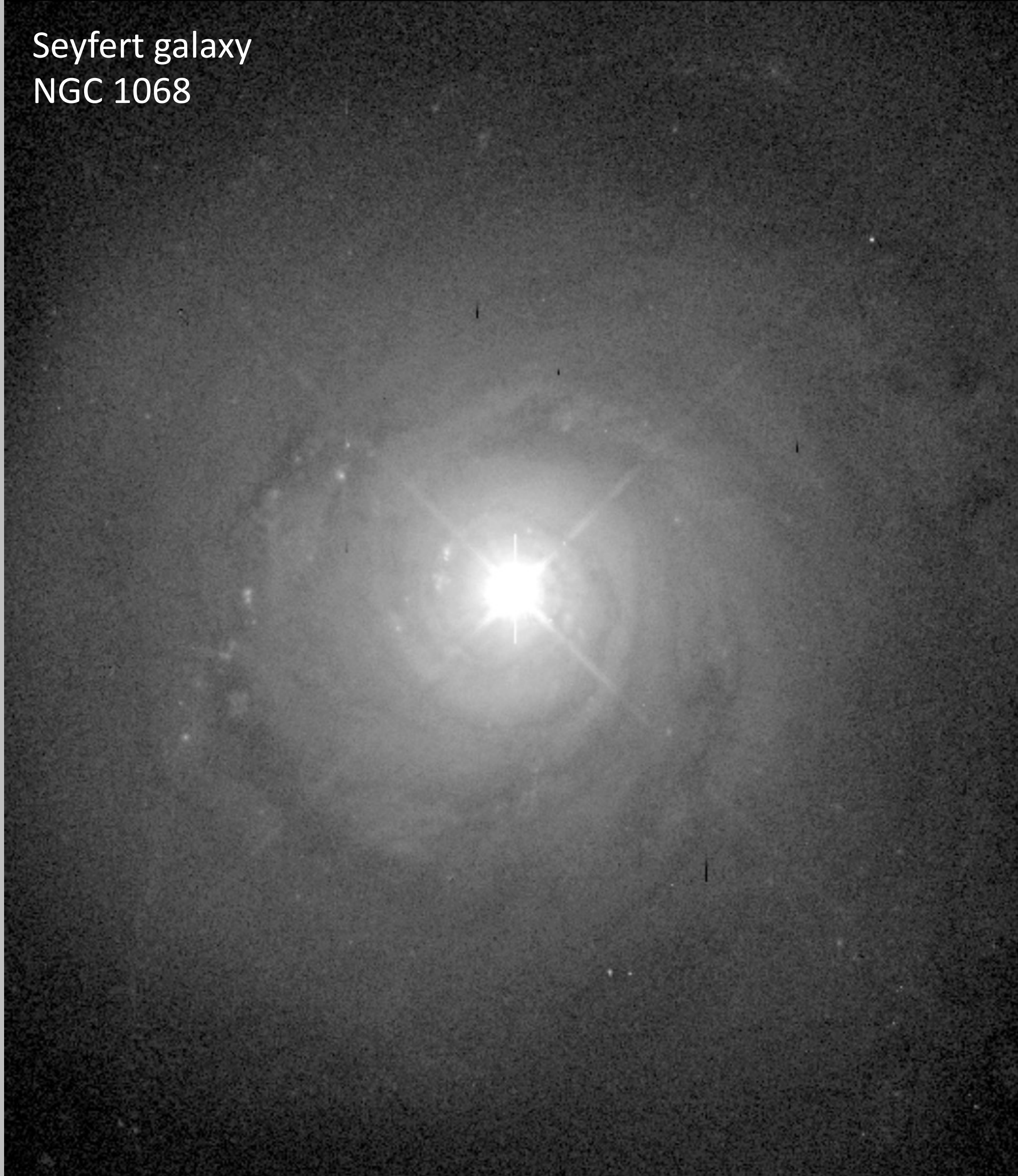


The Discovery of Active Galaxies: Seyfert Galaxies

1940s: Karl Seyfert catalogs spiral galaxies with "point source" (star-like) nuclei.

But the nuclei show very strange spectra, not like stars and not like star forming regions or starburst galaxies.

Karl Seyfert and Jason Nassau at CWRU's Burrell Schmidt telescope

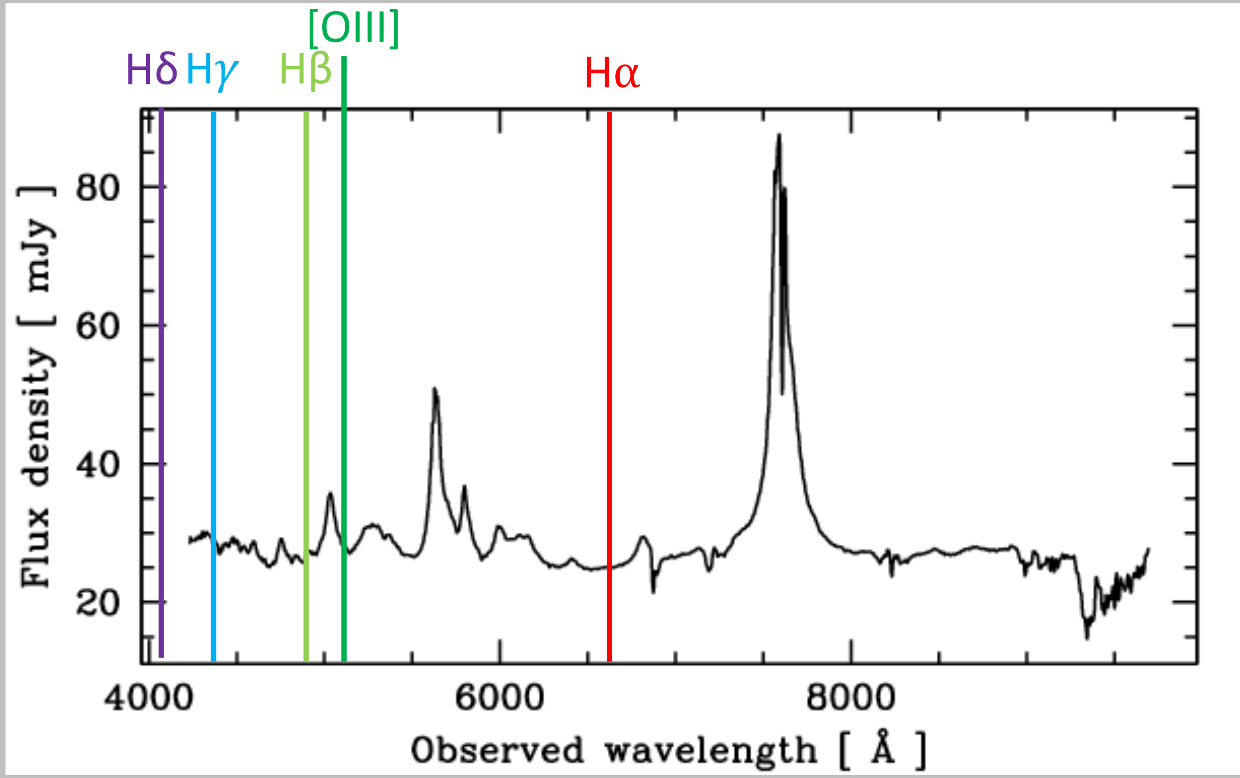


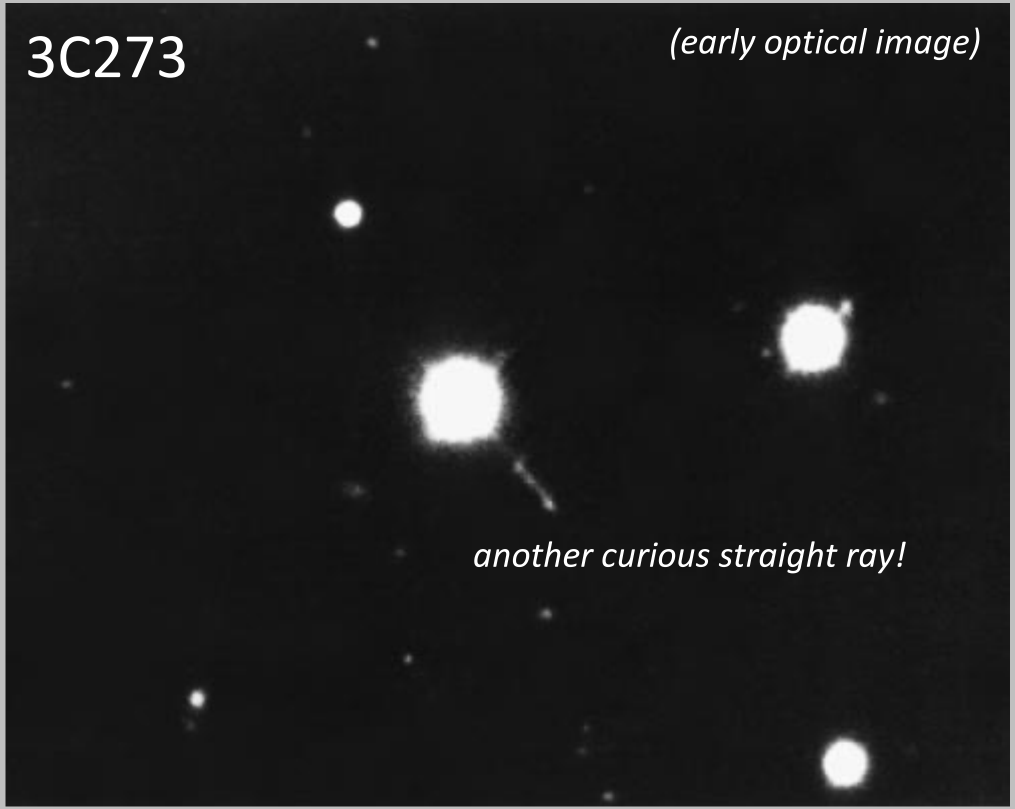
The Discovery of Active Galaxies: Quasars

1950s: Radio telescopes began find bright radio sources, but optical telescopes showed only a faint star-like object.

These were called "quasi-stellar radio sources", or quasars.

Their spectra were bizarre, showing never-before seen emission lines, as well as missing emission lines.





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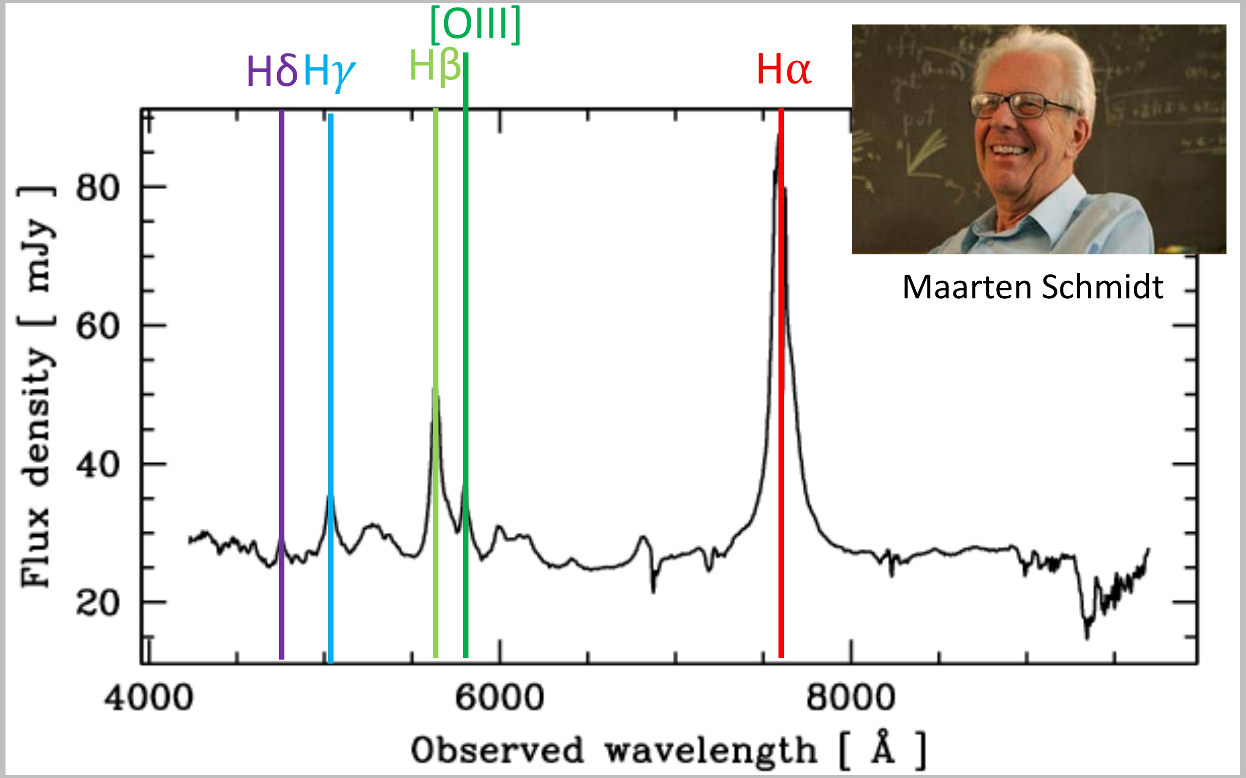
1964: Maarten Schmidt figures out these are regular emission lines, just crazily redshifted as never before seen.

The quasar 3C273 has a redshift of z=0.152, putting it at a distance of about 650 Mpc.

Shortly thereafter another quasar 3C48 was found with a redshift of z=0.367 ⇒ 1,500 Mpc away!

At these huge distances the objects must be very luminous: ≈ 1,000x more luminous than the Milky Way! And yet small and point-like in appearance. *What are these things?*



An aside: **redshifts**

For a shifted spectrum, astronomers define the redshift $z = \Delta\lambda/\lambda$

If the redshift is small, we can describe this as velocity using the non-relativistic Doppler shift: $z = \Delta\lambda/\lambda = v/c$. That velocity can get used in Hubble's law, and astronomers often refer to redshift as a velocity. "That galaxy has a redshift of 1200 km/s" meaning its redshift is $z = v/c = 0.004$.

For larger redshifts this interpretation of a non-relativistic Doppler shift does not hold, and we refer to the redshift itself: "That is a redshift z=0.2 galaxy".

Quasar Properties

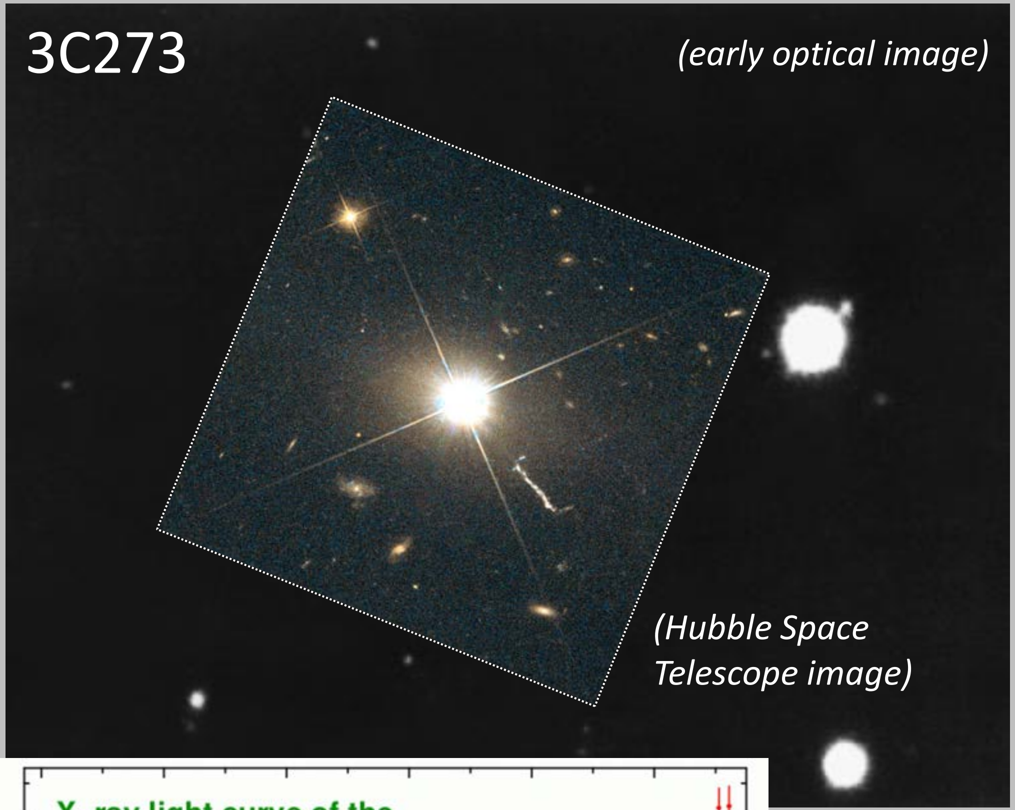
We now know quasars to be the bright nuclei of galaxies: an active galactic nucleus (AGN). The nucleus outshines the host galaxy by a factor of 1000. But what are they?

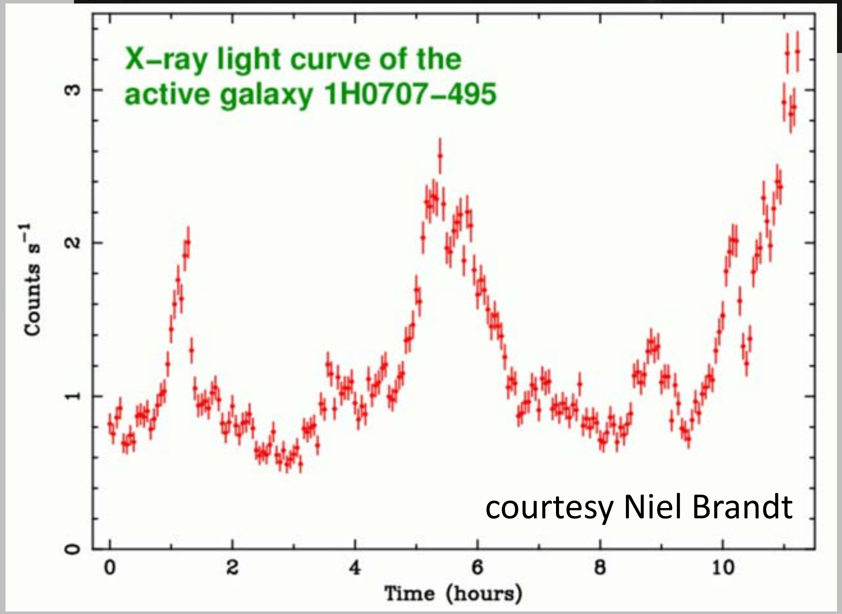
Clue #1: They have high luminosities: $L \approx 10^{13} L_{\odot}$

Clue #2: They have emission lines that show ***very*** highly ionized gas, so the energy source must be much hotter than even hot young stars.

Clue #3: They often vary significantly in brightness, over timescales of days or even hours. Remember causality: if an object varies in brightness over a timescale of Δt, it must be smaller than the light travel time: $R < c\Delta t$. That means sizes < 10 AU.

Thats 1000 Milky Way galaxies' worth of high energy radiation packed into an area the size of our solar system!

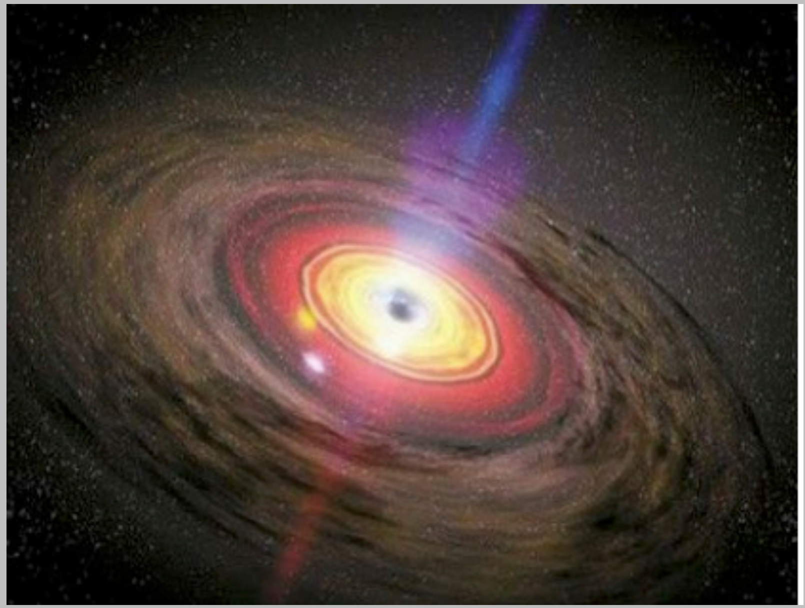




Active Galactic Nuclei: The central engines

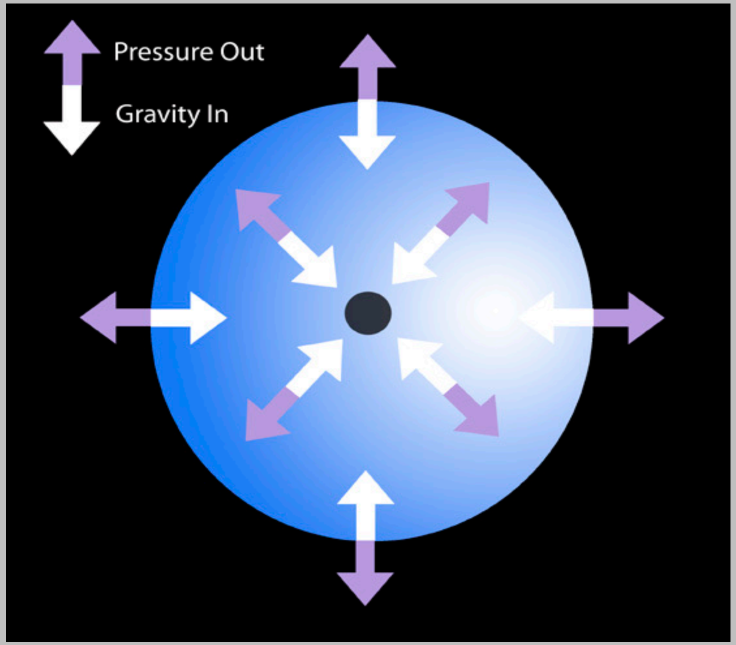
The only thing we know of that can produce that much energy in a small region of space is a rapidly accreting super-massive black hole.

As gas falls inwards toward the black hole, it settles into a hot accretion disk. As the gas swirls around, friction heats it up to $10^5 - 10^7$ K, causing it to emit UV light, X-rays, and γ-rays, highly ionizing the gas all around it.



How massive is the black hole?

Let's balance radiation pressure and gravity to find out.



Photons produce an outward pressure on nearby particles given by:

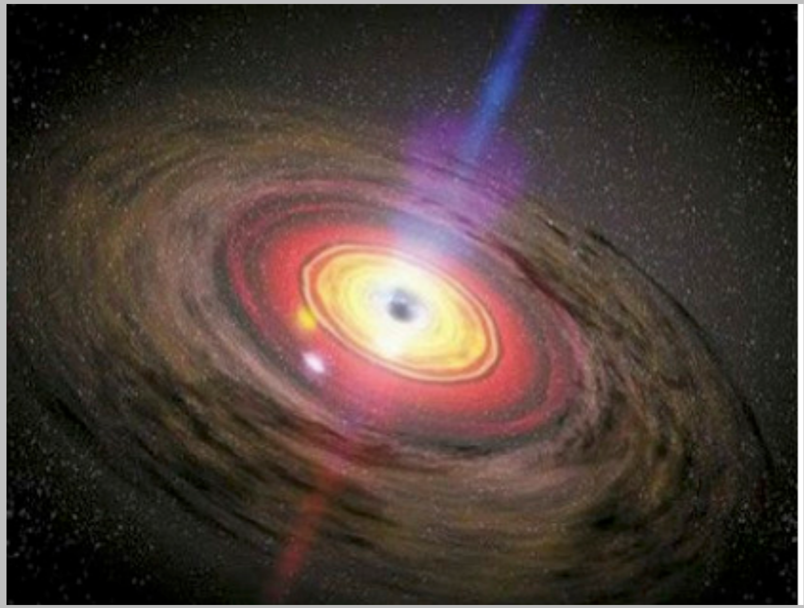
$$P_{rad} = \frac{L}{4\pi R^2 c}$$

An electron feels this pressure as a force pushing it away from the nucleus:

$$F_{rad} = \sigma_T P_{rad} = \frac{\sigma_T L}{4\pi R^2 c}$$

where σ_T is the Thomson cross-section for the interaction between electrons and photons.

Active Galactic Nuclei: The central engines



While photon pressure pushes out, gravity pulls in. In a ionized gas where protons (p) and electrons (e) are coupled by electrostatic forces,

$$F_{grav} = -\frac{GM(m_p + m_e)}{R^2} \approx -\frac{GMm_p}{R^2}$$

For the whole thing to remain bound together, $F_{grav} > F_{rad}$, or:

$$\frac{GMm_p}{R^2} \geq \frac{\sigma_T L}{4\pi R^2 c}$$

Solving for mass, we get the ***Eddington mass***

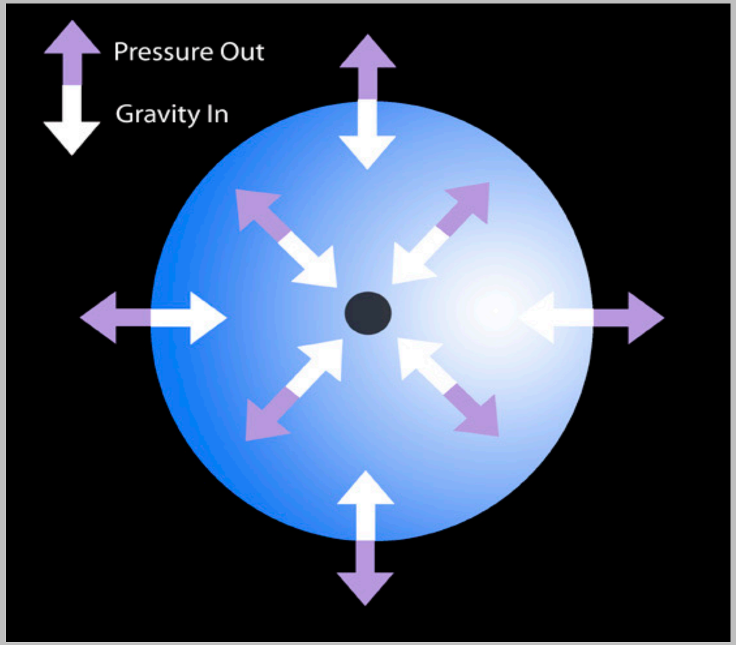
$$M_{Edd} = \frac{\sigma_T L}{4\pi G m_p c} = 3.1\times10^{-5}\left(\frac{L}{L_\odot}\right)M_\odot$$

The black hole must be at least this massive, or radiation pressure will blow the whole thing apart. For a $10^{13} L_\odot$ AGN, the Eddington mass is $\approx 3\times10^{8} M_\odot$.

Important Notes:

1. The R's canceled out. Handy!

2. Nowhere did the calculation assume a black hole. This works for any luminous object, even individual stars!



The AGN Zoo: Type 1 and Type 2 Seyfert Galaxies

Seyfert galaxies are spirals, and come in two types characterized by their spectra.

Type 1 Seyferts:

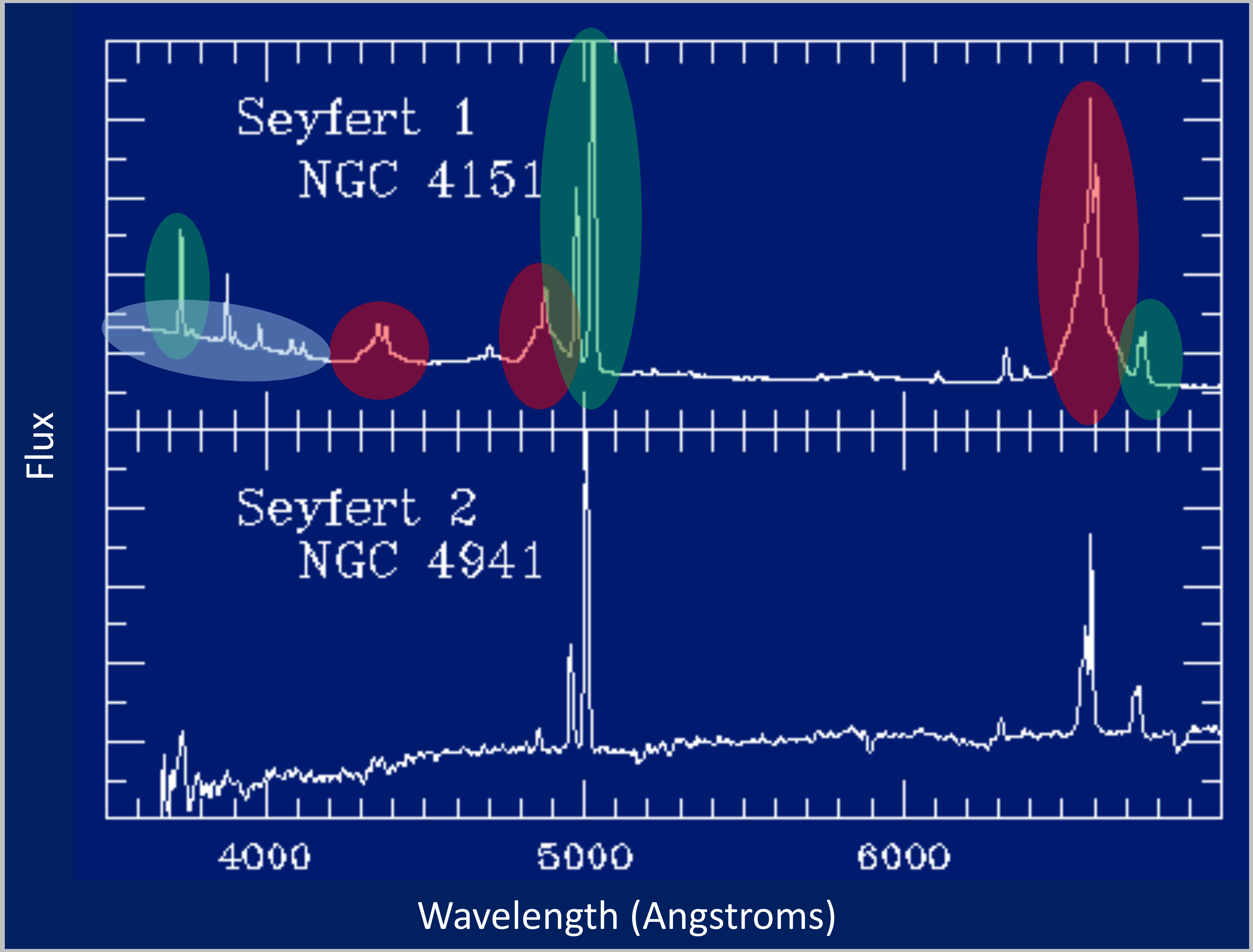
- Broad emission lines with a Doppler width of 1000 – 5000 km/s.
- Narrow emission lines ≈ 500 km/s.
- Spectrum rising in the blue

Type 2 Seyferts:

- Lines are all narrow
- No broad lines
- Spectrum flat or falling in the blue.

Quasars show similar types (1 and 2) as well.

courtesy Bill Keel

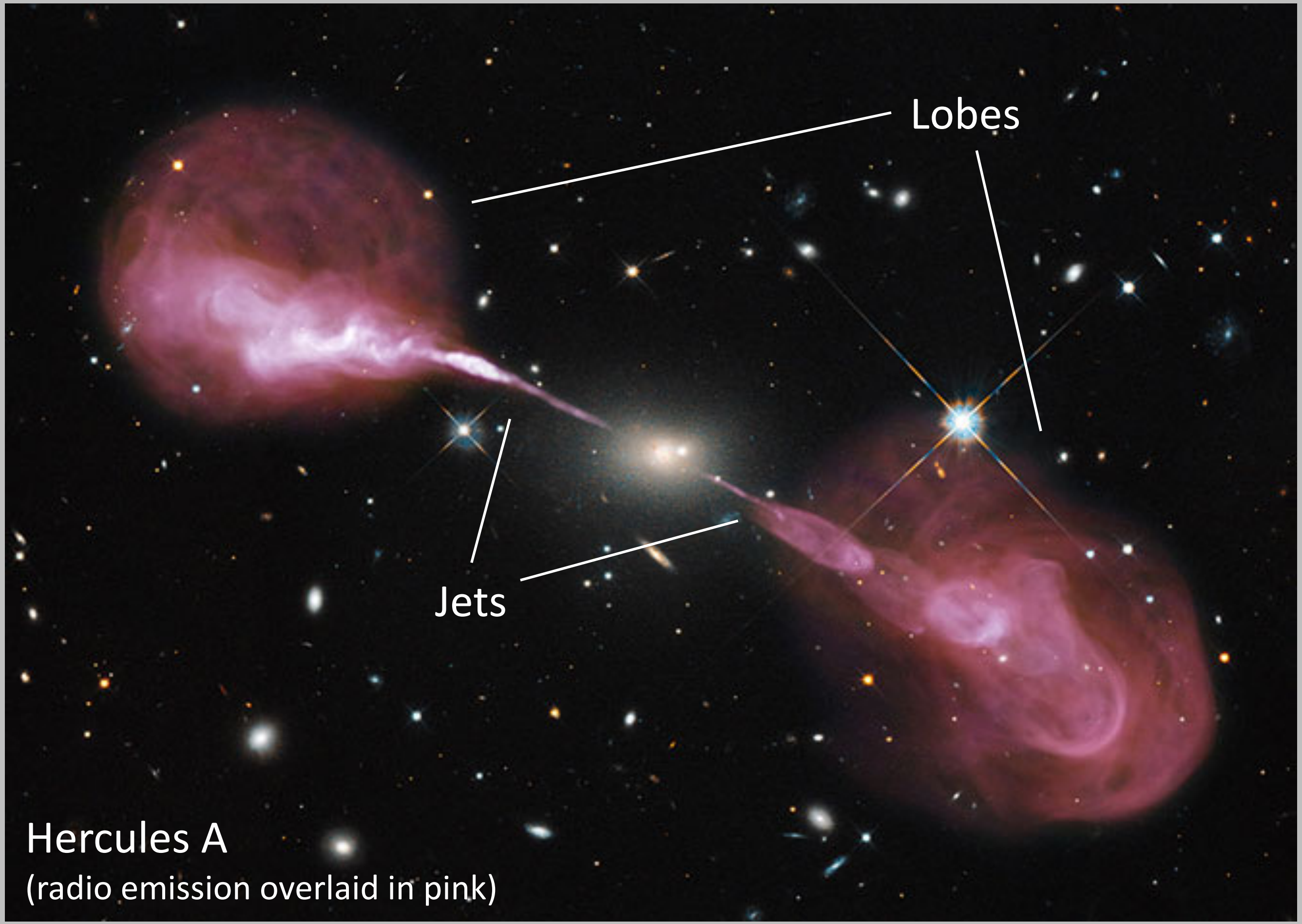


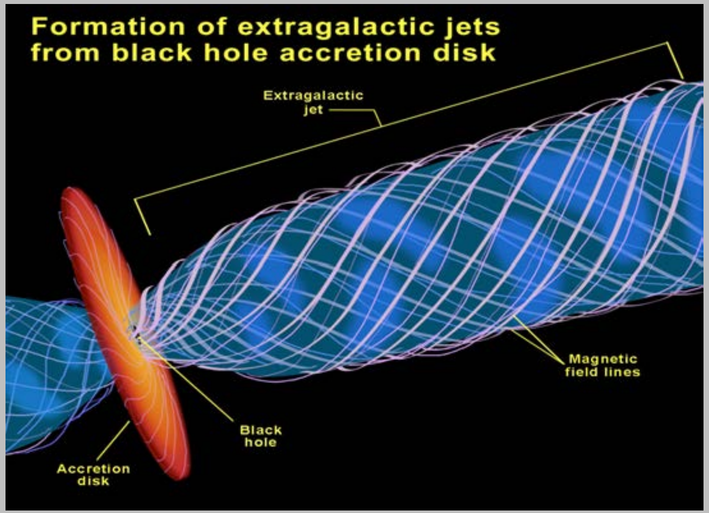
The AGN Zoo: Radio galaxies

Some AGN put out lots of radio emission as well. These "radio galaxies" are usually ellipticals, and often have radio jets and lobes.

Hercules A

- z=0.155 (distance ≈ 650 Mpc)
- radio lobes span ≈ 250 kpc
- radio luminosity ≈ 10^{45} erg/s ($10^6 \times$ typical galaxy)
- Jets show **synchroton** radio emission (electrons spiraling around magnetic fields)
- Lobes show **free-free** radio (interactions between charged particles)





AGN jets

The black hole + accretion disk has wound up the magnetic fields and launched a collimated jet of relativistic charged particles. (synchroton jet)

When the particles get out far enough they diffuse to form the broad radio lobes

The "Unified Model" for AGN: how to describe these various types of AGN with one basic model?

Central black hole: $\mathcal{M} \approx 10^7 - 10^9\ \mathcal{M}_{\odot}$, accreting mass at $\approx 1 - 10\ \mathcal{M}_{\odot}$/yr.

Accretion disk: hot, luminous gas accreting onto the black hole, ≈ solar system sized.

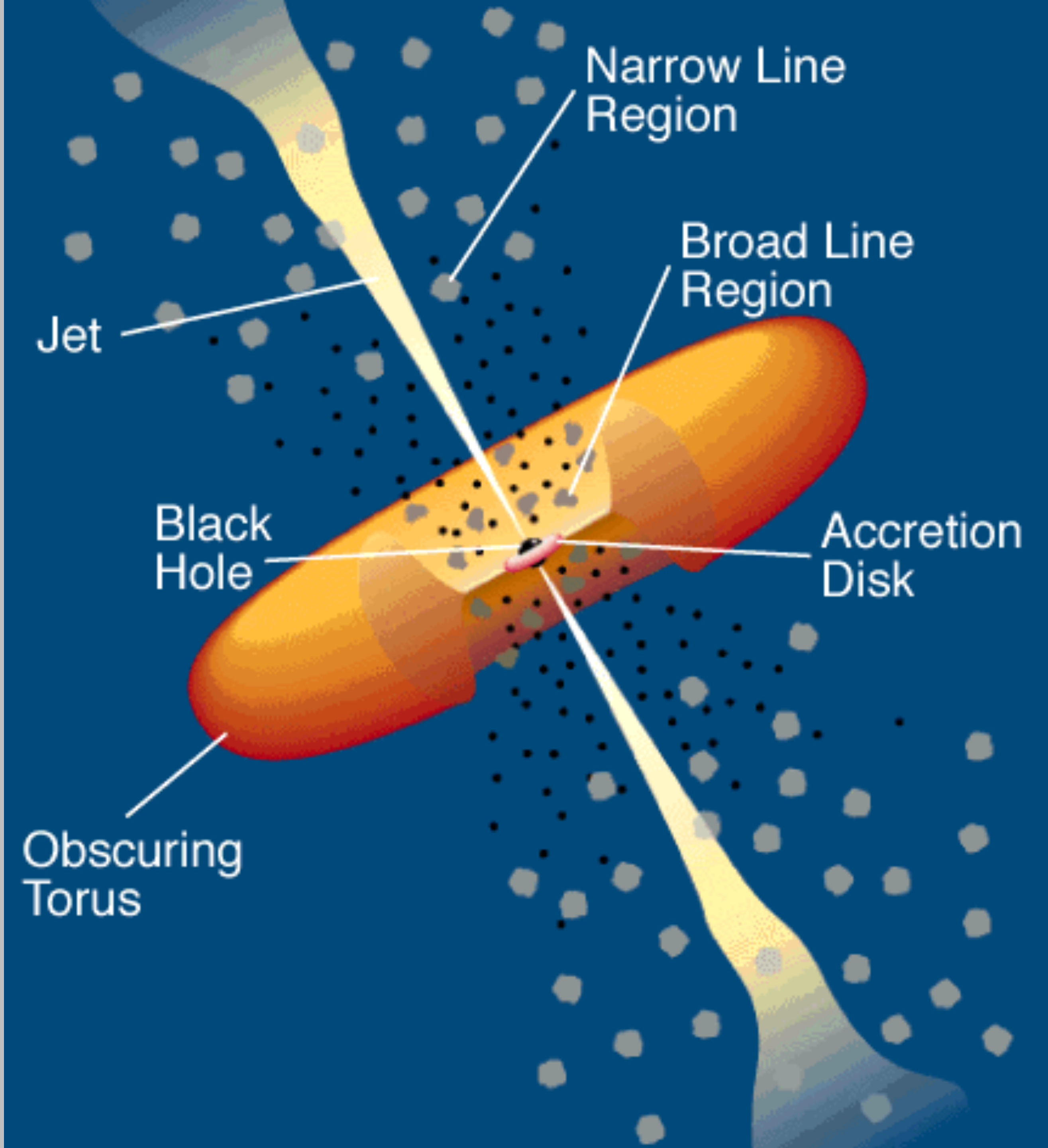
Jets: charged particles moving at relativistic speeds out of the nucleus

Broad-line region: Gas clouds near the accretion disk, turbulent motions at high speed.

Dusty torus: a ring of denser gas and dust surrounding the nucleus. ≈ 0.1 pc in size.

Narrow-line clouds: Gas clouds further out, moving more slowly.

Important: This is all happening on size scales too small to be resolved at the distances of most AGN.

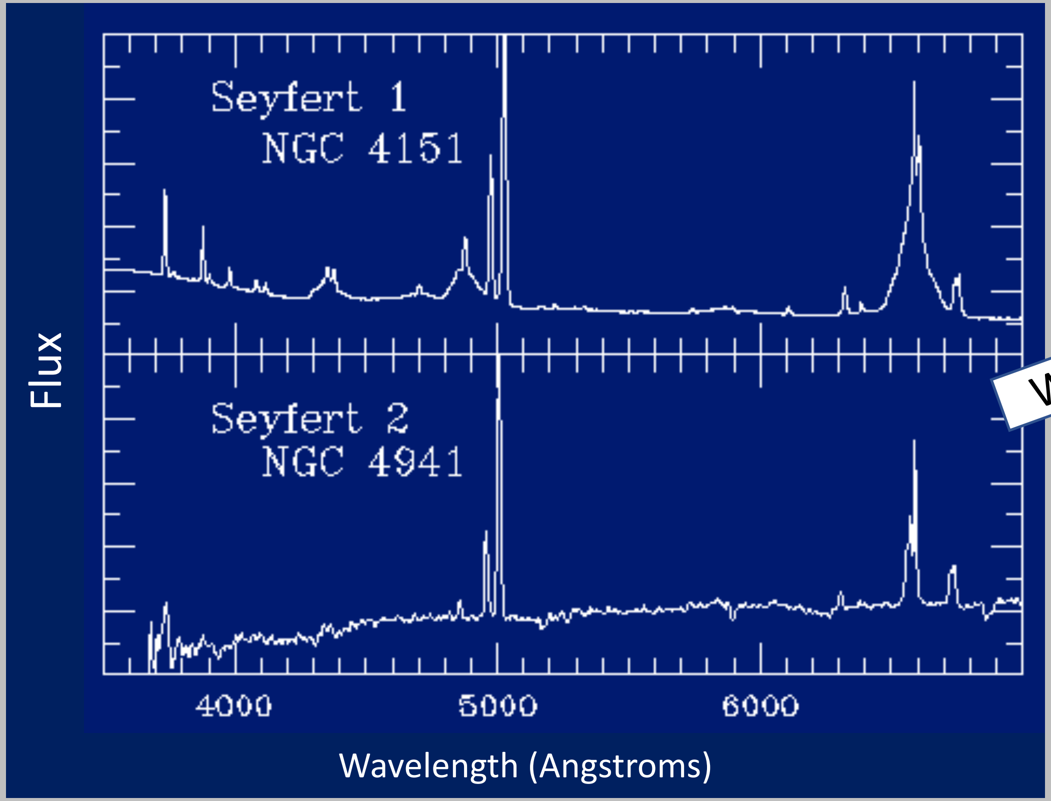


How does this "unify" the different kinds of AGN?

Seyfert (and other) Type 1 and Type 2 AGN: same things seen from different angles.

Type 1: we see light from the inner and outer regions: broad lines, narrow lines, hot accretion disk (blue)

Type 2: we see only the light from outer regions, light from the inner regions is blocked by dust: narrow lines only



courtesy Bill Keel