Announcements

- Today: Finish Chapter 15, start Chapter 16
- **Quiz 11** on Chapters 14, 15 due Monday
- **Midterm 3: Wednesday April 23**
  - Neutron stars and black holes (Ch 13)
  - The solar system (Chs 4, 6, 7, + bits of Ch 5 [Earth] and 8 [moons of Jupiter, Saturn])
  - The Milky Way Galaxy (Ch 14)
- Review in class on Monday April 21

Astronomy 103

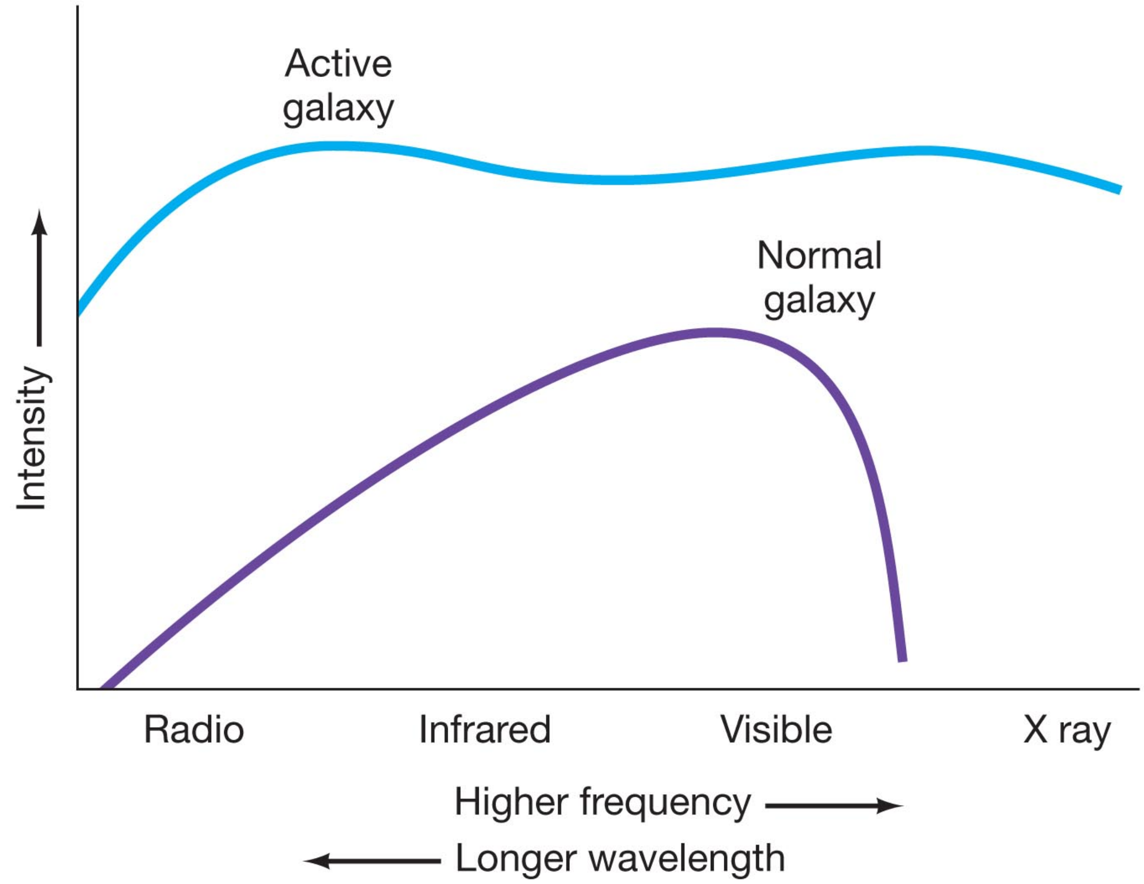
Galaxies: Active Galaxies

Please read chapter 15

Active Galaxies

About 20–25 percent of galaxies don't fit well into the Hubble scheme – they are far too luminous.

Such galaxies are called active galaxies. They differ from normal galaxies in both their luminosity and in the type of radiation they emit.

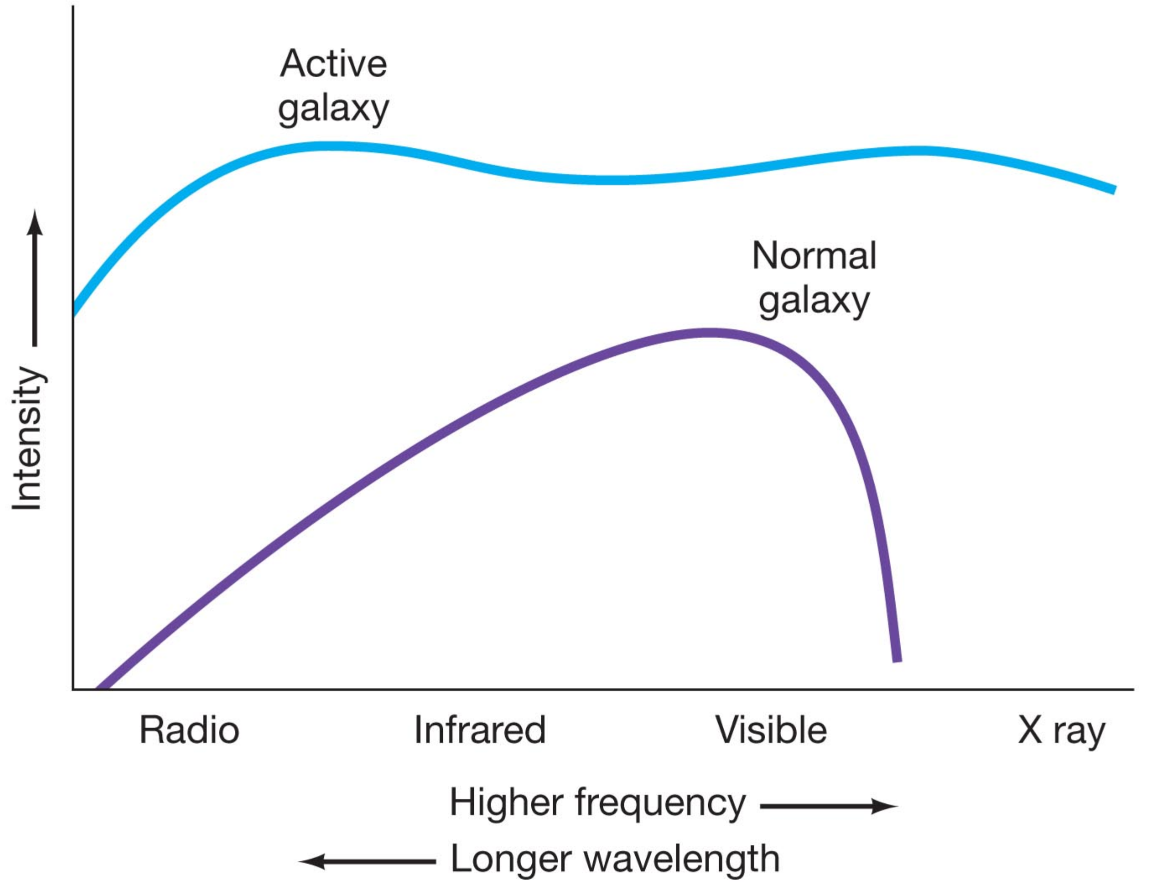


Galactic Spectra

Galaxies are made of large collections of stars, so we might expect their spectra to look like the spectra of a bunch of stars, peaking in visible light

This is true for most galaxies, but not for all of them. Some galaxies show strong **nonstellar radiation**.

Because they are bright, they are called **active galaxies**



Active Galaxies

The radiation from these galaxies is called nonstellar radiation, meaning that it is not produced by stars.

Many luminous galaxies are experiencing an outburst of star formation, probably due to interactions with a neighbor. These galaxies are called starburst galaxies, and we will discuss them later.

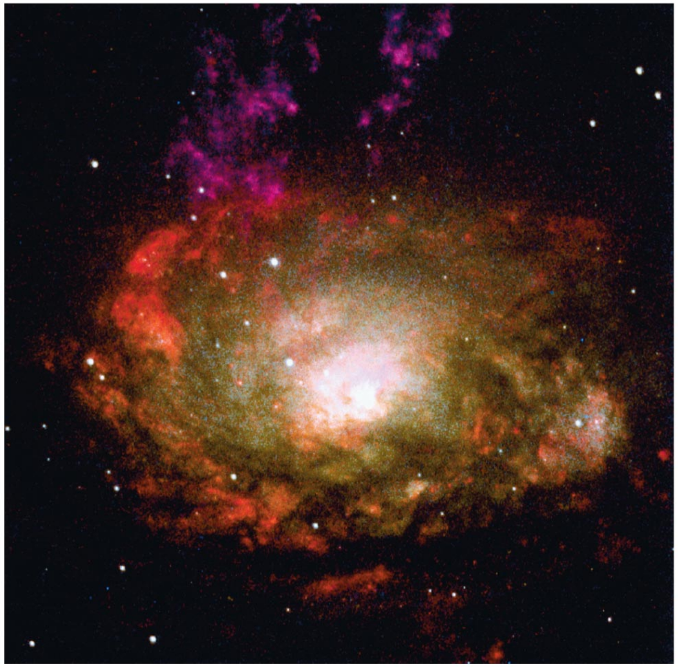
The galaxies we will discuss now are those whose activity is due to events occurring in and around the galactic center. For this reason they are called active galactic nuclei or AGN.

Active Galaxies

Active galaxies are much more luminous than normal galaxies and have nonstellar spectra, emitting most of their energy outside the visible part of the electromagnetic spectrum.

Active galaxies are classified into three types: Seyfert galaxies, radio galaxies, and quasars.

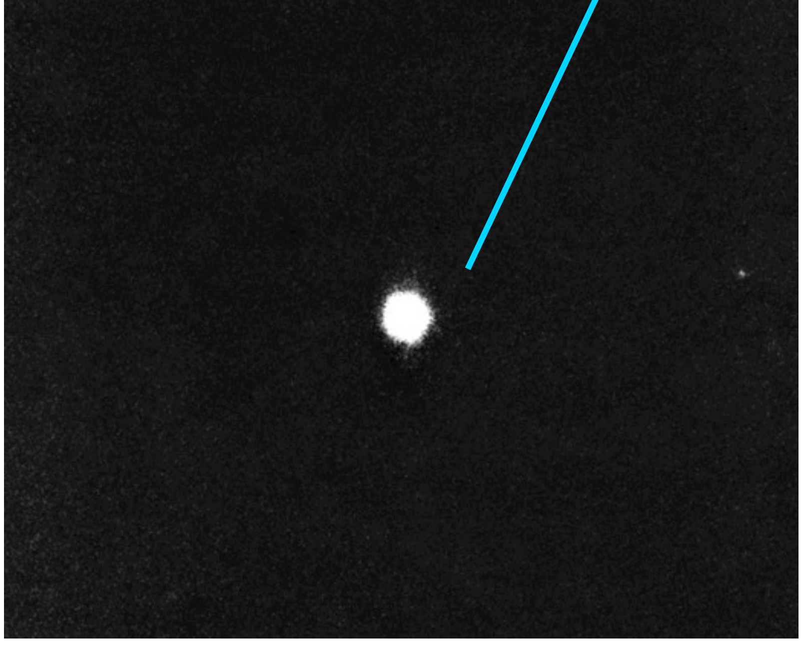
Seyfert galaxies resemble normal spiral galaxies, but their cores are thousands of times more luminous.

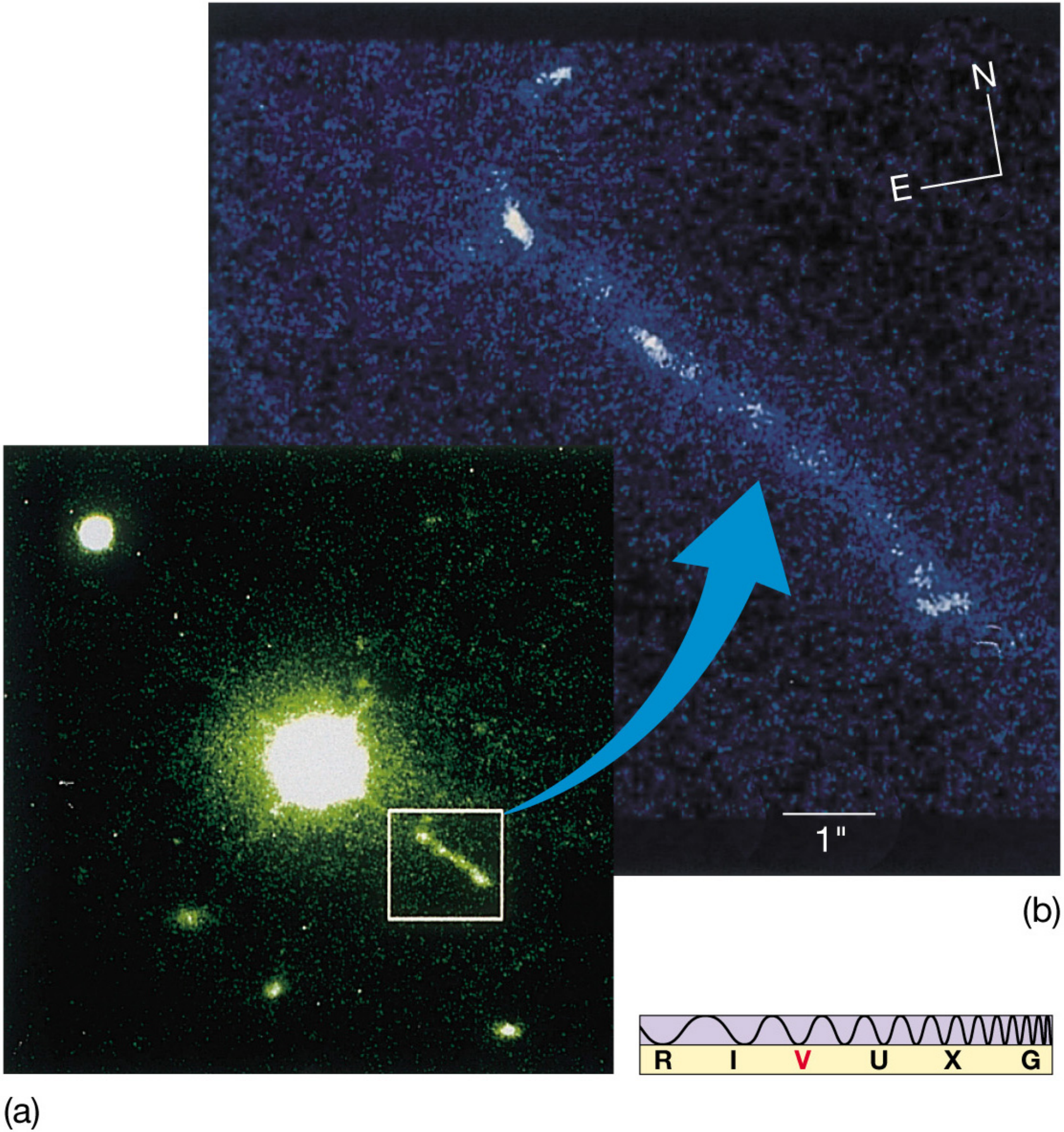


Quasars

Some active galaxies are strong radio sources.

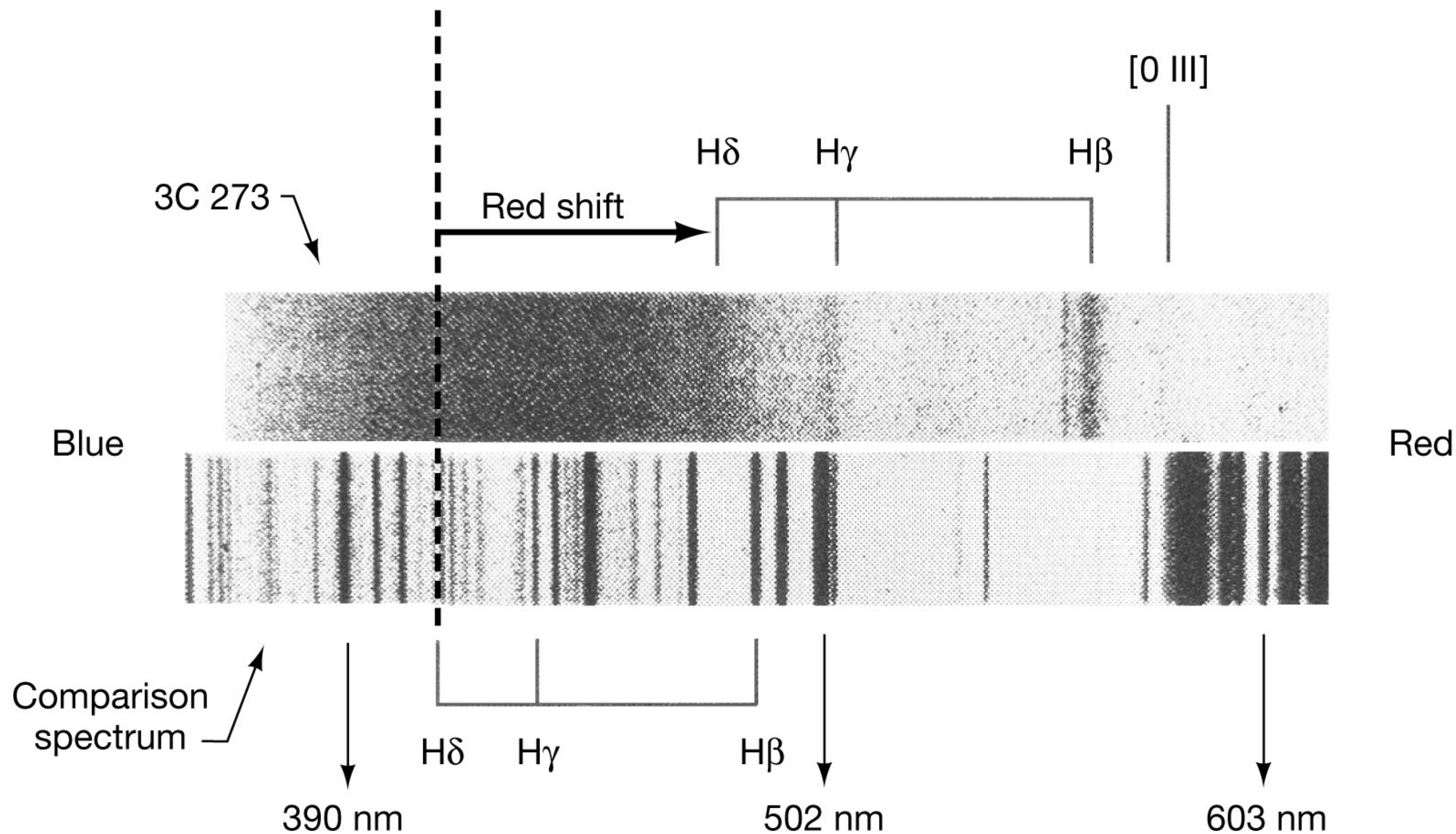
Several of the strongest radio sources seemed to be identified with funny-looking stars: They were called *quasi-stellar objects*, or quasars for short, because they looked like stars





Quasars can emit thousands of times more energy than normal galaxies.

For a long time, it wasn't clear how far away these quasars were until Maarten Schmidt finally identified the spectrum of one of the brightest as simply hydrogen redshifted by a velocity 15% of the speed of light! From Hubble's law, we can figure out how far away this is…



Marten Schmidt saw that the quasar is moving away from us at 15% of the speed of light or 48,000 km/s

Remember Hubble's Law: v = H x d

And H is 70 km/s/Mpc

So this gives: 48,000 = 70 x d or d = 642 Mpc away, or almost 2 billion light years away!

Finding the distance introduces a new problem: quasars must be among the most luminous objects in the universe, since they appear so bright and are so far away. What's the source of all that energy?

What powers active galaxies?

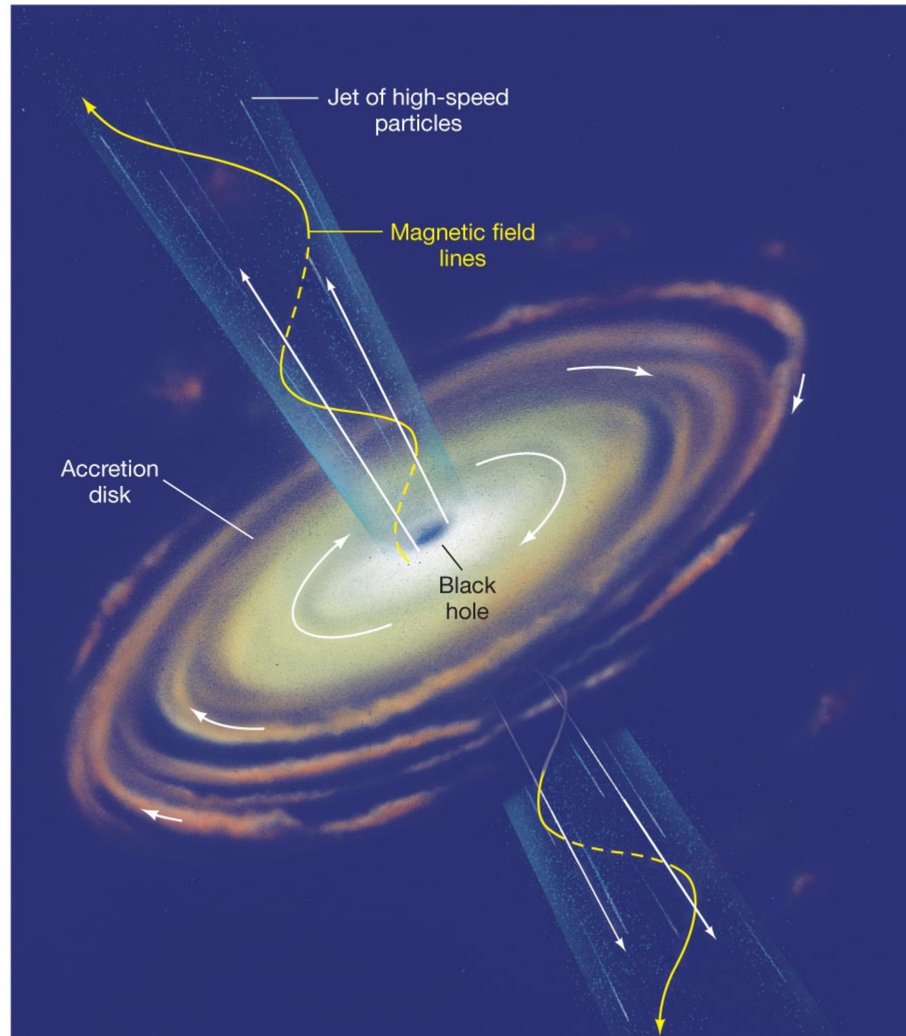
The power source for active galaxies must be phenomenal

- They are bright. They are typically brighter than normal galaxies by a factor of 10^6-10^8
- They are compact – they vary on short (1 week – years) timescales, so they can be at most 1 light-week to light-years in size
- Doppler shifts of spectral lines show evidence of motion with velocities of ~ 10,000 km/s: very fast!

The only power source that can explain all of this is a **supermassive black hole.**

The Central Engine of an Active Galaxy

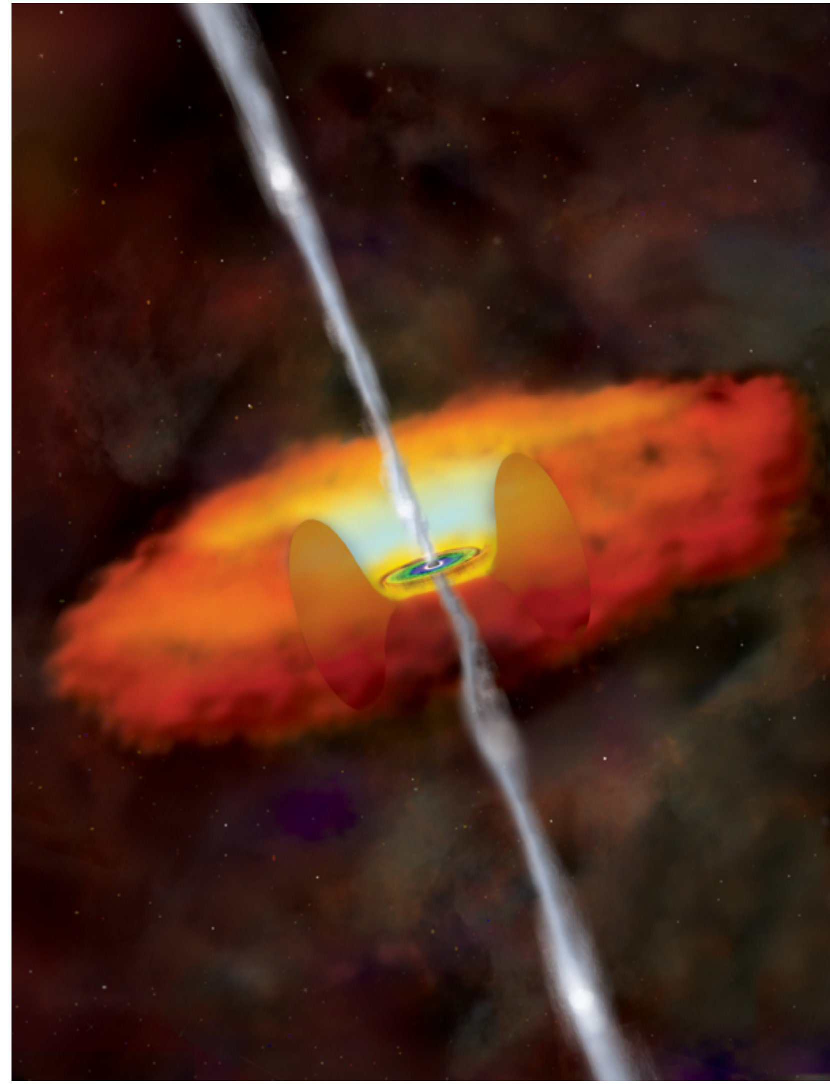
This is the leading theory for the energy source in an active galactic nucleus: a black hole, surrounded by an accretion disk. The strong magnetic field lines around the black hole channel particles into jets perpendicular to the magnetic axis.



The Central Engine of an Active Galaxy

In an active galaxy, the central black hole may be billions of solar masses.

The accretion disk consists of clouds of interstellar gas and dust. As the gas and dust spirals into the central black hole, friction heats the accretion disk to high temperatures. It may radiate away as much as 10–20 percent of its mass before disappearing.

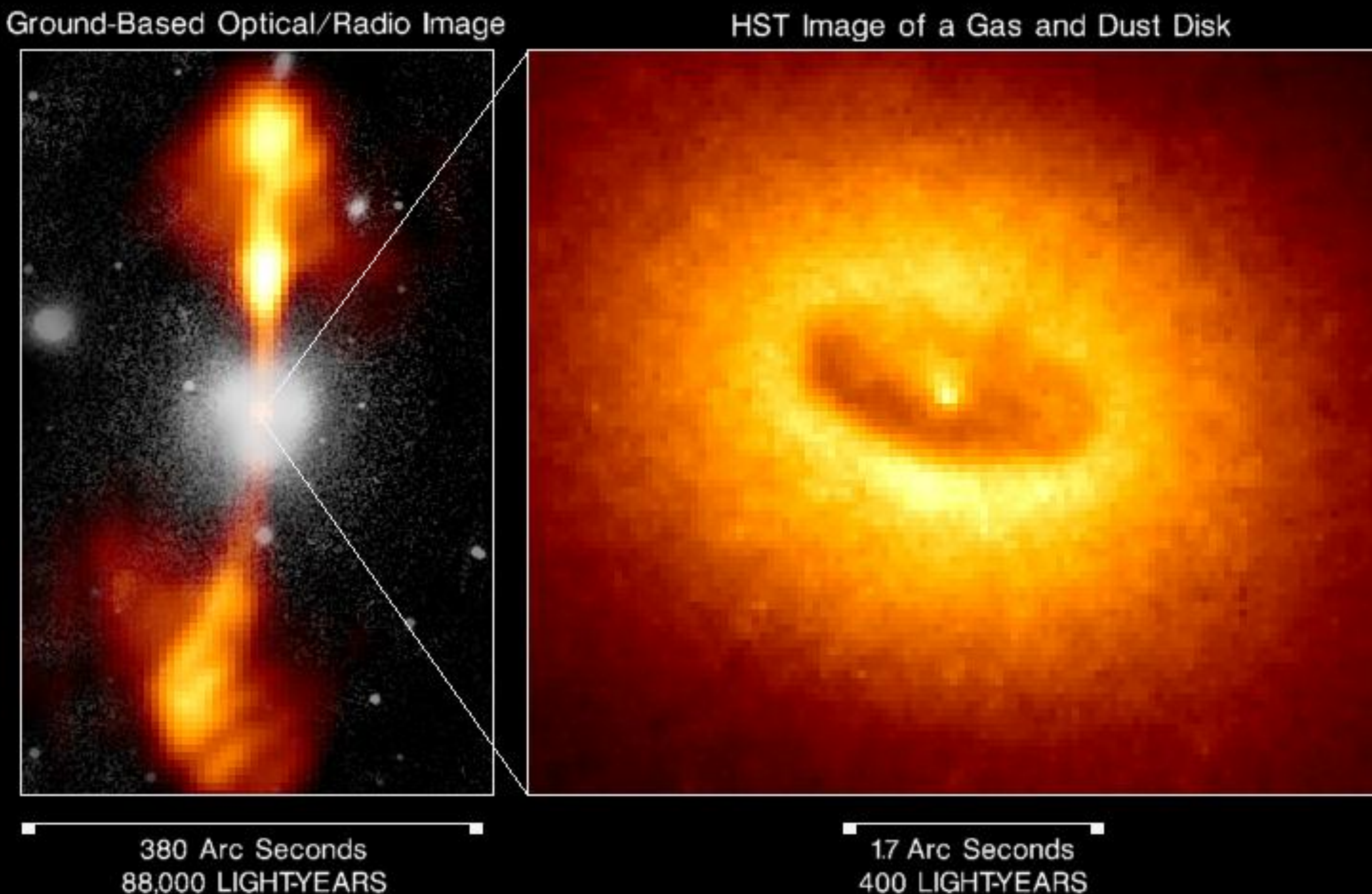


Artist's conception of an AGN

Core of Galaxy NGC 4261

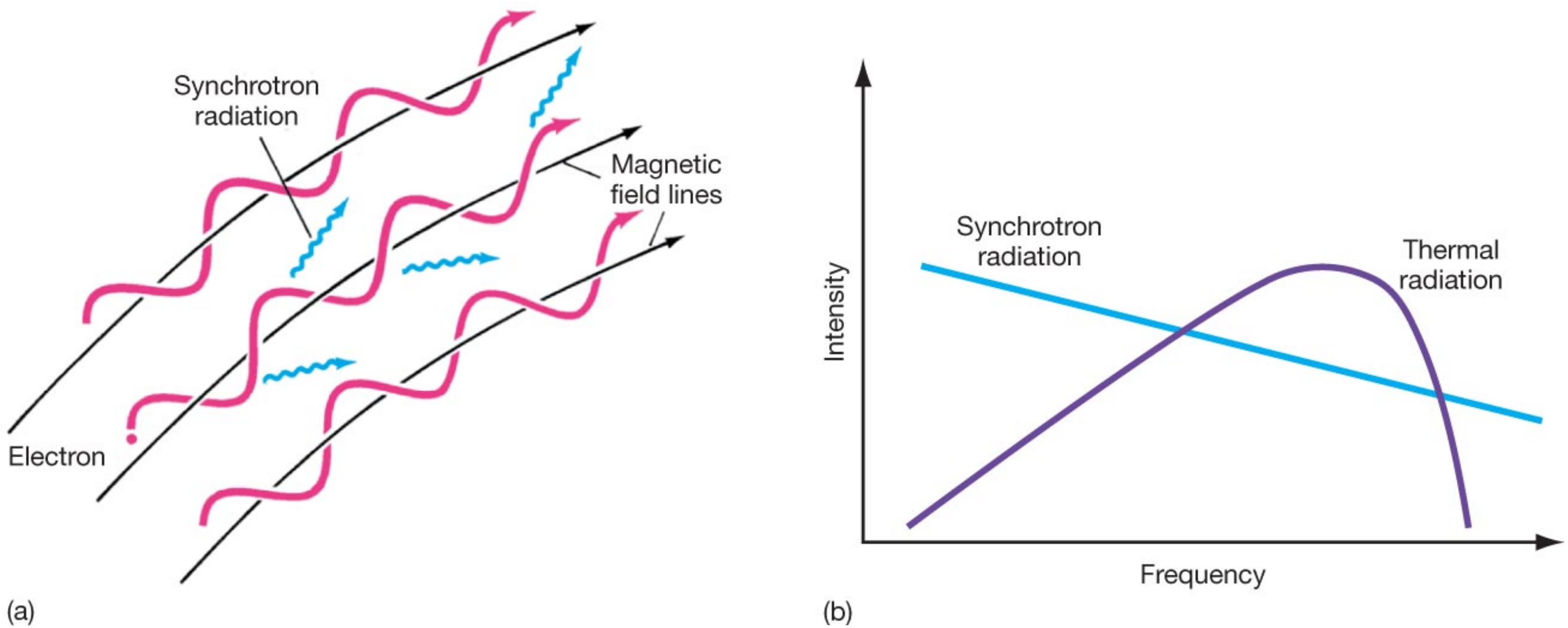
Hubble Space Telescope

Wide Field / Planetary Camera



The Central Engine of an Active Galaxy

Particles will emit synchrotron radiation as they spiral along the magnetic field lines; this is nonstellar radiation we see at radio wavelengths.

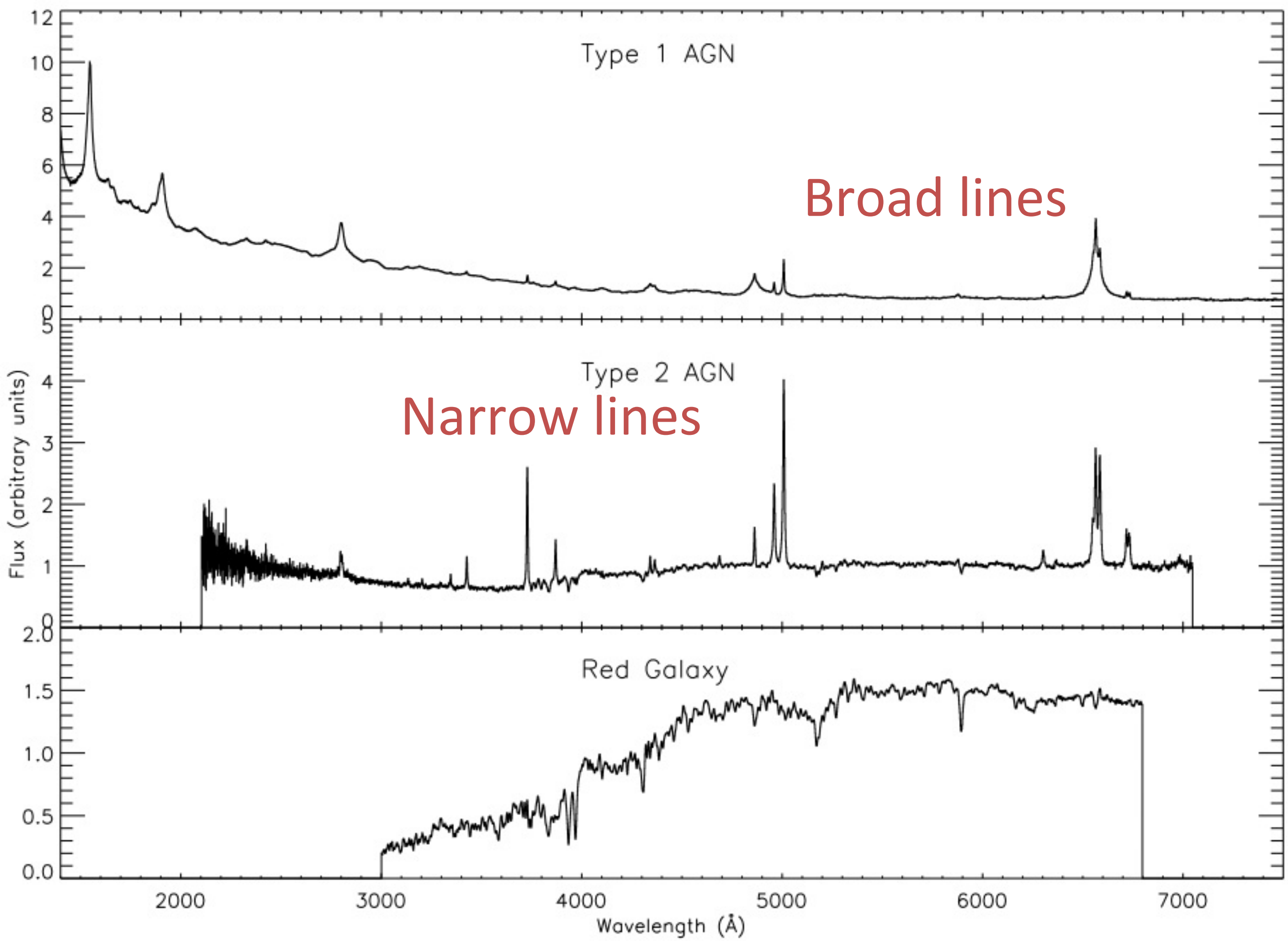


Why a Black Hole?

- Because these active galaxies can be extremely luminous, they must have an extremely efficient power source
- Black holes can convert about 10% of mass into energy ($E=mc^2$). Compare this to hydrogen fusion, which converts 0.7%
- They are also compact. Most of the energy is emitted close to the black hole, where the size is a few light-seconds to 1 light minute across
- Stuff orbits around a black hole very fast – explains why we see evidence for rapid motion

Spectra of Active Galaxies

Active galaxies show two components to their spectra: a narrow component and a broad component.

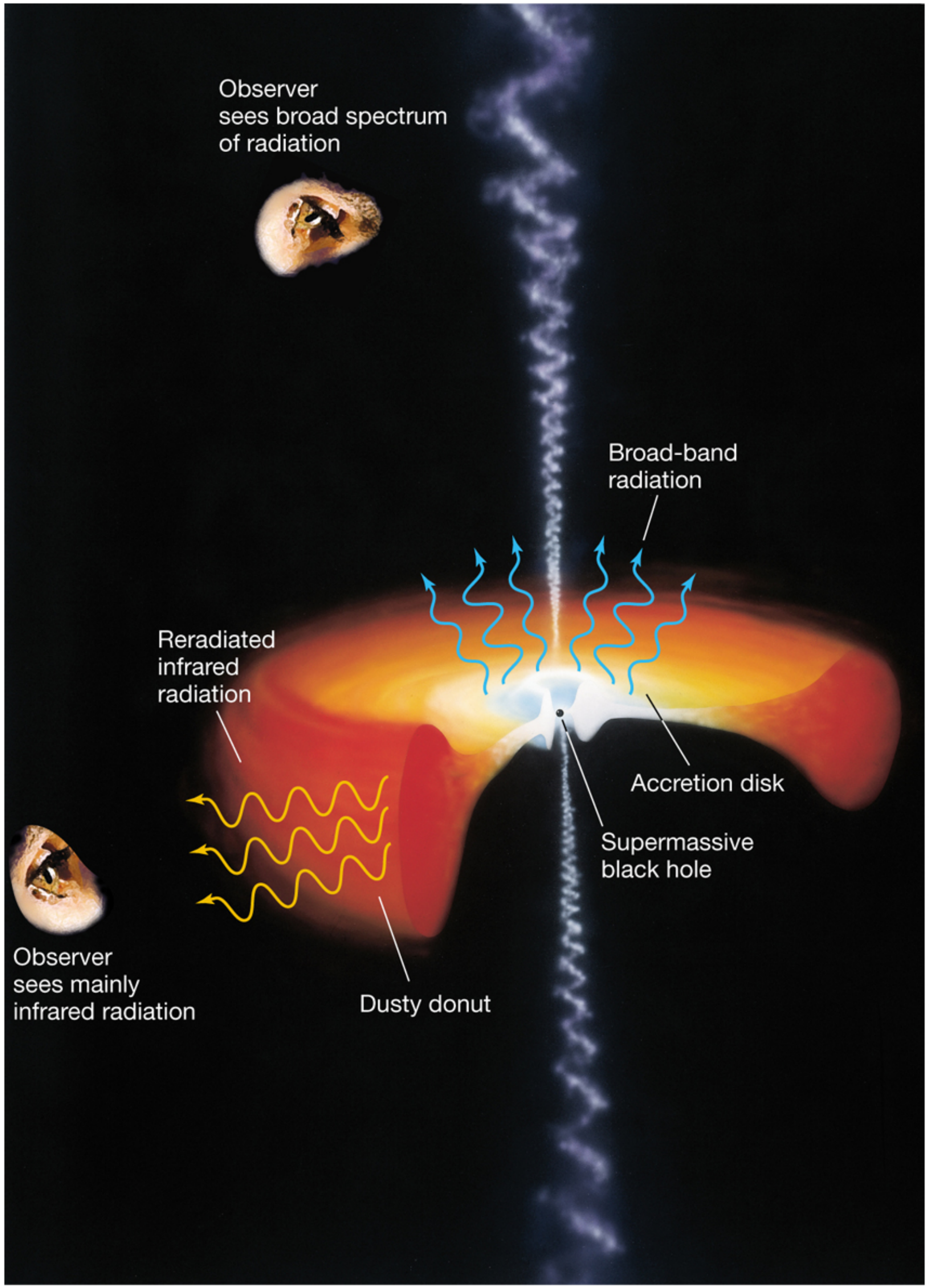


Doppler shifts of the broad component show high velocities – this is why the lines are broad.

But not all active galaxies have broad lines: we don't always see evidence for fast motion.

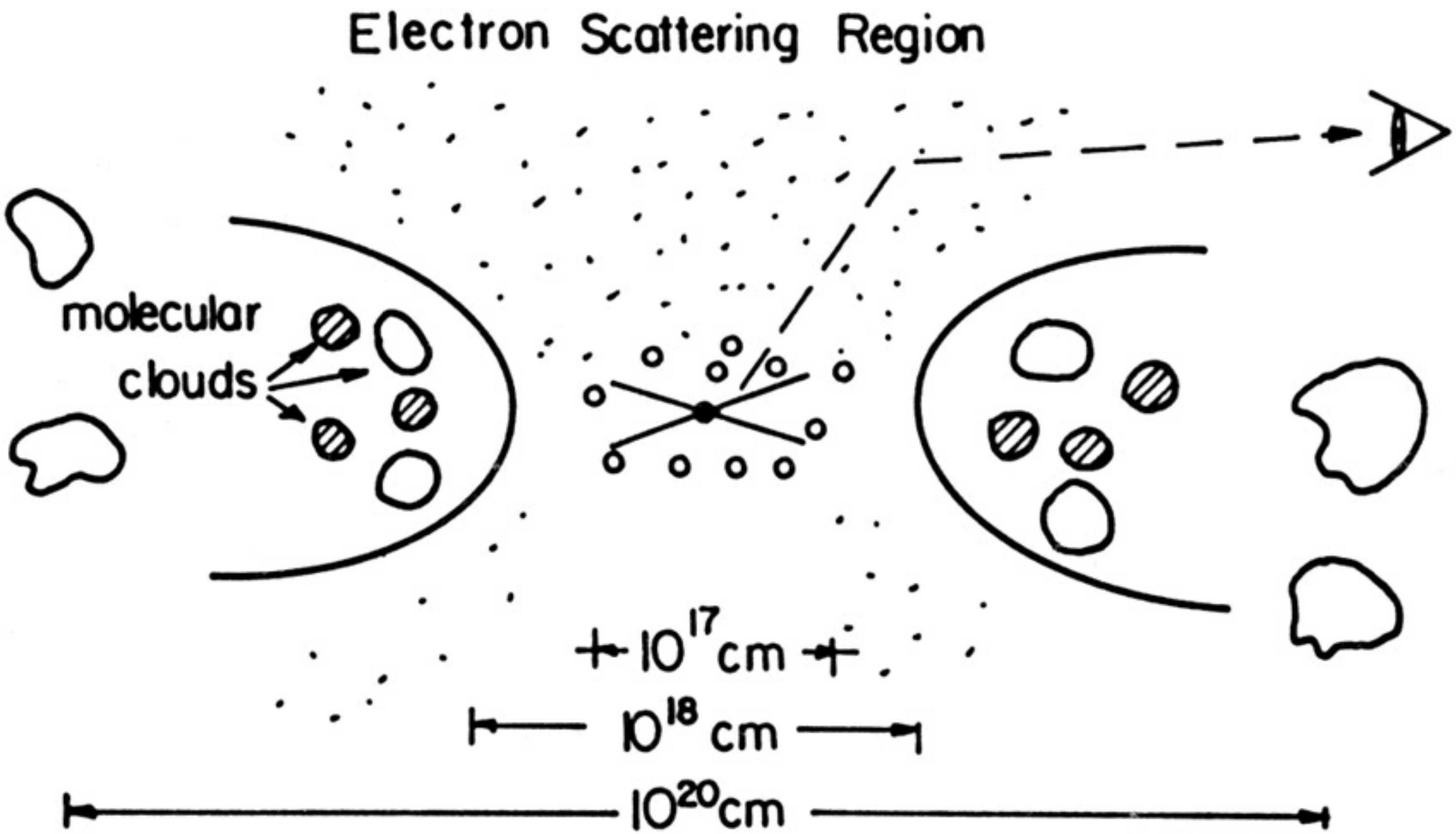
To explain this, astronomers think there is a dusty torus (a donut-shaped ring) that surrounds the black hole.

Only from certain angles can we see the central accretion disk. Otherwise we only see the narrow lines.



The Dusty Donut

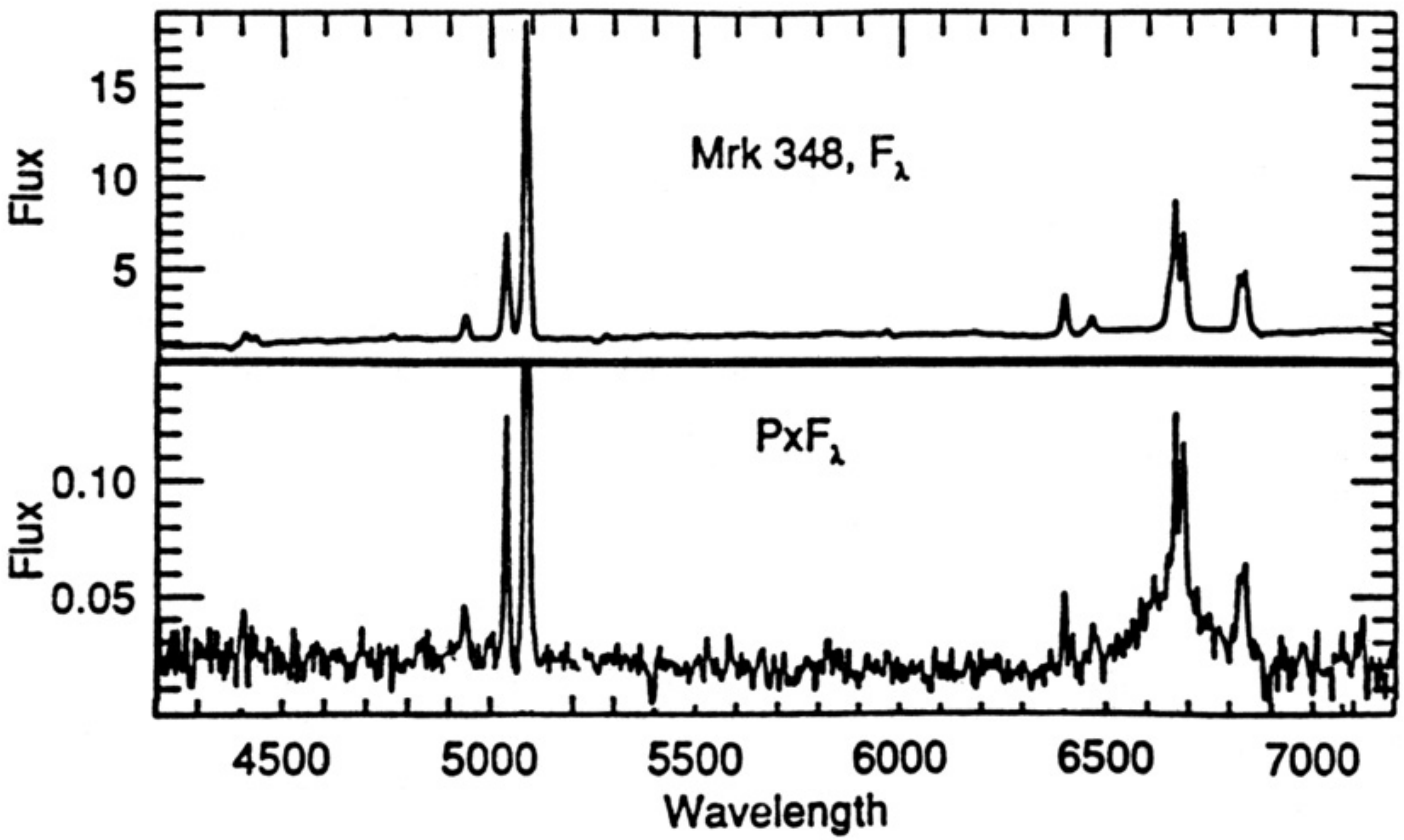
- There is some evidence that this model is correct. If we can look at the same galaxy from multiple angles, we can test this idea.
- We can do this if we look at the scattered light.

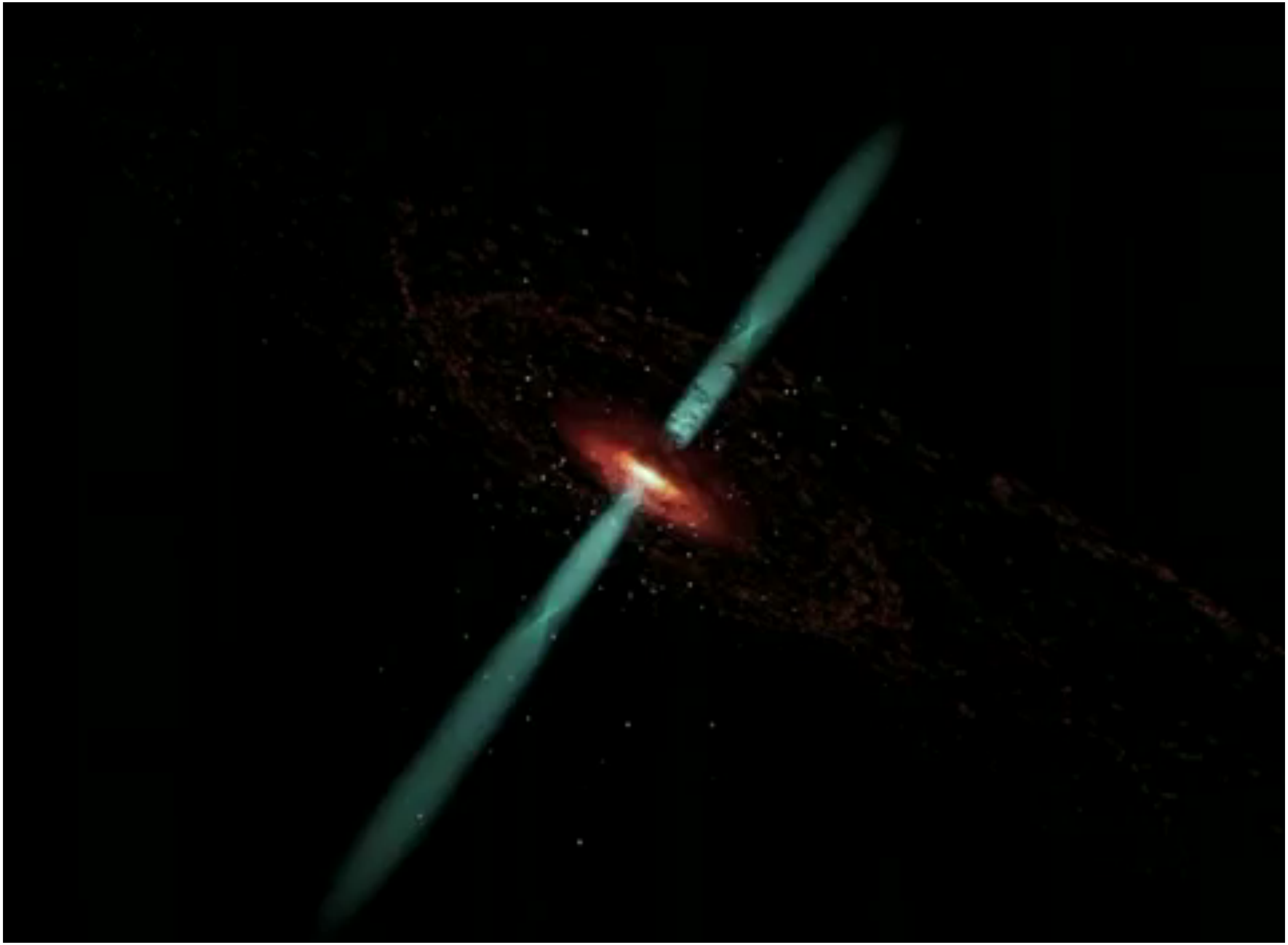


Light from the central accretion disk is blocked by the torus, but some of it is scattered in our direction.

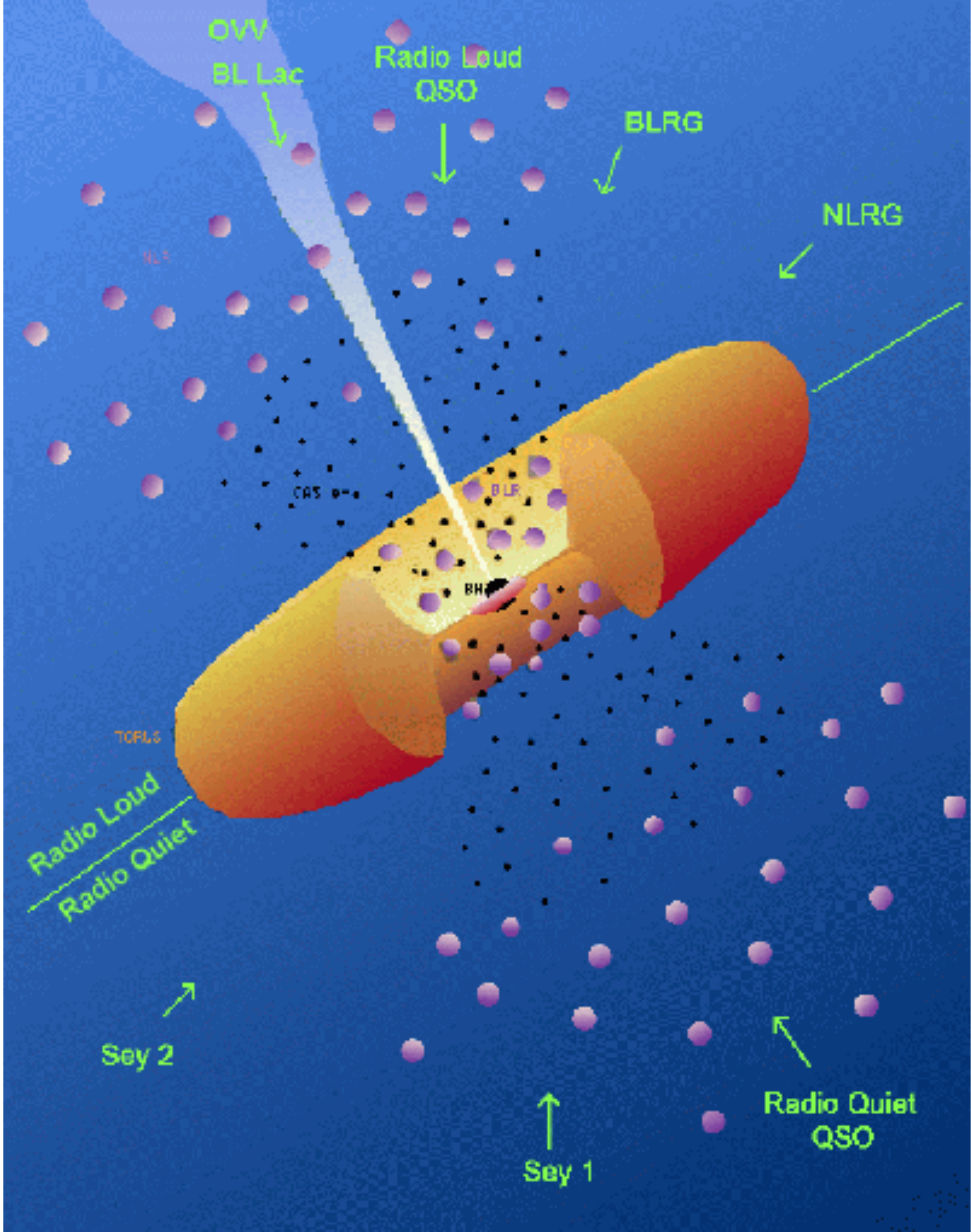
The Dusty Donut

In this system, Mrk 348, we can look for the scattered light and see that it has broad lines. So this broad line is completely scattered light – coming from the central accretion disk!

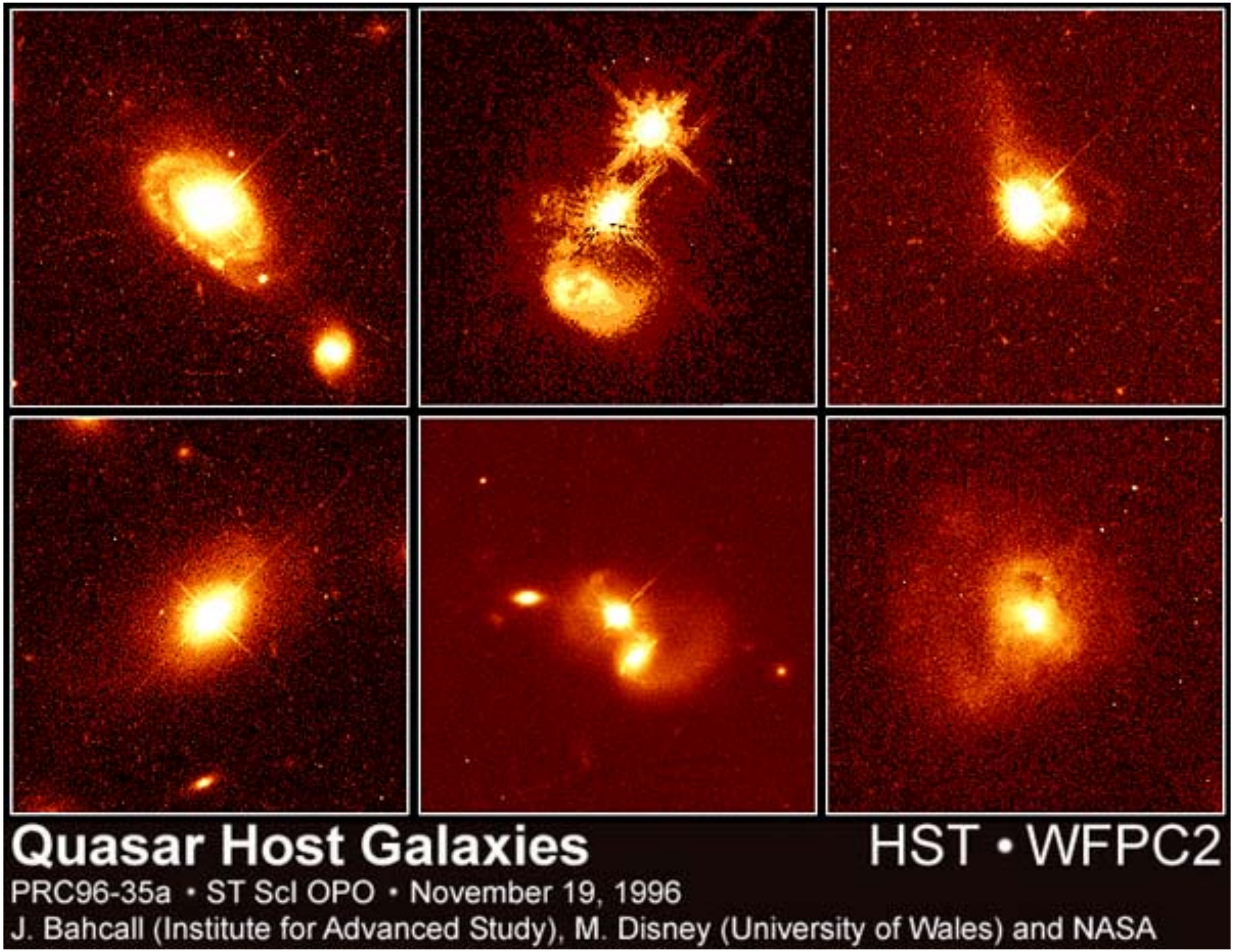




So… active galaxies are all basically the same beast, but they appear different because they are viewed from different angles!

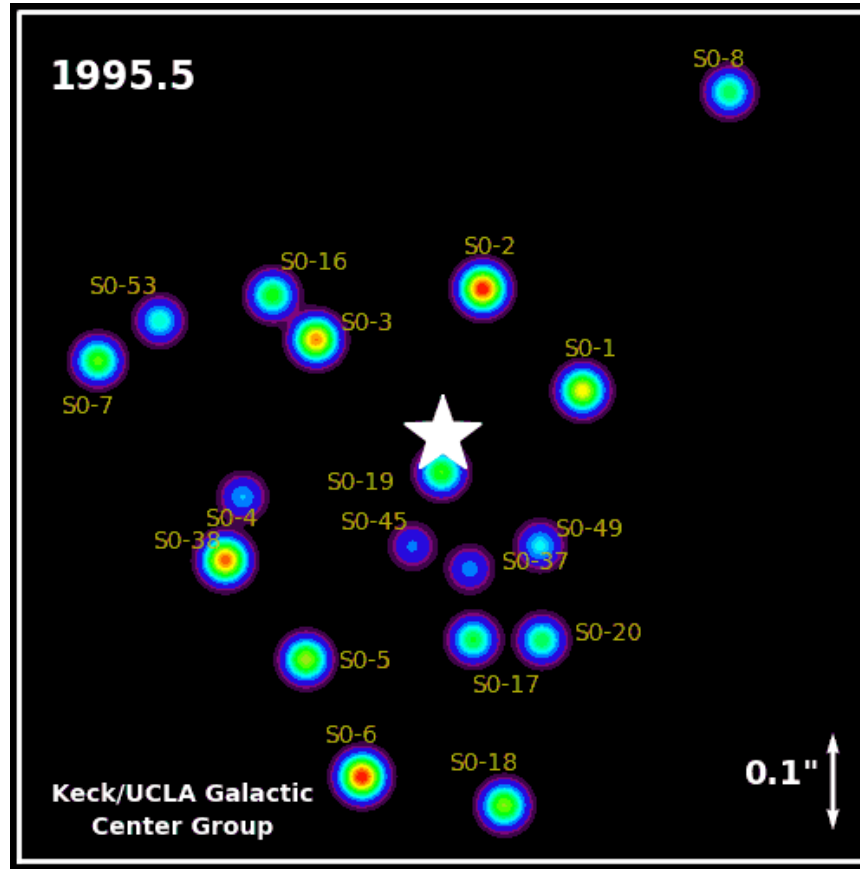


We can now image the host galaxies of quasars with the Hubble Space Telescope.



What about black holes in regular galaxies?

- We think most moderately large galaxies, including the Milky Way, have supermassive black holes at their centers
- So why aren't most galaxies active galaxies?
- They aren't accreting as much stuff onto their black holes
- Many of them were probably more active in the past



Orbits of stars at the center of the Milky Way indicate the presence of a supermassive black hole.

Quasars are called “quasi-stellar” because

A — they generate energy partly through H to He fusion like stars

B — they show spectra similar to extremely bright O stars

C — in short exposures photographs, their images appear stellar

D — they are dense concentrations of millions of stars

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Galaxies and Active Galaxies: Summary

- The Hubble sequence organizes galaxies according to their shapes
- Galaxy types include spiral, barred spiral, elliptical, and irregular
- Objects of relatively uniform luminosities are called "standard candles"; examples include Cepheid variable stars and Type I supernovae. We use them to find distances to other galaxies.
- The Milky Way lies within a small cluster of galaxies called the Local Group
- Other galaxy clusters may contain thousands of galaxies

Galaxies and Active Galaxies: Summary

- Hubble's law: Galaxies are receding from us, and the farther away they are the faster they recede
- Active galaxies are far more luminous than normal galaxies, and their radiation is nonstellar
- Seyfert galaxies, radio galaxies, and quasars all have very small cores; many emit high-speed jets.
- Active galaxies are thought to contain supermassive black holes in their centers; infalling matter is converted to energy, powering the galaxy
- Most normal galaxies probably contain black holes, but they aren't accreting enough gas to be brighter than the stars in the galaxy

Astronomy 103

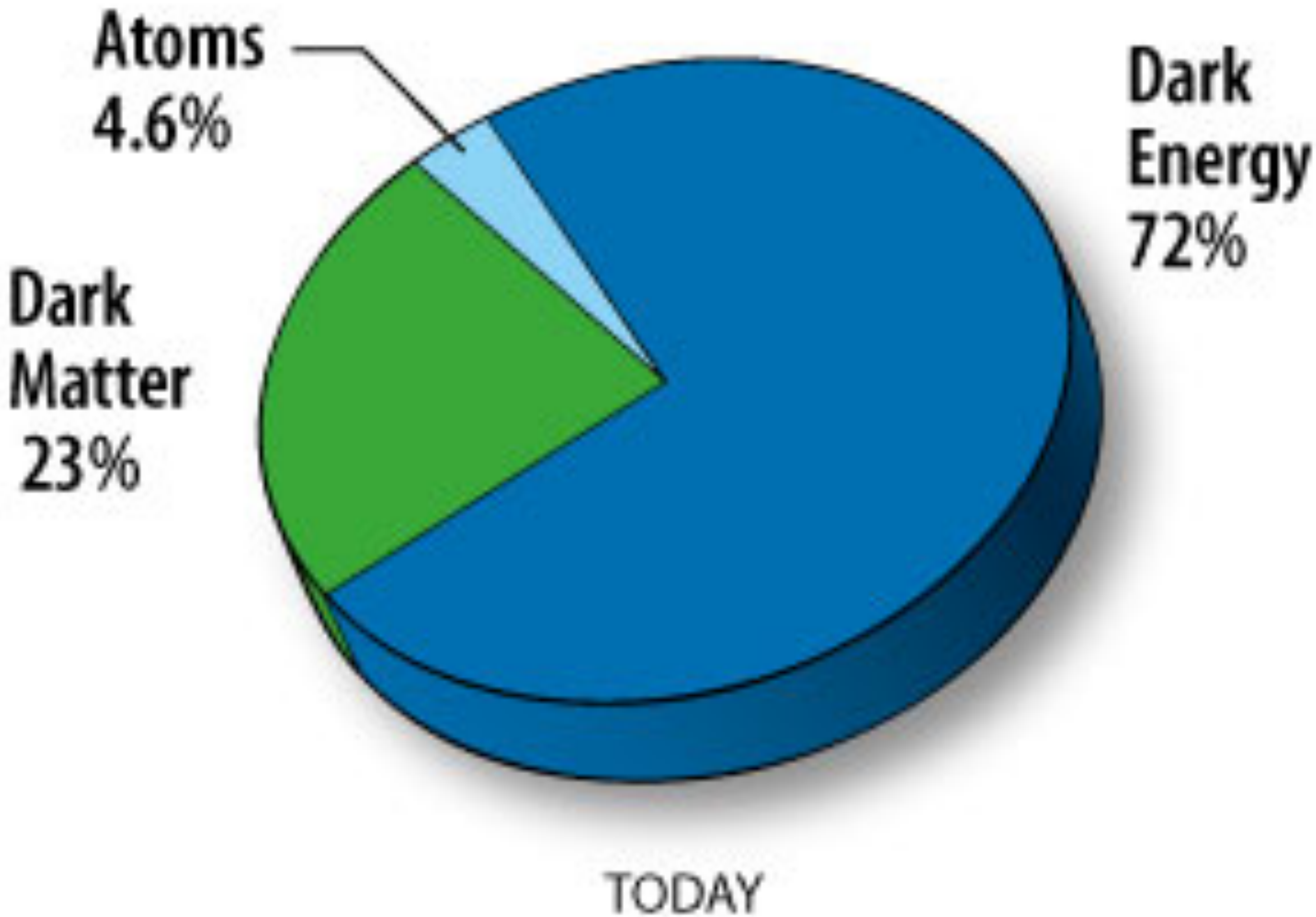
Galaxies and Dark Matter

Please read chapter 16

The Makeup of the Universe

- Up to now, we have talked about stars, planets, galaxies, black holes . . . .
- But this makes up about 1-2% of the universe.
- The stuff that shines doesn't even contain most of the atoms in the universe – most of the atoms are still gas.

The Makeup of the Universe



In fact about 95% of the universe is invisible!
And 23% of it is **dark matter**.

Dark matter

- We don't know what dark matter is – unlike anything else we experience.
- Ordinary matter interacts with other ordinary matter and with light.
- Dark matter doesn't – only interaction is through gravity.

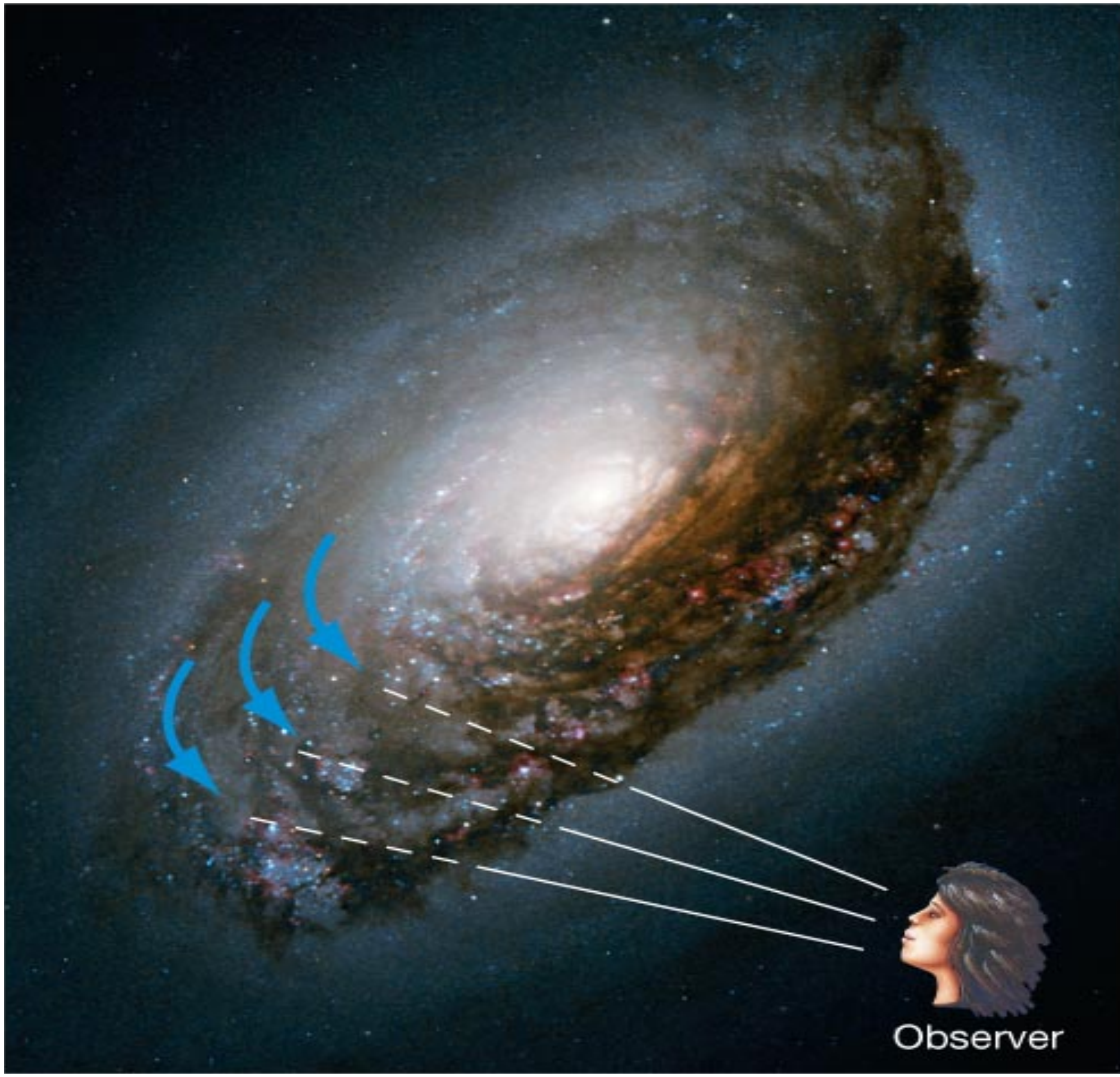
Dark matter

- Right now, dark matter can only be observed via its gravity.

- So we have to look at its effect on the biggest objects in the universe – galaxies and galaxy clusters.

Rotation Curves of Galaxies

- We can measure the mass of a galaxy by looking at how fast gas and stars rotate around it
- By looking at the Doppler shift of stars and gas, we can tell how fast they are moving toward us at different points in a galaxy



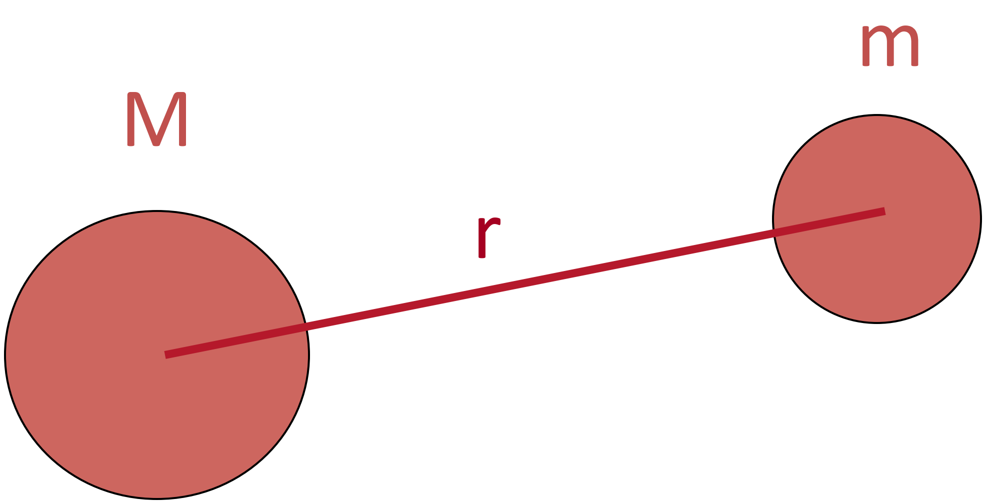
Newton's law of gravity: Any two objects in the universe attract each other with a force given by

$$F = G\frac{Mm}{r^2},$$

With
r in meters
m in kg

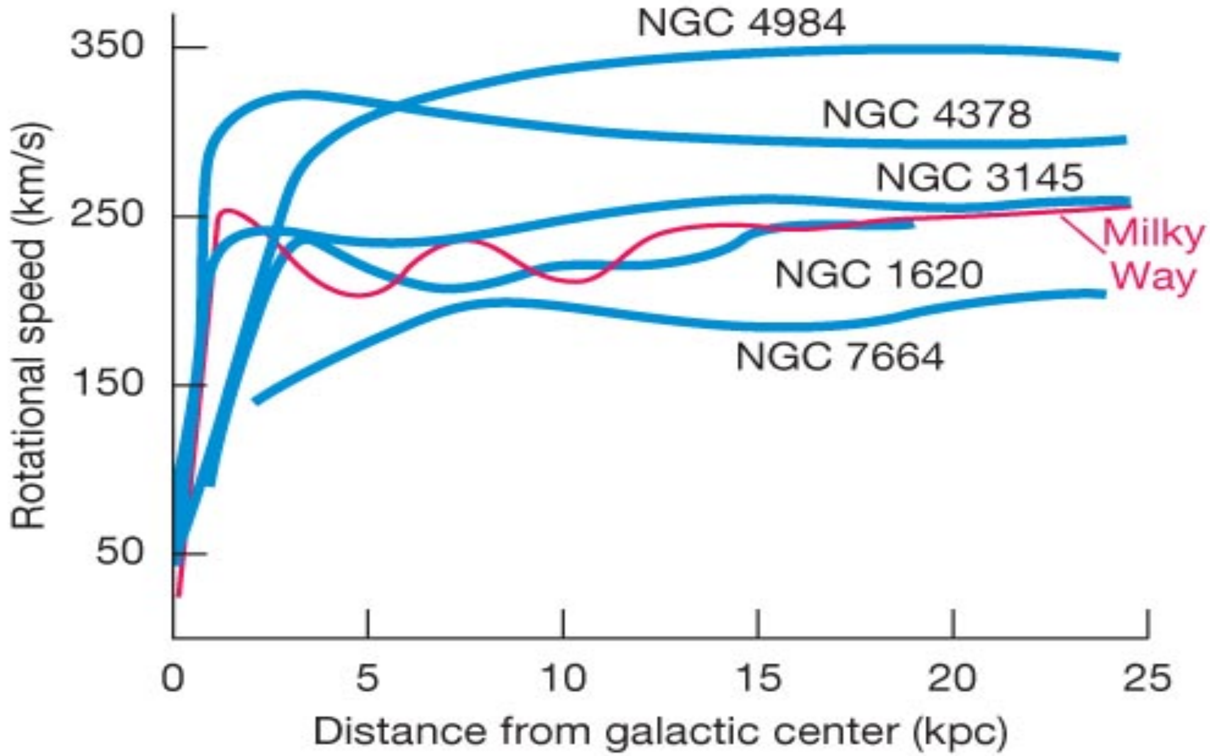
F in Newtons,where
1 Newton = 4.5 lb

$G = 7x10^{-11}$



Rotation Curves of Galaxies

- What we find is that as we move away from the center of a galaxy, the rotational speed tends to flatten to a constant speed
- This means that **the mass of the galaxy continues to increase even in areas where there are very few stars**



(b)

Rotation Curves of Galaxies

- Here is one example. There is apparently more mass beyond the outer regions of this spiral galaxy that there is in the inner parts we can actually see
- So there is some hidden matter or "dark" matter that is adding to the gravity of the galaxy

Galaxy clusters

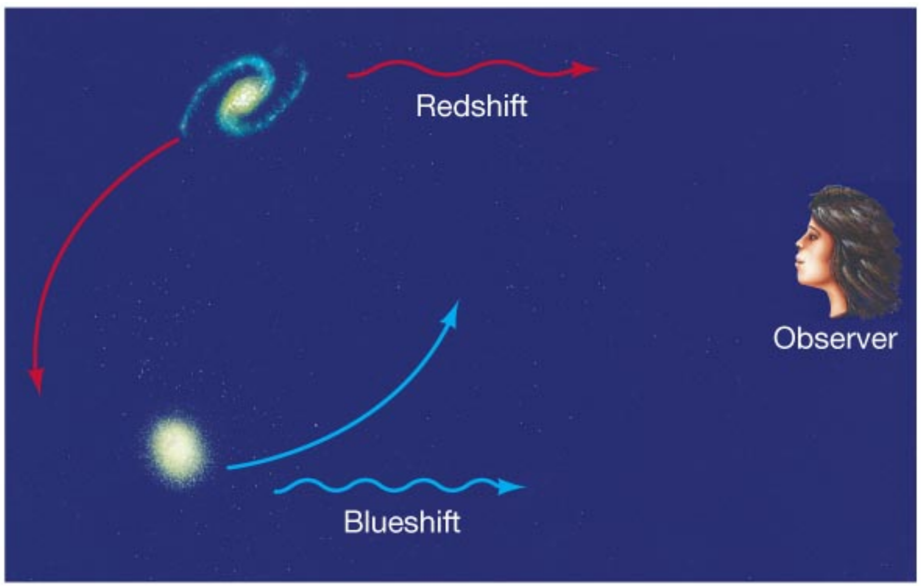
- We can also use individual galaxies and their orbitals speeds to infer the masses of galaxy clusters – the most massive gravitationally bound structures in the universe

- Large galaxy clusters contain thousands of galaxies, many of them as big or bigger than the Milky Way

The **Virgo Cluster**: closest large cluster

Galaxy clusters

- By looking at the redshifts and blueshifts of many galaxies in the cluster, we can figure out how fast they are moving on average



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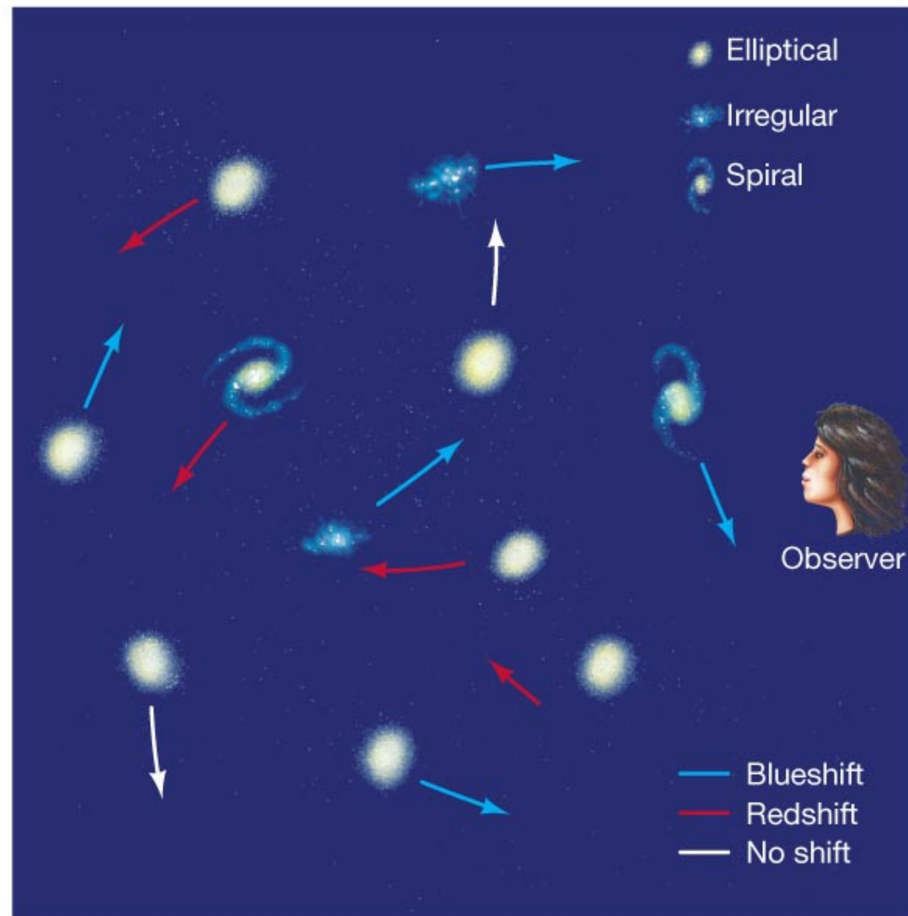
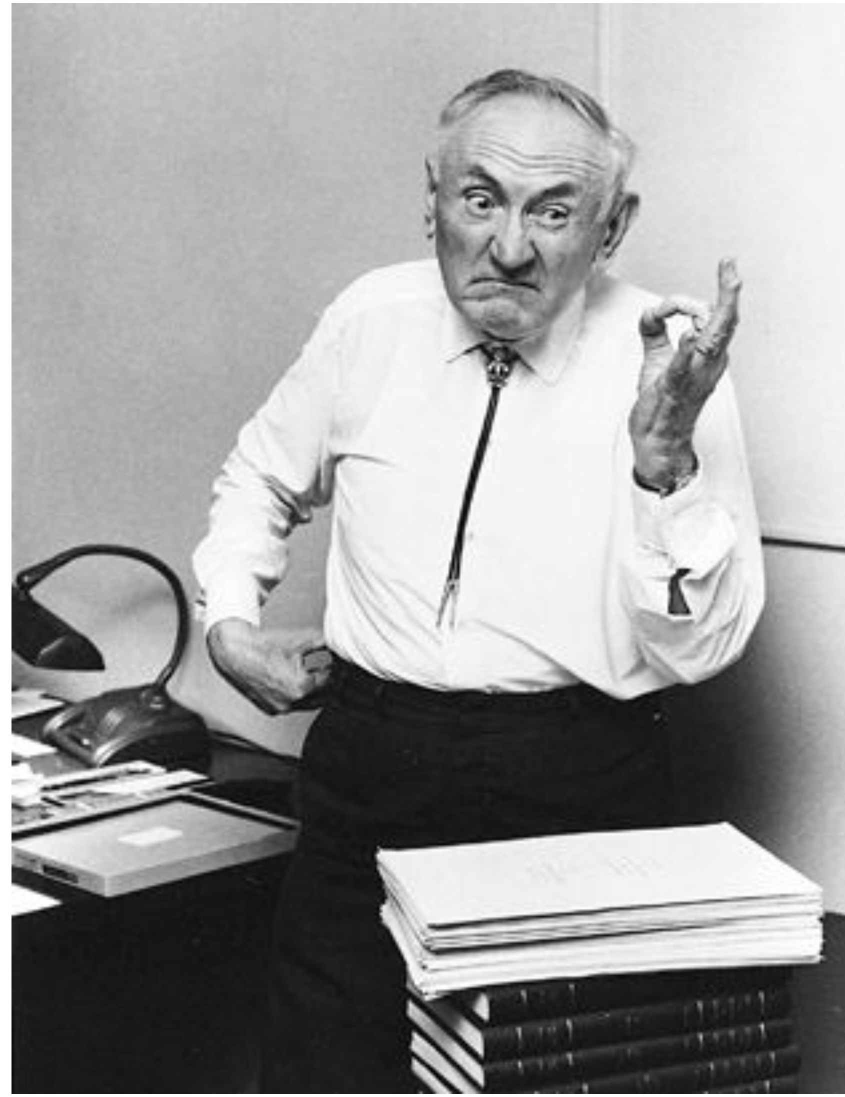


Galaxy clusters

One of the first people to do this was **Fritz Zwicky** – you may remember him as one of the two astronomers who predicted the existence of neutron stars shortly after the discovery of the neutron and 30 years before they were observed



Galaxy clusters

Zwicky looked at the Coma Cluster, the next closest large cluster of galaxies after the Virgo Cluster

Galaxy clusters

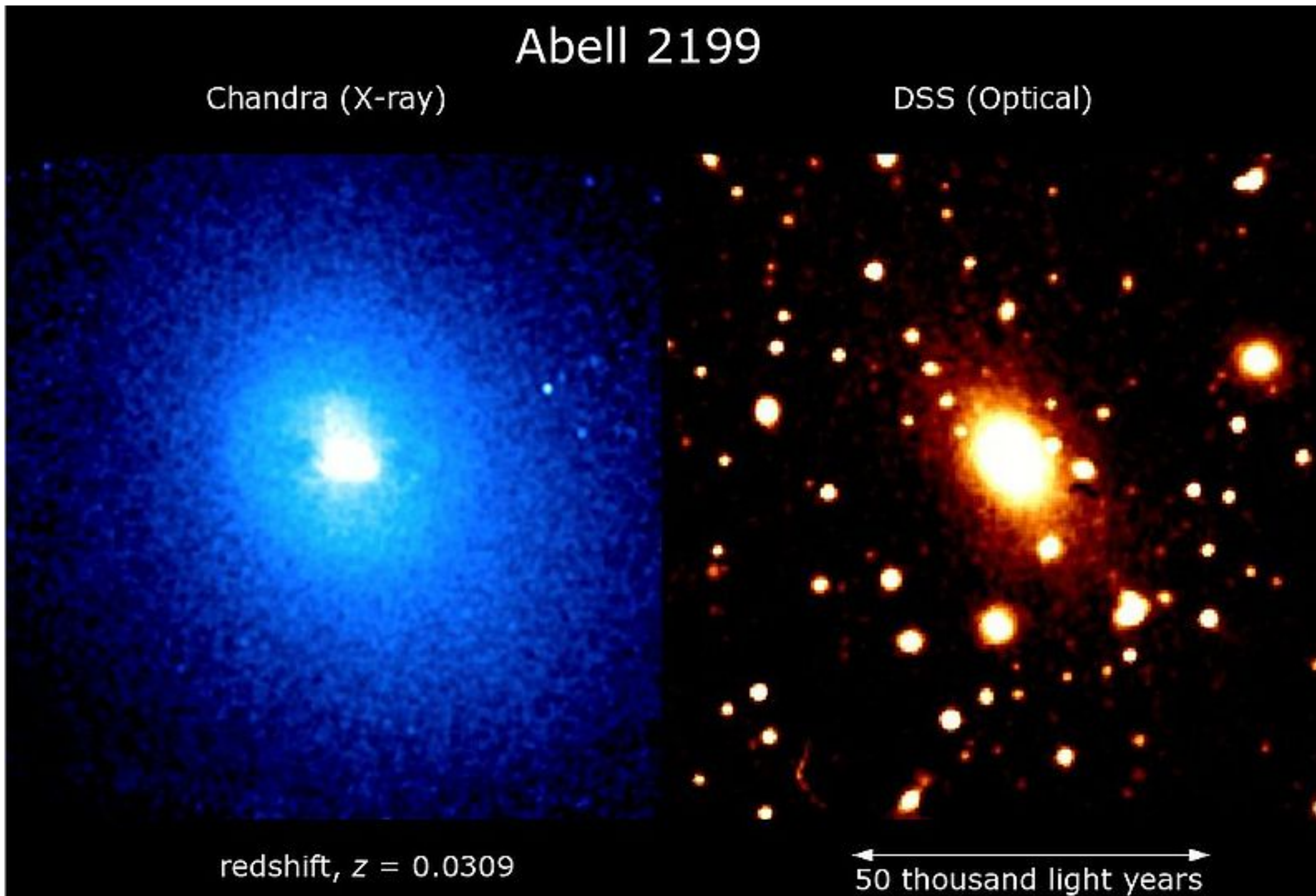
He used the speeds of the galaxies to calculate the mass of the cluster, and found that it was 100 times larger than the mass of all the visible galaxies.

Galaxy clusters

As we have discussed, most of the ordinary matter is not in galaxies in galaxy clusters. Rather it is in gas – **intracluster gas** – which is extremely hot (up to $4x10^7$ K)

But this is not enough.

There is still more matter than the intracluster gas can account for.



Dark Matter

- So the combination of all these measurements means that there is a lot more *gravitating* mass than visible mass in the universe.
  - Flat rotation curve of galaxies
  - Orbital speed of galaxies in clusters
  - Gravitational lensing (more on this later)

- This matter is known collectively as **dark matter**.

- It is generally though to be a particle that doesn't interact with ordinary matter, but even this is not known – could be several particles.

Dark Matter

- Galaxies and galaxy clusters sit in the middle of a collection of dark matter known as a dark matter halo

- The dark matter halo extends for a distance at least 10x bigger than the galaxy