Distance

What's the best distance indicator for:

1) A Local Group Galaxy?
2) A Globular Cluster?
3) A distant galaxy

A) Geometric Parallax
B) Spectroscopic Parallax
C) Cepheid Variables
D) Super Nova

Overview

A. The Great Debate
  1. What was the debate about?
  2. Who settled it and how?
  3. What ELSE did Edwin find?
  4. What is the implication of his discovery?

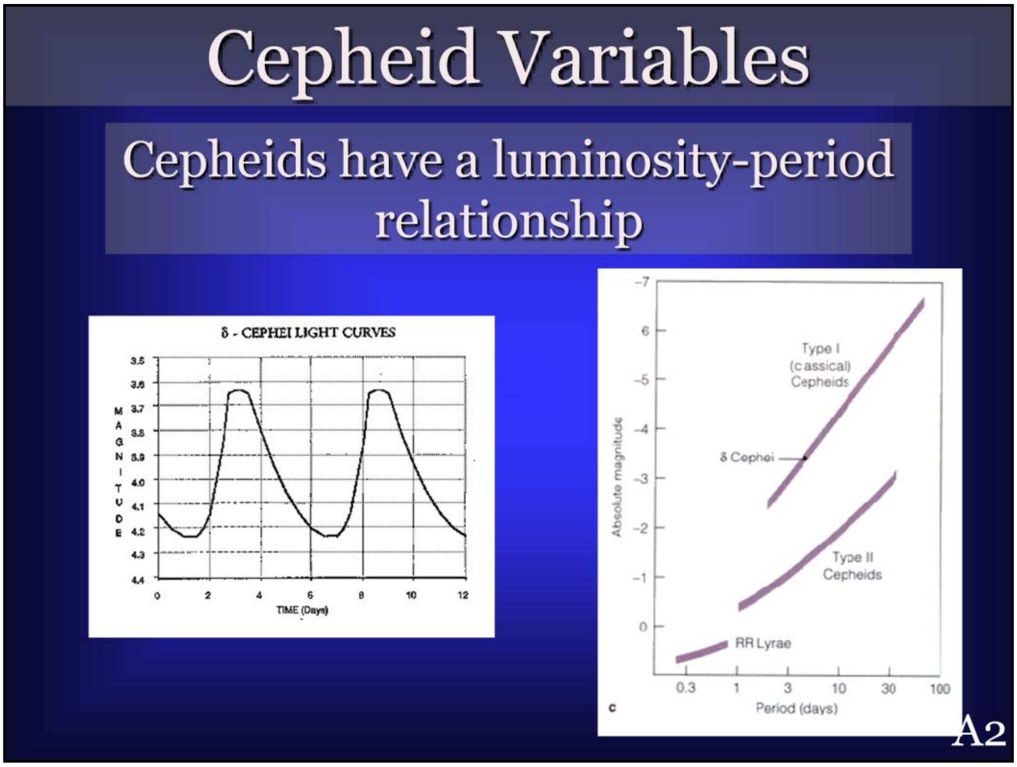
B. Galaxies
  1. What are the primary galaxy types?
  2. What characterizes an Elliptical galaxy?
  3. What characterizes the spiral galaxies?
  4. What about irregulars?
  5. What are groups and clusters?

Overview

C. Galaxy Evolution
1. How do we study galaxy evolution?
2. What are the primary formation scenarios?
3. What evidence do we have for each?

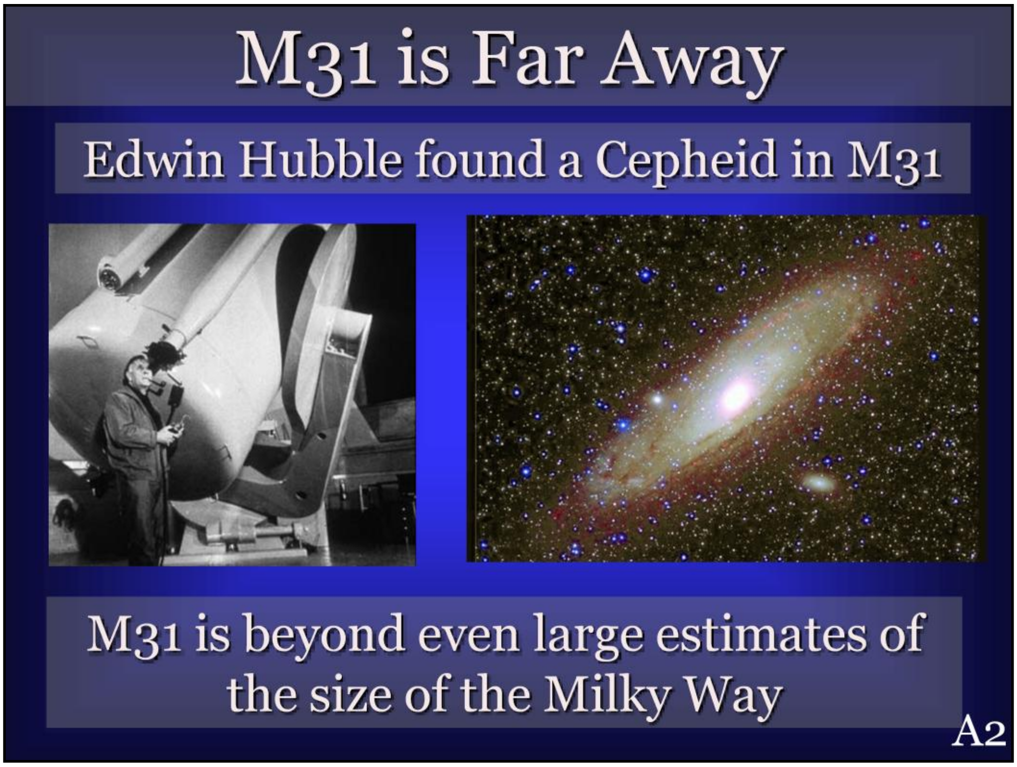
Shapley said that the Milky way is very large. In fact the entire universe is taken up by the Milky Way and the 'spiral nebula' are nearby gas clouds within the Milky Way.

Curtis said that the Milky Way is smallish and the Sun is nearly in the center (40,000 ly across). The 'spiral nebula' are other galaxies like the Milky Way.



Measure the period, look up the luminosity, calculate the distance.

Cepheids are bright enough to see in other galaxies.

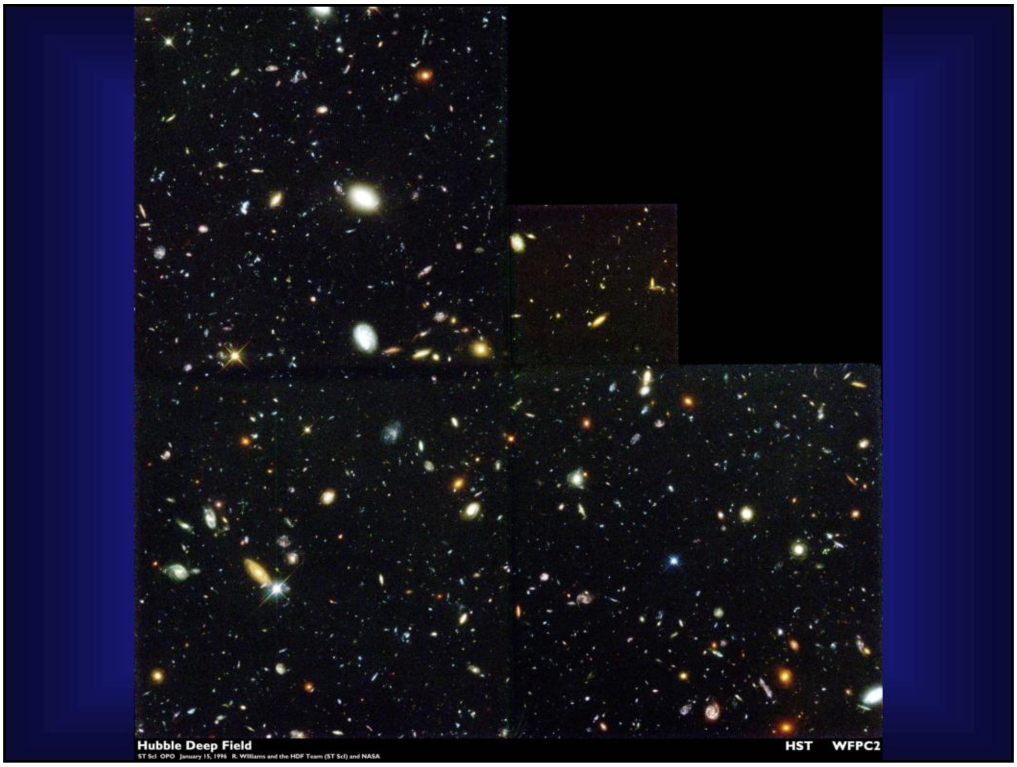


Edwin Hubble (who has a famous telescope named after him) found a Cepheid in M31.

Turns out that M31 is 2.9 million light years away. This really blew their minds.

But… Shapley was right about the overall size of the Milky Way. It's much larger than Kapteyn and Curtis thought.

It turns out that the Universe is a lot larger than anyone thought.



This is the Hubble Deep Field.

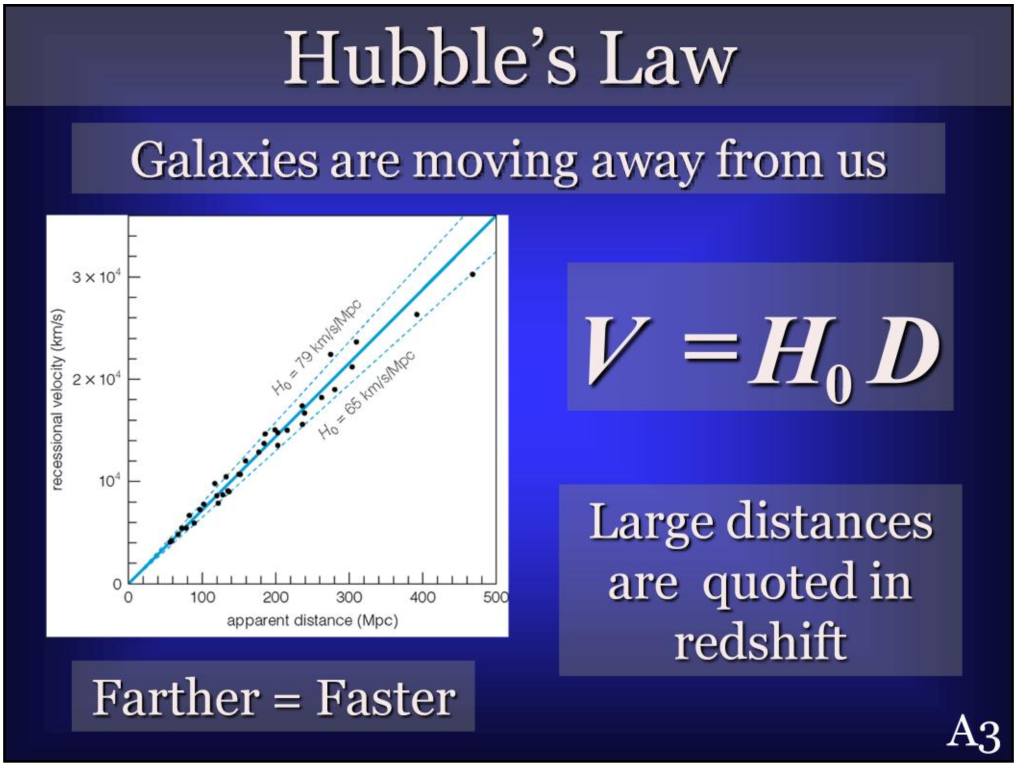
This is a 10 day exposure with HST of 1 ten millionth of the sky.

Within the picture are 10,000 discrete objects.

Many are very small, 10^5 to 10^7 solar masses. (the Milky Way is 10^{12} solar masses)

Many of them are ¾ of the way to the observable edge of the Universe.

If we expand this view to the entire sky, we would find that the observable universe contains over 80 billion galaxies.



Hubble, after his success with M31, was measuring distances to a whole bunch of galaxies.

He noticed something peculiar. The more distant a galaxy is, the more it is red shifted.

In fact, there is a linear relationship between velocity and distance.

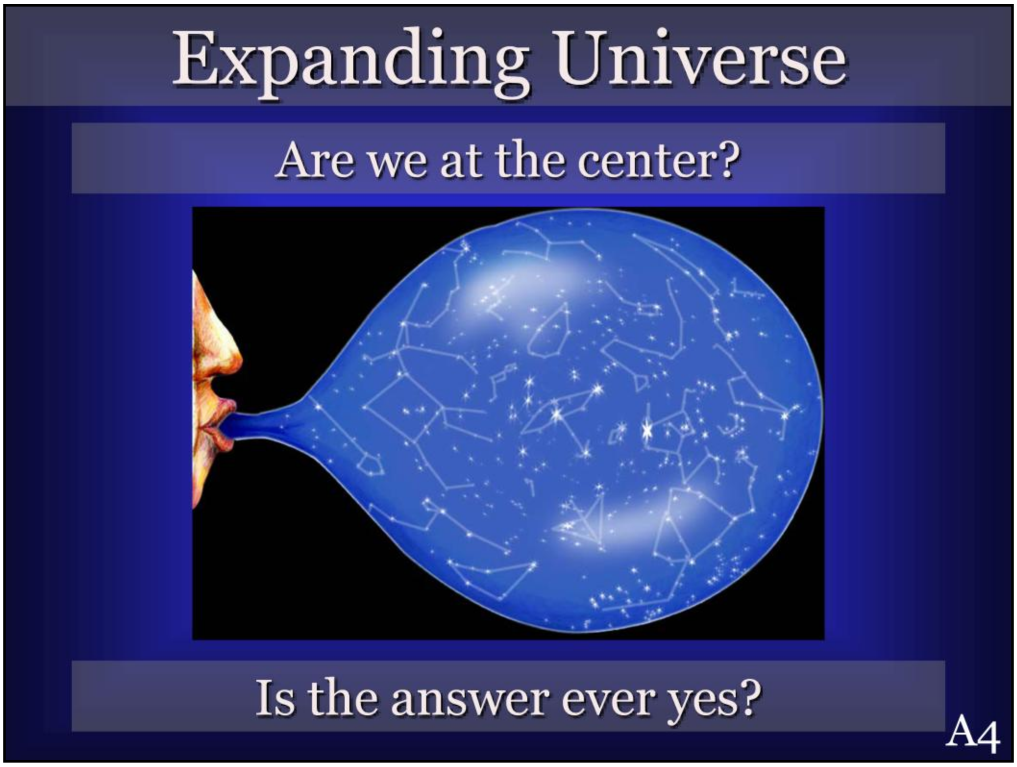
The slope of the line is H_0. We'll discuss the significance of H in the next lecture.

We measure velocity by measuring doppler shift.

Since all distant galaxies appear to be moving away from us, all distant galaxies are red shifted.

More distant objects have a greater redshift, so you will often hear distances quoted as redshifts.

H0 (pronounced H not) is measured in km per second pre Mpc. (kilometers per second per mega parsec) mega = million



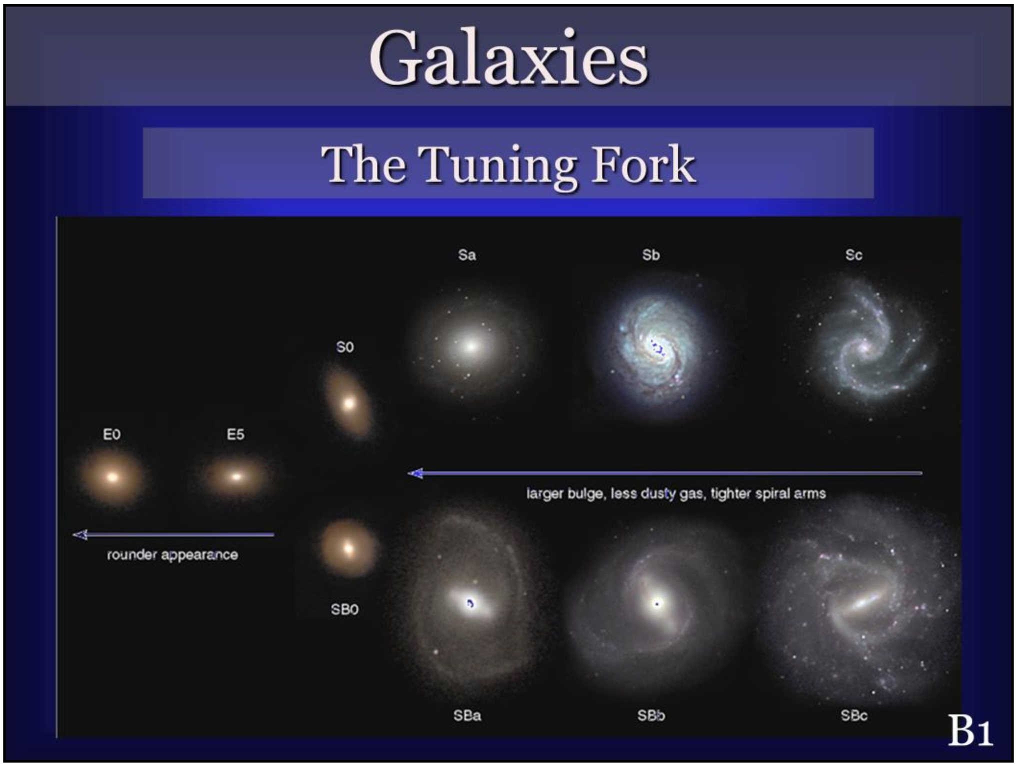
Although everything appears to be moving away from us, and the farther away it is, the faster its moving…

We are NOT at the center.

Everything is moving away from everything else. The space between all galaxies is getting larger.

For nearby galaxies, like those in the local group such as M31, the peculiar velocity dominates.

Hubble flow dominates at large distances. Like halfway across the observable universe.



The galaxy classification scheme was developed by Edwin Hubble in the 1920's

Elliptical galaxies are … well … elliptical.

The E0 types are more spherical.

The E5 types are more elliptical.

Then the diagram splits into S and SB

S type galaxies are spirals characterized by a bulge, disk, and spiral arms.

SB galaxies are barred spirals. They have a bar in the center that appears to rotate like a rigid body.

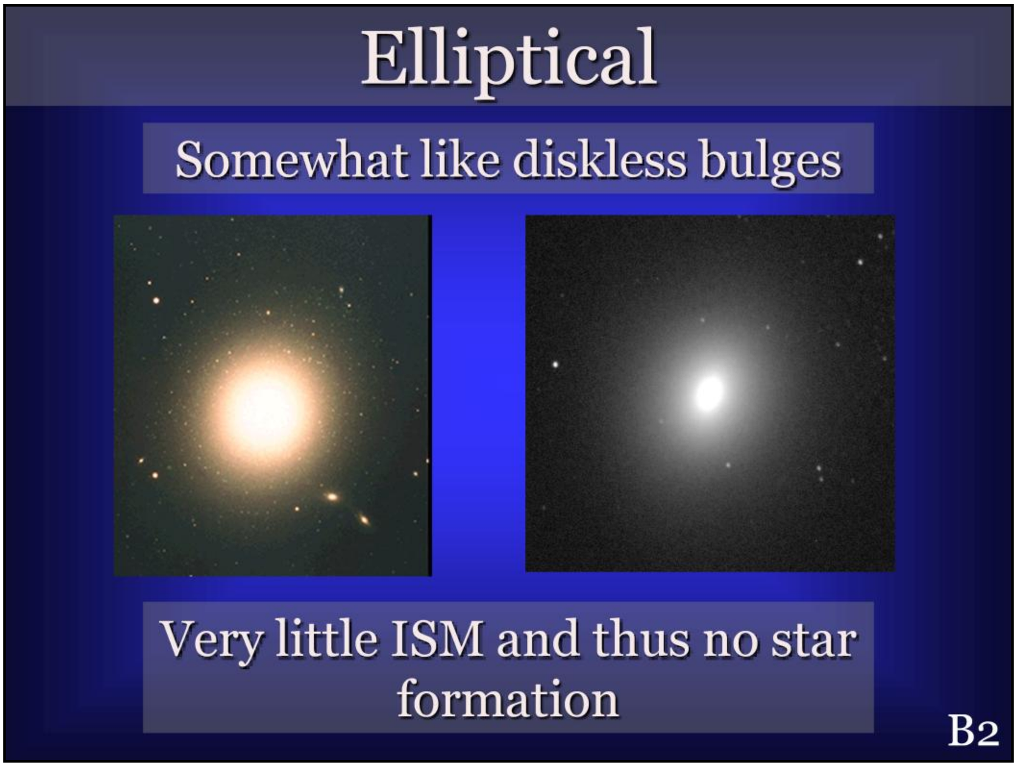
The S0 and SB0 are intermediate objects. Not quite elliptical and not quite spiral

Sa and SBa have loose spiral arms, large bulge to disk ratio, and low dust to gas ratio

Sc and SBc are the opposite. Tightly wound arms, small bulge to disk ratio, high dust to gas ratio

Irregular galaxies are not represented on the diagram. They don't fit well into any of the classifications.

All galaxy types come in a wide variety of sizes, from 100 million stars to more than a trillion.



They have no disk.

About 10 percent of observed galaxies are ellipticals

The ISM consists mostly of low density very hot gas that emits in X-rays.

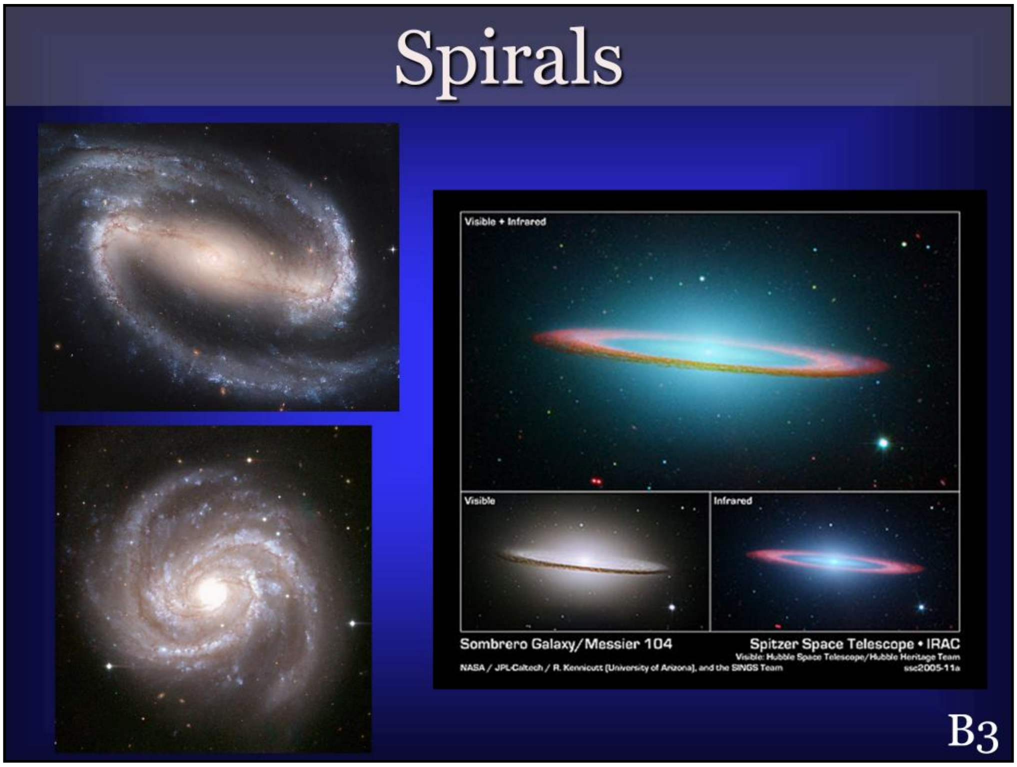
Since there is no ISM, there is no star formation so the stellar population tends to be lower mass redder stars.

Huge range of sizes.

Dwarf ellipticals can be as small as 10 million solar masses, on the order of the globular clusters.

Giant ellipticals, like M87 can be as large as 10^{13} solar masses, among the largest galaxies in the universe.

Orbital motions are like those in the Bulge or Halo of the Milky Way… Highly elliptical orbits, no orderly motion like in a spiral.



Spirals have a three component structure as we talked about when we were discussing the Milky Way.

There is a thin disk composed of gas, dust, and stars.

In the center there is a bulge.

They are surrounded by a spherical halo.

Some spirals contain a bar that rotates like a rigid body

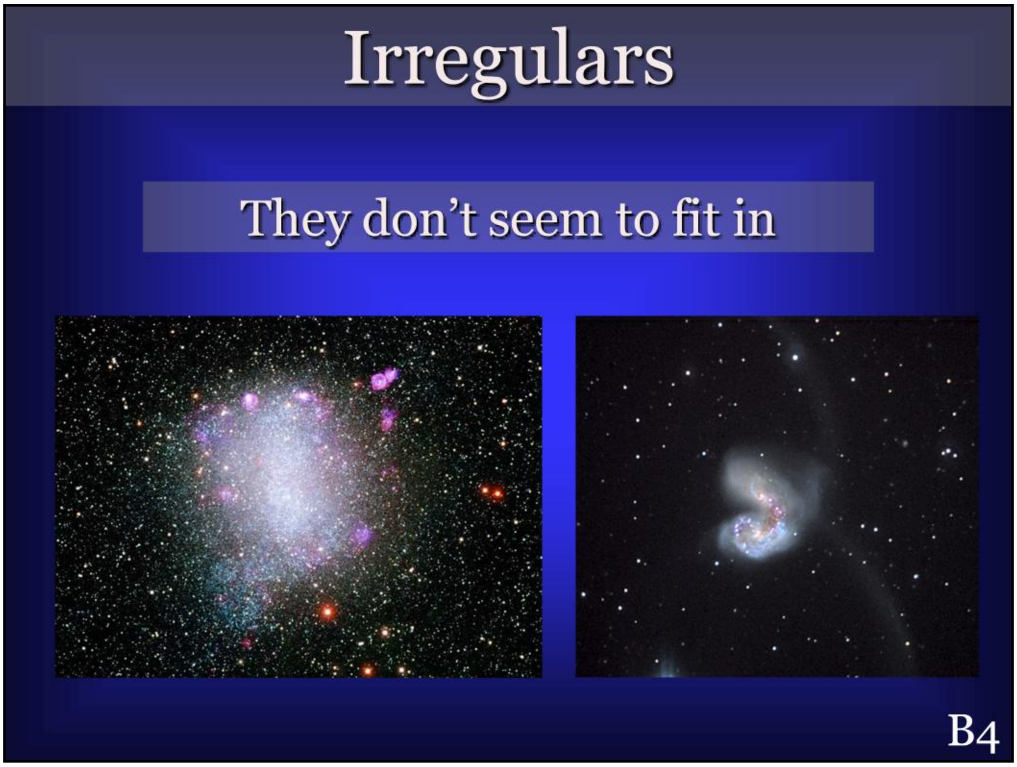
The arms are connected to the ends of the bar.

What a spiral galaxy looks like from our perspective depends on its inclination.

Some are face on, some are edge on, most are somewhere in between

The Sombrero Galaxy is nearly edge on. Above is a really cool image of it combining the visible image from HST with the infrared image from Spitzer.

In the infrared image, the dust in the disk pops out and looks really nifty.

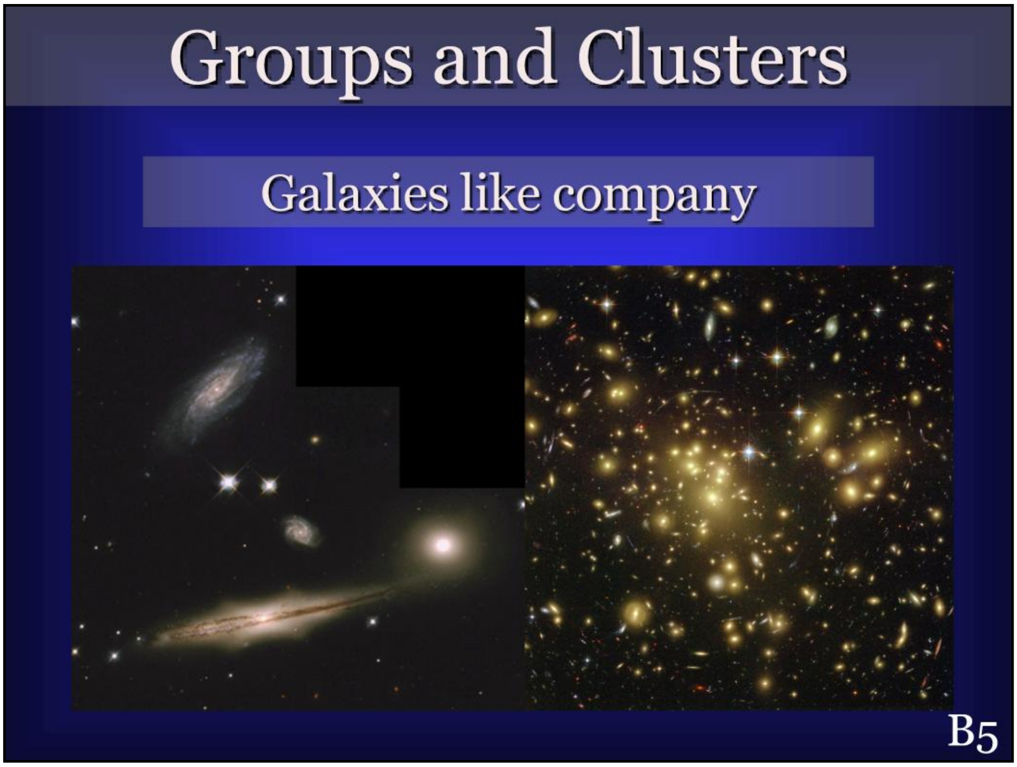


Neither spiral or elliptical… They tend to have a mix of young and old stars

Generally have some gas and dust component.

Some are the result of mergers, like the antenna galaxy.

They have more in common with spiral disks than with ellipticals.



About 75% of large galaxies are spirals. They tend to hand out in loose groups of several galaxies

Our local group of galaxies contains two large spirals, the Milky Way and Andromeda as well as over 30 smaller galaxies.

Clusters are larger than groups and tend to contain hundreds of galaxies.

Elliptical galaxies tend to hang out in large clusters.

Large elliptical galaxies are rare outside of clusters.

Type Ia supernova are the result of a white dwarf collapse and detonation.

A white dwarf in a binary system goes nova nova nova nova

Each time a little more material is left behind until the Chandrasekhar limit is reached.

And then KABOOM!

The peak luminosity is the same for all Type Ia SN.

They are 500 times brighter than Cepheids

Have to catch one as it's happening.

Light

A light year is a unit of:

A) Distance
B) Time
C) Velocity
D) Acceleration

A) Distance. It's the distance that light can go in one year.

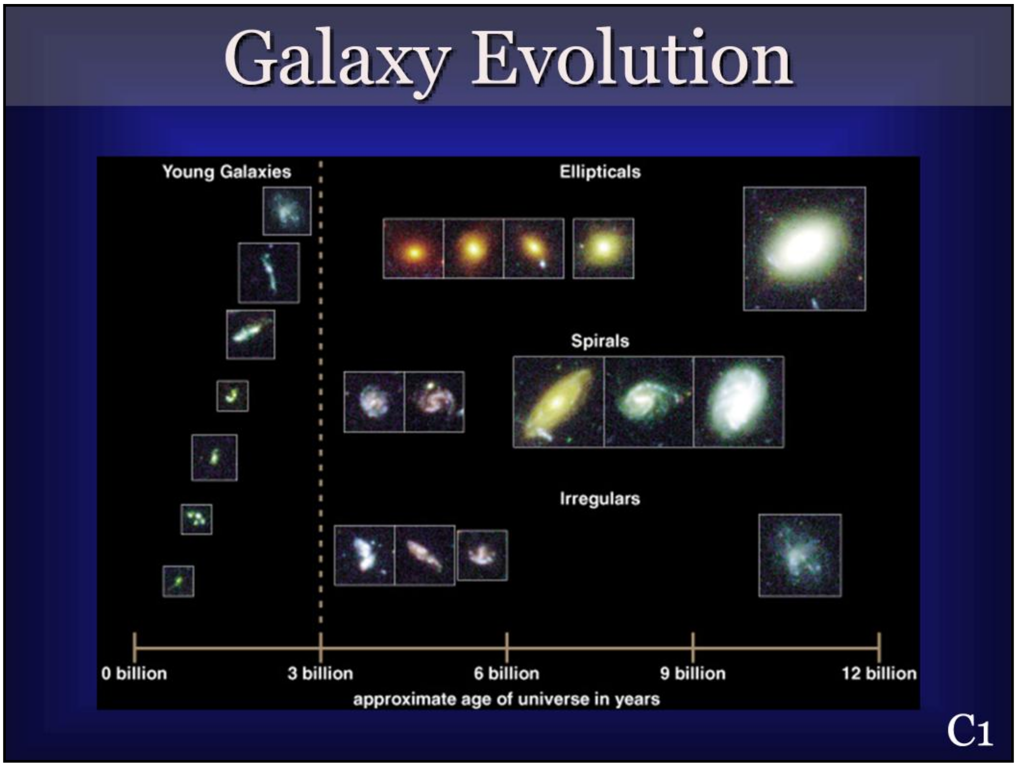
C1

Age

Judi lives 5 Lyr from you.
Beth lives 10 Lyr from you.
They each transmit a picture to you on the day of their 12th birthday.
You receive both pictures at the same time. Who is older?

A) Judi
B) Beth

C1



The study of how galaxies change over time.

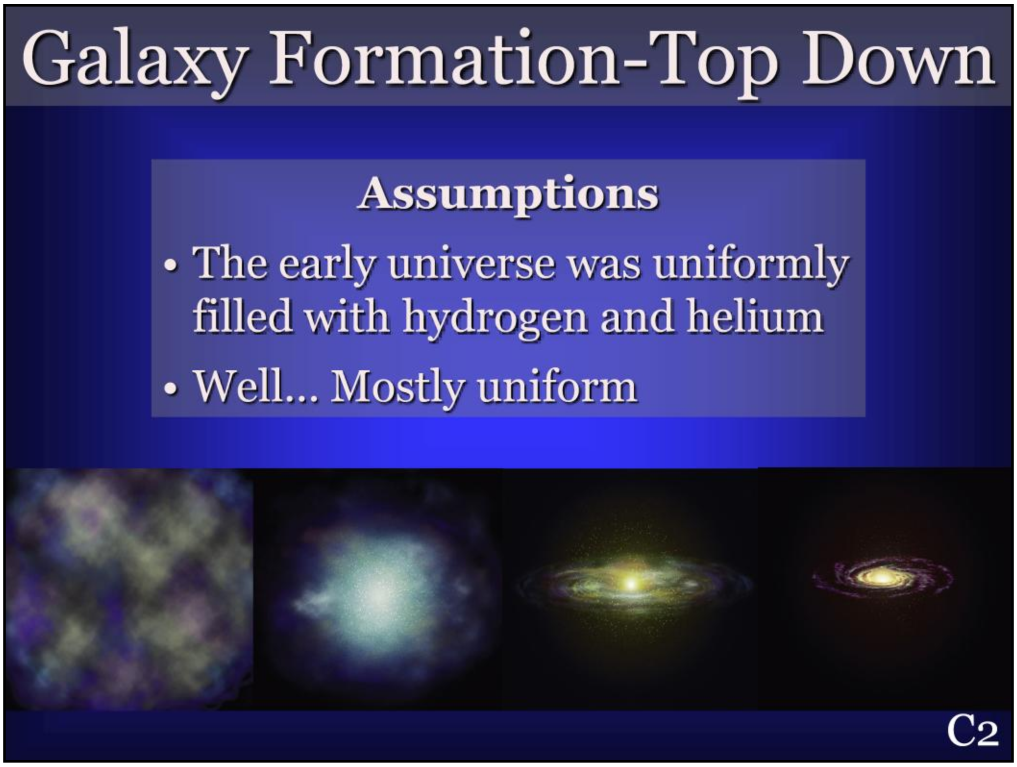
Of course galaxies evolve over long periods of time, so we can't watch a single galaxy evolve.

We CAN see galaxies at various stages of evolution since looking out means looking back in time.

Greater distances or redshifts means that the galaxy was younger when it emitted its light.

The galaxy images above were taken from the Hubble Deep Field. Ages are based on redshift.

They only go back to about 2 billion years. We can't see what the galaxies looked like when the universe very young.



We make our assumptions, plug everything that we know about physics into the computer and turn the thing loose.

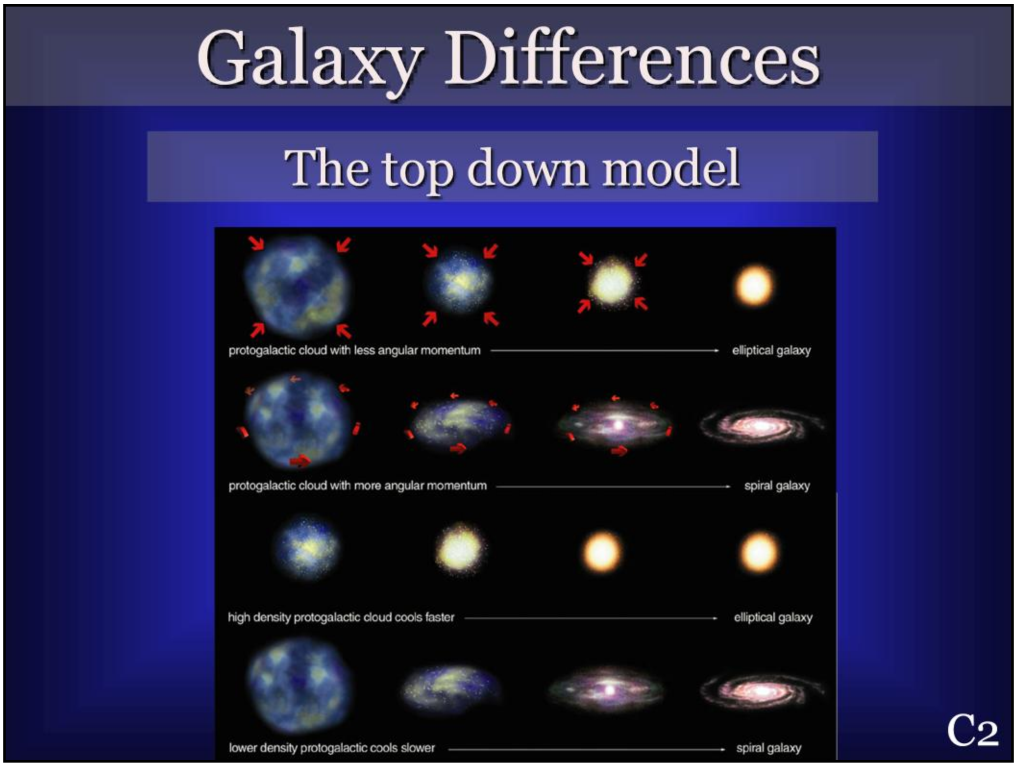
The slight over densities of the early universe eventually condensed into proto-galactic clouds.

The proto-galactic cloud contains only hydrogen and helium and a non-uniform density structure.

As the cloud collapses, halo stars begin to form.

The cloud had angular momentum, and as in the proto-planetary disk scenario, the disk of gas flattens.

Star formation is ongoing in the disk of the galaxy. The gas that used to be in the halo is now in the disk and star formation there ceases.



Low angular momentum versus high angular momentum cloud.

Low angular momentum cloud turns into an elliptical

High angular momentum cloud turns into a spiral.

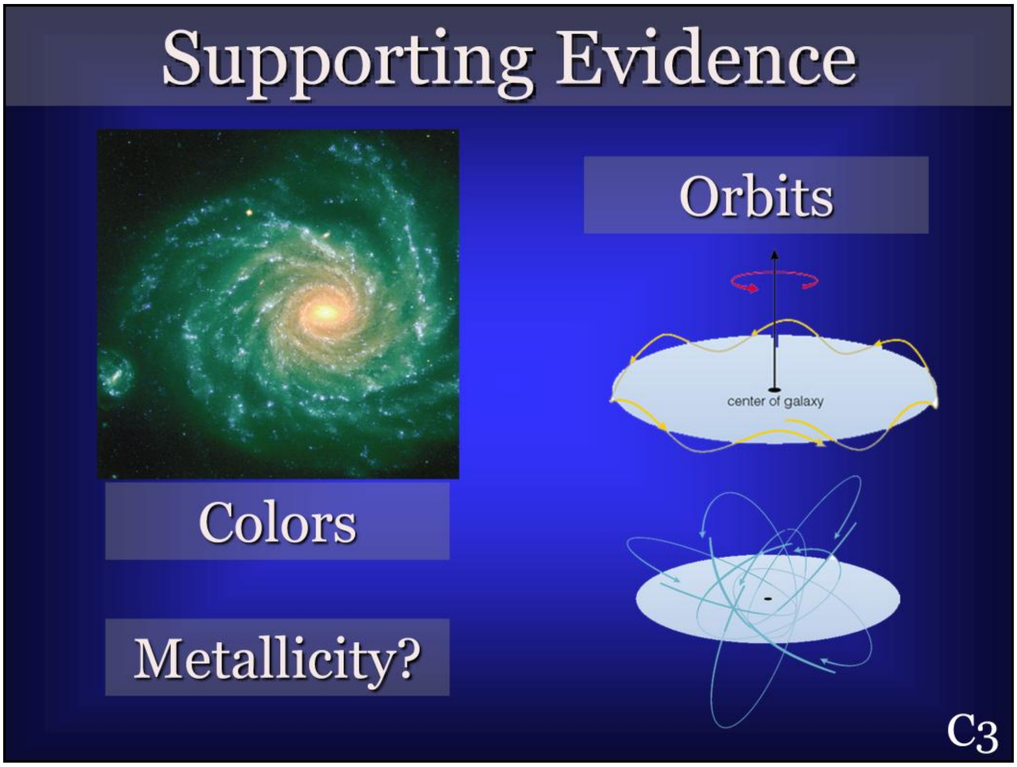
Remember that ellipticals tend to form in tight clusters, so they most likely formed from areas of high density.

There are some giant ellipticals observed at high redshifts that have a red population of stars suggesting no ongoing star formation.

We expect high density clouds to cool more efficiently.

Stars formed before viscosity in the gas could spin the disk out.

The star formation rate was high enough that all the gas was used up.



Are our models correct?

The components of the various components of spiral galaxies provide clues.

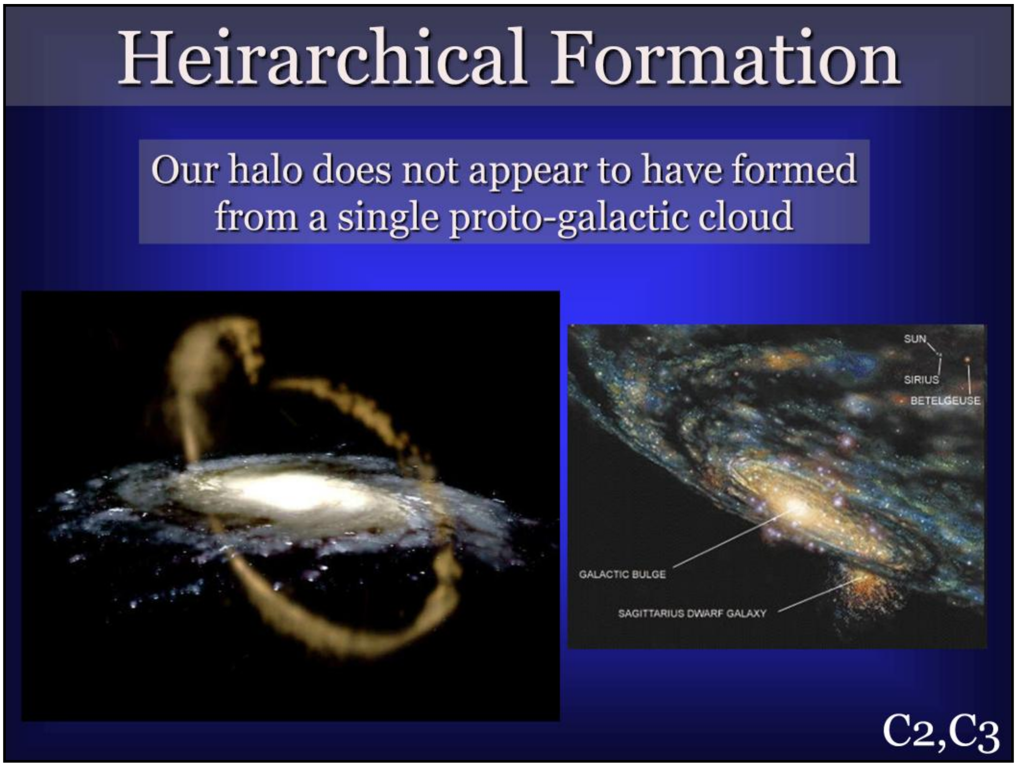
The disks appear white with bits of blue. There must be ongoing star formation there.

The spheroidal component appears reddish suggesting an older population of stars. (remember that hot young blue stars die quickly)

It appears that the spheroidal component formed before the disk.

The orbits AND colors of milky way halo stars suggest that these stars formed before the proto-galactic cloud spun out into a disk.

The disk stars orbit in circles around the galactic center, just like planets.



Above is an artists misconception of the Sagittarius dwarf

Halo stars are at least 12 billion years as told by the main sequence turnoff on the HR diagram.

Halo stars are metal deficient compared to the Sun, so they must have formed from metal poor gas.

BUT, the halo stars do not have consistent metalicities, suggesting that they did not form from the same gas cloud.

The answer is not clear. It is likely that both the initial conditions of galaxy formation AND galaxy interactions are important.

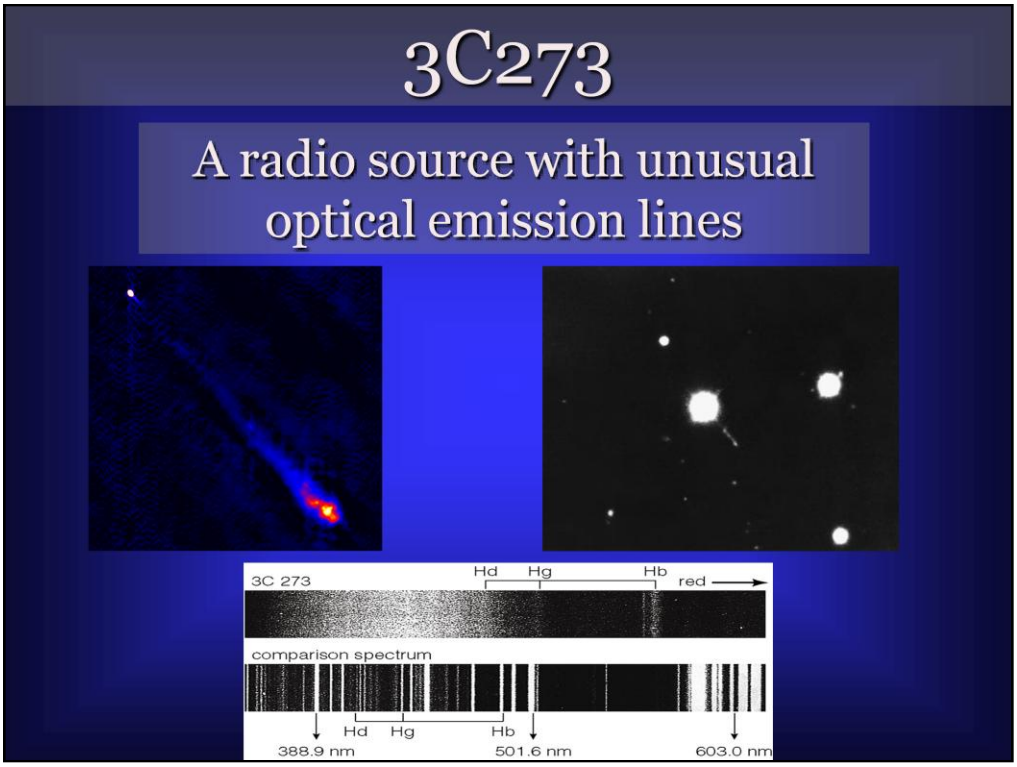
The metal content does not simply decrease with distance from the galactic center.

So… It appears that mergers may be the answer.

Stellar orbits get all bungled up and chaotic.

Star formation rate is so high that the gas gets blown out of the galaxy and becomes part of the ICM (intercluster medium).

What is left is an elliptical galaxy which has lost its gas. No new star formation means that it appears red.

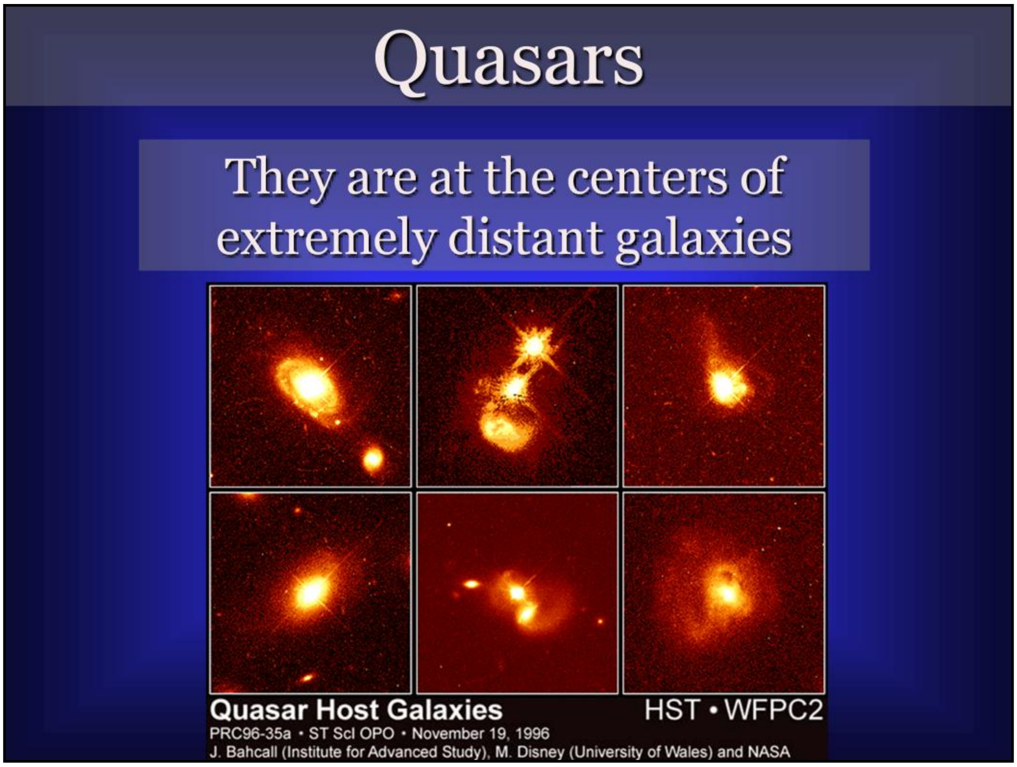


Trying to find optical counterparts of radio sources.
Most of them were galaxies.
This one was a blue star with an odd spectrum.

They soon figured out that the emission lines were highly red shifted hydrogen.

It was receding at 47,000 km/s!
Using Hubble's Law, that puts it at 2.2 billion light years! Wow!
That means it must have over 1 trillion solar luminosities.

Could there be another explanation for its red shift?



They are called quasars because they are quasi stellar objects.

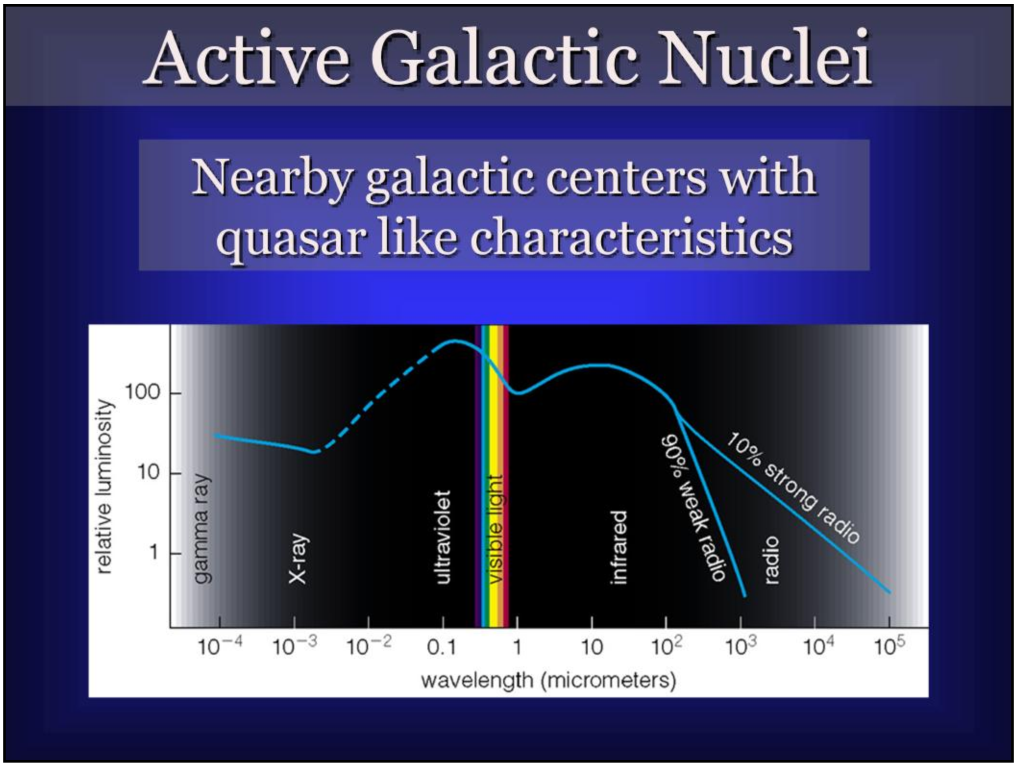
Their spectrum, instead of looking like a blackbody, is flat, meaning that they have lots of power across the spectrum.

They outshine the entire galaxy. They are about 1000 times brighter than the Milky Way.

Highly variable on very short time scale (about an hour)

They all reside at high redshifts suggesting that they were common billions of years ago but not any more.

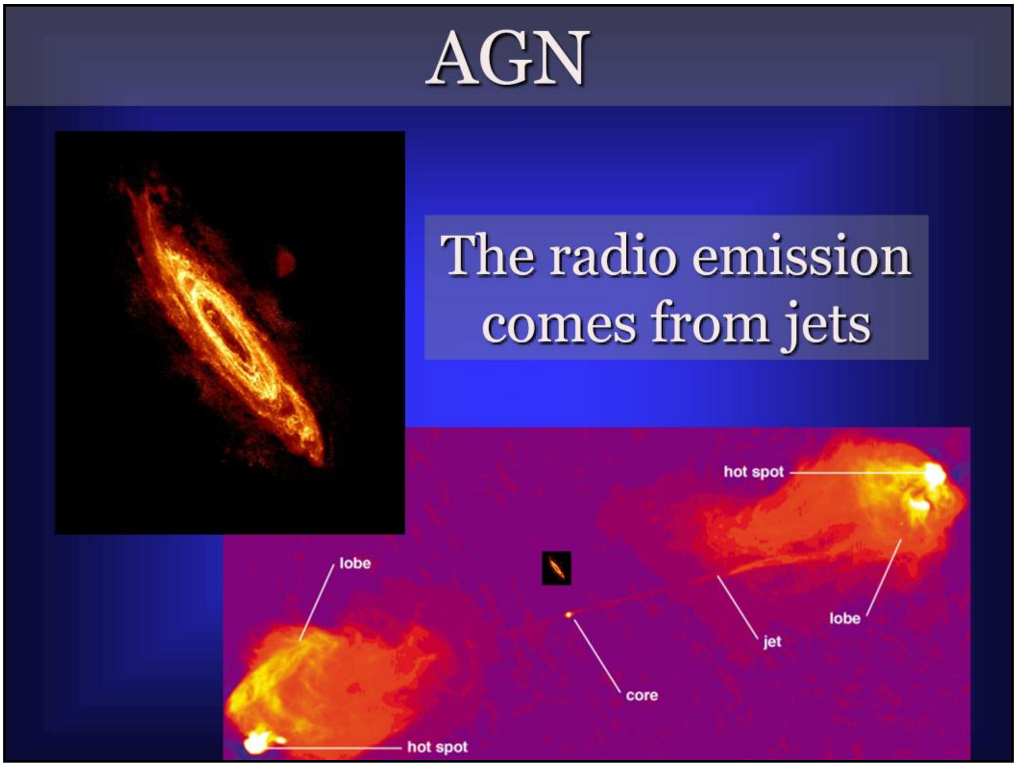
What in the world are they?



Except for their luminosities, AGN look much like quasars.

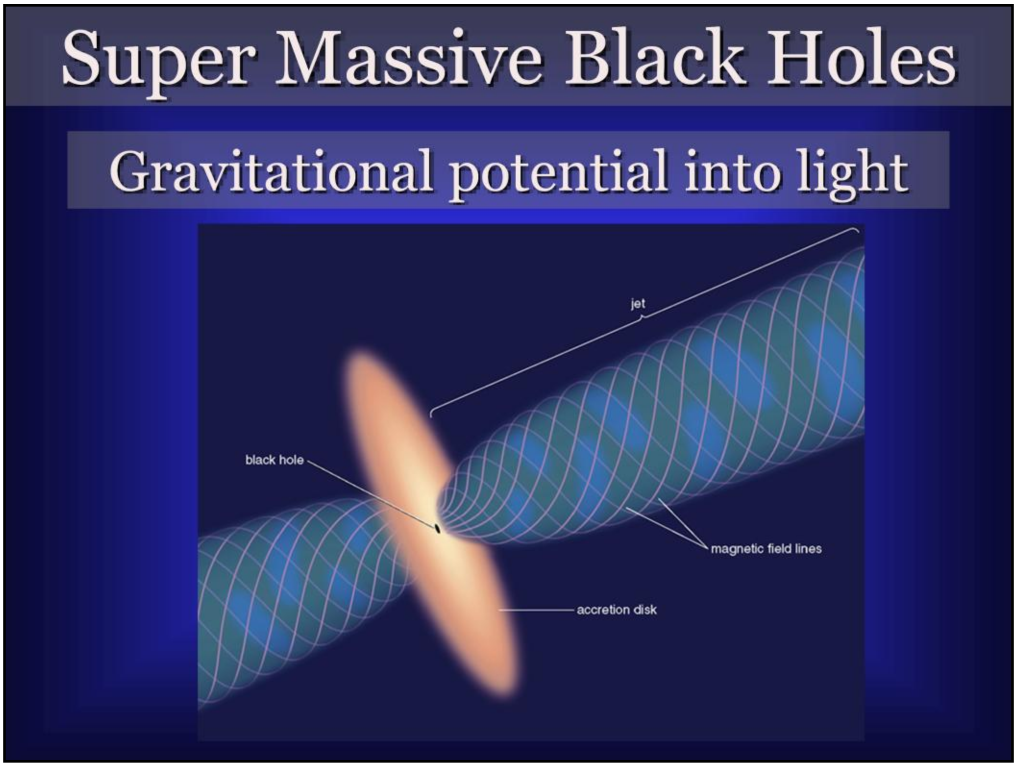
Its easier to see the host galaxy because it is closer and the central source isn't swamping the light from the entire galaxy.

The source of the emission is tiny. No telescope can resolve it.



Since their luminosities change on such small time scales, they must be very small. The size must be on the order of the variability

The radio lobes extend out to enormous distances, much larger than the disk of the galaxy.



An accretion disk forms around the black hole.
It gets really hot and emits at a wide variety of wavelengths.
Twisty magnetic fields collimate the light.

Quasars must consume 17 solar masses per year to be as luminous as they are.