Astronomy 122

This Class (Lecture 24):

Large Scale Structure

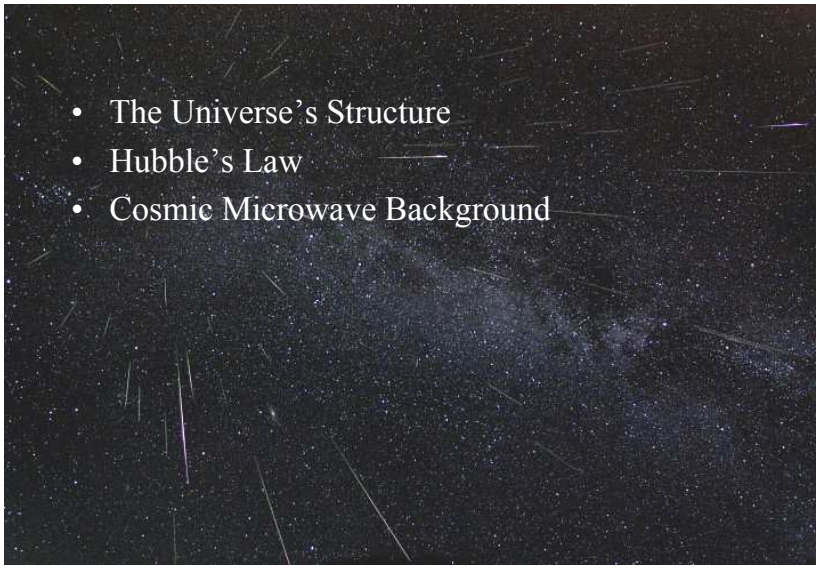
HW10 due on Friday.

Next Class:

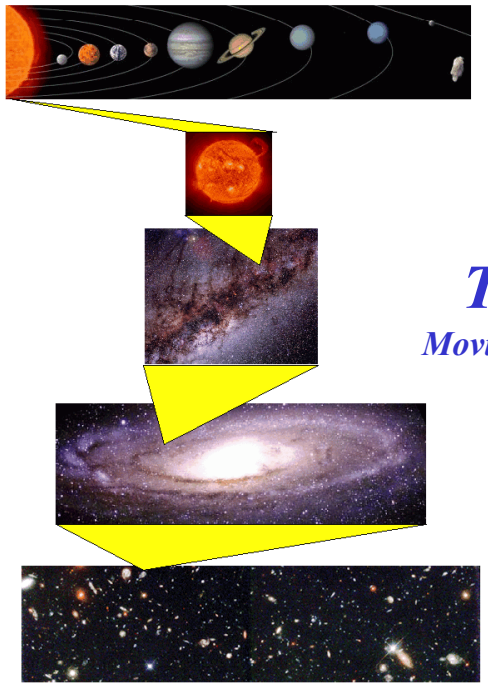
Active Galaxies & Quasars

Music: *Rocket Man* – Elton John

Outline



- The Universe's Structure
- Hubble's Law
- Cosmic Microwave Background

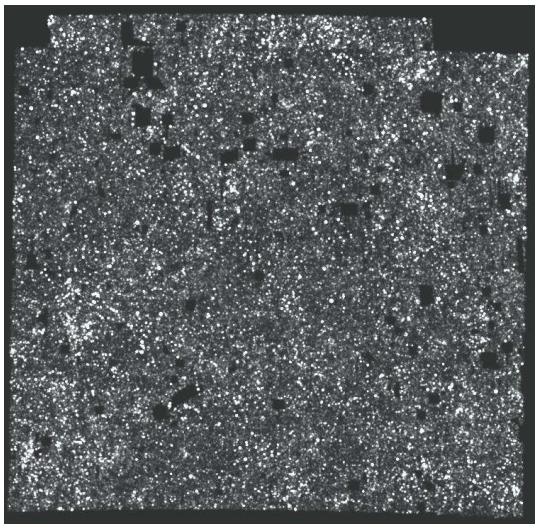


Astronomy: The Big Picture

Moving from our Galaxy outward!

The Universe

- On small scales– clumpy
- On large scale– smooth
  - 4 deg x 4 deg
  - Each point is a Galaxy
  - About 710,000



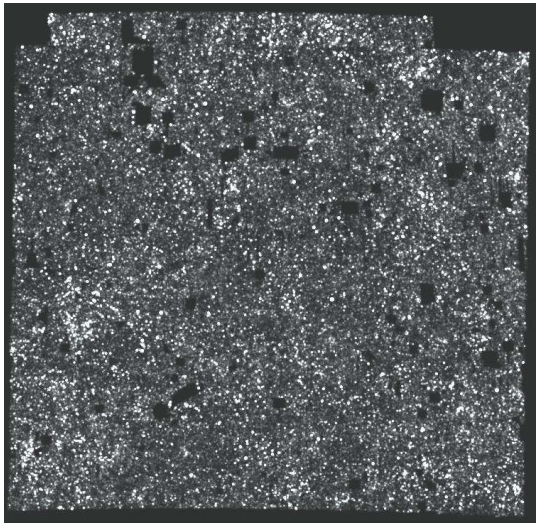
 http://www-int.stsci.edu/~postman/deeprange.html

The Universe

The Universe is

1. Homogeneous (gal's uniformly fill space)
2. Isotropic (looks same in all directions)

   – These are the starting points for our Cosmological journey



http://www-int.stsci.edu/~postman/deeprange.html

Measuring the Distance

- Basic idea:
  - Find the intrinsic brightness of an object
  - Compare to the observed brightness
  - Use brightness difference to determine distance
- No method is good for all distances
  - Different techniques have been developed for different distances
  - To find distance to Andromeda galaxy, Hubble used Cepheid variables.

How are Galaxies Moving?

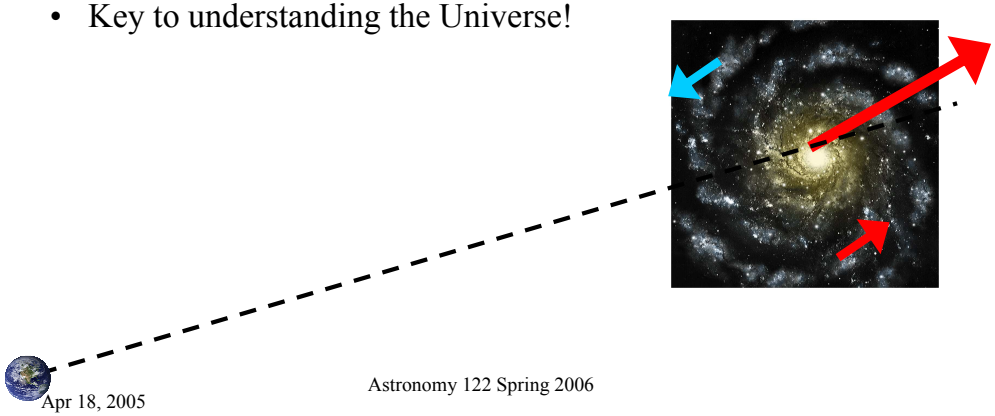
It's 1928 and Edwin Hubble is measuring how galaxies move by measuring the velocity WRT us.

What does he find?

a) More galaxies receding than approaching.
b) More galaxies approaching than receding.
c) About equal numbers of each.

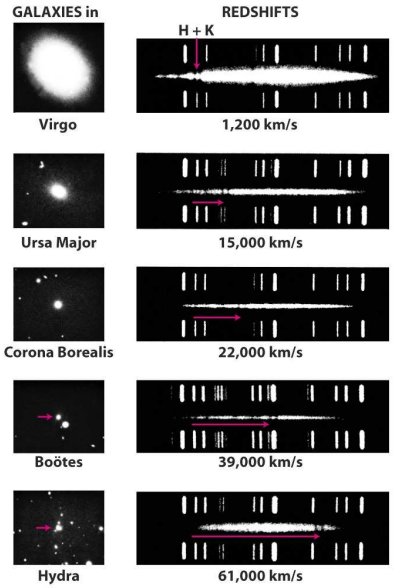
Redshift of Galaxies

- Most galaxies are moving away from us!
- The farther away, the faster they are moving away.
- What does this mean?
- Key to understanding the Universe!



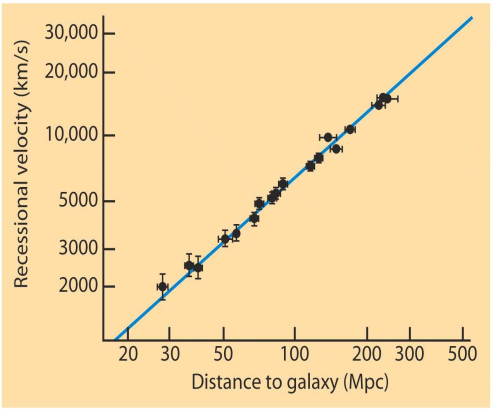
Redshifted Galaxies

- Hubble observed that the spectrum lines of most galaxies are **redshifted**
- Redshift: $z = (\lambda_{obs}-\lambda)/\lambda$
- At low redshifts, z<<1 & $v = cz$
- *Exceptions are the closest galaxies*



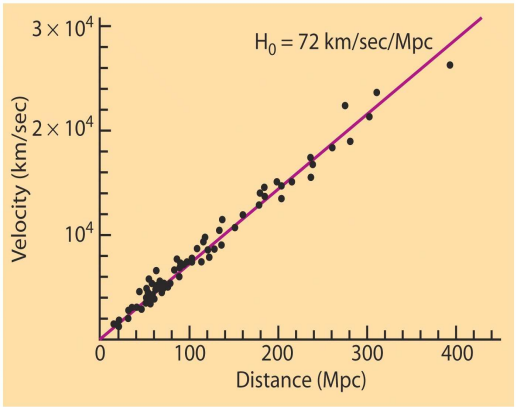
The Hubble Law

- Calculate velocity from Doppler and distance from Cepheid variables
- $V = H_o \times D$
  - Where v is velocity, d is distance, and H_o is the Hubble constant
- Current best value is H_o=72 km/s/Mpc



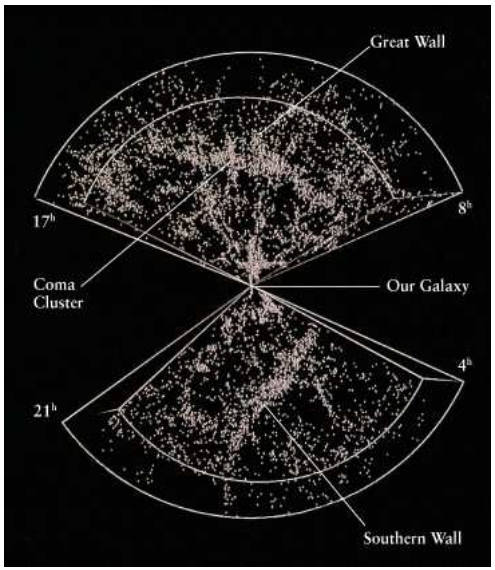
Redshift and Distance

- The Hubble Law gives us a new way of finding distances
- Remember,
  - $v=cz$
  - $v=H_o d$
- Therefore, $d=cz/H_o$!
- We can now measure distances to extremely distant galaxies!

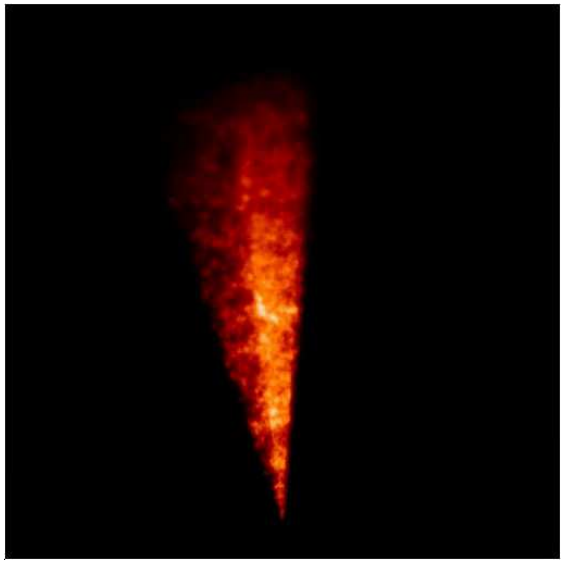


Structure of the Universe

Clusters of galaxies are grouped together in **superclusters**

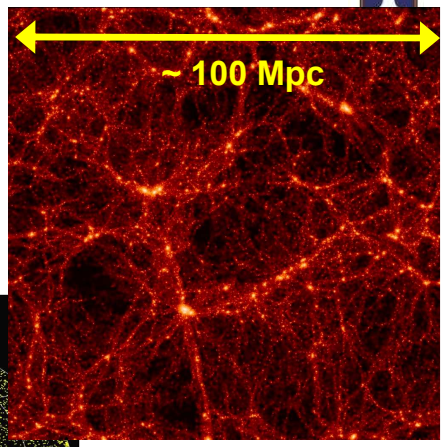


Structure of the Universe

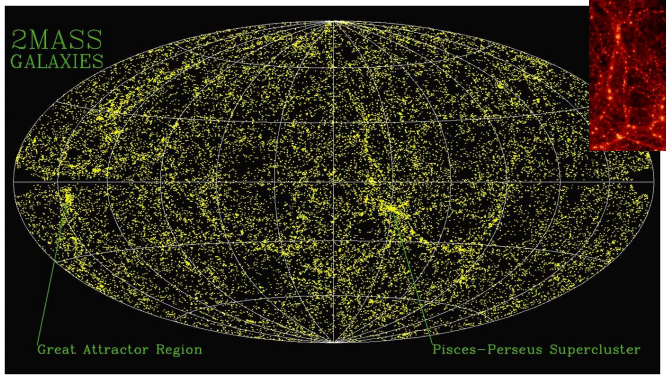


Structure of Universe

- Superclusters are distributed in Universe.
- Filamentary and sheet structure.
- Voids of nothing between them.

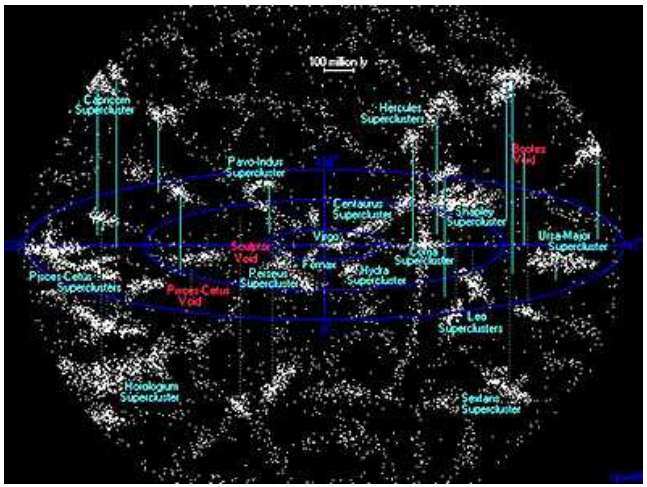


Computer simulation (A. Jenkins)



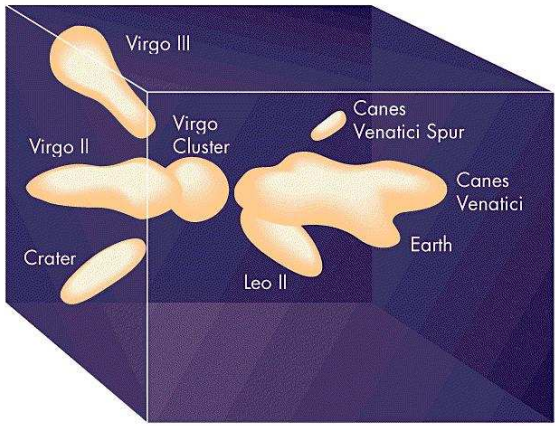
"Sudsy" Universe

The arrangement of walls, filaments, and voids resembles soap bubbles



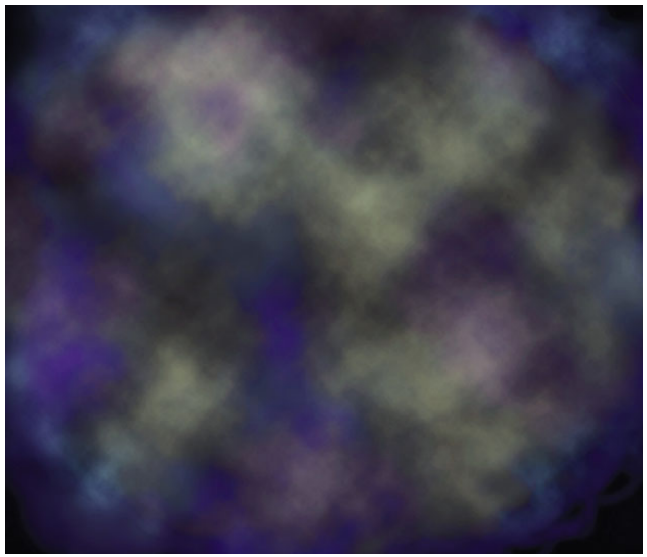
The Local Supercluster

- Our Local Group is part of a supercluster centered on the Virgo Cluster
- The local supercluster is still expanding
- We are getting farther from the galaxies in the local supercluster



How did galaxies form?

Galaxy Birth



Basic Assumptions

- Matter originally filled all of space almost uniformly
- Gravity of denser regions pulled in surrounding matter
- Probably condensed around regions of dark matter

Galaxy Birth

- Denser regions contracted, forming ***protogalactic clouds***
- H and He gases in these clouds formed the first stars

Galaxy Birth

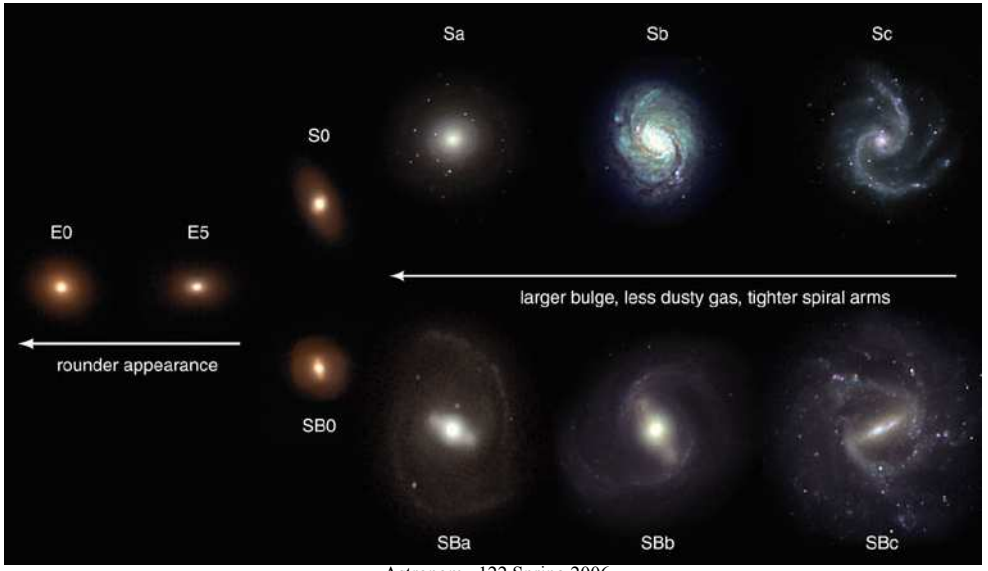
- Supernova explosions from first stars kept much of the gas from forming stars
- Leftover gas settled into spinning disk
- ***Conservation of spin***

But why do some galaxies end up looking so different?

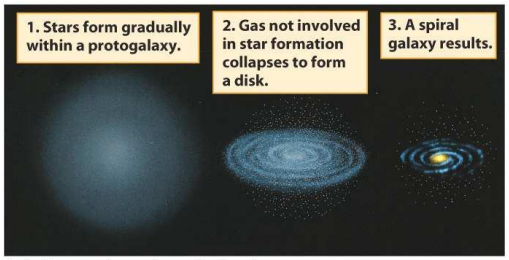
NGC 4414

M87

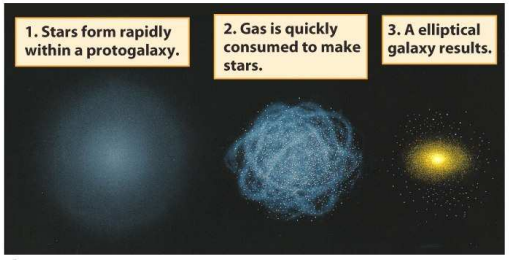
Why don't all galaxies have similar disks?



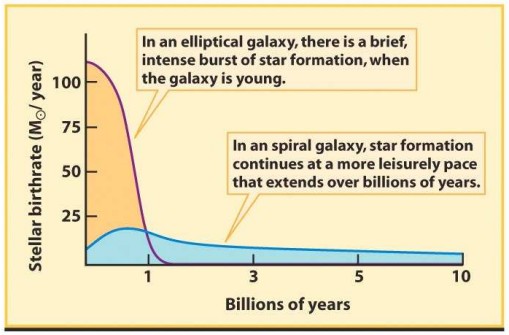
Conditions in the Protogalactic Cloud?



(a) Formation of a spiral galaxy

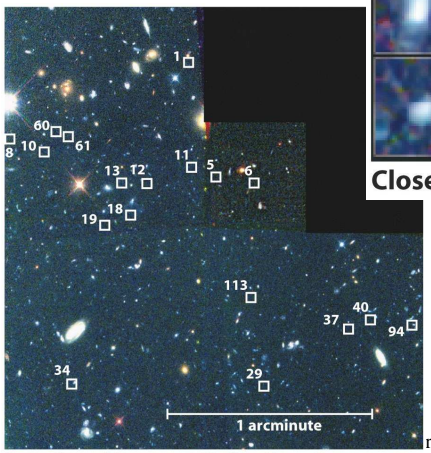


(b) Formation of an elliptical galaxy

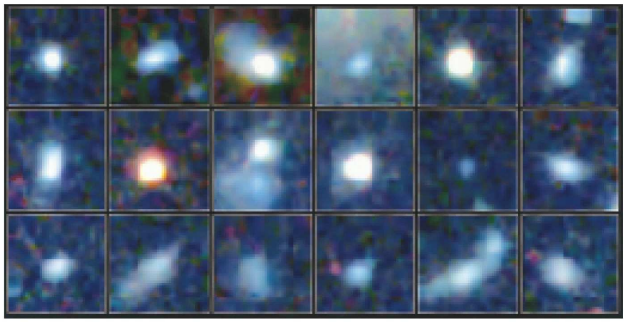


(c) The stellar birthrate in galaxies

Looking Back in Time



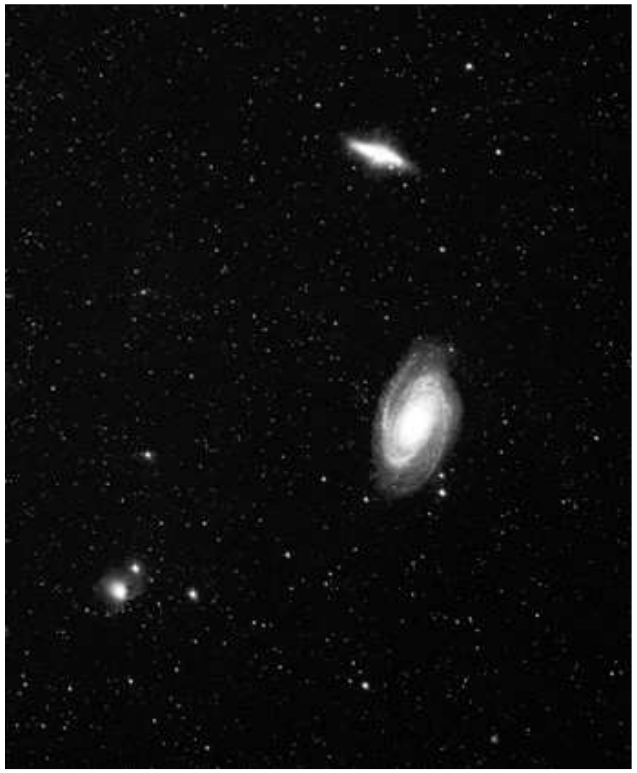
A portion of the constellation Hercules



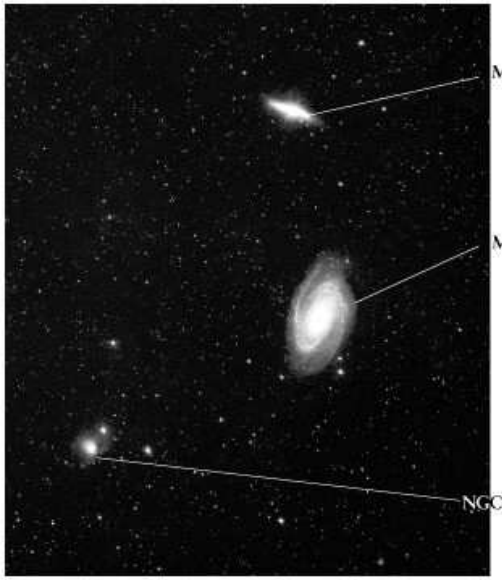
Closeup images of the numbered objects in (a)

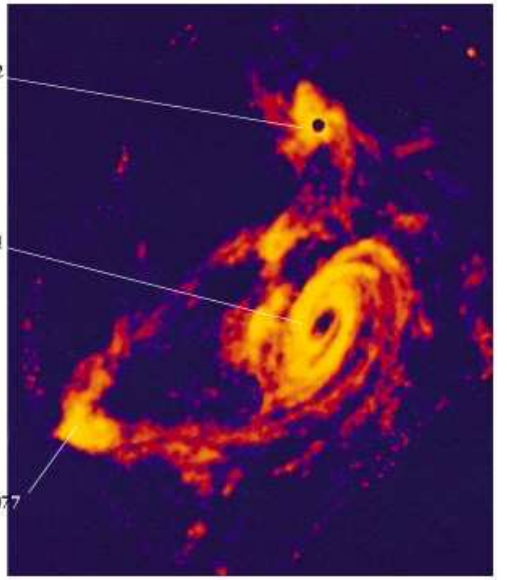
- Older galaxies are around 11 billion lyrs.
- They are small and blue.
- Add a number together would make a modern galaxy.

Any connection between these galaxies?

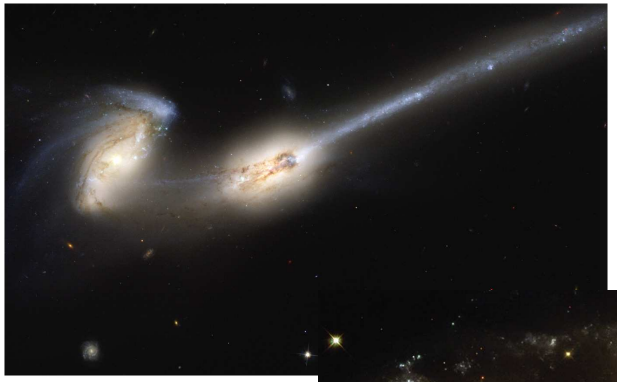


Collisions





Galaxies Collide



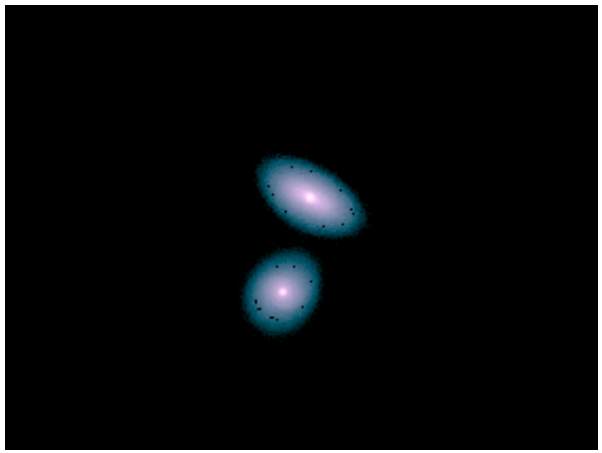
NGC 2207 &
IC 2163

NGC 7676
"The Mice"

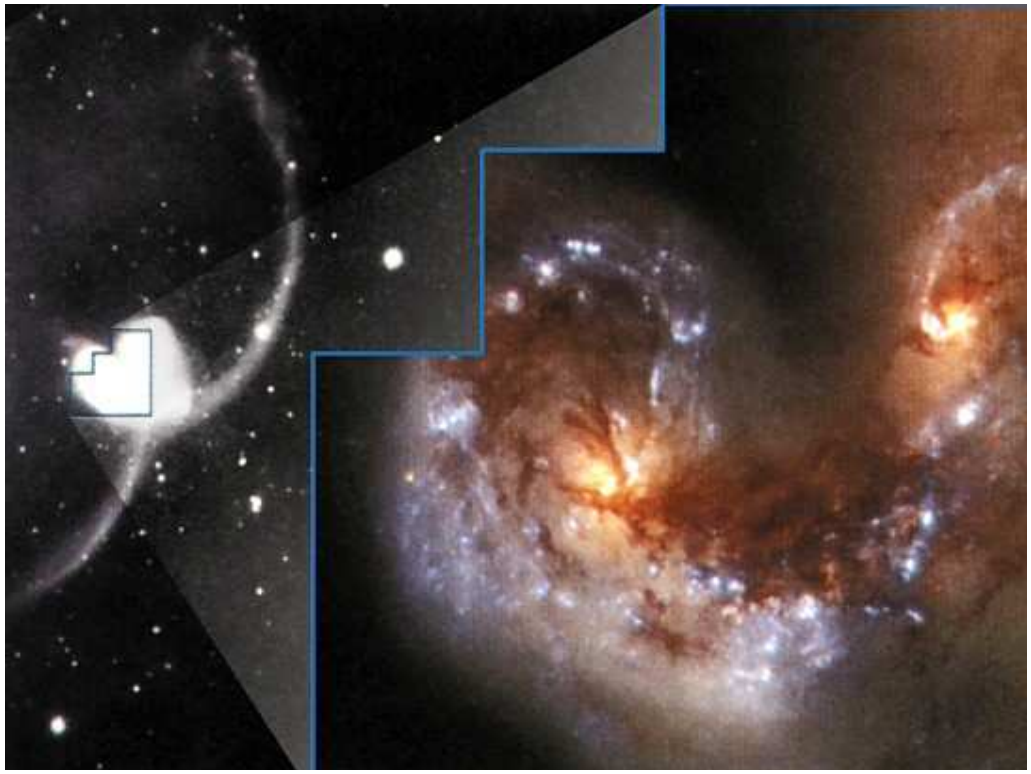
Collisions

- They do not involve colliding stars– but rather gravitational fields
- Might form hot intergalactic gas
- Could initiate rapid star formation - called *Starburst Galaxies*
- Collision causes stars to be scattered into "tails"
- Causes galaxy mergers called "galactic cannibalism"

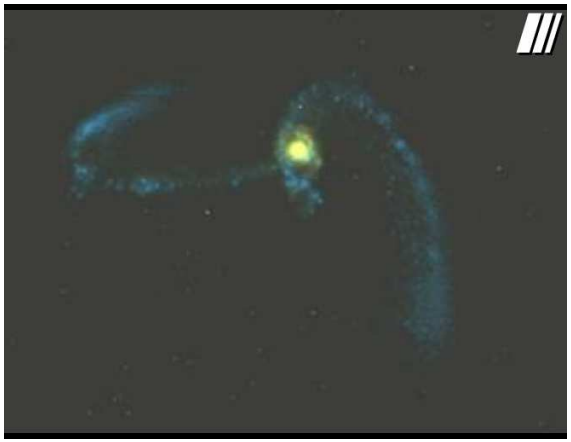
Galaxy Collisions



Computer simulation of two galaxies colliding by John Dubinski and Lars Hernquist

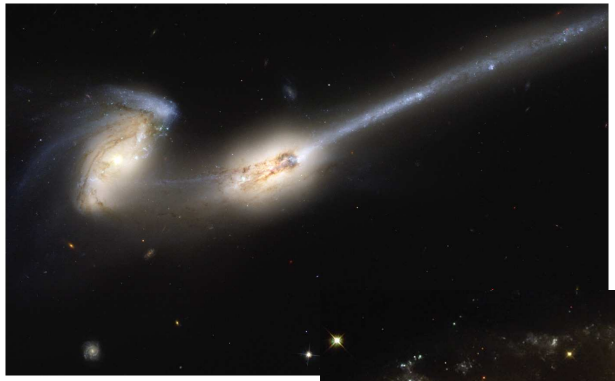


Galaxies Collide



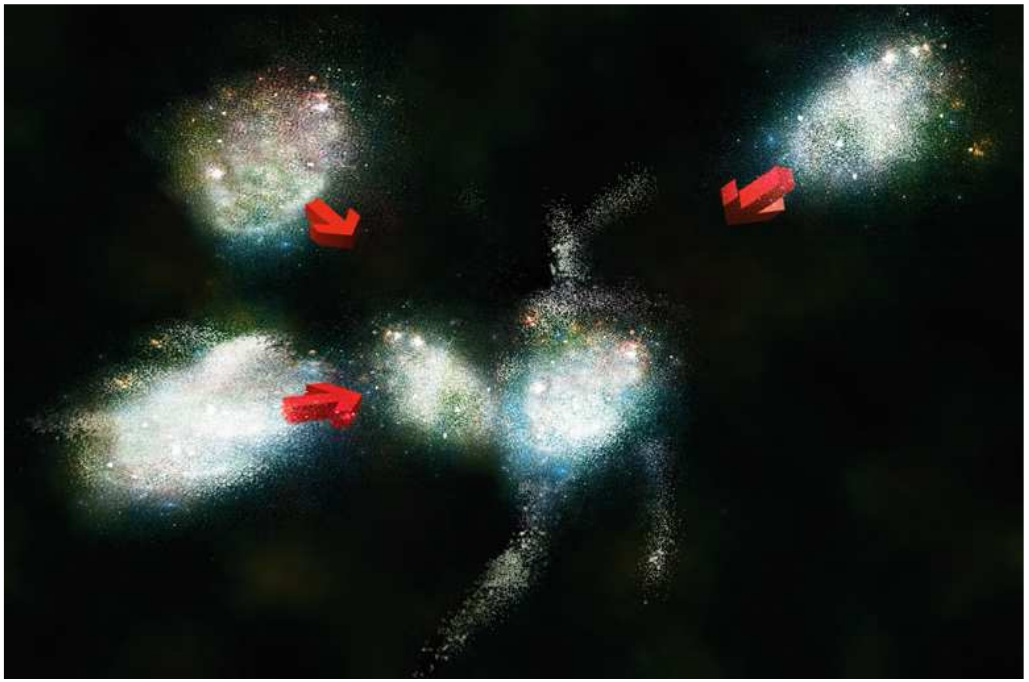
When spiral galaxies collide, their bulges merge, while the disks are turned into *tidal tails*

Galaxies Collide



NGC 2207 & IC 2163

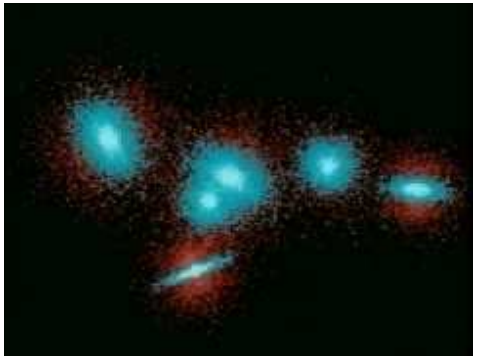
NGC 7676 "The Mice"

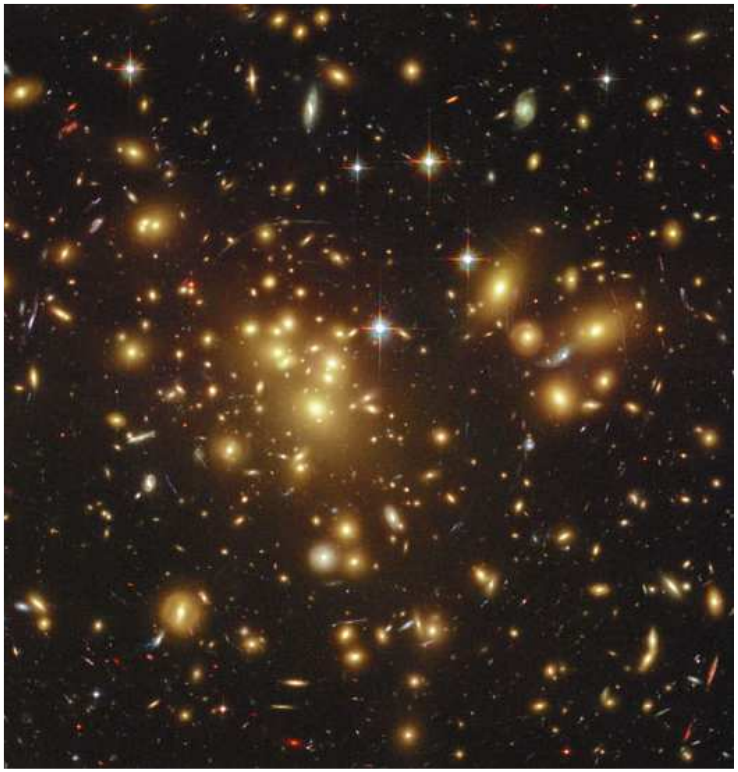


Collisions are also a factor in galaxy evolution!

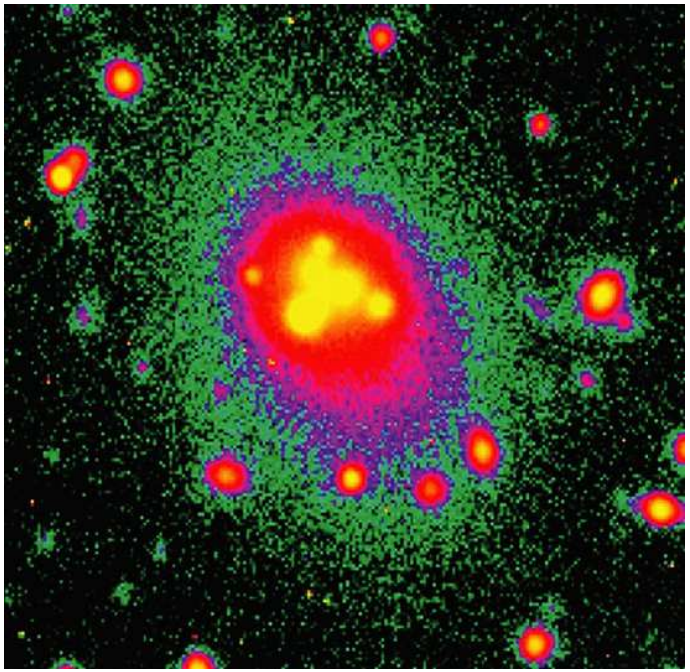
Multi-galaxy Collisions

Modeling such collisions on a computer shows that spiral galaxies can merge to make a giant elliptical





Collisions may explain why elliptical galaxies tend to be found where galaxies are closer together



Giant elliptical galaxies at the centers of clusters seem to have consumed a number of smaller galaxies

Thought Question

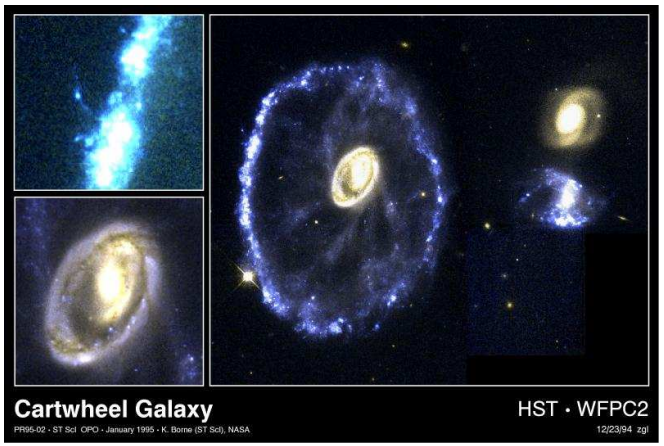
When galaxies collide, what happens to the stars? Do they collide as well?

Why do galaxies differ?

- Angular momentum may determine size of disk
- Density of protogalactic cloud may determine how fast a galaxy forms
- Collisions shape galaxies early on
  - Mergers of small objects make halo & bulge
  - Mergers of larger objects make elliptical galaxies
- Relatively undisturbed galaxies can still have disks

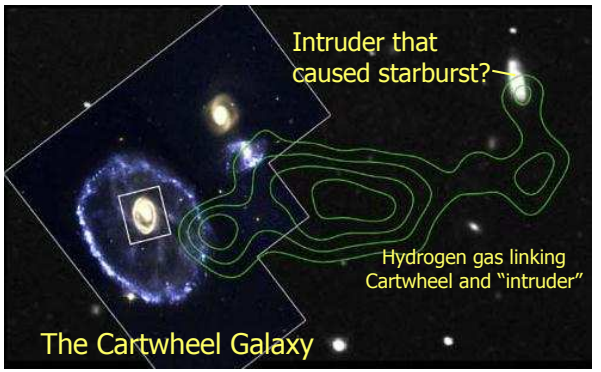
Starburst Galaxies

- Galaxies with enhanced rates of star formation
- Usually forming massive stars for a short period (few Myr).
- Probably due to collisions



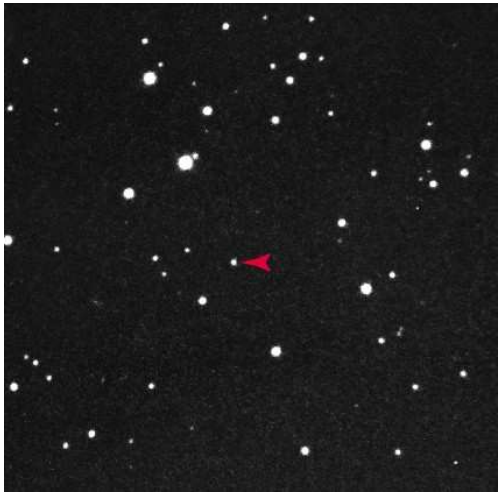
Starburst Galaxies

- Appear very blue, lots of young stars
- Gas is compressed by interactions, triggers galaxy-wide star formation



A Very Strange Star !?!

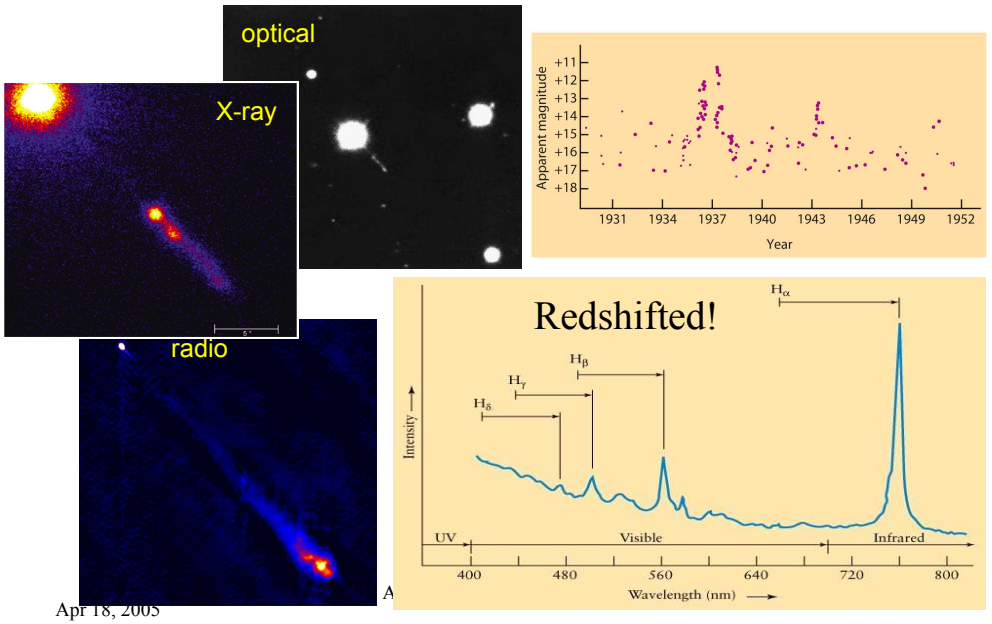
- Looked like a blue star, but had very odd spectrum lines
- Turned out it was simply greatly redshifted ⇒ z = 0.16
- That's 2 billion light years away!
- It must be 100 times brighter than the entire Milky Way!
- **Not** a star



Quasars…

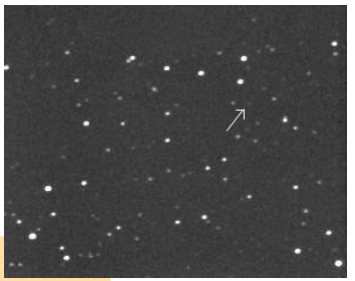
- These objects have a spectrum much like a dim star
  - But highly redshifted
  - Appear to moving away from us very fast!
- Dubbed **quasars** (quasi-stellar radio sources)
- Hubble's Law tells us that they are at "astronomical" distances
  - Up to 13 billion light years away!
- Great distances - must be very bright
  - Some 1 million times the brightness of our Galaxy!
- Highly variable
  - Must be small - about the size of our Solar System

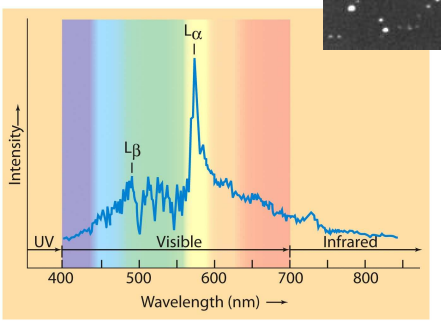
The First Quasar Discovered: 3C 273



PKS 2000-330

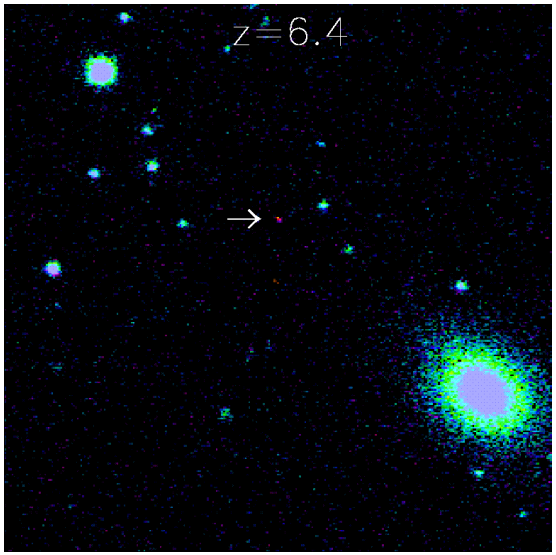
- Redshifted so much that UV emission can be seen in the optical
- This quasar appears to be moving away from us at 92% of the speed of light!





The Furthest Known Object

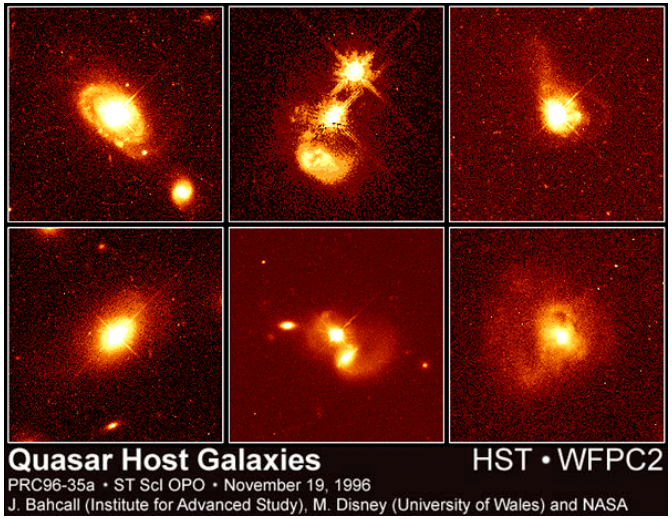
- Although there are now sources that may beat it, this galaxy is at z=6.4!
- That means only 800 Myrs after the Big Bang!
- Probably only current record holder.
- Seems to be moving at 95% the speed of light!



http://www.sdss.org/news/releases/20030109.quasar.html

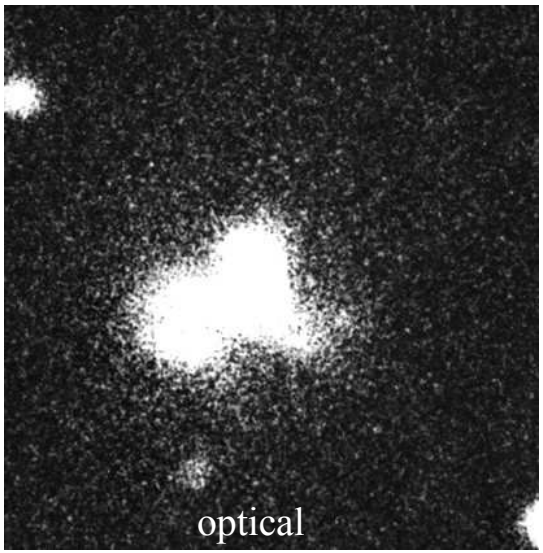
Quasar Host Galaxies

- Quasars live in distant galaxies
- They are *galactic nuclei!*



Are there quasars in the nearby Universe?

The Cygnus A Galaxy



- Looks like a star
- But bright in the radio
- And it's moving away from us fast!
- Moving away at 14,000 km/s.
- That's about 5% the speed of light!
- 635 million light years away! Or 194 Mpc.
- Similar to a quasar??

Active Galaxies

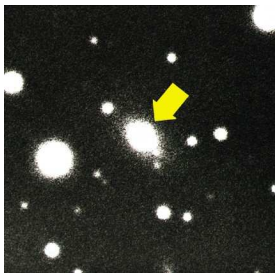
- There are no quasars in the nearby Universe *now*
- But there are some very energetic galaxies (about 1% of all galaxies)
  - Very bright, star-like nuclei
  - Often, energetic outflows of matter from the nucleus
- Called **active galaxies**
- Types of active galaxies
  - **Seyfert galaxies**
  - **Blazars**
  - **Radio galalxies**
- Like quasars, but not as energetic

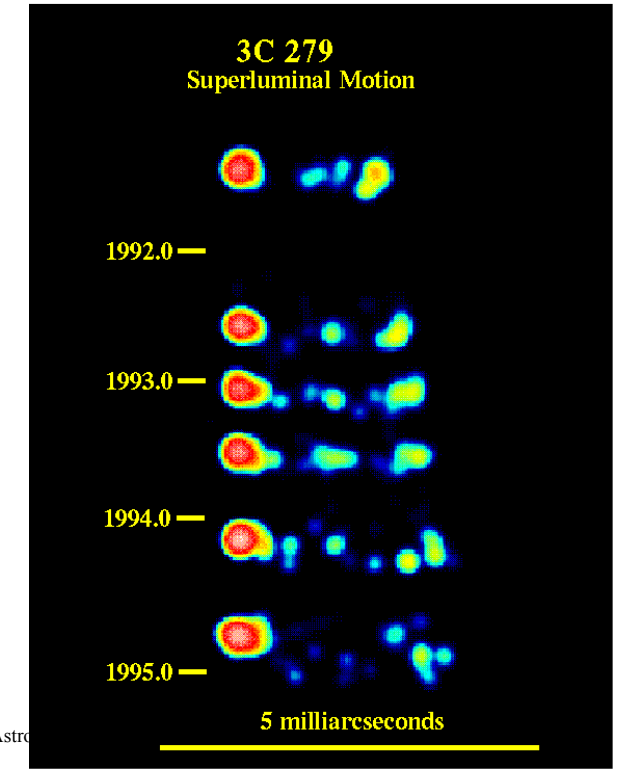
Seyfert Galaxies

- Look like normal spiral galaxies, but with incredibly bright nuclei
- Potentially as bright as a trillion Suns!
- Brightness varies tremendously
- Over a few weeks it's brightness can change by the ENTIRE brightness of the Milky Way

Blazars

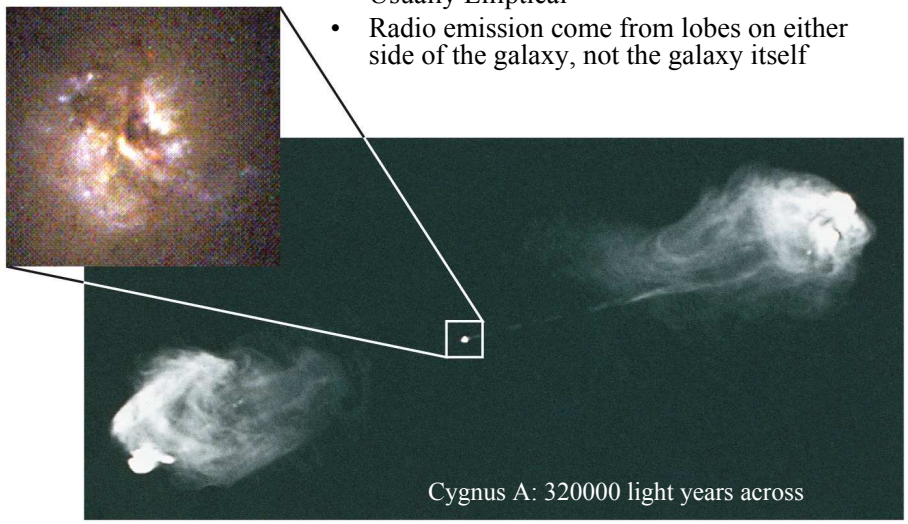
- Bright nuclei with almost completely featureless spectrum.



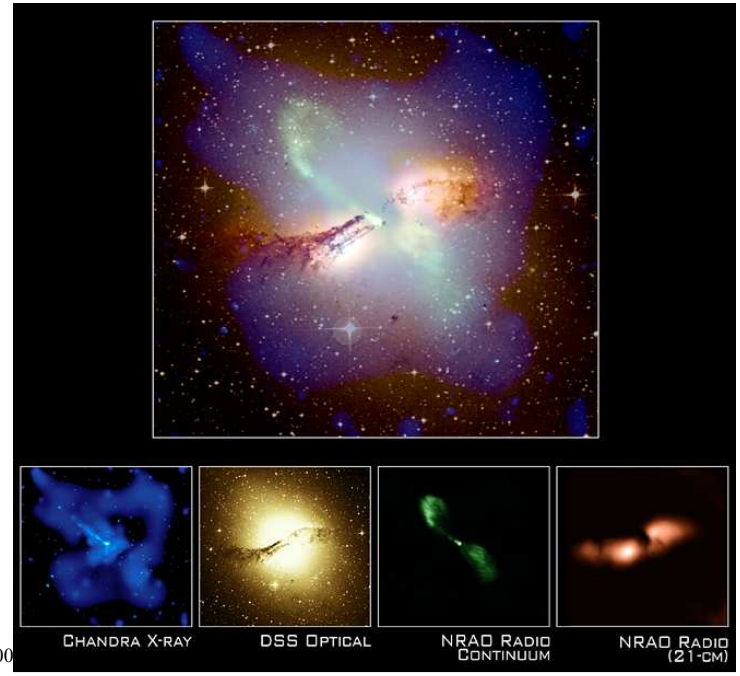


Radio Galaxies

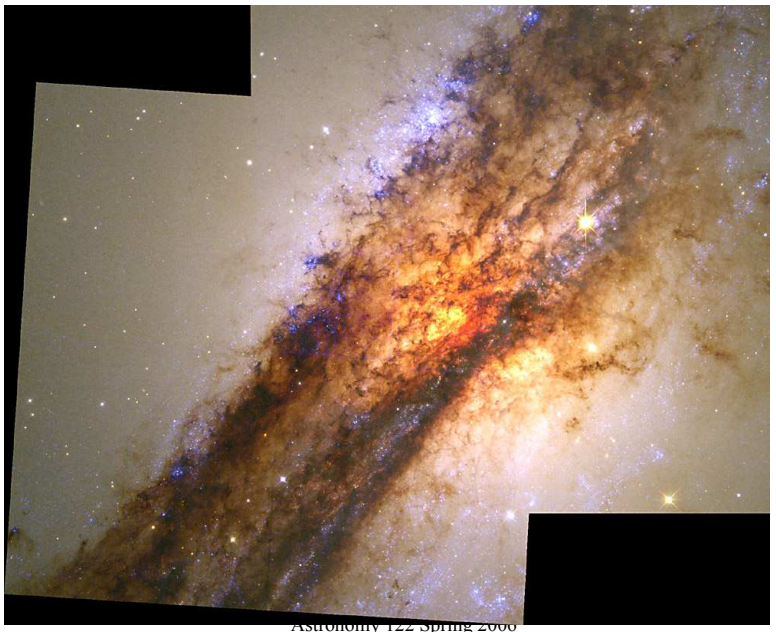
- Galaxies that emit large amounts of radio waves
- Usually Elliptical
- Radio emission come from lobes on either side of the galaxy, not the galaxy itself



Radio Galaxies: Centaurus A

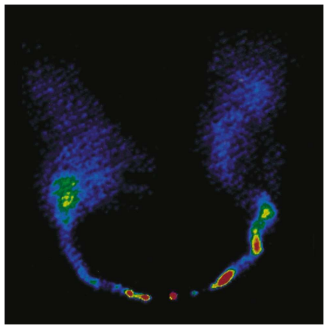


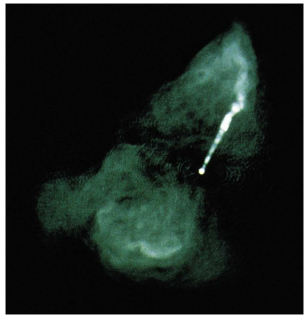
Centaurus A

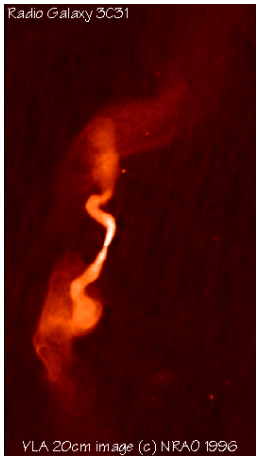


Radio Galaxies

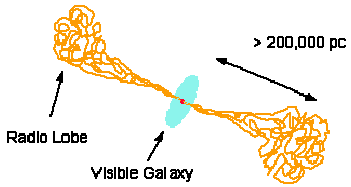
- There are varying types of radio galaxies
- Called *radio loud* as they can be 10 million times as bright as the Milky Way at radio wavelengths

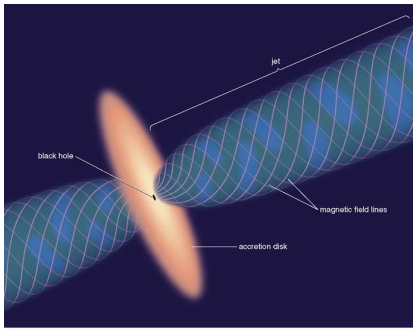


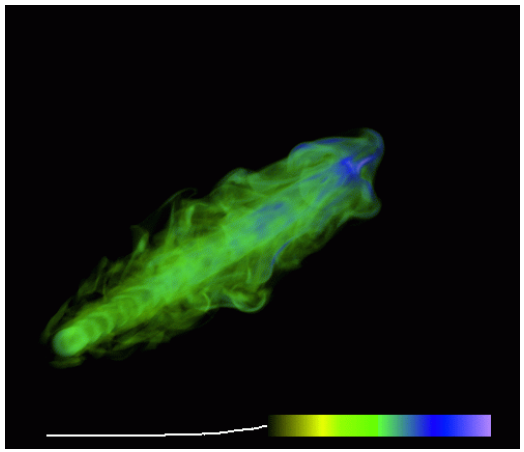




Radio Galaxy Jets



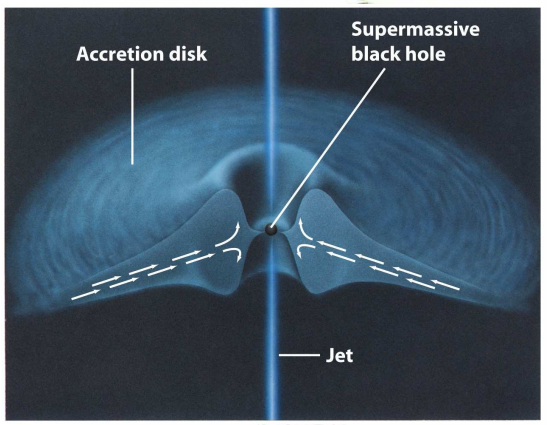




What is the power source for quasars and other active galaxies?

Driving Active Galaxies: The Monster Within

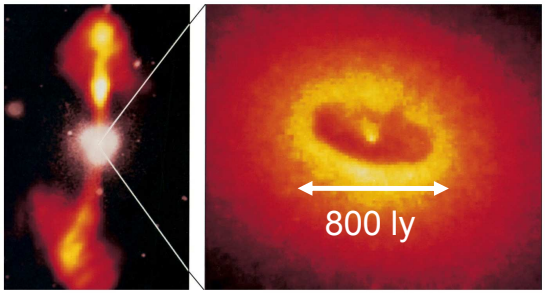
- A scary blue monster?
- Probably not
- More likely - the energy source is a supermassive black hole
- Accretion disk emits tremendous amounts of energy as it falls onto the black hole



The Central Engine

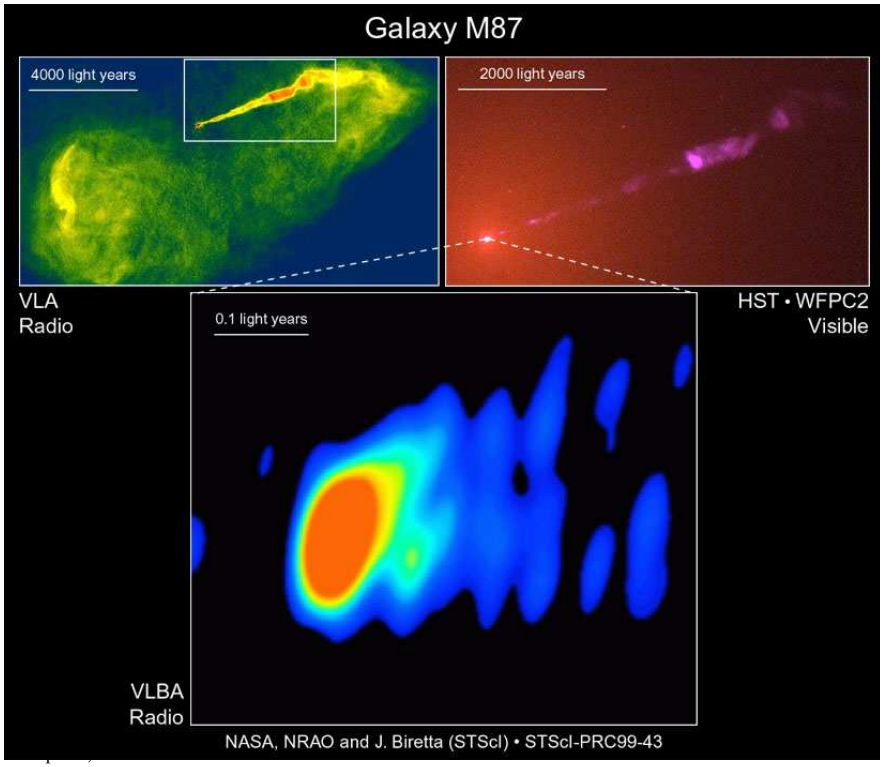
Supermassive Black Holes

- Energy source for active galaxies
- Only thing compact enough and energetic enough



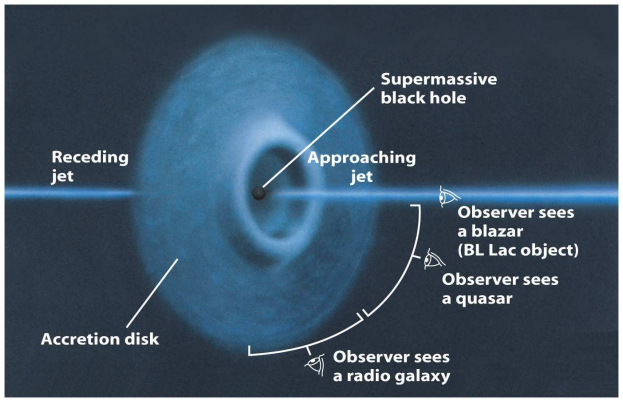
NGC 4261 in the Virgo Cluster

- Black holes > 1 billion solar masses
- Compression of material falling into black hole heats it up and forces some into jet



A Unified Model

- Active galaxies and quasars have the same energy source (supermassive black holes)
- Orientation matters!



Quasars and Active Galaxies

- Supermassive black holes probably exist in most if not all galaxies' cores
- In the past, active galaxies were more common then now
- Very powerful active galaxies were at one time quasars?
- As the Universe evolved, the quasars calmed down
  - Turned off?
  - Became today's active galaxies?

TABLE 16-1 Galaxy and Quasar Luminosities

Object	Luminosity (watts)
Sun	4×10^{26}
Milky Way Galaxy	10^{37}
Seyfert galaxies	$10^{36} - 10^{38}$
Radio galaxies	$10^{36} - 10^{38}$
Quasars	$10^{38} - 10^{42}$

Think-Pair-Share

If our Galaxy's supermassive black hole were fed, would it turn into an active galaxy?