Astronomy 122

This Class (Lecture 24):

Clusters and Quasars

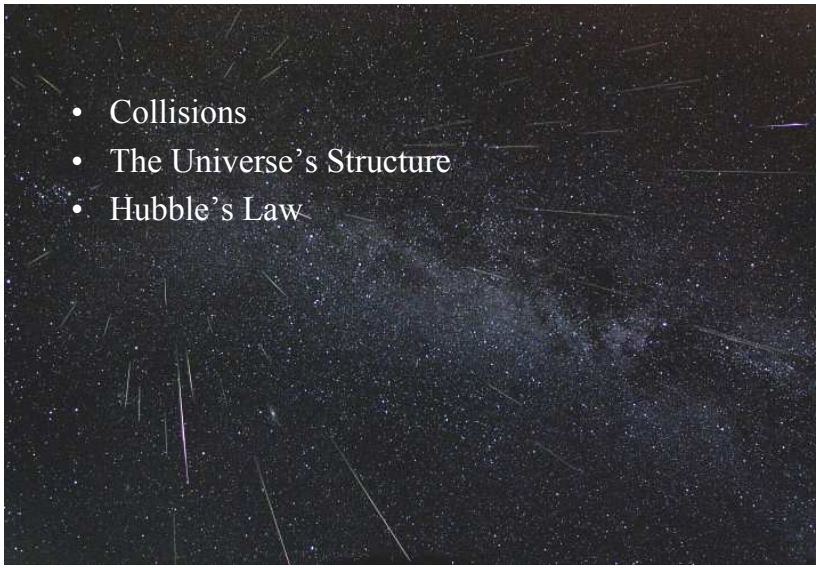
Next Class:

Active Galaxies

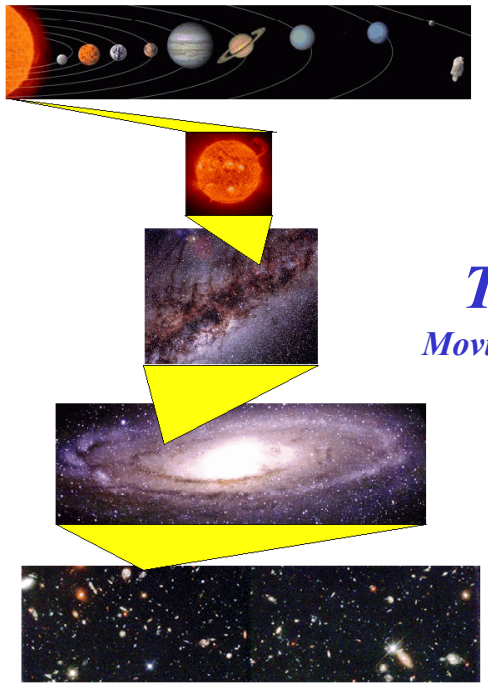
HW10 due on Sunday.

Music: *Where Gravity is Dead* – Laura Veirs

Outline



- Collisions
- The Universe's Structure
- Hubble's Law

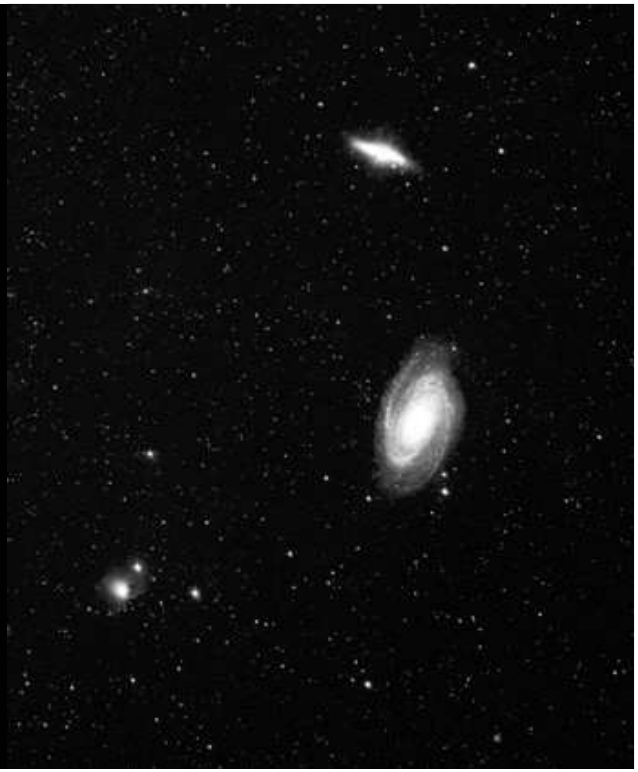


Astronomy: The Big Picture

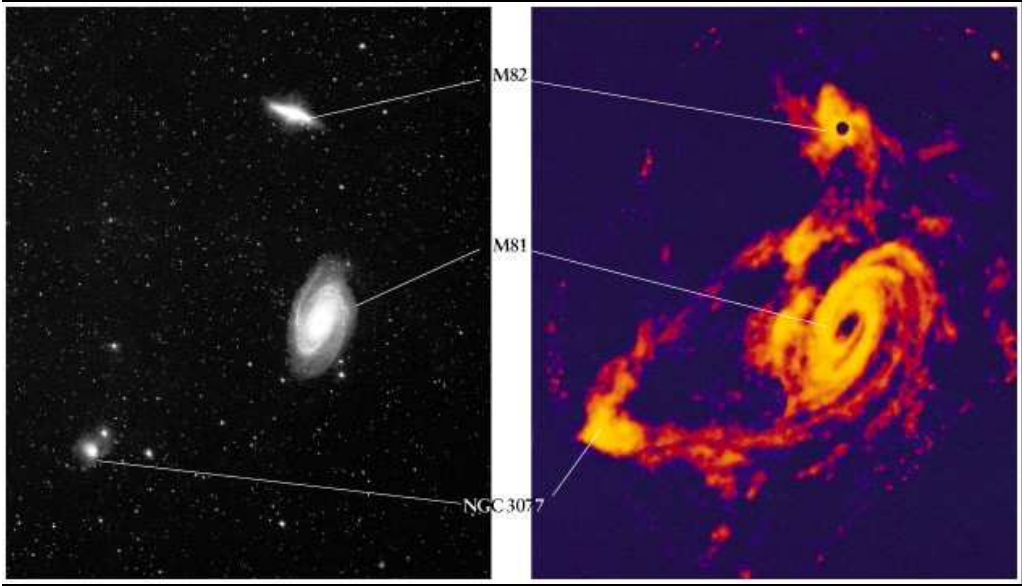
Moving from our Galaxy outward!

Three galaxies,
M81 (big),
M82 (medium), and
NGC 3077 (small).

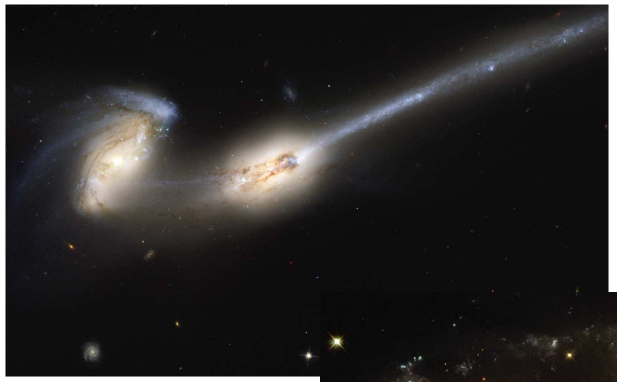
Are they related to one another?



Collisions



Galaxies Collide



NGC 2207 &
IC 2163

NGC 7676
"The Mice"

Question

Do galaxies ever collide?

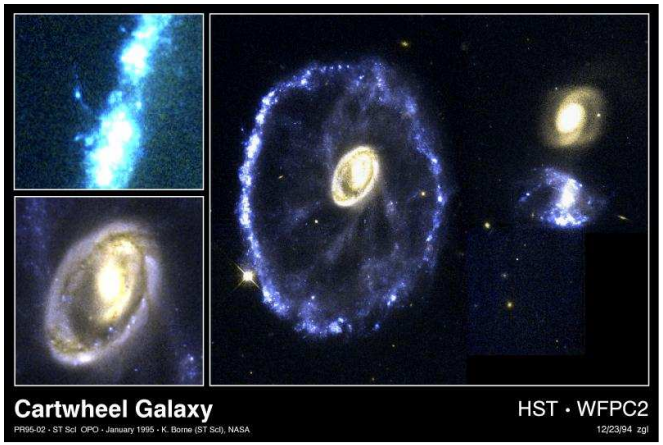
a) No, they are too far away from each other.
b) No, they move too slow.
c) Yes, every galaxy is colliding with another.
d) Yes, sometimes.
e) Yes, if I throw two Milky Way candy bars together.

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"

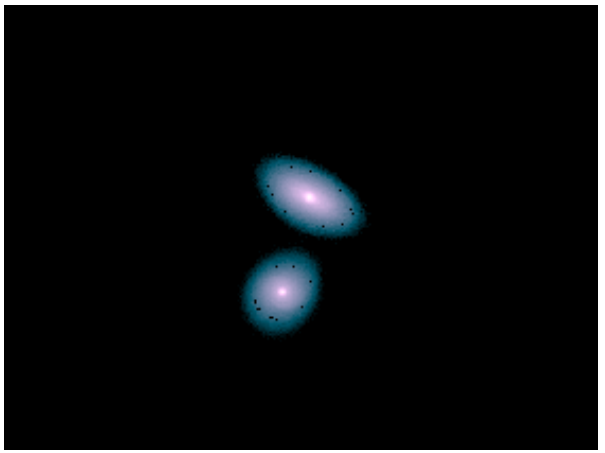
Starburst Galaxies

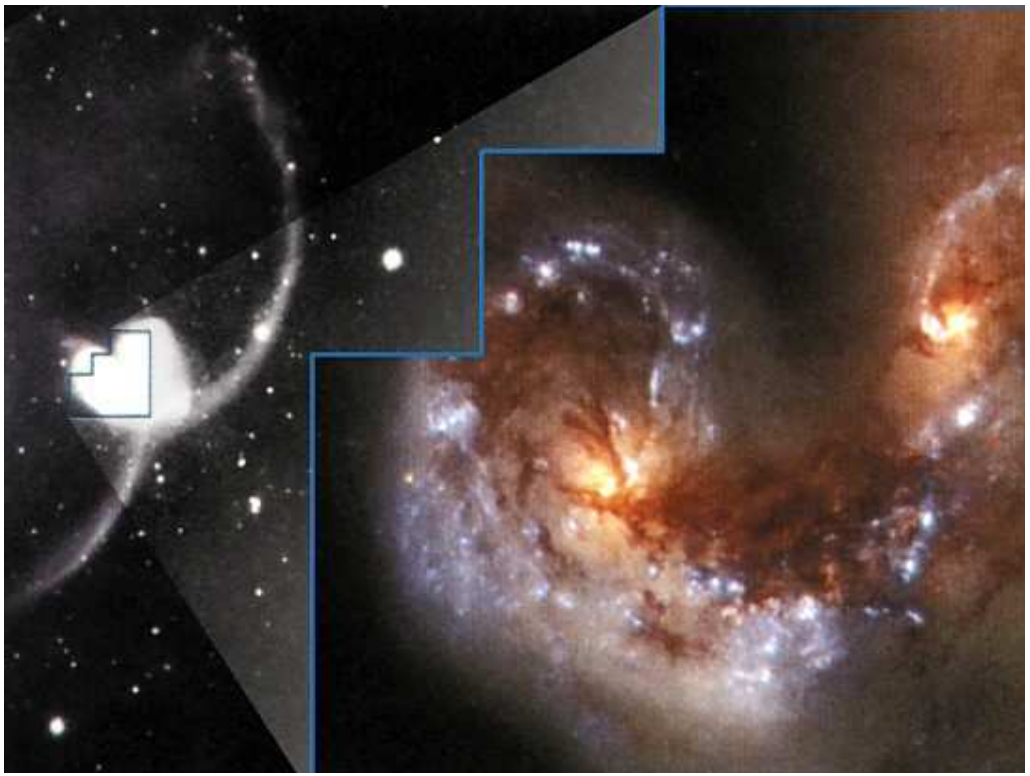
- Galaxies with enhanced rates of star formation
- Usually forming massive stars for a short period (few Myr).
- Probably due to collisions



Galaxy Collisions

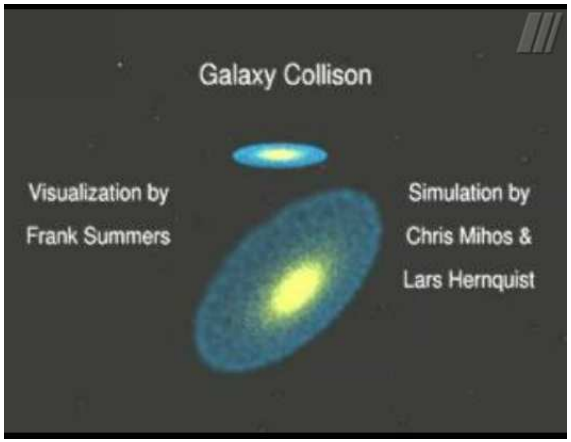
Computer simulation of two galaxies colliding by John Dubinski and Lars Hernquist



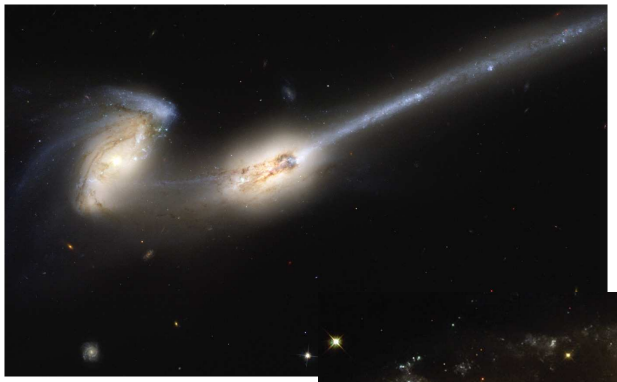


Galaxies Collide

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



Galaxies Collide



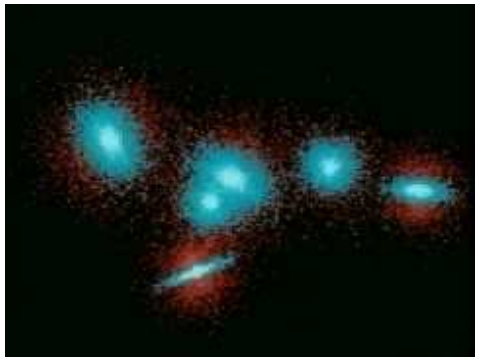
NGC 2207 &
IC 2163

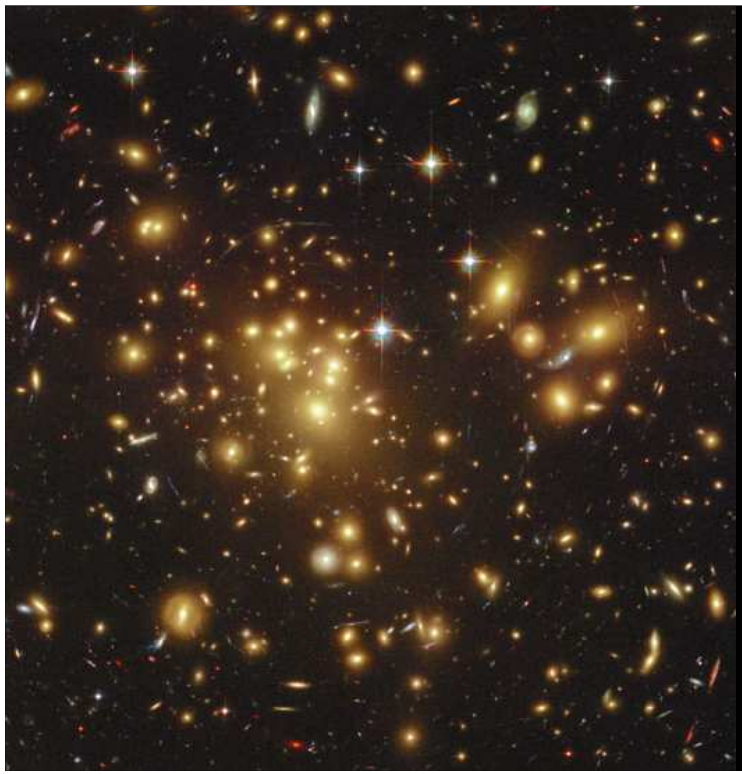
NGC 7676
"The Mice"

Collisions are also a factor in galaxy evolution!

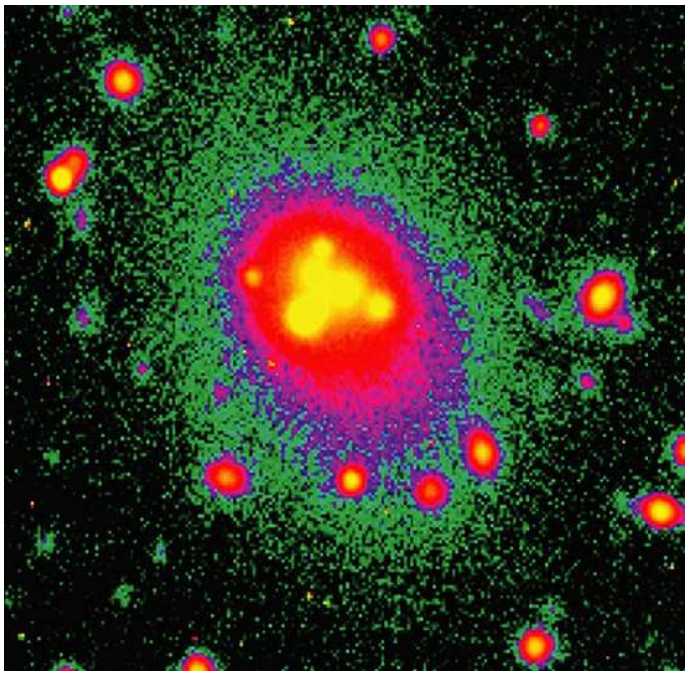
Multi-galaxy Collisions

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





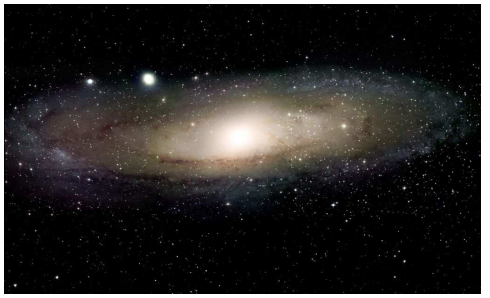
Collisions may explain why elliptical galaxies tend to be found where galaxies are closer together.



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

Fate of the Milky Way: It's coming right for us!

- What will happen to the Milkyway?
  - It will continue to grow as it cannibalizes the smaller orbiting galaxies.
  - The Andromeda galaxy is on a collision course.
  - Eventually (billions of years) we will end up a combined galaxy.
  - Probably look like an elliptical galaxy.



http://www.seds.org/messier/small/m87.gif

A Possible Future

- Simulation of what that may look like
- Assuming we have not died and can fix the increased brightness of the Sun as it ages
- So, 3 billion years in the future..
- What would the night sky look like?

Question

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

a) Yes, they will be torn apart.
b) No, a galaxy is mostly empty space, so very small chance that stars collide.
c) About half of the stars (the bigger ones) will collide, due to their high mass.
d) It depends on the size of the two galaxies.

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?

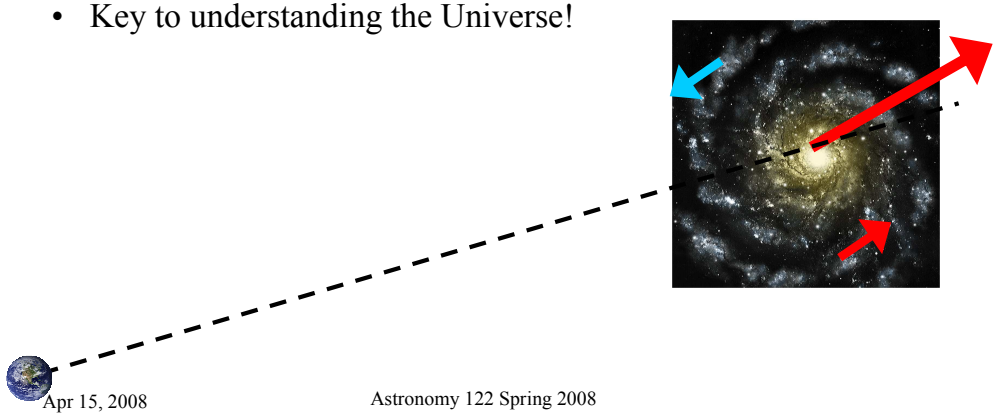
It's 1928 and Edwin Hubble is measuring how galaxies move by measuring the velocity WRT us.

What does he find?

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

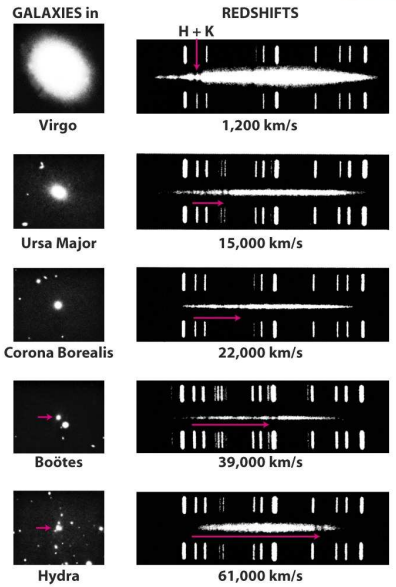
Redshift of Galaxies

- 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!



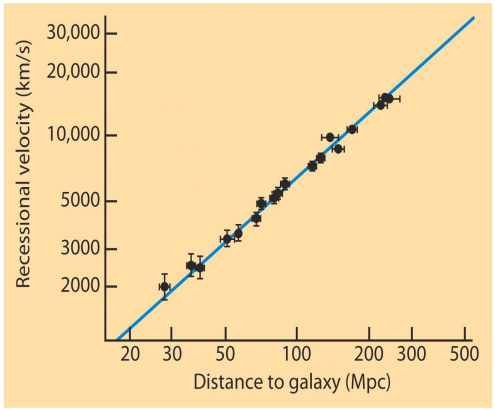
Redshifted Galaxies

- 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*



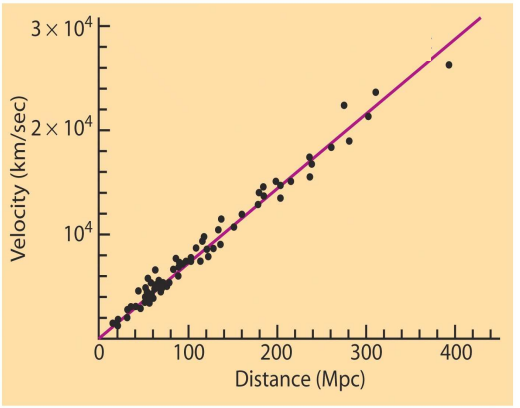
The Hubble Law

- 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=71 km/s/Mpc



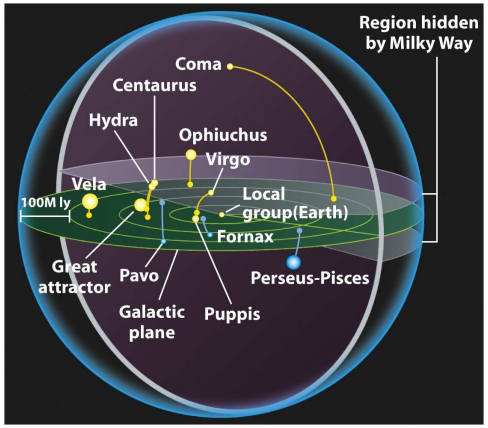
Redshift and Distance

- 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!



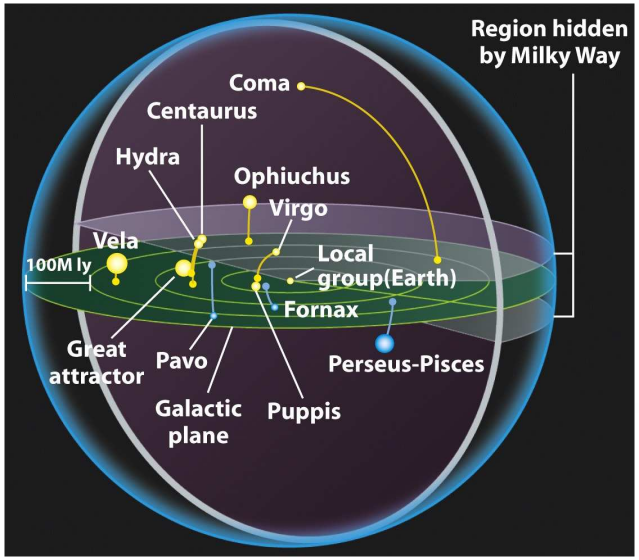
Galaxies Are Not Alone

- Galaxies are **not** scattered randomly throughout the Universe
- Galaxies are found in **clusters**
- Like clusters of stars, clusters of galaxies come in a wide variety
  - Poor or rich?
    - Dozens or thousands of members?
  - Regular or irregular?
    - Is the cluster concentrated towards the center?



800 Mly sphere, centered on Earth

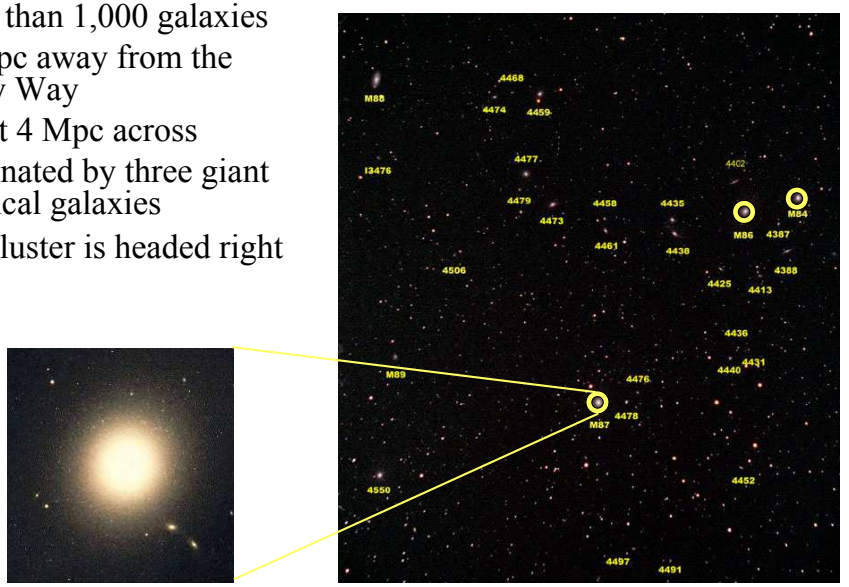
Nearby Clusters



800 Mly sphere, centered on Earth

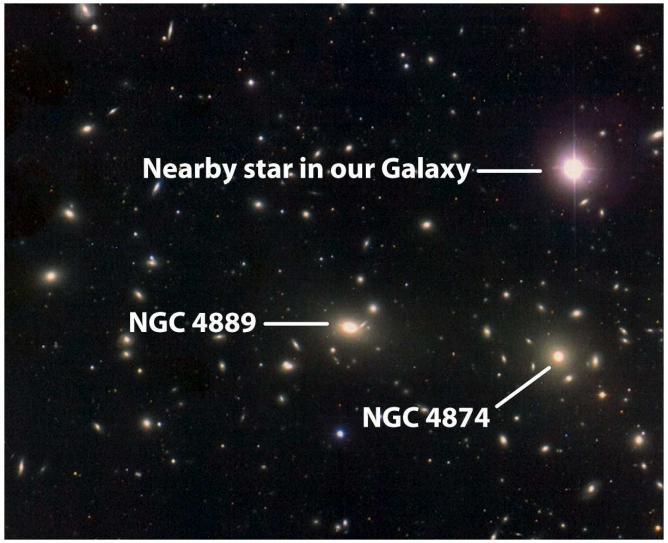
The Virgo Cluster

- More than 1,000 galaxies
- 16 Mpc away from the Milky Way
- About 4 Mpc across
- Dominated by three giant elliptical galaxies
- Our cluster is headed right for it.



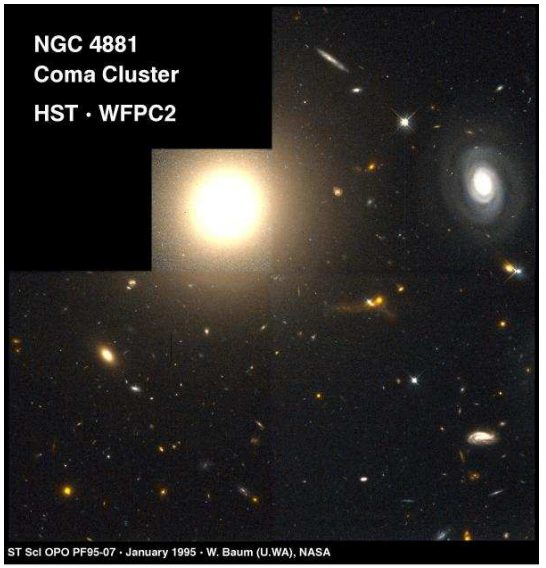
The Coma Cluster

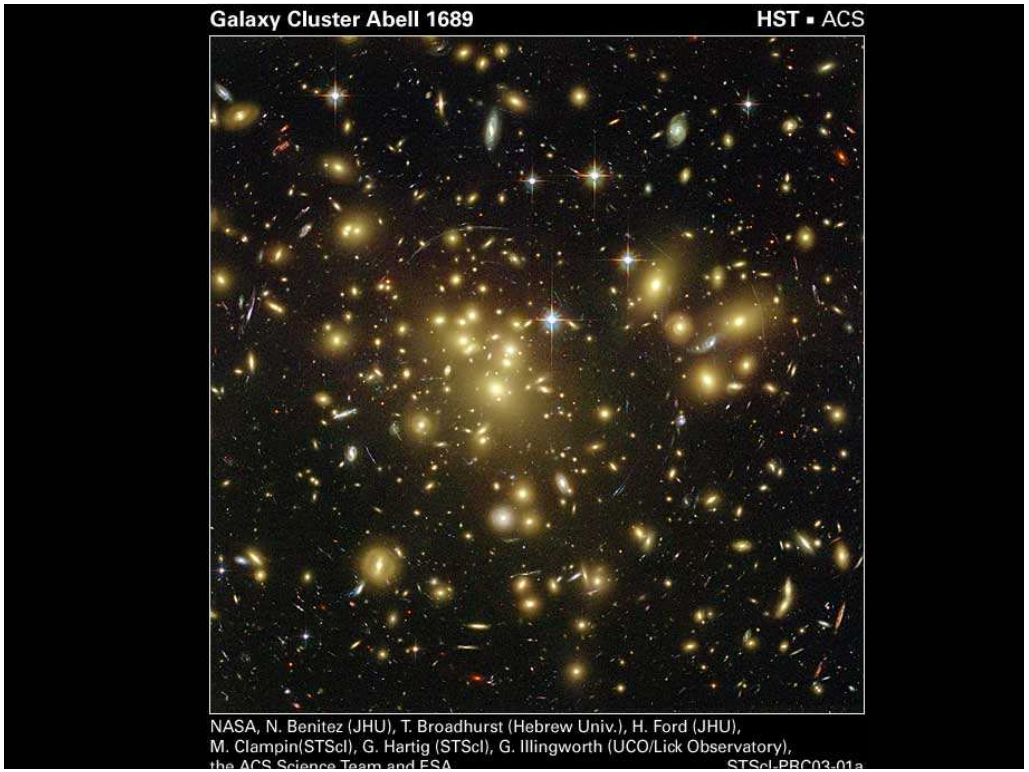
- Rich, regular cluster
- 90 Mpc = 300 million lyrs.
- Over 2000 galaxies.
- Dominated by two ellipticals



Coma Cluster

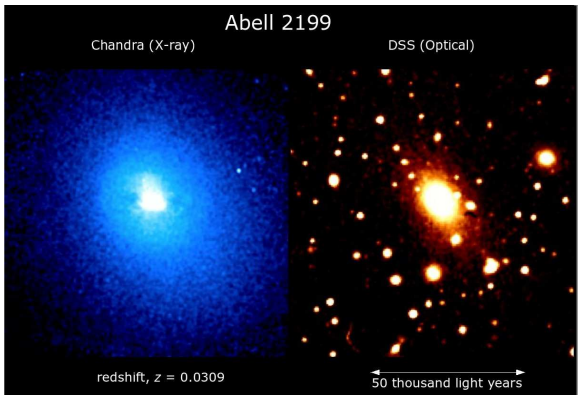
- A zoom near one of the ellipticals
- Contains many spirals





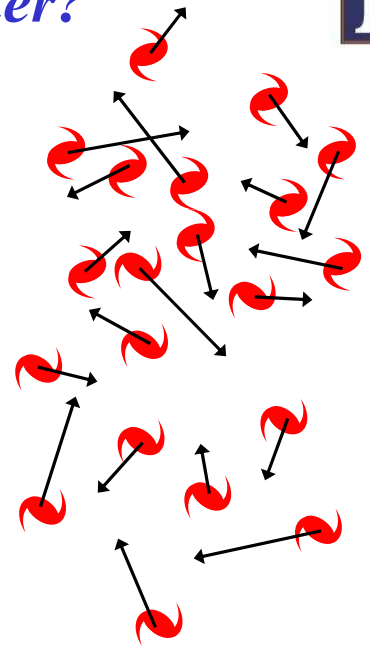
Intracluster Medium

- Clusters have bright X-ray emitting gas
  - Hot! – 10-100 million K
- Low density, but lots of it.
- Total mass of intergalactic gas is about twice that of the galaxies!

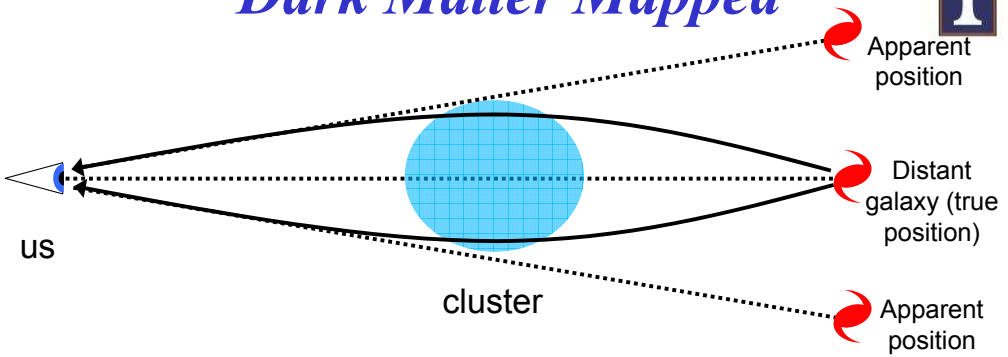


Dark Matter?

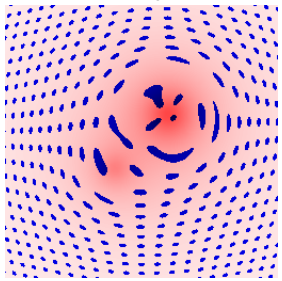
- If the clusters only have the visible mass in the cluster, then the cluster should dissipate.
- Not enough mass to hold the cluster together.
- Visible matter must only be about 10% of the total mass.
- **Dark Matter!**
- **Again!**



Dark Matter Mapped



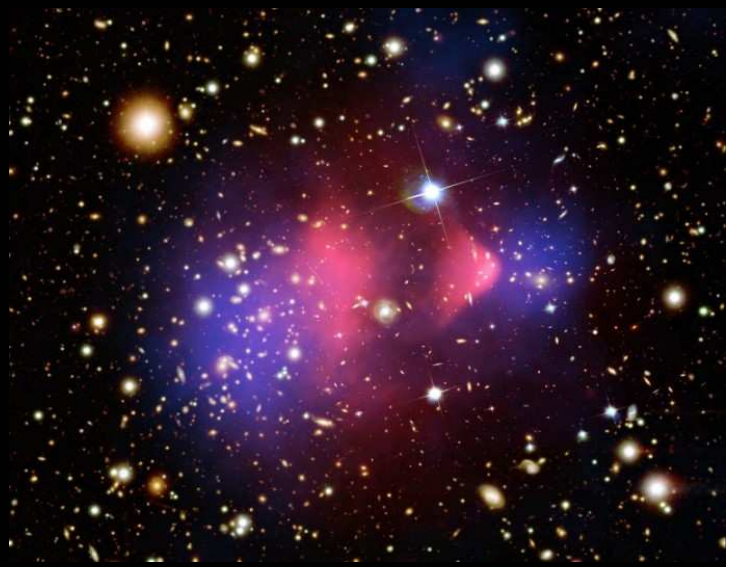
- Mass causes gravity lensing.
- Can use the warping of light to estimate the mass distribution in the cluster.



N. Wright (UCLA)

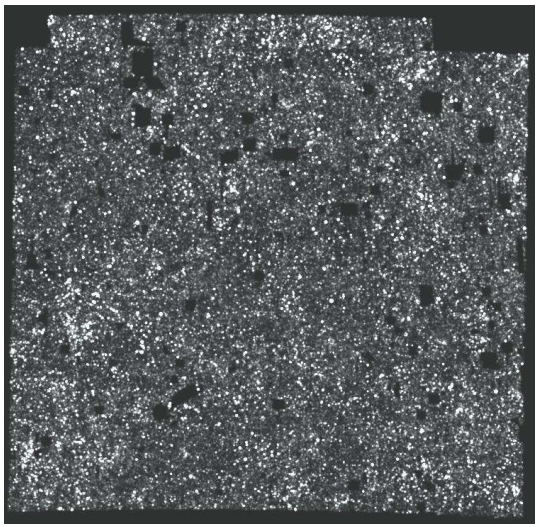
The Bullet Cluster

- Collision of 2 clusters!
- Best case for dark matter.
- The galaxies are shown in the HST image.
- Red is the x-ray gas.
- Blue is where the mass is located!



The Universe

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

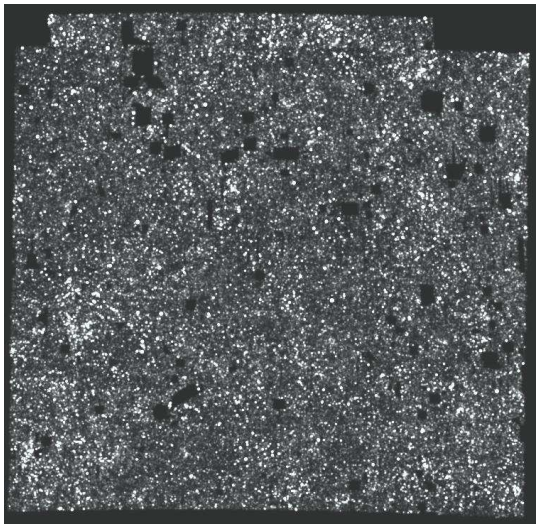


http://www-int.stsci.edu/~postman/deeprange.html

The Universe

The Universe is

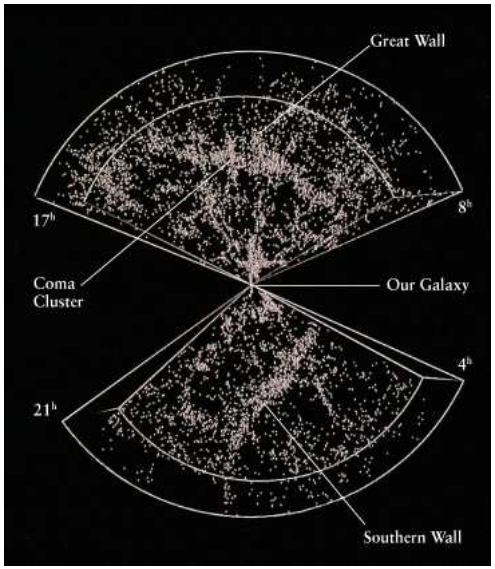
1. Homogeneous (gal's uniformly fill space)
2. Isotropic (looks same in all directions)
   - These are the starting points for our Cosmological journey



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

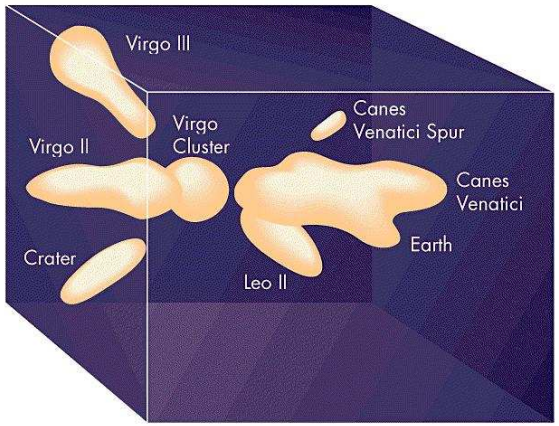
Structure of the Universe

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



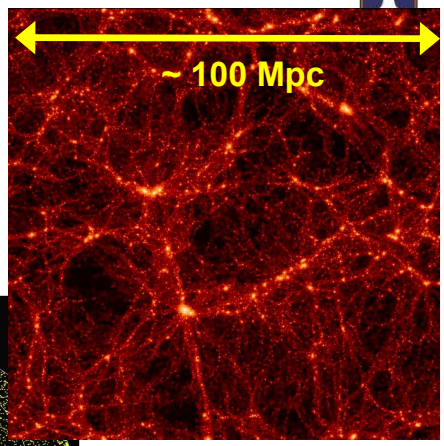
The Local Supercluster

- 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

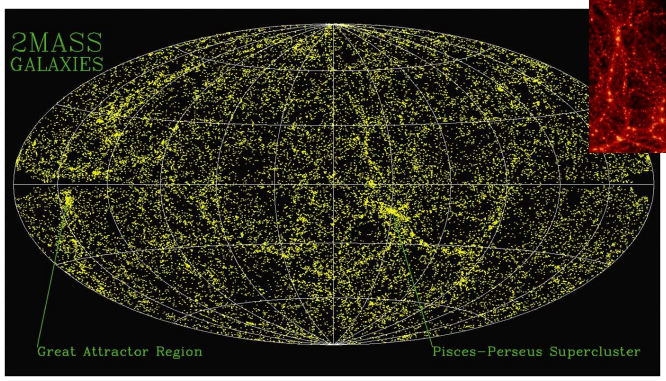


Structure of Universe

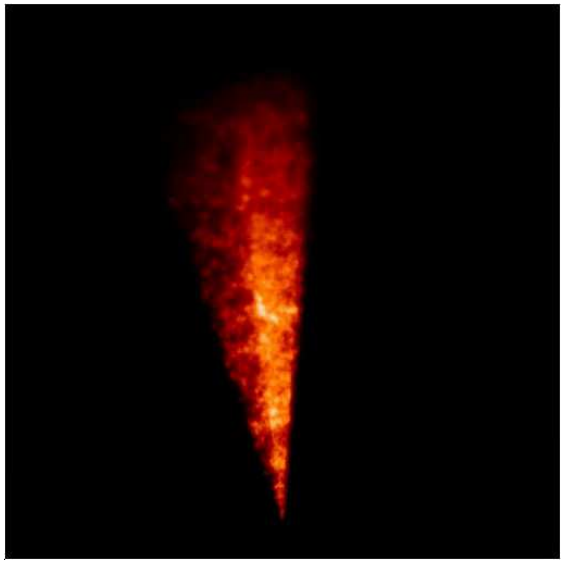
- Superclusters are distributed in Universe.
- Filamentary and sheet structure.
- Voids of nothing between them.



Computer simulation (A. Jenkins)

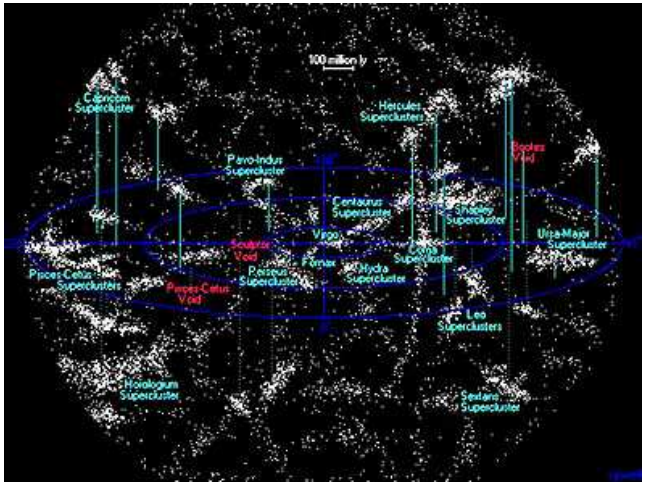


Structure of the Universe



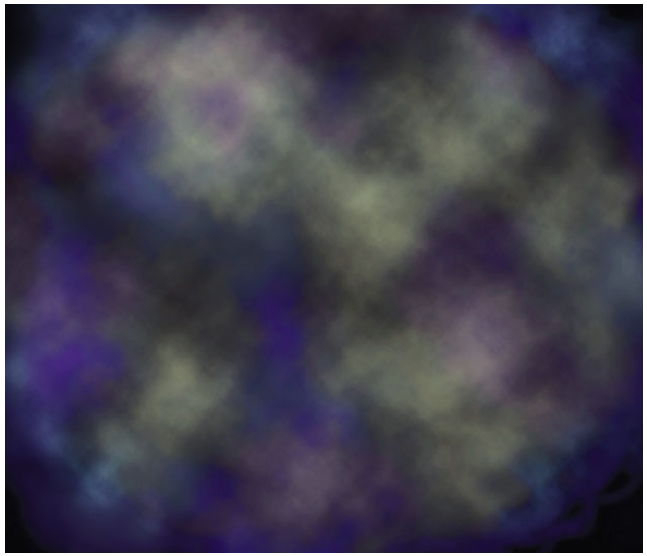
"Sudsy" Universe

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



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

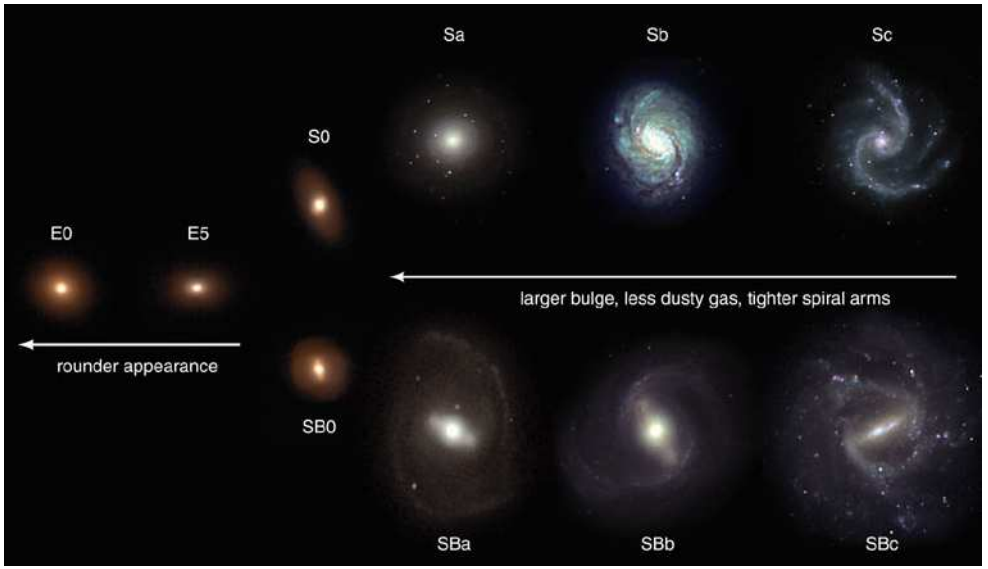
- Supernova explosions from first stars kept much of the gas from forming stars
- Leftover gas settled into spinning disk
- ***Conservation of spin***

But why do some galaxies end up looking so different?

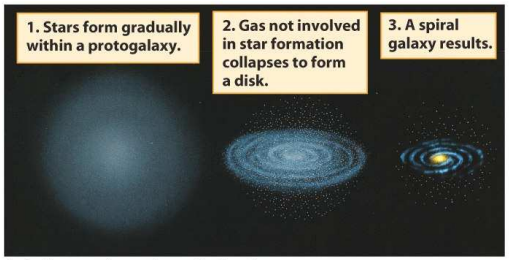
NGC 4414

M87

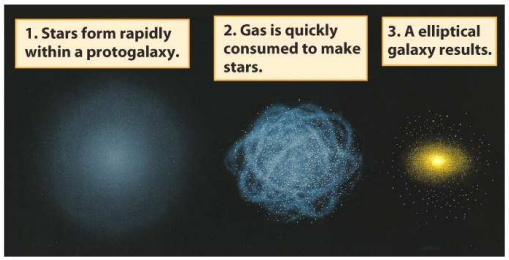
Why don't all galaxies have similar disks?



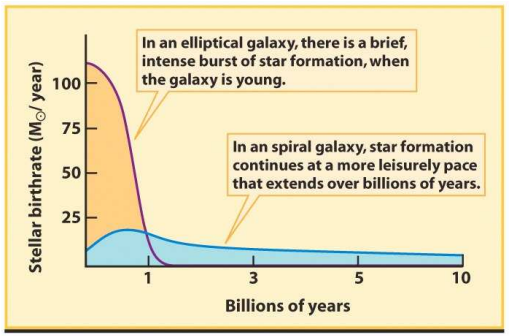
Conditions in the Protogalactic Cloud?



(a) Formation of a spiral galaxy

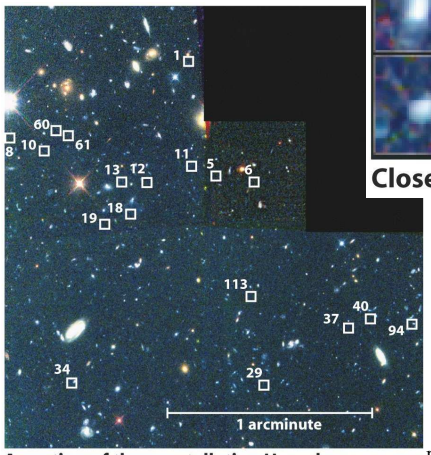


(b) Formation of an elliptical galaxy

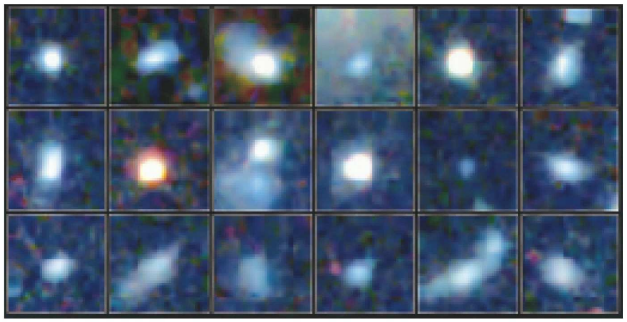


(c) The stellar birthrate in galaxies

Looking Back in Time



A portion of the constellation Hercules



Closeup images of the numbered objects in (a)

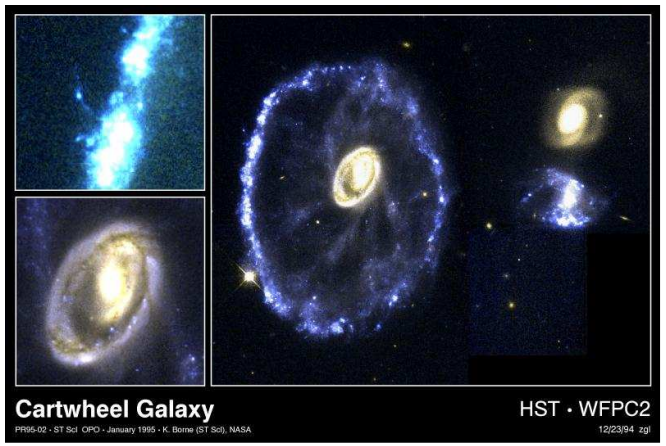
- Older galaxies are around 11 billion lyrs.
- They are small and blue.
- Add a number together would make a modern galaxy.

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

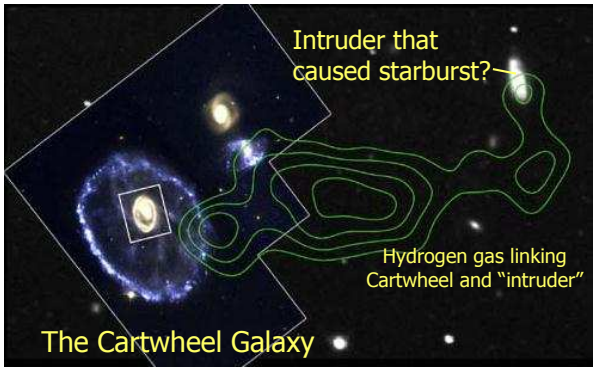
Starburst Galaxies

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



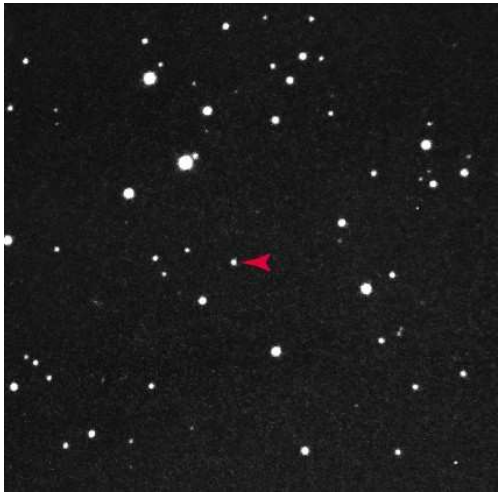
Starburst Galaxies

- 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 $\Rightarrow z = 0.16$
- 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