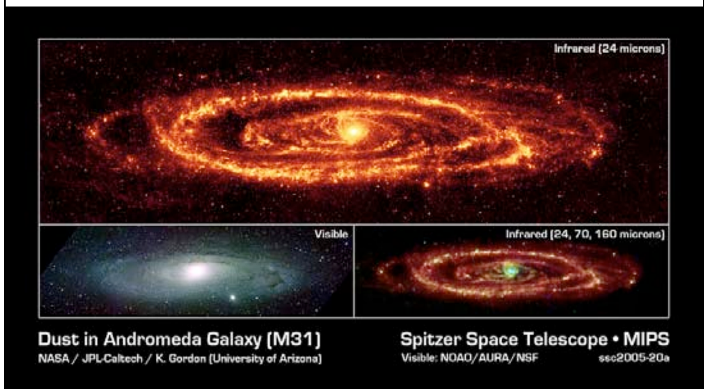
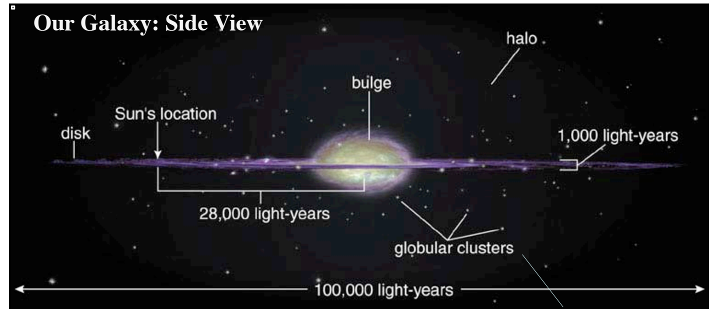
Lecture 14: Other Galaxies
A2020 Prof. Tom Megeath

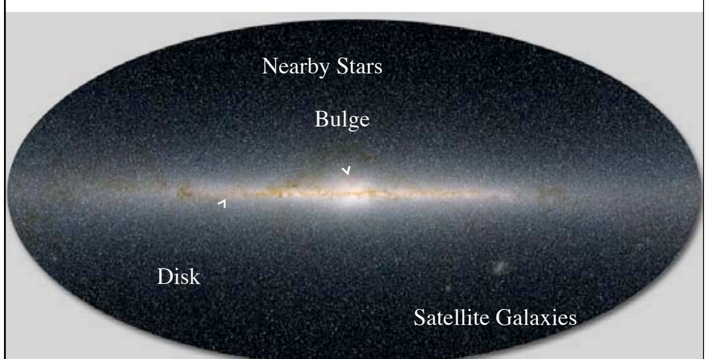




We see our galaxy edge-on

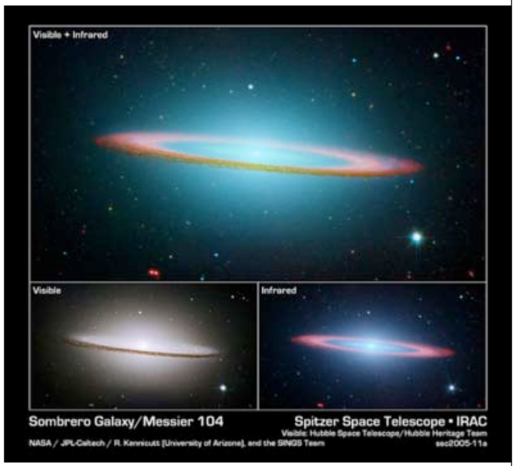
Primary features:
Disk: young and old stars – where we live.
Bulge: older stars
Halo: oldest stars, globular clusters, dark matter

The Milky Way in the Infrared



View from the Earth: *Edge On*

Disk Component:
stars of all ages,
many gas clouds



Spheroidal Component:
bulge & halo, old stars, few gas clouds

Disk Component:
stars of all ages,
many gas clouds

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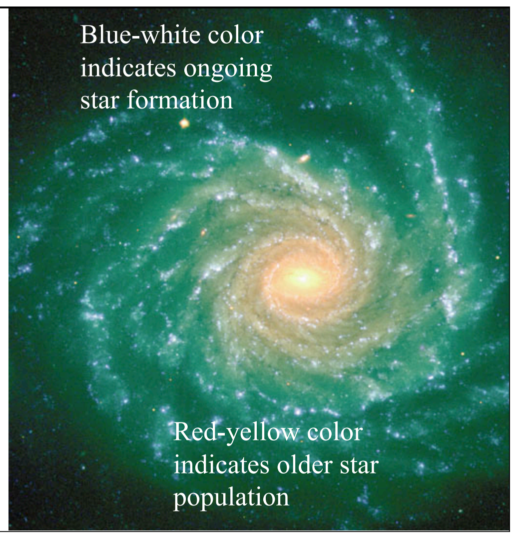

Thought Question

Why does ongoing star formation lead to a blue-white appearance?

A. There aren't any red or yellow stars
B. Short-lived blue stars outshine others
C. Gas in the disk scatters blue light

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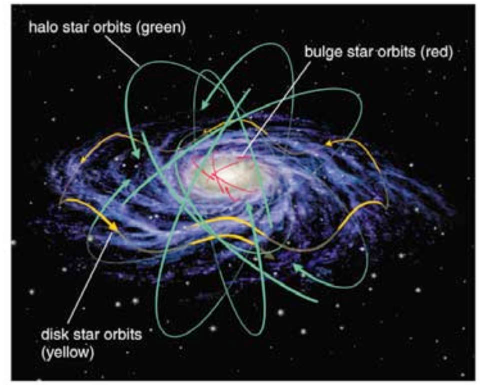
How do stars orbit in our galaxy?



Orbits of stars in the bulge and halo have random orientations

Stars in the disk all orbit in the same direction with a little up-and-down motion

Thought Question

Why do orbits of bulge stars bob up and down?

A. They're stuck to interstellar medium
B. Gravity of disk stars pulls toward disk
C. Halo stars knock them back into disk

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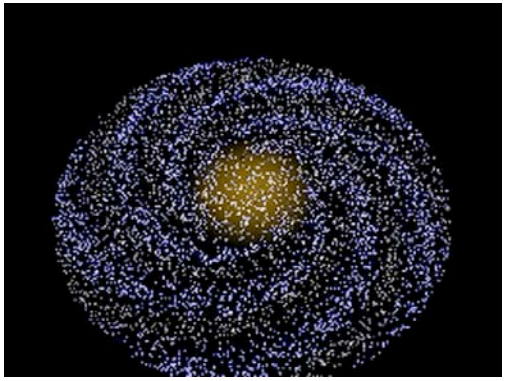
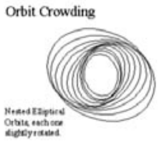
Spiral Density Waves



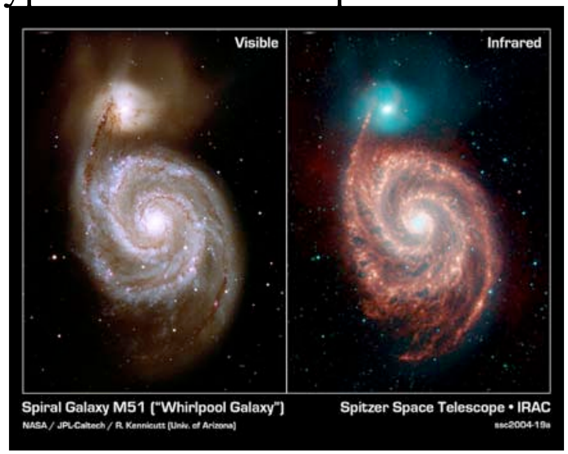
What causes spiral density waves?

Why don't spiral arms wrap up into tighter and tighter configurations?

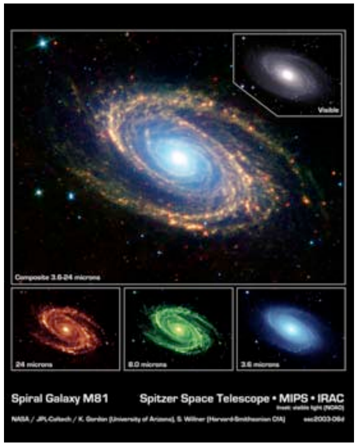
Spiral density waves are gravity induced "traffic jams"



Types of Galaxies: Spiral Galaxies



Gas and Dust in Spiral Galaxies



3.6 micron light traces stars

8.0 and 24 micron light traces dust in the interstellar medium.

Gas and dust get trapped and concentrated in spiral density waves - leading to the formation of molecular cloud complexes and star formation.

Barred Spiral Galaxy: Has a bar of stars across the bulge

Lenticular Galaxy

Share characteristics of ellipticals and spirals.

Like spirals they have disks, halos, bulges, and sometimes bars.

Like ellipticals they have little if no gas. Do not show spiral arms and have little ongoing star formation.

Elliptical Galaxy:

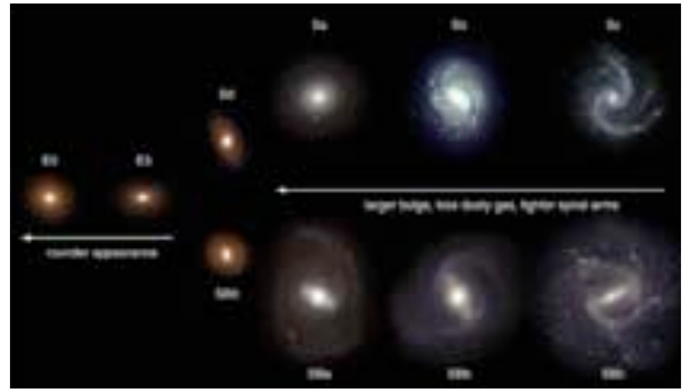
Elliptical or spherical shape, no disk component

Red-yellow color indicates older stars: no gas or star formation

Random orbits!

Irregular Galaxy

Large Magallenic Cloud



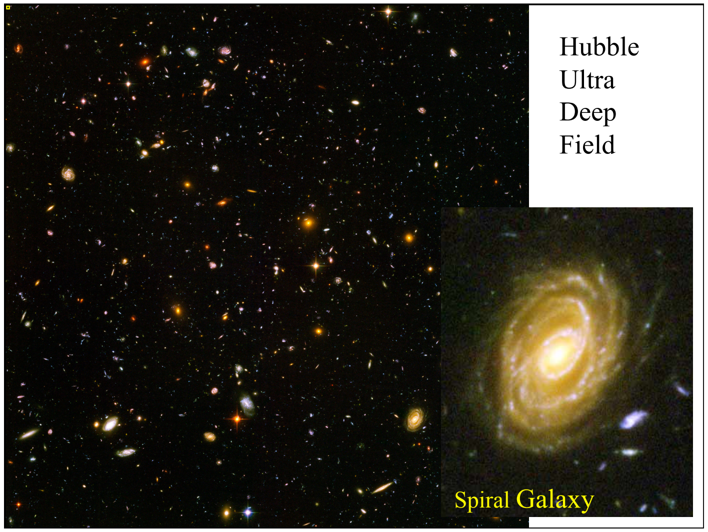
Spheroid Dominates

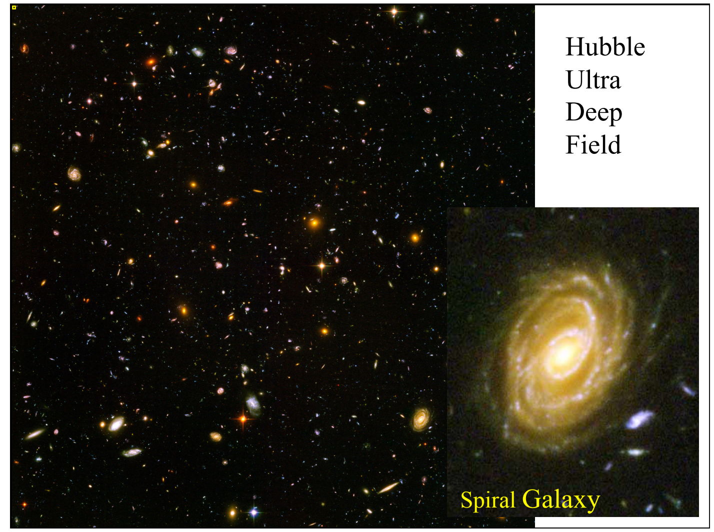
Hubble's galaxy classes

Disk Dominates

Hubble Ultra Deep Field

Hubble Ultra Deep Field


Hubble
Ultra
Deep
Field
Spiral Galaxy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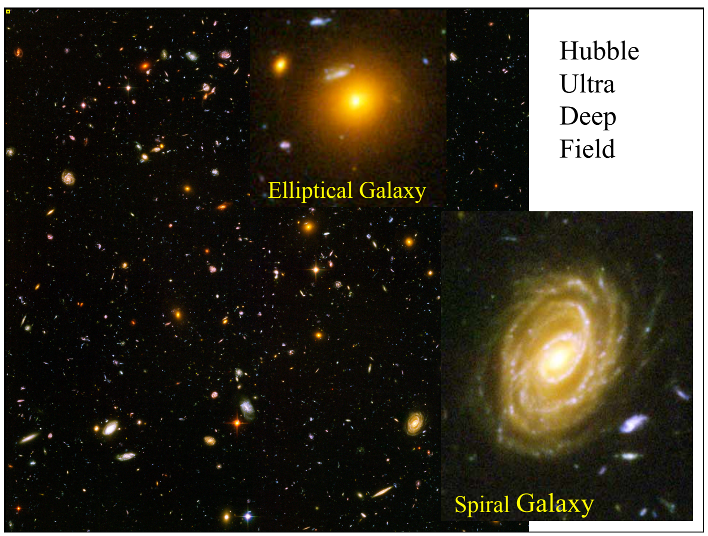
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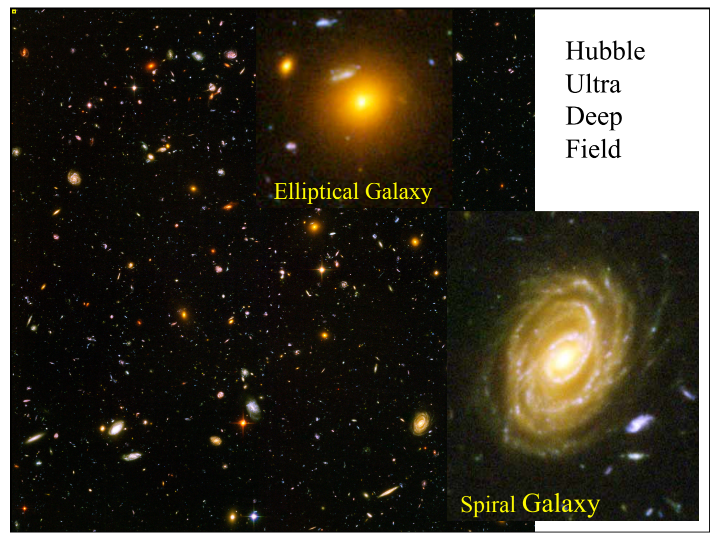
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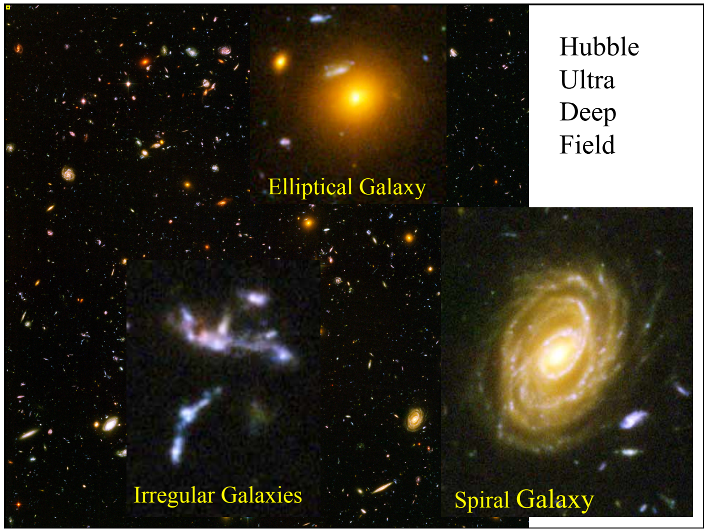
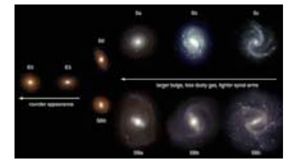


Hubble Ultra Deep Field

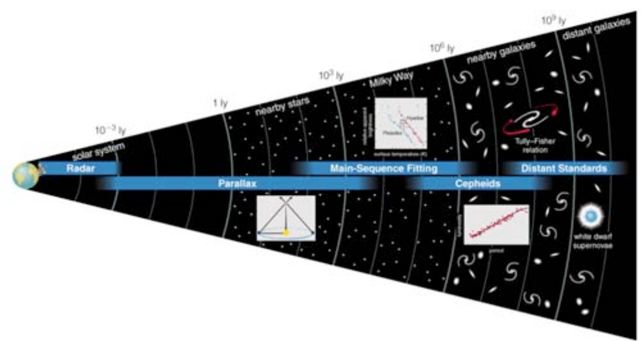
Our Own Galaxy

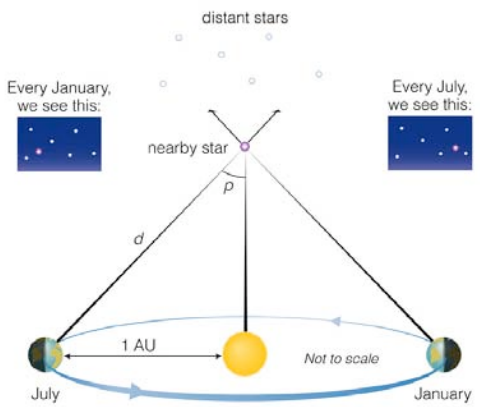


What have we learned?

- What are the four major types of galaxies?
  - Spiral galaxies, elliptical galaxies, lenticular galaxies and irregular galaxies
  - Spirals and lenticulars have both disk and spheroidal components; ellipticals have no disk
- Stars are always in motions
  - In spheroidal components of spirals and in ellipticals, orbits are randomly distributed
  - In spiral disks, stars orbit around disk, bound together by the common gravity of the stars.
  - Spiral arms are traffic jams in galaxy disks

How do we measure the distances to galaxies?

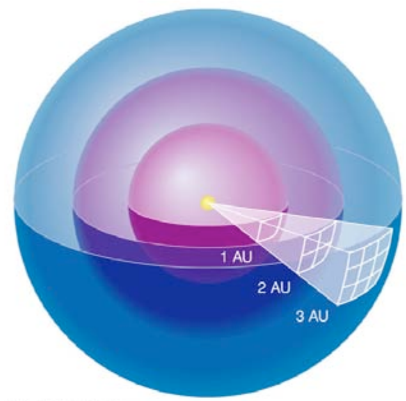




Step 1

Determine distances of stars out to a few hundred light-years using parallax

Standard Candles



Luminosity passing through each sphere is the same

Area of sphere:

$4\pi\ (\text{radius})^2$

Divide luminosity by area to get brightness

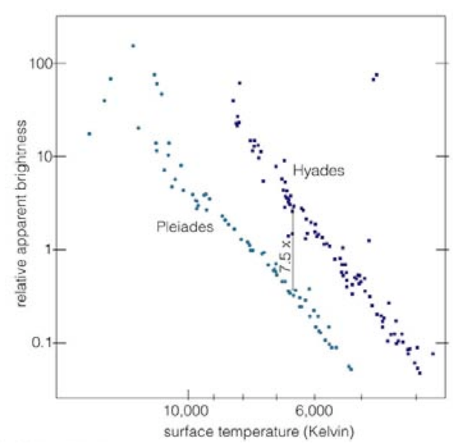
The relationship between apparent brightness and luminosity depends on distance:

$$\text{Brightness} = \frac{\text{Luminosity}}{4\pi\ (\text{distance})^2}$$

We can determine a star's distance if we know its luminosity and can measure its apparent brightness:

$$\text{Distance} = \sqrt{\frac{\text{Luminosity}}{4\pi \times \text{Brightness}}}$$

A ***standard candle*** is an object whose luminosity we can determine without measuring its distance



Step 2

Apparent brightness of star cluster's main sequence tells us its distance.

Clusters can be used as standard candles.

Knowing a star cluster's distance, we can determine the luminosity of each type of star within it

Thought Question

Which kind of stars are best for measuring large distances?

A. High-luminosity stars
B. Low-luminosity stars

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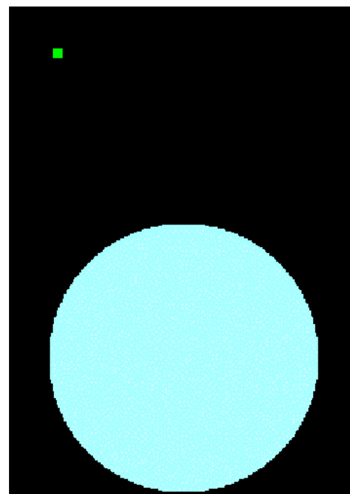
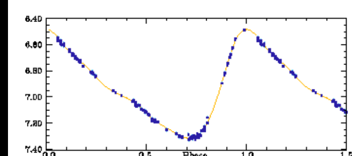


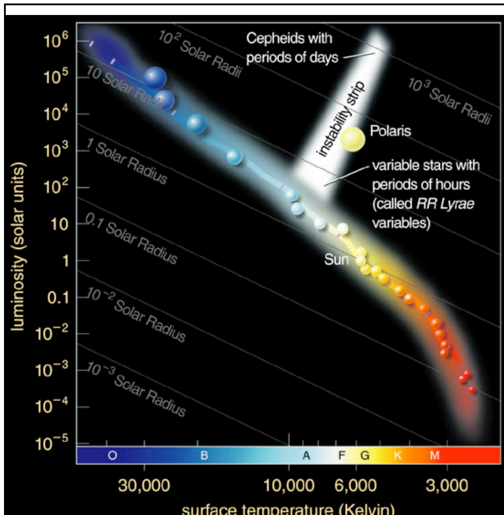
http://www.konkoly.hu/staff/kollath/gallery.html

Rung 3: Cepheid Variables as standard candles

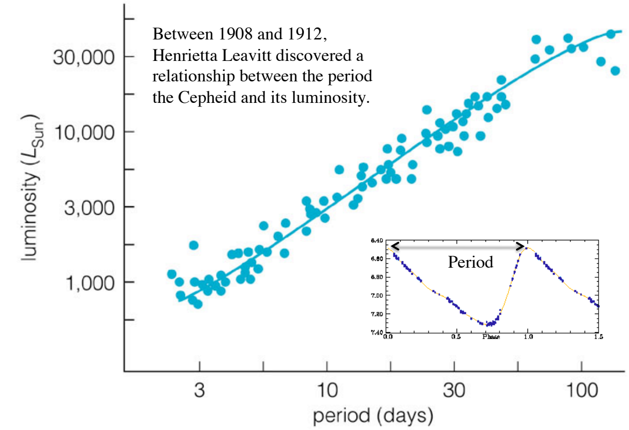


http://www.calstatela.edu/faculty/kaniol/a360/cepheids.htm

Cepheids pulsate with a period between 1 and 100 days. The pulsation causes changes in brightness which can be easily measured.



Cepheid variable stars are very luminous



This meant that Cepheids are a powerful standard candle

Rung 3: Cepheids as Standard Candles

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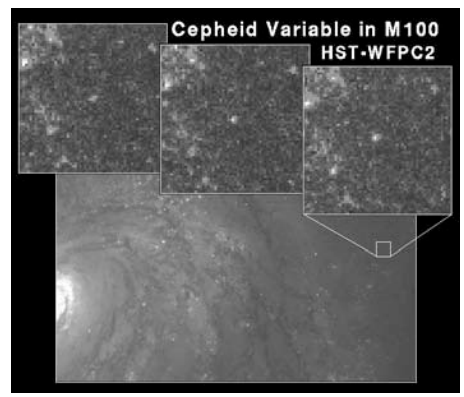
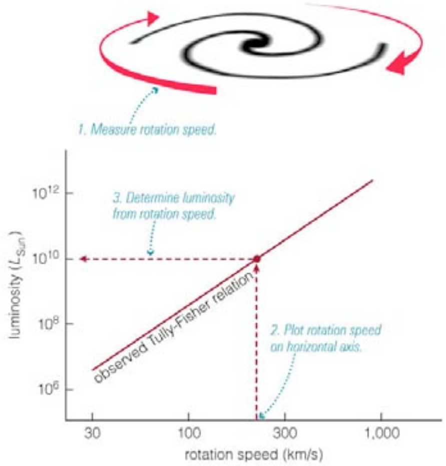


Because Cepheids are bright, they can be detected in distant galaxies. As we learned, Hubble used Cepheids to obtain the first measurements of the distances of the M31 and M33 galaxies.

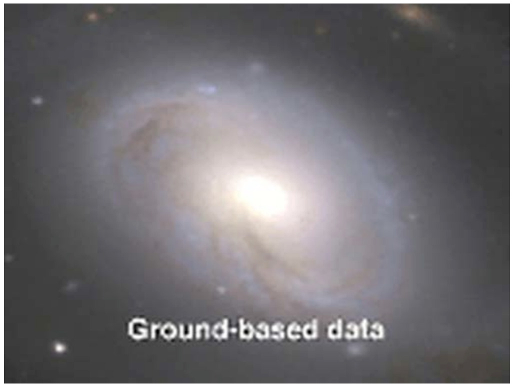
With the Hubble space telescope, astronomers can now measure the periods of Cepheids in distant galaxies.

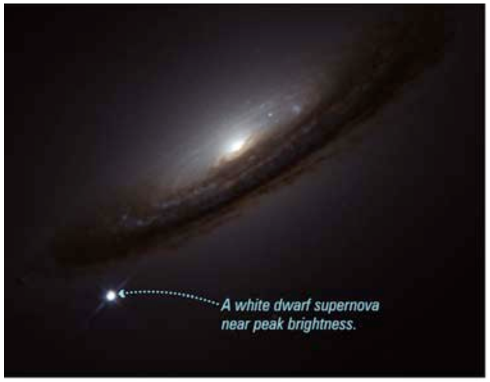


Tully-Fisher Relation

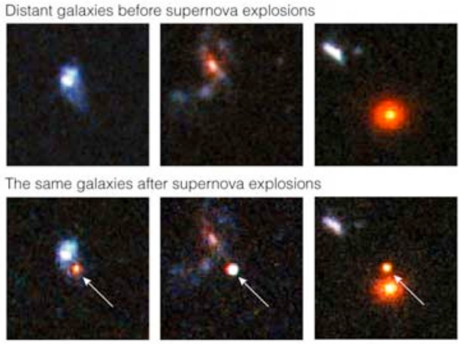
Entire galaxies can also be used as standard candles because galaxy luminosity is related to rotation speed

Rung 5 (the ultimate rung): White Dwarf Supernova





White-dwarf supernovae can also be used as standard candles

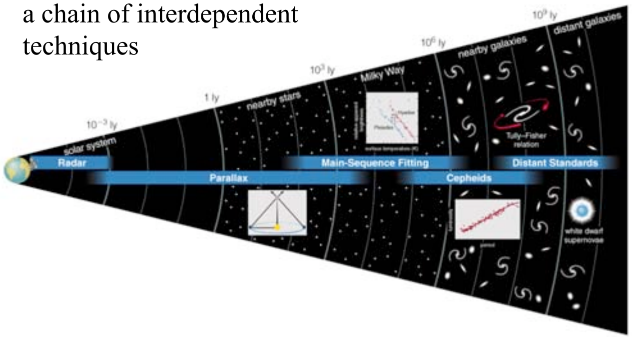


Step 4

Apparent brightness of white-dwarf supernova tells us the distance to its galaxy

(up to 10 billion light-years)

We measure galaxy distances using a chain of interdependent techniques



How did Hubble prove that galaxies lie far beyond the Milky Way?

Spiral Nebulae and Island Universes

M33: Earl of Rose 1850

In the 1920s, a debate raged about the nature of spiral nebulae.

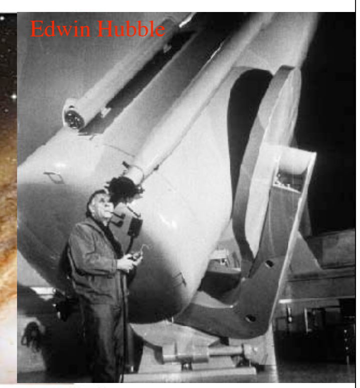
In small telescopes, these looked like nebulae.

Some thought these might be forming solar systems in our galaxy.

In the late nineteenth century, it was arugued that spiral nebulae were not nebulae, but island universes like our own Milky Way.

As we now know, the island universe was correct.

Edwin Hubble finds the Distances to M31 and M33 & Shows that Galaxies are Island Universes like the Milky Way



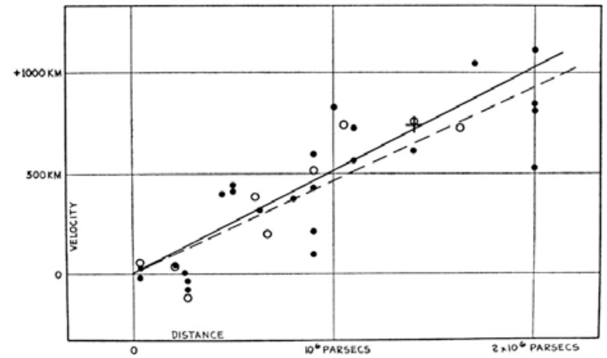
Hubble used newly built 100" telescope to find CepheidsVariable Stars in M31 & M33
Measurements of Cepheid Variables gave distances of 1,000,000 light years

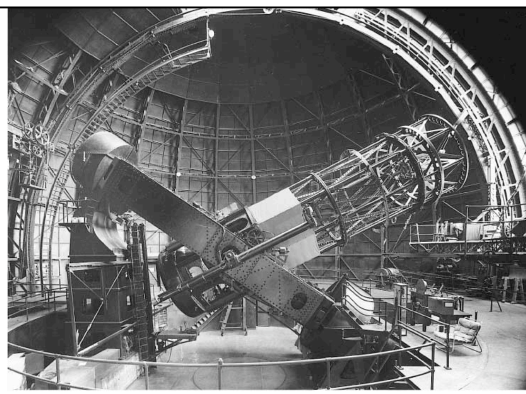
Photographic Techniques began to Resolve Galaxies into Stars and Nebulae

M33: Earl of Rose 1850

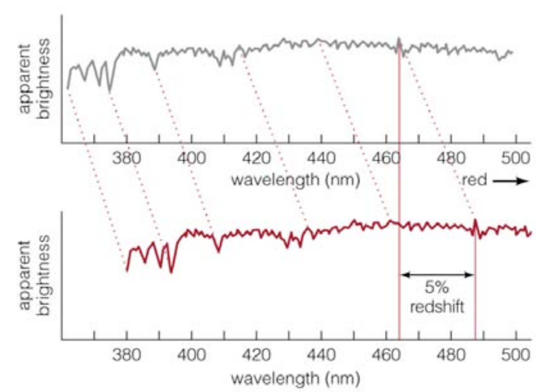
M33: Modern image

What is Hubble's Law?

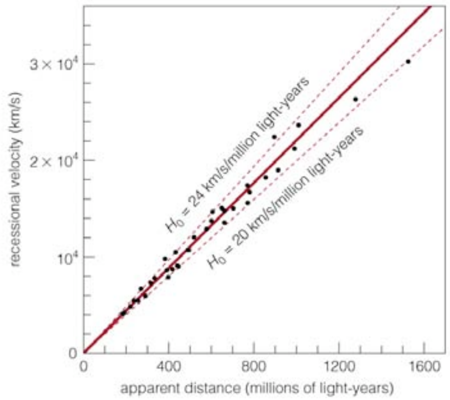




Using new large telescopes (the advanced technology of the 1930s) Hubble could measure redshifts of galaxies and measure their distances using Cepheids.

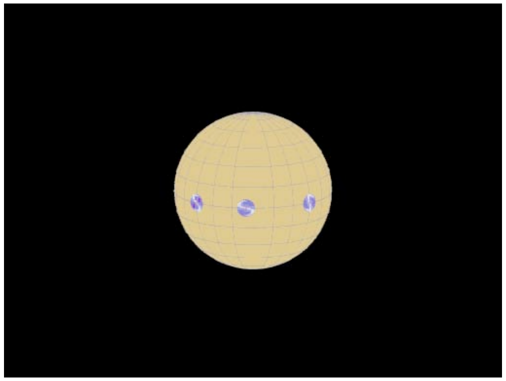


The spectral features of virtually all galaxies are ***redshifted*** ⇒ They're all moving away from us



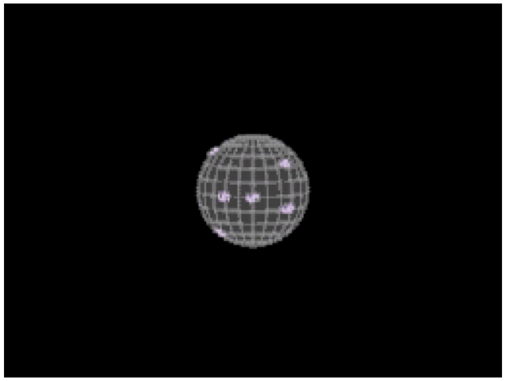
Hubble's Law: velocity = H_0 x distance

Hubble's Law and the Expanding Universe



http://phys23p.sl.psu.edu/phys_anim/astro/indexer_astro.html

Hubble's Law and the Expanding Universe



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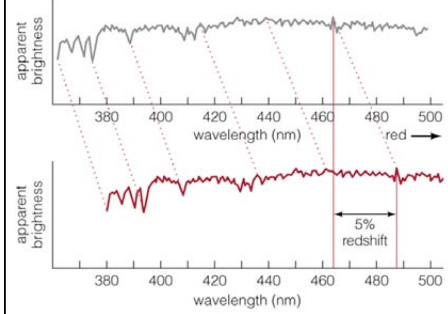
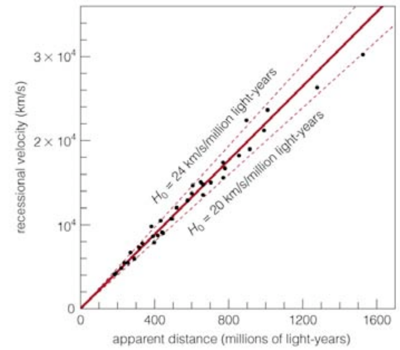


Redshift of a galaxy tells us its distance through Hubble's Law:

$$\text{distance} = \frac{\text{velocity}}{H_0}$$

Distances of farthest galaxies are measured from redshifts

How do distance measurements tell us the age of the universe?



Thought Question

Your friend leaves your house. She later calls you on her cell phone, saying that she's been driving at 60 miles an hour directly away from you the whole time and is now 60 miles away. How long has she been gone?

A. 1 minute
B. 30 minutes
C. 60 minutes
D. 120 minutes

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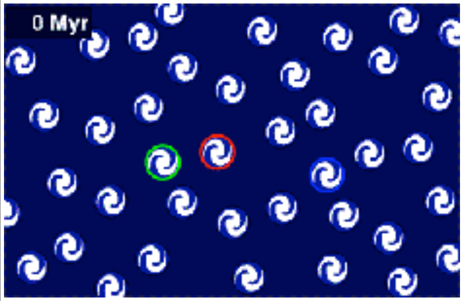
Hubble's Law and the Expanding Universe



The Universe is expanding by following the Hubble law:

The more distant the object, the faster it is moving away from us.

http://www.einstein-online.info/en/elementary/cosmology/expansion/index.html

The Age of the Universe

We can use a similar approach toward finding the age of the universe.

Ho = 22 km s^{-1} / million light years implies that a galaxy 1 million light years away is moving at 22 kms^{-1}.

How long could the galaxy be moving at this velocity?

Distance = 1million light years = 9.4×10^{8} km
Velocity = 22 km s^{-1}
Time = Distance/Velocity = 1/Ho = 4.3×10^{17} seconds
= 13.6 billion years

Because of the Hubble relation - you would find the same time for every galaxy! *This is the time elapses from the Big Bang - when the expansion of the universe started!!*

Summary

1. Morphologies of galaxies and Hubble's tuning fork
   a. ellipitical
   b. disk galaxies
      i. lenticulars
      ii. spiral
      iii. barred spiral
   c. Irregular

2. The cosmic distance ladder
   a. Parallax
   b. Clusters
   c. Cepheids
   d. Tully Fisher
   e. White dwarf supernovae

3. Hubble's law and the expanding universe
   a. velocity proportional to distance
   b. Age of the universe is 13.7 billion years