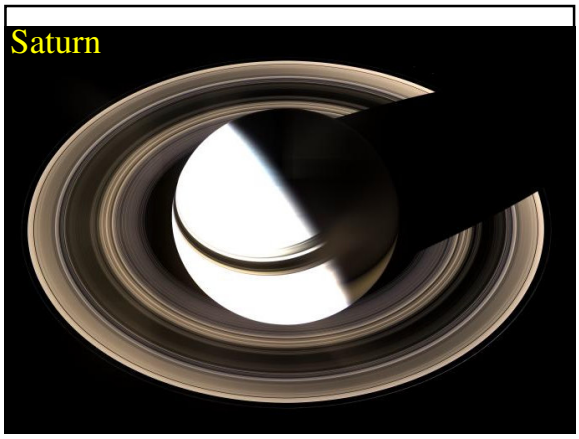
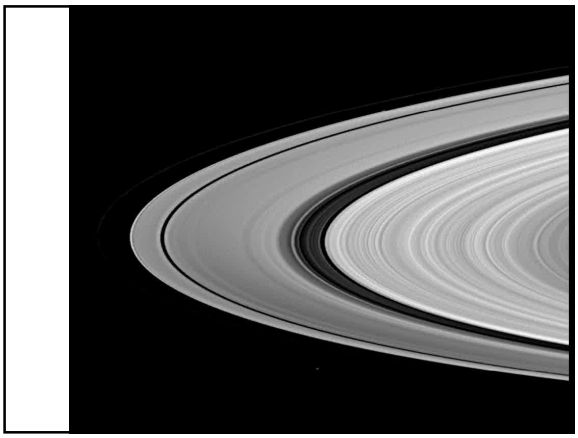
Chapter 20
Galaxies
And the Foundation of Modern Cosmology

Agenda

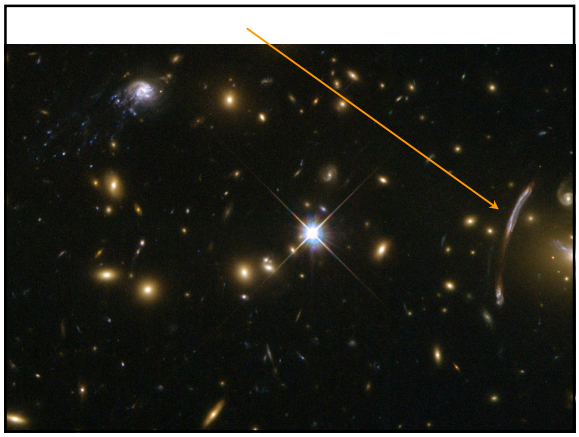
- Lunar Eclipse Gallery
- Saturn Pic/Movie
- Jim Carrey on Quantum Physics
- Gravitational Lensing Picture
- Ch. 20—Galaxies
- Crab Lab

Lunar Eclipse





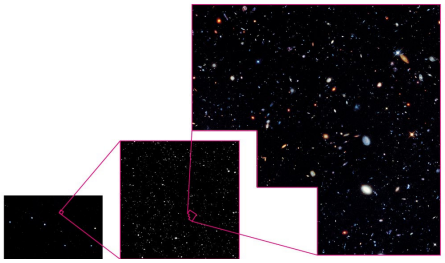
Jim Carrey



20.1 Islands of Stars

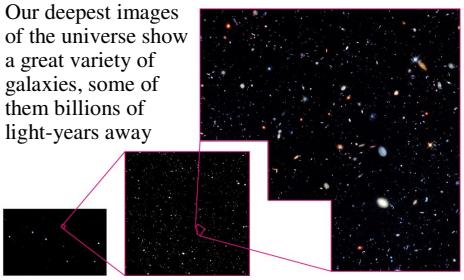
- Our goals for learning
- How are the lives of galaxies connected with the history of the universe?
- What are the three major types of galaxies?
- How are galaxies grouped together?

How are the lives of galaxies connected with the history of the universe?

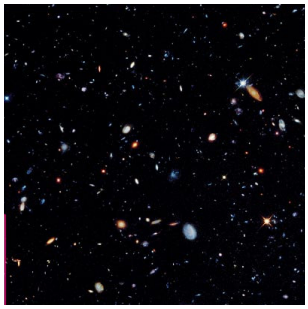


Hubble Deep Field

- Our deepest images of the universe show a great variety of galaxies, some of them billions of light-years away

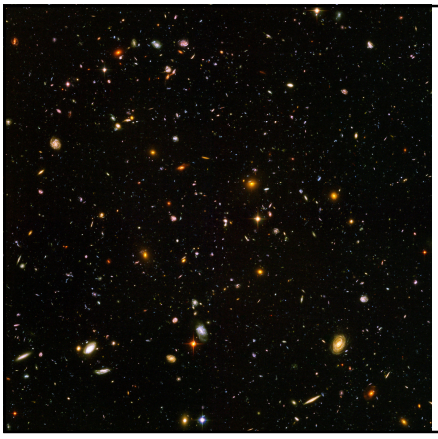


Galaxies and Cosmology

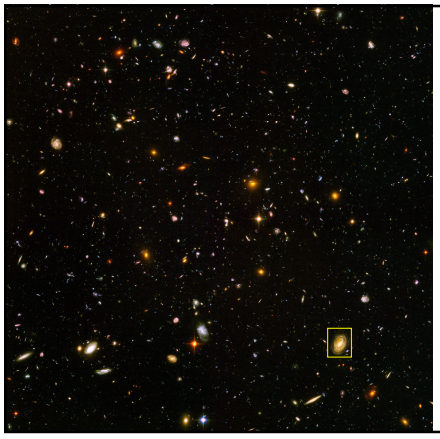


- A galaxy's age, its distance, and the age of the universe are all closely related
- The study of galaxies is thus intimately connected with **cosmology**— the study of the structure and evolution of the universe

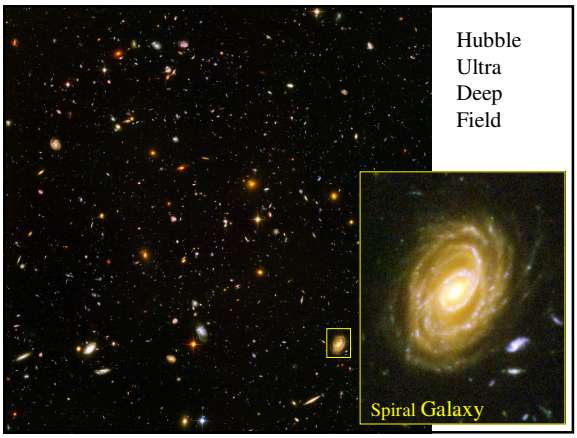
What are the three major types of galaxies?

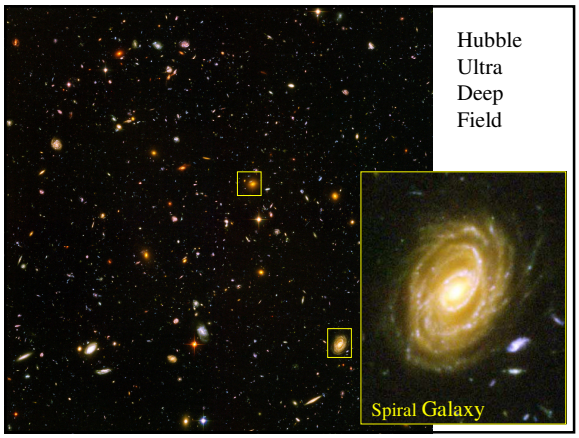


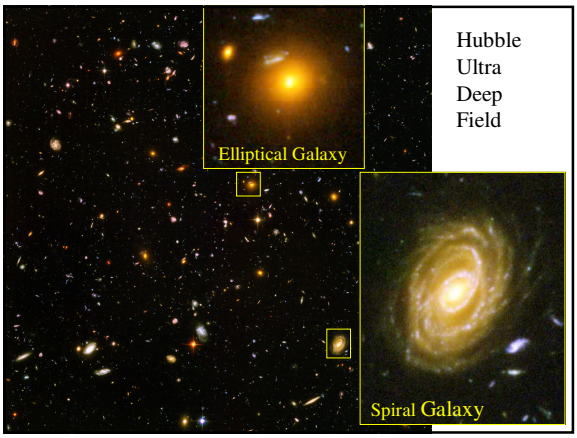
Hubble Ultra Deep Field

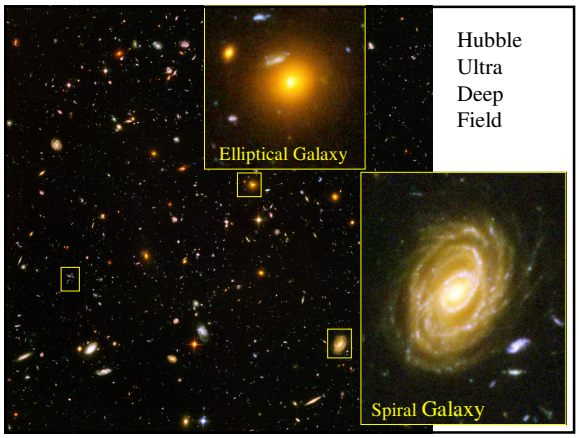


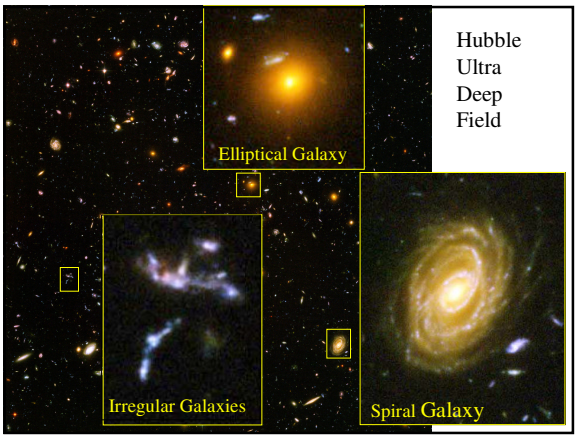
Hubble Ultra Deep Field

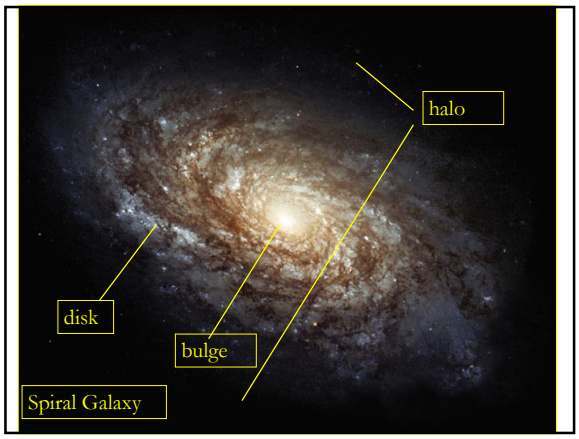

Hubble
Ultra
Deep
Field
Spiral Galaxy


Hubble
Ultra
Deep
Field
Spiral Galaxy

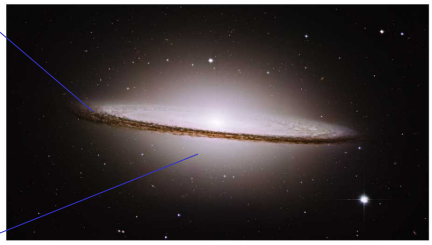

Hubble
Ultra
Deep
Field
Elliptical Galaxy
Spiral Galaxy


Hubble
Ultra
Deep
Field
Elliptical Galaxy
Spiral Galaxy


Hubble
Ultra
Deep
Field
Elliptical Galaxy
Irregular Galaxies
Spiral Galaxy


halo
disk
bulge
Spiral Galaxy

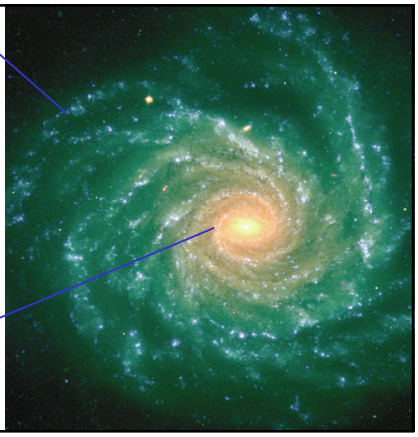
Disk Component:
stars of all ages,
many gas clouds



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

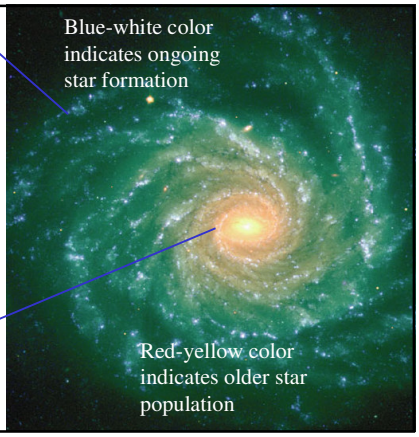
Disk Component:
stars of all ages,
many gas clouds

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



Disk Component:
stars of all ages,
many gas clouds

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



Disk Component:
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Spheroidal Component:
bulge & halo, old stars,
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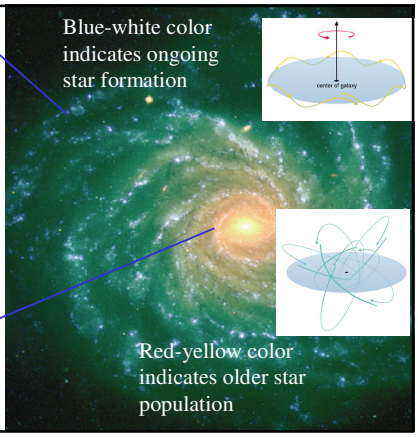

Thought Question

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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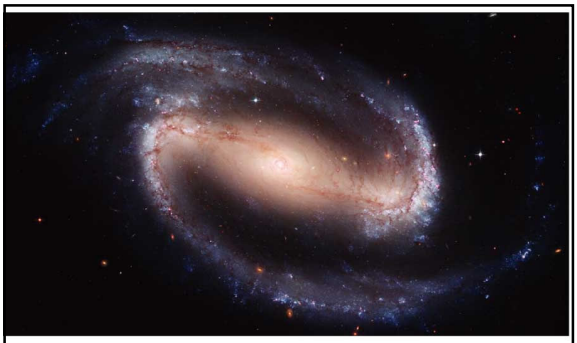
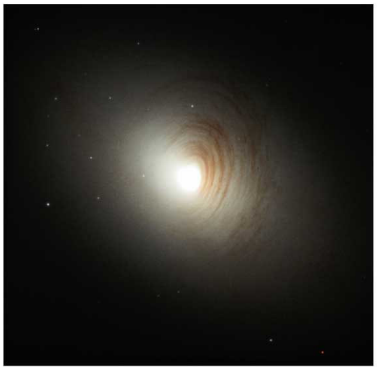
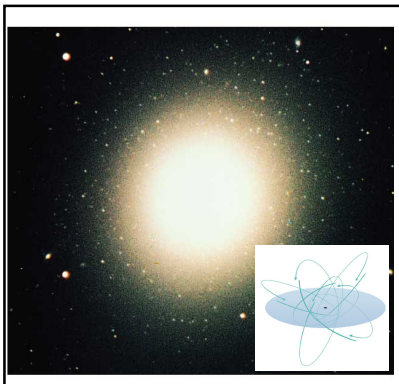


Barred Spiral Galaxy: Has a bar of stars across the bulge



Lenticular Galaxy: Has a disk like a spiral galaxy but much less dusty gas (intermediate between spiral and elliptical)

Elliptical Galaxy: All spheroidal component, virtually no disk component



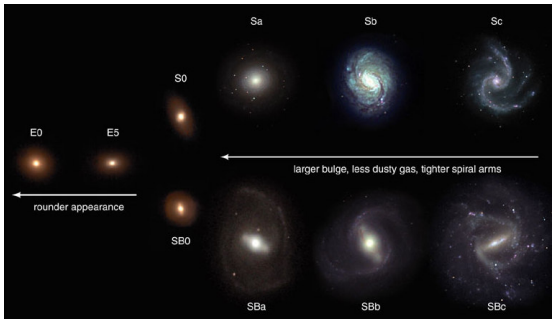
Elliptical Galaxy: All spheroidal component, virtually no disk component

Red-yellow color indicates older star population

Irregular Galaxy

Irregular Galaxy

Blue-white color indicates ongoing star formation



Spheroid Dominates

Hubble's galaxy classes

Disk Dominates

How are galaxies grouped together?

Spiral galaxies are often found in ***groups*** of galaxies

(up to a few dozen galaxies)

Elliptical galaxies are much more common in huge ***clusters*** of galaxies

(hundreds to thousands of galaxies)

What have we learned?

- How are the lives of galaxies connected with the history of the universe?
  - Galaxies generally formed when the universe was young and have aged along with the universe
- What are the three major types of galaxies?
  - Spiral galaxies, elliptical galaxies, and irregular galaxies
  - Spirals have both disk and spheroidal components; ellipticals have no disk

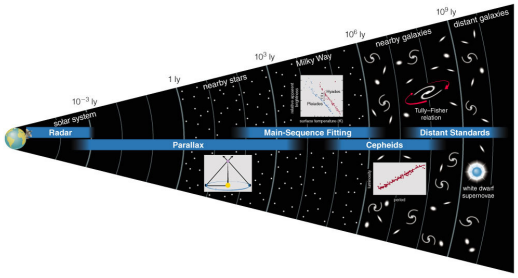
What have we learned?

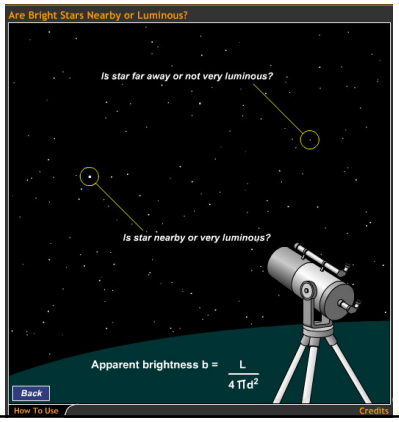
- How are galaxies grouped together?
  - Spiral galaxies tend to collect into groups of up to a few dozen galaxies
  - Elliptical galaxies are more common in large clusters containing hundreds to thousands of galaxies

20.2 Measuring Galactic Distances

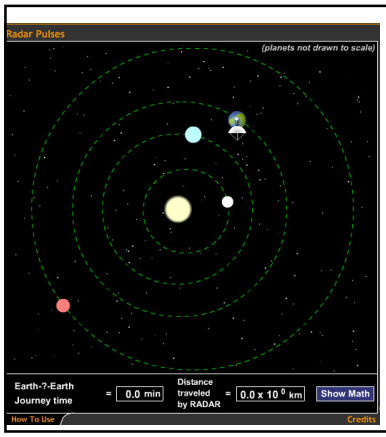
- Our goals for learning
- How do we measure the distances to galaxies?

How do we measure the distances to galaxies?



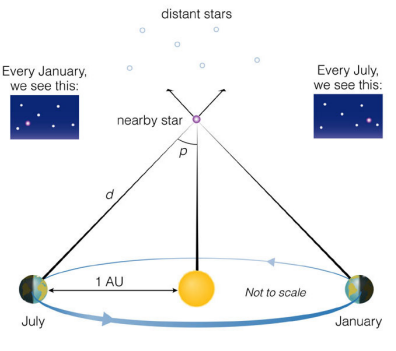


Brightness alone does not provide enough information to measure distance



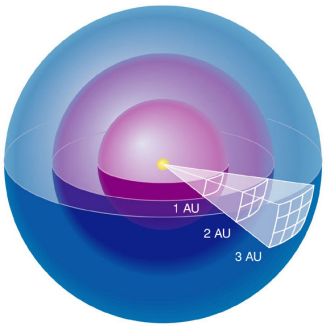
Step 1

Determine size of solar system using radar



Step 2

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



Luminosity passing through each sphere is the same

Area of sphere:

4π (radius)^2

Divide luminosity by area to get brightness

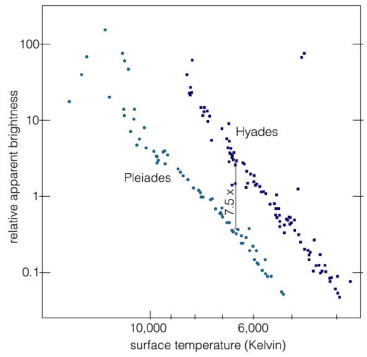
The relationship between apparent brightness and luminosity depends on distance:

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

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

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

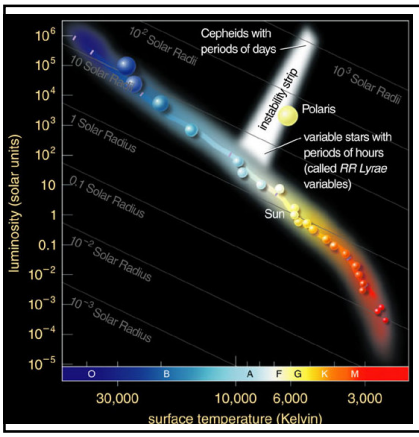
A ***standard candle*** is an object whose luminosity we can determine without measuring its distance



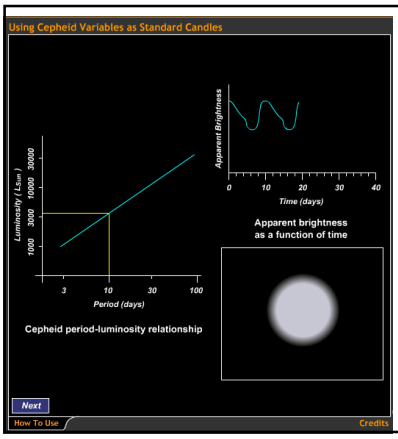
Step 3

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

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

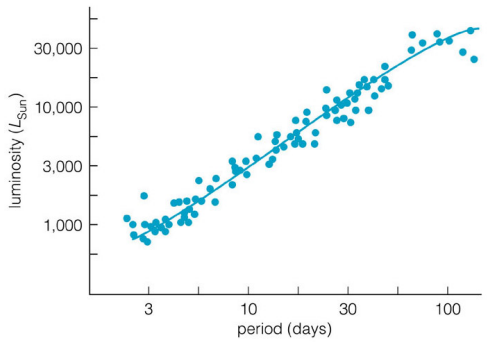


Cepheid variable stars are very luminous

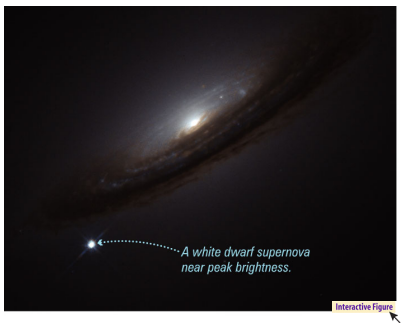


Step 4

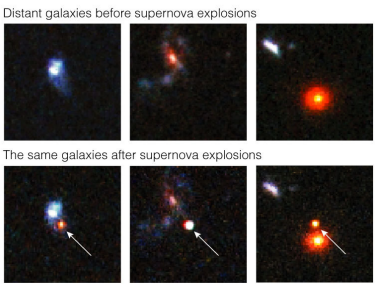
Because the period of a Cepheid variable star tells us its luminosity, we can use these stars as standard candles



Cepheid variable stars with longer periods have greater luminosities



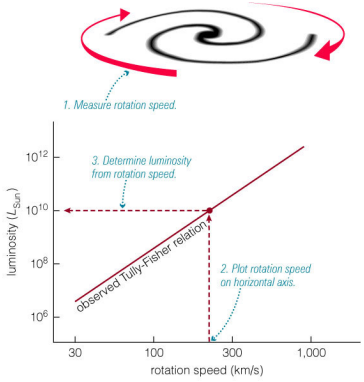
White-dwarf supernovae can also be used as standard candles



Step 5

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

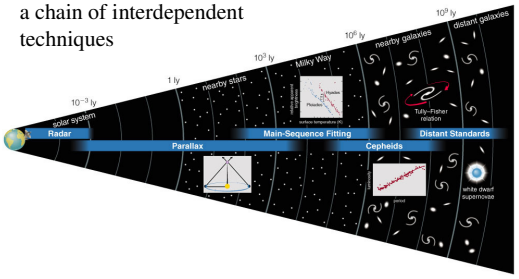
(up to 10 billion light-years)



Tully-Fisher Relation

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

We measure galaxy distances using a chain of interdependent techniques



What have we learned?

- How do we measure the distances to galaxies?
  - The distance-measurement chain begins with parallax measurements that build on radar ranging in our solar system
  - Using parallax and the relationship between luminosity, distance, and brightness, we can calibrate a series of standard candles
  - We can measure distances greater than 10 billion light years using white dwarf supernovae as standard candles

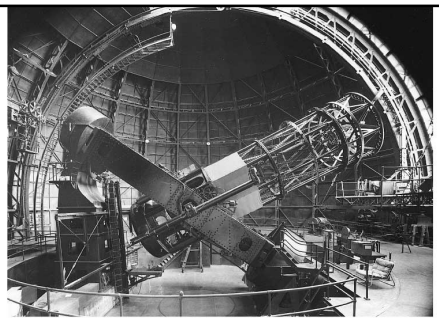
20.3 Hubble's Law

- Our goals for learning
- How did Hubble prove that galaxies lie far beyond the Milky Way?
- What is Hubble's Law?
- How do distance measurements tell us the age of the universe?
- How does the universe's expansion affect our distance measurements?

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

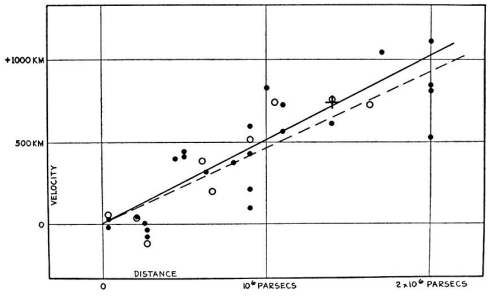
The Puzzle of "Spiral Nebulae"

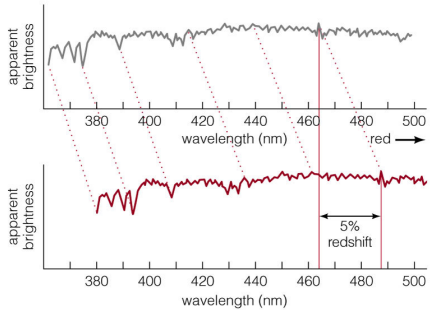
- Before Hubble, some scientists argued that "spiral nebulae" were entire galaxies like our Milky Way, while others maintained they were smaller collections of stars within the Milky Way
- The debate remained unsettled until someone finally measured their distances



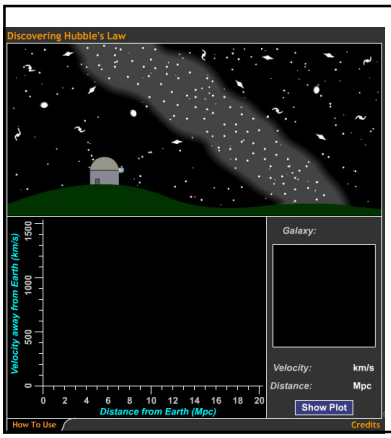
Hubble settled the debate by measuring the distance to the Andromeda Galaxy using Cepheid variables as standard candles

What is Hubble's Law?

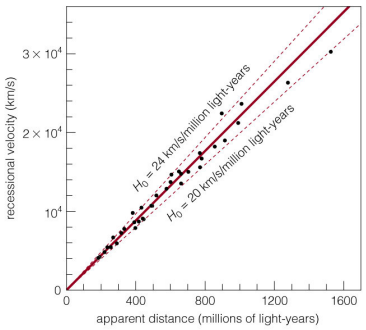




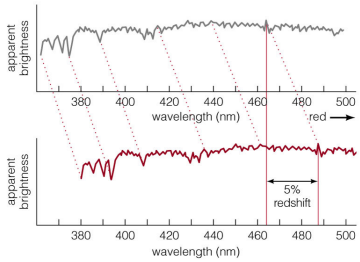
The spectral features of virtually all galaxies are ***redshifted*** ⇒ They're all moving away from us



By measuring distances to galaxies, Hubble found that redshift and distance are related in a special way



Hubble's Law: velocity = H_0 x distance

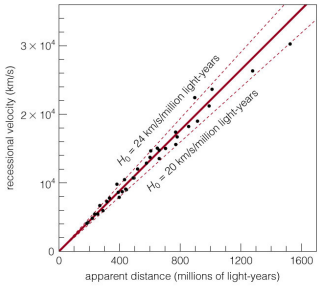


Redshift of a galaxy tells us its distance through Hubble's Law:

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

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

Thought Question

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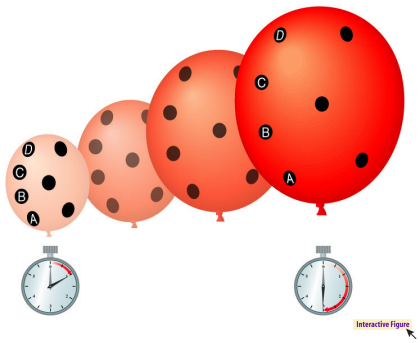
A. 1 minute
B. 30 minutes
C. 60 minutes
D. 120 minutes

The expansion rate appears to be the same everywhere in space

The universe has no center and no edge (as far as we can tell)



One example of something that expands but has no center or edge is the surface of a balloon

Cosmological Principle

The universe looks about the same no matter where you are within it

- Matter is evenly distributed on very large scales in the universe
- No center & no edges
- Not proved but consistent with all observations to date

Thought Question

Your observe a galaxy moving away from you at 0.1 light-years per year, and it is now 1.4 billion light-years away from you. How long has it taken to get there?

A. 1 million years
B. 14 million years
C. 10 billion years
D. 14 billion years

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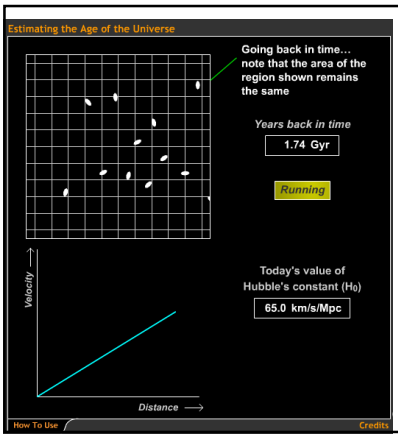
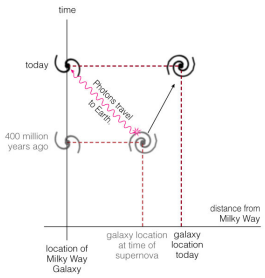


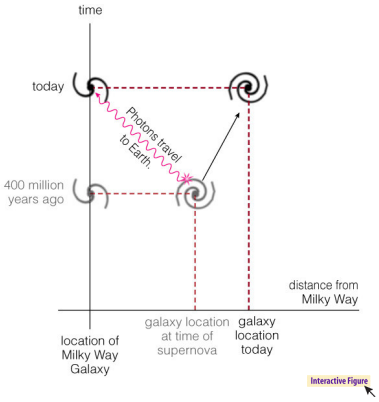
Hubble's constant tells us age of universe because it relates velocities and distances of all galaxies

$$\text{Age} = \frac{\text{Distance}}{\text{Velocity}}$$

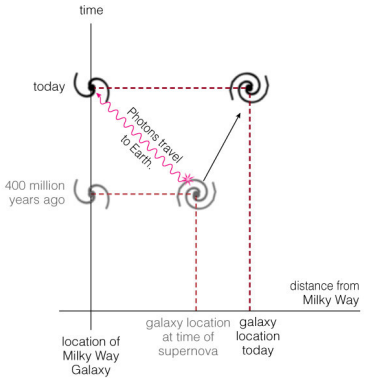
$$\sim 1 / H_0$$

How does the universe's expansion affect our distance measurements?



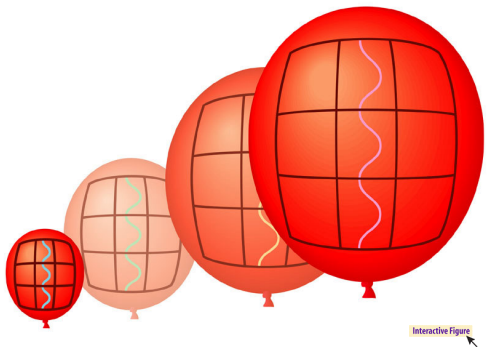


Distances between faraway galaxies change while light travels



Distances between faraway galaxies change while light travels

Astronomers think in terms of ***lookback time*** rather than distance



Expansion stretches photon wavelengths causing a ***cosmological redshift*** directly related to lookback time

What have we learned?

- How did Hubble prove that galaxies lie far beyond the Milky Way?
  - He measured the distance to the Andromeda galaxy using Cepheid variable stars as standard candles
- What is Hubble's Law?
  - The faster a galaxy is moving away from us, the greater its distance:

velocity = H_0 x distance

What have we learned?

- How do distance measurements tell us the age of the universe?
  - Measuring a galaxy's distance and speed allows us to figure out how long the galaxy took to reach its current distance
  - Measuring Hubble's constant tells us that amount of time: about 14 billion years
- How does the universe's expansion affect our distance measurements?
  - Lookback time is easier to define than distance for objects whose distances grow while their light travels to Earth