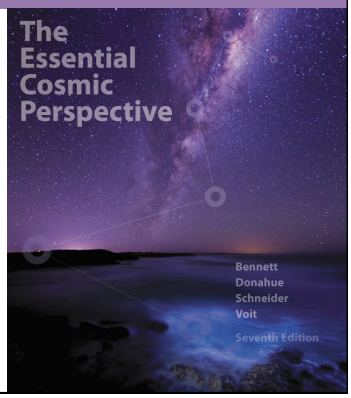
Lecture Outline

Chapter 16: A Universe of Galaxies



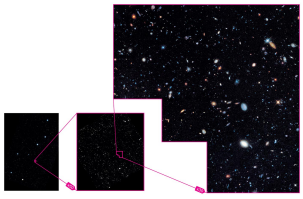
16.1 Islands of Stars

Our goals for learning:

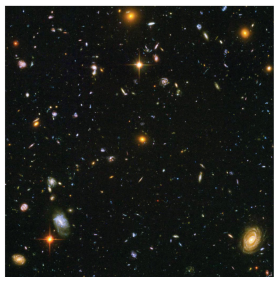
- What are the three major types of galaxies?
- How are galaxies grouped together?

Hubble Deep Field

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

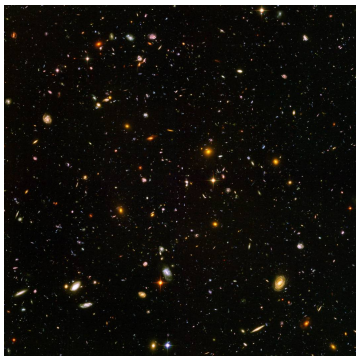


Galaxies and Cosmology

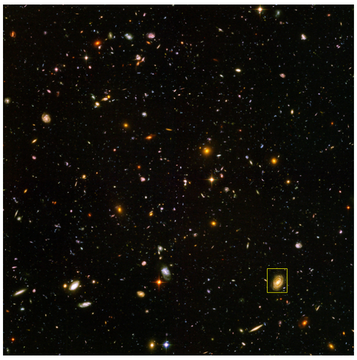


- A galaxy's age, its distance, and the age of the universe are all closely related.
- The study of galaxies is thus intimately connected with **cosmology**—the study of the structure and evolution of the universe.

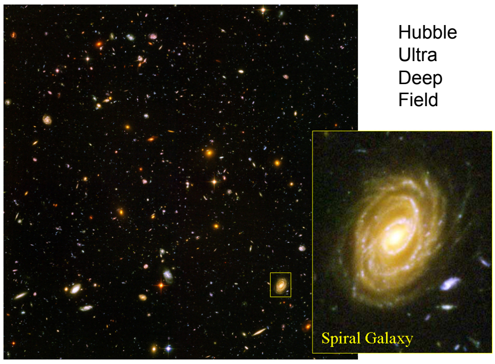
•What are the three major types of galaxies?



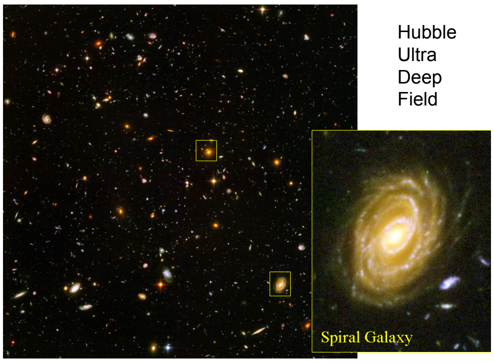
Hubble Ultra Deep Field



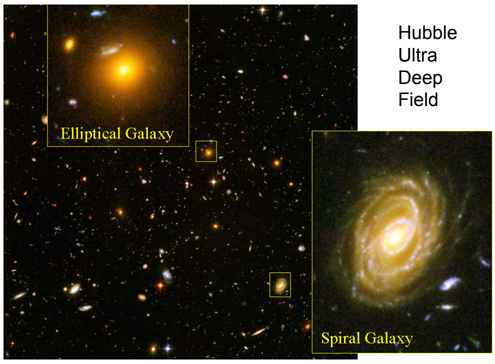
Hubble Ultra Deep Field



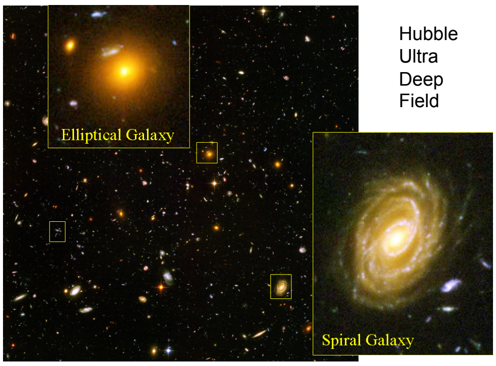
Hubble Ultra Deep Field



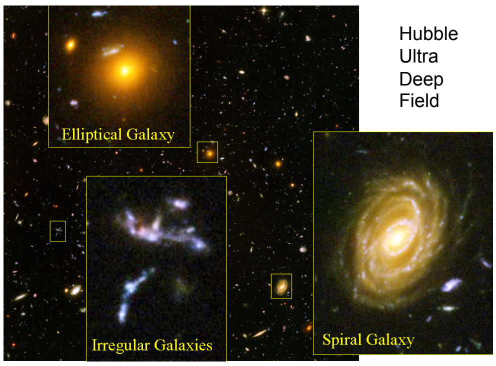
Hubble Ultra Deep Field



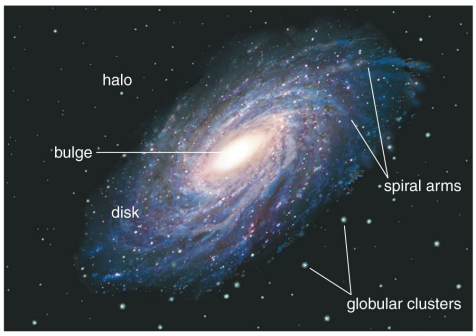
Hubble Ultra Deep Field



Hubble Ultra Deep Field

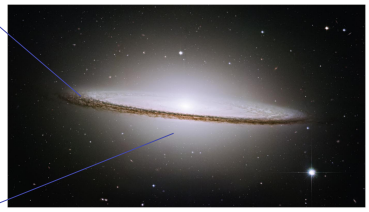


Hubble Ultra Deep Field



Spiral galaxy

Disk Component: stars of all ages, many gas clouds



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

Disk Component: stars of all ages, many gas clouds

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

Disk Component: stars of all ages, many gas clouds

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

Blue-white color indicates ongoing star formation.

Red-yellow color indicates older star population.

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

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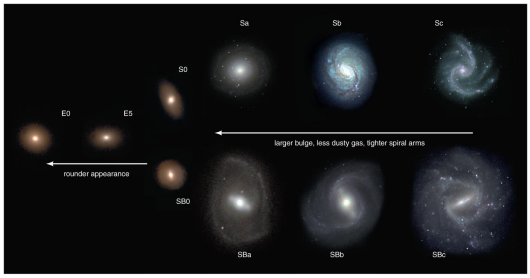
All spheroidal component, virtually no disk component

Red-yellow color indicates older star population.

Irregular Galaxy: Neither spiral nor elliptical. 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 per group).

Elliptical galaxies are much more common in huge ***clusters*** of galaxies (hundreds to thousands of galaxies).

What have we learned?

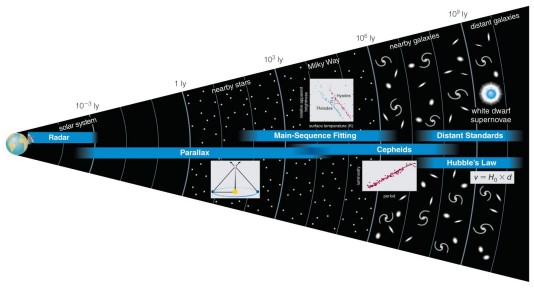
- What are the three major types of galaxies?
  - Spiral galaxies, elliptical galaxies, and irregular galaxies
  - Spirals have both disk and spheroidal components; ellipticals have no disk.
- How are galaxies grouped together?
  - Spiral galaxies tend to collect into groups of up to a few dozen galaxies.
  - Elliptical galaxies are more common in large clusters containing hundreds to thousands of galaxies.

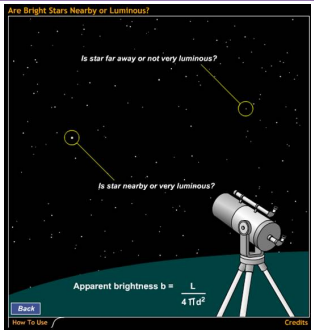
16.2 Distances of Galaxies

Our goals for learning:

- How do we measure the distances to galaxies?
- What is Hubble's law?
- How do distance measurements tell us the age of the universe?

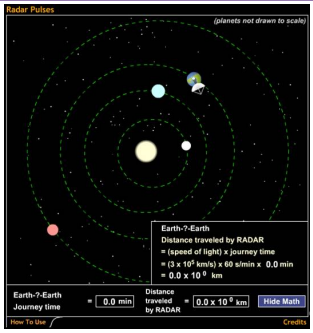
•How do we measure the distances to galaxies?





Brightness alone does not provide enough information to measure distance.

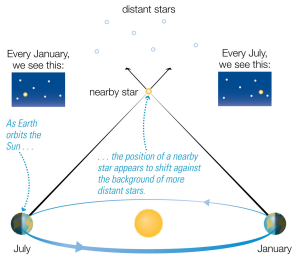
PLAY Are Bright Stars Nearby or Luminous?



Step 1

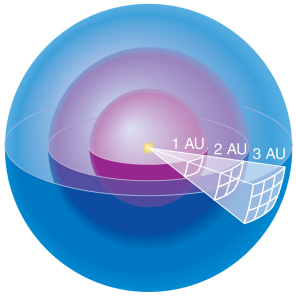
Determine size of solar system using radar.

PLAY Radar Pulses



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.

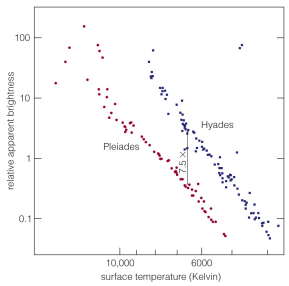
The relationship between apparent brightness and luminosity depends on distance.

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

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.

Thought Question

Which kind of stars are best for measuring large distances?

A. High-luminosity stars

B. Low-luminosity stars

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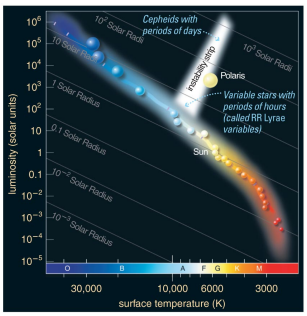
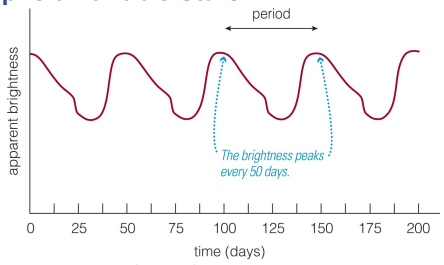
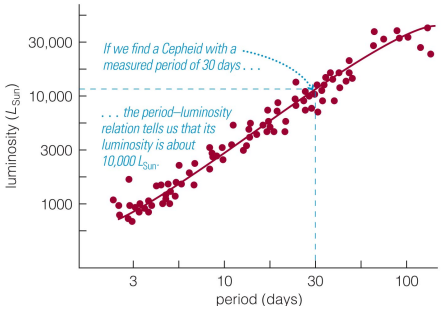


Cepheid variable stars are very luminous.

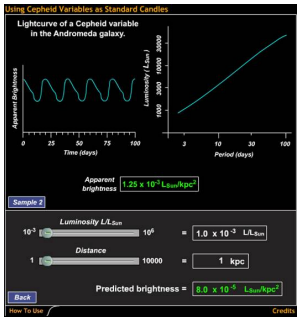
Cepheid Variable Stars



The light curve of this *Cepheid variable* star shows that its brightness alternately rises and falls over a 50-day period.



Cepheid variable stars with longer periods have greater luminosities.



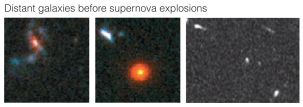
Step 4

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

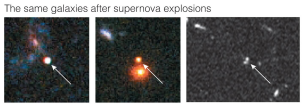
PLAY Using Cepheid Variables as Standard Candles

White dwarf supernovae can also be used as standard candles.

Distant galaxies before supernova explosions



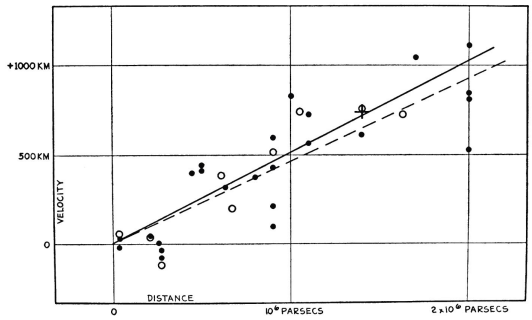
The same galaxies after supernova explosions



Step 5

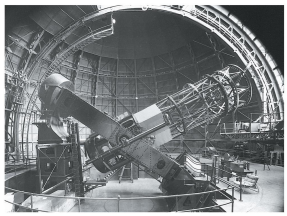
Apparent brightness of a white dwarf supernova tells us the distance to its galaxy (up to 10 billion light-years).

•What is Hubble's law?

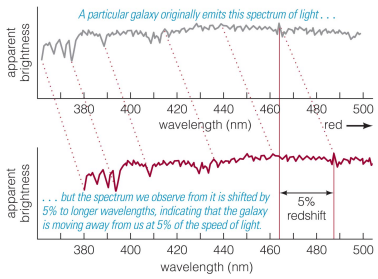


The Puzzle of "Spiral Nebulae"

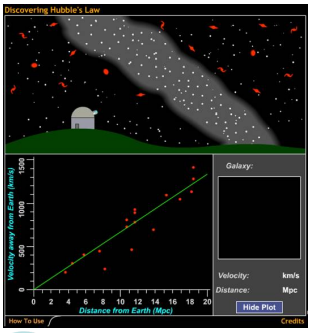
- Before Hubble, some scientists argued that "spiral nebulae" were entire galaxies like our Milky Way, whereas other scientists maintained they were smaller collections of stars within the Milky Way.
- The debate remained unsettled until someone finally measured the distances of spiral nebulae.



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

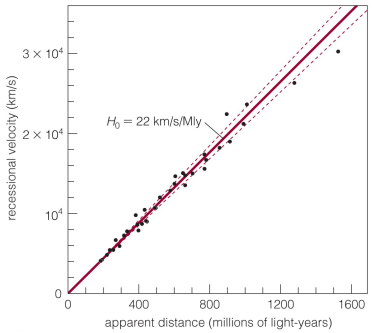


Hubble also knew that the spectral features of virtually all galaxies are ***redshifted*** ⇒ they're all moving away from us.

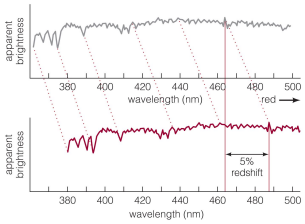


By measuring distances to galaxies, Hubble found that redshift and distance are related in a special way.

PLAY Discovering Hubble's Law

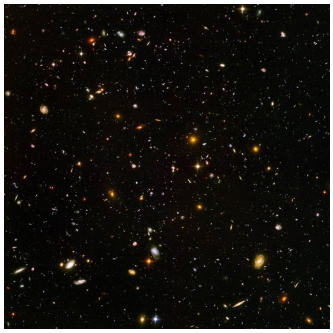


Hubble's law: velocity = H_0 × distance



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

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



Distances of the farthest galaxies are measured from redshifts.

We measure galaxy distances using a chain of interdependent techniques.