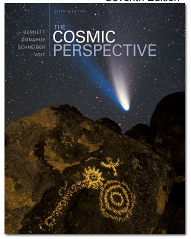
Chapter 20 Lecture

The Cosmic Perspective

Seventh Edition

Galaxies and the Foundation of Modern Cosmology

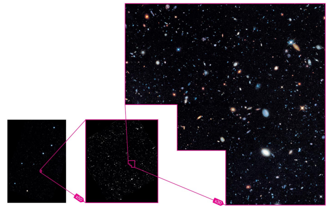


Galaxies and the Foundation of Modern Cosmology

20.1 Islands of Stars

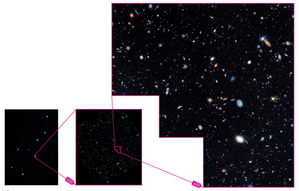
- Our goals for learning:
  - **How are the lives of galaxies connected with the history of the universe?**
  - **What are the three major types of galaxies?**
  - **How are galaxies grouped together?**

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

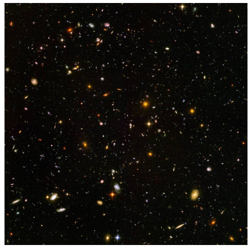


Hubble Deep Field

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

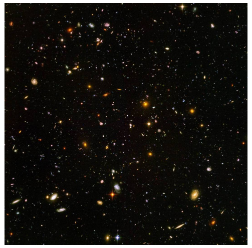


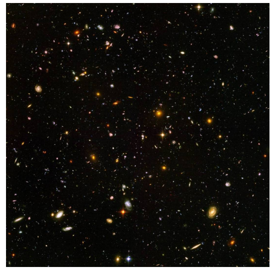
Galaxies and Cosmology



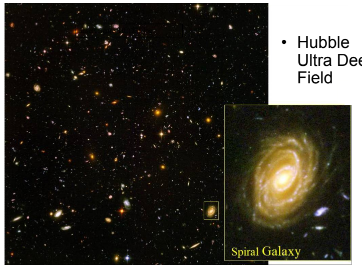
- A galaxy's age, its distance, and the age of the universe are all closely related.
- The study of galaxies is thus intimately connected with **cosmology**—the study of the structure and evolution of the universe.

What are the three major types of galaxies?





- Hubble Ultra Deep Field



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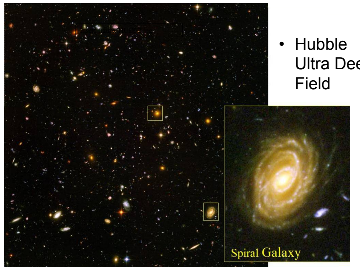

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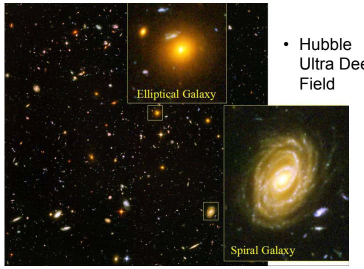

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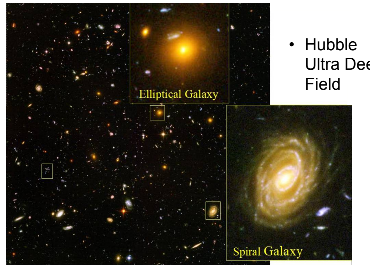

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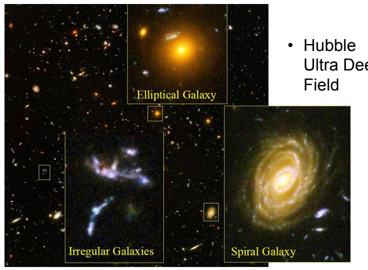

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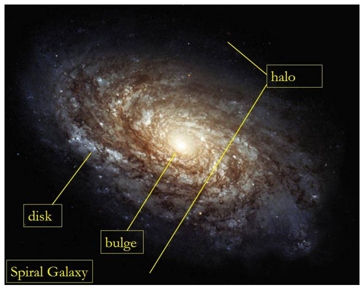
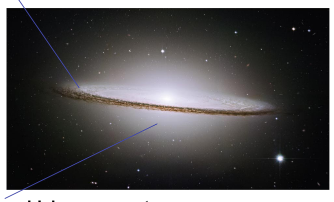


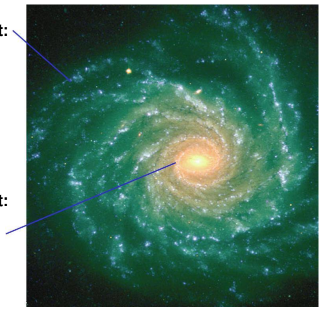
Disk component:
stars of all ages, many gas clouds



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

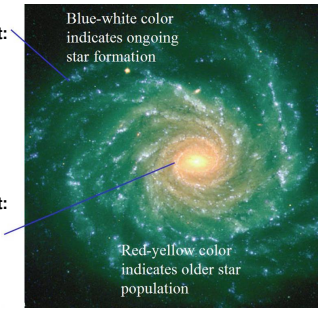
Disk component: stars of all ages, many gas clouds

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



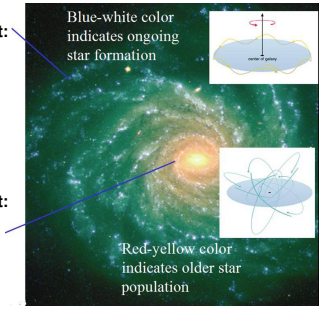
Disk component: stars of all ages, many gas clouds

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



Disk component: stars of all ages, many gas clouds

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



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 the others.
C. Gas in the disk scatters blue light.

Thought Question

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- **Barred spiral galaxy:** has a bar of stars across the bulge

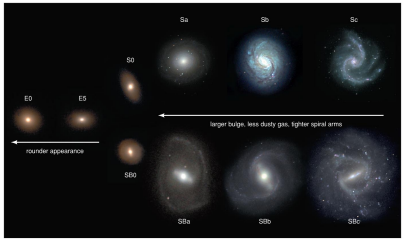
- **Lenticular galaxy:** has a disk like a spiral galaxy but much less dusty gas (intermediate between spiral and elliptical)

a M87, a giant elliptical galaxy in the Virgo Cluster, is one of the most massive galaxies in the universe. The region shown is more than 300,000 light-years across.

- **Elliptical galaxy:** all spheroidal component, virtually no disk component
- Red-yellow color indicates older star population.

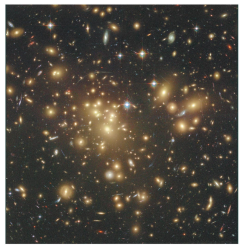
- Irregular galaxy

Blue-white color indicates ongoing star formation.

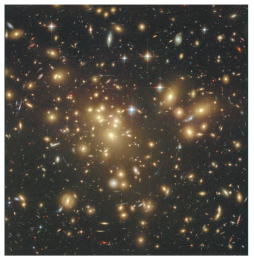


Spheroid dominates — Hubble's galaxy classes — Disk dominates

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?**
  - The major types are spiral galaxies, elliptical galaxies, and irregular galaxies.
  - Spirals have both disk and spheroidal components; ellipticals have no disk.

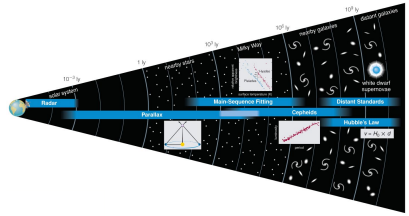
What have we learned?

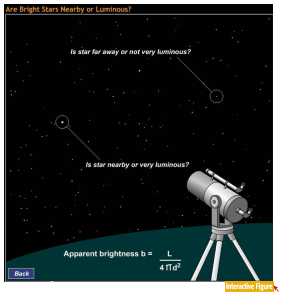
- **How are galaxies grouped together?**
  - Spiral galaxies tend to collect into groups of up to a few dozen galaxies.
  - Elliptical galaxies are more common in large clusters containing hundreds to thousands of galaxies.

20.2 Measuring Galactic Distances

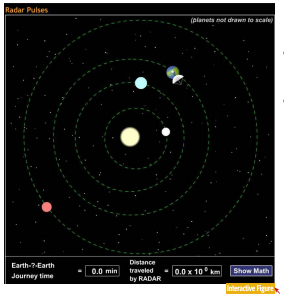
- Our goals for learning:
  - **How do we measure the distances to galaxies?**
  - **How did Hubble prove that galaxies lie far beyond the Milky Way?**
  - **What is Hubble's law?**

How do we measure the distances to galaxies?

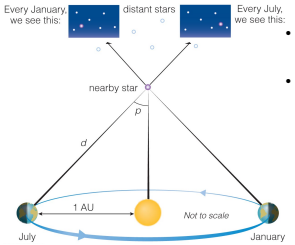




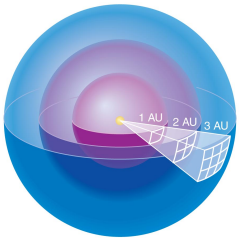
- Brightness alone does not provide enough information to measure the distance to an object.



- ***Step 1***
- Determine size of the solar system using radar.



- ***Step 2***
- Determine the 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.

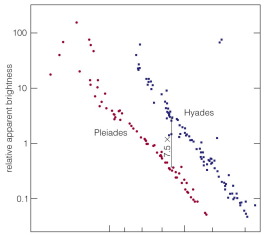
- The relationship between apparent brightness and luminosity depends on distance:

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

- 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***
- The apparent brightness of a 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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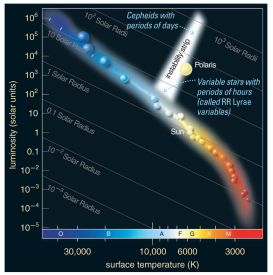
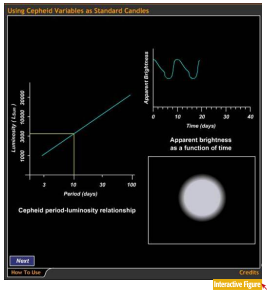
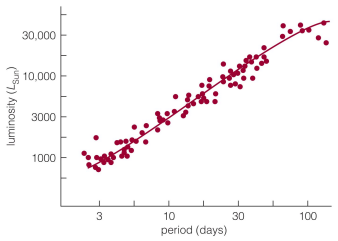


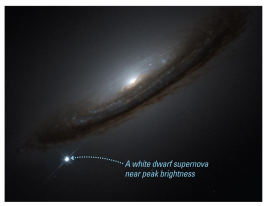
- Cepheid variable stars are very luminous.



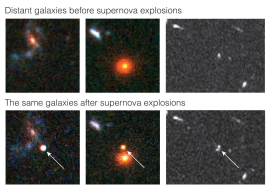
- ***Step 4***
- Because the period of Cepheid variable stars tells us their luminosities, we can use them as standard candles.



- Cepheid variable stars with longer periods have greater luminosities.



- White-dwarf supernovae can also be used as standard candles.

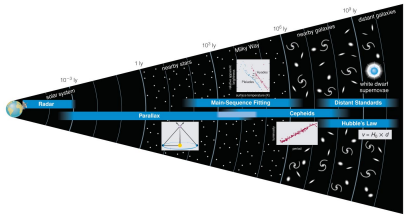


- ***Step 5***
- The apparent brightness of a white dwarf supernova tells us the distance to its galaxy (up to 10 billion light-years).

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

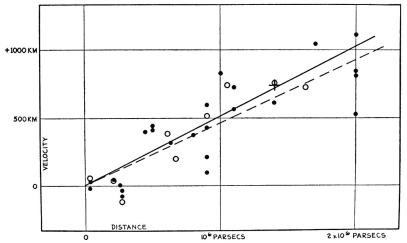
The Puzzle of "Spiral Nebulae"

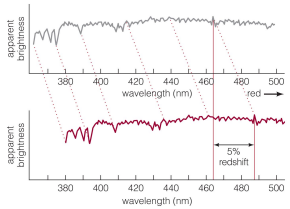
- Before Hubble, some scientists argued that "spiral nebulae" were entire galaxies like our Milky Way, while others maintained they were smaller collections of stars within the Milky Way.
- The debate remained unsettled until Edwin Hubble finally measured their distances.



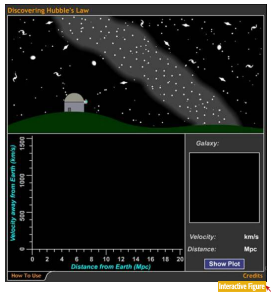
- Hubble settled the debate by measuring the distance to the Andromeda Galaxy using Cepheid variables as standard candles.

What is Hubble's law?

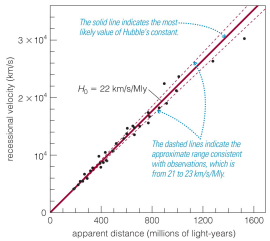




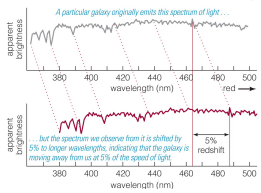
- The spectral features of virtually all galaxies are redshifted, which means that they're all moving away from us.



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

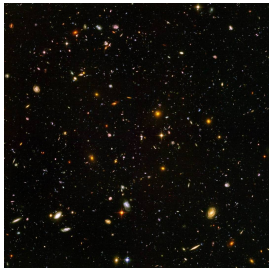


- Hubble's law: Velocity = H_0 × distance



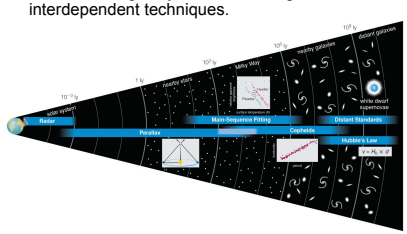
- Redshift of a galaxy tells us its distance through Hubble's law:

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



- Distances of the farthest galaxies are measured from their redshifts.

- 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.

What have we learned?

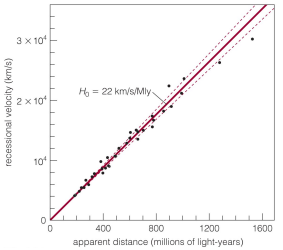
- **How did Hubble prove that galaxies lie far beyond the Milky Way?**
  - He measured the distance to the Andromeda Galaxy using Cepheid variable stars as standard candles.
- **What is Hubble's law?**
  - The faster a galaxy is moving away from us, the greater its distance:

Velocity = H_0 × distance

20.3 The Age of the Universe

- Our goals for learning
  - **How does Hubble's Law tell us the age of the universe?**
  - **How does expansion affect distance measurements?**
  - **Why does the observable universe have a horizon?**

How does Hubble's Law 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?

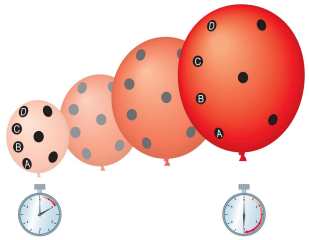
A. 1 minute
B. 30 minutes
C. 60 minutes
D. 120 minutes

Thought Question

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

- 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.
- It has no center or edges.
- The cosmological principle has not been proven beyond a doubt, but it is consistent with all observations to date.

Thought Question

You 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

Thought Question

You 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?

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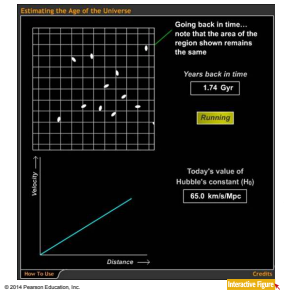
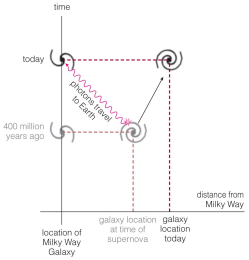


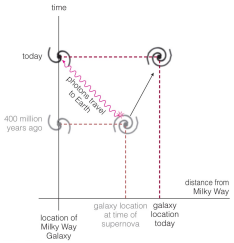
- Hubble's constant tells us the age of universe because it relates the velocities and distances of all galaxies.

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

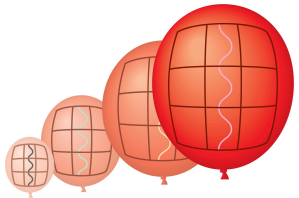
$$\sim 1/H_0$$

How does expansion affect distance measurements?



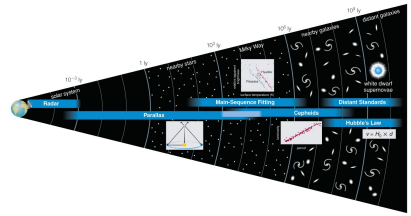


- Distances between faraway galaxies change while light travels.
- Astronomers think in terms of ***lookback time*** rather than distance.



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

Why does the observable universe have a horizon?



- The **Cosmological Horizon** marks the limits of the observable universe.
- It is a horizon in *time* rather than *space*. Since looking far away means looking back in time, there must be a limit – the beginning of the universe!

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.

What have we learned?

- **Why does the observable universe have a horizon?**
  - We cannot see back to a time before the beginning of the universe!