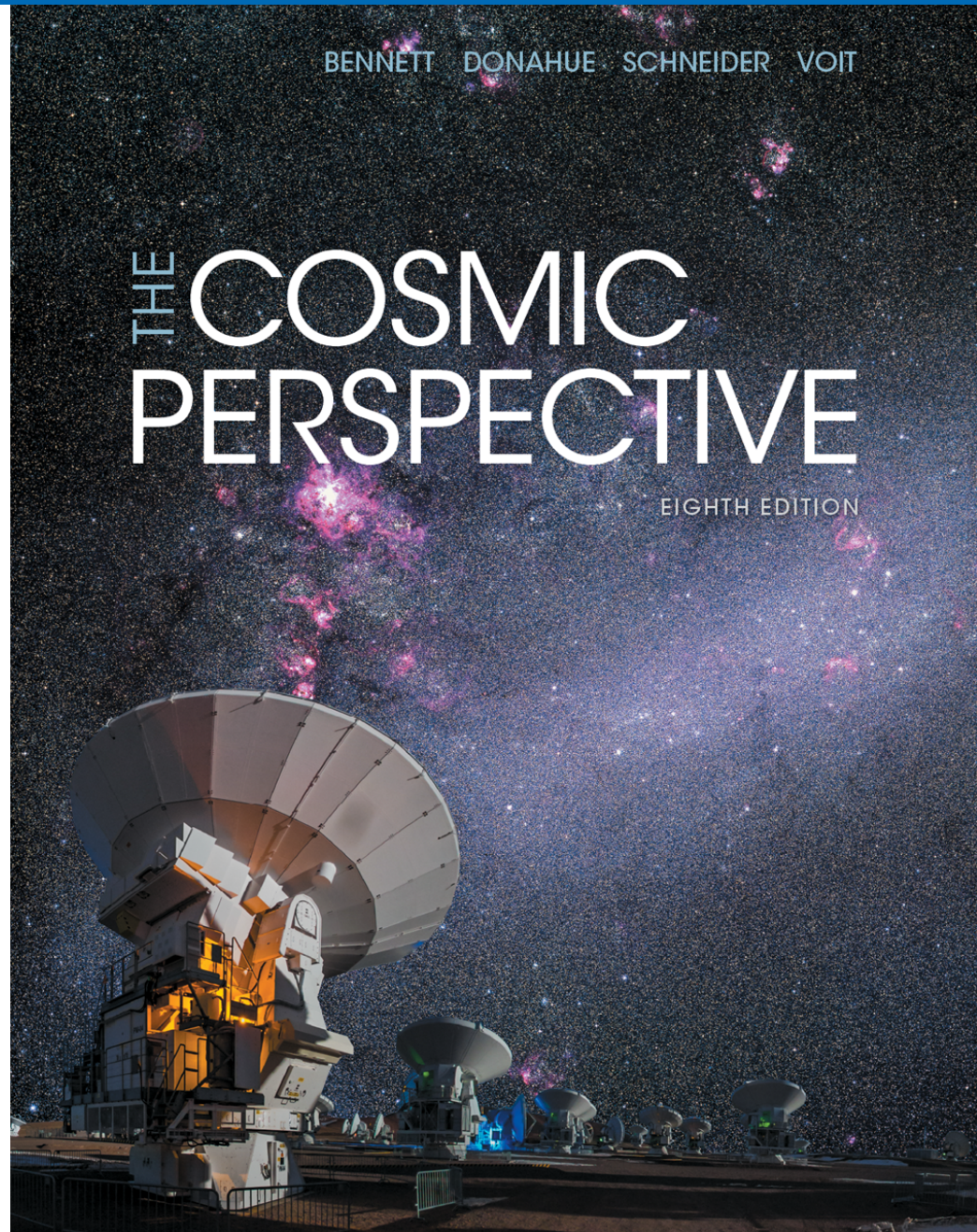
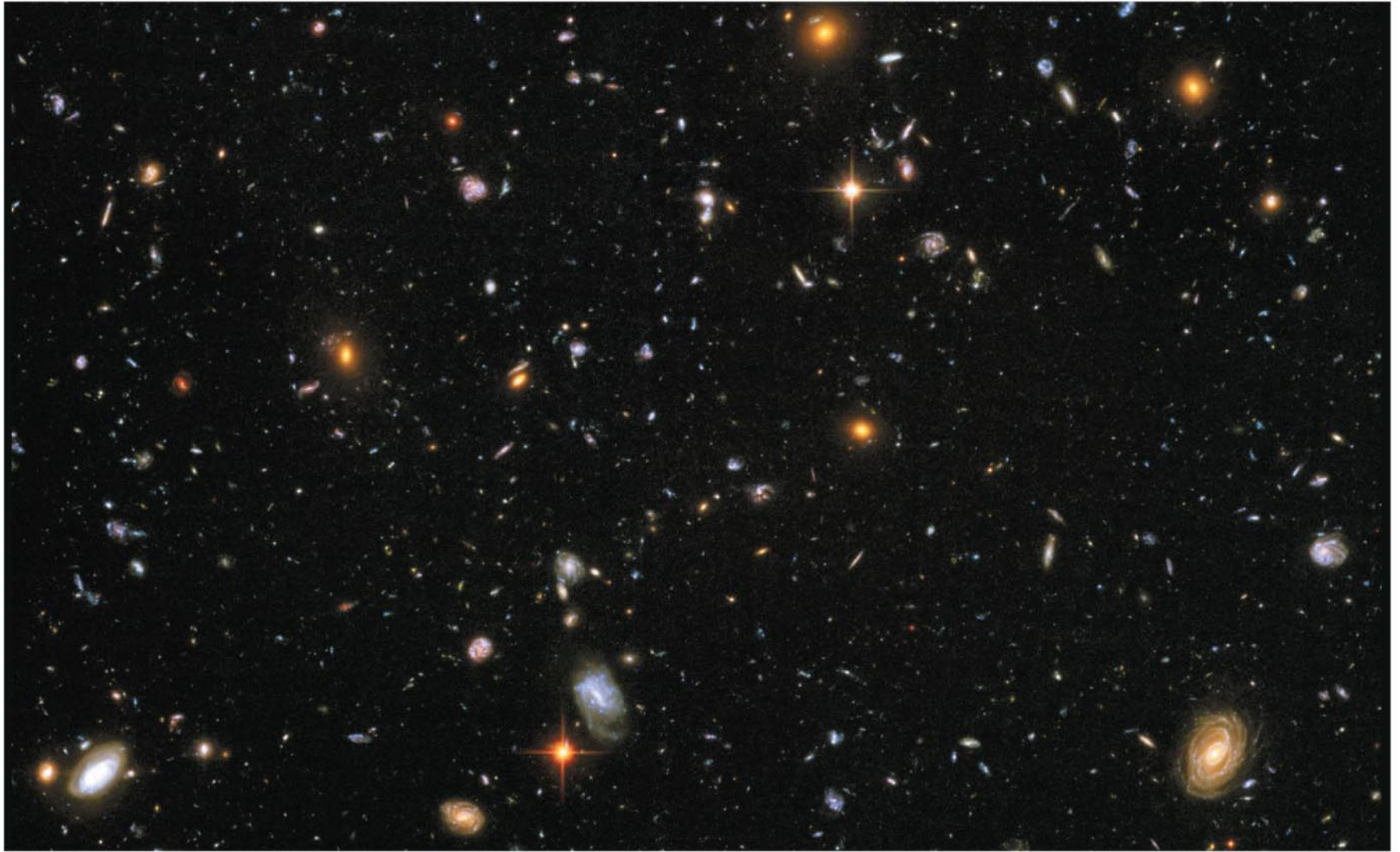


Chapter 1 Lecture

Chapter 1: A Modern View of the Universe



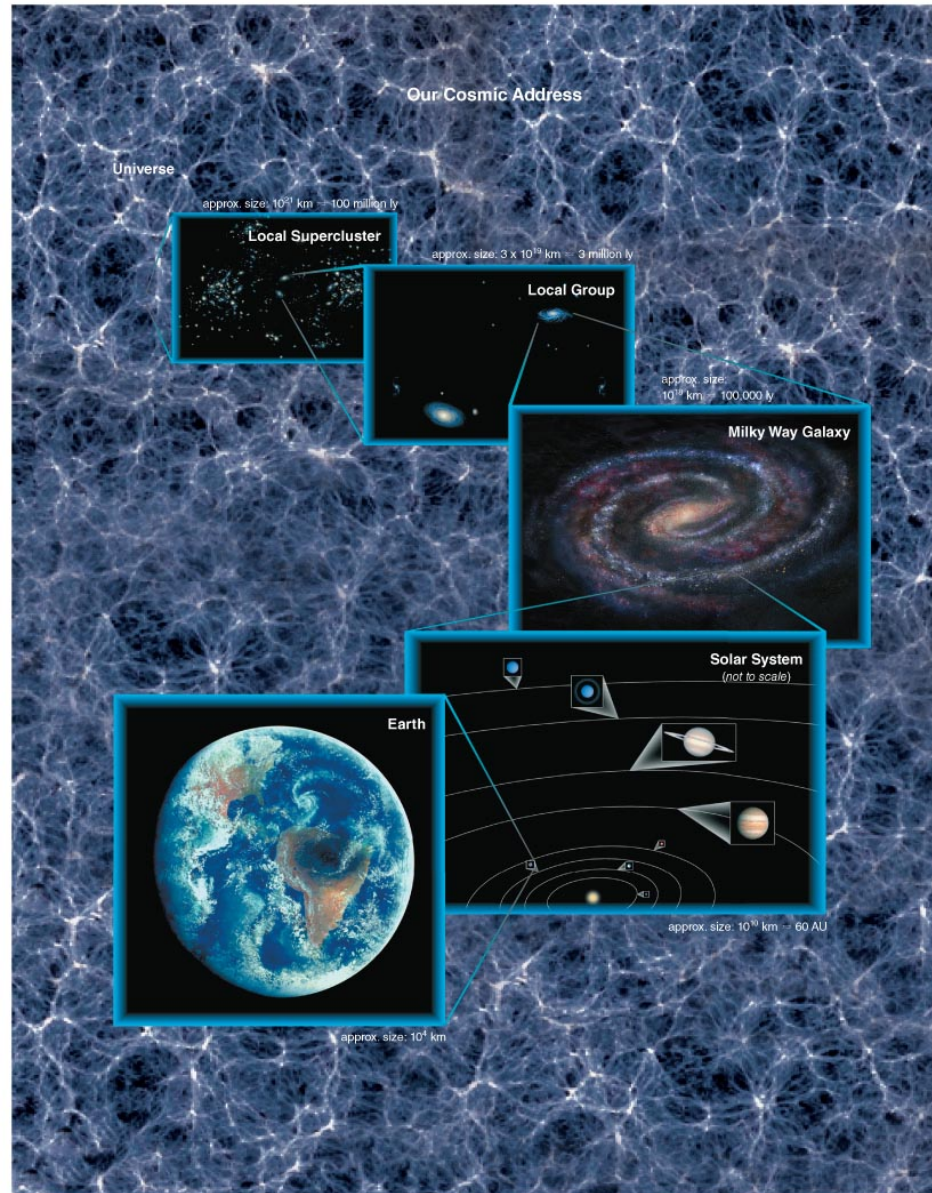
A Modern View of the Universe



1.1 The Scale of the Universe

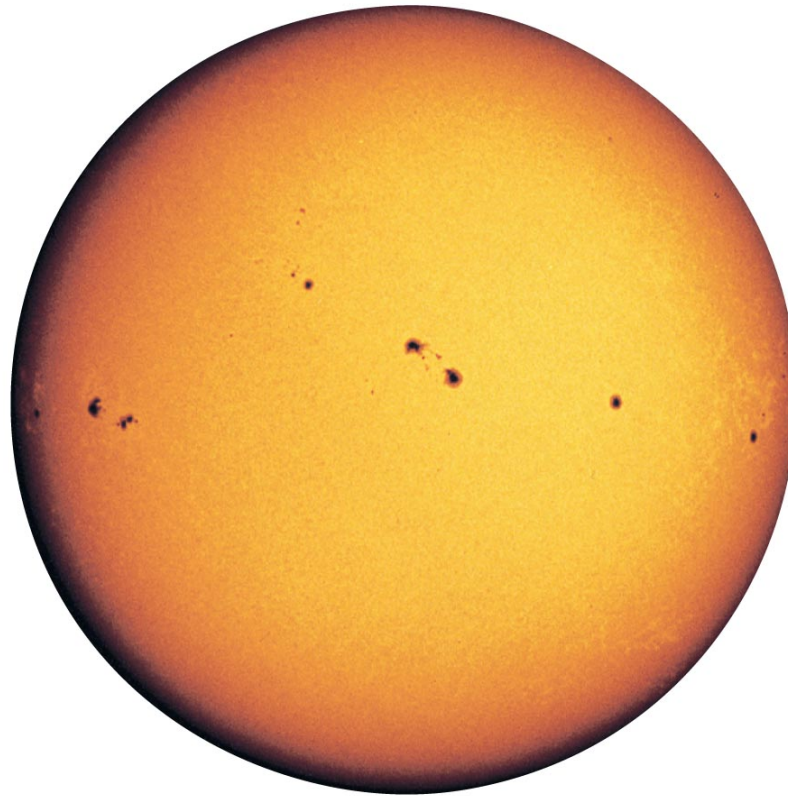
- Our goals for learning:
 - **What is our place in the universe?**
 - **How big is the universe?**

What is our place in the universe?



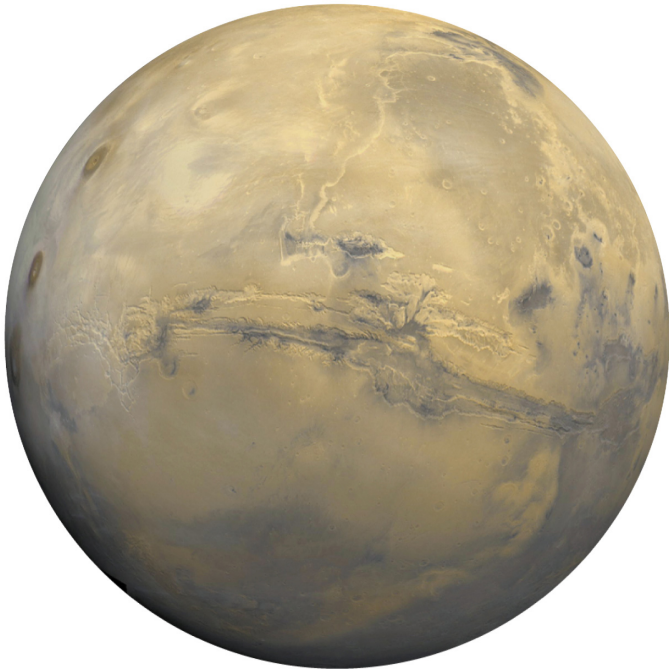
Star

- A large, glowing ball of gas that generates heat and light through nuclear fusion

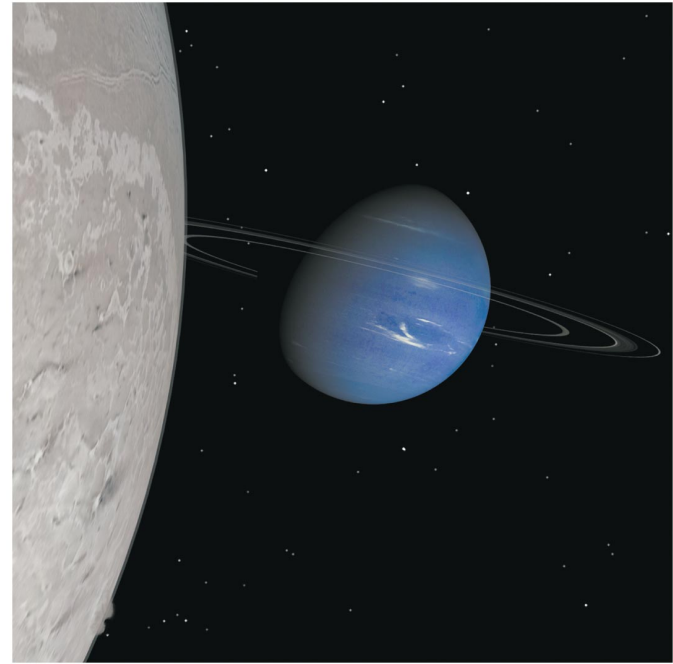


a A visible-light photograph of the Sun's surface. The dark splotches are sunspots—each large enough to swallow several Earths.

Planet



Mars

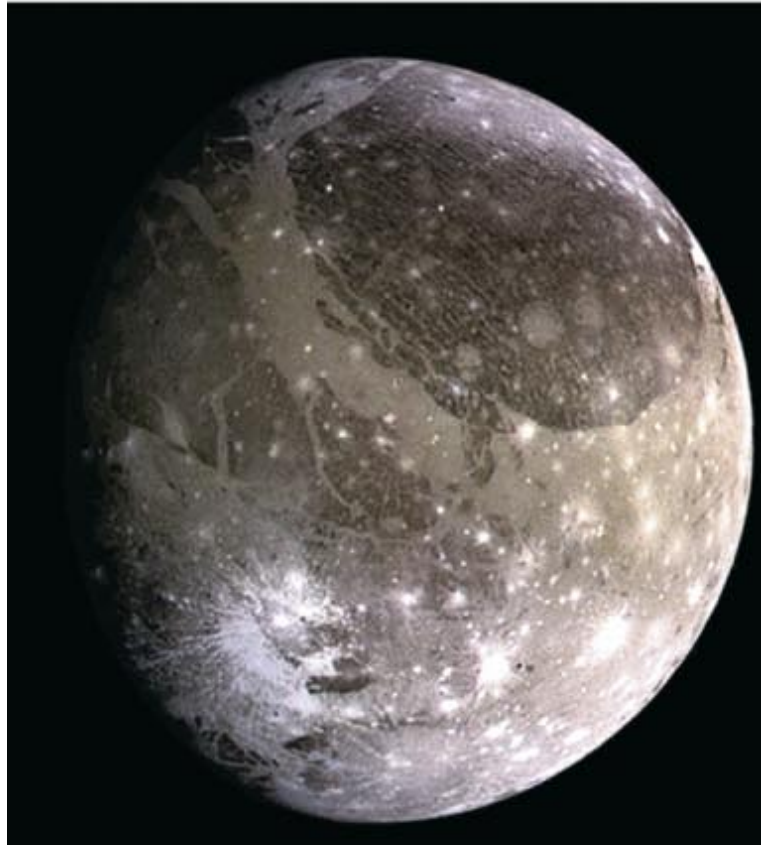


Neptune

- A moderately large object that orbits a star; it shines by reflected light. Planets may be rocky, icy, or gaseous in composition.

Moon (or Satellite)

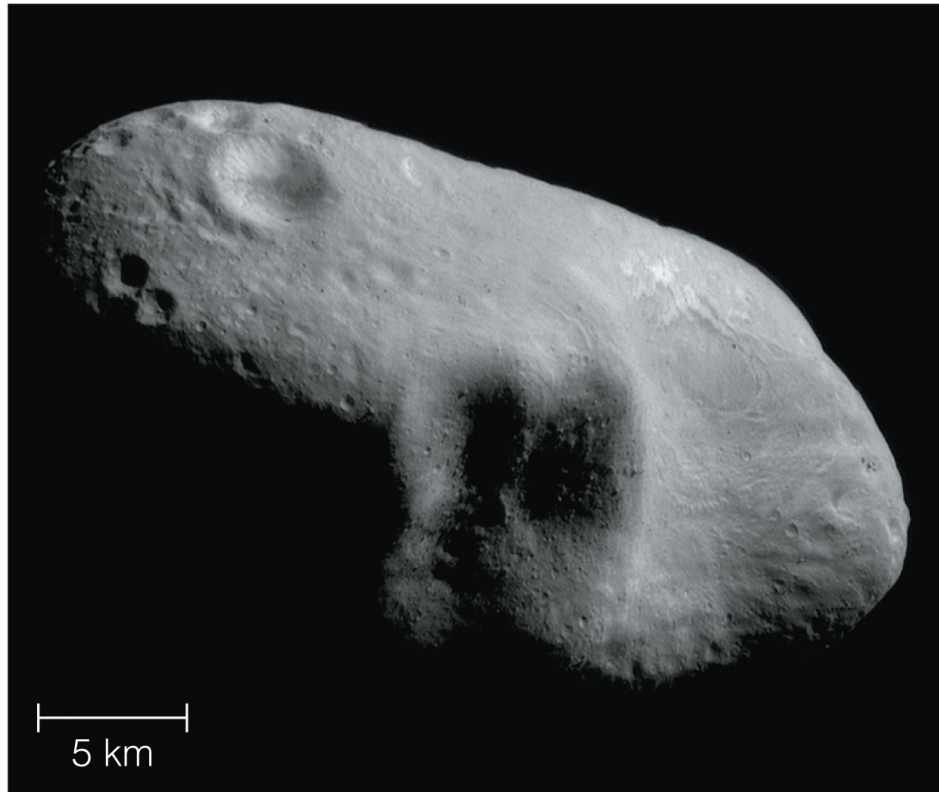
- An object that orbits a planet



Ganymede (orbits Jupiter)

Asteroid

- A relatively small and rocky object that orbits a star



Eros, an asteroid

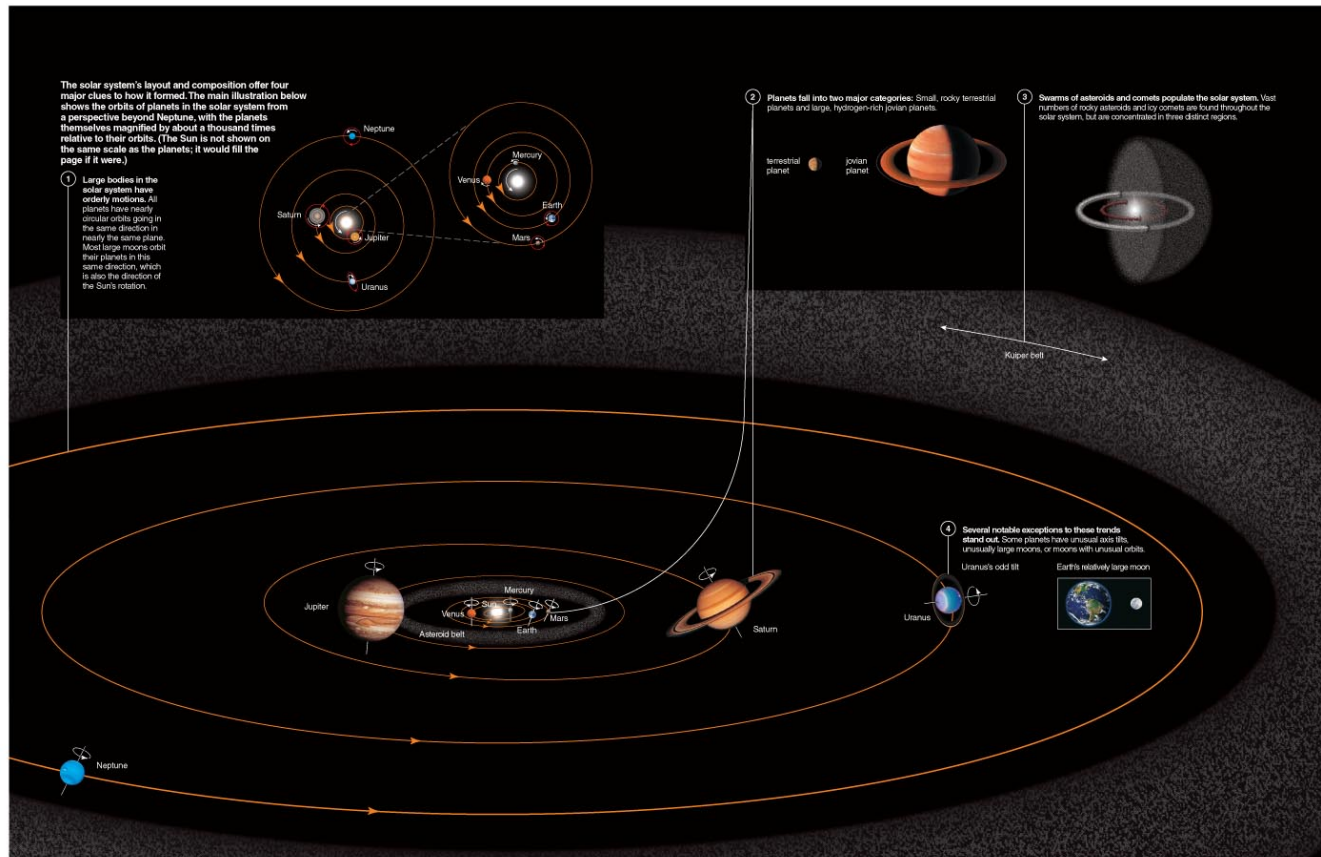
Comet

- A relatively small and icy object that orbits a star



Solar (Star) System

- A star and all the material that orbits it, including its planets and moons



Nebula

- An interstellar cloud of gas and/or dust



Galaxy

- A great island of stars in space, all held together by gravity and orbiting a common center



Universe

- The sum total of all matter and energy; that is, everything within and between all galaxies

Far away means back in time?

- Light travels at a finite speed (300,000 km/s).

Destination	Light travel time
Moon	1 second
Sun	8 minutes
Sirius	8 years
Andromeda Galaxy	2.5 million years

- Thus, we see objects as they were in the past:
The farther away we look in distance, the further back we look in time.

Far away means back in time?

Example:

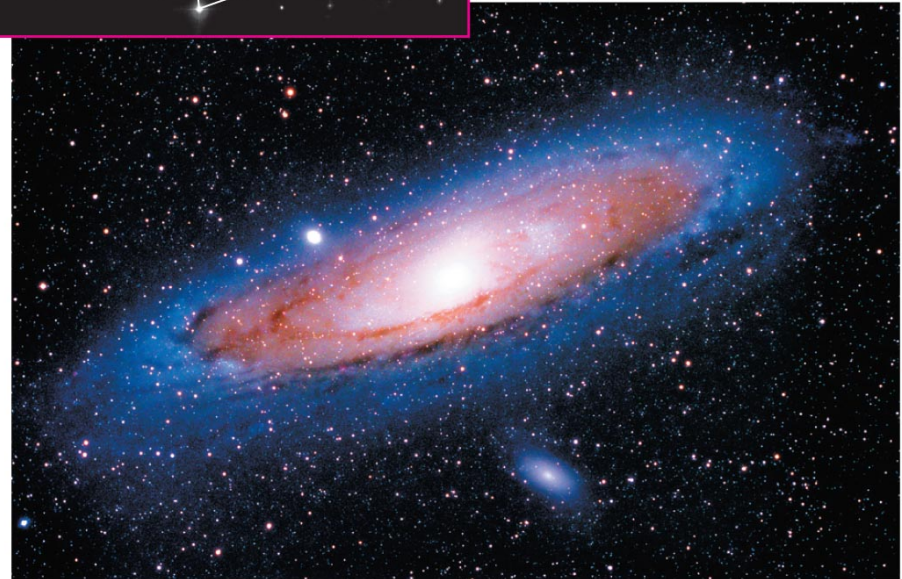
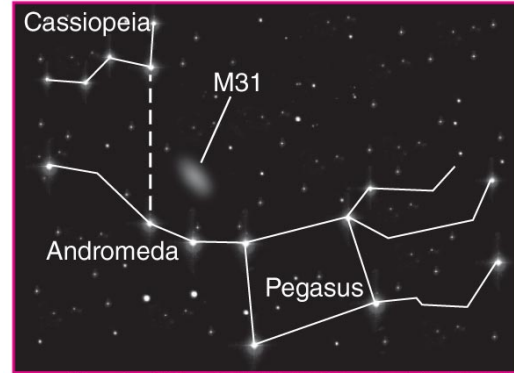
- We see the Orion Nebula as it looked 1500 years ago.



Far away means back in time?

Example:

- This photo shows the Andromeda Galaxy as it looked about 2 1/2 million years ago.
- **Question: When will we be able to see what it looks like now?**



Light-year

- The **distance** light can travel in 1 year
- About 10 trillion kilometers (6 trillion miles)

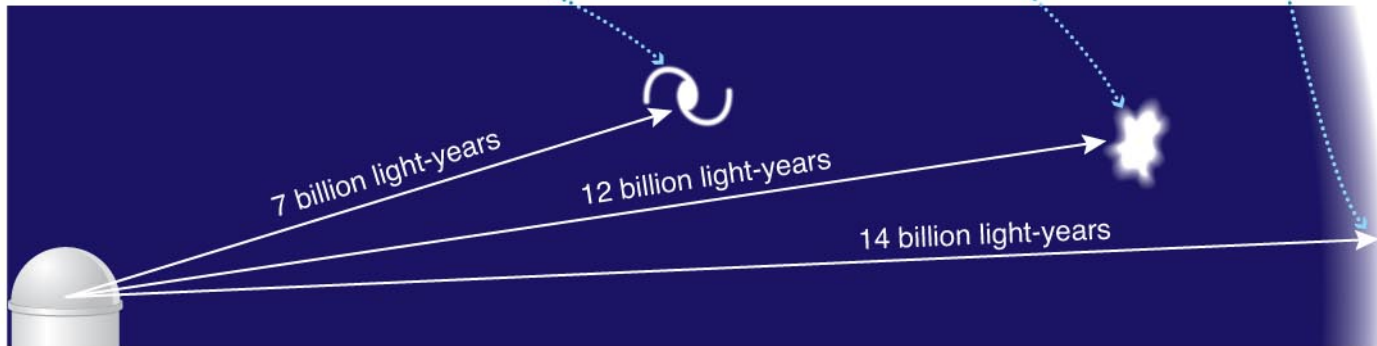
Light-year

- At great distances, we see objects as they were when the universe was much younger.

Far: We see a galaxy 7 billion light-years away as it was 7 billion years ago—when the universe was about half its current age of 14 billion years.

Farther: We see a galaxy 12 billion light-years away as it was 12 billion years ago—when the universe was only about 2 billion years old.

The limit of our observable universe: Light from nearly 14 billion light-years away shows the universe as it looked shortly after the Big Bang, before galaxies existed.



Beyond the observable universe: We cannot see anything farther than 14 billion light-years away, because its light has not had enough time to reach us.

How far is a light-year?

$$1 \text{ light-year} = (\text{speed of light}) \times (1 \text{ year})$$

$$= \left(300,000 \frac{\text{km}}{\text{s}} \right) \times \left(\frac{365 \text{ days}}{1 \text{ yr}} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{60 \text{ s}}{1 \text{ min}} \right)$$

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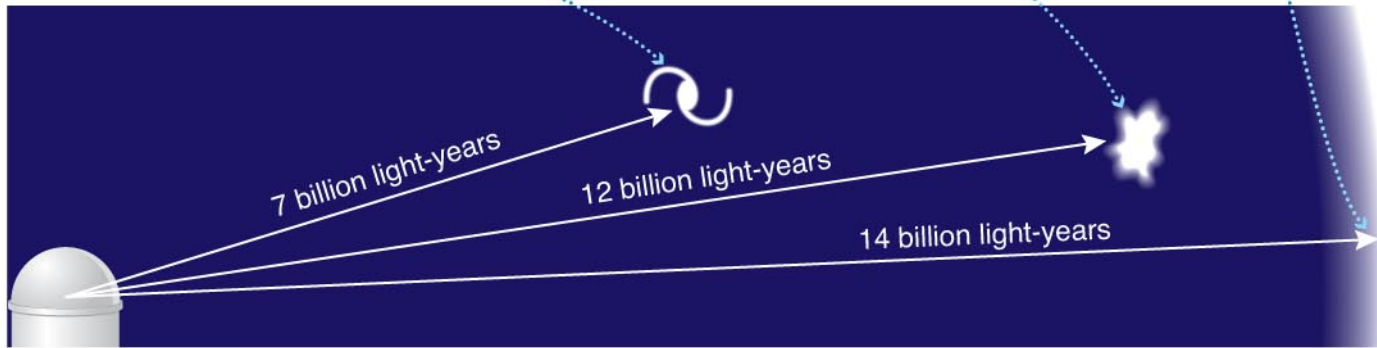
$$= 9,460,000,000,000 \text{ km}$$

Can we see the entire universe?

Far: We see a galaxy 7 billion light-years away as it was 7 billion years ago—when the universe was about half its current age of 14 billion years.

Farther: We see a galaxy 12 billion light-years away as it was 12 billion years ago—when the universe was only about 2 billion years old.

The limit of our observable universe: Light from nearly 14 billion light-years away shows the universe as it looked shortly after the Big Bang, before galaxies existed.



Beyond the observable universe: We cannot see anything farther than 14 billion light-years away, because its light has not had enough time to reach us.

Thought Question

Why can't we see a galaxy 15 billion light-years away?

(Assume the universe is 14 billion years old.)

- A. Because no galaxies exist at such a great distance.
- B. Galaxies may exist at that distance, but their light would be too faint for our telescopes to see.
- C. Because looking 15 billion light-years away means looking to a time before the universe existed.

Thought Question

Why can't we see a galaxy 15 billion light-years away?

(Assume the universe is 14 billion years old.)

- A. Because no galaxies exist at such a great distance.
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- C. Because looking 15 billion light-years away means looking to a time before the universe existed.**

What have we learned?

- **What is our place in the universe?**
 - Earth is part of the solar system, which is the Milky Way Galaxy, which is a member of the Local Group of galaxies in the Local Supercluster.

How big is Earth compared to our solar system?

Let's reduce the size of the solar system by a factor of 10 billion; the Sun is now the size of a large grapefruit (14 cm diameter).

How big is Earth on this scale?

- A. an atom
- B. a ball point
- C. a marble
- D. a golf ball

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- B. a ball point**
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The Scale of the Solar System

- On a 1-to-10-billion scale:
 - The Sun is the size of a large grapefruit (14 cm).
 - Earth is the size of a ball point, 15 meters away.

How far away are the stars?

On our 1-to-10-billion scale, it's just a few minutes' walk to Pluto.

How far would you have to walk to reach Alpha Centauri?

- A. 1 mile
- B. 10 miles
- C. 100 miles
- D. the distance across the United States
(2500 miles)

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How far would you have to walk to reach Alpha Centauri?

A. 1 mile

B. 10 miles

C. 100 miles

**D. the distance across the United States
(2500 miles)**

How big is the Milky Way Galaxy?

- The Milky Way has about 100 billion stars.
- On the same 1-to-10-billion scale, how big is the Milky Way?

Thought Question

Suppose you tried to count the more than 100 billion stars in our galaxy, at a rate of one per second.

How long would it take you?

- A. a few weeks
- B. a few months
- C. a few years
- D. a few thousand years

Thought Question

Suppose you tried to count the more than 100 billion stars in our galaxy, at a rate of one per second.

How long would it take you?

- A. a few weeks
- B. a few months
- C. a few years
- D. a few thousand years**

How big is the universe?

- The Milky Way is one of about 100 billion galaxies.
- 10^{11} stars/galaxy x 10^{11} galaxies = 10^{22} stars



- There are as many stars as grains of (dry) sand on *all* Earth's beaches.

What have we learned?

- **How big is the universe?**
 - The distances between planets are huge compared to their sizes—on a scale of 1-to-10-billion, Earth is the size of a ball point and the Sun is 15 meters away.
 - On the same scale, the stars are thousands of kilometers away.
 - It would take more than 3000 years to count the stars in the Milky Way Galaxy at a rate of one per second, and they are spread across 100,000 light-years.
 - The observable universe is 14 billion light-years in radius and contains over 100 billion galaxies with a total number of stars comparable to the number of grains of sand on all of Earth's beaches.

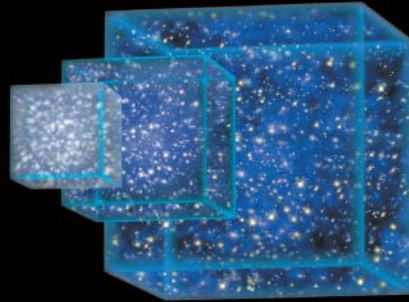
1.2 The History of the Universe

- Our goals for learning:
 - **How did we come to be?**
 - **How do our lifetimes compare to the age of the universe?**

How did we come to be?

Throughout this book we will see that human life is intimately connected with the development of the universe as a whole. This illustration presents an overview of our cosmic origins, showing some of the crucial steps that made our existence possible.

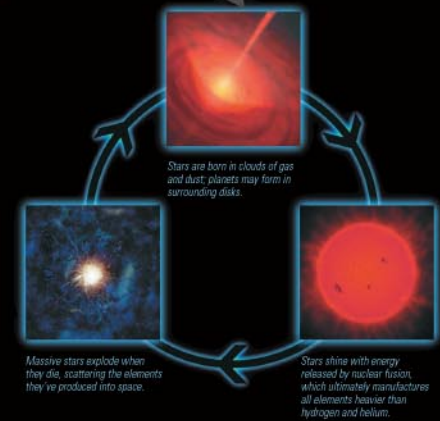
- ① **Birth of the Universe:** The expansion of the universe began with the hot and dense Big Bang. The cubes show how one region of the universe has expanded with time. The universe continues to expand, but on smaller scales gravity has pulled matter together to make galaxies.



- ② **Galaxies as Cosmic Recycling Plants:** The early universe contained only two chemical elements: hydrogen and helium. All other elements were made by stars and recycled from one stellar generation to the next within galaxies like our Milky Way.



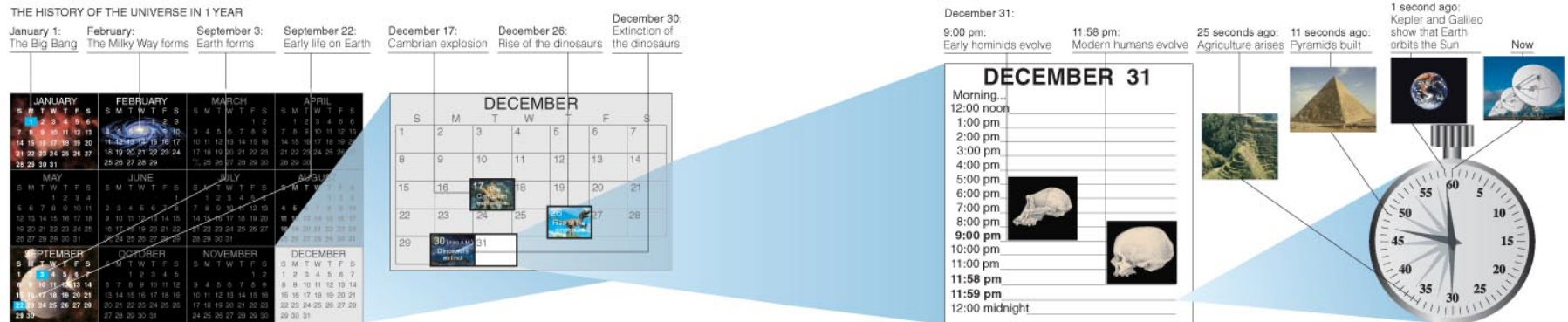
- ④ **Earth and Life:** By the time our solar system was born, 4½ billion years ago, about 2% of the original hydrogen and helium had been converted into heavier elements. We are therefore "star stuff," because we and our planet are made from elements manufactured in stars that lived and died long ago.



- ③ **Life Cycles of Stars:** Many generations of stars have lived and died in the Milky Way.

How do our lifetimes compare to the age of the universe?

- The cosmic calendar: a scale on which we compress the history of the universe into 1 year.



What have we learned?

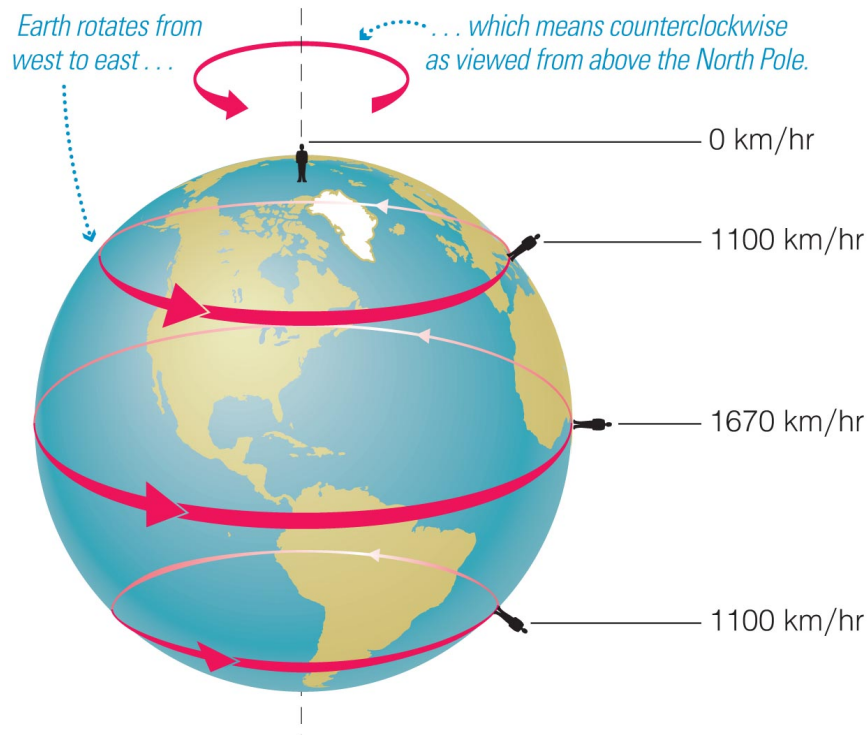
- **How did we come to be?**
 - The matter in our bodies came from the Big Bang, which produced hydrogen and helium.
 - All other elements were constructed from H and He in stars and then recycled into new star systems, including our solar system.
- **How do our lifetimes compare to the age of the universe?**
 - On a cosmic calendar that compresses the history of the universe into 1 year, human civilization is just a few seconds old, and a human lifetime is a fraction of a second.

1.3 Spaceship Earth

- Our goals for learning:
 - **How is Earth moving through space?**
 - **How do galaxies move within the universe?**

How is Earth moving through space?

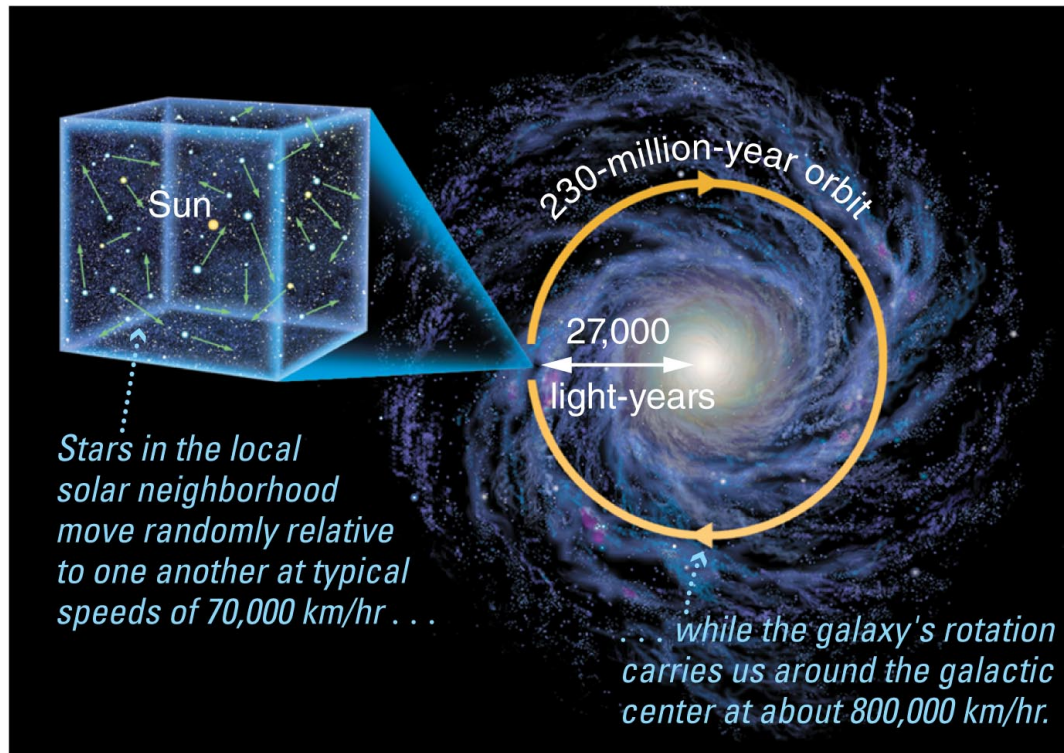
- Contrary to our perception, we are not "sitting still."
- We are moving with Earth in several ways, and at surprisingly fast speeds.



The Earth **rotates** around its axis once every day.

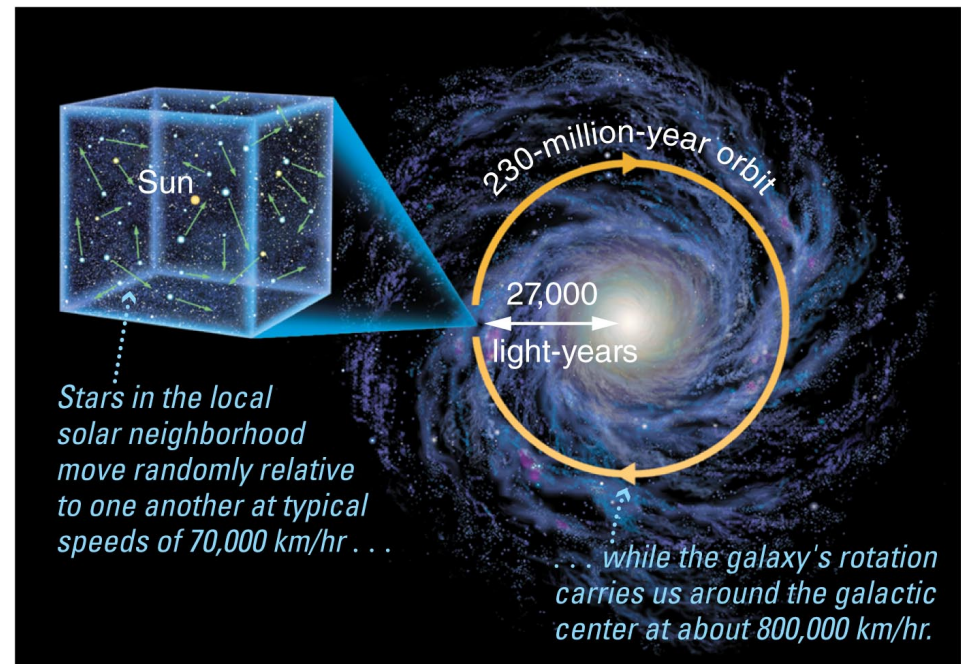
How is Earth moving through space?

- Earth **orbits** the Sun (revolves) once every year:
 - at an average distance of 1 AU \approx 150 million kilometers.
 - with Earth's axis tilted by 23.5° (pointing to Polaris)
- It rotates in the same direction it orbits, **counterclockwise** as viewed from above the North Pole.



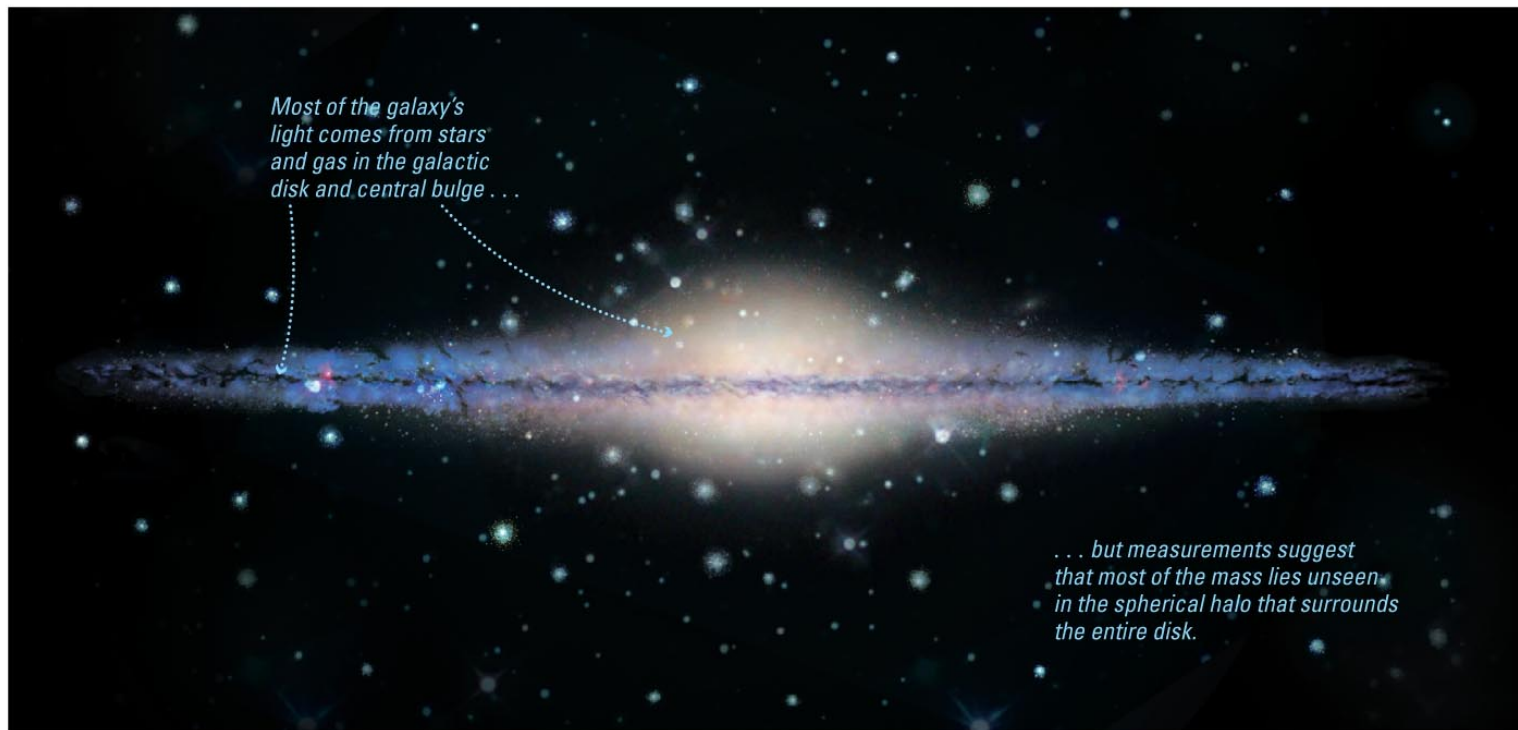
How is our Sun moving in in the Milky Way Galaxy?

- Our Sun moves randomly relative to the other stars in the local solar neighborhood...
 - typical relative speeds of more than 70,000 km/hr
 - but stars are so far away that we cannot easily notice their motion
- ... and orbits the galaxy every 230 million years.



How is our Sun moving in in the Milky Way Galaxy?

- More detailed study of the Milky Way's rotation reveals one of the greatest mysteries in astronomy:



How do galaxies move within the universe?

- Galaxies are carried along with the expansion of the universe. But how did Hubble figure out that the universe is expanding?

Hubble Discovered That:

- All galaxies outside our Local Group are moving away from us.
- The more distant the galaxy, the faster it is racing away.
- Conclusion: We live in an expanding universe.

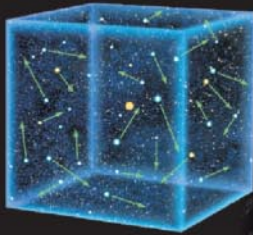
Are we ever sitting still?



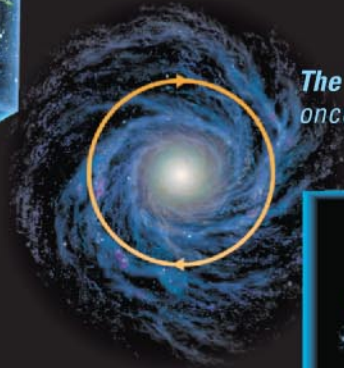
Earth rotates around its axis once each day, carrying people in most parts of the world around the axis at more than 1000 km/hr.



Earth orbits the Sun once each year, moving at more than 100,000 km/hr.



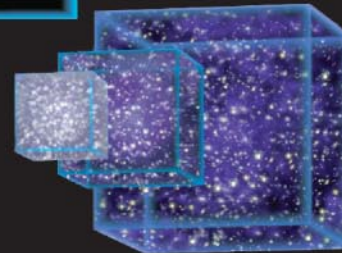
The Solar System moves relative to nearby stars, typically at a speed of 70,000 km/hr.



The Milky Way Galaxy rotates, carrying our Sun around its center once every 230 million years, at a speed of about 800,000 km/hr.



Our galaxy moves relative to others in the Local Group; we are traveling toward the Andromeda Galaxy at about 300,000 km/hr.



The universe expands. The more distant an object, the faster it moves away from us; the most distant galaxies are receding from us at speeds close to the speed of light.

What have we learned?

- **How is Earth moving through space?**
 - It rotates on its axis once a day and orbits the Sun at a distance of 1 AU = 150 million kilometers.
 - Stars in the Local Neighborhood move randomly relative to one another and orbit the center of the Milky Way in about 230 million years.

What have we learned?

- **How do galaxies move within the universe?**
 - All galaxies beyond the Local Group are moving away from us with expansion of the universe: the more distant they are, the faster they're moving.

1.4 The Human Adventure of Astronomy

- Our goals for learning:
 - **How has the study of astronomy affected human history?**

How has the study of astronomy affected human history?

- The Copernican revolution showed that Earth was not the center of the universe (Chapter 3).
- Study of planetary motion led to Newton's laws of motion and gravity (Chapter 4).
- Newton's laws laid the foundation of the industrial revolution.
- Modern discoveries are continuing to expand our "cosmic perspective."

What have we learned?

- **How has the study of astronomy affected human history?**
 - Throughout history, astronomy has provided an expanded perspective on Earth that has grown hand in hand with social and technological developments.