Chapter 1:
A Modern View of the Universe

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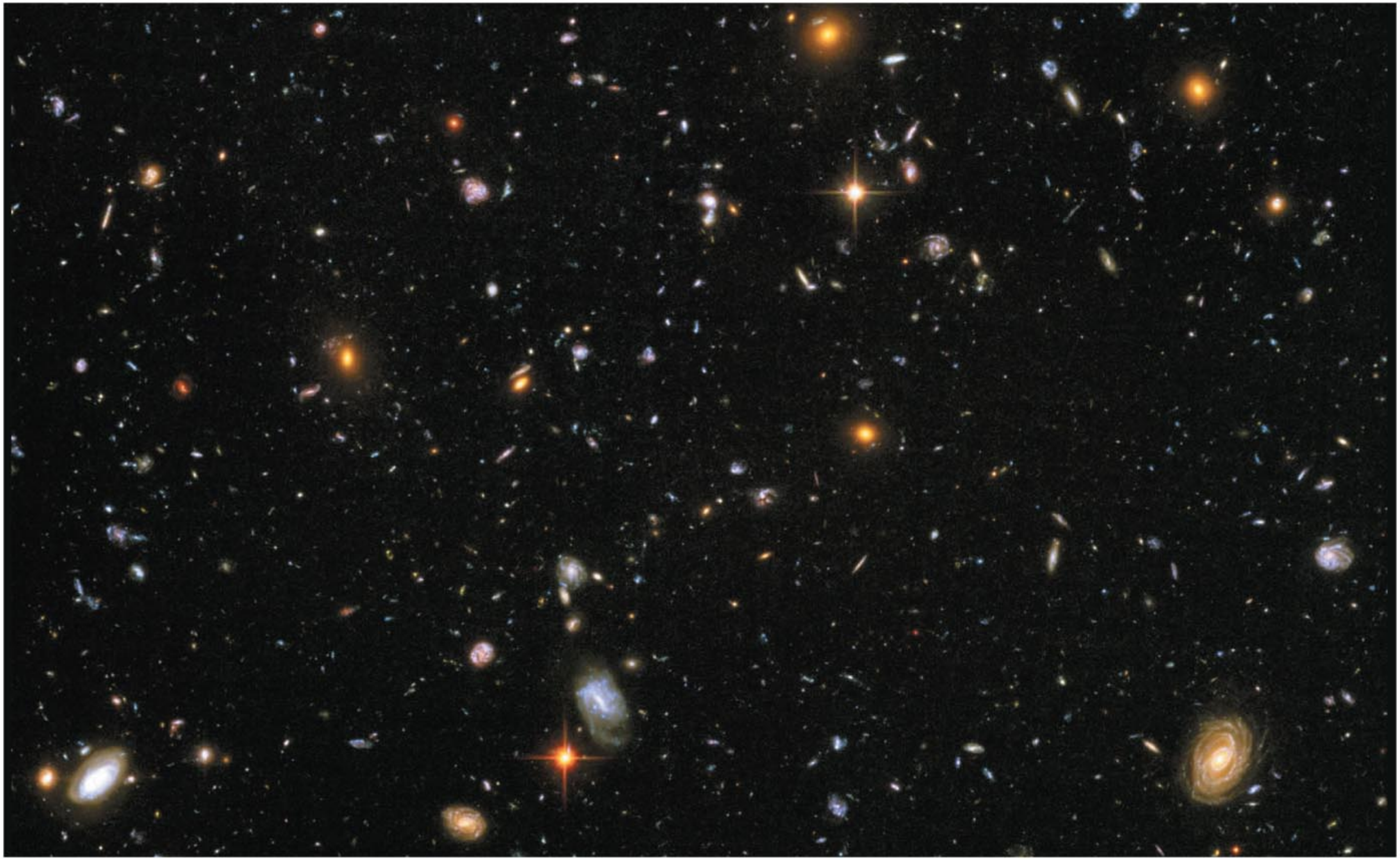
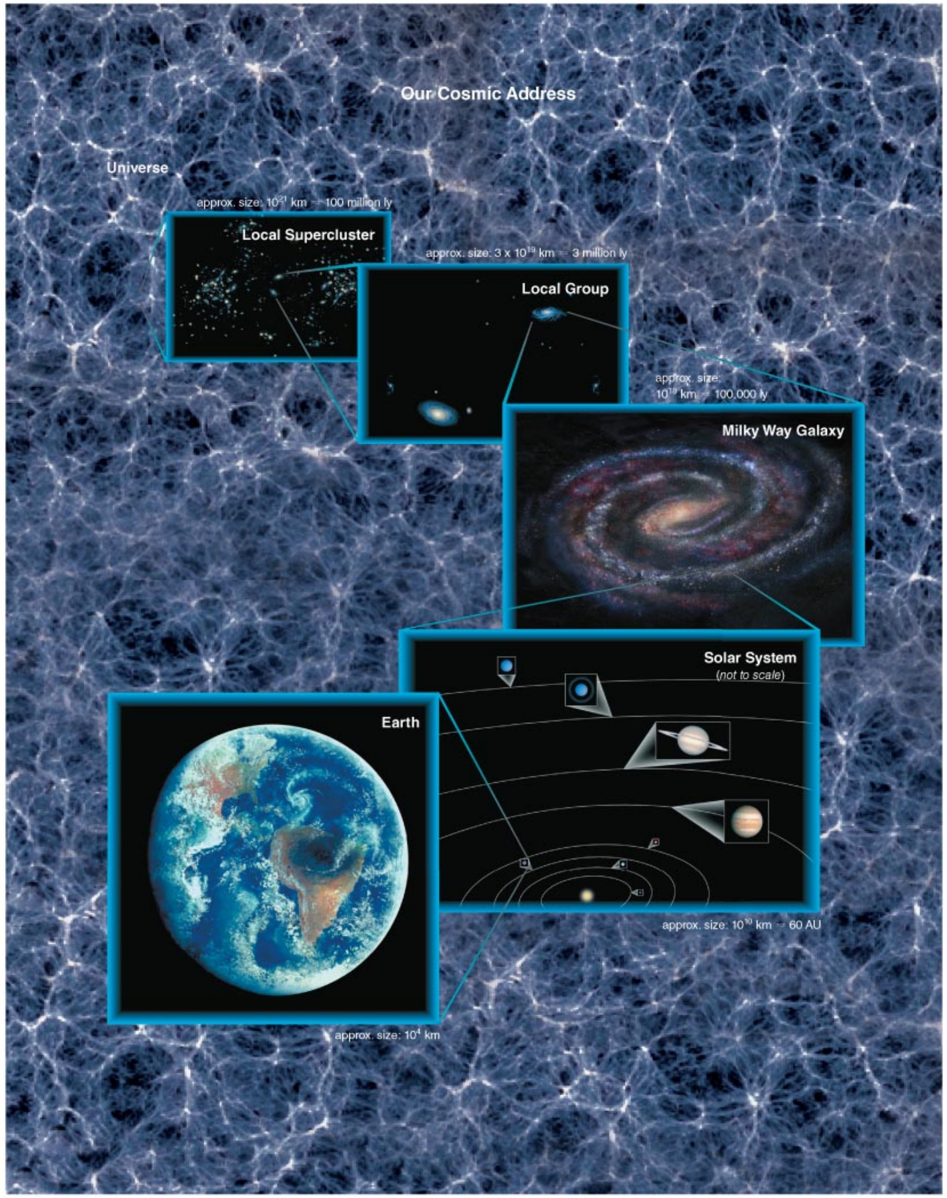


1.1 The Scale of the Universe

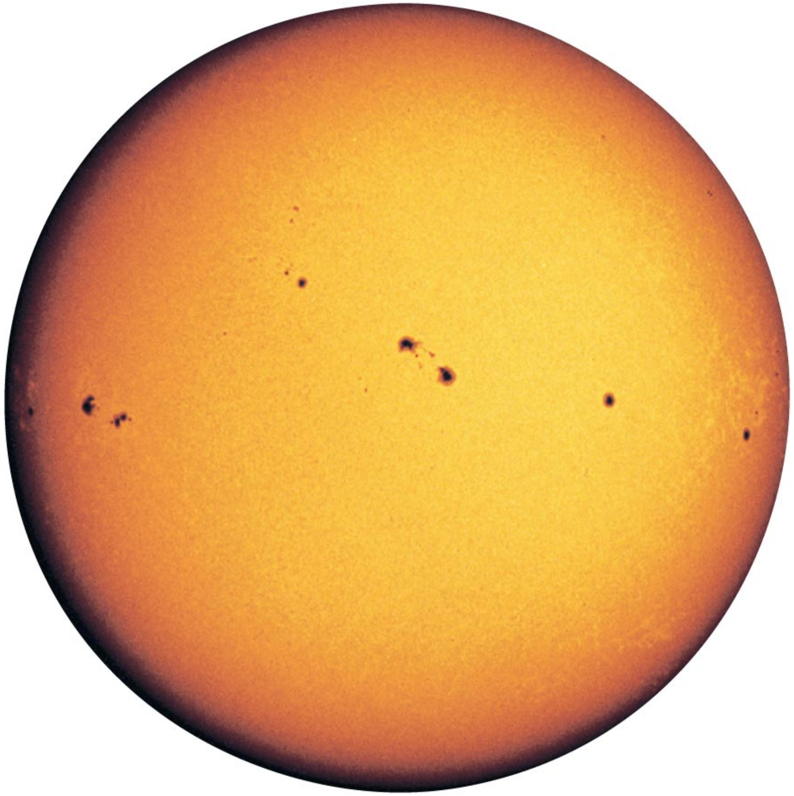
- Our goals for learning:
  - **What is our place in the universe?**
  - **How big is the universe?**

What is our place in the universe?



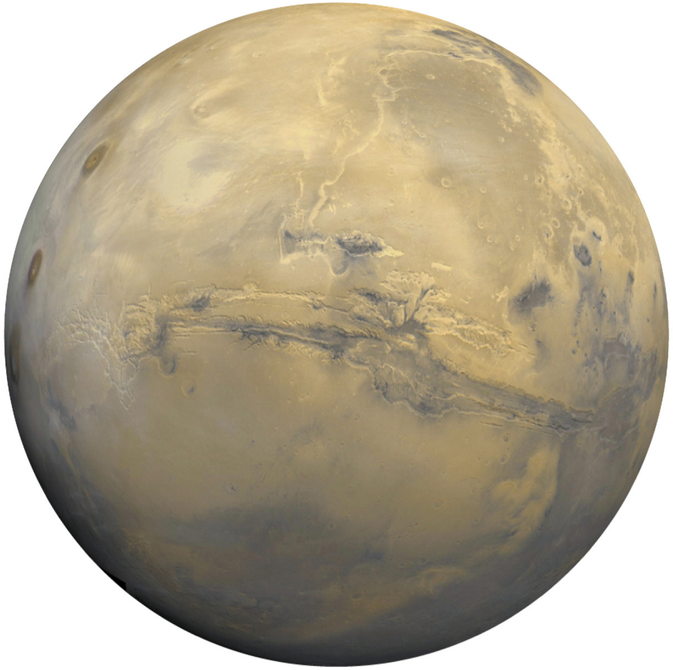
Star

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

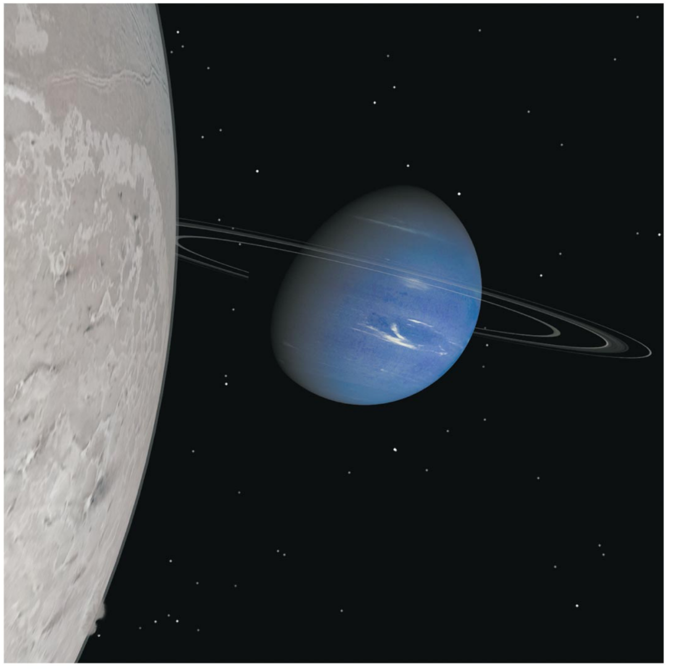


a A visible-light photograph of the Sun's surface. The dark splotches are sunspots—each large enough to swallow several Earths.

Planet



Mars

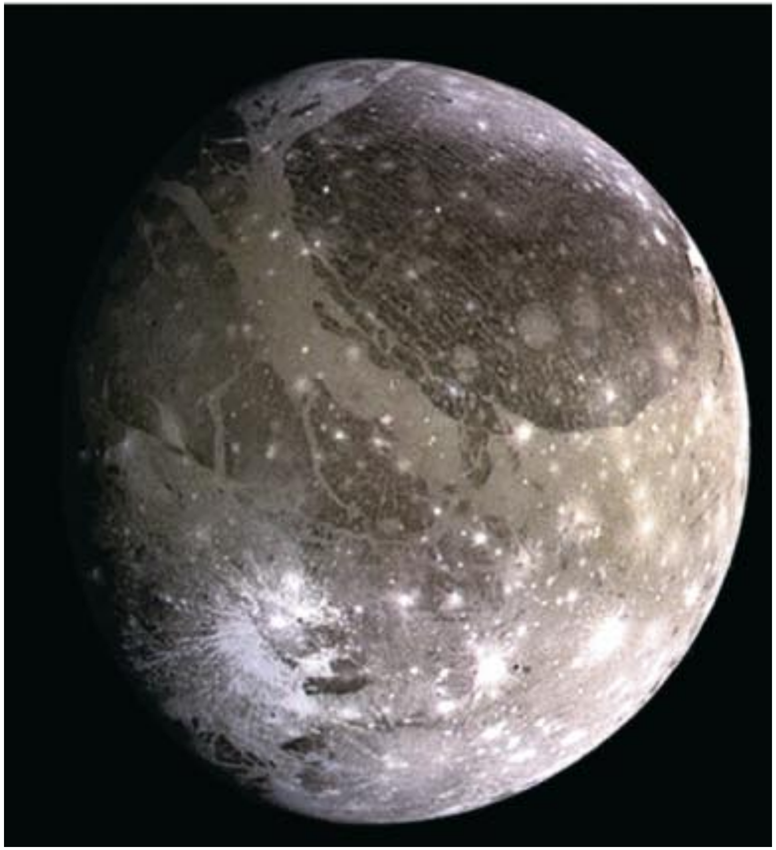


Neptune

- 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)

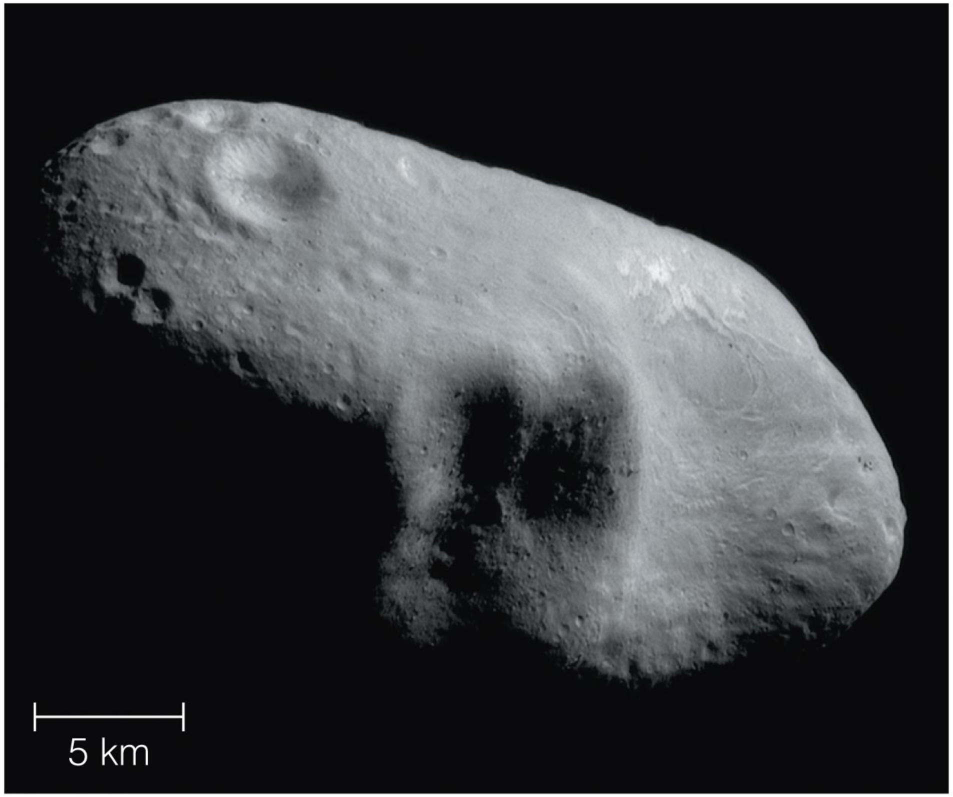
- An object that orbits a planet



Ganymede (orbits Jupiter)

Asteroid

- A relatively small and rocky object that orbits a star



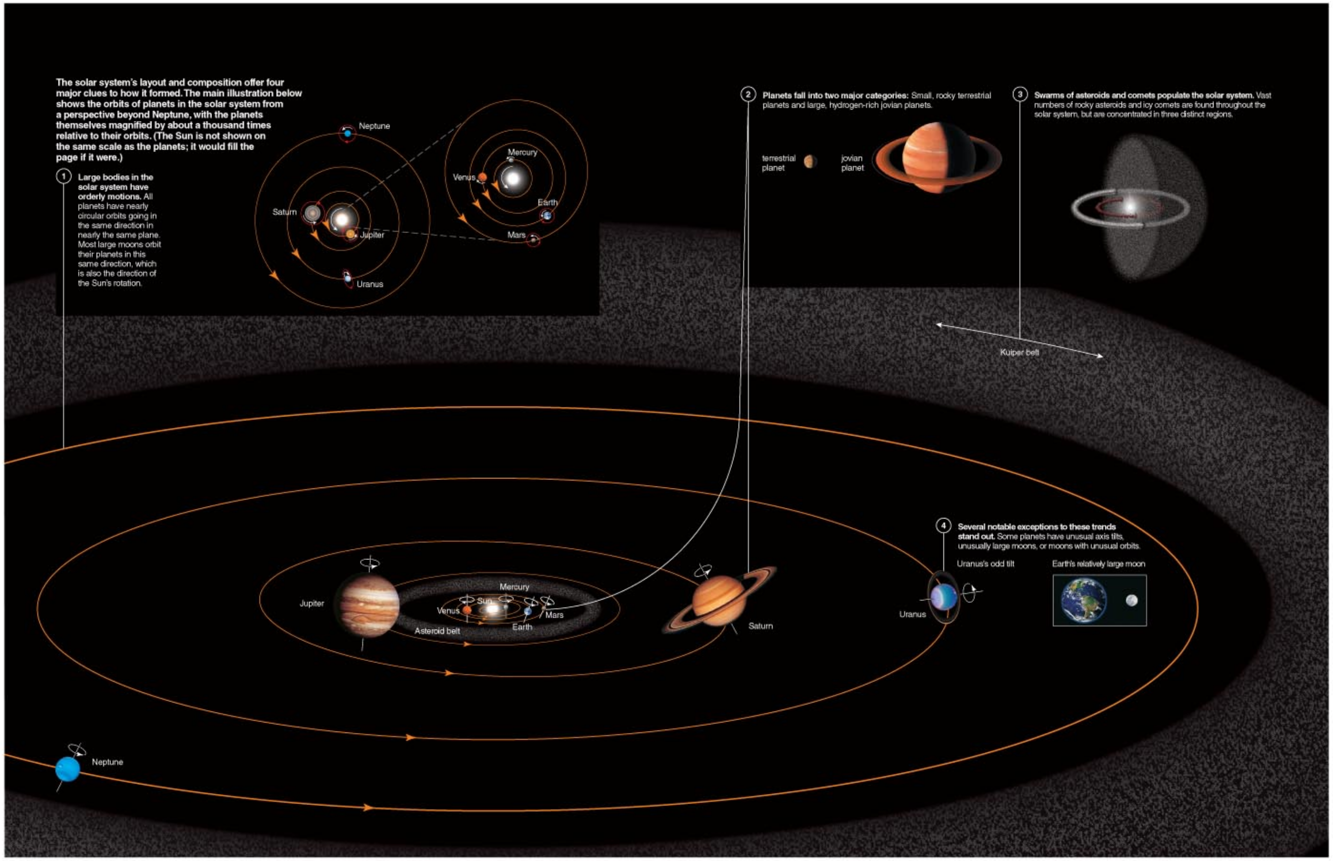
Eros, an asteroid

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?

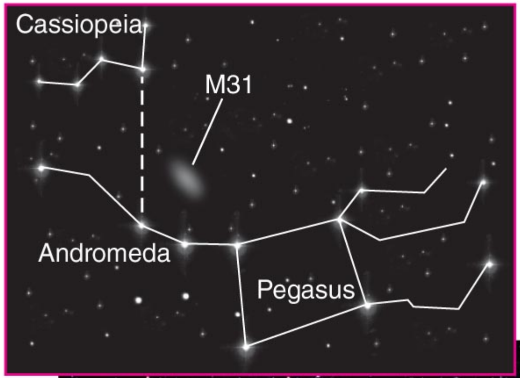
Example:

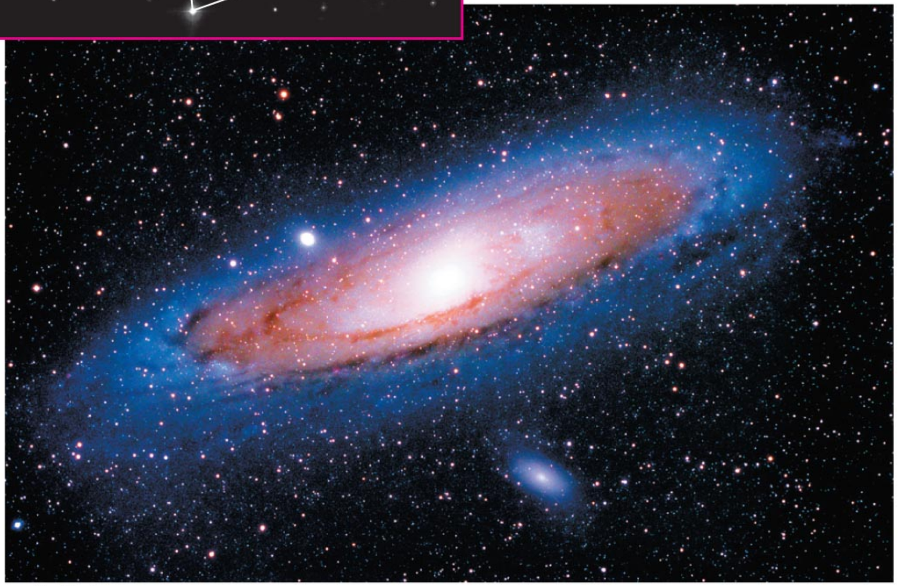
- We see the Orion Nebula as it looked 1500 years ago.

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?**



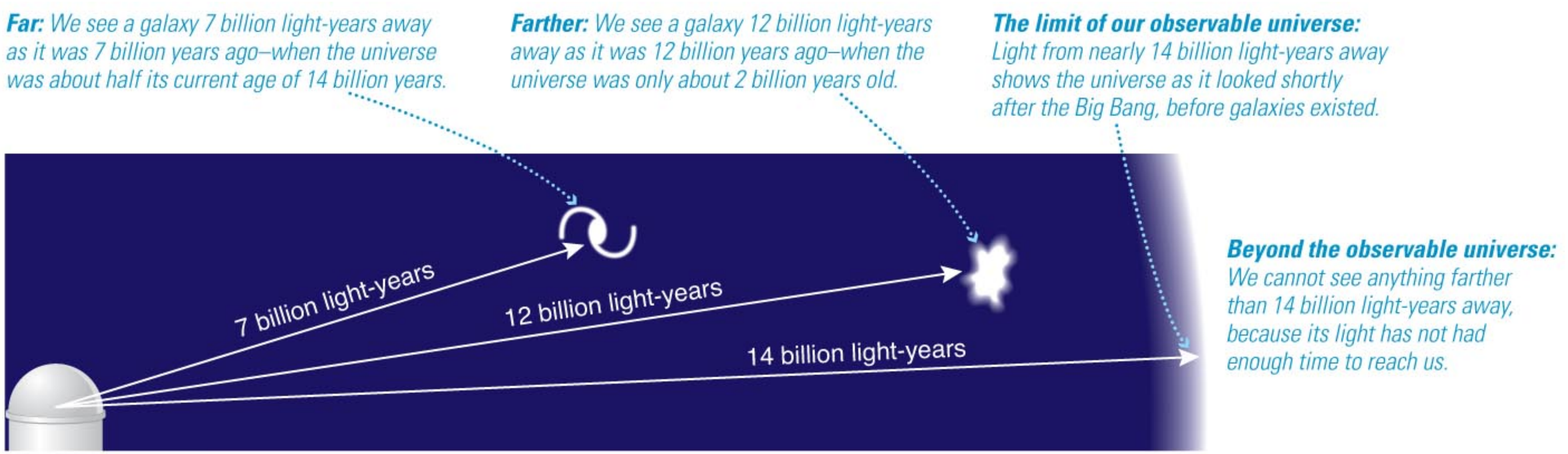


Light-year

- 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.



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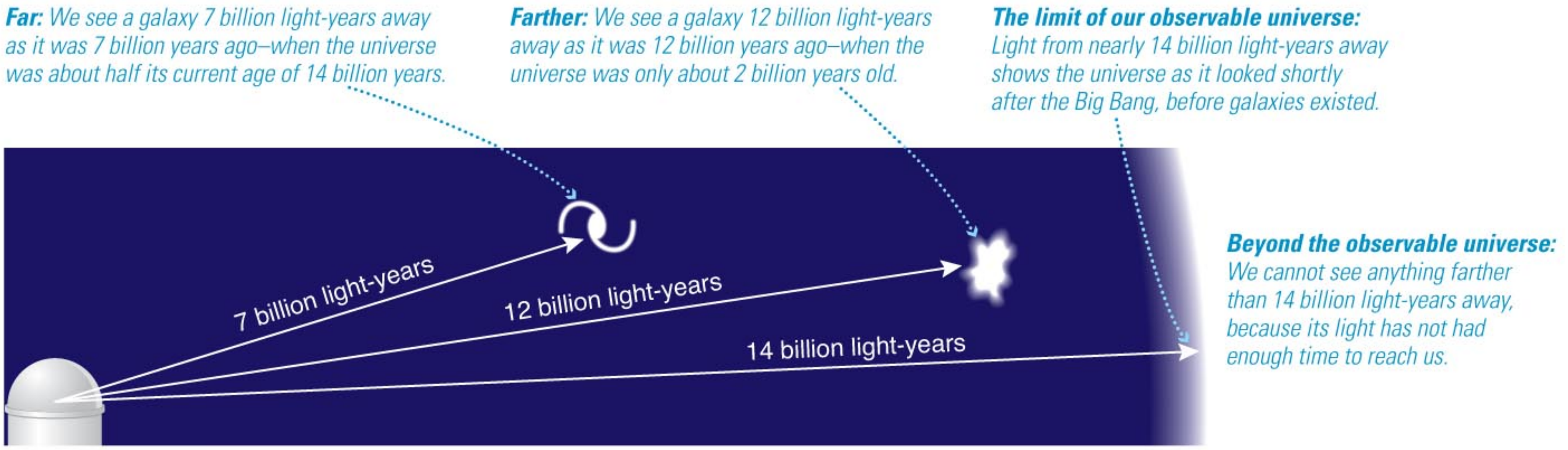
$$= 9{,}460{,}000{,}000{,}000 \text{ km}$$

Can we see the entire universe?



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.

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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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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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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

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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.

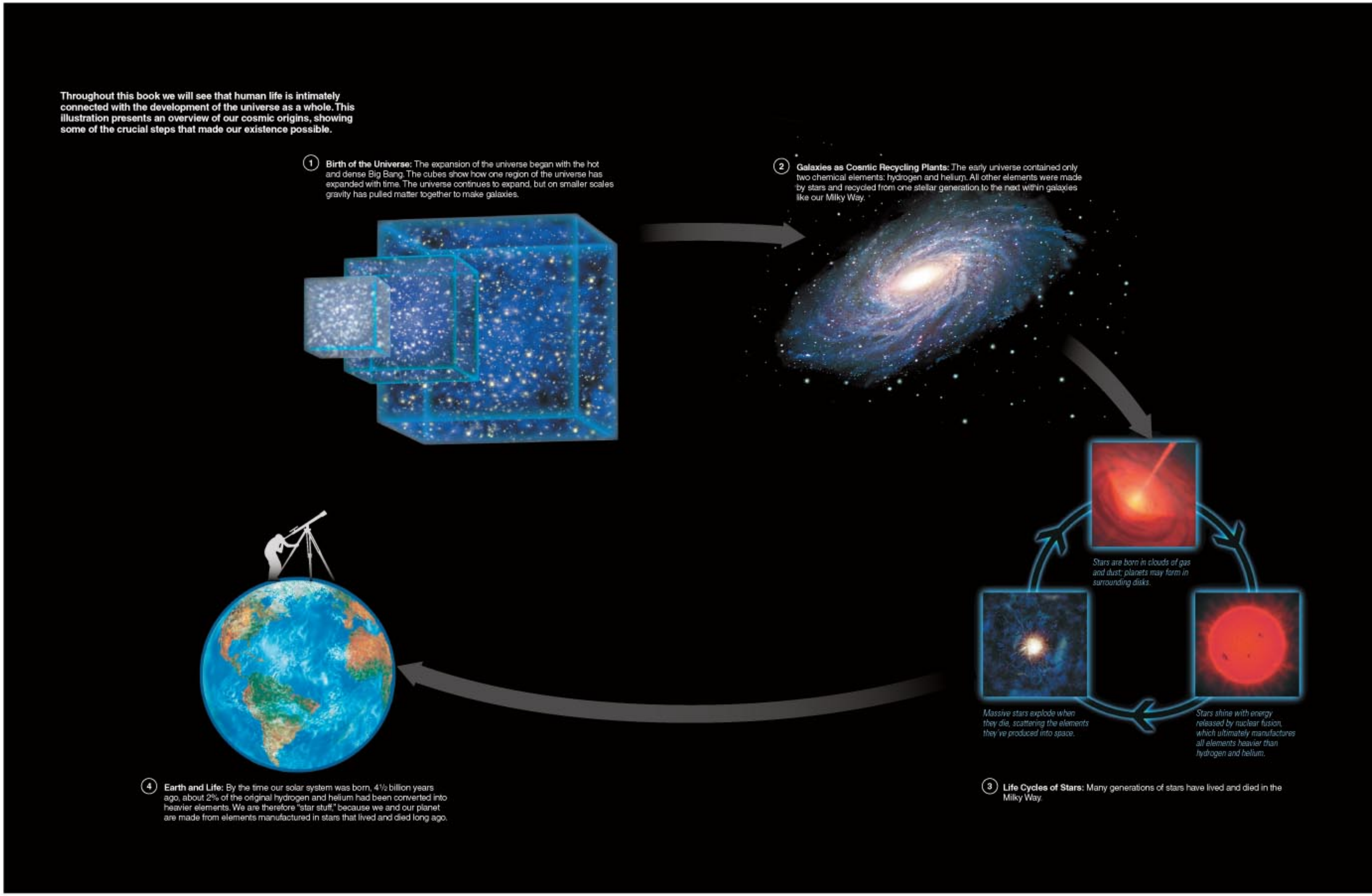
What have we learned?

- **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

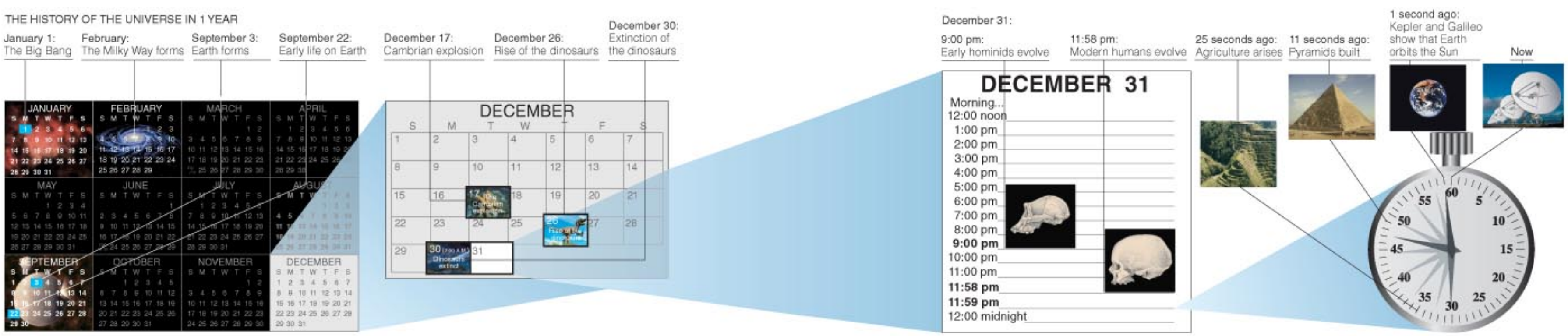
- Our goals for learning:
  - **How did we come to be?**
  - **How do our lifetimes compare to the age of the universe?**

How did we come to be?



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?

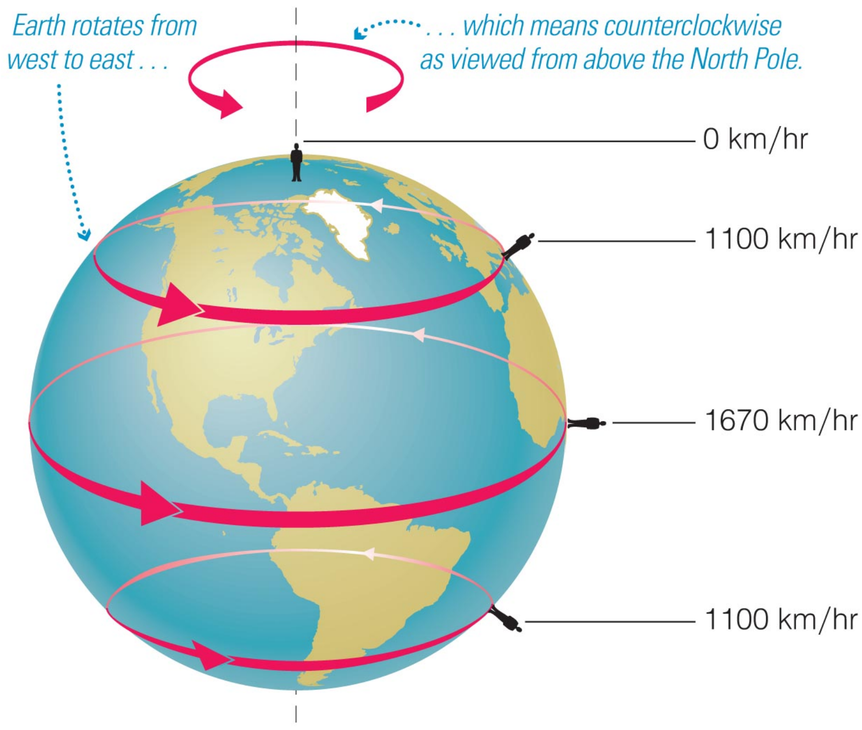
- **How did we come to be?**
  - The matter in our bodies came from the Big Bang, which produced hydrogen and helium.
  - All other elements were constructed from H and He in stars and then recycled into new star systems, including our solar system.
- **How do our lifetimes compare to the age of the 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?

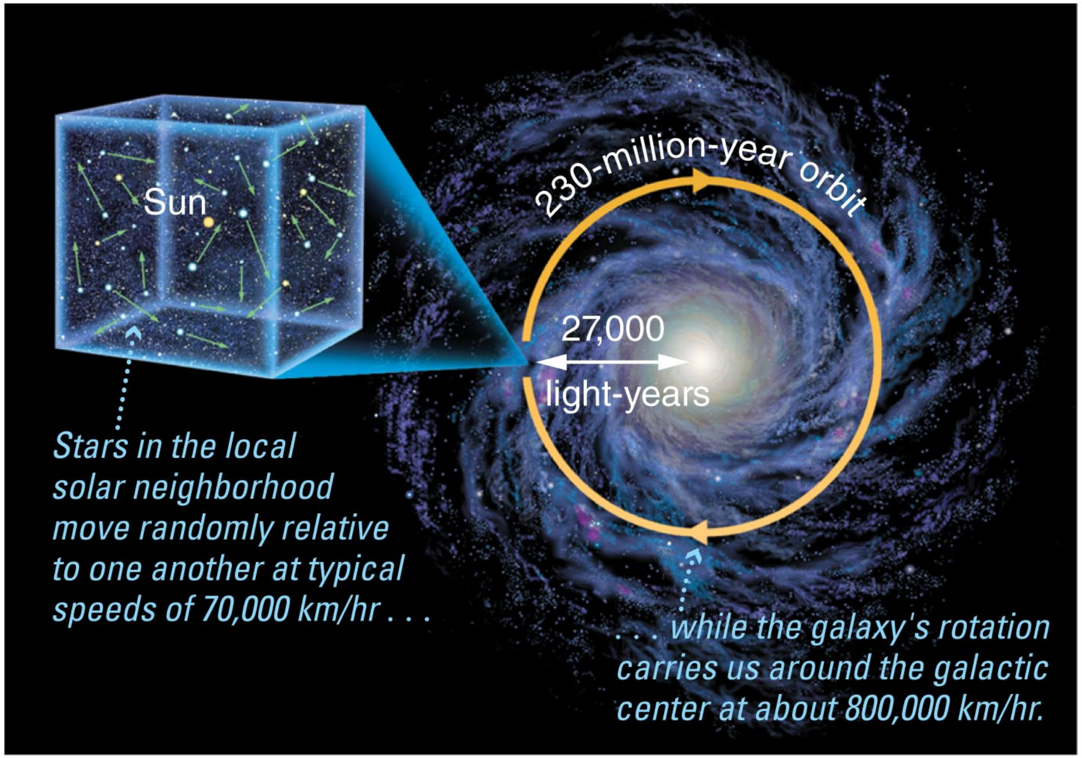
- Contrary to our perception, we are not "sitting still."
- We are moving with Earth in several ways, and at surprisingly fast speeds.



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

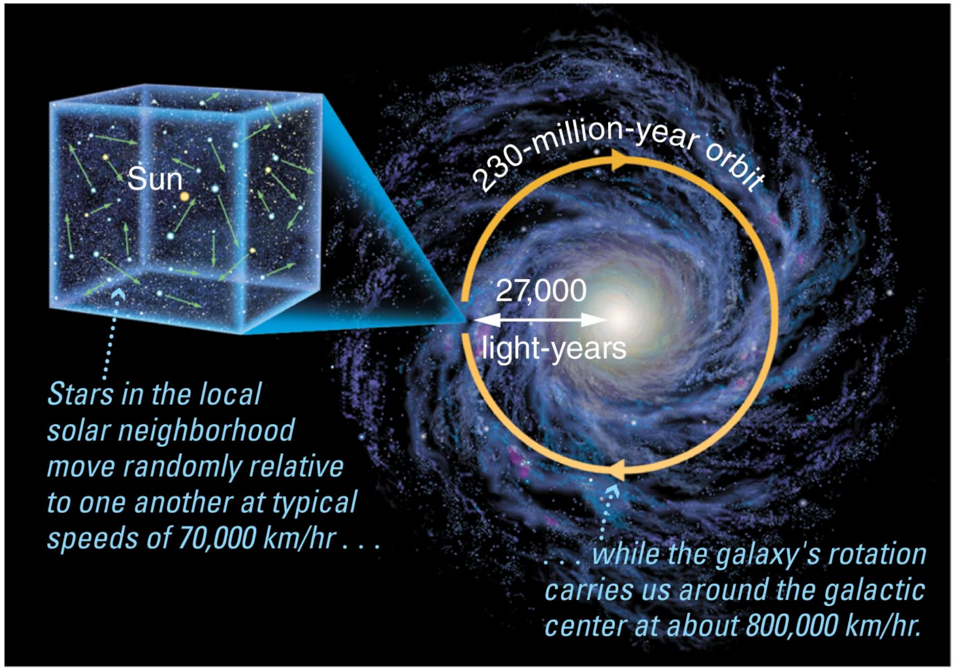
How is Earth moving through space?

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



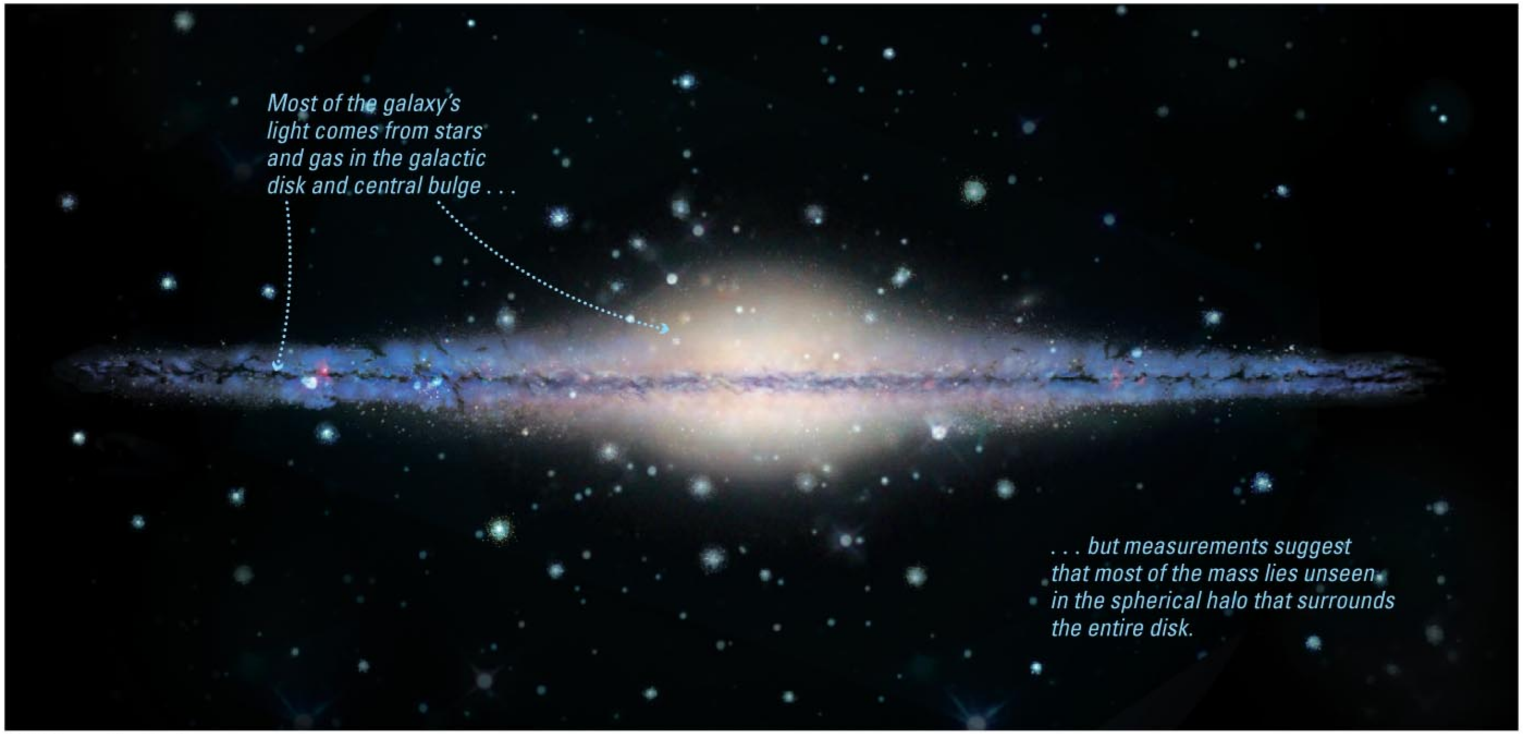
How is our Sun moving in in the Milky Way Galaxy?

- 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:



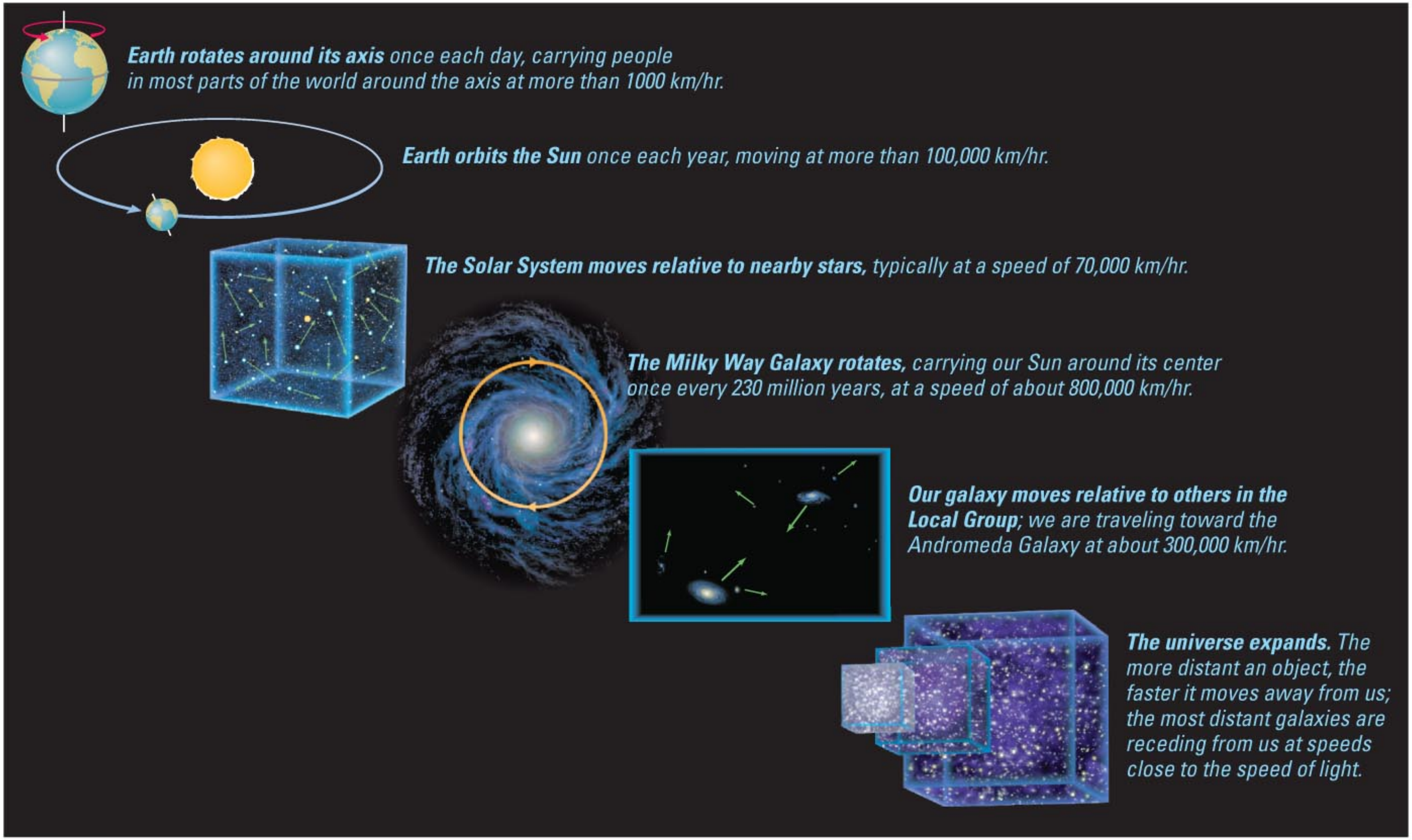
How do galaxies move within the universe?

- 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?



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.