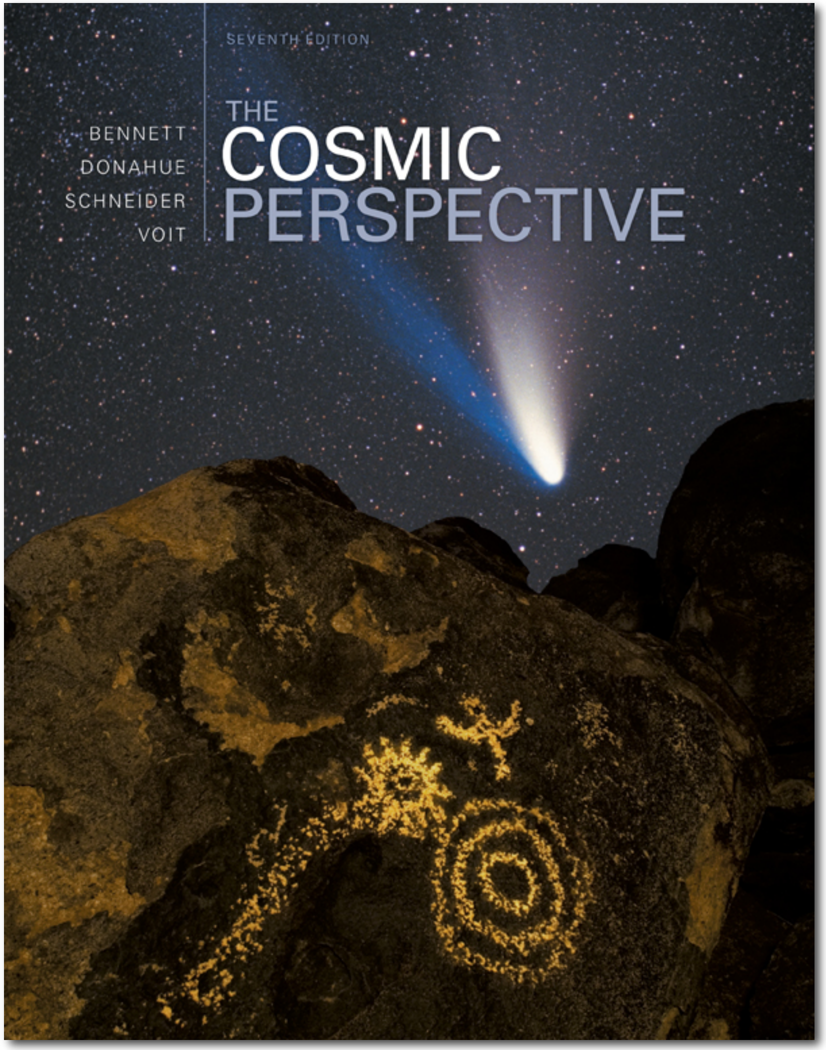
The Cosmic Perspective

Seventh Edition

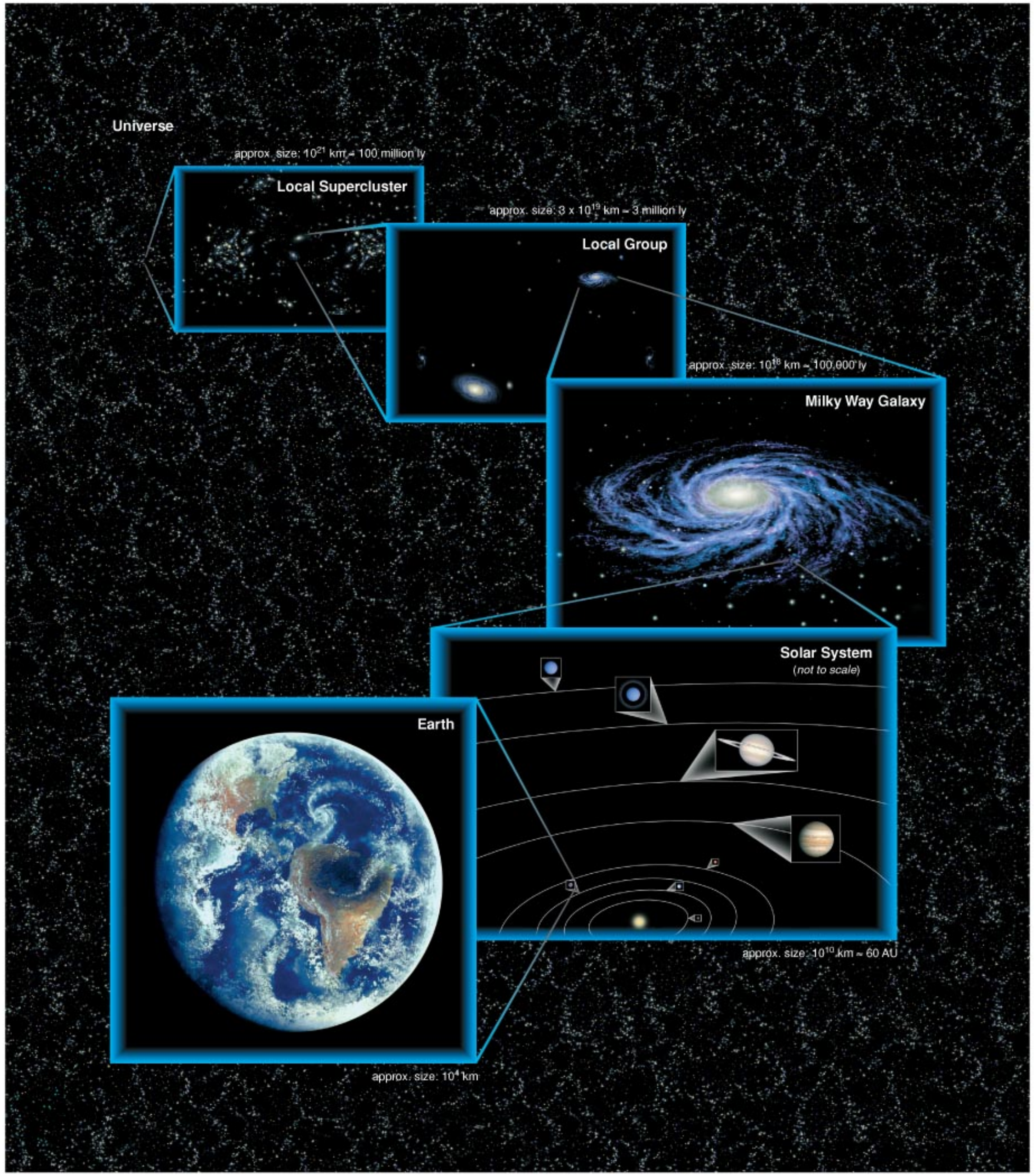
A Modern View of the Universe



1.1 The Scale of the Universe

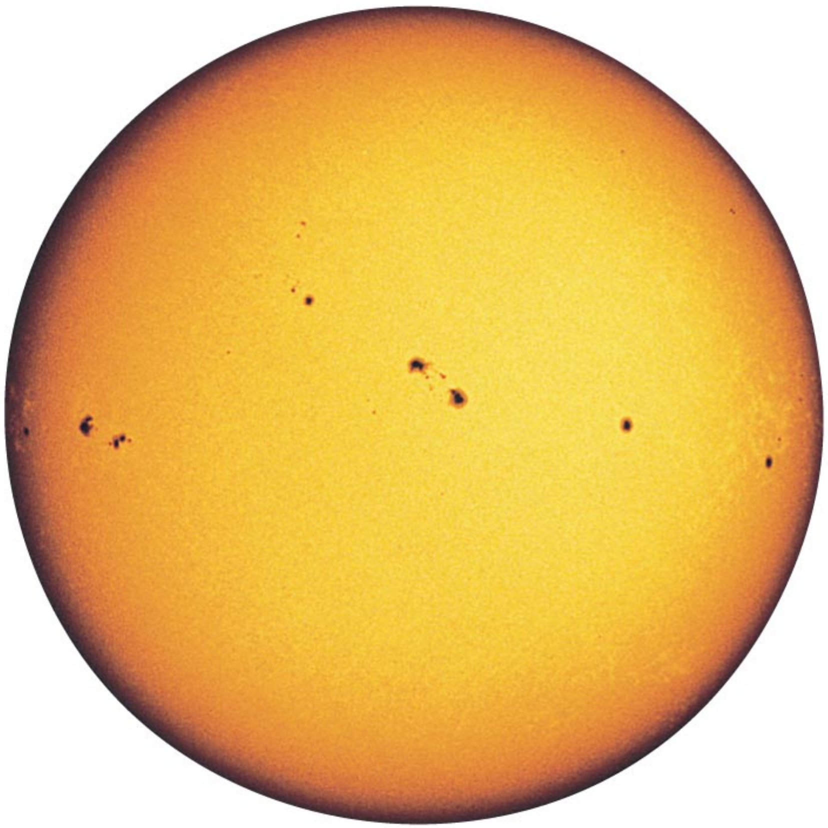
- Our goals for learning:
  - **What is our place in the universe?**
  - **How big is the universe?**

What is our place in the universe?

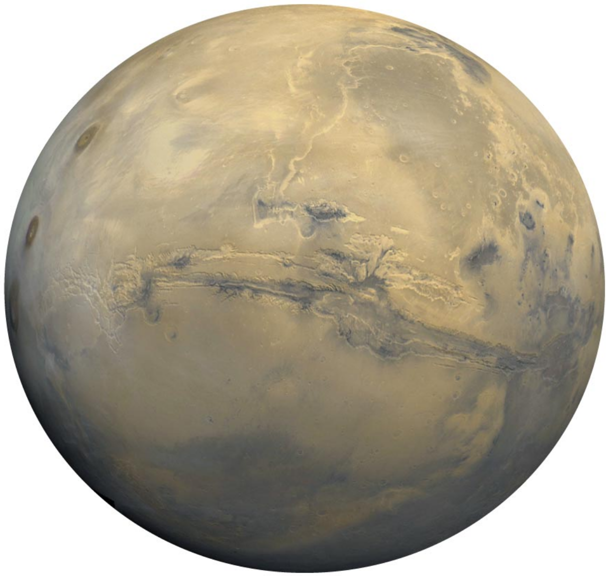


Star

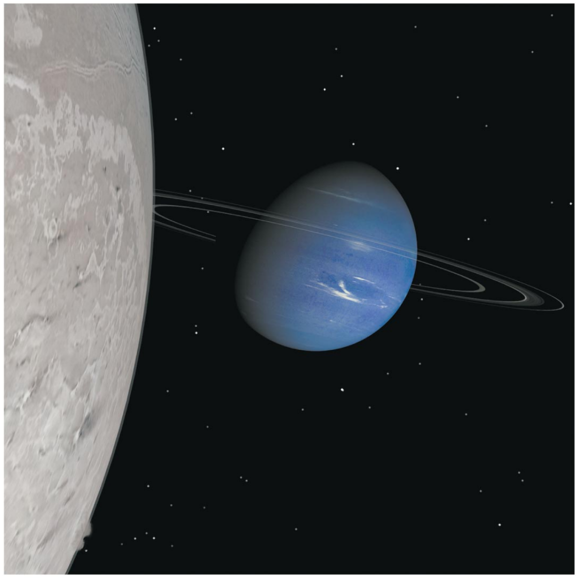
- A large, glowing ball of gas that generates heat and light through nuclear fusion



Planet



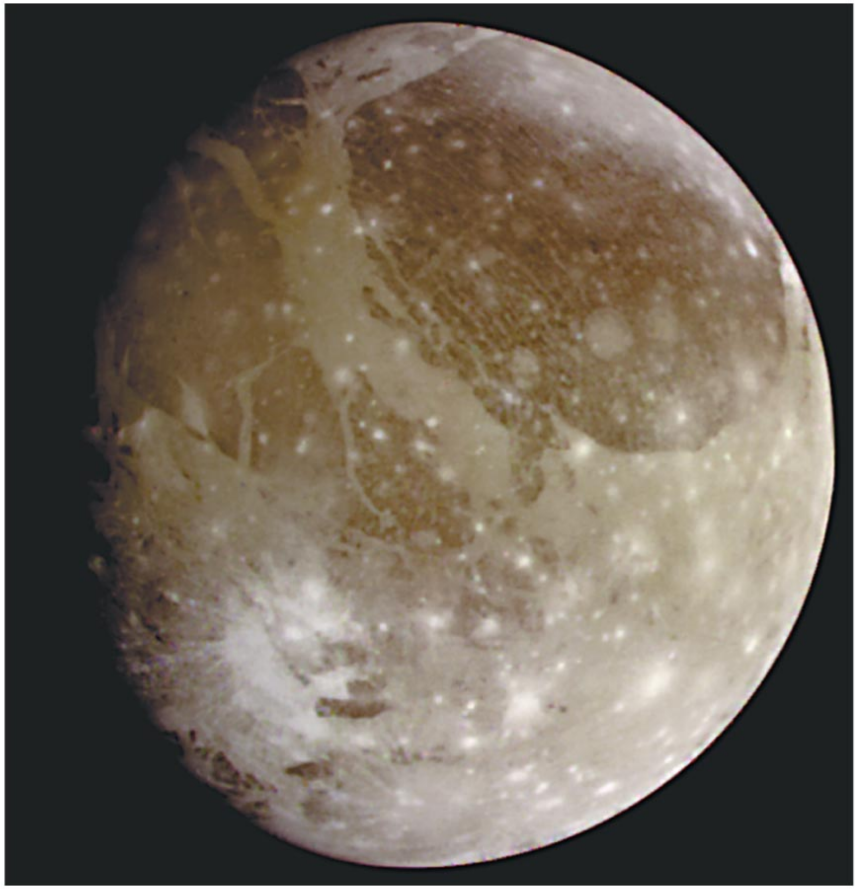
Mars



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)

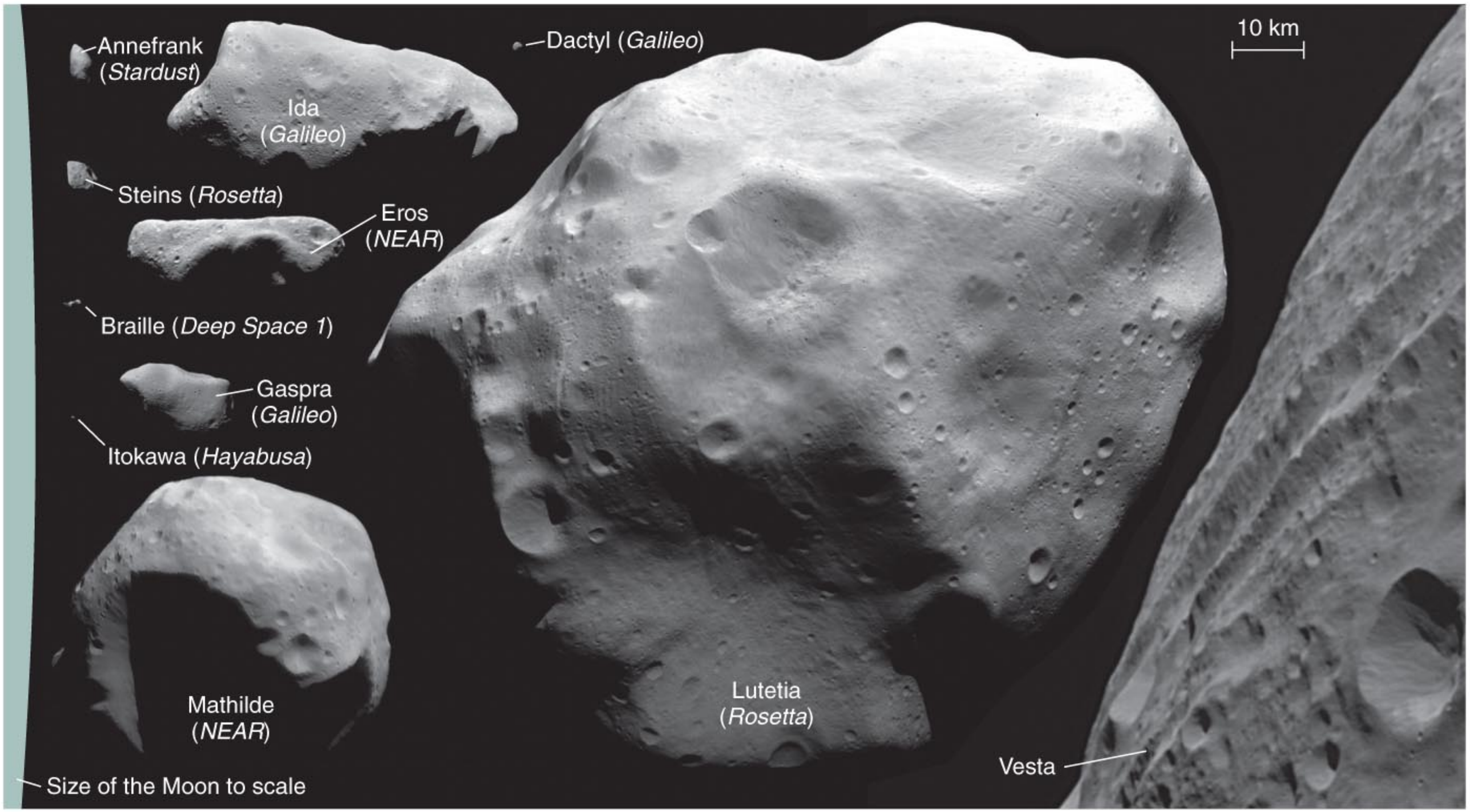


Ganymede (orbits Jupiter)

- An object that orbits a planet

Asteroid

- A relatively small and rocky object that orbits a star

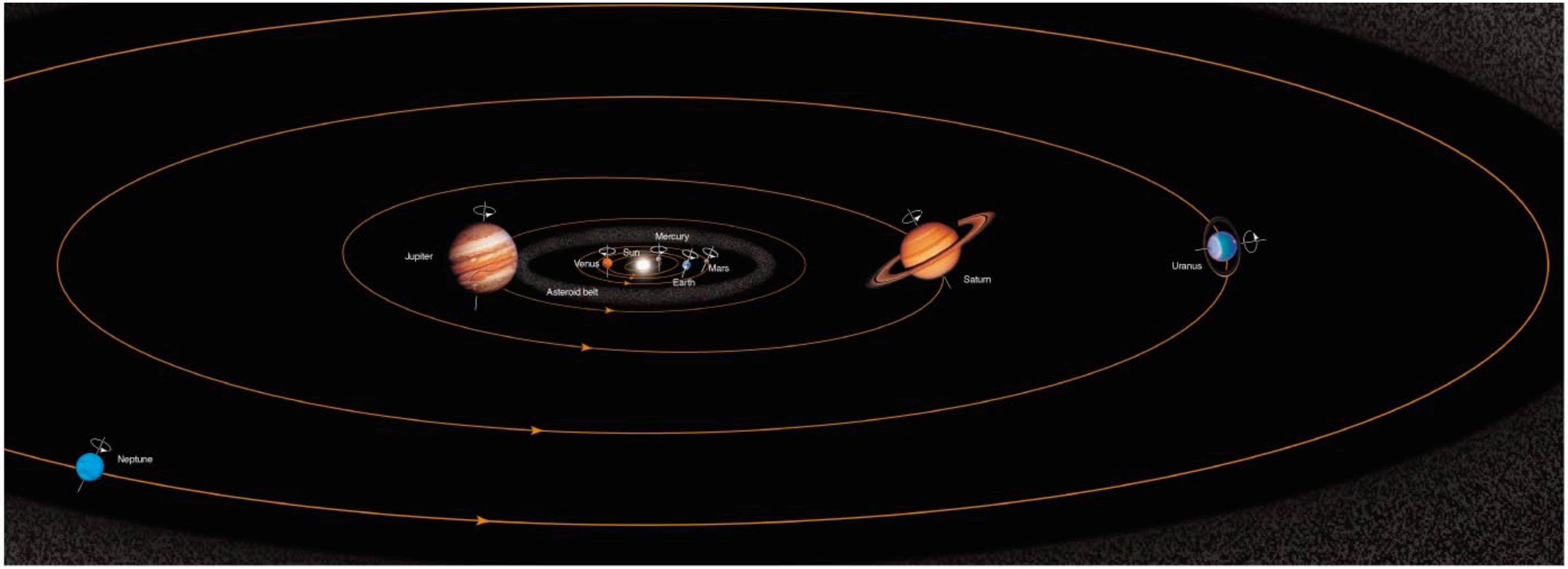


Comet

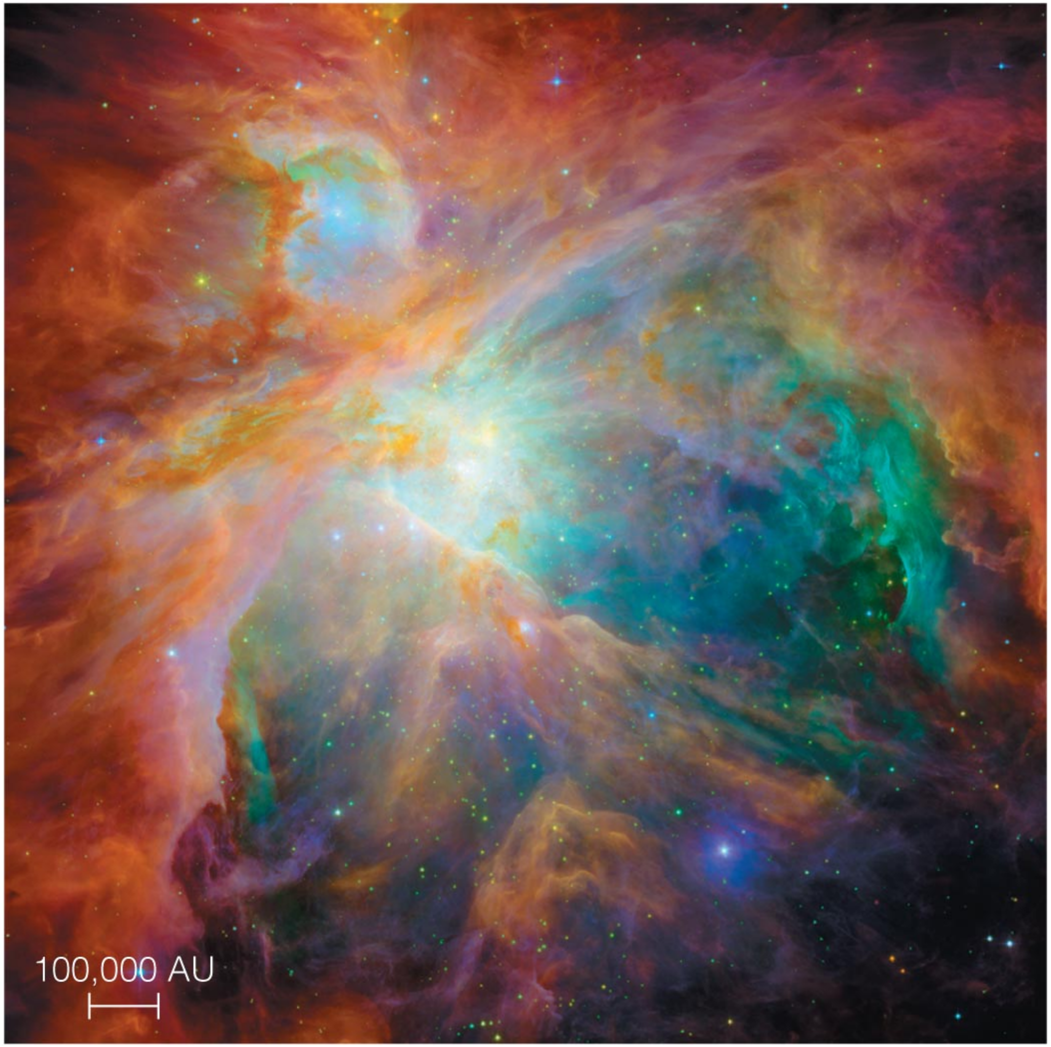
- A relatively small and icy object that orbits a star

Solar (Star) System

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



Nebula



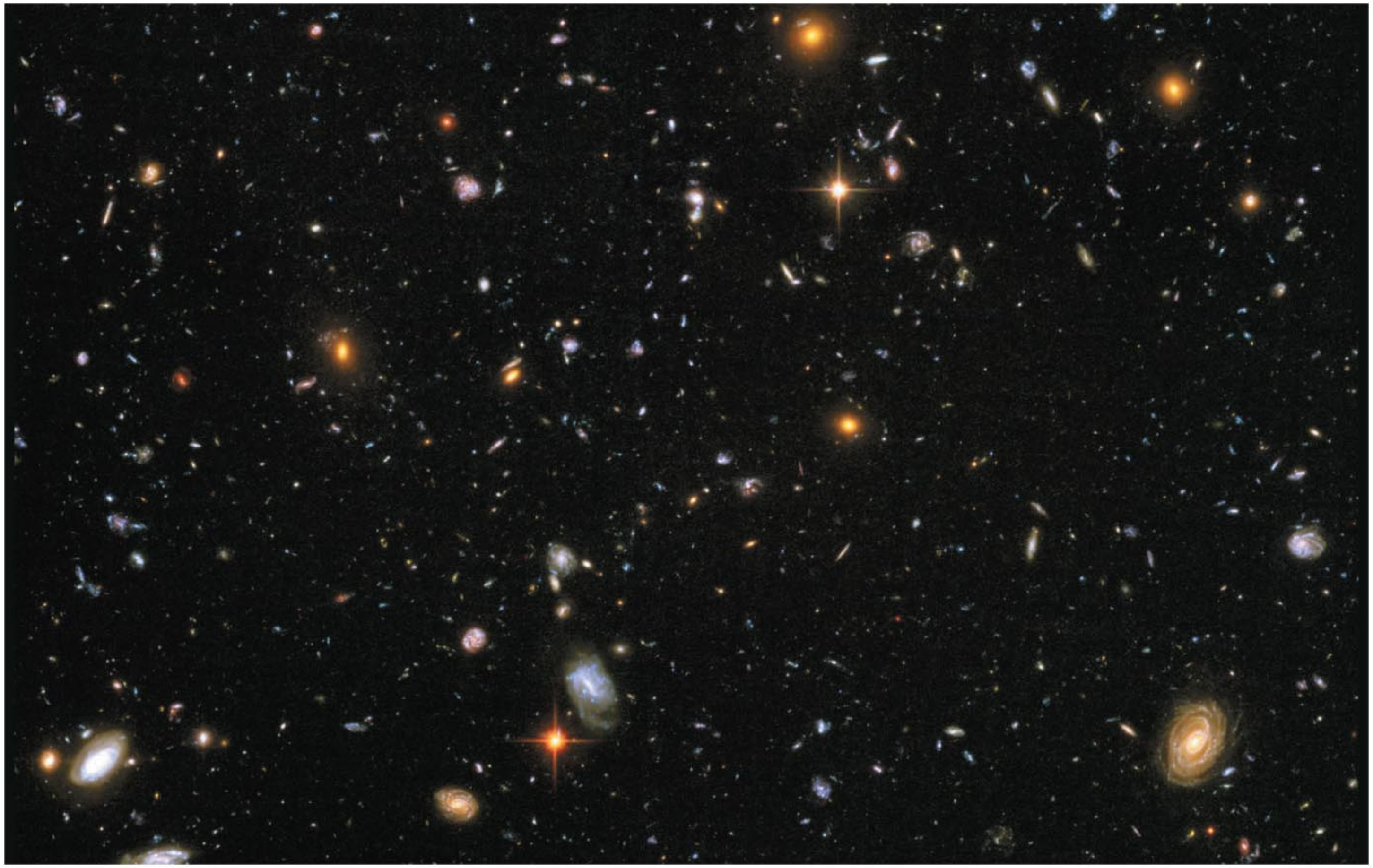
- An interstellar cloud of gas and/or dust

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

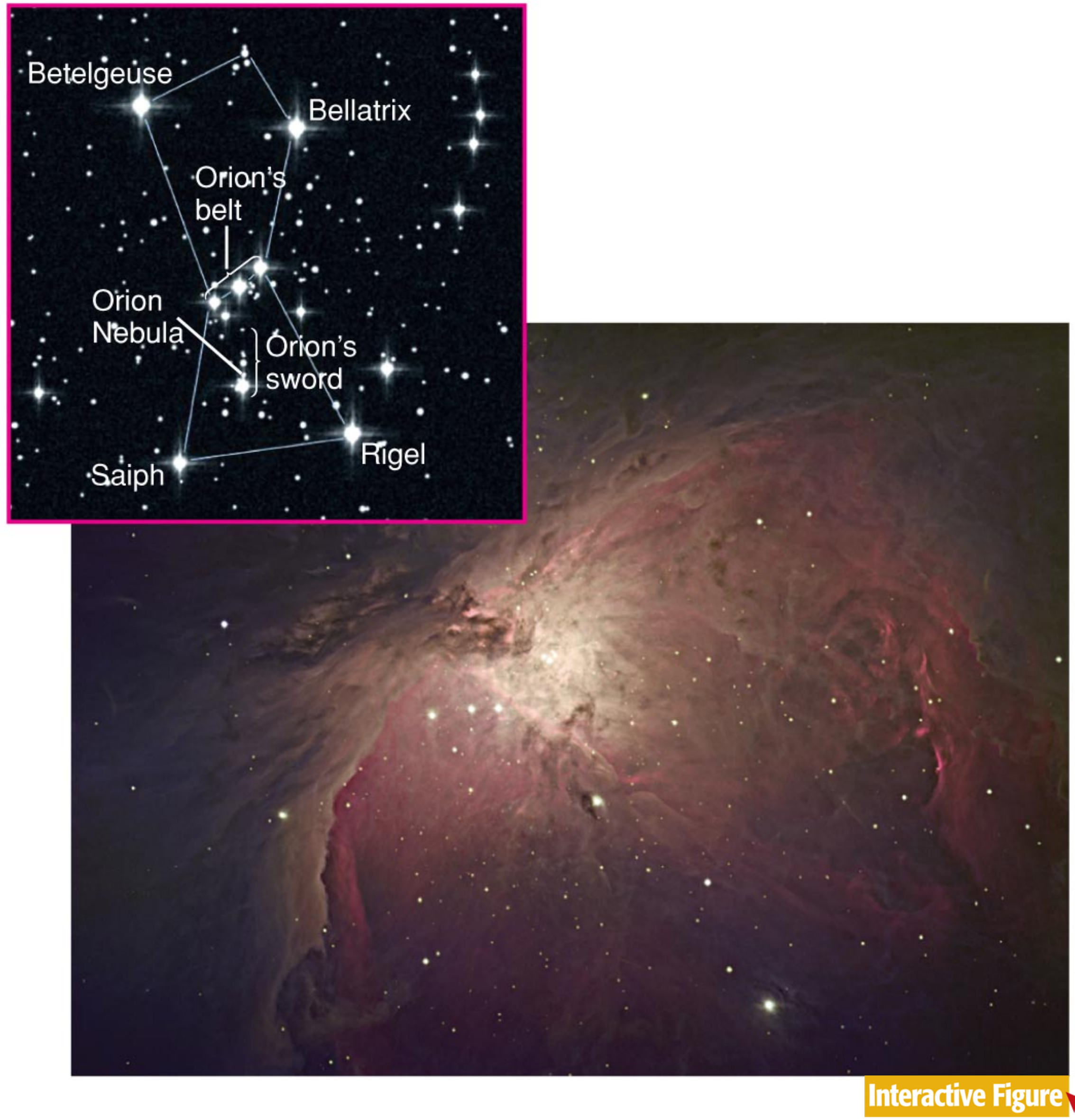
- Thus, we see objects as they were in the past:

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.

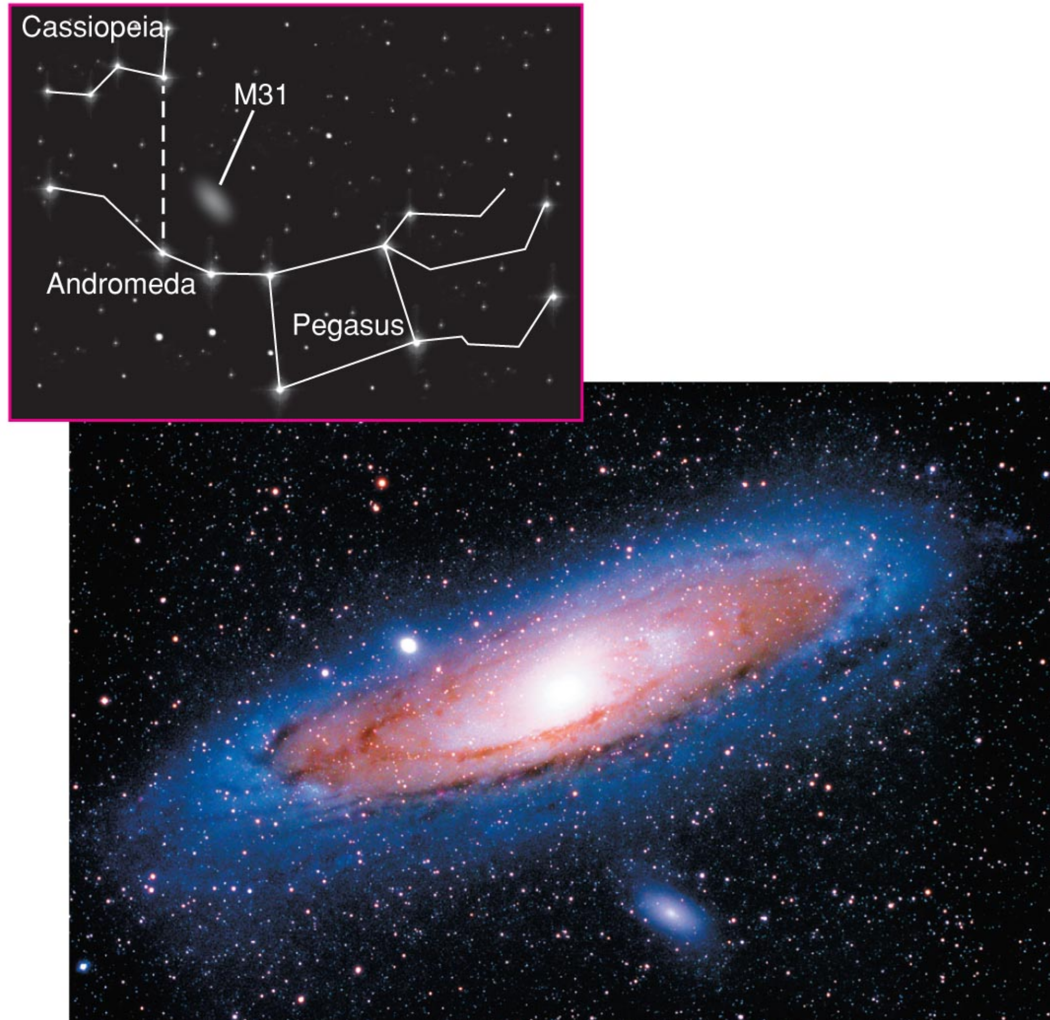


Far away means back in time?

Example:

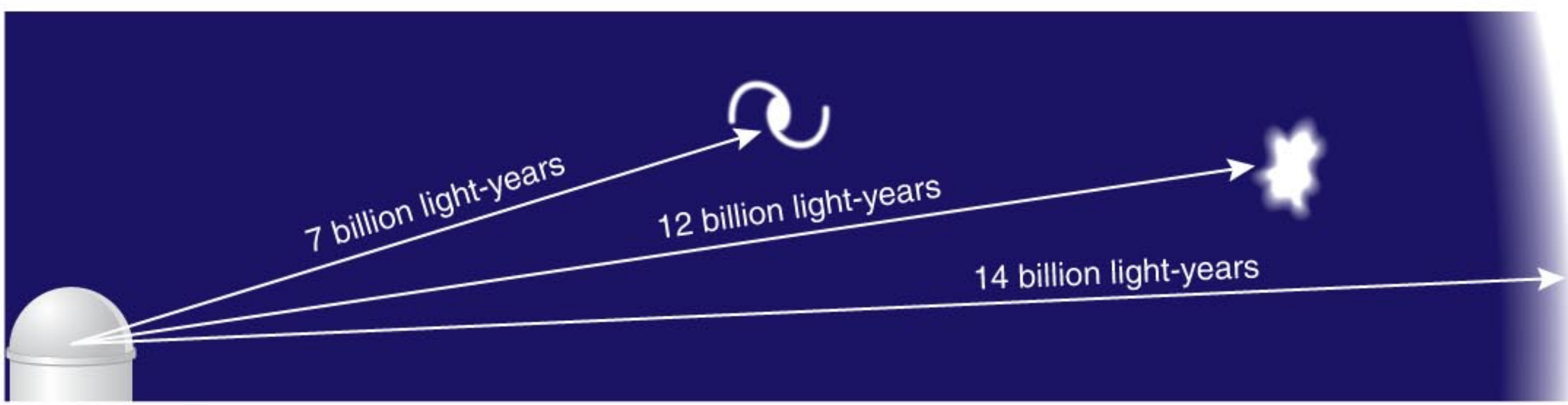
This photo shows the Andromeda Galaxy as it looked about 2 1/2 million years ago.

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



What have we learned?

- **What is our place in the universe?**
  - Earth is part of the solar system…
  - …which is in the Milky Way Galaxy…
  - …which is just one of many billions of galaxies in the observable universe.

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.

On this scale, Earth orbits the Sun at a distance of

A. 1 foot
B. 1 meter
C. 15 meters
D. 100 meters

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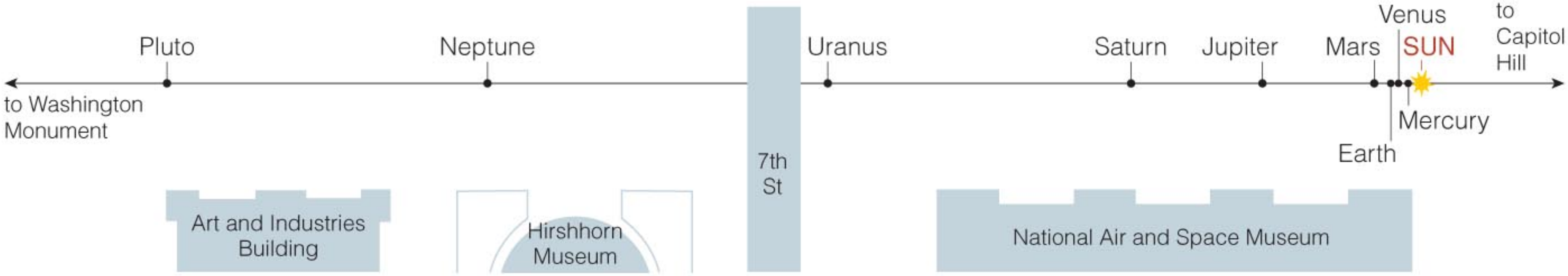
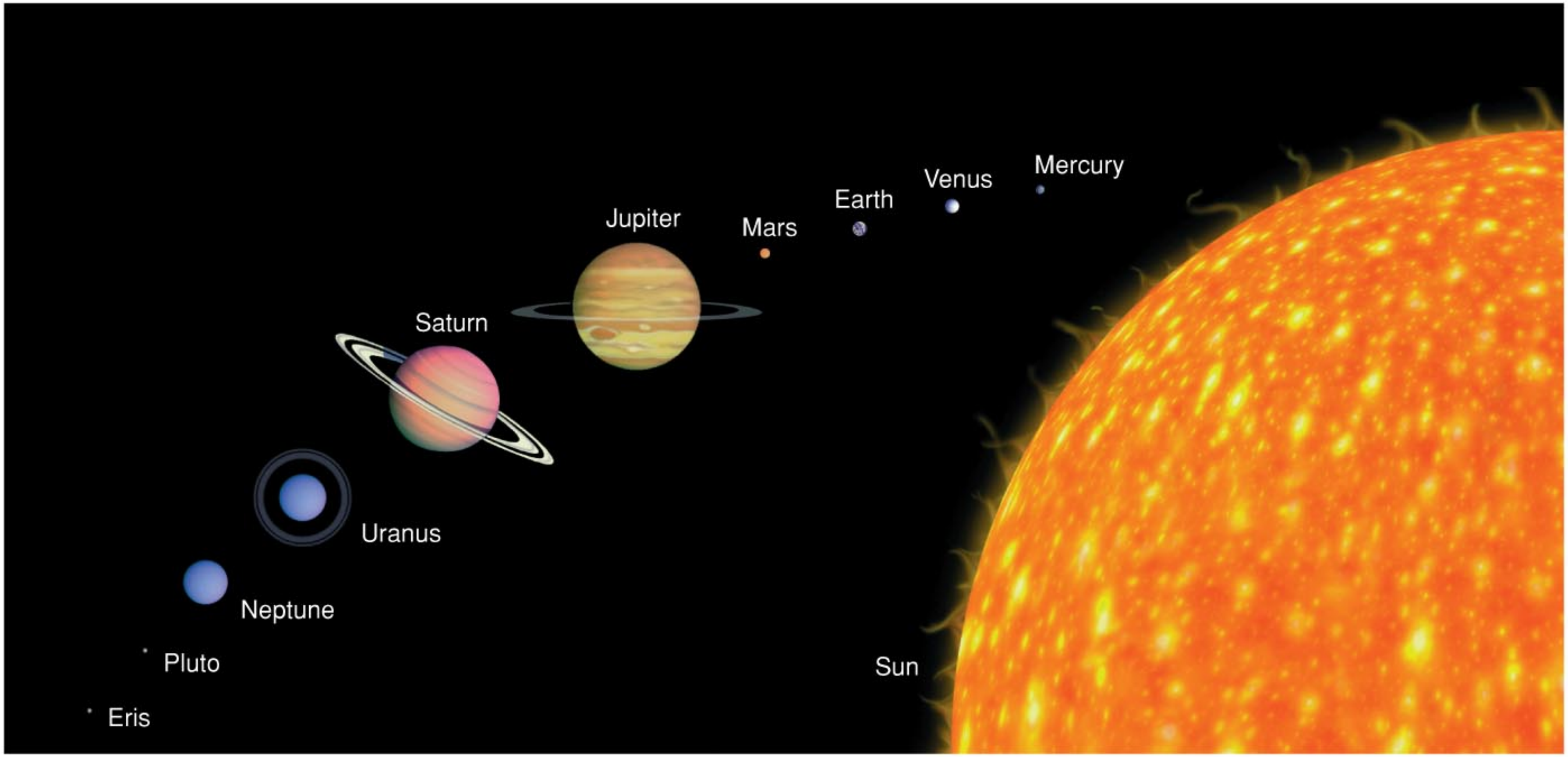
The scale of the solar system



b Locations of the Sun and planets in the Voyage model, Washington, D.C.; the distance from the Sun to Pluto is about 600 meters (1/3 mile). Planets are lined up in the model, but in reality each planet orbits the Sun independently and a perfect alignment never occurs.

The sizes of planets



a The scaled sizes (but not distances) of the Sun, planets, and two largest known dwarf planets.

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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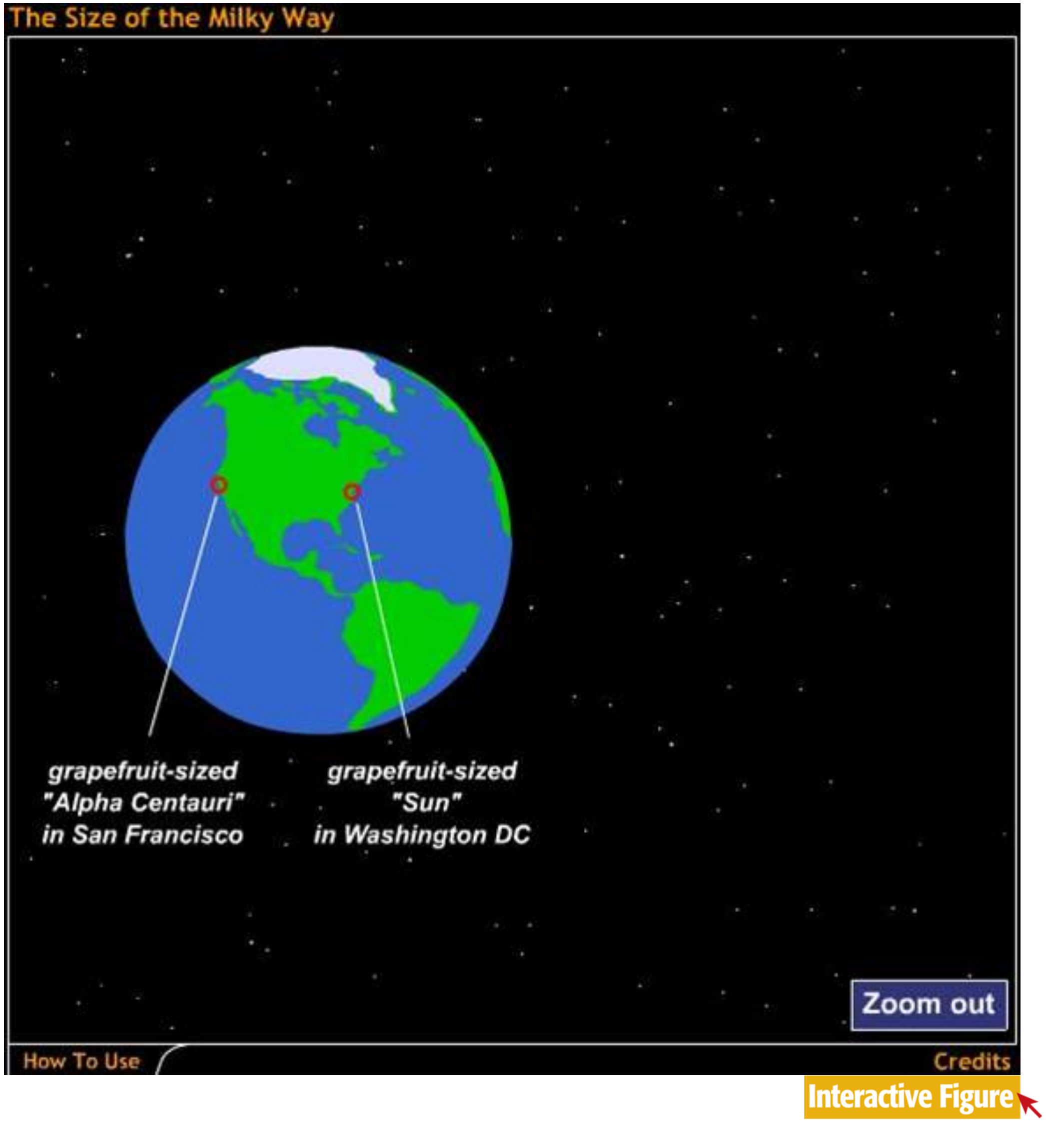
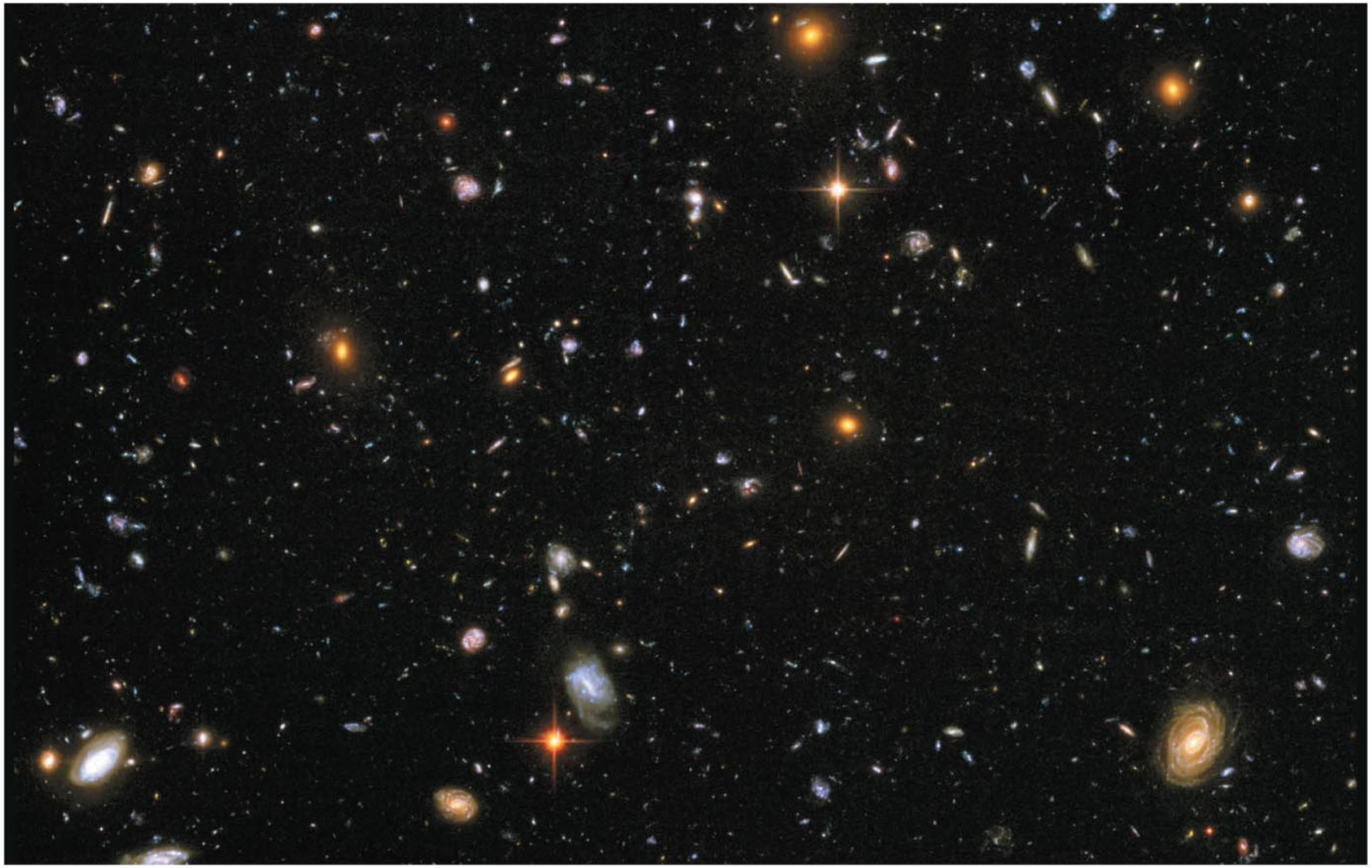
How big is the Milky Way Galaxy?

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



How big is the universe?

There are hundreds of billions of galaxies in the observable universe, and hundreds of billions of stars in each galaxy.



There are as many stars in the observable universe as there are grains of sand on all of Earth's beaches combined.

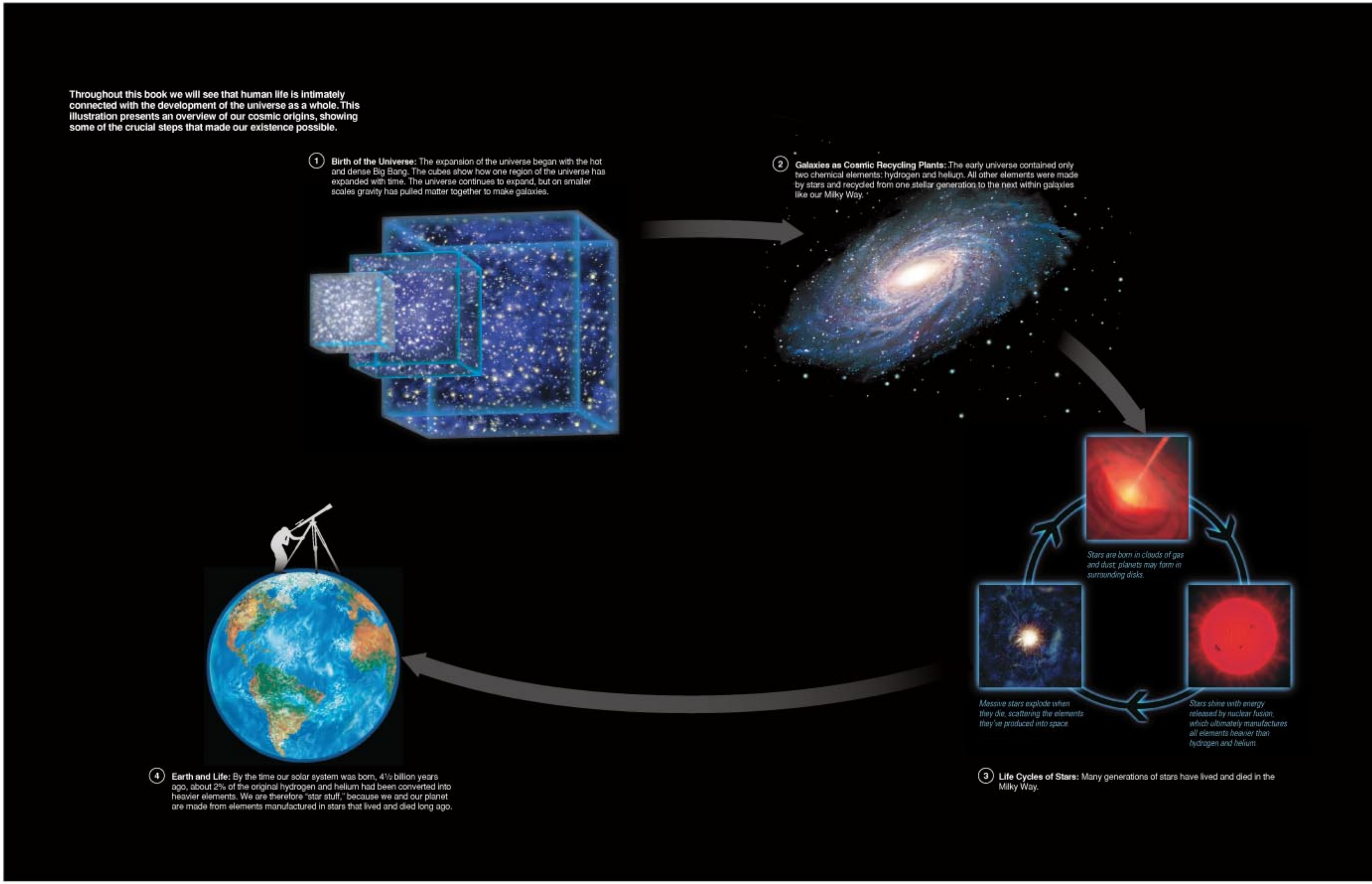
What have we learned?

- **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

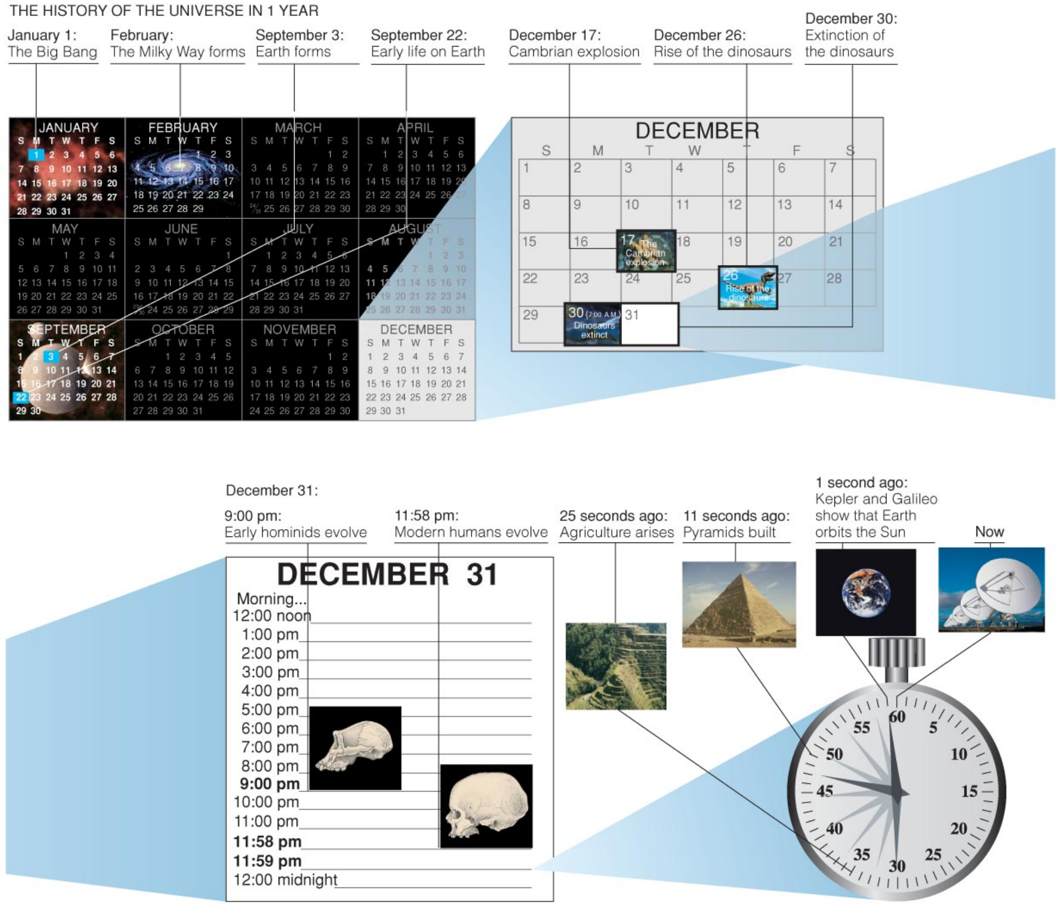
- Our goals for learning:
  - **How did we come to be?**
  - **How do our lifetimes compare to the age of the universe?**

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.



Universe is 13.6 billion years old; let's compress this into a single year

Cosmic Date	Event	Fraction of Age
Jan 1	Big Bang	0%
mid February	Milky Way Galaxy Forms	10%
Spring/Summer	Generations of stars are born and die	
September 3	The Sun and planets form	67%
late September	Early life present on Earth	80%
Dec 17	Invertebrate life forms	
Dec 26	Dinosaurs!	99%
Dec 30	No Dinosaurs!	
Dec 31, 9pm	Upright hominids	99.97%
Dec 31, 11:58pm	Modern humans	
Dec 31, 11:59:49pm	Pyramids built	
Dec 31, 11:59:59pm	Kepler/Galileo show Earth orbits the Sun	

What have we learned?

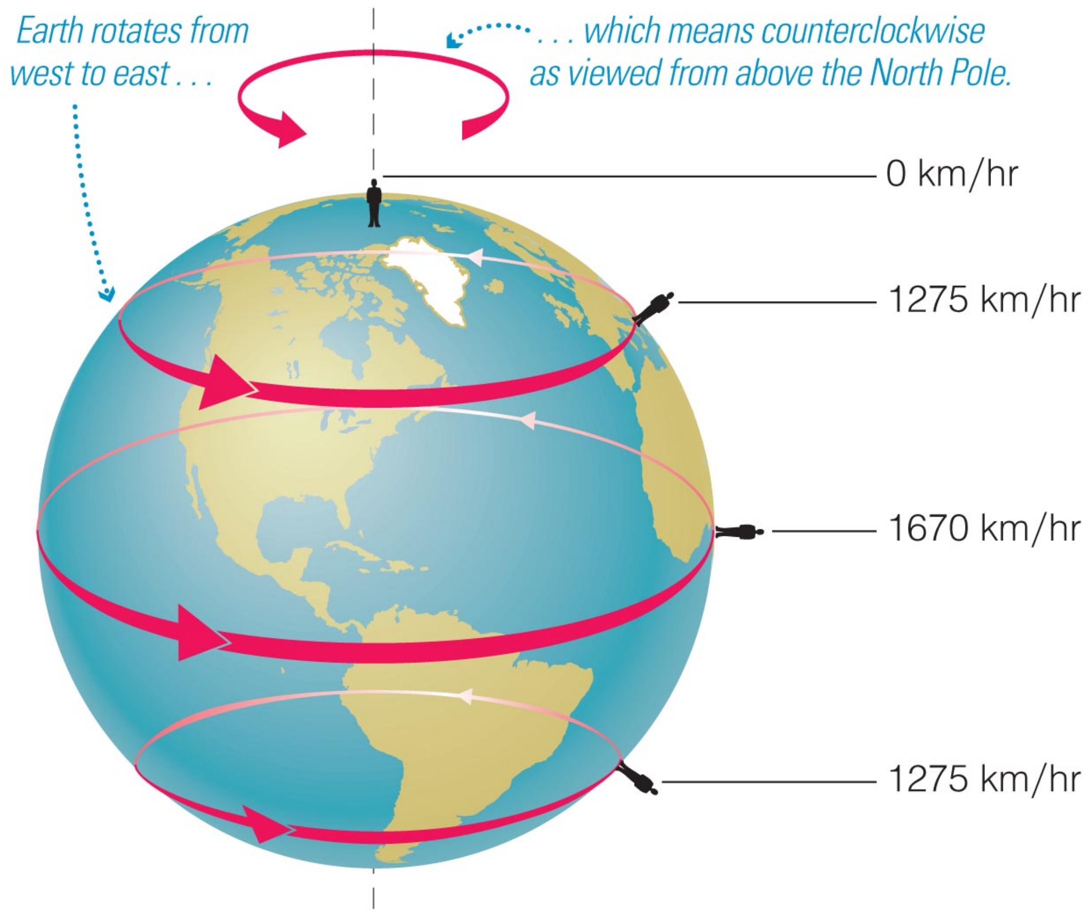
- **How did we come to be?**
  - The matter in our bodies came from the Big Bang, which produced hydrogen and helium.
  - All other elements were constructed from H and He in stars and then recycled into new star systems, including our solar system.
- **How do our lifetimes compare to the age of the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

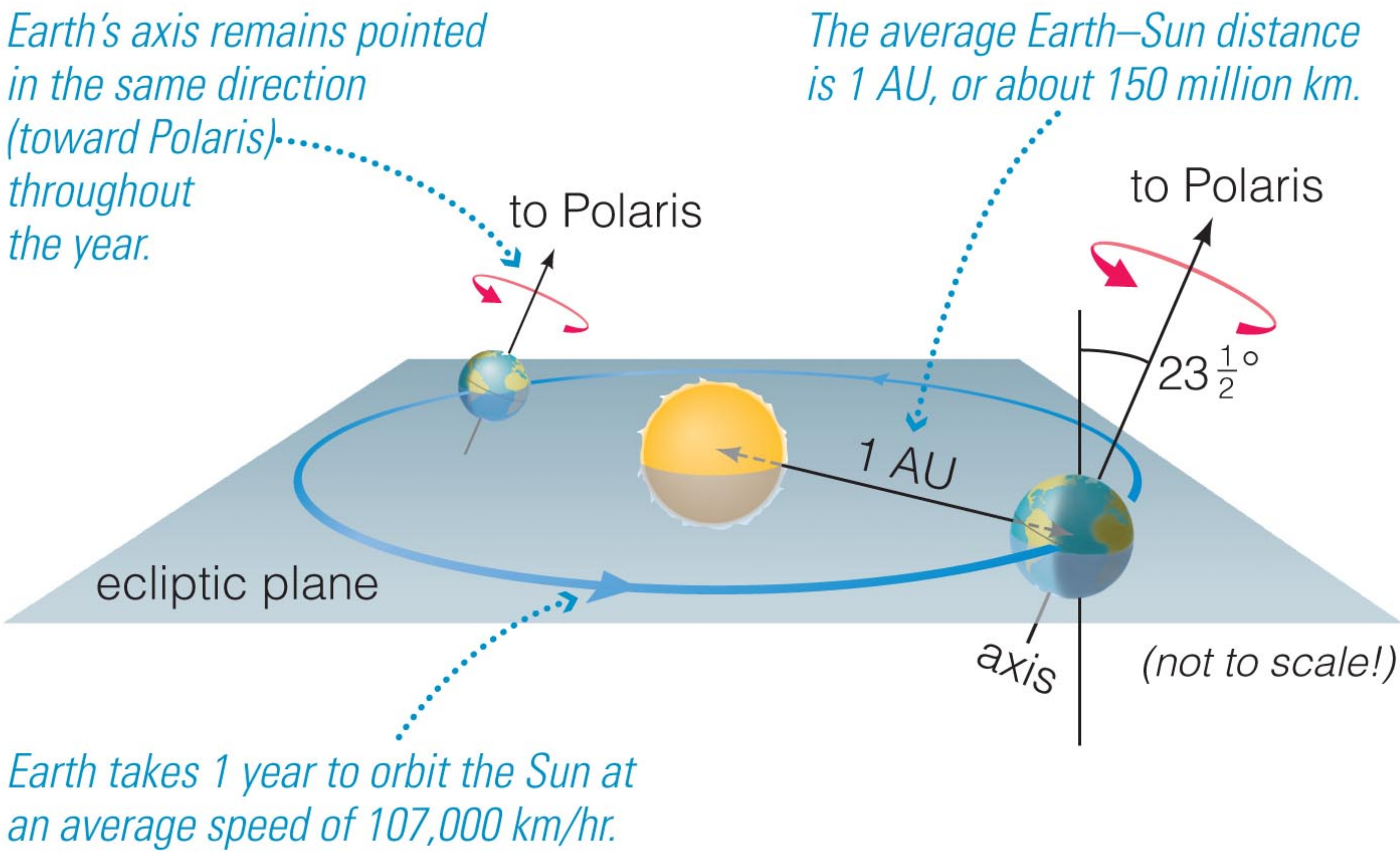
- Contrary to perception, we are not "sitting still."
- We are moving with Earth in several ways, and at surprisingly fast speeds.



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.



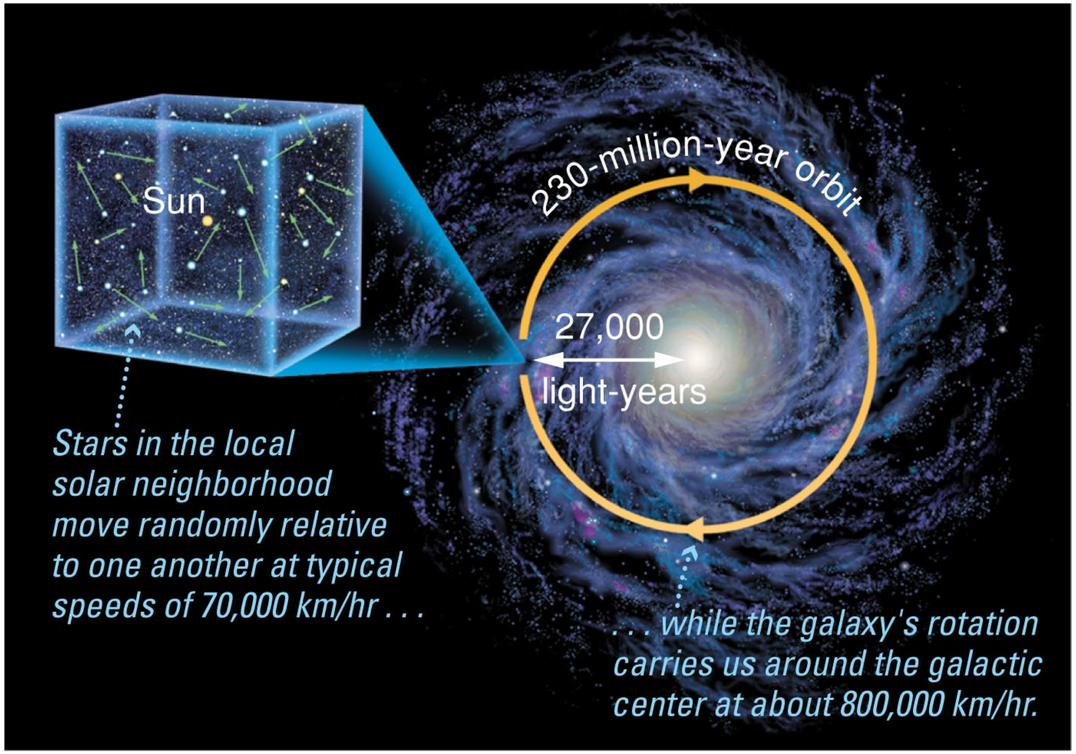
How is our Sun moving in the Milky Way Galaxy?

Our Sun moves randomly relative to the other stars in the local solar neighborhood…

typical relative speeds of more than 70,000 km/hr

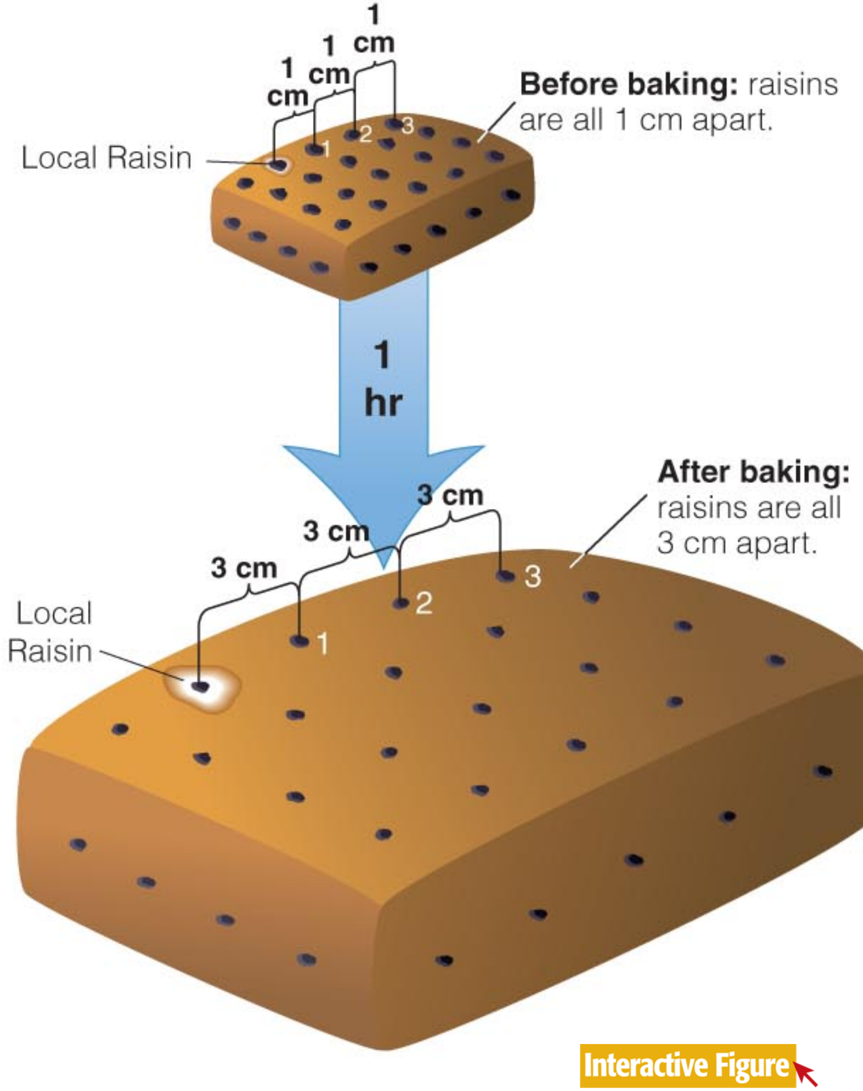
but stars are so far away that we cannot easily notice their motion

… and orbits the galaxy every 230 million years.



How 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?

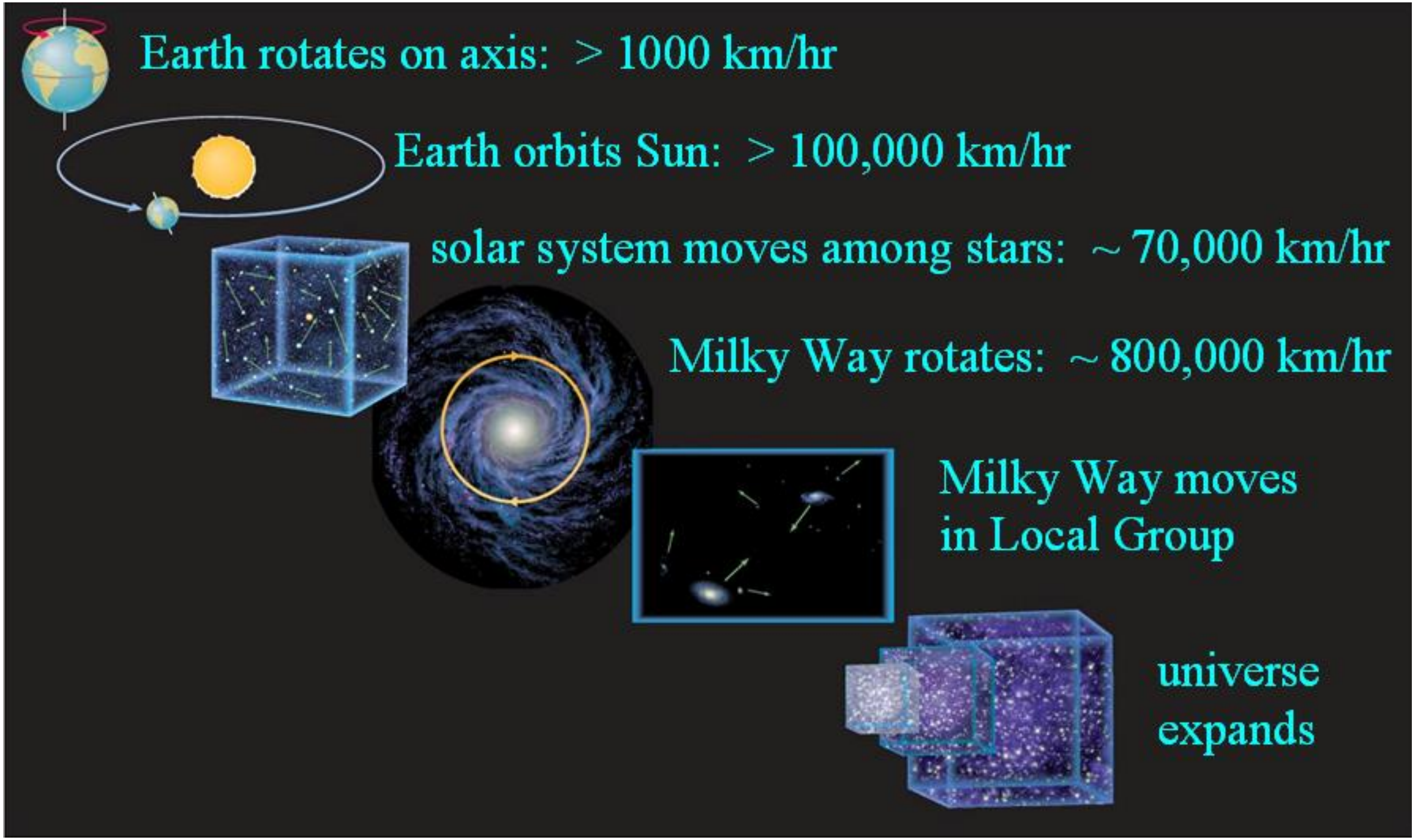


Hubble discovered that

- 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.