1.1 A Modern View of the Universe

Our goals for learning:

- What is our place in the universe?
- How did we come to be?
- How can we know what the universe was like in the past?
- Can we see the entire universe?

What is our place in the universe?

Star

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

Planet

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.
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.
How did we come to be?

How can we know what the universe was like in the past?

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

<table>
<thead>
<tr>
<th>Destination</th>
<th>Light travel time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td>1 second</td>
</tr>
<tr>
<td>Sun</td>
<td>8 minutes</td>
</tr>
<tr>
<td>Sirius</td>
<td>8 years</td>
</tr>
<tr>
<td>Andromeda Galaxy</td>
<td>2.5 million years</td>
</tr>
</tbody>
</table>

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

Example:

We see the Orion Nebula as it looked 1,500 years ago.

Example:

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

Question: When will be able to see what it looks like now?

Light-year

- The **distance** light can travel in one year.
- About 10 trillion km (6 trillion miles).

- At great distances, we see objects as they were when the universe was much younger.
How far is a light-year?

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

= \left( 300,000 \text{ km/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)

= 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 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.

What have we learned?

• What is our physical 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 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 star and then recycled into new star systems, including our solar system
What have we learned?

- How can we know that the universe was like in the past?
  - When we look to great distances we are seeing events that happened long ago because light travels at a finite speed
- Can we see the entire universe?
  - No, the observable portion of the universe is about 14 billion light-years in radius because the universe is about 14 billion years old

1.2 The Scale of the Universe

Our goals for learning:

- How big is Earth compared to our solar system?
- How far away are the stars?
- How big is the Milky Way Galaxy?
- How big is the universe?
- How do our lifetimes compare to the age of the 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

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 U.S. (2500 miles)
Answer: D, the distance across the U.S.

How big is the Milky Way Galaxy?

The Milky Way has about 100 billion stars.

On the same ten billion-to-one scale….

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.
• \(10^{11} \text{ stars/galaxy} \times 10^{11} \text{ galaxies} = 10^{22} \text{ stars}\)

As many stars as grains of (dry) sand on all Earth’s beaches…

• Now let’s step through the Universe in powers of 10:
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 big is Earth compared to our solar system?
  - 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.
- How far away are the stars?
  - On the same scale, the stars are thousands of km away.
- How big is the Milky Way galaxy?
  - It would take more than 3,000 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.

What have we learned?

- How big is the universe?
  - 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.
- How do our lifetimes compare to the age of the universe?
  - On a cosmic calendar that compresses the history of the Universe into one 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 in our solar system?
- How is our solar system moving in the Galaxy?
- How do galaxies move within the Universe?
- Are we ever sitting still?

How is Earth moving in our solar system?

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

The Earth rotates around its axis once every day.
Earth orbits the Sun (revolves) once every year:
- at an average distance of 1 AU ≈ 150 million km.
- with Earth’s axis tilted by 23.5° (pointing to Polaris)
- and rotating in the same direction it orbits, counter-clockwise as viewed from above the North Pole.

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.

More detailed study of the Milky Way’s rotation reveals one of the greatest mysteries in astronomy:
- Most of Milky Way’s light comes from disk and bulge …
- … but most of the mass is in its halo

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.
What have we learned?

- How is Earth moving in our solar system?
  - It rotates on its axis once a day and orbit the Sun at a distance of 1 A.U. = 150 million km

- How is our solar system moving in the Milky Way galaxy?
  - 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

- Are we ever sitting still?
  - No!

1.4 The Human Adventure of Astronomy

Our goals for learning:

- How has the study of astronomy affected human history?

  - 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