Chapter 1 Lecture

The Cosmic Perspective
Seventh Edition

A Modern View of the Universe
The Distant Universe
Course Introduction

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Textbook: Bennett, The Cosmic Perspective 7th Edition
Lecture website: http://chartasg.people.cofc.edu/chartas/Teaching.html

Lectures: Tuesday and Thursday
Time: 12:45-1:55pm

Lecture Hall: Harbor Walk West, room 112
Course Requirements

- Read text before course
- Attend lectures
- Participate in discussions during lecture, ask questions
- Homework (5% of your grade)
- Quizzes in class (15% of your grade)
- THREE MIDTERM EXAMS (45% of your grade)
- FINAL EXAM (35% of grade)
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?
The Nearest Star to Earth

- A large ball of gas that generates heat, light and energetic particles through nuclear fusion.

- The Sun is the nearest star to Earth at an average distance of

1 AU \sim 150,000,000,000 \text{ m} 

\left(= 1.5 \times 10^{11} \text{ m}\right)

\textbf{AU = Astronomical Unit}

The next nearest star is about 100,000 \left(= 1 \times 10^5 \right) times further away.
Why Study Stars?

Stellar Evolution: A Journey with Chandra
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
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

- Nebulae are huge clouds of interstellar gas and are the birth places of stars.

- By studying many stars in nebulae we can learn about the life-cycles of stars.

- Intense ultraviolet light from newborn stars excites the surrounding gas and causes it to glow.

The Orion Nebular, Birthplace of Stars
Exploding Stars

- Exploding stars enrich their interstellar neighborhood with heavy elements.
- The Sun and the planets were created from material ejected from a supernova.
- The carbon in our bodies was manufactured deep inside stars that exploded many many years ago.

The Crab Nebula, Core collapse supernova
Distance to Earth ~ 6,500 ly
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).

<table>
<thead>
<tr>
<th>Destination</th>
<th>Light travel time</th>
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<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.*
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?
Scientific Notation

$10^0 = 1$ (one)
$10^1 = 10$ (ten)
$10^2 = 100$ (one hundred)
$10^3 = 1000$ (one thousand)
$10^4 = 10,000$ (ten thousand)
$10^6 = 1,000,000$ (one million)
$10^9 = 1,000,000,000$ (one billion)
$10^{12} = 1,000,000,000,000$ (one trillion)

$10^0 = 1$ (one)
$10^{-1} = 1/10 = 0.1$ (one tenth)
$10^{-2} = 1/10 \times 1/10 = 1/10^2 = 0.01$ (one hundredth)
$10^{-3} = 1/10 \times 1/10 \times 1/10 = 1/10^3 = 0.001$ (one thousandth)
$10^{-4} = 1/10 \times 1/10 \times 1/10 \times 1/10 = 1/10^4 = 0.0001$ (one ten-thousandth)
Scientific Notation
Express Numbers in the form :

\[ A \times 10^n \]

This is referred to as the powers-of-ten notation.

Some rules:

\[ 10^{-n} = \frac{1}{10^n} \]

\[ 10^{a+b} = 10^a \times 10^b \quad \text{example:} \quad 10^2 \times 10^3 = 10^{2+3} \]

\[ (10^a)^b = 10^{ab} \quad \text{example:} \quad (10^2)^3 = 10^{2 \times 3} = 10^6 \]

Examples:

\[ 3500 = 3.5 \times 10^3, \quad 0.0035 = 3.5 \times 10^{-3} \]

\[ 12900000. = ?, \quad 0.000000129 = ? \]

\[ 10^6 \times 10^3 = ?, \quad 10^2 \times 10^{-2} = ?, \quad (10^2)^{-3} = ? \]
Scientific Numerical Prefixes

<table>
<thead>
<tr>
<th>SI prefixes</th>
<th>$10^n$</th>
<th>Prefix</th>
<th>Symbol</th>
<th>Decimal</th>
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<tbody>
<tr>
<td>$10^{12}$</td>
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</tr>
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<td>$10^{-9}$</td>
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<td>n</td>
<td>0.00000001</td>
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International System Of Units

SI units:
length is measured in meters (m)

time is measured in seconds (s)

and mass is measured in kilograms (kg)
The **light-year** (abbreviated ly) is the distance that light travels in one year.

The **speed of light** in empty space is \( c = 3 \times 10^5 \text{ km/s} \)

1 light-year = 1ly = \( 9.46 \times 10^{12} \text{ km} \) (derive this)

1 Astronomical Unit = 1 AU = Average distance between Sun and Earth = 149,598,000 km \( \approx 1.5 \times 10^8 \text{ km} \)
Light year

1 light-year = (speed of light) × (1 year)

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

= 9,460,000,000,000 km
Example: Estimate the time it takes for light to reach us from the sun
Example: Estimate the time it takes for light to reach us from the sun

\[ speed = \frac{\text{Distance}}{\text{time}} \]

If we denote \( c \) as the speed of light we can write:

\[ c = \frac{\text{Distance}}{\text{time}} \Rightarrow \text{time} = \frac{\text{Distance}}{c} = \frac{1.5 \times 10^8 \text{ km}}{3 \times 10^5 \text{ km/s}} = 500 \text{ sec} \]
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.
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 diagram presents an overview of our cosmic origins, showing some of the crucial steps that made our existence possible.

1. Birth of the Universe: This explosion of the universe began with the hot and dense Big Bang. The fabric of the universe continues to expand, filling entire galaxies with hot gas. As this gas cools, it pulls matter together to make stars and planets.

2. Galaxy and Stars: The early universe contained only a few simple elements: hydrogen and helium. At later times, nuclei were made heavier and cooler from the matter produced by the stars. This matter is our Milky Way.

3. Earth and Life: By the time our solar system was born, 4.6 billion years ago, about 90% of the original hydrogen and helium had been converted into metallic elements. Life on Earth began in the oceans and then spread ashore.

4. Life Cycle 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 ≈ 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 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 the Milky Way Galaxy?

- 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.
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 on axis: > 1000 km/hr
- Earth orbits Sun: > 100,000 km/hr
- Solar system moves among stars: ~ 70,000 km/hr
- Milky Way rotates: ~ 800,000 km/hr
- Milky Way moves in Local Group
- Universe expands
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."
Multi-Wavelength Observations of the Universe

The Hubble Space Telescope (near-infrared, ultraviolet and optical)

The Very Large Array (Radio)

The Chandra X-ray Observatory (X-ray)

Gamma-ray Astronomy at the Whipple Observatory