Chapter 2

Birth of the Earth

2.1 Scientific Cosmology

- The systematic study of the overall structure and history of the Universe.
- The Universe contains two basic entities:

  Matter – the substance that makes up objects

  Energy – the inherent ability of a region of space and the matter within it to do "work"

- In this lecture, we will learn
  - Architecture of the overall Universe (including our Solar System)
  - Formation of the Universe – Big Bang Theory
  - Production of Sun, the Earth, and other celestial objects

2.2 Structure of the Universe

2.2.1 Galaxies

- An immense group of **stars** held together by gravity.
- Our sun is one of over 300 billion **stars** in the Milky Way Galaxy.

2.2.2 Star

- An immense sphere of incandescent gas that emits intense energy.
- Stars, including our sun, are distant from each other, but all share similar structures.

2.2.3 Solar System

- The Sun's gravitational pull holds many objects in orbit, forming the Solar System.
- Approximately 99.8% of the Solar System's mass is contained within the Sun; the remaining 0.2% consists of a wide variety of objects.
- Solar System includes *planets*, *moons*, *asteroids*, *dwarf planets*, and *comets*.

2.2.4 Planets

- The astronomers' definition of a planet:
  1) An object that orbits a star
  2) Roughly spherical
  3) Cleared its neighborhood of other objects (planet's gravity has pulled in all particles of matter in its orbit)
- Solar system includes eight planets:
  - Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune
- Until 2005, astronomers considered Pluto to be a planet.
  - Why is Pluto's planet status revoked?
  - Pluto has no cleared its orbit!

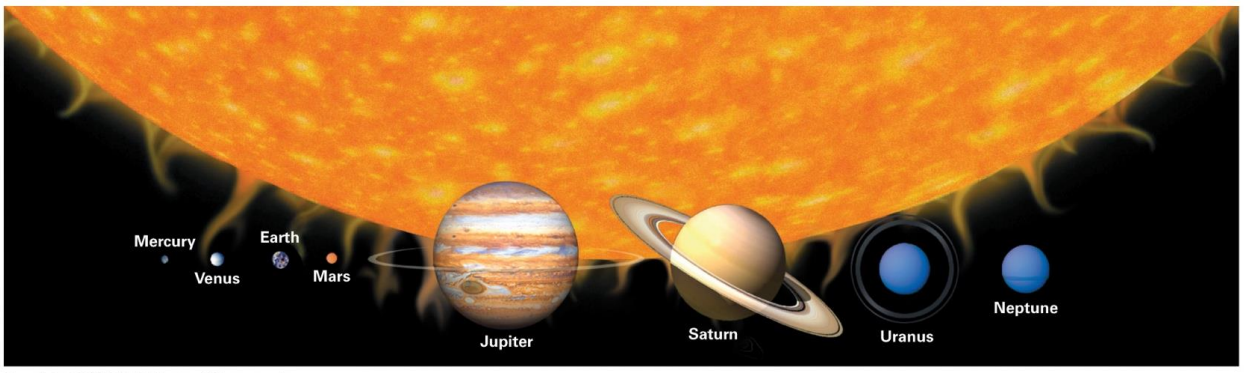

Figure 2.1: Relative sizes of the planets.

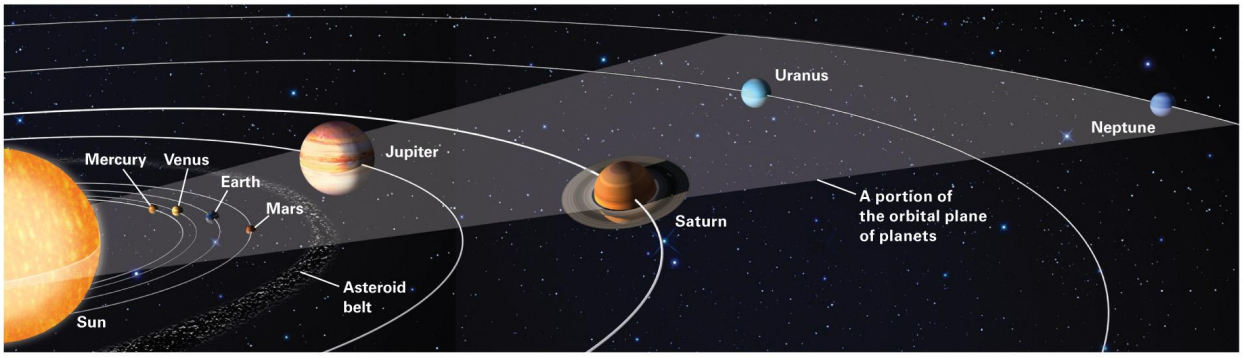

Figure 2.2: Relative positions of the planets.

Terrestrial Planets (inner planets)

- Mercury, Venus, Earth, and Mars
- Closer to the Sun & relatively small
- A shell of rock surrounding a ball of metal

Giant Planets (outer planets)

- Jupiter, Saturn, Uranus, and Neptune
- Most of the matter in Jupiter and Saturn consists of hydrogen and helium as a gas, liquid, or as a strange liquid-metal state – referred to as *gas giants*.
- Most of the matter in Neptune and Uranus consists of water, carbon dioxide, and methane that has been frozen into solid ice – referred to as *ice giants*.

All planetary orbits lie roughly in the same plane.

2.2.5 Moons

- A solid object that orbits a planet.
- All planets except Mercury and Venus have moons.
  - Earth has the Moon.
  - Mars has two.
  - Jupiter has at least 63.
  - Saturn has at least 62.
- Moons vary greatly in size, composition, and surface characteristics.

2.2.6 Other Objects

Asteroids

- Relatively small rocky or metallic objects that orbits the Sun
- Most lie in the region between the orbits of Mars and Jupiter.

Kuiper Belt and Oort Cloud Objects

- A trillion icy bodies that form a donut-like ring **outside Neptune's orbit** make up the Kuiper Belt.
- More distant ones form the spherical-shaped Oort Cloud.

Dwarf Planets

- Asteroids and Kupier Belt objects with a diameter greater than ~ 900 km.
- Maybe up to 200 dwarf planets present, only five have yet been identified.
- Pluto and Eris are the largest known dwarf planets.

Comets

- Kuiper Belt and Oort Cloud objects that follow elliptical orbits that bring them into the inner Solar System.

2.3 Formation of the Universe – The Big Bang

- According to the Big Bang Theory, all matter and energy in the Universe was initially concentrated in an infinitesimally small point.
- This point suddenly exploded, making the beginning of the Universe.
- The initial expansion, known as the inflation epoch, occurred extremely rapidly and lasted less than a second.
- Following this brief period, the Universe continued to expand (at a slower rate).

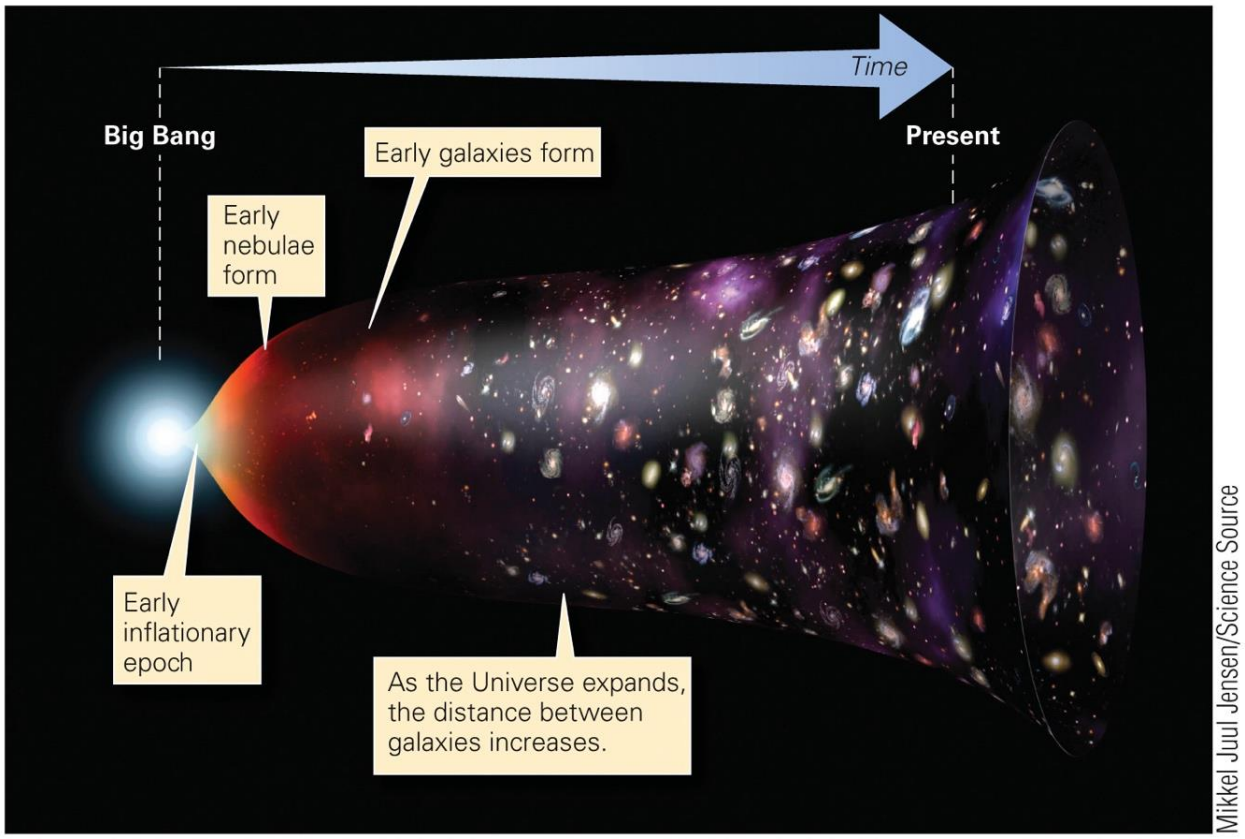

Figure 2.3: The concepts of the expanding Universe and the Big Bang.

2.4 Birth of the First Stars

- By the time the Universe reached its 200 millionth year, it was filled with immense, slowly swirling dark nebulae–giant clouds of dust and gas–separated by vast, empty voids.

Figure 2.4: A representation of a starless nebula in the early Universe (modified from a Hubble Space Telescope photograph)

2.4.1 Formation Process

- With the gravitational pull, a nebula began to draw in surrounding ice and gas, increasing its mass and density.
- As it grew, the cloud's slow swirling motion transformed into a rotation around a central axis, forming a disk-like shape.
- As gravity continued to pull material inward, the inner region of the disk collapsed into a dense, hot core.
- Eventually, the core became hot enough to emit light–this glowing core marked the birth of a *protostar*.

2.4.2 From Protostar to Star

- As the protostar accumulated more mass, its core grew even denser and hotter.
- Under these extreme conditions, hydrogen nuclei began to move rapidly and fuse into helium in a process known as nuclear fusion.
- Once fusion began, the protostar ignited, and the first true star was born.
- Around 800 million years after the Big Bang, stars lit up the Universe.
- This process repeated over and over, giving rise to the first generation of stars, marking a new era in cosmic evolution.

2.5 Supernova

- The larger the star, the hotter it burns, and the faster it runs out of fuel and dies. The explosion of a giant star produces a supernova!

2.5.1 Crab Nebula

- One of the largest ever taken by NASA's Hubble Space Telescope.
- A six-light-year-wide expanding remnant of a star's supernova explosion.
- Japanese and Chinese astronomers recorded this violent event in 1054 CE.

2.5.2 The Nebular Theory

- How the planets and other objects in our Solar System originated?
- *The nebular theory (or condensation theory)* – the Sun and all other objects in the Solar System formed from material that had been swirling about in a nebula.
- Tiny particles of ice and dust condensed within a nebula.
- Gradually, more atoms and molecules stuck to these particles, forming larger clumps.
- Once these clumps grow big enough, their gravity pulled them together, growing into even larger bodies.
- As gravity pulled the swirling gas and dust inward, the nebula flattened into a spinning disk with a dense, central region.
- This central "bulb" became the *Sun*, while the rest of the disk became the *protoplanetary disk*.
- Within this disk, dust and rocky debris collided and stuck together to form *planetesimals*.

- These planetesimals, acting like vacuum cleaner, attracted more material and gew into *protoplanets*–early versions of the planets we see today.