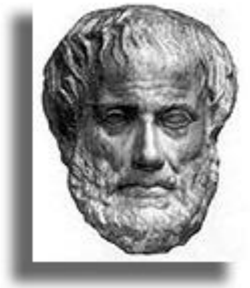
The following statements summarize the primary objectives presented in the chapter.



- Early Greeks held the **geocentric** ("Earth-centered") view of the universe, believing that Earth was a sphere that stayed motionless at the center of the universe. Orbiting Earth were the seven wanderers (**planetai** in Greek), which included the Moon, Sun, and the known planets—Mercury, Venus, Mars, Jupiter, and Saturn. To the early Greeks, the stars traveled daily around Earth on a transparent, hollow sphere called the **celestial sphere**. In A.D. 141, **Claudius Ptolemy** presented the geocentric outlook of the Greeks in its most sophisticated form in a model that became known as the **Ptolemaic system**. The Ptolemaic model had the planets moving in circular orbits around a motionless Earth. To explain the **retrograde motion** of planets (the apparent westward, or opposite motion planets exhibit for a period of time as Earth overtakes and passes them) Ptolemy proposed that the planets orbited in small circles (**epicycles**), revolving along large circles (**deferents**).
- In the fifth century B.C., the Greek **Anaxagoras** reasoned that the Moon shines by reflected sunlight, and because it is a sphere, only half is illuminated at one time. **Aristotle** (384-322 B.C.) concluded that Earth is spherical. The first Greek to profess a sun-centered, or **heliocentric**, universe was **Aristarchus** (312-230 B.C.). The first successful attempt to establish the size of Earth is credited to **Eratosthenes** (276-194 B.C.). The greatest of the early Greek astronomers was **Hipparchus** (second century B.C.), best known for his star catalog.
- Modern astronomy evolved through the work of many dedicated individuals during the 1500s and 1600s. **Nicolaus Copernicus** (1473-1543) reconstructed the solar system with the Sun at the center and the planets orbiting around it, but erroneously continued to use circles to represent the orbits of planets. **Tycho Brahe's** (1546-1601) observations were far more precise than any made previously and are his legacy to astronomy. **Johannes Kepler** (1571-1630) ushered in the new astronomy with his three laws of planetary motion. After constructing his own telescope, **Galileo Galilei** (1564-1642) made many important discoveries that supported the Copernican view of a sun-centered solar system. **Sir Isaac Newton** (1643-1727) was the first to formulate and test the law of universal gravitation, develop the laws of motion, and prove that the force of **gravity**, combined with the tendency of an object to move in a straight line (**inertia**), results in the elliptical orbits discovered by Kepler.

- As early as 5000 years ago people began naming the configurations of stars, called **constellations**, in honor of mythological characters or great heroes. Today, 88 constellations are recognized that divide the sky into units, just as state boundaries divide the United States.
- One method for locating stars, called the **equatorial system**, divides the celestial sphere into a coordinate system similar to the latitude-longitude system used for locations on Earth's surface. **Declination**, like latitude, is the angular distance north or south of the **celestial equator**. **Right ascension** is the angular distance measured eastward from the position of the **vernal equinox** (the point in the sky where the Sun crosses the celestial equator at the onset of spring).

- The two primary motions of Earth are **rotation** (the turning, or spinning, of a body on its axis) and **revolution** (the motion of a body, such as a planet or moon, along a path around some point in space). Another very slow motion of Earth is **precession** (the slow motion of Earth's axis that traces out a cone over a period of 26,000 years).

Earth's rotation can be measured in two ways, making two kinds of days. The **mean solar day** is the time interval from one noon to the next, which averages about 24 hours. On the other hand, the **sidereal day** is the time it takes for Earth to make one complete rotation with respect to a star other than the Sun, a period of 23 hours, 56 minutes, and 4 seconds. Earth revolves around the Sun in an elliptical orbit at an average distance from the Sun of 150 million kilometers (93 million miles). At **perihelion** (closest to the Sun), which occurs in January, Earth is 147 million kilometers from the Sun. At **aphelion** (farthest from the Sun), which occurs in July, Earth is 152 million kilometers distant. The imaginary plane that connects Earth's orbit with the celestial sphere is called the **plane of the ecliptic**.

- One of the first astronomical phenomenon to be understood was the regular cycle of the phases of the Moon. The cycle of the Moon through its phases requires 29.5 days, a time span called the **synodic month**. However, the true period of the Moon's revolution around Earth takes 27.33 days and is known as the **sidereal month**. The difference of nearly two days is due to the fact that as the Moon orbits Earth, the Earth-Moon system also moves in an orbit around the Sun.
- In addition to understanding the Moon's phases, the early Greeks also realized that eclipses are simply shadow effects. When the Moon moves in a line directly between Earth and the Sun, which can occur only during the new-moon phase, it casts a dark shadow on Earth, producing a **solar eclipse**. A **lunar eclipse** takes place when the Moon moves within the shadow of Earth during the full-moon phase. Because the Moon's orbit is inclined about 5 degrees to the plane that contains the Earth and Sun (the plane of the ecliptic), during most new- and full-moon phases no eclipse occurs. Only if a new- or full-moon phase occurs as the Moon crosses the plane of the ecliptic can an eclipse take place. The usual number of eclipses is four per year.

After reading, studying, and discussing Chapter 21, you should be able to:

- Describe the geocentric theory of the universe held by many early Greeks.
- List the astronomical contributions of the ancient Greek philosophers Aristotle, Anaxagoras, Aristarchus, Eratosthenes, Hipparchus, and Ptolemy.
- Describe the Ptolemaic model of the universe.
- List the contributions to modern astronomy of Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, Galileo Galilei, and Sir Isaac Newton.
- Describe the equatorial system for locating stars.
- List and describe the primary motions of Earth.
- Discuss the phases of the Moon, lunar motions, and eclipses.

Chapter 21: **Origin of Modern Astronomy**

I. Early history of astronomy
  A. Ancient Greeks
    1. Used philosophical arguments to explain natural phenomena
    2. Also used some observational data
    3. Most ancient Greeks held a geocentric (Earth-centered) view of the universe
      a. "Earth-centered" view
        1. Earth was a motionless sphere at the center of the universe
        2. Stars were on the celestial sphere

            a. Transparent, hollow sphere
            b. Celestial sphere turns daily around Earth
        b. Seven heavenly bodies (planetai)
            1. Changed position in sky
            2. The seven wanderers included the
                a. Sun
                b. Moon
                c. Mercury through Saturn (excluding Earth)
    4. Aristarchus (312-230 B.C.) was the first Greek to profess a Sun-centered, or heliocentric, universe
    5. Planets exhibit an apparent westward drift
        a. Called retrograde motion
        b. Occurs as Earth, with its faster orbital speed, overtakes another planet
    6. Ptolemaic system
        a. A.D. 141
        b. Geocentric model
        c. To explain retrograde motion, Ptolemy used two motions for the planets
            1. Large orbital circles, called deferents, and
            2. Small circles, called epicycles

B. Birth of modern astronomy
    1. 1500s and 1600s
    2. Five noted scientists
        a. Nicolaus Copernicus (1473-1543)
            1. Concluded Earth was a planet
            2. Constructed a model of the solar system that put the Sun at the center, but he used circular orbits for the planets
            3. Ushered out old astronomy
        b. Tycho Brahe (1546-1601)
            1. Precise observer
            2. Tried to find stellar parallax – the apparent shift in a star's position due to the revolution of Earth
            3. Did not believe in the Copernican system because he was unable to observe stellar parallax
        c. Johannes Kepler (1571-1630)
            1. Ushered in new astronomy
            2. Planets revolve around the Sun
            3. Three laws of planetary motion
                a. Orbits of the planets are elliptical
                b. Planets revolve around the Sun at varying speed
                c. There is a proportional relation between a planet's orbital period and its distance to the Sun (measured in astronomical units (AUs) – one AU averages about 150 million kilometers, or 93 million miles)
        d. Galileo Galilei (1564-1642)
            1. Supported Copernican theory
            2. Used experimental data
            3. Constructed an astronomical telescope in 1609
            4. Galileo's discoveries using the telescope
                a. Four large moons of Jupiter
                b. Planets appeared as disks
                c. Phases of Venus
                d. Features on the Moon
                e. Sunspots

5. Tried and convicted by the Inquisition
e. Sir Isaac Newton (1643-1727)
1. Law of universal gravitation
2. Proved that the force of gravity, combined with the tendency of a planet to remain in straight-line motion, results in the elliptical orbits discovered by Kepler

II. Constellations
A. Configuration of stars named in honor of mythological characters or great heroes
B. Today 88 constellations are recognized
C. Constellations divide the sky into units, like state boundaries in the United States
D. The brightest stars in a constellation are identified in order of their brightness by the letters of the Greek alphabet – alpha, beta, and so on

III. Positions in the sky
A. Stars appear to be fixed on a spherical shell (the celestial sphere) that surrounds Earth
B. Equatorial system of location
1. A coordinate system that divides the celestial sphere
2. Similar to the latitude-longitude system that is used on Earth's surface
3. Two locational components
a. Declination – the angular distance north or south of the celestial equator
b. Right ascension – the angular distance measured eastward along the celestial equator from the position of the vernal equinox

IV. Earth motions
A. Two primary motions
1. Rotation
a. Turning, or spinning, of a body on its axis
b. Two measurements for rotation
1. Mean solar day – the time interval from one noon to the next, about 24 hours
2. Sidereal day – the time it takes for Earth to make one complete rotation (360) with respect to a star other than the Sun – 23 hours, 56 minutes, 4 seconds
2. Revolution
a. The motion of a body, such as a planet or moon, along a path around some point in space
b. Earth's orbit is elliptical
1. Earth is closest to the Sun (perihelion) in January
2. Earth is farthest from the Sun (aphelion) in July
c. The plane of the ecliptic is an imaginary plane that connects Earth's orbit with the celestial sphere
B. Other Earth motions
1. Precession
a. Very slow Earth movement
b. Direction in which Earth's axis points continually changes
2. Movement with the solar system in the direction of the star Vega
3. Revolution with the Sun around the galaxy
4. Movement with the galaxy within the universe
V. Motions of the Earth-Moon system
A. Phases of the Moon
1. When viewed from above the North Pole, the Moon orbits Earth in a counter-clockwise (eastward) direction
2. The relative positions of the Sun, Earth, and Moon constantly change
3. Lunar phases are a consequence of the motion of the Moon and the sunlight that is reflected from its surface

B. Lunar motions
   1. Earth-Moon
      a. Synodic month
         1. Cycle of the phases
         2. Takes 292 days
      b. Sidereal month
         1. True period of the Moon's revolution around Earth
         2. Takes 27 α days
         c. The difference of two days between the synodic and sidereal cycles is due to the Earth-Moon system also moving in an orbit around the Sun
   2. Moon's period of rotation about its axis and its revolution around Earth are the same, 27α days
      a. Causes the same lunar hemisphere to always face Earth
      b. Causes high surface temperature on the day side of the Moon

C. Eclipses
   1. Simply shadow effects that were first understood by the early Greeks
   2. Two types of eclipses
      a. Solar eclipse
         1. Moon moves in a line directly between Earth and the Sun
         2. Can only occur during the new-Moon phase
      b. Lunar eclipse
         1. Moon moves within the shadow of Earth
         2. Only occurs during the full-Moon phase
   3. For any eclipse to take place, the Moon must be in the plane of the ecliptic at the time of new- or full-Moon
   4. Because the Moon's orbit is inclined about 5 degrees to the plane of the ecliptic, during most of the times of new- and full-Moon the Moon is above or below the plane, and no eclipse can occur
   5. The usual number of eclipses is four per year

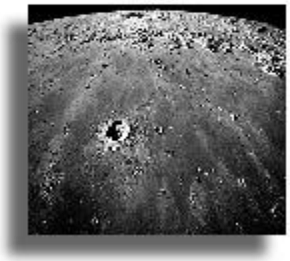
Chapter 22

Touring Our Solar System
Objectives

The following statements summarize the primary objectives presented in the chapter.

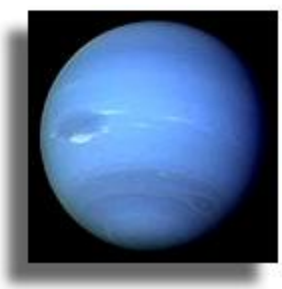
- The planets can be arranged into two groups: the **terrestrial** (Earth-like) **planets** (Mercury, Venus, Earth, and Mars) and the **Jovian** (Jupiter-like) **planets** (Jupiter, Saturn, Uranus, and Neptune). Pluto is not included in either group. **When compared to the Jovian planets, the terrestrial planets are smaller, more dense, contain proportionally more rocky material, have slower rates of rotation, and lower escape velocities**.
- The **nebular hypothesis** (discussed in the textbook Introduction) describes the formation of the solar system. Because of **chemical differentiation**, as the terrestrial planets formed, the denser metallic elements (iron and nickel) sank toward their centers, whereas the lighter substances (silicate minerals, oxygen, hydrogen) migrated toward their surfaces. Owing to their surface gravities, Earth and Venus were able to retain the heavier gases, such as nitrogen, oxygen, and carbon dioxide. Because of the very cold temperatures existing far from

the Sun, the fragments from which the Jovian planets formed contained a high percentage of ices—water, carbon dioxide, ammonia, and methane.



- The lunar surface exhibits several types of features. Most **craters** were produced by the impact of rapidly moving interplanetary debris (**meteoroids**). Bright, densely cratered **highlands** make up most of the lunar surface. The dark, fairly smooth lowlands are called **maria** (singular, **mare**). Maria basins are enormous impact craters that have been flooded with layer-upon-layer of very fluid basaltic lava. All lunar terrains are mantled with a soil-like layer of gray, unconsolidated debris, called **lunar regolith**, which has been derived from a few billion years of meteoric bombardment. Much is still unknown about the Moon's origin. One hypothesis suggests that a giant asteroid collided with Earth to produce the Moon. Scientists conclude that **the Moon evolved in three phases** 1) **the original crust (highlands)**, 2) **maria basins**, and 3) **youthful rayed craters**.

- **Mercury** is a small, dense planet that has no atmosphere and exhibits the greatest temperature extremes of any planet. **Venus**, the brightest planet in the sky, has a thick, heavy atmosphere composed of 97 percent carbon dioxide, a surface of relatively subdued plains and inactive volcanic features, a surface atmospheric pressure ninety times that of Earth's, and surface temperatures of 475°C (900°F). **Mars**, the "Red Planet," has a carbon dioxide atmosphere only 1 percent as dense as Earth's, extensive dust storms, numerous inactive volcanoes, many large canyons, and several valleys of debatable origin exhibiting drainage patterns similar to stream valleys on Earth. **Jupiter**, the largest planet, rotates rapidly, has a banded appearance caused by huge convection currents driven by the planet's interior heat, a **Great Red Spot** that varies in size, a thin ring system, and at least sixteen moons (one of the moons, **Io**, is a volcanically active body). **Saturn** is best known for its system of rings. It also has a dynamic atmosphere with winds up to 930 miles per hour and "storms" similar to Jupiter's Great Red Spot. **Uranus** and **Neptune** are often called "the twins" because of similar structure and composition. A unique feature of Uranus is the fact that it rotates "on its side." Neptune has white, cirruslike clouds above its main cloud deck and an Earth-sized **Great Dark Spot**, assumed to be a large rotating storm similar to Jupiter's Great Red Spot. **Pluto** is a small frozen world with one moon (Charon). Pluto's noticeably elongated orbit causes it to occasionally travel inside the orbit of Neptune, but with no chance of collision.



- The minor members of the solar system include the **asteroids**, **comets**, and **meteoroids**. Most asteroids lie between the orbits of Mars and Jupiter. No conclusive evidence has been found to explain their origin. Comets are made of frozen gases (water, ammonia, methane, carbon dioxide, and carbon monoxide) with small pieces of rocky and metallic material. Many travel in very elongated orbits that carry them beyond Pluto and little is known about their origin. Meteoroids, small solid particles that travel through interplanetary space, become **meteors** when they enter Earth's atmosphere and vaporize with a flash of light. **Meteor showers** occur when Earth encounters a swarm of meteoroids, probably material lost by a comet. **Meteorites** are the remains of meteoroids found on Earth. The three types of meteorites (classified by their composition) are 1) **irons**, 2) **stony**, and 3) **stony-irons**. One rare kind of meteorite, called a **carbonaceous chondrite**, was found to contain amino acids and other organic compounds.

After reading, studying, and discussing Chapter 21, you should be able to:

- Describe the general characteristics of the two groups of planets in the solar system.
- Describe the major features of the lunar surface and discuss the Moon's history.
- List the distinguishing features of each planet in the solar system.
- List and describe the minor members of the solar system.

I. Overview of the solar system
  A. Solar system includes
    1. Sun
    2. Nine planets and their satellites
    3. Asteroids
    4. Comets
    5. Meteoroids
  B. A planet's orbit lies in an orbital plane
    1. Similar to a flat sheet of paper
    2. The orbital planes of the planets are inclined
      a. Planes of seven planets lie within 3 degrees of the Sun's equator
      b. Mercury's is inclined 7 degrees
      c. Pluto's is inclined 17 degrees
  C. Two groups of planets occur in the solar system
    1. Terrestrial (Earth-like) planets
      a. Mercury through Mars
      b. Small, dense, rocky
      c. Low escape velocities
    2. Jovian (Jupiter-like) planets
      a. Jupiter through Neptune
      b. Large, low density, gaseous
      c. Massive
      d. Thick atmospheres composed of
        1. Hydrogen
        2. Helium
        3. Methane
        4. Ammonia
      e. High escape velocities
    3. Pluto not included in either group
  D. Planets are composed of
    1. Gases
      a. Hydrogen
      b. Helium
    2. Rocks
      a. Silicate minerals
      b. Metallic iron
    3. Ices
      a. Ammonia (NH_3)
      b. Methane (CH_4)
      c. Carbon dioxide (CO_2)
      d. Water (H_2O)

II. Evolution of the planets (see textbook Introduction)
- A. Nebular hypothesis
  - 1. Planets formed about 5 billion years ago
  - 2. Solar system condensed from a gaseous nebula
- B. As the planets formed, the materials that compose them separated
  - 1. Dense metallic elements (iron and nickel) sank toward their centers
  - 2. Lighter elements (silicate minerals, oxygen, hydrogen) migrated toward their surfaces
  - 3. Process called chemical differentiation
- C. Due to their surface gravities, Venus and Earth retained atmospheric gases
- D. Due to frigid temperatures, the Jovian planets contain a high percentage of ices

III. Earth's Moon

- A. General characteristics
  - 1. Diameter of 3475 kilometers (2150 miles) is unusually large compared to its parent planet
  - 2. Density
    - a. 3.3 times that of water
    - b. Comparable to Earth's crustal rocks
    - c. Perhaps the Moon has a small iron core
  - 3. Gravitational attraction is one-sixth of Earth's
  - 4. No atmosphere
  - 5. Tectonics no longer active
  - 6. Surface is bombarded by micrometeorites from space which gradually makes the landscape smooth

- B. Lunar surface
  - 1. Two types of terrain
    - a. Maria (singular, mare), Latin for "sea"
      - 1. Dark regions
      - 2. Fairly smooth lowlands
      - 3. Originated from asteroid impacts and lava flooding the surface
    - b. Highlands
      - 1. Bright, densely cratered regions
      - 2. Make up most of the Moon
      - 3. Make up all of the "back" side of the Moon
      - 4. Older than maria
  - 2. Craters
    - a. Most obvious features of the lunar surface
    - b. Most are produced by an impact from a meteoroid that produces
      - 1. Ejecta
      - 2. Occasional rays (associated with younger craters)
  - 3. Lunar regolith
    - a. Covers all lunar terrains
    - b. Gray, unconsolidated debris
    - c. Composed of
      - 1. Igneous rocks
      - 2. Breccia
      - 3. Glass beads
      - 4. Fine lunar dust
    - d. "Soil-like" layer
    - e. Produced by meteoric bombardment

C. Lunar History
1. Hypothesis suggests that a giant asteroid collided with Earth to produce the Moon
2. One method used to work out lunar history is to observe crater density
   a. Older areas have a higher density
   b. Younger areas are still smooth
3. Moon evolved in three phases
   a. Original crust (highlands)
      1. As Moon formed, its outer shell melted, cooled, solidified, and became the highlands
      2. About 4.5 billion years old
   b. Formation of maria basins
      1. Younger than highlands
      2. Between 3.2 and 3.8 billion years old
   c. Formation of rayed craters
      1. Material ejected from craters is still visible
      2. e.g., Copernicus (a rayed crater)

IV. Planets: a brief tour

A. Mercury
1. Innermost planet
2. Second smallest planet
3. No atmosphere
4. Cratered highlands
5. Vast, smooth terrains
6. Very dense
7. Revolves quickly
8. Rotates slowly
   a. Cold nights (-280°F)
   b. Hot days (800°F)

B. Venus
1. Second to the Moon in brilliance
2. Similar to Earth in
   a. Size
   b. Density
   c. Location in the solar system
3. Shrouded in thick clouds
   a. Impenetrable by visible light
   b. Atmosphere is 97% carbon dioxide
   c. Surface atmospheric pressure is 90 times that of Earth's
4. Surface
   a. Mapped by radar
   b. Features
      1. 80% of surface is subdued plains that are mantled by volcanic flows
      2. Low density of impact craters
      3. Tectonic deformation must have been active during the recent geologic past
      4. Thousands of volcanic structures

C. Mars
1. Called the "Red Planet"
2. Atmosphere
   a. 1% as dense as Earth's
   b. Primarily carbon dioxide
   c. Cold polar temperatures (-193°F)
   d. Polar caps of water ice, covered by a thin layer of frozen carbon dioxide
   e. Extensive dust storms with winds up to 270 kilometers (170 miles) per hour

3. Surface
    a. Numerous large volcanoes – largest is Mons Olympus
    b. Less-abundant impact craters
    c. Tectonically dead
    d. Several canyons
        1. Some larger than Earth's Grand Canyon
        2. Valles Marineras – the largest canyon
            a. Almost 5000 km long
            b. Formed from huge faults
    e. "Stream drainage" patterns
        1. Found in some valleys
        2. No bodies of surface water on the planet
        3. Possible origins
            a. Past rainfall
            b. Surface material collapses as the subsurface ice melts
4. Moons
    a. Two moons
        1. Phobos
        2. Deimos
    b. Captured asteroids

D. Jupiter
1. Largest planet
2. Very massive
    a. 2.5 more massive than combined mass of the planets, satellites, and asteroids
    b. If it had been ten times larger, it would have been a small star
3. Rapid rotation
    a. Slightly less than 10 hours
    b. Slightly bulged equatorial region
4. Banded appearance
    a. Multicolored
    b. Bands are aligned parallel to Jupiter's equator
    c. Generated by wind systems
5. Great Red Spot
    a. In planet's southern hemisphere
    b. Counterclockwise rotating cyclonic storm
6. Structure
    a. Surface thought to be a gigantic ocean of liquid hydrogen
    b. Halfway into the interior, pressure causes liquid hydrogen to turn into liquid metallic hydrogen
    c. Rocky and metallic material probably exists in a central core
7. Moons
    a. At least 28 moons
    b. Four largest moons
        1. Discovered by Galileo
        2. Called Galilean satellites
        3. Each has its own character
            a. Callisto
                1. Outermost Galilean moon
                2. Densely cratered
            b. Europa
                1. Smallest Galilean moon
                2. Icy surface

            3. Many linear surface features
        c. Ganymede
            1. Largest Jovian satellite
            2. Diverse terrains
            3. Surface has numerous parallel grooves
        d. Io
            1. Innermost Galilean moon
            2. Volcanically active (heat source could be from tidal energy)
            3. Sulfurous
    8. Ring system
E. Saturn
    1. Similar to Jupiter in its
        a. Atmosphere
        b. Composition
        c. Internal structure
    2. Rings
        a. Most prominent feature
        b. Discovered by Galileo in 1610
        c. Complex
        d. Composed of small particles (moonlets) that orbit the planet
            1. Most rings fall into one of two categories based on particle density
                a. Main rings contain particles from a few centimeters to several meters in diameter
                b. Faintest rings are composed of very fine (smoke-size) particles
            2. Thought to be debris ejected from moons
        e. Origin is still being debated
    3. Other features
        a. Dynamic atmosphere
        b. Large cyclonic storms similar to Jupiter's Great Red Spot
        c. Thirty named moons
        d. Titan – the largest Saturnian moon
            1. Second largest moon (after Jupiter's Ganymede) in the solar system
            2. Has a substantial atmosphere
F. Uranus
    1. Uranus and Neptune are nearly twins
    2. Rotates "on its side"
    3. Rings
    4. Large moons have varied terrains
G. Neptune
    1. Dynamic atmosphere
        a. One of the windiest places in the solar system
        b. Great Dark Spot
        c. White cirrus-like clouds above the main cloud deck
    2. Eight satellites
    3. Triton – largest Neptune moon
        a. Orbit is opposite the direction that all the planet's travel
        b. Lowest surface temperature in the solar system (-391°F)
        c. Atmosphere of mostly nitrogen with a little methane
        d. Volcanic-like activity
        e. Composed largely of water ice, covered with layers of solid nitrogen and methane
H. Pluto
    1. Not visible with the unaided eye
    2. Discovered in 1930

3. Highly elongated orbit causes it to occasionally travel inside the orbit of Neptune, where it resided from 1979 thru February 1999
4. Moon (Charon) discovered in 1978
5. Average temperature is -210°C

V. Minor members of the solar system

A. Asteroids

1. Most lie between Mars and Jupiter
2. Small bodies – largest (Ceres) is about 620 miles in diameter
3. Some have very eccentric orbits
4. Many of the recent impacts on the Moon and Earth were collisions with asteroids
5. Irregular shapes
6. Origin is uncertain

B. Comets

1. Often compared to large, "dirty snowballs"
2. Composition
   a. Frozen gases
   b. Rocky and metallic materials
3. Frozen gases vaporize when near the Sun
   a. Produces a glowing head called the coma
   b. Some may develop a tail that points away from Sun due to
      1. Radiation pressure and the
      2. Solar wind
4. Origin
   a. Not well known
   b. Form at great distance from the Sun
5. Most famous short-period comet is Halley's comet
   a. 76 year orbital period
   b. Potato-shaped nucleus (16 km by 8 km)

C. Meteoroids

1. Called meteors when they enter Earth's atmosphere
2. A meteor shower occurs when Earth encounters a swarm of meteoroids associated with a comet's path
3. Meteoroids are referred to as meteorites when they are found on Earth
   a. Types of meteorites classified by their composition
      1. Irons
         a. Mostly iron
         b. 5-20% nickel
      2. Stony
         a. Silicate minerals with
         b. Inclusions of other minerals
      3. Stony-irons – mixtures
      4. Carbonaceous chondrites
         a. Rare
         b. Composition
            1. Simple amino acids
            2. Other organic material
   b. May give an idea as to the composition of Earth's core
   c. Give an idea as to the age of the solar system

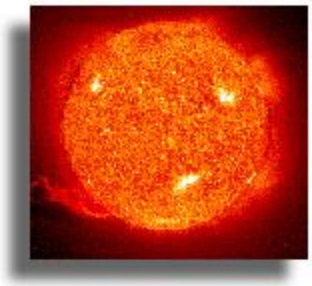
Chapter 23

Light, Astronomical Observations, and the Sun.

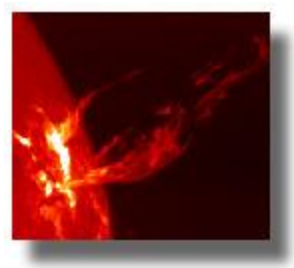
The following statements summarize the primary objectives presented in the chapter.

- Visible light constitutes only a small part of an array of energy generally referred to as **electromagnetic radiation**. Light, a type of electromagnetic radiation, can be described in two ways 1) as waves and 2) as a stream of particles, called **photons**. The wavelengths of electromagnetic radiation vary from several kilometers for **radio waves** to less than a billionth of a centimeter for **gamma rays**. The shorter wavelengths correspond to more energetic photons.
- **Spectroscopy** is the study of the properties of light that depend on wavelength. When a prism is used to disperse visible light into its component parts (wavelengths), one of three possible types of **spectra** (a **spectrum**, the singular form of spectra, is the light pattern produced by passing light through a prism) is produced. The three types of spectra are 1) **continuous spectrum**, 2) **dark-line** (absorption) **spectrum**, and 3) **bright-line** (emission) **spectrum**. The spectra of most stars are of the dark-line type. Spectroscopy can be used to determine 1) the state of matter of an object (solid, liquid, high or low pressure gas), 2) the composition of gaseous objects, 3) the temperature of a radiating body, and 4) the motion of an object. Motion (direction toward or away and velocity) is determined using the **Doppler effect**—the apparent change in the wavelength of radiation emitted by an object caused by the relative motions of the source and the observer.
- There are two types of optical telescopes; 1) the **refracting telescope**, which uses a **lens** as its **objective** to bend or refract light so that it converges at an area called the **focus**, and 2) the **reflecting telescope**, which uses a **concave mirror** to focus (gather) the light. When examining an image directly, both types of telescopes require a second lens, called an **eyepiece**, which magnifies the image produced by the objective.

- Telescopes have three properties that aid astronomers; 1) **light-gathering power**, which is a function of the size of the objective—large objectives gather more light and therefore "see" farther into space, 2) **resolving power**, which allows for sharper images and finer detail, is the ability of a telescope to separate objects that are close together, e.g. Pluto and its moon Charon, and 3) **magnifying power**, the ability to make an object larger. Most modern telescopes have supplemental devices that enhance the image.
- Invisible radio wave radiation is detected by "big dishes" called **radio telescopes**. A parabolic shaped dish, often consisting of a wire mesh, operates in the same manner as the mirror of a reflecting telescope. Radio telescopes have poor resolution, making it difficult to pinpoint a radio source. To reduce this problem, several can be wired together into a network called a **radio interferometer**. The advantages of radio telescopes over optical telescopes are that radio telescopes are less affected by the weather, they are less expensive to construct, "viewing" is possible 24 hours a day, they can detect material in the universe too cool to emit visible radiation, and they can "see" through interstellar dust clouds.



- The **Sun** is one of the 200 billion stars that make up the Milky Way galaxy. The Sun can be divided into four parts 1) the **solar interior**, 2) the **photosphere** (visible surface), and the two layers of its atmosphere, 3) the **chromosphere** and 4) **corona**. The photosphere radiates most of the light we see. Unlike most surfaces, it consists of a layer of incandescent gas less than 500 kilometers (300 miles) thick with a grainy texture consisting of numerous, relatively small, bright markings called **granules**. Just above the photosphere lies the chromosphere, a relatively thin layer of hot, incandescent gases a few thousand kilometers thick. At the edge of the uppermost portion of the solar atmosphere, called the corona, ionized gases escape the gravitational pull of the Sun and stream toward Earth at high speeds producing the **solar wind**.
- Numerous features have been identified on the active Sun. **Sunspots** are dark blemishes with a black center, the **umbra**, which is rimmed by a lighter region, the **penumbra**. The number of sunspots observable on the solar disk varies in an 11-year cycle. **Plages** are large "clouds" that appear as bright centers of solar activity often directly above sunspot clusters. **Prominences**, huge cloudlike structures best observed when they are on the edge, or limb, of the Sun, are produced by ionized chromospheric gases trapped by magnetic fields that extend from regions of intense solar activity. The most explosive events associated with sunspots are **solar flares**. Flares are brief outbursts that release enormous quantities of energy that appear as a sudden brightening of the region above sunspot clusters. During the event, radiation and fast-moving atomic particles are ejected, causing the solar wind to intensify. When the ejected particles reach Earth and disturb the ionosphere, radio communication is disrupted and the **auroras**, also called the Northern and Southern Lights, occur.
- The source of the Sun's energy is **nuclear fusion**. Deep in the solar interior, at a temperature of 15 million K, a nuclear reaction called the **proton-proton chain** converts four hydrogen nuclei (protons) into the nucleus of a helium atom. During the reaction some of the matter is converted to the energy of the Sun. A star the size of the Sun can exist in its present stable state for 10 billion years. Since the Sun is already 5 billion years old, it is a "middle-aged" star.



Objectives

After reading, studying, and discussing Chapter 22, you should be able to:

- Describe electromagnetic radiation and the two models used to explain its properties.
- List and describe the three types of light spectra.
- Explain how light (electromagnetic radiation) can be used to investigate the properties of a star.
- Describe the two types of optical telescopes and list their component parts.
- List and describe the three properties of optical telescopes that aid astronomers in their work.
- Describe radio telescopes and list some of their advantages over optical telescopes.
- List and describe the four parts of the Sun.
- Describe several features found on the active Sun.
- Describe the source of the Sun's energy.

Light, Astronomical Observations, and the Sun

I. The study of light
- A. Electromagnetic radiation
  - 1. Visible light is only one small part of an array of energy
  - 2. Electromagnetic radiation includes
    - a. Gamma rays
    - b. X-rays
    - c. Ultraviolet light
    - d. Visible light
    - e. Infrared light
    - f. Radio waves
  - 3. All forms of radiation travel at 300,000 kilometers (186,000 miles) per second
- B. Light (electromagnetic radiation) can be described in two ways
  - 1. Wave model
    - a. Wavelengths of radiation vary
      - 1. Radio waves measure up to several kilometers long
      - 2. Gamma ray waves are less than a billionth of a centimeter long
    - b. White light consists of several wavelengths corresponding to the colors of the rainbow
  - 2. Particle model
    - a. Particles called photons
    - b. Exert a pressure, called radiation pressure, on matter
    - c. Shorter wavelengths correspond to more energetic photons
- C. Spectroscopy
  - 1. The study of the properties of light that depend on wavelength
  - 2. The light pattern produced by passing light through a prism, which spreads out the various wavelengths, is called a spectrum (plural: spectra)
  - 3. Types of spectra
    - a. Continuous spectrum
      - 1. Produced by an incandescent solid, liquid, or high pressure gas
      - 2. Uninterrupted band of color
    - b. Dark-line (absorption) spectrum
      - 1. Produced when white light is passed through a comparatively cool, low pressure gas
      - 2. Appears as a continuous spectrum but with dark lines running through it
    - c. Bright-line (emission) spectrum
      - 1. Produced by a hot (incandescent) gas under low pressure
      - 2. Appears as a series of bright lines of particular wavelengths depending on the gas that produced them
  - 4. Most stars have a dark-line spectrum
  - 5. Instrument used to spread out the light is called a spectroscope
- D. Doppler effect
  - 1. The apparent change in wavelength of radiation caused by the relative motions of the source and observer
  - 2. Used to determine
    - a. Direction of motion
      - 1. Increasing distance – wavelength is longer ("stretches")
      - 2. Decreasing distance – makes wavelength shorter ("compresses")
    - b. Velocity – larger Doppler shifts indicate higher velocities

II. Astronomical tools
- A. Optical (visible light) telescopes

1. Two basic types
    a. Refracting telescope
        1. Uses a lens (called the objective) to bend (refract) the light to produce an image
        2. Light converges at an area called the focus
        3. Distance between the lens and the focus is called the focal length
        4. The eyepiece is a second lens used to examine the image directly
        5. Have an optical defect called chromatic aberration (color distortion)
    b. Reflecting telescope
        1. Uses a concave mirror to gather the light
        2. No color distortion
        3. Nearly all large telescopes are of this type
2. Properties of optical telescopes
    a. Light-gathering power
        1. Larger lens (or mirror) intercepts more light
        2. Determines the brightness
    b. Resolving power
        1. The ability to separate close objects
        2. Allows for a sharper image and finer detail
    c. Magnifying power
        1. The ability to make an image larger
        2. Calculated by dividing the focal length of the objective by the focal length of the eyepiece
        3. Can be changed by changing the eyepiece
        4. Limited by atmospheric conditions and the resolving power of the telescope
        5. Even with the largest telescopes, stars (other than the Sun) appear only as points of light

B. Detecting invisible radiation
1. Photographic films are used to detect ultraviolet and infrared wavelengths
2. Most invisible wavelengths do not penetrate Earth's atmosphere, so balloons, rockets, and satellites are used
3. Radio radiation
    a. Reaches Earth's surface
    b. Gathered by "big dishes" called radio telescopes
        1. Large because radio waves are about 100,000 longer than visible radiation
        2. Often made of a wire mesh
        3. Have rather poor resolution
        4. Can be wired together into a network called a radio interferometer
        5. Advantages over optical telescopes
            a. Less affected by weather
            b. Less expensive
            c. Can be used 24 hours a day
            d. Detects material that does not emit visible radiation
            e. Can "see" through interstellar dust clouds
        6. A disadvantage is that they are hindered by man-made radio interference

III. Sun
A. One of 200 billion stars that make up the Milky Way galaxy
B. Only star close enough to allow the surface features to be studied
C. An average star

D. Structure can be divided into four parts
   1. Solar interior
   2. Photosphere
      a. "Sphere of light"
      b. Sun's "surface" – actually a layer of incandescent gas less than 500 kilometers thick
      c. Grainy texture made up of many small, bright markings, called granules, produced by convection
      d. Most of the elements found on Earth also occur on the Sun
      e. Temperature averages approximately 6000 K (10,000°F)
   3. Chromosphere
      a. Just above photosphere
      b. Lowermost atmosphere
      c. Relatively thin, hot layer of incandescent gases a few thousand kilometers thick
      d. Top contains numerous spicules – narrow jets of rising material
   4. Corona
      a. Outermost portion of the solar atmosphere
      b. Very tenuous
      c. Ionized gases escape from the outer fringe and produce the solar wind
      d. Temperature at the top exceeds 1 million K

E. Solar features
   1. Sunspots
      a. On the solar surface
      b. Dark center, the umbra, surrounded by a lighter region, the penumbra
      c. Dark color is due to a cooler temperature (1500 K less than the solar surface)
      c. Follow an 11-year cycle
      d. Large spots are strongly magnetized
      e. Pairs have opposite magnetic poles
   2. Plages
      a. Bright centers of solar activity
      b. Occur above sunspot clusters
   3. Prominences
      a. Huge arching cloud-like structures that extend into the corona
      b. Condensations of material in the corona
   4. Flares
      a. Explosive events that normally last an hour or so
      b. Sudden brightening above a sunspot cluster
      c. Release enormous quantities of energy
      d. Eject particles that reach Earth in about one day and interact with the atmosphere to cause the auroras (the Northern and Southern Lights)

IV. Solar interior

A. Cannot be observed directly

B. Nuclear fusion occurs here
   1. Source of the Sun's energy
   2. Occurs in the deep interior
   3. Nuclear reaction that produces the Sun's energy is called the proton-proton reaction
      a. Four hydrogen nuclei are converted into a helium nuclei
      b. Matter is converted to energy
      c. 600 million tons of hydrogen is consumed each second
   4. Sun has enough fuel to last another five billion years

Chapter 24

Beyond Our Solar System

The following statements summarize the primary objectives presented in the chapter.

- One method for determining the distance to a star is to use a measurement called **stellar parallax**, the extremely slight back-and-forth shifting in a nearby star's position due to the orbital motion of Earth. **The farther away a star is, the less its parallax**. A unit used to express stellar distance is the **light-year**, which is the distance light travels in one Earth year—about 9.5 trillion kilometers (5.8 trillion miles).
- The intrinsic properties of stars include **brightness**, **color**, **temperature**, **mass**, and **size**. Three factors control the brightness of a star as seen from Earth: how big it is, how hot it is, and how far away it is. **Magnitude** is the measure of a star's brightness. **Apparent magnitude** is how bright a star appears when viewed from Earth. **Absolute magnitude** is the "true" brightness if a star were at a standard distance of about 32.6 light-years. The difference between the two magnitudes is directly related to a star's distance. Color is a manifestation of a star's temperature. Very hot stars (surface temperatures above 30,000 K) appear blue; red stars are much cooler (surface temperatures generally less than 3000 K). Stars with surface temperatures between 5000 and 6000 K appear yellow, like the Sun. The center of mass of orbiting **binary stars** (two stars revolving around a common center of mass under their mutual gravitational attraction) is used to determine the mass of the individual stars in a binary system.

- A **Hertzsprung-Russell diagram** is constructed by plotting the absolute magnitudes and temperatures of stars on a graph. A great deal about the sizes of stars can be learned from H-R diagrams. Stars located in the upper-right position of an H-R diagram are called **giants**, luminous stars of large radius. **Supergiants** are very large. Very small **white dwarf** stars are located in the lower-central portion of an H-R diagram. Ninety percent of all stars, called **main-sequence stars**, are in a band that runs from the upper-left corner to the lower-right corner of an H-R diagram.
- **Variable stars** fluctuate in brightness. Some, called **pulsating variables**, fluctuate regularly in brightness by expanding and contracting in size. When a star explosively brightens, it is called a **nova**. During the outburst, the outer layer of the star is ejected at high speed. After reaching maximum brightness in a few days, the nova slowly returns in a year or so to its original brightness.

- New stars are born out of enormous accumulations of dust and gases, called **nebula**, that are scattered between existing stars. A **bright nebula** glows because the matter is close to a very hot (blue) star. The two main types of bright nebulae are **emission nebulae** (which derive their visible light from the fluorescence of the ultraviolet light from a star in or near the nebula) and **reflection nebulae** (relatively dense dust clouds in interstellar space that are illuminated by reflecting the light of nearby stars). When a nebula is not close enough to a bright star to be illuminated, it is referred to as a **dark nebula**.
- Stars are born when their nuclear furnaces are ignited by the unimaginable pressures and temperatures in collapsing nebulae. New stars not yet hot enough for nuclear fusion are called **protostars**. When collapse causes the core of a protostar to reach a temperature of at least 10 million K, the fusion of hydrogen nuclei into helium nuclei begins in a process called **hydrogen burning**. The opposing forces acting on a star are **gravity** trying to contract it and **gas pressure** (**thermal nuclear energy**) trying to expand

it. When the two forces are balanced, the star becomes a stable main-sequence star. When the hydrogen in a star's core is consumed, its outer envelope expands enormously and a **red giant star**, hundreds-to-thousands of times larger than its main-sequence size, forms. When all the usable nuclear fuel in these giants is exhausted and gravity takes over, the stellar remnant collapses into a small dense body.

- The **final fate of a star is determined by its mass**. Stars with less than one-half the mass of the Sun collapse into hot, dense **white dwarf** stars. Medium-mass stars (between 0.5 and 3.0 times the mass of the Sun) become red giants, collapse, and end up as white dwarf stars, often surrounded by expanding spherical clouds of glowing gas called **planetary nebulae**. Stars more than three times the mass of the Sun terminate in a brilliant explosion called a **supernova**. Supernovae events can produce small, extremely dense **neutron stars**, composed entirely of subatomic particles called neutrons; or even smaller and more dense **black holes**, objects that have such immense gravity that light cannot escape their surface.
- The **Milky Way galaxy** is a large, disk-shaped, **spiral galaxy** about 100,000 light-years wide and about 10,000 light-years thick at the center. There are three distinct **spiral arms** of stars, with some showing splintering. The Sun is positioned in one of these arms about two-thirds of the way from the galactic center, at a distance of about 30,000 light-years. Surrounding the galactic disk is a nearly spherical halo made of very tenuous gas and numerous **globular clusters** (nearly spherically shaped groups of densely packed stars).

- The various types of galaxies include 1) **spiral galaxies**, which are typically disk-shaped with a somewhat greater concentration of stars near their centers, often containing arms of stars extending from their central nucleus, 2) **barred spiral galaxies**, a type of spiral galaxy that has the stars arranged in the shape of a bar, which rotates as a rigid system, 3) **elliptical galaxies**, the most abundant type, which have an ellipsoidal shape that ranges to nearly spherical, and lack spiral arms, and 4) **irregular galaxies**, which lack symmetry and account for only 10 percent of the known galaxies.
- Galaxies are not randomly distributed throughout the universe. They are grouped in **galactic clusters**, some containing thousands of galaxies. Our own, called the **Local Group**, contains at least 28 galaxies.

- By applying the **Doppler effect** (the apparent change in wavelength of radiation caused by the motions of the source and the observer) to the light of galaxies, galactic motion can be determined. Most galaxies have Doppler shifts toward the red end of the spectrum, indicating increasing distance. The amount of Doppler shift is dependent on the velocity at which the object is moving. Because the most distant galaxies have the greatest red shifts, Edwin Hubble concluded in the early 1900s that they were retreating from us with greater recessional velocities than more nearby galaxies. It was soon realized that an **expanding universe** can adequately account for the observed red shifts.
- The belief in the expanding universe led to the widely accepted **Big Bang theory** of the origin of the universe. According to this theory, the entire universe was at one time confined in a dense, hot, supermassive concentration. About 15 billion years ago, a cataclysmic explosion hurled this material in all directions, creating all matter and space. Eventually the ejected masses of gas cooled and condensed, forming the stellar systems we now observe fleeing from their place of origin.

Objectives

After reading, studying, and discussing Chapter 24, you should be able to:

- Discuss the principle of parallax and explain how it is used to measure the distance to a star.
- List and describe the major intrinsic properties of stars.
- Describe the different types of nebulae.
- Describe the most plausible model for stellar evolution and list the stages in the life cycle of a star.
- Describe the possible final states that a star may assume after it consumes its nuclear fuel and collapses.
- List and describe the major types of galaxies.
- Describe the Big Bang theory of the origin of the universe.

Beyond Our Solar System

I. Properties of stars
  A. Distance
    1. Measuring a star's distance can be very difficult
    2. Stellar parallax
      a. Used for measuring distance to a star
      b. Apparent shift in a star's position due to the orbital motion of Earth
      c. Measured as an angle
      d. Near stars have the largest parallax
      e. Largest parallax is less than one second of arc
    3. Distances to the stars are very large
    4. Units of measurement
      a. Kilometers or astronomical units are too cumbersome to use
      b. Light-year is used most often
        1. Distance that light travels in 1 year
        2. One light-year is 9.5 trillion km (5.8 trillion miles)
    5. Other methods for measuring distance are also used
  B. Stellar brightness
    1. Controlled by three factors
      a. Size
      b. Temperature
      c. Distance
    2. Magnitude
      a. Measure of a star's brightness
      b. Two types of measurement
        1. Apparent magnitude
          a. Brightness when a star is viewed from Earth
          b. Decreases with distance
          c. Numbers are used to designate magnitudes
            1. Dim stars have large numbers
              a. First magnitude appear brighter
              b. Sixth magnitude are the faintest stars visible to the eye
            2. Negative numbers are also used

2. Absolute magnitude
    a. "True" or intrinsic brightness of a star
    b. Brightness at a standard distance of 32.6 light-years
    c. Most stars' absolute magnitudes are between -5 and +15

C. Color and temperature
  1. Hot star
    a. Temperature above 30,000 K
    b. Emits short-wavelength light
    c. Appears blue
  2. Cool star
    a. Temperature less than 3000 K
    b. Emits longer-wavelength light
    c. Appears red
  3. Between 5000 and 6000 K
    a. Stars appear yellow
    b. e.g., Sun

D. Binary stars and stellar mass
  1. Binary stars
    a. Two stars orbiting one another
      1. Stars are held together by mutual gravitation
      2. Both orbit around a common center of mass
    b. Visual binaries are resolved telescopically
    c. More than 50% of the stars in the universe are binary stars
    d. Used to determine stellar mass
  2. Stellar mass
    a. Determined using binary stars – the center of mass is closest to the most massive star
    b. Mass of most stars is between one-tenth and fifty times the mass of the Sun

II. Hertzsprung-Russell diagram

A. Shows the relation between stellar
  1. Brightness (absolute magnitude) and
  2. Temperature

B. Diagram is made by plotting (graphing) each star's
  1. Luminosity (brightness) and
  2. Temperature

C. Parts of an H-R diagram
  1. Main-sequence stars
    a. 90% of all stars
    b. Band through the center of the H-R diagram
    c. Sun is in the main-sequence
  2. Giants (or red giants)
    a. Very luminous
    b. Large
    c. Upper-right on the H-R diagram
    d. Very large giants are called supergiants
    e. Only a few percent of all stars
  3. White dwarfs
    a. Fainter than main-sequence stars
    b. Small (approximate the size of Earth)
    c. Lower-central area on the H-R diagram
    d. Not all are white in color
    e. Perhaps 10% of all stars

D. Used to study stellar evolution

III. Variable stars
A. Stars that fluctuate in brightness
B. Types of variable stars
1. Pulsating variables
a. Fluctuate regularly in brightness
b. Expand and contract in size
2. Eruptive variables
a. Explosive event
b. Sudden brightening
c. Called a nova

IV. Interstellar matter
A. Between the stars is "the vacuum of space"
B. Nebula
1. Cloud of dust and gases
2. Two major types of nebulae
a. Bright nebula
1. Glows if it close to a very hot star
2. Two types of bright nebulae
a. Emission nebula
1. Largely hydrogen
2. Absorb ultraviolet radiation
3. Emit visible light
b. Reflection nebula
1. Reflect the light of nearby stars
2. Composed of interstellar dust
b. Dark nebula
1. Not close to any bright star
2. Appear dark
3. Contains the material that forms stars and planets

V. Stellar evolution
A. Stars exist because of gravity
B. Two opposing forces in a star are
1. Gravity – contracts
2. Thermal nuclear energy – expands
C. Stages
1. Birth
a. In dark, cool, interstellar clouds
b. Gravity contracts the cloud
c. Temperature rises
d. Radiates long-wavelength (red) light
e. Becomes a protostar
2. Protostar
a. Gravitational contraction of gaseous cloud continues
b. Core reaches 10 million K
c. Hydrogen nuclei fuse
1. Become helium nuclei
2. Process is called hydrogen burning

        d. Energy is released
        e. Outward pressure increases
        f. Outward pressure balanced by gravity pulling in
        g. Star becomes a stable main-sequence star
    3. Main-sequence stage
        a. Stars age at different rates
            1. Massive stars use fuel faster and exist for only a few million year
            2. Small stars use fuel slowly and exist for perhaps hundreds of billions of years
        b. 90% of a star's life is in the main-sequence
    4. Red giant stage
        a. Hydrogen burning migrates outward
        b. Star's outer envelope expands
            1. Surface cools
            2. Surface becomes red
        c. Core is collapsing as helium is converted to carbon
        d. Eventually all nuclear fuel is used
        e. Gravity squeezes the star
    5. Burnout and death
        a. Final stage depends on mass
        b. Possibilities
            1. Low-mass star
                a. 0.5 solar mass
                b. Red giant collapses
                c. Becomes a white dwarf
            2. Medium-mass star
                a. Between 0.5 and 3 solar masses
                b. Red giant collapses
                c. Planetary nebula forms
                    1. Cloud of gas
                    2. Outer layer of the star
                d. Becomes a white dwarf
            3. Massive star
                a. Over 3 solar masses
                b. Short life span
                c. Terminates in a brilliant explosion called a supernova
                d. Interior condenses
                e. May produce a hot, dense object that is either a
                    1. Neutron star (from a massive star) or a
                    2. Black hole (from a very massive star)
D. H-R diagrams are used to study stellar evolution

VI. Stellar remnants

A. White dwarf
    1. Small (some no larger than Earth)
    2. Dense
        a. Can be more massive than the Sun
        b. Spoonful weighs several tons
        c. Atoms take up less space
            1. Electrons displaced inward
            2. Called degenerate matter
    3. Hot surface
    4. Cools to become a black dwarf

B. Neutron star
  1. Forms from a more massive star
     a. Star has more gravity
     b. Squeezes itself smaller
  2. Remnant of a supernova
  3. Gravitational force collapses atoms
     a. Electrons combine with protons to produce neutrons
     b. Small size
  4. Pea size sample
     a. Weighs 100 million tons
     b. Same density as an atomic nucleus
  5. Strong magnetic field
  6. First one discovered in early 1970s
     a. Pulsar (pulsating radio source)
     b. Found in the Crab nebula (remnant of an A.D. 1054 supernova)

C. Black hole
  1. More dense than a neutron star
  2. Intense surface gravity lets no light escape
  3. As matter is pulled into it
     a. Becomes very hot
     b. Emits x-rays
  4. Likely candidate is Cygnus X-1, a strong x-ray source

VII. Galaxies

A. Milky Way galaxy
  1. Structure
     a. Determined by using radio telescopes
     b. Large spiral galaxy
        1. About 100,000 light-years wide
        2. Thickness at the galactic nucleus is about 10,000 light-years
     c. Three spiral arms of stars
     d. Sun is 30,000 light-years from the center
  2. Rotation
     a. Around the galactic nucleus
     b. Outermost stars move the slowest
     c. Sun rotates around the galactic nucleus once about every 200 million years
  3. Halo surrounds the galactic disk
     a. Spherical
     b. Very tenuous gas
     c. Numerous globular clusters

B. Other galaxies
  1. Existence was first proposed in mid-1700s by Immanuel Kant
  2. Four basic types of galaxies
     a. Spiral galaxy
        1. Arms extending from nucleus
        2. About 30% of all galaxies
        3. Large diameter of 20,000 to 125,000 light years
        4. Contains both young and old stars
        5. e.g., Milky Way
     b. Barred spiral galaxy
        1. Stars arranged in the shape of a bar

2. Generally quite large
3. About 10% of all galaxies

c. Elliptical galaxy
1. Ellipsoidal shape
2. About 60% of all galaxies
3. Most are smaller than spiral galaxies; however, they are also the largest known galaxies

d. Irregular galaxy
1. Lacks symmetry
2. About 10% of all galaxies
3. Contains mostly young stars
4. e.g., Magellanic Clouds

C. Galactic cluster
1. Group of galaxies
2. Some contain thousands of galaxies
3. Local Group
a. Our own group of galaxies
b. Contains at least 28 galaxies
4. Supercluster
a. Huge swarm of galaxies
b. May be the largest entity in the universe

VIII. Red shifts

A. Doppler effect
1. Change in the wavelength of light emitted by an object due to its motion
a. Movement away stretches the wavelength
1. Longer wavelength
2. Light appears redder
b. Movement toward “squeezes” the wavelength
1. Shorter wavelength
2. Light shifted toward the blue
2. Amount of the Doppler shift indicates the rate of movement
a. Large Doppler shift indicates a high velocity
b. Small Doppler shift indicates a lower velocity

B. Expanding universe
1. Most galaxies exhibit a red Doppler shift
a. Moving away
b. Far galaxies
1. Exhibit the greatest shift
2. Greater velocity
2. Discovered in 1929 by Edwin Hubble
3. Hubble's Law – the recessional speed of galaxies is proportional to their distance
4. Accounts for red shifts

IX. Big Bang theory

A. Accounts for galaxies moving away from us

B. Universe was once confined to a "ball" that was
1. Supermassive
2. Dense
3. Hot

C. Big Bang marks the inception of the universe

1. Occurred about 15 billion years ago
2. All matter and space was created

D. Matter is moving outward

E. Fate of the universe

1. Two possibilities
    a. Universe will last forever
    b. Outward expansion sill stop and gravitational; contraction will follow
2. Final fate depends on the average density of the universe
    a. If the density is more than the critical density, then the universe would contract
    b. Current estimates point to less then the critical density and predict an ever-expanding, or open, universe