I. MINOR MEMBERS OF THE SOLAR SYSTEM

A. Dwarf planets

1. Pluto!!—a dwarf planet: designated 2006
   a. Discovered in 1930, misnamed as a planet
   b. Not visible with the unaided eye—smaller than Moon, Triton, Titan, and Galilean moons
   c. Highly elongated orbit causes it to occasionally travel inside the orbit of Neptune, where it resided from 1979 thru February 1999
      1) orbits do not cross, so they will not hit one another
      2) Pluto's orbit is inclined to plane of the ecliptic about 17^o
      3) axis tilts over 120^o to plane of the ecliptic
   d. Moon (Charon) discovered in 1978—
      1) over half diameter of Pluto
      2) orbit of Charon is at high angle to plane of the ecliptic
      3) mutually synchronous orbits—same sides of each always face one another
      4) Charon is mostly ices, formed independently from Pluto
   e. Average temperature is -210˚C—icy surface of N_2 (98%), methane and CO_2
   f. Is it largest object of Kuiper Belt, comet, large asteroid?
2. Ceres—largest object in the asteroid belt
3. Eris (formerly known as Xena)
   a. Discovered in 2003
   b. Larger than Pluto, with a more eccentric orbit
   c. Nearly 100 times as far from Sun as Earth is

B. Asteroids

1. Most between Mars/Jupiter; some in Jupiter's orbit, or 'Near Earth'
2. Small bodies – largest (Ceres) is about 620 miles in diameter—discovered in 1801
3. Some have very eccentric orbits—those not in asteroid belt
4. Irregular shapes—
5. Composition
   a. 75% carbonaceous chondrite
   b. 17% nickel-iron silicate
   c. most others nickel-iron
6. Origin is uncertain—total mass is 1/2 of Moon
7. Many of the recent impacts on Moon and Earth were asteroids—
   a. Meteor Crater—
      1) 20,000 to 50,000 years ago
      2) 10 meter diameter
   b. Tunguska event—1908
      1) large explosion above Siberia of 60 m asteroid
      2) no surface crater ever found
      3) what if it was made of methane ice?

c. Near Misses
   1) in 2004 with 30 meter asteroid (43,000 km from surface)
   2) in 2002 with 70 m 461000 km (1.2 x Moon’s diatance)
   3) Asclepius March 29, 1989, 1000 m, 400,000 km (passed where Earth was 6 hours earlier

C. Comets
1. Often compared to large, "dirty snowballs"
2. Composition
   a. Frozen gases—ices of water, ammonia, methane, CO_2, CO
   b. Rocky and metallic materials—cemented by the ices
3. Frozen gases vaporize when near the Sun
   a. Produces a glowing head called the coma ~ Jupiter diameter, with tiny nucleus inside
   b. Some may develop a tail that points away from Sun due to
      1) Radiation pressure on dust
      2) Solar wind pressure on ionized gases
      3) this material is lost from comet forever, reduced in size
   c. gases recondense upon leaving Sun, so no longer spectacular
4. Origin Not well known—form at great distance from Sun
   a. Short-period comets < 200 years
      1) Probably from Kuiper belt beyond Neptune
         a) fairly circular orbits—close to plane of other planets
         b) occasional collisions, perhaps perturbed orbits due to gravity of gas giants, throw Kuiper belt objects into eccentric orbits that pass close to Sun
      2) Most famous short-period comet is Halley's comet
         a) 76 year orbital period
            i. tail 1 million miles long,
            ii. could be seen in daytime 1910
         b) Potato-shaped nucleus (16 km by 8 km)—fizzing, cratered per “Giotto” probe in 1986
      3) Hale-Bopp in 1997—spectacular!
         a) had twin tail 1/5 of night sky—15 million miles long
         b) 40 km diameter nucleus
   b. Long-period comets
      1) period perhaps > 100,000 years
      2) may originate in Oort Cloud
         a) hypothetical region containing a combined mass of objects greater thanmass of Jupiter beyond Kuiper Belt
         b) in spherical shell around solar system

D. Meteoroids
   1. Called meteors when they enter Earth's atmosphere—"shooting star"
   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—most commonly found
            a) Mostly iron, 5-20% nickel
            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—4.5 billion years
         2) Stony—most common type
            a) Silicate minerals with
            b) Inclusions of other minerals
         3) Stony-irons – mixtures
         4) Carbonaceous chondrites—Rare
            a) Simple amino acids
            b) Other organic material
      b. Meteor crater
         1) 1.2 km across, 170 m deep
         2) Significant amount of iron debris surrounding the crater
      c. Manicouagan, Quebec structure is 200 million years old
      d. Shoemaker-Levy 9 collision with Jupiter
   4. origins of meteoroids
      a. interplanetary debris not swept up on accretion of planetary bodies
      b. displaced objects from asteroid belt
      c. remains of disintegrated comets

II. Vibrations and waves
   A. Wiggle in time is a vibration—needs elapsed time to occur
   B. Wave is created by vibration—exists over space and time
   C. Types
      1. Sound wave—needs medium to traverse through
      2. Light wave—can traverse vacuum
   D. Periodic or not, depending if repeating or not
   E. Pendulum vibrates through period—length of time to go a full cycle
      1. period depends on length of pendulum, not size of arc or mass
      2. harmonic motion describes a sine curve

III. parts of a wave
   A. crest and trough—maximum distance from midpoint
   B. amplitude—displacement from midpoint
   C. wavelength—from one place on wave to same place on next
   D. period—length of time for one wave to pass
   E. frequency—how many in a given time interval

        1. usually per second—Hertz
        2. inverse of period (in seconds)

IV. Wave motion
    A. Rope shaken up and down
    B. Pebble dropped into still water
    C. Particles return to initial location—like grass blowing in wind

V. Wave speed
    A. Speed is distance per unit of time
    B. Need wavelength, and period (time to pass)
    C. Wave speed = wave length / period
        1. frequency = 1 / period so
        2. wave speed = wave length x frequency (also)

VI. Wave types
    A. Transverse wave
        1. movement of particles across direction of travel
        2. rope shaken at one end
        3. cannot travel through fluids
        4. examples—
            a. ripples, vibrating string (guitar, piano), light
            b. tone, color of light depends on wavelength
    B. longitudinal wave
        1. movement in direction of wave propagation
        2. slinky spring is a longitudinal wave
            a. alternation of expansion and compression of medium
            b. can travel through fluids
        3. examples—sound, primary earthquake waves: wavelength controls tone of sound

VII. Doppler Effect
    A. Wavelength, period, frequency measured at fixed point from fixed wave source has no ‘Doppler effect’
    B. Movement of source or observation point has an **apparent** effect on the speed, size, etc. of wave
        1. moving source would compress or elongate wavelength, and change apparent frequency and period of the wave
            a. toward observation—compress, shorten period, increase frequency
            b. away from observation—elongate wavelength, increase period, decrease frequency
            c. moving observer has similar effect on the apparent parameters of the wave
        2. since perception of wave depends on its wavelength, Doppler effect changes perception of wave
            a. sound converging is higher pitch, retreating lower
            b. light converging is bluer, retreating is more red
                1) can calculate divergence of distant galaxies
                2) can calculate spin velocity of star
        3. sonic boom function of source moving faster than wave

VIII. Light

A. Electromagnetic radiation—vibration of electrons
   1. behaves like both waves and particles, in different measuring regimes
   2. from radio waves (long wavelength) to gamma rays (short)
   3. includes visible spectrum
      a. wavelengths measured in billionths of meters (nanometers) or 100 millionths of meters (angstroms)
      b. shine white light through prism, it bends and separates into separate wavelengths
         1) spectrum from red to violet—ROYGBIV
         2) shorter wavelengths in violet, longer in red
         3) constant speed penetrating any particular medium
            a) shorter wavelengths, greater frequency
            b) longer wavelengths, lower frequency

B. Spectra
   1. continuous spectrum—created by incandescent material: pressured and heated to glowing
   2. dark line spectrum—white light passes through cool, low-pressure gas.
      a. This gas absorbs some of the wavelengths, dependent upon elements in the gas.
      b. Result is continuous spectrum with some dark lines missing.
      c. These wavelengths are diagnostic for elements in the gas—always the same ones for a particular gas
   3. bright line spectrum—the same wavelengths are emitted when that gas is heated in a low-pressure environment as absorbed by that gas when white light is passed through it
   4. Spectroscope used to study spectra from light sources
      a. See light from violet (short wavelength) to red (long wavelength)
      b. In lab, report proper wavelength and units
         1) 400 nanometers (nm) = 4000 angstroms (Å)
         2) Put colors in order, at proper locations
   5. spectra of stars used to determine
      a. its composition—spectral signature of elements has lines in particular locations
      b. receding or approaching stars results in Doppler effect
         1) shifts the signature toward the red end when receding
         2) shifts the signature toward the blue end when approaching
         3) does NOT make light absolutely red or blue in most cases
      c. temperature of star also indicated by color
         1) hotter objects emit shorter wavelengths than cooler ones

IX. Astronomical tools
  A. Optical (visible-light) telescopes
    1. Two basic types—refracting and reflecting
      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) eyepiece is second lens to examine image directly
        5) Have color distortion defect: *chromatic aberration*
      b. Reflecting telescope
        1) Uses a concave mirror to gather the light
        2) Advantages
          a) No color distortion—does not have chromatic aberration
          b) Does not need to be optically clear
          c) Can be supported from the back
        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
    3. space telescopes, like Hubble, do not have interference of atmosphere
  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. History of radio astronomy
      a. James Maxwell
        1) 1860-70 summarized known electrical and magnetic phenomena in theoretical equations showing these to be aspects of the same force

        2) *"We can scarcely avoid the conclusion that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena." ~1862*
   b. Heinrich Hertz demonstrated existence of em radiation 1888
   c. Thomas Edison proposed experiment to detect em radiation from Sun in 1890—never explored
   d. Guglielmo Marconi—sensitive radio receiver in 1901
   e. Bell communications exploring transatlantic communications assigned Karl Jansky to determine cause of static
      1) Discovered radio frequency emitted from Milky Way--1933
      2) Bell dropped research because it did not interfere with communication
   f. Grote Reber
      1) Built dish radio antenna in 1937 in his back yard
      2) Published galactic map of radio emissions in Milky Way—1949

4. Radio wavelength 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) Detect material that does not emit visible radiation
         e) Can "see" through interstellar dust clouds
      6) A disadvantage: hindered by man-made radio interference
   c. Radio astronomy
      1) Best resolution from 1 to 20 cm
         a) Longer wavelengths filtered by ionosphere
         b) Shorter wavelengths subject to atmospheric interference
      2) Components
         a) Large radio antenna
         b) Sensitive radio receiver
      3) hotter objects emit more energy than cooler ones