GS104: The Earth in Context: Universe and Solar System

I. Astronomy

A. Astronomy- Study of the origin, evolution and composition of the universe, solar system and planetary bodies.

1. Cosmology: origin of the universe
2. Astrogeology: comparison of extra-terrestrial planetary bodies with Earth
3. Astrophysics: quantitative study of the physical nature of the universe

B. History of Astronomy

1. Early Thoughts (Greeks in 100-300 BC)
   a. Geocentric Universe - all stars revolve around the Earth
      (1) Earth = center of universe
   b. Heliocentric Solar System -
      (1) Earth Solar System = planets revolve around Sun

2. Catholic Church Influence on Astronomy
   a. Promoted Book of Genesis for Cosmology
   b. Promoted Geocentric Universe

3. Copernicus (1400's)
   a. Studied planetary and stellar motion
   b. supported heliocentric model
   c. Earth rotates on axis
   d. moon revolves around Earth

4. Kepler (1500-1600's)
   a. supported Copernican theory
   b. Kelpler's Laws (via observation)
      (1) the orbit of each planet is elliptical about Sun
      (2) Planets speed up closer to Sun, slow down farther away
      (3) the farther the planet from the Sun, the longer the orbital period (or "year")

5. Galileo and Newton (1500-1600's)

   a. Galileo's Telescope
      (1) planetary and stellar observations
      (2) looked at gravity and free-falling objects
   b. Newton - studied gravity

      (1) Law of Gravity - all objects in universe exert force of gravity

II. Structure of the Universe

A. Hierarchy of Bodies in the Universe

1. Earth's Solar System: portion of universe occupied by earth's sun and the nine planets of the solar system

a. Earth Facts: *Home!* Seemingly infinite in its size and abundance relative to our personal lives, our Earth however is merely an infinitesimal speck floating in the vastness of space, the buffer of life between us as individuals and the hostile vacuum of space.

b. Planets bound to orbit about the sun under the influence of gravitational attraction

(1) Planets = spheroids of rock, ice and/or gas; bound by gravitational attraction of a star / sun.

(2) Earth is rotating about its polar axis
(a) one rotation/24 hrs

(3) Earth is revolving around sun
(a) one revolution/365.25 days

(4) Moons or planetoid bodies of rock and/or frozen gas orbiting around planets under the influence of gravity (satellites)

(a) moon light: result of reflection of suns electromagnetic radiation

c. Earth's Solar System

(1) Inner Planets = "Terrestrial" = made of rocky material
(a) Mercury
(b) Venus
(c) Earth
(d) Mars

(2) Outer Planets = "Jovian" = made of frozen gases
(a) Jupiter
(b) Saturn
(c) Uranus
(d) Neptune
(e) Pluto

d. Sun = Star: accumulation of hydrogen and helium, spontaneously undergoing fusion, emitting electromagnetic radiation of varying wavelength.

(1) Sun's radiant energy responsible for warming planet, driving climate system, allowing life to exist on planet.

2. Universal Perspective

a. Earth's Sun: one of > 100 billion stars in the Galaxy Milky Way

(1) Galaxy: Accumulation of stars organized about a nucleus, bound by common larger scale gravitational point

(a) Milky Way Galaxy one of hundreds of billions of galaxies in the universe

(b) Interstellar matter: dust and gases between stars

(c) Globular Clusters: smaller accumulations of stars, less than scale of galaxy

(d) Nebula - diffuse clouds of gas and dust

"There are more stars than sand on all the beaches of the earth"

i) Universe: all of matter in space

3. Smaller Scale Bodies

a. Comets: mixture of ice and rock bound by the gravity of sun and solar system, at scale smaller than planets, orbiting sun

b. Asteroids of Solar System: solid rocky bodies orbiting a limited portion of solar system

(1) range in size from dust to >400 Mi in diameter

c. Meteroids: Millions of rocky or metallic bodies orbting free form in the solar system

(1) meteors: "falling stars" or meteroids that enter the earth's gravitational field, accelerate through atmosphere and burn through frictional heating

(a) meteorites: meteoritic material that reaches and impacts the surface of the earth

Increasing Order of Scale: Interstellar dust ---meteroids/asteroids/comets----moons-----planets----solar system----galaxy----galaxy clusters-----galaxy superclusters

III. Tools for the Astronomer: Spectroscopy

A. Nature of Light and Electromagnetic Radiation

1. Light and EM Radiation used to study the nature of the universe through optical and radio-telescopes

2. Electromagnetic Radiation: radiant energy emitted from stars/sun

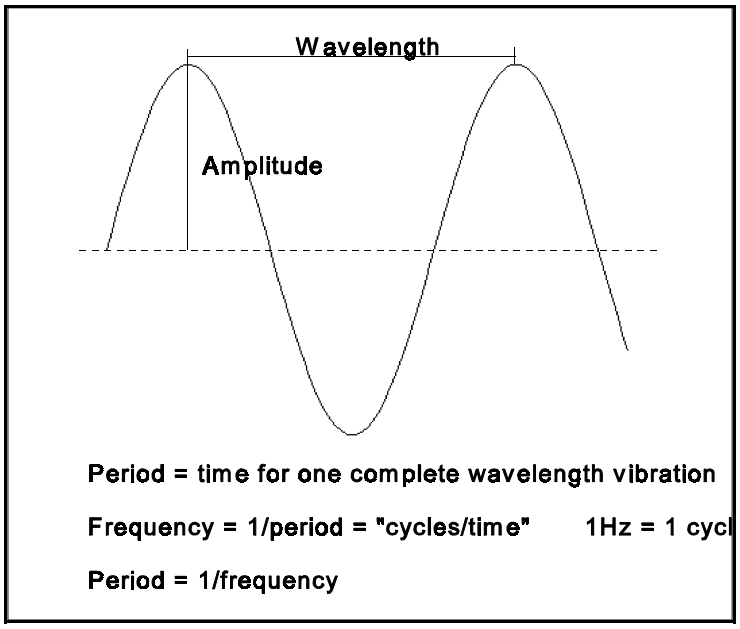
a. The type of radiation based on wavelength of waves

(1) gamma rays (short wavelength:1 x 10^{-9} cm)
(2) x rays (too short to see)
(3) ultraviolet
(4) visible light (detectable by eye)
(a) violet
(b) indigo
(c) blue
(d) green
(e) yellow
(f) orange
(g) red
(5) infrared (too long to see)
(6) radio waves (long wavelength: several km)

B. Wave Basics

1. Waves = Vibrational Energy
a. e.g. Light, Sound, Water, Radio Waves, the Electromagnetic Spectrum

2. Basic Form = "Sine Curve"



Remember to Show: Node Points - points of mimimum energy on the wave form (points at equilibrium)

a. Units of Frequency
   (1) Hz = cycles /sec
   (2) kHz = kiloHz = 1000 Hz = 1000 cycles/sec
   (3) MHz = MegaHz = 1000000 Hz = 1000000 cycles /sec

3. Wave Speed

   a. Wave Speed = wavelength x frequency = (λ)(f)

      (1) wave speed = how fast the front of the wave travels; linear velocity
      (2) wave frequency = rate of vibration

   b. Speed of Light and All Electromagnetic Radiation
      (1) constant = 3×10^8 m/sec = 3×10^5 km/sec

4. Nature of Visible Light

   a. Light as waves: some phenomena best explained as wave theory

      (1) White light: amalgamation of a number of wavelengths of light ROYGBIV from long to short)

         (a) eg. light passing through a prism or "crystal" is separated into component spectrum of wavelengths

   b. Light as particles: some phenomena best explained as particle theory

      (1) Photons: bundles of energy, analogous to microscopic bullets fired rapidly from machine gun.

      (2) Solar Wind: photons exert pressure on matter, analogous to wind/air flow

5. EM Radiation travels through vacuum of space in a straight line
   a. speed: 186,000 mi/sec = 300,000 km/sec = 26 billion km/day

6. Spectroscopy: study of wavelength properties of light: breaking light and electromagnetic radiation into its component wavelengths or "spectrum"

   a. spectroscope: telescope equipped with a prism: divides light from sun or stars into spectrum
      (1) "Dark-line" spectrum

         (a) produced when white light is passed through a gas under low pressure, the gas has a tendancy to absorb certain wavelengths of light, depending on which elements are involved

(b) results in spectrum of light showing up with dark lines in various positions of spectrum (absorbed wavelengths) depending upon the nature of the "gas filter".

(2) Most stars/sun show a dark line spectrum, coupled with laboratory experimentation, can identify the composition of the gas surrounding the hot core of the star or sun.

7. The Doppler Effect and Light

a. e.g. passing train: approaching sound has higher pitch, moving away the pitch sounds lower

b. also occurs with light waves (as well as sound waves)

(1) bodies moving away, waves have stretched or longer wavelenth
(a) stars moving away will display, dark line spectrum (i.e. the dark lines) will shift towards the red end of spectrum, longer wavelenths

(2) bodies moving towards, waves have shortened wavelenth
(a) stars moving towards will display dark lines shifting towards the blue end of the spectrum, shorter wavelengths

(3) spectral examination of stars over time allow detection of shifting lines
(a) "Red Shift" stars = moving away from earth
(b) "Blue Shift" stars = moving towards earth

IV. STARS

A. Stars: accumulations of dominantly Hydrogen and Helium, with hydrogen undergoing spontaneous fusion of atoms, result in heat and emission of electromagnetic radiation

1. Types of Stars

a. Binary Stars: pairs of stars that occur in close proximity
(1) typically smaller and larger stars which orbit one abother under gravity
(2) ~50% of stars in universe occur in pairs or multiples
(3) orbits result in variations of intensity emitted from star complex with time

b. Stars classified on basis of brightness and temperature (classified according to Hertzsprung-Russell diagram)

(1) Main Sequence Stars: e.g. contains our sun

(a) hottest stars = brightest = most massive
(b) coolest stars = dimest = least massive

(2) Giants or Red Giants: very large stars much more massive that sun, very bright (100 x larger than sun)

(3) Supergiants: 800 times larger than sun, very luminous

(4) White Dwarfs: smaller, less bright class of stars, much smaller than sun, most on size order of earth

c. Variable Stars: stars that fluctuate in intensity or brightness

(1) expand and contract in size over time

(2) Eruptive Variables: periodic explosive events on star that emits high energy radiation

(a) Nova: sudden brightness increase in star, decreases over time and returns to normal brightness with small amount of overall mass loss (nova brightness = x10)

(b) Supernova: cataclysmic explosion of star, millions of times increase in brightness, with massive loss of mass, thought to represent final stages of stars fuel

d. Unusual Stars:

(1) Dwarfs: = "collapsed stars": extremely small stars with very great densities, on size scale of earth (density on order of million times denser than water, spoonful = several tons)

(a) to attain such high density, atoms must be compressed with electrons collapsed about nucleus

(b) smallest white dwarfs = most massive, results from large gravitation field, resulting in collaps of star and nuclear compression into very small body
i) i.e. the more mass the more gravity the more compression

(2) Neutron Stars: = "extremely collapsed stars"
(a) variation on dwarf, except when very large stars collapse and compress, gravitation force of compression is so great that electrons are drawn into the nucleus of atom, combining with p+ to form neutrons, hence the name "neutron star"

(b) Pulsars = rapidly rotating neutron stars that emit characteristic pulsating radio waves

(3) Black Holes: very large stars collapse into very small- dense stars

(a) force of gravitation is so great: even though stars are very hot, gravity would not allow even light from leaving the mass

(b) very high F of gravity, any body coming close would be attracted and devoured

(c) i.d. of black holes based on observations of tales of gas being pulled into area of space from larger red giants

i) "stellar theft" : gravitational pull of gases / matter by black hole

B. Life Cycle of Stars and Stellar Evolution

1. Intitial: Nebula- cloud of atomic dust and gases (up to several light years thick)

a. comprised largely of hydrogen (92%) with lesser amount of helium (7%)

b. Nebular Collapse: gravitational collapse of cloud under force of gravity, nebula increases in density and begins to rotate

2. Dust and gases self-accumulate under gravity to form protostar

a. protostar = large-diameter, diffuse accumulation, red poorly developed star

b. hydrogen fusion reaction takes place

(1) hydrogen converted to helium (hydrogen = fuel)

(2) temperatures increase, EM radiation begins to emit from star

(3) Protostar unstable/pulsating gravitational and fusion processes

3. Main sequence star or yellow star like sun: protostar stabilizes to equilibrium (operating temperature of sun @ 6000 K surface temperature)

a. Much of the life of the star is spent as a main sequence star

4. As hydrogen is converted to helium (100's of millions to billions of years), at approximately 60% of Hydrogen fused---instability

a. Yellow star ---- Red Giant, star expands in size

(1) Red Giants on order of 10 Astronomical Units

(2) Interior of star collapses with expanding outer layers

5. Gravitational collapse begins to occur

a. Red Giant ---- variable stage (expansion and contraction)
b. Variable Giant ---- contracts to white star (under gravitation contraction)
c. White star to Planetary Nebula Stage

(1) Planetary Nebula = white dwarf emitting/ losing mass, forms ring of gaseous material about dwarf

d. Further collapse and increase in density to white dwarf

e. Eventually, gravitational collapse to black hole

6. Instaneous Death of "High-Mass" Stars = Super Nova
a. Extreme gravitational collapse and explosion

V. Scales of the Universe

A. Astronomical Measurement and Study of Universe
1. Distance

a. Light-year: distance light travels in one earth year, @ the speed of light
(1) c = 186,000 mi/sec = 6 x 10^{12} miles (6 trillion mi)

b. Parsec = 3.26 light years

c. Astronomical Units = reference distance of that from earth to sun = 93 x 10^{6} mi

2. Measuring Motion of Stars

a. Doppler effect: apparent changes in wavelengths of light spectrum, applicable relative to radial motion (moving away or towards)

(1) Red Shift Stars (moving away)
(2) Blue Shift Stars (moving Towards)

b. Parallax: apparent change of position of an object that results from change in perspective of viewer
(1) e.g. holding finger up, alternately closing left and right eye

(2) Measuring apparent positions of stars at various times of year in earth's orbit around sun can provide trigonometric solution to distance

(3) Apparent motion of stars (as earth revolves around sun)

(a) Plane of ecliptic = Path of orbit of earth around sun
(b) lying perpendicular to plane of ecliptic = circular
(c) lying within plane of ecliptic = straight line
(d) lying at oblique angle to plane of ecliptic = ellipse

i) Applicable to only ~ 700 of the closest stars that can be reasonably measured

c. Magnitude: relative brightness of stars
(1) the more distant the star, the less apparent brightness
(2) the closer the star the more apparent brightness

(a) relative scale: the dimmer the magnitude: the more positive the number (i.e. more distant the star

i) scale reference = distant bright stars Aldebaran and Altair

ii) Brighter Stars = Lower Magnitudes

(b) brightness of star related to chemical reactions on star, degree of heat, and emission of electromagnetic radiation

(c) Absolute magnitude: brightness of star if it were located 10 parsecs away

	Apparent Magnitude	Distance (lt-yr)
Our sun	-26.5	1/62,365
Sirius	-1.58	8.7
Vega	0.14	26.5
Aldebaran	1.06	68
Polaris	2.12	680

(3) Variable Magnitude: some stars emit pulsing magnitudes of light

(a) stars expand and contract in size at certain periodicity
i) results in shifting frequences of radiation

(b) Formula for calculating star distance

i) M = m+5-(5logd); M = absolute brightness, m = apparent brightness, d = distance

VI. **Earth Solar System**

A. Solar System: comprised of sun + 9 planets

1. 99.85% of mass of solar system contained in sun
   a. Planets comprised of remaining 0.15%

2. Planets (in order from sun): Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto

   a. Eliptical paths of orbit
   b. Counterclockwise direction

      (1) Earth year = 365 earth days
      (2) Mercury year = 88 earth days
      (3) Pluto year = 248 earth years

   c. Terrestrial Planets
      (1) Mercury, Venus, Earth, Mars
         (a) rocky framework, silicate rocks and metals
         (b) small in diameter compared to outer planets
         (c) higher densities: 5x D of water
         (d) relatively thin atmospheres
         (e) small diameters: lower gravitational force

            i) small body like moon, does not have enough gravity to hold atmospheric gases

   d. Jovian Planets
      (1) Jupiter, Saturn, Uranus, and Neptune
         (a) Very large Diameter planets
         (b) lower densities: 1.5 x D of water
         (c) composed of gases (Hydrogen and helium) and frozen ices (ammonia, water and methane)
         (d) relatively thick atmospheres
         (e) larger diameters: higher gravitational force

   e. Pluto: in class of its own, due to small size at outermost edge of solar system

3. Basic Planetary Structure
   a. Core - innermost zone of planet
   b. Mantle - zone surrounding core
   c. Crust - outermost layer of planet, at surface boundary

B. Planetary Inventory
   1. Mercury: innermost planet
      a. small diameter (4878 km)

b. no atmosphere
c. similar in appearance to moon
(1) extensively cratered surface
d. temp range: -173 c to 427 c
e. Mercury year: 88 earth days

2. Venus: "veiled planet"
a. very high reflective planet, very bright
b. year: 225 days
c. similar in size to diameter of earth
d. planet shrouded with thick cloud cover
e. atmosphere: 97% carbon dioxide
(1) dramatic greenhouse effect
(a) temp: up to 480 degrees C

(2) Carbon dioxide derived from volcanic eruptions

(earth has high oxygen and low carbon dioxide environment because of plant life and photosynthesis)

3. Mars: "the red planet"
a. most readily observable planet from earth
b. Atmosphere composed primarily of carbon dioxide
c. Polar ice caps: temps down to -125 degrees C
(1) ice caps: made of water vapor and carbon dioxide

d. atmosphere is very thin, with high wind speeds up to several hundred miles per hour common

e. Landscape similar to rocky desert of earth
(1) impact craters
(2) windblown dust covers
(3) single isolated, very large shield volcanoes
(4) Very large canyons present, 6 km deep and 160 km wide
(a) thought associated with rifting processes

(5) Presence of "stream-like" erosion valleys
(a) suggests past climate capable of supporting water cycle

f. Mars possesses two "moons" or satellites
(1) irregular rocky masses with impact craters
(2) probably captured asteroids

4. Jupiter: "Lord of the Heavens"

a. largest planet in solar system
(1) 2.5 x larger than mass of all remaining planets, satellites, and asteroids
(2) however only 1/800 as massive as Sun

b. Very high and intense gravitational field
c. Very fast rotation: l daily rotation in 10 hrs earth time
(1) rapid rotation + centrifugal force results in equatorial bulge and polar flattening

d. Jupiter characterized by alternating color bands on surface

(1) with giant red spot visible
(a) variable expanding/contracting in size
(b) thought to be caused by cyclonic storm in atmosphere

e. Atmosphere: mainly hydrogen and helium, with lesser amounts of methane, ammonia, water and sulfer

f. Jupiter internal heat engine drives atmospheric circulation (as opposed to earth's atmosphere driven by sun)

(1) atmospheric color bands associated with convection

g. Moons of Jupiter:
(1) contains at least 16 orbiting satellites
(a) moons very large on scale of planets
(b) gravitational attraction of floating debris of solar system
(c) Moons generally cratered

i) Io, a moon of Jupiter, has known active volcanism similar to earth

5. Saturn: "The elegant planet"
a. Saturn year = 29.5 earth years
b. atmosphere, compositin similar to Jupiter
c. Rings of Saturn
(1) concentric bands (A, B, and C rings)
(2) composed of ice-covered debris (failed moon systems)
(3) no more than rew hundred meters thick, however 200,000 km wide
d. Saturn Moons: up to 17 known bodies

6. Uranus and Neptune: "The twins"
a. similar in size
b. methane-based atmospheres with pale greenis-blue appearance
c. Uranus
(1) pole of rotation tipped to only 8 degrees from plane of orbit around sun
(a) i.e. rotation has a rolling appearance

(2) In 1977, discovered that Uranus has ring system similar to Saturn
(3) up to 15 moons recognized

d. Neptune
(1) atmosphere composed of hydrogen, helium and methane
(a) dynamic atmosphere with winds up to 1000 km/hr

(2) Bluish appearance
(3) 8 known satellites/moons
(a) Titon: large moon
i) lowest temp. of any body in solar system (-391 degree F)
ii) composed of frozen water, nitrogen and methane

(4) atmospheric rings also encircle the planet

7. Pluto:
a. lies on outermost fringe of solar system (40 x farther from sun than earth)
b. Pluto year = 248 earth years
(1) highly eccentric/elongated orbit

(2) periodically inside orbit of Neptune

c. Thought to be smallest planet in solar system
d. Avg. Temp = -210 degrees C
e. composed of frozen gases and minor rocky substances
f. has been proposed that Pluto was once a satellite or moon of Neptune, that has since broken loose into it's own orbital path
g. very little is known about Pluto, due to its great distance from earth.

VII. The Earth and Lunar Cycles

A. Earth's Moon

a. D = 3484 km = 2160 mi
(1) mass = 1/81 of earth
(2) ~236,000 mi from earth

b. Gravitational force of moon = 1/6 of that of earth

(1) e.g. 150 lb person on earth = 25 lb on moon
(2) F of gravity so weak, moon not capable of sustaining an atmosphere

c. Moon orbits earth in an elliptical orbit
(1) Perigee = closest point of passage
(2) Apogee = farthest point of passage

d. Lunar orbital month = "synodic" month
(1) one orbit around earth = 29.5 earth days
(2) moon orbits on its axis 1/29.5 days

(a) hence observers from earth constantly see one side of the moon (leaving an unobserved "dark side of the moon")

e. Phases of the moon

(1) The relative appearance of reflected light from the moon at various positions of moons rotation and orbital revolution

(a) New Moon: sunlit side of moon facing away from earth

i) moon in line between earth and sun

(b) Full Moon: sunlit side of moon facing towards earth

(c) Waxing and Waning of moon

i) Waxing moon = new moon to full

a) Crescent Moon = first crescent appearance of moon after new moon

b) First quarter moon = "half moon"

c) Gibbous moon = 3/4 moon

d) Full moon

ii) Waning moon = full to new moon

a) Gibbous Moon

b) Third Quarter Moon

c) Crescent Moon

d) New Moon

f. Solar and Lunar eclipse

(1) solar eclipse: moons position between sun and earth, moons shadown blocks out light to earth

(2) Lunar eclipse: earth's position between sun and moon, earth's shadow blocks out light to moon

VIII. EARTH-SUN RELATIONSHIPS

A. General

1. The earth's dependence on the sun for solar energy is essential for all life, drives biosphere, atmosphere, and hydrosphere.

2. Movements of the Earth: Rotation vs. Revolution

a. Rotation- the earth rotates on its axis from west to east (counter clockwise direction viewed from top), complete revolution of 360 ^{o} every 24 hrs.

(1) Since the earth spins from west to east, the moon and sun and stars appear to relatively move (rising and setting) in the opposite sense:

east to west.

(2) Speed of rotation of the earth is greatest at the equator and decreases to 0 at the poles, function of revolving different diameters about a pole.

b. Effects of the Rotation of the earth

(1) Constancy of the earth's rotation results in coriolis effect in which the flow of air and water on the earth's surface is deflected by the centrifugal forces

(2) rotation brings varying portions of the earth into increasing and decreasing gravitational fields relative to the moon and sun, thus driving diurnal tidal fluctuations

(3) rotation results in diurnal variation of lightness and darkness, as the earth turns relative to the position of the sun

c. Revolution Around the Sun: earth revolves around the sun in a similar west to east rotation, once every 365.25 days (known as the tropical year)

(1) The path of the earth's orbit around the sun is not a circle but an ellipse with varying radius of orbit.

(2) Perihelion- position on January 3, the earth = 91,445,00 miles from the sun

(3) aphelion - position on July 4, the earth = 94,555,000 miles (farthest from the sun in our summer).

Perihelion and aphelion are oriented at 180^{o} to one another: do not so significant effects on seasonal temperature variation.

B. Season Temperature/Weather/Insolation Changes

1. Plane of the ecliptic- the plane the passes through the sun and earth, enscribing the orbital path of the earth around the sun.

2. The axis of the earth and the plane of the equator is tilted approximately 23.5^{o} with respect to the plane of the ecliptic (i.e. polar axis is not perpendicular to the plane of the ecliptic).

a. The axis of the earth is always parallel to itself, pointing at all seasons of the year towards polaris the north star..

b. The rotation, revolution, and tilt of the earths axis is such that the amount of insolation or energy the hits the earth is at different angles throught the year of revolution.

THE MORE DIRECT THE STRIKE OF THE SUN'S RAYS, THE EFFECTIVE IS THE HEATING OF THE EARTH'S SURFACE

THE MORE OBLIQUE THE STRIKE OF THE SUN'S RAYS, THE MORE DIFFUSED THE ENERGY IS OVER A LARGER LAND SURFACE.

3. Latitudinal changes in insolation with seasons

a. SUMMER SOLISTICE: NORTHERN HEMISPHERE

(1) Tropic of Cancer- 23.5^{o} north latitude, marks the northernmost location reached by the vertical/direct rays of the sun in annual revolution pattern (occurs on the summer solistice in the northern hemisphere, June 21)

(2) At solistice, all points lying north of the Arctic Circle (66.5^{o} N.) are placed within the circle of illumination for 24 hours continuously

(3) At northern solistice, all points south of the anarctic circle (66.5^{o} S) are placed in continual darkness, outside the circle of illumination

b. WINTER SOLISTICE: NORTHERN HEMISPHERE

(1) Tropic of Capricorn- 23.5^{o} S. latitude, marks the southernmost location reached by the vertical/direct rays of the sun in annual revolution pattern (occurs on Dec. 21, more or less).

(2) At winter solistice, all points lying south of the Antarctic Circle lay continually within the circle of illumination, whereas, points north of Arctic circle lay within continual darkness.

c. EQUINOXES: (spring March 20, and fall: sept. 22)

(1) The perpendicular rays of the sun strike the equator

(2) The circle of illumination just touches both poles

(3) The periods of daylight and darkness are each 12 hours long all over the earth

(4) equinoxes represent midpoints in the shifting of direct rays of the sun between the Tropic of Cancer and the Tropic of Capricorn

IX. **MODEL FOR ORIGIN OF UNIVERSE AND SOLAR SYSTEM**

A. Observations

1. Universe is presently expanding

   a. as evidenced by red shift stars and galaxies
   b. thought that all galaxies and entire universe is expanding

B. Model for the Universe: Bang Theory
   1. >20 B.y. ago: incipient universe: a giant ball of superheated matter
      a. superheated matter = plasma
         (1) very hot atoms, heat does not allow atoms to form

   2. 20 B.Y. ago = cataclysmic explosion occurred
      a. Rapid expansion and cooling of plasma
         (1) rapid temperature decrease
            (a) formation of atomic particles and atoms (neutrinos, electrons, protons and neutrons)

         (2) Subatomic particles coalesce to form atoms and matter
            (a) Molecules and compounds formed

   3. Ejected masses of gases cooled and condensed, forming the stellar/star systems

C. Model for the Solar System
   1. Nebular Hypothesis: all bodies of earth's solar system formed from an enormous nebular cloud consisting of 80% H, 15% He, and few % of other heavier elements
      a. viewed as frozen cloud of dust and gases
      b. Heavier substances
         (1) silicon, aluminum, iron, calcium (rock forming elements)
         (2) oxygen, carbon, and nitrogen

   2. 5 B.Y. Ago: contraction of nebular cloud of rock and gases under force of gravity
      a. contracting cloud began to rotate
      b. contraction and rotational speed >
         (1) formation of disk-like shape

      c. Greatest gravitational contraction accumulated most mass to form protosun in center

   3. Heating of protosun in central portion of mass

   4. Accumulation of heavier masses of rocky material to form 4 inner planets or terrestrial planets
      a. Planetesimals: small bodies to accumulate into protoplanets

      b. debris collision and amalgamation into planet-like bodies (protoplanets)
         (1) early planet life one of large-scale collisions and accumulation

c. radioactive decay on interior of planets resulted in internal melting and lithospheric segregation
(1) gases segregated to form atmosphere

5. Accumulation of frozen gases at distance from sun to form outer "Jovian" planets

a. composed of water, carbon dioxide, ammonia and methane

b. largest planets (Jupiter and Saturn) had highest gravitational force, attracted hydrogen and helium to atmospheres
(1) Loose cosmic material unable to form planets, attracted by gravitation to form moons/satellites.

D. Recent Models on Planetary Formation (Cold Matter Models: Collision-Accumulation)

1. Aggregation of solid matter into spheres via gravity-collision
a. planetesimals - baby planet snow balls
b. planets - larger, evolved spheres
(1) Oxide Compounds = denser rocky planets
(2) Water = ice fragments
c. Solar Gravity Sorting Arranged Planets into Ecliptic Orbits
d. Gravity = drives collisions / orbital configurations
e. Moons = runaway planet balls, trapped in orbit

2. Timing of Planet Formation
a. Meteors - remnant space debris left over from planet formation
(1) Ages of Meteorites
(a) Consistent: ~4.5 Billion Years
i) based on radiometric dating
b. Total Time for Planet Formation ~100,000 million years
(1) Earth-size Planet = ~ 1 M.Y. to form
(2) chaotic collisions of space debris
(a) collisions = building planetesimals
(b) collisions = disturbed orbits / spins

ES104 Class Notes - Origin of Terrestrial Planets and the Earth-Moon System

I. Introduction to Inner Planet Origins (mercury, venus, earth, mars)

A. Current theories

1. Earth solar system established over 4.5 billion years ago

a. planet formation process ranged from 10 million to several hundred million years

2. Recent planet discoveries

a. 100 planetary systems discovered around other stars
(1) highly variable planet characteristics
(2) planet detection limited to giant, Jupiter-scale planets

3. Research Question: how do planets form? What processes operate to create their characteristics? How did the Earth and Moon form?

4. Solar Nebula Hypothesis

a. The solar system formed from an immense rotating cloud of gas and dust called the solar nebula.

b. The sun's nuclear reaction began at the dense center of the nebula.

c. The planets formed by accumulating material within the swirling currents of the cloud.

d. Planets near the sun evolved as relatively small spheres of rocky material.

e. In the outer portions of the solar nebula, debris and gases accumulated to form massive gaseous planets.

II. Planetesimal Hypothesis

A. Early solar system morphology

1. sun and orbiting disk of gas and dust ("solar nebula")

a. original solar nebula: abundant mass of hydrogen gas
b. process: "photoevaporation" - removal of hydrogen by solar wind

(1) net result: > in solid object concentration through time
(2) Estimated time for nebular gas dispersion 10^6 to 10^7 years after after formation

2. Dating of oldest meteorites ~ 4.56 b.y. ago

(a) provides time constraint = planet formation must have occurred before 4.5 b.y.

B. Inner Planet Accretion Hypothesis ("Planetesimal Hypothesis")
1. solid terrestrial planets form from collisional accretion via gravity
a. eccentric / elliptical orbits about sun with collisions
(1) high velocity collisions = fragmentation
(2) low velocity collisions = accretional planet growth

2. Stages of terrestrial planet accretion

a. Stage 1 - Planetesimals Accretion
(1) km-scale accumulation of dust/particles
(2) self-gravitational collapse and accumulation from solar nebula
b. Stage 2 - Planetary Embryo Phase

(1) planetesimal aggregation
(a) eccentric orbits result in orbit crossings / collisions
(b) As embryos increase / accrete: gravitational attraction increases resulting in positive feedback (thus more accretion)

(2) embryo = 1-10% mass accumulation of Earth
(a) mass of Earth = 6×10^{24} kg

(3) high density collision/accretion of planetesimals in nebular disk

(4) planetary growth rate initially high, exponentially decreases as fragment number decreases

(5) Model for Earth Solar System (based on computer modeling)
(a) 22 planetary embroyos formed in inner solar system within 1 m.y. time frame
(b) embryos contained 90% of total solid mass available in solar system at this time

(c) Stage 3 - Late-Stage Terrestrial Accretion:

(1) Final planet formation via continued accretion of embryos
(2) Final planet composition and characteristics of mercury, venus, earth, mars a function of random processes
(3) Planetary impacts / collisions diminished with time as nebular mass was accreted into planetesimals, embryos, and planets
(4) Final collisions to form planets likely involved moon to mars sized objects
(5) Modeled time frame 10^7 - 10^8 years for stage 3

III. Origin of Earth-Moon System

Moon/Earth Comparison

Bulk parameters

	Moon	Earth	Ratio (Moon/Earth)
Mass (10^{24} kg)	0.07349	5.9736	0.0123
Volume (10^{10} km^3)	2.1958	108.321	0.0203
Mean density (kg/m^3)	3350	5515	0.607
Surface gravity (m/s^2)	1.62	9.80	0.165
Topographic range (km)	16	20	0.800

Orbital parameters (for orbit about the Earth)

	Moon
Revolution period (days)	27.3217
Synodic period (days)	29.53

Mean values at opposition from Earth

Distance from Earth (km)	384,467

Lunar Atmosphere

Diurnal temperature range: >100 K to <400 K (roughly -250 F to +250 F)
Total mass of atmosphere: ~25,000 kg
Surface pressure (night): 3 x 10^{-15} bar (2 x 10^{-12} torr)

Estimated Composition (particles per cubic cm):
Helium 4 (^4He) - 40,000 ; Neon 20 (^{20}Ne) - 40,000 ; Hydrogen (H_2) - 35,000
Argon 40 (^{40}Ar) - 30,000 ; Neon 22 (^{22}Ne) - 5,000 ; Argon 36 (^{36}Ar) - 2,000
Methane - 1000 ; Ammonia - 1000 ; Carbon Dioxide (CO_2) - 1000
Trace Oxygen (O^+), Aluminum (Al^+), Silicon (Si^+)
Possible Phosphorus (P^+), Sodium (Na^+), Magnesium (Mg^+)

A. Classic Moon Formation Hypotheses

1. Capture - capture of external moon by Earth's gravitational field
2. Fission - earth in rotation splits off Earth materials to form lunar body
3. Coformation - moon and earth formed by nebular disk accumulation, independently, but in gravitational proximity to one another

B. Current Favored Hypothesis - "Giant Impact Theory"

1. Late Stage Earth Impact = ejected rock material to form moon

a. impact ejecta spun off of Earth and captured in orbit
    (1) early moon formation = "orbiting proto-lunar disk"
    (2) late moon formation = disk coalescence into spheroid
b. Result: impact-generated heating and melting of Earth material
    (1) potential heating to 7000 K
c. Result: high angular momentum of earth-moon
    (1) Require impact velocity = minimum 10 km/sec
d. Result: Iron-poor composition of moon
    (1) moon is comprised of lighter silicate rocks derived from the mantle-crust of the Earth
    (2) Earth and impact object predicted to have iron core and silicic mantle prior to moon formation