1. Age of Reason
    a. Nicolaus Copernicus 1473-1543
        i. Commenteriolus manuscript circulated from 1512
            1. unpublished
            2. Heliocentric hypothesis
        ii. ‘On the Revolutions of the Planets’ published year of his death
            1. incorporated some epicycles to account for lack of perfect agreement with perfectly circular orbits around Sun (did not consider ellipse shape of orbits)
            2. publisher’s preface declared it ‘hypothesis’ to predict location of planets
            3. not much notice taken by Church at that time
            4. Galileo began “Copernican Crusade” in early 1600’s that lead to it being banned from 1632-1835 by Catholic Church
    b. Tycho Brahe 1546-1601 Danish astronomer
        i. Observations very exact thorough
            1. 1572 Supernova in Cassiopeia
            2. Comet in 1577 convinced him Aristotle’s hypothesis was wrong—celestial sphere not solid and unchanging
        ii. “great quadrant” and corrections for refraction of atmosphere allowed him to plot very accurately
            1. calculated Earth’s axial tilt to 1/100 of degree
            2. tropical year length to one second accuracy
        iii. rejected Ptolemaic system, and Copernican system
            1. Tychonian model
                a. Sun orbits Earth
                b. All other planets orbit Sun
                c. Earth is fixed—there is no stellar parallax
        iv. Took on assistant Johannes Kepler in 1600
    c. Johannes Kepler 1571-1630
        i. Used Tycho’s observations to formulate laws of planetary motion
            1. Planets move in elliptical orbits around Sun
            2. Planets sweep equal area in equal time period
            3. distances of planets to Sun are proportional to period of orbit around Sun ($p^2=d^3$)
        ii. fanatic about finding ‘causes’ for natural observations—hindered him at times
        iii. Vigorous supporter of Galileo’s observations of the moons of Jupiter

d. Galileo Galilei 1564-1642
    i. Heard about lenses being used to magnify objects
        1. created his own telescopes to 30 power—not the inventor!
        2. looked at planets and Sun
    ii. Planetary observations
        1. discovered planets are discs, not points
        2. found Jupiter has moons
            a. implication that Earth not the only center of orbit
            b. disputes the argument that if Earth orbits Sun, then Moon would be left behind
        3. Venus has phases, and this supports heliocentric hypothesis also. He noticed that when Venus is full, it appears smallest, because it is farther away than when it is crescent
        4. Moon surface is cratered and mountainous
        5. Sun has sunspots, that move around on Sun's surface
    iii. *Dialogue of the Great World Systems* published in 1630, banned by Church, he was house-arrested for the rest of his life—exonerated in 1992
e. Isaac Newton 1642-1727
    i. Formulated and tested the Law of Universal Gravitation—every body in the universe attracts every other body with a force proportional to their masses, and inversely proportional to the distance between them
    ii. Accounted for why Kepler's laws worked
    iii. Also explains perturbations of orbits due to other bodies
f. Foucault's pendulum proved that Earth rotates on axis
    i. Pendulum continues to swing in same plane unless acted upon by outside influence
    ii. Pendulum set into motion changes apparent position over full day period
    iii. It doesn't really swing in a changing plane, Earth is rotating under it.

2. Solar System
    a. Sun is the center
    b. Planets have elliptical orbits around Sun
    c. Orbits function of inertia and gravity
3. Constellations
    a. Apparent groups of stars, actually unrelated
    b. 88 recognized divide sky into units to identify areas—such as Orion
    c. Many bright stars have proper names—Sirius, Arcturus brightest in northern sky
4. Position in sky also divided by geometry: celestial poles and equator extended from Earth's poles and equator
    a. declination—from the equator, in degrees N and S
    b. right ascension—rising from where Sun crosses celestial equator on the March equinox, in hours of Earth turning

5. Motion of Earth
    a. Rotation—turns on axis one complete rotation about 24 hours
        i. Turn on axis pointing at Polaris—Big Dipper 'rotates' around Polaris daily
        ii. Mean solar day—for Sun to get to High Noon again
        iii. Sidereal day—for star to get to same sky position: about four minutes less than mean solar day
        iv. Astronomical observatories use sidereal day
    b. Revolution—orbit around Sun
        i. Average of 150 million km from Sun
            1. Perihelion—147 million km; Occurs about January 3
            2. Aphelion—152 million km; Occurs about July 4
            3. This is a result of Earth's elliptical orbit around Sun, which varies from closest to a circle to about 5% from a circle in a 100,000 year cycle
        ii. Earth's axis of rotation is inclined to our orbital plane around Sun
            1. Results in the plane of the ecliptic at 23.5^{o} angle to celestial equator
            2. Tilt of Earth's axis results in seasons we have
                a. rotation with north pole facing Sun results in greater heating of northern hemisphere
                b. rotation with south pole facing Sun results in less heating of northern hemisphere
                c. seasons are NOT the result of Earth being closer to Sun (notice distance vs. northern hemisphere seasons)
            3. Sun appears to cross celestial equator on the Equinox: ~22 March and September
            4. Sun furthest from celestial equator (23.5^{o}) on the Solstice: ~ 21 June and December
        iii. Sun appears to be displaced against star backdrop
            1. about 1 degree/day
            2. path through stars called ECLIPTIC
            3. planets and moon have orbits in about same plane of Earth around Sun, so they travel near the ecliptic also
    c. Precession is the wobble of Earth's axial tilt
        i. Slowly changing position in the sky—full circle 28,000 years
            1. as axis changes position, it will bring seasonal change to differing coincidence with perihelion and aphelion
            2. in 14,000 years, June solstice will occur nearer to perihelion, warming northern hemisphere more
        ii. Angle varies a slight amount also, between 21.5^{o} and 24.5^{o}—in a 41,000 year cycle.
        iii. These Earth-Sun variations can affect overall Earth temperature: see http://www.homepage.montana.edu/~geol445/hyperglac/time1/milankov.htm for a detailed explanation and competing hypotheses of Earth's reaction to these variations

6. Motions of the Earth-Moon system
    a. Moon has an elliptical orbit around Earth
        i. 6% variation in distance throughout its cycle—it is on average 384,401 km
        ii. Orbit accounts for phases of Moon, and eclipses of Moon and Sun
    b. Phases of Moon—
        i. New→crescent→1/4 Moon→Full→3/4 Moon→crescent→New
        ii. Waxing for two weeks: greater amount illuminated each night
        iii. Waning for two weeks: lesser amount illuminated each night
        iv. Sunlight is reflected off of Moon's surface
            1. when Moon is opposite Sun, it is a full disc
            2. when Moon is between Earth and Sun, it is a crescent, or not illuminated (New)
            3. a Full Moon rises at sunset, and sets at sunrise, as a result of it orbital position to be shown as Full
    c. Lunar Motions
        i. It takes Moon 29 ½ days to come to the same position relative to the Sun—'Synodic Month': apparent period lengthened due to Earth's orbit of Sun
        ii. However since Earth-Moon system has progressed 1/12 of the way around the Sun orbit, the period for Moon to go exactly all the way around Earth needs to be compared to a distant star.
            1. it takes 27 $^{1}/_{3}$ days to go around Earth
            2. 'sidereal month'
            3. Moon also rotates on its axis, once every 27 $^{1}/_{3}$ days
                a. The same side of Moon always faces Earth
                b. Days and nights last two weeks on Moon
                c. Lack of moisture and atmosphere allow temperatures to vary widely during these extraordinarily long days and nights
                    i. 127^{o} C in day
                    ii. -173^{o} in night
    d. Eclipses—shadow effects of Moon and Earth
        i. Moon's orbit is inclined about 5^{o} to Earth's orbit around Sun
        ii. Lunar eclipse occurs when Earth's shadow falls on Moon
            1. Earth is between Sun and Moon
            2. occurs only when Moon is full
            3. Moon is still visible because of some bending of light around Earth
        iii. Solar eclipse occurs when Moon's shadow falls upon Earth
            1. Moon is between Earth and Sun
            2. only occurs when Moon is new
            3. Total eclipse is within the 275 km wide umbra
                a. Lasts at most for 7 minutes in any area
                b. Total eclipses are rare: next one in August 2017
            4. partial eclipse over larger area in penumbra
        iv. Earth usually 'misses' Moon's shadow, so on average, there are four eclipses per year: two lunar, and two solar

7. Moon
    a. Earth's only natural satellite
        i. Large in reference to Earth, compared to other natural satellites of other planets
            1. about ¼ of Earth's diameter
            2. 3475 km
        ii. Density similar to Earth's mantle material, small iron core
    b. Surface—not protected by atmosphere
        i. Craters
            1. impact of meteoroids
                a. ejecta
                b. rays
            2. more common in early part of Moon's history
        ii. lunar highlands—most of Moon's surface, all of back side
            1. original surface: intensely cratered
            2. low-iron content compared to *maria*
        iii. maria—plural of mare
            1. high iron content lowlands
            2. younger than lunar highlands
            3. created by large asteroid impact
                a. caused sub-crustal melting and basalt flows
                b. similar to Columbia Plateau basalts
        iv. lunar regolith
            1. soil-like surface produced by numerous meteoroid impacts
            2. fine dust, glass beads, breccia, igneous rock
8. Lunar history
    a. Earth impacted by large asteroid about 4.5 billion years ago
        i. Caused part of Earth to be ejected into orbit around Earth
        ii. Dust accreted into lunar body
            1. Gravitational contraction caused melting and formation of crust, mantle and core.
            2. original surface was the present lunar highlands
    b. Maria basins formed 3.8 to 3.2 billion years ago by asteroid impact
    c. Continued bombardment created craters, including the 'rayed craters' such as the Copernican crater