History of Astronomy Outline

1. ***Introduction: Science and the Modern world***

- The nature of the universe at the end of the 20th century
    1. The earth is one of nine major ***planets*** (relatively small, cold bodies) orbiting the ***sun*** (a large body which radiates energy)
    2. The sun is comprised mostly of hydrogen and helium. The energy radiated by the sun originates in ***thermonuclear reactions*** taking place deep its core. These reactions fuse hydrogen into helium, releasing energy in the process.
    3. The sun is one of billions of stars which make up the Milky Way ***galaxy***. The distance between stars is measured in ***light years***, the distance light travels in one year (approximately 6 trillion miles).
    4. The stars which comprise the Milky Way appear to form a circular spiral when viewed face on and a thin line with a central bulge when viewed from the edge. It is approximately 100,000 light years in diameter and no more than 10,000 light years thick.
    5. The Milky Way is only one of billions of other galaxies, each consisting of billions of stars
    6. The visible universe is approximately 30 billion light years across and, in addition to galaxies, appears to be filled with "***dark matter***" which is undetectable by any known method
    7. The space between galaxies is increasing, a phenomenon known as the "expanding universe"
    8. This expansion leads logically to the notion that in the beginning all of the matter, energy and space in the universe was compressed into a very small volume and began to expand. The event is known as the ***Big Bang***, the current scientific model of the origin of the universe.
    9. The current estimate for the age of the universe is approximately 15 billion years
- What is science?
    1. Science postulates an objective reality (nature) which behaves according to a set of rational rules (the laws of nature)
    2. About an event, science asks "What previous events were antecedent to the current event?", rather than "What is the purpose of this event?"
    3. Science consists of *experiment* and *theory*
        1. **Experiment** is the systematic collection of facts (data)
        2. **Theory** is the metaphor which explains the data

3. A good theory explains all of the existing facts in detail, is compatible with other well established theories, and suggests further experiments for collecting new facts.
4. The ultimate arbitrator in science is ***empirical evidence*** (the facts collected by experiment)
5. In keeping with attribute number 4, ***in order for a theory to be truly scientific it must be empirically testable***. Strictly speaking, a theory can never be proven ***true*** beyond doubt, but it should be possible to prove a theory ***false*** (*i.e., not in agreement with observed facts*). A theory is considered valid only as long as it remains in agreement with all empirical evidence.
6. Thus, all theories are subject to modification when confronted with new facts

4. Non-scientific ways of looking at reality include ***idealism*** (abstract postulates which cannot be deduced by empirical observation), ***subjectivism*** (there is no accessible objective world, reality is in the eye of the beholder) and ***mysticism*** (nature is controlled by supernatural forces which cannot be explained rationally, but are knowable through revelation)
5. **Science and Technology**: ***Science*** seeks to discover the laws of nature by which the universe operates; ***Technology*** is the process of applying the laws of nature to practical problems .

- World Maps and Timelines
  1. Map
  2. Timelines
  3. 3. Timelines (Graphical)

Readings: *Aveni, Preface, Chapter 1*

2. ***Basic Motions of the Sky***

- Celestial Sphere
  - The sky appears as inverted bowl or dome
  - ***Constellations*** are the fixed patterns formed by the stars which appear to be permanently attached to the dome.
  - The stars do not move relative to each other (the patterns remain fixed) - daily (***diurnal***) motion appears to be *the rotation of the sky*. Thus, the bowl extrapolates to a sphere, the ***celestial sphere***.
  - temperate zones (star paths make steep angle with horizon)
  - tropics (star paths make shallow angel with horizon)
- Motion of the Sun
  - The sun's motion through constellations deduced from ***helical*** rising and settings (first and last appearance) of stars

    - The sun travels completely around the celestial sphere in one year (365.25 days) along a path called the ***ecliptic.***
    - ***solstices*** (maximum north and south position of the sun)
    - ***equinoxes*** (sun crosses celestial equator in spring and fall)
    - ***zenith***/***nadir*** passages (zenith directly overhead, nadir directly below)
- Motion of the Moon
    - The moon travels completely around the celestial sphere in one month (see below for types of months), changing phase (shape) daily.
    - The major phases are defined as ***new*** (moon invisible, near the sun), ***first quarter*** (moon appears as a half disk, 90 degrees from the sun), ***full*** (moon appears as a full disk, 180 degrees from the sun), and ***last quarter*** (moon again appears as a half disk, 270 or –90 degrees from the sun). the illuminated part of the moon always points toward the sun, so opposite halves of the disk are illuminated for first and last quarters.
    - ***synodic*** month (new moon to new moon – 29.5 days)
    - ***sidereal*** month (moon returns to same spot on the celestial sphere – 27.3 days)
    - The moon's orbit is inclined approximately 5 degrees to the ecliptic (earth's orbital plane). The two points where the moon's orbit crosses the ecliptic are called ***nodes***.
    - ***draconic*** month (moon returns to same node – 27.2 days)
    - A ***lunar standstill*** occurs when a full moon, positioned the maximum distance (5 degrees) from the ecliptic, occurs at one of the solstices. A given standstill (north or south) occurs every 18.6 years.
    - ***eclipses***
        - an eclipse occurs when a ***new moon*** (solar eclipse) or ***full moon*** (lunar eclipse) is at a ***node***
        - Since the line of nodes is ***precessing***, eclipses do not occur at the same time every year. Eclipses repeat when multiples of solar and lunar cycles (synodic month and draconic month) are most nearly whole numbers.
        - Best known eclipse series is the ***saros*** cycle (18.03 years, 6,585.32 days)
        - other cycles
- Motion of the Planets
    - planets = "wanderers"
        - Saturn = old man (moves slowly)
        - Venus = *femme fatale* (tantalizing sun)
        - Jupiter = king of gods (bright at midnight)
        - Mars = god of war (red in color)
        - Mercury = messenger (fast moving)
    - two types of planets

        - Mars, Jupiter, Saturn –free ranging
            - up all night
            - ***retrograde*** motion (reverses west-to-east motion and moves east-to-west)
        - Mercury, Venus – always near the Sun
            - experience ***elongations*** (maximum angular distance from the sun); ***maximum western elongation*** before sunrise, ***maximum eastern elongation*** after sunset.
            - Venus cycle
                - synodic cycle = 584 days = 263 +50+263+8
                - appearance = 9 mo.
                - years:Venus = 8:5
                - Venus patterns (5 different)
            - Mercury too hard to see
    - different planets are of interest to different cultures

- Sky Roads
    - ecliptic
    - Milky Way
- Calendars
    - direct observation
    - mathematical formula
    - calendar problem: mesh cycle of the Sun with cycle of the Moon
        - The ***lunar calendar*** is based on the phases of the moon. Every month begins with a new moon.
        - The ***solar calendar*** is based on the position of the sun on the celestial. Every year starts with the sun very near the position on the celestial sphere that it was the previous year.
        - It is not possible to devise a calendar which simultaneously agrees with both the sun and the moon.
    - Metonic cycle (months by observation):
        - 12 x 12 + 7 x 13 = 235 mo (19 years)
        - (365.2422 x 19)/29.5306 = 235

Readings: *Aveni, Chapter 2*

3. ***Astronomy in Three Selected Cultures***

- Neolithic Britons (Stonehenge)
    - very ancient ~ 3,000 B.C.
    - Stonehenge clearly aligned with solstices

    - Controversial theory in 1960s about sophisticated computer
    - necessary to understand culture to understand monument
    - currently viewed as theater, not precision
- Mayans (Chichen Itza)
    - Mesoamerican culture began about 1800 B.C.
    - greatest sophistication between 200 A.D. – 900 A.D.
    - Mayan accomplishments
        - Venus cycle accurate to one day in 500 years
        - eclipse prediction accurate to today
        - zodiac to follow Mars
        - mathematics with zero
    - Mayan math
    - Eclipse predictions with saros cycle in Dresden codex
    - Venus cycle in Dresden codex
    - 2,920 days (Maya, Greeks)
        - 8 years
        - 99 synodic months
        - 5 Venus cycles (584 days)
    - noting difference between 583.92 and 584
    - serpent descending pyramid
- Incas (Cuzco)
    - no written language
    - Cuzco (and other cities) laid out in *ceques* (rays)
    - city a calendar – ceques aligned with helical setting of Pleiades

Readings *Aveni*, Chapters 3, 4 and 5

4. Astronomy in Classical Antiquity

o ***Greek Astronomy Before Ptolemy***

- Thales (*Miletus[Ionia]*, 624 B.C. – 547 B.C.)
    - "Father of philosophy"
    - everything is water
    - predicted eclipse of 585 B.C.
- Plato (*Athens*, 427 B.C. – 347 B.C.)
    - world is surface, masking reality underneath
    - astronomers should account for planetary motions by a combination of perfect circular motions.
- Eudoxus of Cnidus (*Asia Minor*, 408 B.C. –355 B.C.)
    - celestial motions by means of concentric spheres
    - mathematical models are computational only
- Aristotle (*Macedonia*, 384 B.C. – 322 B.C.)
    - spherical earth
    - circular motions of heavenly bodies

    - heavens perfect, earth imperfect
    - all things fall toward the earth, their "natural" place.
    - four "elements": *earth, air, fire and water* make up the world; a fifth element, *quintessence*, makes up the heavens
- Aristarchus of Samos (*Samos [Ionian island]*, 310 B.C. – 230 B.C.)
    - distance to sun and moon
    - size of sun and moon
    - proposed a heliocentric system
- Erathosthenes of Alexandria (*Alexandria[Egypt]*, 276 B.C. - 194 B.C.)
    - head librarian of Alexandria Library
    - measured size of the earth
- Hipparchus of Nicaea (*Asia Minor*, 190 B.C. – 120 B.C.)
    - made star map
    - discovered precession

Readings Crowe, "Theories of the World..", Chapter 2; Aveni, Chapter 5

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o ***<u>The Ptolemaic System</u>***

- Ptolemy (*Alexandria [Egypt]*, 85 A.D. – 165 A.D.) summarized ancient knowledge in the ***Almagest*** (150 A.D.)
- Ptolemy's system was ***geocentric*** (*<u>Earth centered</u>*)
- The heavens move like a sphere
- The Earth is also a sphere
- The Earth is in the middle of the heavens
- The Earth is a point with respect to the heavens
- The Earth does not move
- Two primary heavenly motions: (1) around equatorial pole and (2) around ecliptic pole
- The planets move on epicycles (circles moving on circles)
- The ***day*** is defined as one complete rotation of the celestial sphere around the Earth
- The ***year*** is defined as one complete circuit of the Sun around the celestial sphere
- The **month** is defined as one complete circuit of the Moon around the celestial sphere
- ***precession*** is defined as a very slow rotation of the ecliptic
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Readings Crowe, "Theories of the World..", Chapter 3

5. Astronomy of the Renaissance

- ***Copernicus*** (*Poland*, 1473 – 1573)
    - Copernicus proposed a ***heliocentric*** (*Sun centered*) system
    - Features of Copernicus' system:
        - planets move around the Sun in perfect circles
        - Earth is one of the planets
        - o the ***day*** is defined as one rotation of the Earth.
        - o the ***year*** is defined as one complete revolution of the Earth around the Sun.
        - o the ***month*** is defined as one one revolution of the moon around the Earth (same as geocentric system).
        - o ***precession*** is defined as a "wobble" of the Earth as it rotates on its axis.
        - retrograde motion explained by Earth passing planet
        - behavior of Venus and Mercury explained by the fact that their orbits are *between* Earth and Sun
        - relative scale of the solar system can be determined
    - How did Copernicus come up with this system?
        - didn't seem to know about Aristarchus
        - did not use any new observations
        - rotating Earth had been proposed before (*Nicole d'Oresme*)
        - reasons mostly aesthetic
            - Ptolemy's system very complicated
            - the Sun is clearly central to life and some philosophies
    - What were the strengths of the heliocentric system?
        - much more "harmonious, natural and simpler" than Ptolemy
        - retrograde motion, Venus and Mercury explained in a natural way
        - explained why retrograde motion always occurred at opposition
        - enabled the scale of the solar system to be established
    - What were the objections to the system?
        - did not really predict the position of planets any better than Ptolemy
        - no stellar parallax seen, as would be expected if the Earth moved around the Sun
        - no evidence that the Earth rotates (shouldn't we feel it?)
    - What philosophical issue is summarized as "***saving the phenomena***"?
        - "***saving the phenomena***" simply means to account for or predict *mathematically* a particular phenomenon (e.g., the position of a planet at a specified time)
        - the fact that a phenomena is correctly predicted *does not mean that the mathematical edifice is physically "true*". For example,

the fact that Ptolemy's epicycles "work" does not necessarily mean that planets actually move that way; the epicycles are simply a mathematical technique for calculating purposes. Copernicus's system could be (and was) viewed the same way.

- Did Copernicus believe that his system was "*true*"?
    - is a system more likely to be true if it predicts phenomena better?
    - is a system more likely to be true if it "explains" previously unexplained phenomena?
    - is a system more likely to be true if it is more aesthetically pleasing (simpler)?

Readings: Crowe, "Theories of the World..", Chapters 5 and 6

o ***Tycho Brahe*** (*Denmark*, 1546 – 1601)

- Tycho Brahe was last great naked eye astronomer
- Prepared star map of unprecedented accuracy
- Demonstrated the heavens are not unchanging
    - observed a "new star" (***nova***)
    - showed that comets were not atmospheric phenomena
- "Moderate" on Copernicus – proposed a compromise system where all planets *except* the Earth orbited the Sun
- Provided Kepler with data of sufficient accuracy to compel changes in Copernicus' model

Readings: Crowe, "Theories of the World..", Chapter 7

o ***Johannes Kepler*** (*Hungary*, 1571 – 1630)

- Kepler believed in the *physical truth* of the Copernican system
- Kepler had many mystical beliefs; mother burned as a witch
- Felt planetary orbits could fit into 5 harmonic solids
- Worked with Tycho to achieve accurate data
- Used Tycho's data to deduce that orbit of Mars is elliptical
- Kepler's Three Laws of Motion
    - planets move in elliptical orbits
    - planets sweep out equal areas in equal times
    - ratio of semi-major axis cubed divided by period square
- Kepler made Copernicus' system work – predictions which were much simpler and much more accurate than Ptolemy's.

Readings: Crowe, "Theories of the World..", Chapter 8

o ***Galileo*** (*Italy*, 1564 – 1642)

- Mathematician, physicist, astronomer
- Galileo's physics
    - law of inertia (things move at a constant velocity until acted on by a force)
    - excluding wind resistance, all bodies fall at the same rate, regardless of mass
    - pendulum period depends only on length of arm
- Firm believer in truth of heliocentric system; corresponded with Kepler
- Refined and used the telescope for astronomical observations
    - rudiments of telescope date to the 13th century – convex lens for nearsightedness, concave for farsightedness
    - Galileo used convex lens for objective, concave for eyepiece
    - discovered that magnification equals ration of two focal lengths
    - problems with telescopic image included, colored fringes, blurriness, elongations
    - Galileo reduced some problems by covering part of objective
- Major telescopic discoveries
    - surface features on the Moon
    - satellites of Jupiter
    - phases of Venus
    - "ears" on Saturn
    - all planets are more or less disk shaped
    - sunspots
    - the Milky Way is composed of stars not visible to the naked eye
- Major published works
    - *The Starry Messenger*
    - *Letters on Sunspots*
    - *The Assayer*
    - *Dialogue Concerning the Two Great World Systems*
- How did telescopic discoveries strengthen heliocentric theory?
    - observations of the Moon, showed that it was another "world"; planetary disks implied the same (required by Copernican theory: if Earth is a planet, then the planets must be "earths")
    - observations of Jupiter, showed that objects orbit something other than Earth (contrary to Aristotle); could be viewed as a "miniature solar system"
    - observations of the Sun showed that its surface is not perfect (contrary to Aristotle)
    - observations of the Milky Way implied that space is three dimensional and that stars are very far away (required by Copernican theory to explain lack of parallax)

- What were the objections to Galileo's findings?
  - "I don't see that"; either I *won't* see it or I *can't* see it
  - images might be artifacts of instrument
  - interpretation of observations wrong
- Conflict with the Church
  - background
    - friendship with patrons and cardinals
    - Venice vs. Florence
    - how should ideas be presented?
  - Church's conditions for publishing
  - Why did officials believe that conditions were violated?
  - Trial of Galileo
    - What were the real issues?
      - Galileo was teaching that heliocentric theory was *true*, rather than a *hypothesis*
      - Galileo was telling how to reconcile scriptures and the new astronomy (a prerogative of the Church)
      - Galileo insisted that the truth of a proposition was to be determined *empirically*, while the Church insisted that *it* was the final arbiter
    - What was the outcome?
      - Galileo was forbidden to teach or publish
      - confined to a house in Arcetri (near Florence) until his death.
- Status of heliocentric theory at the time Galileo's death (1642)
  - widely believed to be true by scholars
  - no physical theory to explain *why* it worked (contradicted Aristotle)

Readings: Panek, "Seeing and Believing", Chapters 1 and 2
Galileo "The Starry Messenger" (in "Discoveries and Opinions of Galileo")

- ***Isaac Newton (England, 1642 – 1700)***
  - Cambridge Mathematician
  - Devised physical laws which explained the heliocentric theory of Copernicus and the empirical findings of Kepler
    - Universal Law of Gravity:
      Every body in the universe attracts every other body in the universe with a force proportional to the product of their two masses divided by the square of the distance between them.
    - Three Laws of Motion

- *Every body at rest or moving at a uniform (constant) velocity continues in that state unless acted upon by an external force (Law of Inertia)*
- *The force acting on a body is proportional to the product of its mass and its acceleration (change in velocity)*
- *For every force there is an equal and opposite force.*

- Newton was able to show that a planet under the influence of gravity (a force which varied as the inverse square of the distance between the planet and the sun) would automatically follow an elliptical orbit, just as Kepler had deduced from observation
- This work was published as the ***Philosophiae Naturalis Principia Mathematica*** (Mathematical Principles of Natural Philosophy) in 1689
- Caused a sensation among the educated classes – a major force behind the "Enlightenment".

Nature and Nature's laws lay hid in night;
God said "Let Newton be", and all was light.

Readings: Panek, "Seeing and Believing", Chapters 4

6. Astronomy from the Enlightenment to the 20th Century

- ***Improving the Telescope***
  - Kepler model (convex objective, convex eyepiece)
  - Image upside down
  - Long focal lengths for far larger magnification
  - Spherical and chromatic aberration
  - Measuring devise can be inserted at focal plane
  - Measuring devises enabled an objective standard which could be compared with other observations

Readings: Panek, "Seeing and Believing", Chapter 3

- ***Discoveries in the 17th century***
  - Transit of Mercury demonstrates that solar system is large
  - Rings of Saturn
  - Moon of Saturn
  - Markings on Mars, Jupiter and Saturn
  - Absolute distance to Mars
  - Speed of Light

Readings: Panek, "Seeing and Believing", Chapters 3

- ***William Herschel and Stellar Astronomy***
  - William Herschel (England, 1738 – 1822) a professional musician who be came the best known astronomer since Galileo
  - Perfected the reflecting telescope for light gathering capabilities – made a 40 inch diameter reflector, the largest of its time
  - First astronomer to seriously study the stars
  - Searched for stellar parallax
  - Proposed a "lens" shaped model of star distribution from star counts
  - Cataloged over 2,000 nebulae (smudges of light whose natures were unclear)
- ***The Universe at the End of the 19th Century***
  - Dimensions of the solar system known – orbital sizes, diameters and masses of the planets; all major planet known except Pluto
  - Distance to nearest stars determined
  - Distance confirms that stars are as luminous as the Sun, indicating that they are the same kind of object
  - Energy source of the Sun and stars unknown
  - The universe is believed to consist of the Milky Way *galaxy*, a lens shaped group of millions of stars with the Sun near the center

Readings: Panek, "Seeing and Believing", Chapter 4
Crowe, "Modern Theories…", Chapter 3

7. Astronomy in the Twentieth Century

- ***Instruments***
  - Large reflectors
    - special locations for good seeing
    - George Ellery Hale builds the largest telescope in the world four times
  - Photography
    - observations become permanent
    - has the ability to see things the eye doesn't see (more stars, nebulae, etc)
  - The spectroscope
    - *astrophysics* becomes possible – chemical elements in stars can be identified
    - makes it possible to distinguish between clouds of gas and clusters of faint stars
  - Astronomy beyond the visible
  - Spacecraft astronomy
- ***Structure of the Milky Way***

- The periods of Cephid variables are shown to be directly related to their luminosities.
- Harlow Shapley uses Cephid variables to determine the distance to globular clusters.
- Distribution of globular clusters shows that the Sun is not in the center of the galaxy.
- Shapley's model of the Milky Way
  - Sun about 2/3 of the distance from center to edge
  - Center of galaxy in direction of Sagittarius

o ***Debate about the Uniqueness of the Milky Way***

- Distribution of nebulae argues that they are associated with the Milky Way
- Spectra suggests that spiral nebulae are clusters of faint stars
- Nova in Andromeda nebula provides clue and controversy
- "Great Debate" in 1920 between Heber Curtis (many galaxies) and Harlow Shapley (Milky Way the entire universe)
- Distance to nebulae is the key
- Edwin Hubble determines distance to Andromeda using Cephid variables
- By 1930 most astronomers agree that the Milky Way is only one galaxy out of many

o ***The Red Shift of External Galaxies***

- Vesto Slipher notices that the spectra of some spiral galaxies are "red shifted" (absorption lines shifted toward the long wavelength of the spectrum).
- Hubble demonstrates that with the exception of a few nearby galaxies, all external galaxies are red shifted. Further, the greater the distance to the galaxy, the greater the red shift
- Gives rise to the idea of the "expanding universe"

o ***The Universe at the End of the Twentieth Century***

- The Sun is located in a spiral arm of the Milky Way galaxy, an assemblage of approximately 200 billion stars.
- The Milky Way is only one of billions of other galaxies.
- The visible universe is about 30 billion light years in diameter
- Our universe began with the rapid expansion of space and time (the ***Big Bang***) about 15 billion years ago, and this expansion continues.
- The dynamics of galaxy rotation indicate that 90% of the universe consists of material we cannot see (***dark matter***)

Readings: Panek, "Seeing and Believing", Chapters 5 and 6
Crowe, "Modern Theories…", Chapters 8 and 9