Ancient Civilizations

• Astronomical ruins
  – Mayans
  – Aztec
  – European (Stonehenge)
  – Native Americans (Chaco Canyon)
  – Arabs
  – Greeks
• Probably all civilizations watched the sky & we have remains of only a few

Ancient Greek Astronomers

• Pythagorus (550 BCE)
  – relationship between numbers and nature
  – mathematics
• Plato (350 BCE)
  – Geocentric universe, stars revolve around earth
  – circular motion with uniform, constant speed
  – planets - wandering stars, more problematic
    • each planet on its own sphere
    • Mars - retrograde motion
    • problem for 2000 years!!!
Ancient Greek Astronomy

• Models were generally wrong because they were based on wrong "first principles", believed to be "obvious" and not questioned:
  1. Geocentric Universe: Earth at the Center of the Universe.
  2. "Perfect Heavens": Motions of all celestial bodies described by motions involving objects of "perfect" shape, i.e., spheres or circles.

Ancient Greek Astronomers

Aristotle
(384 – 322 B.C.), major authority of philosophy until the late middle ages.
 Universe can be divided in 2 parts:
  1. Imperfect, changeable Earth, • earth, water, air, fire • earth is heaviest, so at center
  2. Perfect Heavens (described by spheres) aether or quintessence

Aristotle’s model
55 spheres!
Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, fixed stars, Prime mover
Fundamental argument for the geocentric universe:

- Motion of Earth should result in an observable parallax, which was not seen.
- In reality, parallax is just too small to be seen with naked eye.

Problems with Geocentric Model

The retrograde (westward) motion of the planets

The “solution”: Epicycles!

Hipparchus (150 BCE)

- Careful catalog of stars
- Placed planets on epicycles in geocentric model
- Hipparchus system did not match
Introduced by Ptolemy (ca. A.D. 140)

The Ptolemaic system was considered the “standard model” of the universe until the Copernican Revolution.

Ptolemaic System

- added “equants” - points about which angular velocity is constant
- Earth is not at the center of spheres
- violated perfect circular motion
- predicted planetary motions well

*We will explore this more using an online simulator.*

The Copernican Revolution

Nicolaus Copernicus (1473 – 1543): heliocentric universe (sun in the center)
Copernicus’ new (and correct) explanation for retrograde motion of the planets:

Retrograde (westward) motion of a planet occurs when Earth passes the planet.

- This made Ptolemy’s epicycles unnecessary.
- Not perfect predictor of planet motions

Aristarchus of Samos (310-230 BCE)

- first reference to heliocentric universe
- amazing geometer
- measured
  - circumference of earth
  - relative size of earth and moon from lunar eclipse
  - relative size of moon and sun from solar eclipse
  - knew sun was much bigger than earth
  - presumably this led him to heliocentric model
- we should see parallax of stars if we are orbiting the sun but don’t
  - Aristarchus reasoned that stars were enormously far away
- Also deduced that the Sun is a star!

Heliocentric Planetary Configurations

See also Fig 1-2

http://astro.unl.edu/haap/ssm/modeling2.html
Heliocentric Planetary Configurations

http://astro.unl.edu/naap/sam/modeling2.html

Synodic vs Sidereal Periods

A sidereal day is measured relative to the stars - how long does it take for the same star to return to the meridian.

Synodic period is measured relative to the Sun - how long does it take the Sun to return to the meridian.

Tycho Brahe (1546 – 1601)

Use of high-precision instruments for precise astronomical observations, meticulously reported in tables.

Later used by Kepler to develop laws of planetary motion.
A Quadrant designed by Brahe

• Used to precisely measure an object’s angular distance above the horizon
• Detected a new star (supernova)
  • heavens changed!

Johannes Kepler (1571 – 1630)

Used the precise observational tables of Tycho Brahe to study planetary motion mathematically.

Found a consistent description by abandoning both:

1. Circular motion and
2. Uniform motion.
• Planets move around the sun on elliptical paths, with non-uniform velocities.

Kepler’s Laws of Planetary Motion

1. The orbits of the planets are ellipses with the sun at one focus.
Ellipse Properties

- \( e \) = eccentricity, where
  - \( e = 0 \) for a circle
  - \( e = 1 \) for a straight line
- \( a \) = semi-major axis
- \( b \) = semi-minor axis
- \( b^2 = a^2 (1 - e^2) \)
- \( A \) - perihelion
  - \( AF = a(1 - e) \)
- \( A' \) - aphelion
  - \( A'F = a(1+e) \)

Eccentricities of planetary orbits

Orbits of planets are virtually indistinguishable from circles:

- Earth: \( e = 0.0167 \)
- Most extreme example: Pluto: \( e = 0.248 \)

But their centers may be significantly offset from the sun.

2. A line from a planet to the sun sweeps over equal areas in equal intervals of time.

3. A planet’s orbital period \( (P) \) squared is proportional to its average distance from the sun \( (a) \) cubed:

\[
P_y^2 = a_{AU}^3
\]

\( (P_y \) = period in years; \( a_{AU} \) = distance in AU)
Galileo Galilei (1594 – 1642)
- Introduced the modern view of science:
  - Transition from a faith-based "science" to an observation-based science.
  - Greatly improved on the newly invented telescope technology.
  - Galileo did NOT invent the telescope!
- Was the first to meticulously report telescope observations of the sky to support the Copernican model of the universe.

Major discoveries of Galileo (I):
- Moons of Jupiter (4 Galilean moons)
- Rings of Saturn

Major discoveries of Galileo (II):
- Sunspots (proving that the sun is not perfect!)
Major discoveries of Galileo (III):

- Phases of Venus (including “full Venus”), proving that Venus orbits the Sun, not Earth!

Models of the Solar System

- Go to
  - http://astro.unl.edu/naap/

- Complete the pre-test, activity, and post-test for the following simulations:
  - Solar System Models
  - Planetary Orbit Simulator