Lecture 2: Early Cosmology

- Before cosmology
- Greek astronomy/cosmology
- The Renaissance (part 1)

1: UN-AIDED OBSERVERS

- Imagine a time before satellites, planes, telephones, telescopes...
- What would you conclude about the world using just your own senses?
  - Earth is at rest (i.e., motionless)
  - Earth is flat
  - Sun, Moon, planets, stars move in the sky (from East to West)
  - Occasional bizarre things happen (comets, meteors)
Discussion: What would an unaided* observer deduce about the Universe?

see http://www.exploratorium.edu/hubble/prologue/naked.html

II: GREEK COSMOLOGY

✦ First culture to look at world in the “modern scientific way”
✦ They...
 ✦ Understood the idea of cause and effect
 ✦ Applied logic to try to understand the world
 ✦ Assumed that the Universe is fundamentally knowable
 ✦ Sought to describe the Universe mathematically
 ✦ Understood the importance of comparing theory with data
✦ BUT...
 ✦ Theoretical principles -- especially geometric symmetry -- came first, with observations subsidiary
The spherical Earth

- Greeks knew the Earth was a sphere!
- View of constellations changes from N to S
- Observations of ships sailing over the horizon (mast disappears last)
- Observations of the Earth’s shadow on the Moon during lunar eclipses
Eratosthenes

- Astronomer/mathematician in Hellenistic Egypt (c.275-195 BC)
- Calculated circumference of Earth

- Measured altitude of Sun at two different points on the Earth (Alexandria & Syene): found 7° difference
- Multiplied \( \left( \frac{360°}{7°} \right) \times 800 \text{km} \) to obtain circumference = 40,000 km

Eratosthenes And Size Of Earth

- Angle of sun from Alexandria compared to Syene = 7.2°
- Size of circle 360°
- IF Alexandria is 787 km due north of Syene this is the angular separation of the 2
- Assuming the earth is a sphere
  \[
  \frac{7.2}{360} = \frac{787}{X}
  \]
  \[
  X = 39,350 \text{ km}
  \]
Cosmology of Eudoxus and Aristotle

- Fundamental “principles”:
  - Earth is motionless
  - Sun, Moon, planets and stars go around the Earth: *geocentric model*

- **Eudoxus** (408-355 B.C.) & **Aristotle** (384-322 B.C.)
  - Proposed that all heavenly bodies are embedded in giant, transparent spheres that revolve around the Earth.
  - Eudoxus needed a complex set of 27 interlocking spheres to explain observed celestial motions.
    - E.G., need to have 24-hr period =day and 365-day period=year for the Sun.
Aristotle’s terrestrial physics

- Four basic elements: earth, water, air, fire
- Each element *tends to move* toward its “natural” place:
  - Rock (earth) in air falls, air bubble in water rises
- “Natural motions” of earthly objects are straight lines toward center of Earth
  - Bodies in motion naturally tend to come to rest on Earth
  - An applied force can cause deviation from natural motion
  - A body at rest on Earth will remain at rest unless a force is applied
  - Continual application of force is needed to sustain any motion other than natural motion

Trajectories of Projectiles

Following Aristotle’s “impetus” theory
Aristotle’s celestial physics

- Heavens are governed by different laws from Earth
- Celestial bodies are composed of “ether,” a fifth element not present on Earth
- “Natural motions” of celestial spheres are different from terrestrial motions:
  - circular, constant, and eternal
  - Aristotle needed 55 spheres to explain observed motions of Sun, Moon, planets, stars
- Space is finite, bounded by outer sphere
  - But the edge is unreachable: motions become circular in the ethereal domain
- Time is infinite
  - (But why is such a perfect universe centered on such an imperfect Earth?)

Aristarchus of Samos (310-230 B.C.)

- Using eclipse data and geometry:
  - Measured relative sizes of Earth, Moon
    - Curvature of Earth’s shadow on Moon during lunar eclipse ⇒ \( R_{\text{Earth}} = 4 \times R_{\text{Moon}} \)
  - Measured distance to Moon
    - \((\text{duration of eclipse}) \div (1 \text{ month}) = (2R_{\text{Earth}}) \div \text{(circumf. of Moon’s orbit)}\)
- Attempted to measure distance Sun
  - Need to measure (using time interval ratios) the angle of Sun when Moon is exactly at 1st or 3rd quarter
  - Then use trigonometry and known Earth-Moon distance to get Sun’s distance
  - Measured angle was too small, but still concluded Sun was very distant from Earth (20×Moon’s distance) and larger than the Earth (5×Earth’s diameter)
  - Note: true distance & size 20×larger

duke.usask.ca/~akkerman/gthought/

http://www.perseus.tufts.edu/GreekScience
Relative size of Earth and Moon

Aristarchus Earth-Sun distance

\[ \cos \alpha = \frac{d}{D} \rightarrow D = \frac{d}{\cos \alpha} \]
Heliocentric model of Aristarchus

- Observations implied Sun is much larger than Earth
- Therefore proposed the first heliocentric model
  - Sun is the center of the Universe
  - Everything goes around the Sun
- Never accepted by others of his time
  - Inconsistent with apparent perception of stationary Earth
  - No apparent shift in stellar positions could be observed over course of seasons
  - Prevailing culture was uncomfortable with the idea that Earth was not central to the Cosmos

Ptolemy (100-170 A.D.)

- Worked at observatory in Alexandria, both as observer and theorist
- Developed theory to accommodate detailed planetary observations:
  - Variations in brightness over months
  - Retrograde motions
  - Variations in observed orbital speed
- Theory involved motion along small circles superposed on top of motion along large circles (think Spirograph!)
- Successors added additional “epicycles” to model to improve agreement with observations
  - Very complex!
  - No underlying law; no predictive power for new planets
Retrograde motion
Motion of Mars over 1 year - notice 'reversal of direction'

Ptolemy’s epicycles

- Ptolemy’s original “epicycles”
- Larger circle ("deferent") not centered on the Earth
- Motion appeared uniform from "equant" (offset from Earth and from center of "deferent")

Needed more and more epicycles to fit observed angular motion
Ptolemy and Homer

• This particular “orbit” required 1000 epicycles
• What do you think this translates to in terms of falsifying the theory?

Renaissance cosmology, part 1

- Pre-Renaissance
- Copernicus
- Tycho

http://www.physics.fsu.edu/users/Lind/AST1002/
Before the Renaissance

- During European “dark ages,” Arab astronomers preserved and extended Ptolemy’s work
- Aristotelian/Ptolemaic view prevailed in Europe, through 1400’s
  - Geocentric model
  - Creation at finite time in past, for consistency with Christian theology
  - Earth known to be round (Columbus battling against “flat Earth”ers is myth!)

Copernicus (1473-1543)

- Nicholas Copernicus was modern founder of the heliocentric (Sun centered) model for the solar system
- Copernicus was born in Poland; studied in Krakow, Bologna, Padua, Ferrara
  - canon, law, medicine, mathematics, astronomy
  - Worked as church canon, physician
- Rejected Ptolemy’s geocentric model because it was too complicated
- Preferred heliocentric model with perfect circular motions
- The Copernican Principle: The Earth is not at a special location in the Universe.
- Later, we will come across the Generalized Copernican Principle: There is no special place in the universe, i.e., the universe has no center.
Copernicus’s first work

- Wrote and distributed to friends the *Little Commentary* (1514)

Axioms:
1. There is no one center in the universe.
2. The Earth’s center is not the center of the universe.
3. The Earth and planets revolve around the Sun.
4. The distance from the Earth to the Sun is imperceptible compared with the distance to the stars.
5. The rotation of the Earth accounts for the apparent daily rotation of the stars.
6. The apparent annual cycle of movements of the Sun is caused by the Earth revolving round it.
7. The apparent retrograde motion of the planets is caused by the motion of the Earth from which one observes.
Copernicus’ s *De Revolutionibus*

- Full title: *De Revolutionibus Orbium Coelestium*
- Printed Nuremberg, 1543, in last year of life
- Spelled out, using observations and mathematics, evidence for his heliocentric model
  - Simple and natural explanation for retrograde motion of planets
  - Included accurate relative spacings of planetary orbits
  - Showed that planetary speeds decrease outward from Sun
  - Still had to include some epicycles to improve agreement with observations
- Book was widely read and appreciated by 16th C. astronomers
  - some believed in Copernicus’ s heliocentric physical model
  - others considered Copernicus’ s approach superior for calculating orbits, but believed in geocentric Universe
- No official position by Catholic church up to 1600

Next time...

- The scientific revolution:
  - Tycho Brahe
  - Kepler
  - Galileo
  - Newton

THIS WEEK: Read Chapter 2 of text