Lecture 2 : Early Cosmology

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

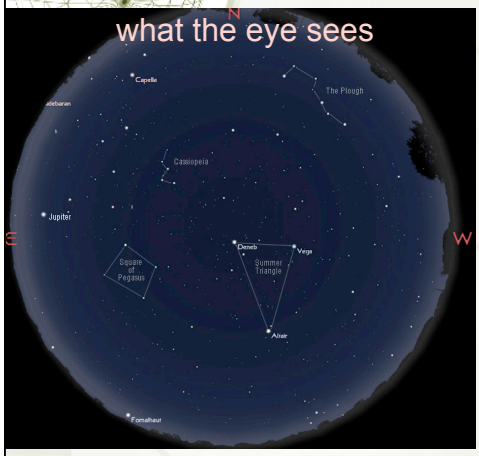
THIS WEEK: *Read Chapter 2 of text*

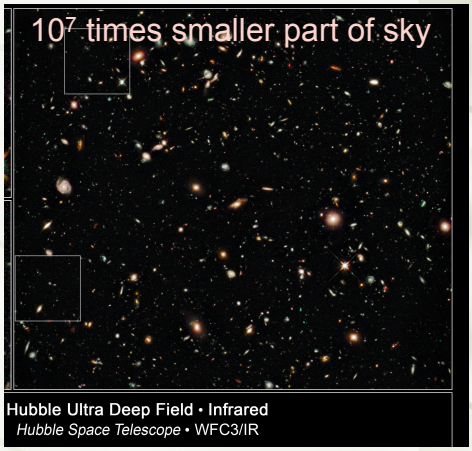
I : UN-AIDED OBSERVERS

- 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





http://www.popastro.com/youngstargazers/skyguide/

http://hubblesite.org/newscenter/archive/releases/cosmology/

8/30/18

*** no telescopes, microscopes, computers etc**

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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

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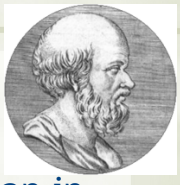
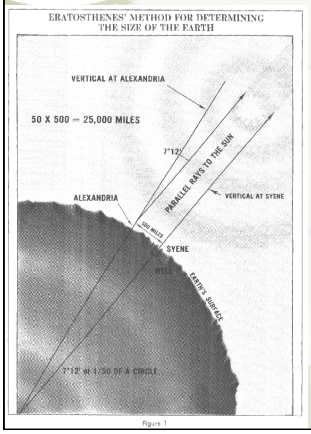
The spherical Earth

- Greeks knew the Earth was a sphere!
  - View of constellations changes from N➠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 (360°/7°)×800km to obtain circumference=40,000km



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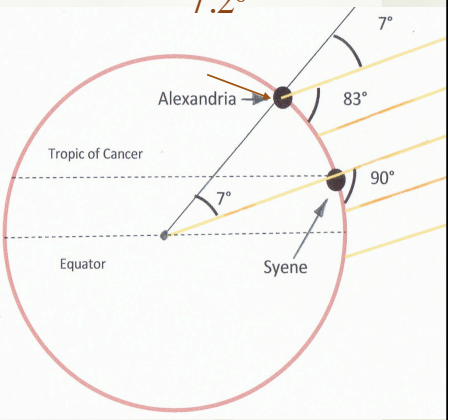
Eratosthenes And Size Of Earth

- Angle of sun from Alexandria compared to Syene =7.2^0
- Size of circle 360^0
- IF Alexandria is 787 km due north of Syene this is the angular separation of the 2
- *Assuming the earth is a sphere*

7.2/360 = 787/X

x=39350 km

7.2^0

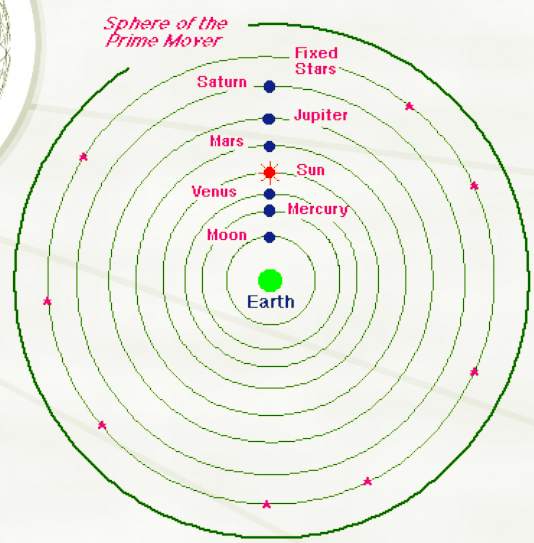


$$\frac{\text{angle of the sun}}{360^0} = \frac{\text{distance to Tropic of Cancer}}{Earth\ \ circumference}$$

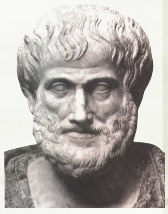
Cosmology of Eudoxus and Aristotle

- 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 Universe



http://graduate.gradsch.uga.edu/archive/Aristotle.html

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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

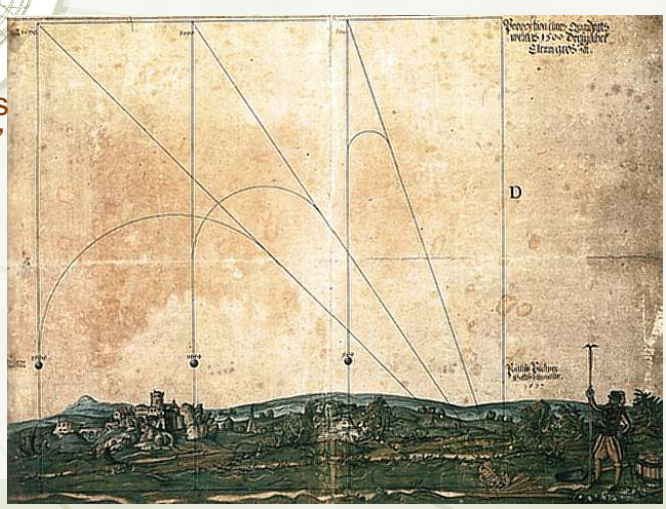
1	2	3	4
E Earth	W Water	A Air	F Fire

5 Et Ether

- "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

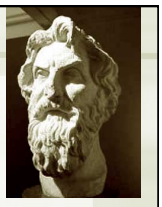
Following Aristotle's "impetus" theory



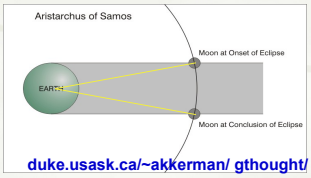
Aristotle's celestial physics

- 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?)

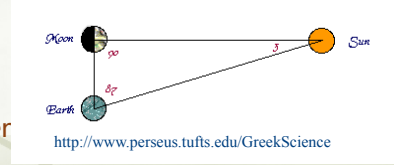
Aristarchus of Samos (310-230 B.C.)



- Using eclipse data and geometry:
  - Measured relative sizes of Earth, Moon
    - Curvature of Earth's shadow on Moon during lunar eclipse ⇒ $R_{Earth}=4\times R_{moon}$
  - Measured distance to Moon
    - (duration of eclipse)÷(1 month)= $(2R_{Earth})$÷(circumf. of Moon's orbit)

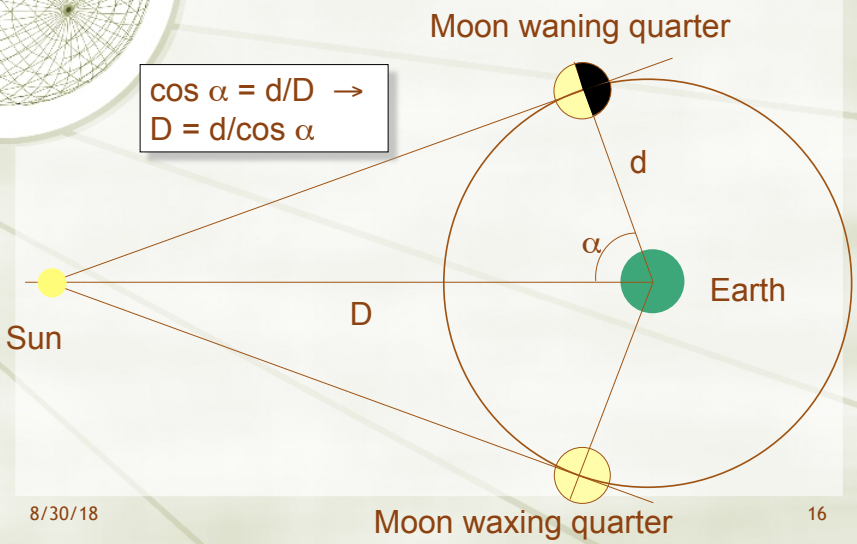


- Attempted to measure distance Sun
  - Need to measure (using time interval ratios) the angle of Sun when Moon is exactly at 1st or 3rd quarter
  - Then use trigonometry and known Earth-Moon distance to get Sun's distance
  - Measured angle was too small, but still concluded Sun was very distant from Earth (20×Moon's distance) and larger than the Earth (5×Earth's diameter
  - Note: *true* distance & size 20×larger



Relative size of Earth and Moon

Aristarchus Earth-Sun distance

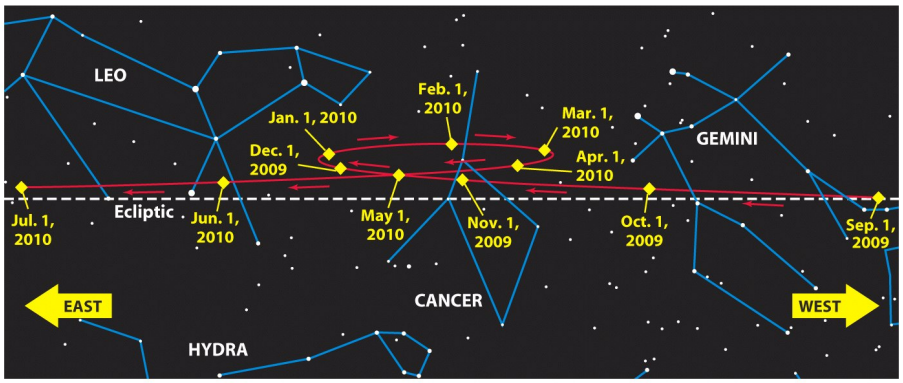


Heliocentric model of Aristarchus

- 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

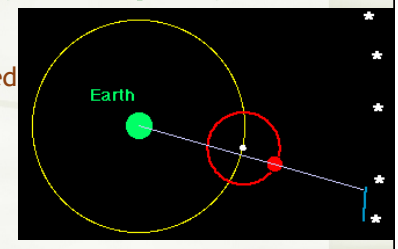


Retrograde motion

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")



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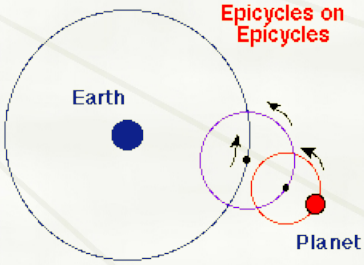


Needed more and more epicycles to fit observed angular motion

Ptolemy and Homer

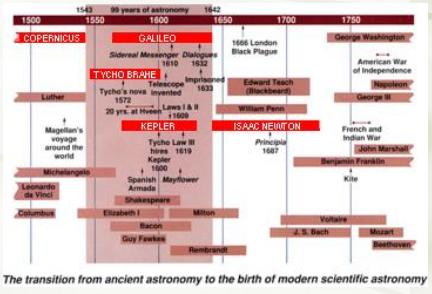
[redacted]

Carman & Serra, from YouTube

- 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



The transition from ancient astronomy to the birth of modern scientific astronomy

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)

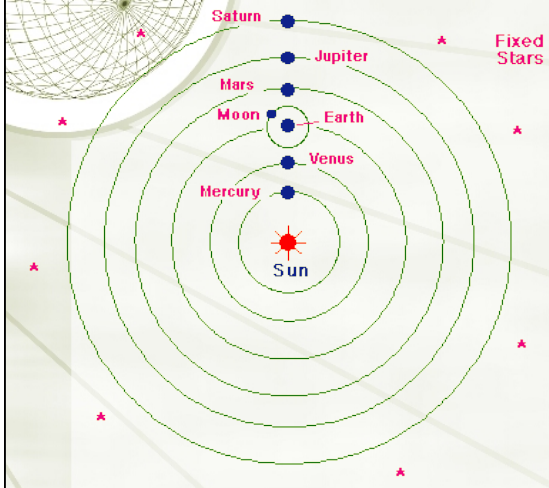
- Nicholas Copernicus was modern founder of the heliocentric (Sun centered) model for the solar system
- Copernicus was born in Poland; studied in Krakow, Bologna, Padua, Ferrara
  - canon law, medicine, mathematics, astronomy
  - Worked as church canon, physician
- Rejected Ptolemy's geocentric model 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.*



Portrait from 1597 by Teothor de Bry

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*