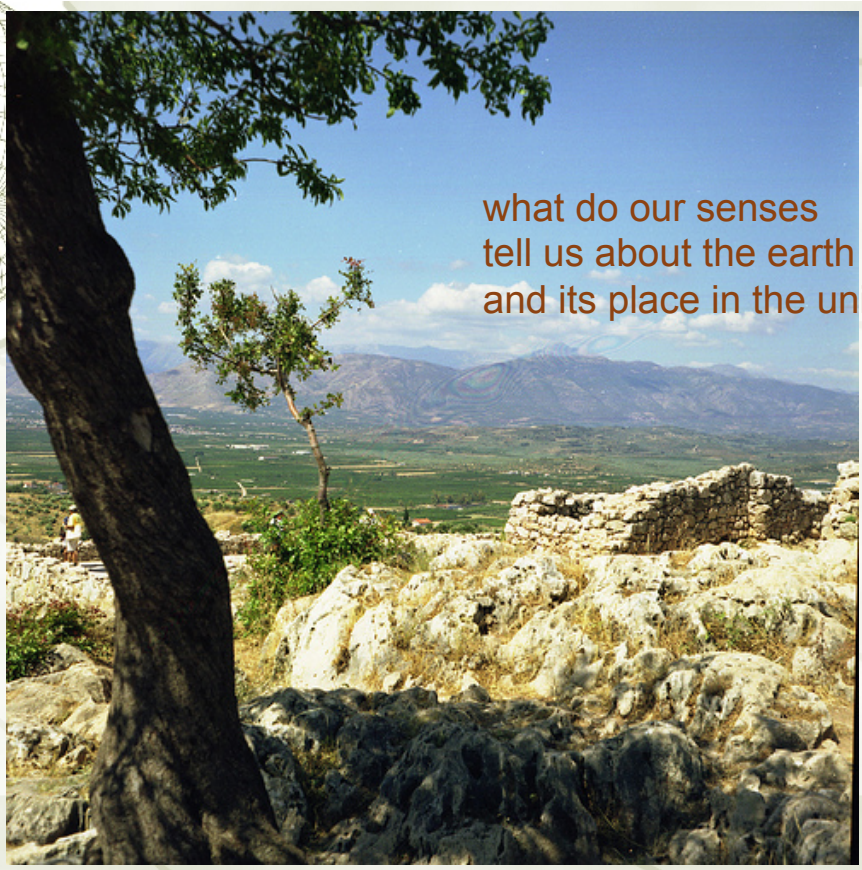
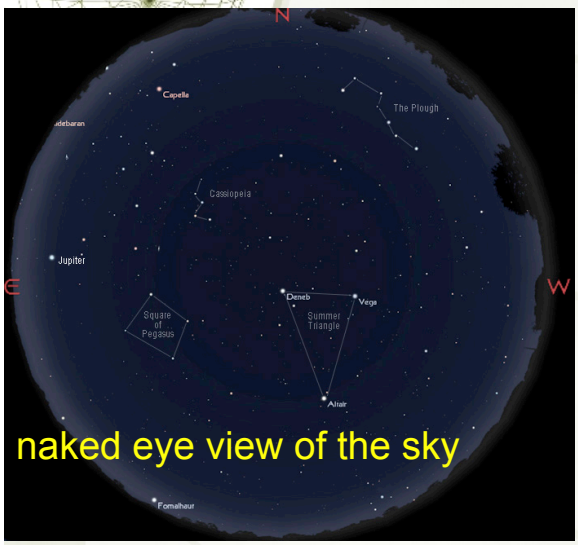
Lecture 2 : Early Cosmology

- Getting in touch with your senses…
- Greek astronomy/cosmology
- The Renaissance (part 1)

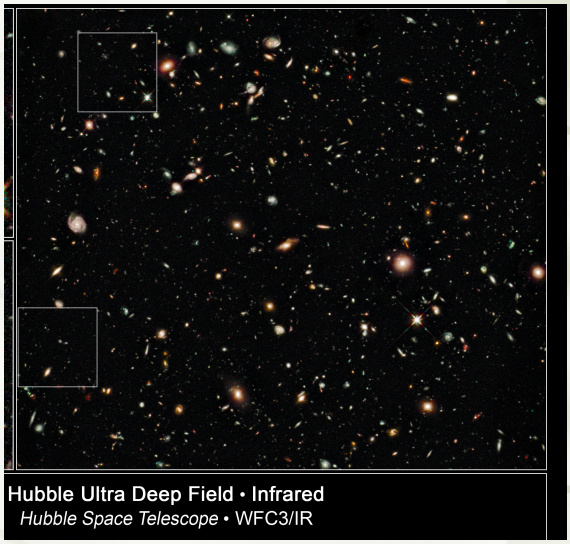


what do our senses
tell us about the earth
and its place in the universe

Discussion : What would an unaided observer deduce about the Universe?*



naked eye view of the sky


Hubble Ultra Deep Field • Infrared
Hubble Space Telescope • WFC3/IR

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

* no telescopes, microscopes, computers etc

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 Babylonians were the first to recognize that astronomical phenomena were periodic and to apply mathematics to predict astronomical events (e.g. eclipses) – Babylon, Newton and All That- a Four Thousand Year History by Patricia Fara

IIa : Digression

The records of Babylonian astronomy are the oldest documented investigations of the natural world: they are quantitative and collaborative and seek to predict the future positions of celestial bodies.

But they also possess two features that confound any simple identification with "science": they lack geometric or physical models for the heavens, remaining content with numerologic regularities; and they are saturated with astrology....

Michael D. Gordin

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5

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
  - Myth of the Flat Earth is a modern misconception that the prevailing cosmological view during ancient and medieval times that the Earth is flat, instead of spherical (Russell (1997)- "The Myth of the Flat Earth", Studies in the History of Science)

Relative size of Earth and Moon

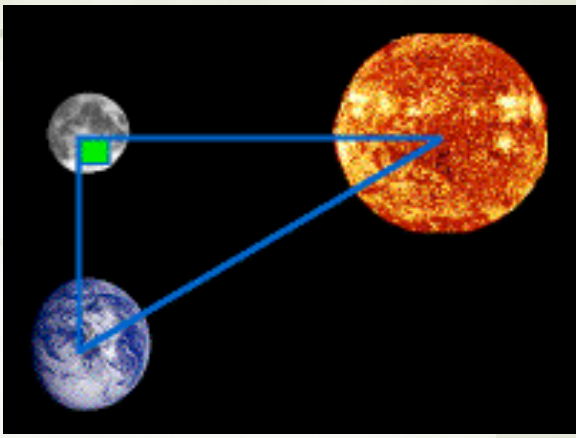
Aristarchus of Samos (310-230 B.C.)

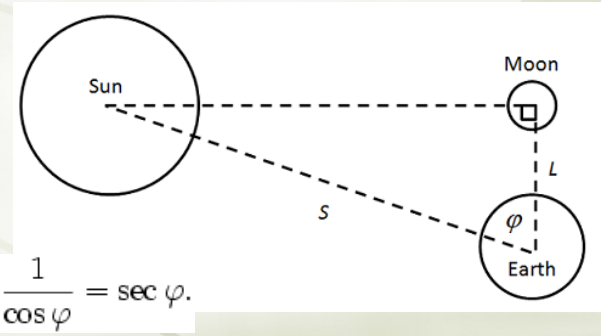
- Using eclipse data and geometry:
  - Measured relative sizes of Earth, Moon
  - Measured distance to Moon (how?)*
- Attempted to measure distance to Sun
  - Need to measure (using time interval ratios) the angle of Sun when Moon is exactly at 1st or 3rd quarter
  - Then use trigonometry and known Earth-Moon distance to get Sun's distance
  - Very difficult measurement… He deduced that Sun is 20 times further from Earth than Moon… actual answer is that Sun is 400 times further.
  - First to propose a **heliocentric model**!

*Aristarchus around 270 B.C. derived the Moon's distance from the duration of Lunar Eclipses (next slide)

Aristarchus

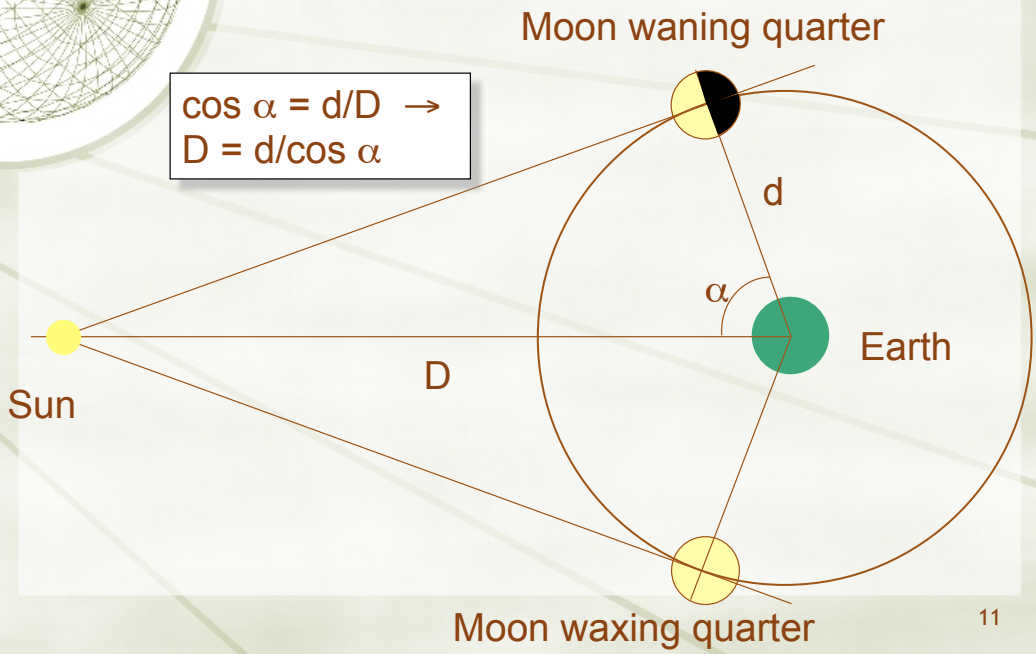
- When the sun casts its rays on the moon to form a half moon at night, a right triangle is formed between the Earth, Sun, and Moon.
- Therefore, the distance from the sun to the moon, the Moon to the Earth, and the Earth to the Sun forms a right triangle





$$\frac{S}{L} = \frac{1}{\cos\varphi} = \sec\varphi.$$

Aristarchus Earth-Sun distance



Distance of Moon from Earth

Lets do the math... its not hard

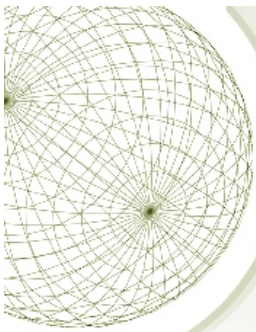
If the Earth is a sphere and the Moon moves in a large circle around the earth

Let d be the radius of that circle (see previous figure) and **T** be the time for the Moon to go around once (1 Month- 720 hours)
Using geometry the Moon covers a distance of **2πd**

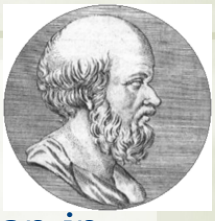
- An eclipse of the Moon occurs when the Moon passes through the shadow of the earth, on the opposite side from the Sun (its a full Moon)

If r is the radius of the Earth the shadows width is **2r**
Let **t** be how long the eclipse lasts (about 3 hours)

It takes time T to cover 2πd and t to cover 2πr- so 2πd/2r=T/t and a little algebra gives d/r=60- so the distance of the Moon is 60 Earth radii- *if they only knew how big the earth is*



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

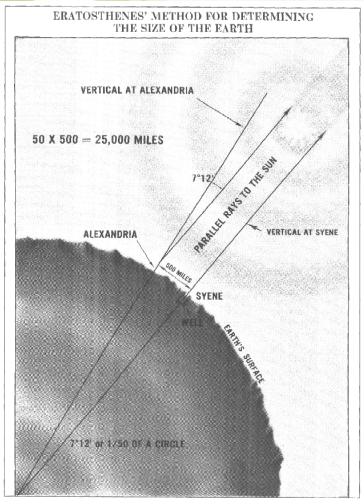
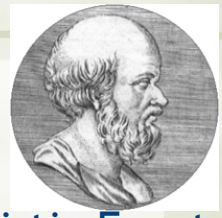


Figure 1

Eratosthenes



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  - How did he do it? (What do you do with those numbers?)
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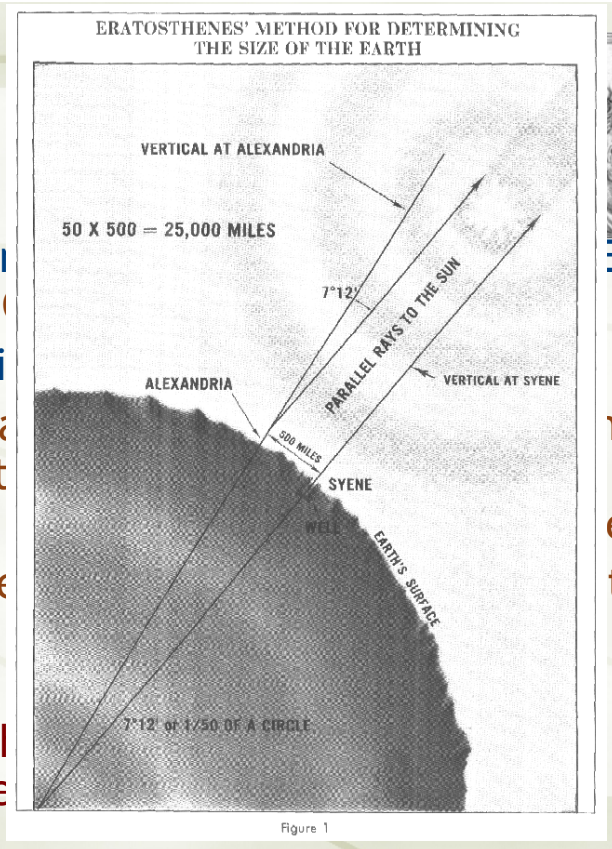

Figure 1

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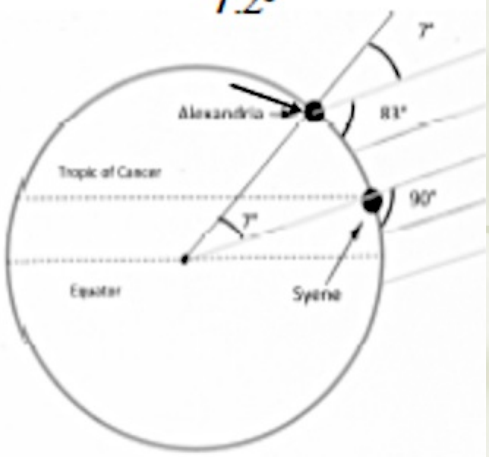
Eratosthenes And Size Of Earth

7.2⁰

- Angle of sun from Alexandria compared to Syene =7.2⁰
- Size of circle 360⁰
- 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

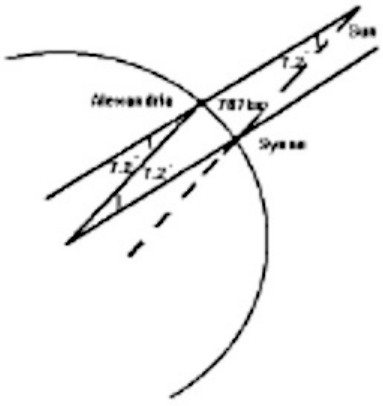


$$\frac{\text{angle of the sun}}{360^0} = \frac{\text{distance to Tropic of Cancer}}{Earth\ \ circumference}$$

- Light waves travel parallel to each other - congruent angles 7.2/360=787/X

(ratio of relative angles=ratio of lengths)

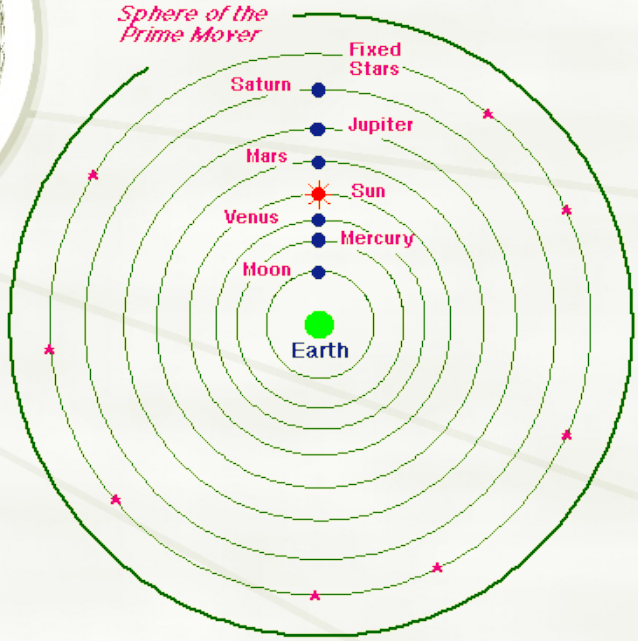
- X=39350 circumference of earth



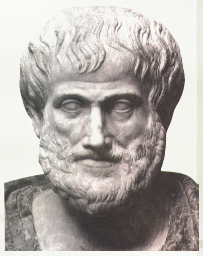
Cosmology of Eudoxus and Aristotle

- 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

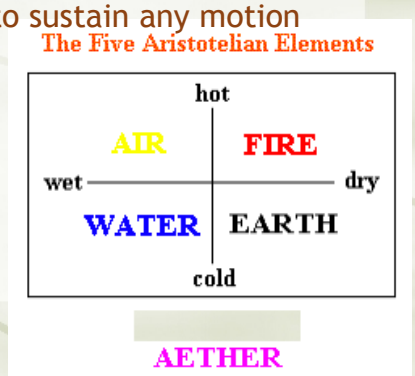


http://graduate.gradsch.uga.edu/archive/Aristotle.html

Aristotle's (384-322 B.C.) physics

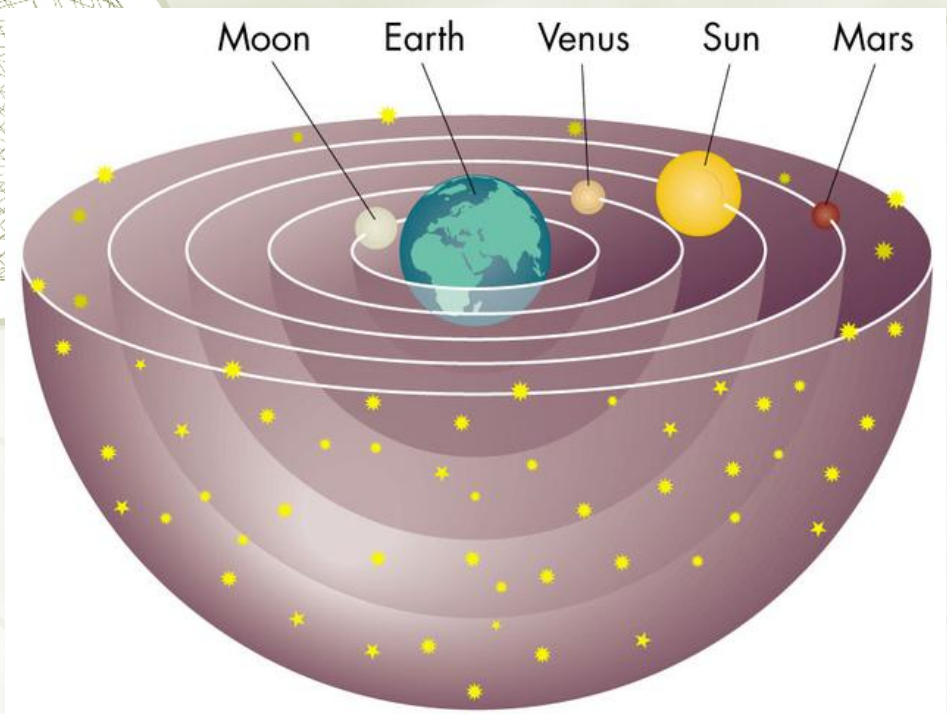
- Four basic (earthly) elements: earth, water, air, fire
- Each element *tends to move* toward its "natural" place:
  - E.g., rock (earth) falls in air/water, air bubble in water rises
  - "Natural motions" of earthly objects
    - straight lines toward center of Earth
    - bodies in motion naturally tend to come to rest
    - applied force causes deviation from natural motion
    - body at rest will remain so unless a force is applied
    - continual application of force needed to sustain any motion *other* than natural motion
  - Why is this in a Cosmology class?

Codification of our experience!



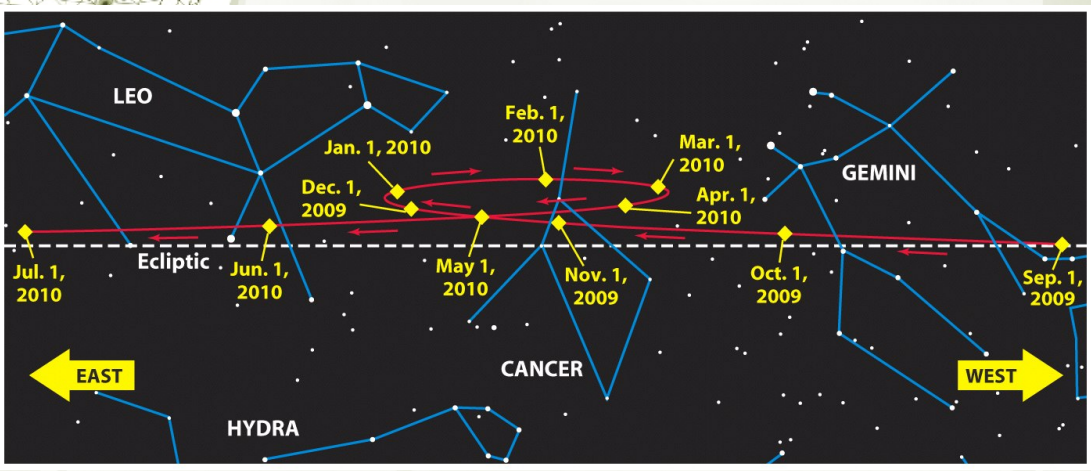
Aristotle's celestial physics

- 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 (observations had gotten better)
- 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?)



Geocentric model

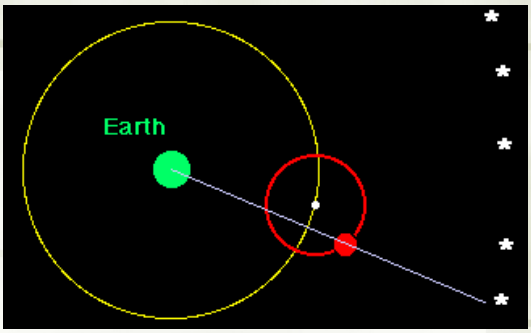
How Do the Planets Move in the Sky with time?



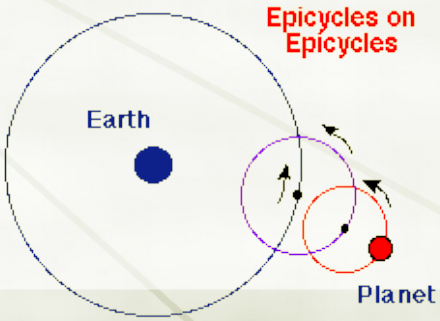
Retrograde motion of Mars with respect to the 'fixed' stars

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")



Dept. of Physics and Astronomy Univ. of Tennesse



Needed more and more epicycles to fit observed angular motion

Ptolemy and Homer…

Why do you care what a bunch of dead Greeks did?
Because

Aristotelian/Ptolemaic view prevailed in Europe and Islamic empire, through 1400's
and set the concepts for physics and astronomy for 1000 years
Geocentric model
Creation at finite time in past, for consistency with Christian theology

II : 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 Earthers 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 (science was international even 500 years ago)
  - 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 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.*

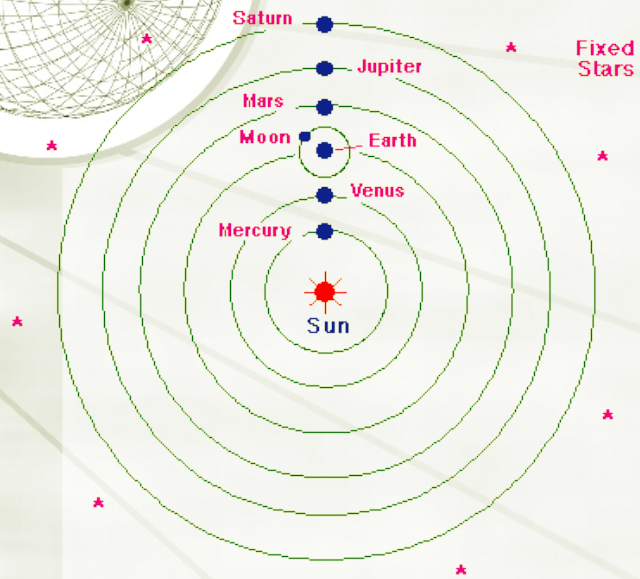
Copernicus

- Even though the mathematics in his description was not any simpler than Ptolemy's, it required fewer basic assumptions. By postulating only the rotation of the Earth, revolution about the sun, and tilt of Earth's rotational axis, Copernicus could explain the observed motion of the heavens. However, because Copernicus retained circular orbits, his system required the inclusion of epicycles.*Out of fear that his ideas might get him into trouble with the church, Copernicus delayed publication of them.*

Copernicus adapted physics to the demands of astronomy, believing that the principles of Ptolemy's system were incorrect, not the math or observations.

He was the first person in history to create a complete and general system, combining mathematics, physics, and cosmology.

http://scienceworld.wolfram.com/biography/Copernicus.html



Portrait from 1597 by Teothor de Bry

Tycho Brahe (1546-1601)

- Flamboyant and tyrannical aristocrat, but devoted to science
- Lived and observed on island off the coast of Denmark
- Last of the great "naked eye" observers
- Made planetary observations much more accurate than any previous… first to estimate *error bar* of a measurement
- Observed "new star" (Tycho's supernova; 1572)
- Demonstrated that a comet was beyond Moon's orbit
- From parallax observations of new star, comet:
  - knew they were not in Earth's atmosphere
  - evidence that heavens were not immutable
- **Collected the premiere dataset on the motion of the planets**

Tycho Brahe and the Origin of Scientific Funding

- He received an annual pension of five hundred dalers.
  - This was far more than the income of any other man of learning in Europe, and even for an aristocrat, it was a substantial income. Tycho set a new European standard for the financial support of scientific research.
  - It is estimated that Brahe's observatory cost about 1% of the Danish government budget during construction.

Uraniborg

Next time…

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

READING: *Finish reading Chapter 2 of text*