# Astronomical Observations

What did Ancient Peoples know?

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## The Sun

- ~1/2 degree angular size
- rises in east, sets in west
- smooth arc across sky
- "Noon" sun @ highest point in sky
- "Day" time between 2 noons
- Daylight depends on season





Sunrises in Greece

# The Moon

- similar to sun:
  - $\sim 1/2^{\circ}$ , rise in east set in west
  - Roughly same path in sky
- A little faster than the sun
- 29.5 day rotation of phases!





### Lunar Eclipse regular long period cycle





### Lunar Eclipse regular long period cycle

#### Eclipse

#### Phase

















# Solar Eclipse

Hard to predict; only possible during new moon and certain times of year







# Celestial Sphere

Constellation Orion

# **Celestial Sphere Motion**

java constellations

# Retrograde Motion

Mars (& Uranus!) - Fall 2003

# Comets

Hale-Bopp, August 6, 1997 Joshua Tree National Monument, CA



# Ancient Greeks

### **Celestial Sphere**



### Summer Solstice in Northern Hemisphere







### Winter Solstice in Northern Hemisphere





### Geocentric Point of View





# Thales of Miletus

- 7th-6th Century BC
- "1st Scientist"
- Distance to ship from shore
- Polaris as navigation aid
- Predicted eclipse of 585 BC?



# Pythagorus of Samos

- 6th Century BC
- "1st Mathematician"
- Earth sphere in center of universe
- Circular orbits and perfect spheres
- Music of the Spheres



# Anaxagoras of Clazomenae

- 6th Century BC
- Sun and moon just places
- Moon lit by sun
- Cause of Eclipses
- Jailed for teaching sun and moon not gods

### Phases of Moon & Eclipses



### Phases of Moon & Eclipses



- Moon's orbit inclined to earth's orbit by 5.1°
- Eclipses only possible at B and D

### Eudoxus of Cnidus

- 4th Century BC
- Observatory on Cnidus/mathematician
- 1st Planetary Model "homocentric" planet





## Aristotle

- 4th Century BC
- "The Philosopher"
- Principle of Uniform Circular Motion
- 55 nested spheres for planetary system
- Proof Earth is sphere (lunar eclipse/polaris/elephants)
- Rejected heliocentric theory (inertia/parallax)





### Aristotle's Bad Physics

- Natural state of motion is to be at rest; moving requires a force.
- Natural place for matter is to be as low as possible. (Good for earth is a sphere, bad for moving earth.)
- Objects fall with constant speed & speed is proportional to weight.
- PUCM only motion that can go forever is celestial constant speed circular motion.
- Celestial stuff and motions are different (perfect & unchanging) than earthly stuff (which decays.)

# Strato of Lampsacus

- 3rd Century BC
- 3rd Director of Lyceum (Aristotle's school.)
- Falling is accelerated motion.
  - Water drops & rock from different heights
- Rate of falling NOT proportional to weight.
- Too bad no one cared. :-(

### Aristarchus of Samos

- 3rd Century BC
- Sun about 19x farther/bigger than moon
- Sun about 7x size of Earth
- Heliocentric theory

Earth-moon-sun at exactly quarter phase





Dotted lines = 1/2 degree angular size: *moon and sun must be tangent to these lines* Shaded region = shadow of earth





# Eratosthenes of Cyrene

- 3rd Century BC
- Head Librarian of Alexandria
- Size of the Earth (~250,000 stadia)





# Hipparchus of Nicea

- 2nd Century BC
- "1st Astronomer"
- Catalogues >800 stars (brightness and position)
- Length of year (only 6 minutes off)
- Precession of Equinoxes
- Applies epicycles & eccentrics to sun and moon
- (Trigonometry 1st table of chords)



# Claudius Ptolemy

- 2nd Century AD
- Syntaxis aka The Almagest
- Total synthesis of Ancient Greek Astronomy
- 1st working/predictive model of the solar system
- Eccentric epicycles and equants applied to all planetary motions



#### Ptolemeic Model for Mars

Ρ Μ Q С Q is equant point E C is deferent center E is earth P is epicycle center M is mars EC = CQQP sweeps with constant angular velocity PM sweeps with constant angular velocity

> Each planet had 7 separate, independent parameters. (2 radii, equant, 2 rotation rate, 2 initial angles)

# Indian Astronomy



# Aryabhata

- 476-550
- 1<sup>st</sup> big mathematical astronomer
- Earth rotates & stars fixed (naturally, this was most criticized thing he said.)
- Possibly argued that planetary orbits were elliptical (but still geocentric.)
- Sine function



## Brahmagupta

- 598-670
- Fully explained "0" and decimal place notation
- Negative numbers
- Big astronomy & mathematics compilation
- Translated into Arabic, and forms basis of Hindu-Arabic decimal number system

# Islamic Astronomy



Abu Ja'far Muhammad ibn Musa Al-Khwarizmi

- ~780-~850
- House of Wisdom, Baghdad
- *Hisab al-jabr w'al-muqabala* = Algebra
- *Algoritmi de numero Indorum* = Hindu-Arabic numerals; "algorithm"
- Astronomy & numbers from India

# Scientific Revolution



# Nicholas Copernicus

- 1473-1543
- 1511: The Little Commentary
- 1543: On the Revolutions of the Heavenly Orbits
  - A coherent system
  - Principle of Uniform Circular Motion
  - Mathematically similar to Ptolemy

### Some Orbital Configurations – Superior Planet



### Some Orbital Configurations – Inferior Planet



- 1. inferior conjunction
- 2. greatest elongation
- 3. superior conjunction
- 4. greatest elongation  $(\theta)$

### Calculating the Sidereal Period of a Planet



Inner planet makes exactly 1 more orbit than outer planet



Gold Nose!

# Tycho Brahe

- 1546-1601
- 1572: Supernova
- 1576-1597: Uraniborg
  - 1577: Comet
  - 1584: Stjerneborg
  - 1588: Tychonic hybrid
- 1598-1601: Prussia















STELLÆBURGUM for OBSERVATORIUM IN INSULA HVENA, EXTRA ARCEM URANIAM.

### Comet of 1577



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# Johannes Kepler

- 1571-1630
- 1596: Mystery of the Cosmos
- 1600-01: Brahe's assistant
- 1609: New Astronomy
  - Ellipses
  - Equal Area
- 1618: Harmony of the Worlds  $T^2/R^3$  constant



### 3 Laws of Planetary Motion (aka Kepler's Laws)

1. Orbits are ellipses; sun @ focus





c = distance from center to focus
R = semi-major axis
p = perihelion
a = aphelion

e = c/R p = R - ca = R + c

### 3 Laws of Planetary Motion (aka Kepler's Laws)

- 2. Equal Areas in Equal Times
- 3. Harmonic Law



 $\frac{T^2}{R^3} = k$ 



# Galileo Galilei

- 1564-1642
- March 1610: Sidereus Nuncius
  - Lot more stars than with naked eye
  - Moon is mountainous
    - Moon isn't "perfect!"
  - Planets are discs, stars still pointlike
  - Jupiter has 4 moons
    - More than one center of motion!



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### • 1616: Bellarmine

- Because there is no proof of earth's motion, G. agrees to not teach the Copernican model
- 1632: Dialogues Concerning the Two Chief Systems of the World
  - Argues against "perfect" heavens because moon is mountainous and sunspots
  - Concept of inertia and basic motion ideas finally straightened out
  - Venus' phases proves Ptolemy wrong, but he doesn't mention Tycho
  - His incorrect theory of tides he used as "proof" that the earth rotates.
  - Pope very upset at mocking tone & ignoring Tycho. Inquisition Time!

- 1633: Big Trial
  - G. admits to teaching C. even though he agreed not to
  - House arrest for the rest of his life
  - Still smuggles out 1 more book published in Holland
    - More details and math on basic motion ideas
    - Law of Falling Bodies

- First stellar parallax finally measured in 1838
- Foucault pendulum in 1851



# Isaac Newton

- 1642-1727
- 1665-7: Plague; Cambridge closed
- 1672: Royal Society (reflecting telescope/optics)
- 1687: Principia Mathematica
  - 3 Laws of Motion
  - Universal Gravitation
  - Tides
  - Fluid Mechanics
- 1704: Optics (after Hooke dies in 1703)