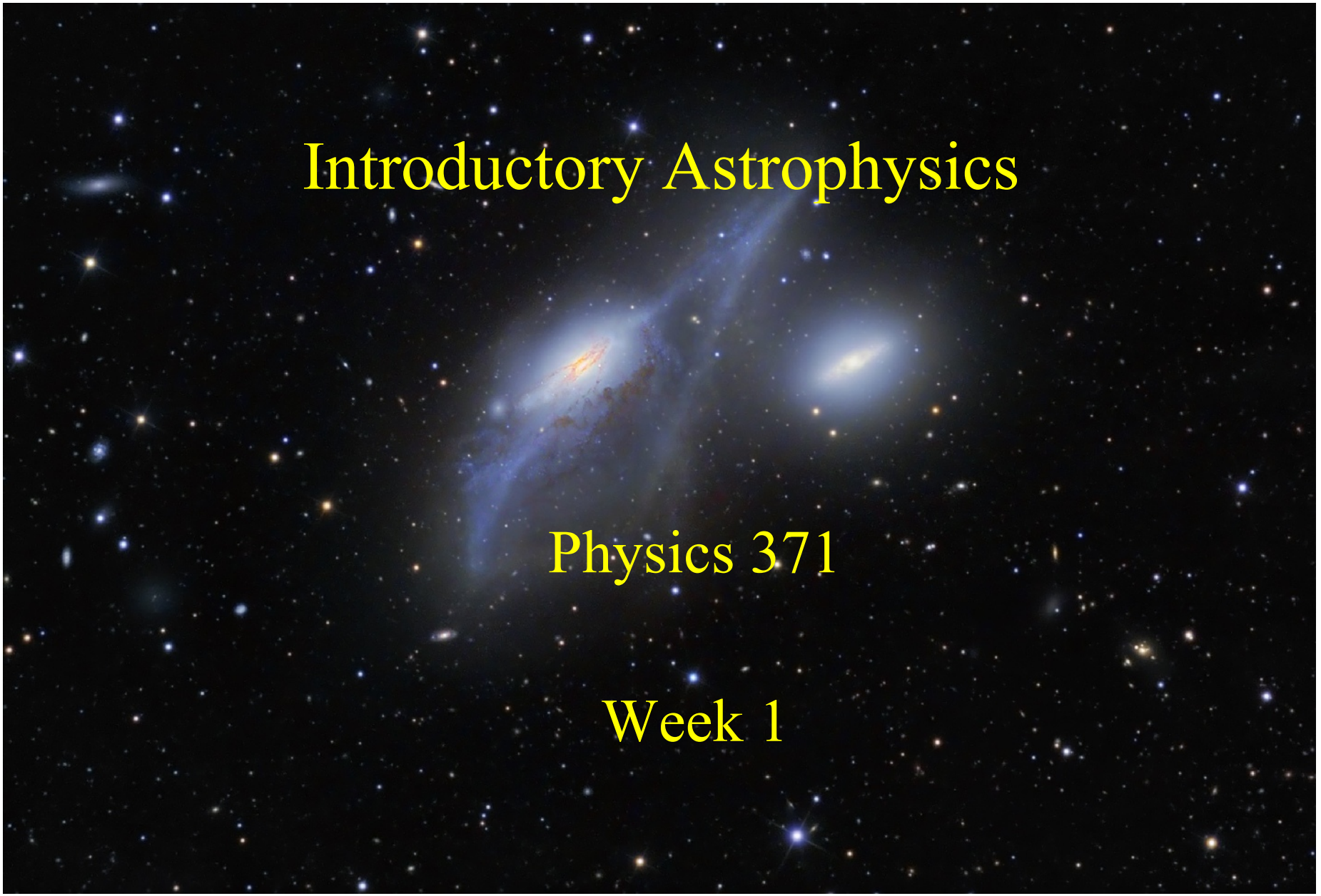

Introductory Astrophysics
Physics 371
Week 1

Outline

- Syllabus
- What did the ancients know about our universe?
  - Naked eye universe
  - Celestial sphere
  - Coordinate systems
- Copernican Revolution (Brief)
- Planetary Configurations.
- Telescope basics

Chapter One "The Celestial Sphere"

1.1 The Greek Tradition

1.2 The Copernican Revolution

1.3 Positions on the Celestial Sphere

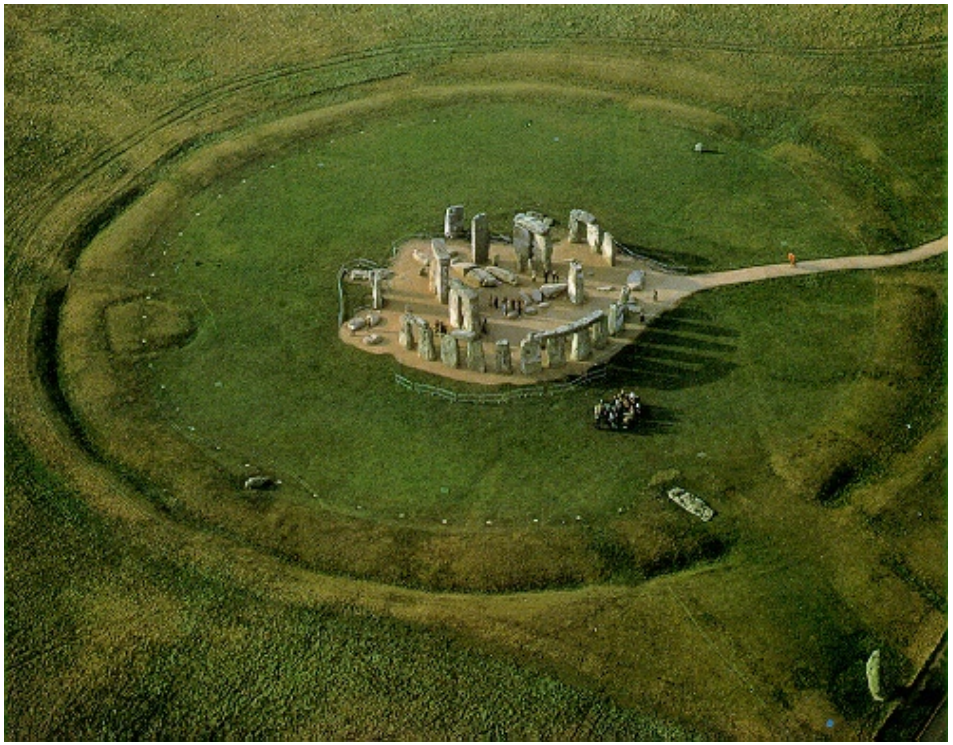
1.4 Physics and Astronomy

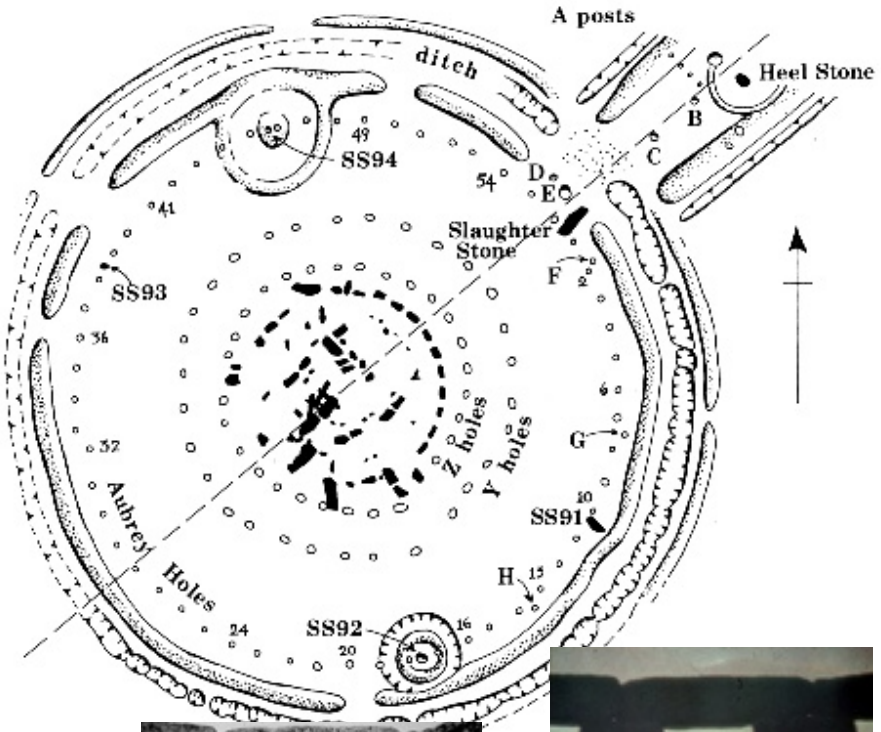
What did the Ancients know?

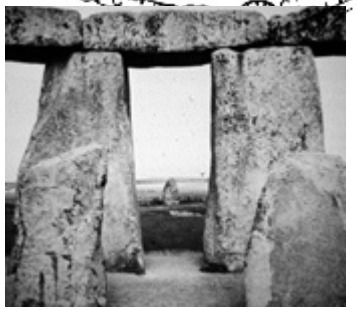
- Poorly documented/understood cultures
  - People of stonehenge
  - Plains Indians, Anasazi
  - Mayans
  - ►These left behind calendar-like constructions.
- Well documented cultures
  - Chinese
  - Mesopotamian (Babylonians, etc), Egyptian
  - Greek
  - Islam
  - Records of Seasons, lunar cycles, eclipses, comets, novae, star maps, models
  - Unknown nature ►superstition► astrology
  - Sky important for farming and religion

Stonehenge

- Check out: http://witcombe.sbc.edu/earthmysteries/EMStonehenge.html
- 2950 BC – 1600 BC (3 phases)
- 56 Aubrey holes = 2xlunar periods = 3 Saros cycles



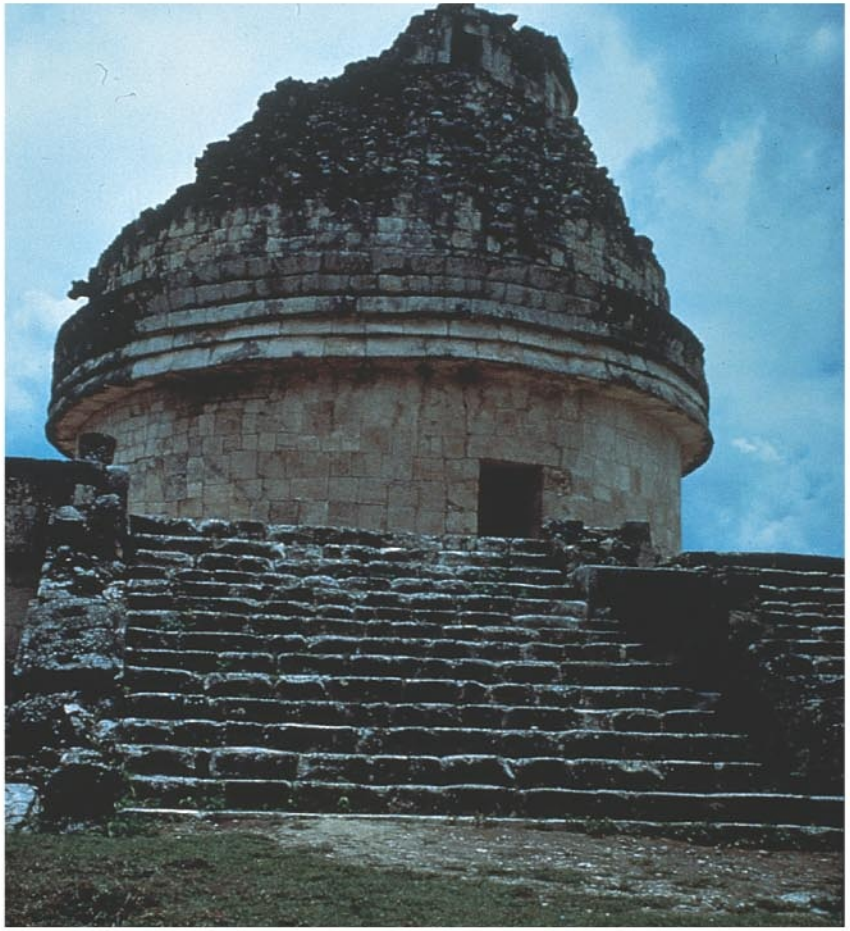




- Heel stone marks sunrise on Summer Solstice

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

(a)



(b)

(c)

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

The naked-eye universe

- The Sun
- The Moon (and its phases)
  Eclipses
- 5 Planets (plus the Earth)
  - Mercury, Venus, Mars, Jupiter, Saturn
- 6500 Stars (contained within 88 constellations)
- 3 galaxies
- Occasional novae and supernovae
- comets
- Aurora, meteors, and other atmospheric phenomena

- Cyclic phenomena

Knowledge of the Ancient Greeks

- Ideas and philosophies were rich and varied, some bad for science:
  - Plato: truth through pure thought over observations
  - Aristotle (and almost everybody): Earth is unmoving, heavens are perfect
  - Philolaus: Earth in motion around invisible "fire"
  - The Geocentric universe model (Ptolemy AD 140 – he added equants)
- Many ideas still accepted today:

1) Earth, Moon and planets are spherical (Pythagoras c 570-497 BC)

2) Phases of Moon due to shadows cast by Sun (Aristotle c 384-322 BC)

3) Eclipses caused by Earth-Moon-Sun alignments (Aristotle)
   - A moving Earth *should* cause parallax effects (Aristotle)

5) Earth revolves around the Sun (Aristarchus 310-230 BC)

6) Distance ratios between Earth, Moon, and Sun (Aristarchus)

7) Measured size of Earth (Eratosthenes c 276-195 BC)

8) Earth's spin axis precesses with 26,000 yr period (Hipparchus 160-127 BC)

9) Approximate sizes and distances of Earth, Moon and Sun (Hipparchus)

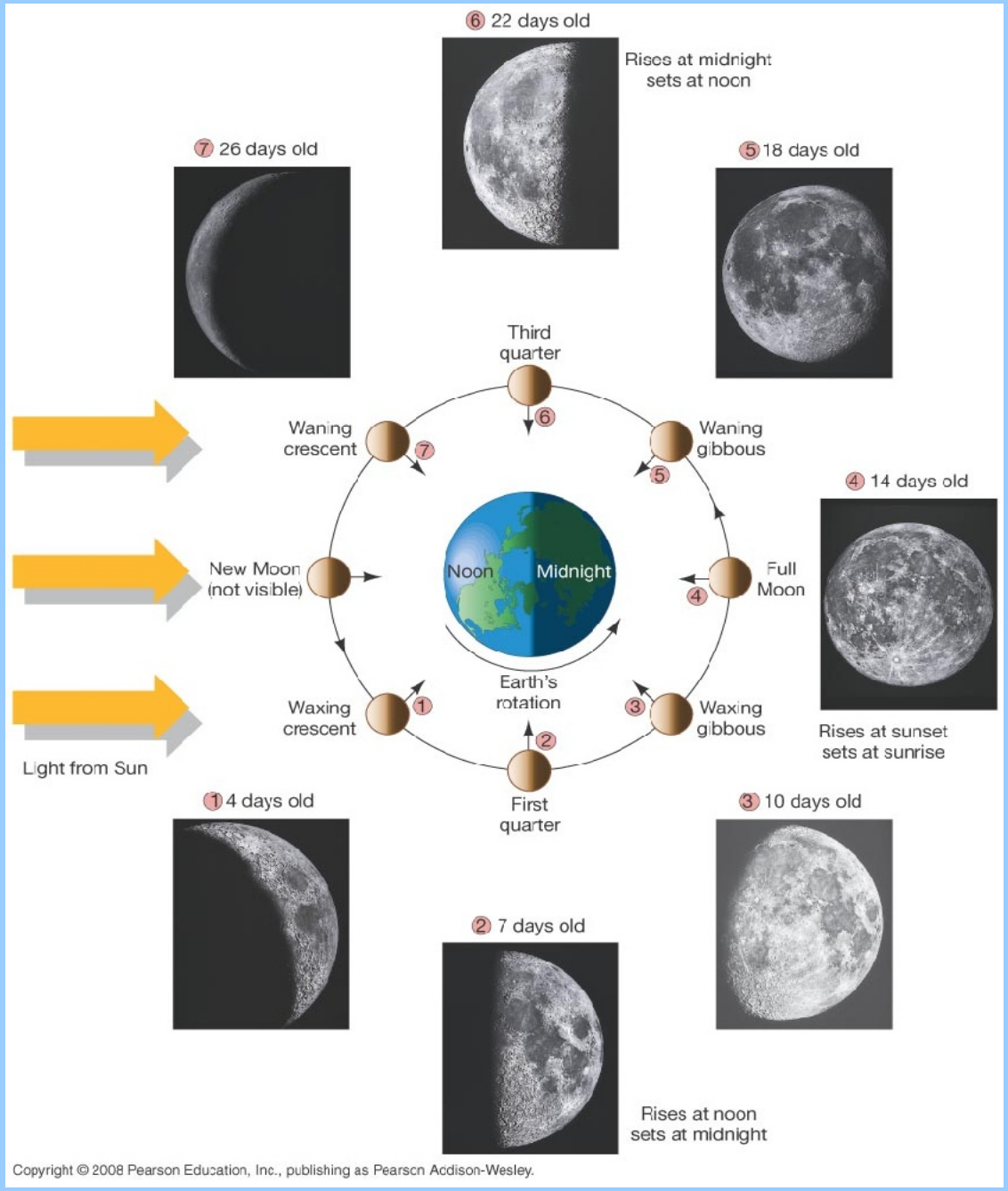
10) Retrograde motion of planets can be modelled with epicycles and deferent

Knowledge of the Ancient Greeks

(1) How do we know the Earth is a sphere?

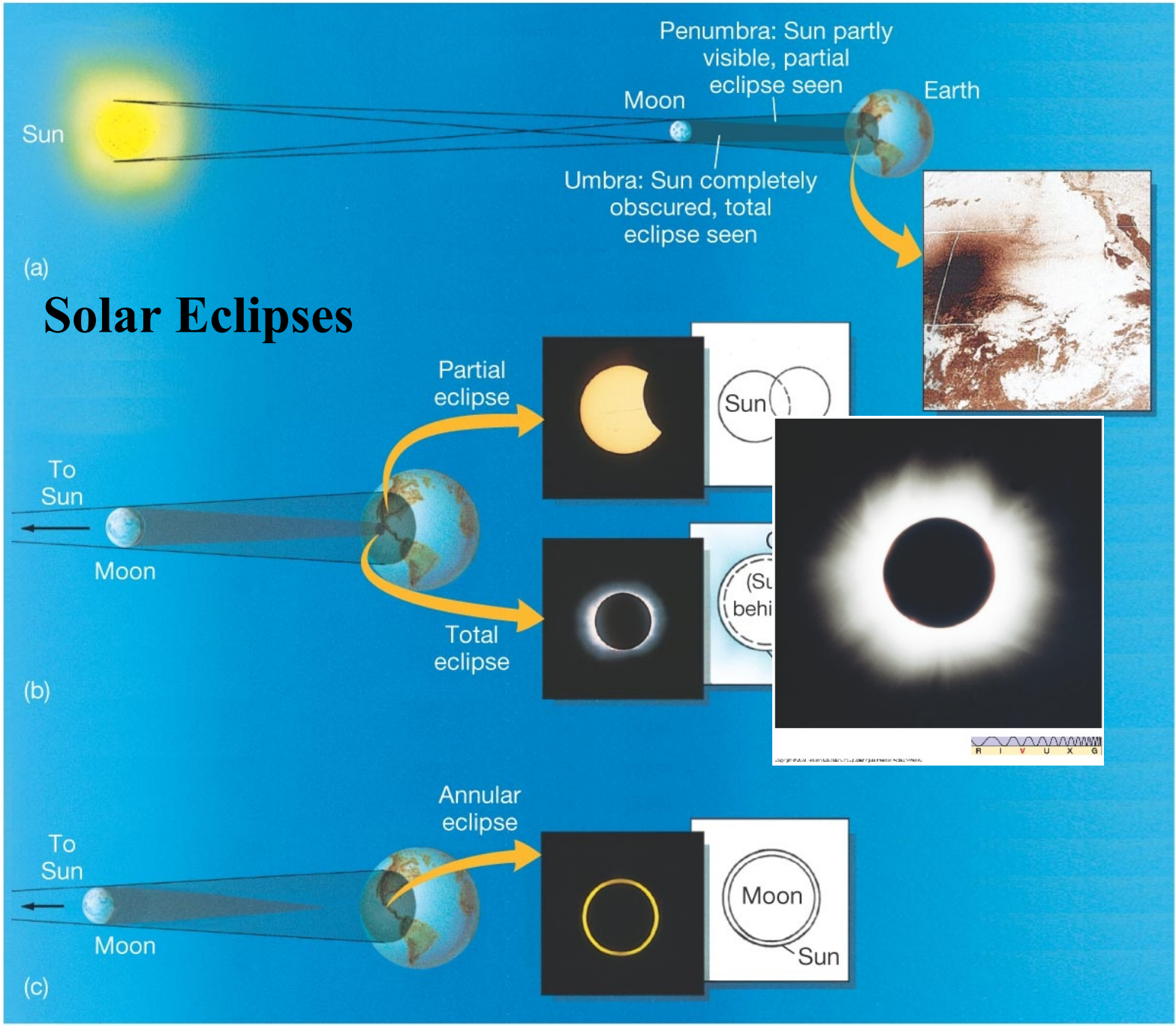
Knowledge of the Ancient Greeks

(2) What causes the phases of the Moon?



Knowle
Ancient G

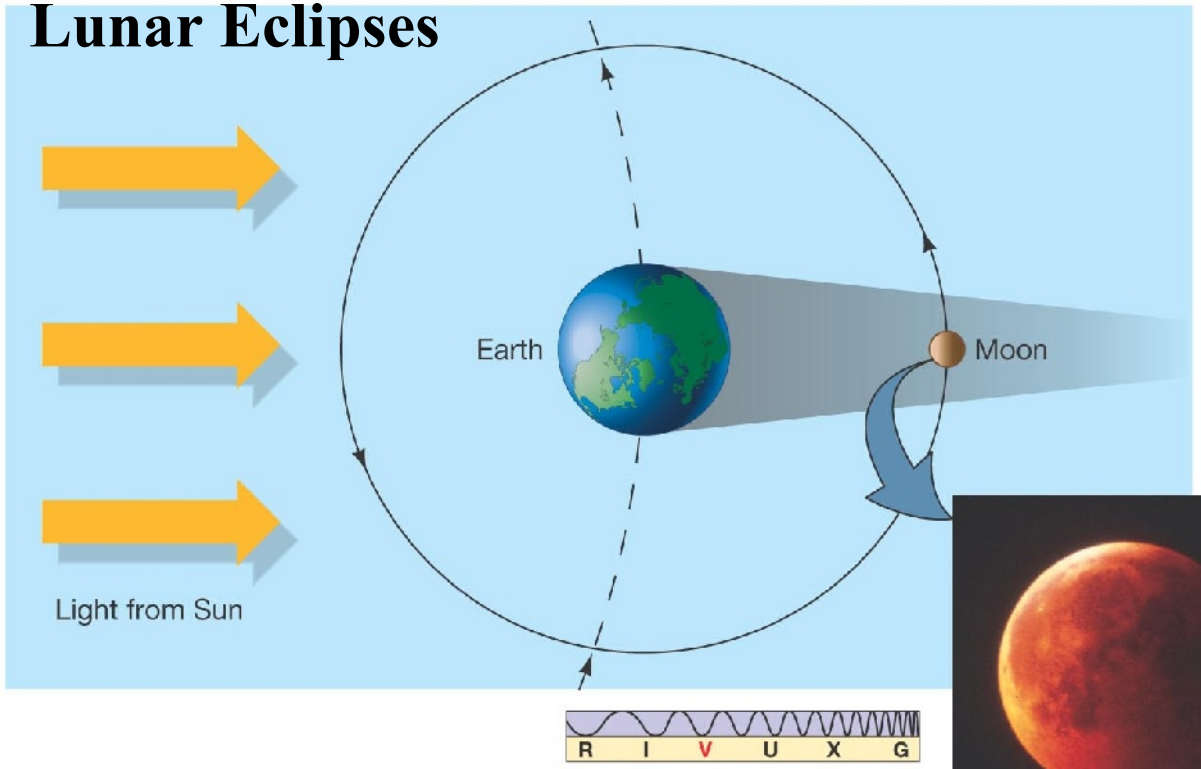
(3) E
caused
Moc
align



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

Knowledge of t
Ancient Greeks (c

(3) Eclipse
caused by Ea
Moon-Sun
alignments?

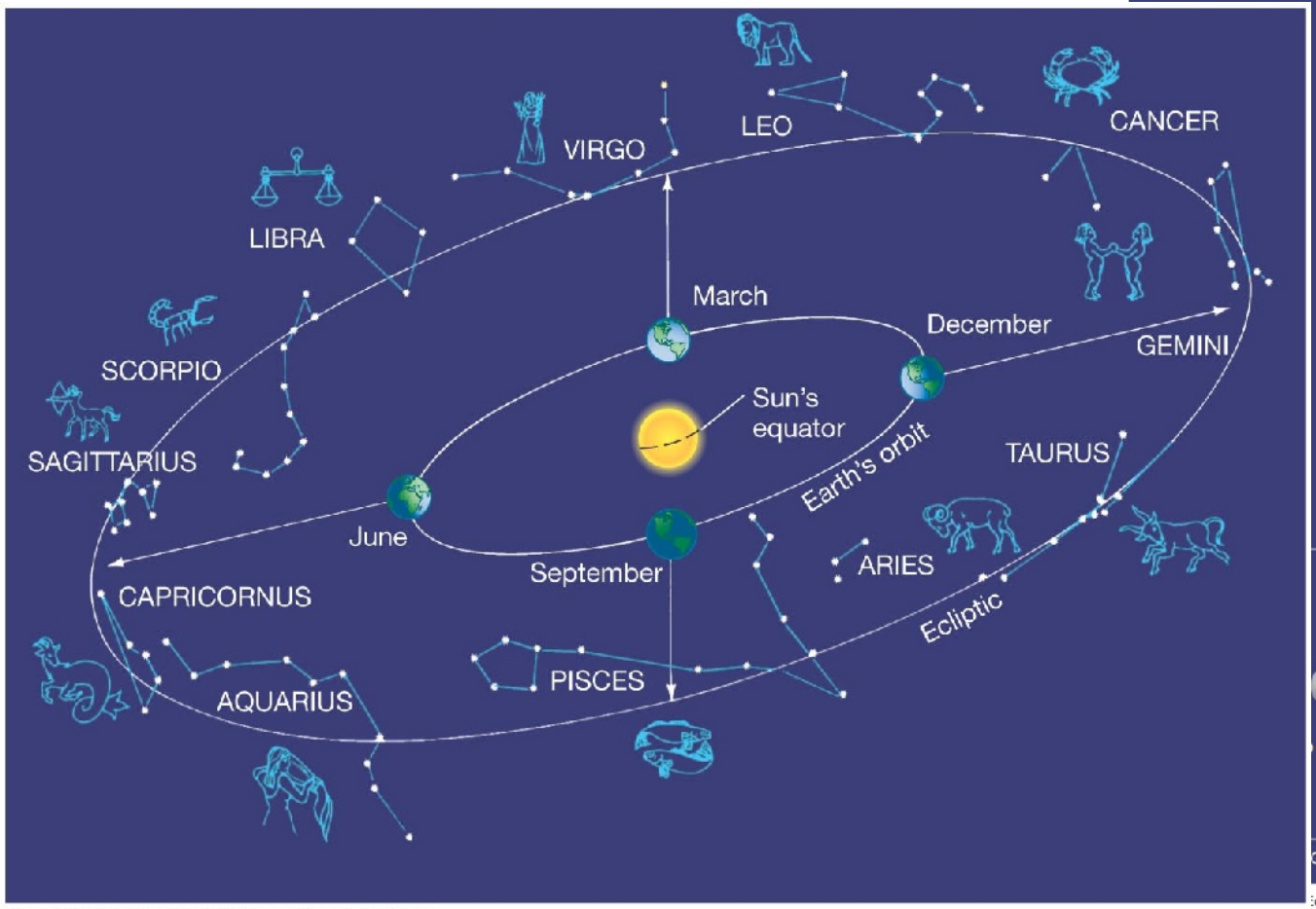


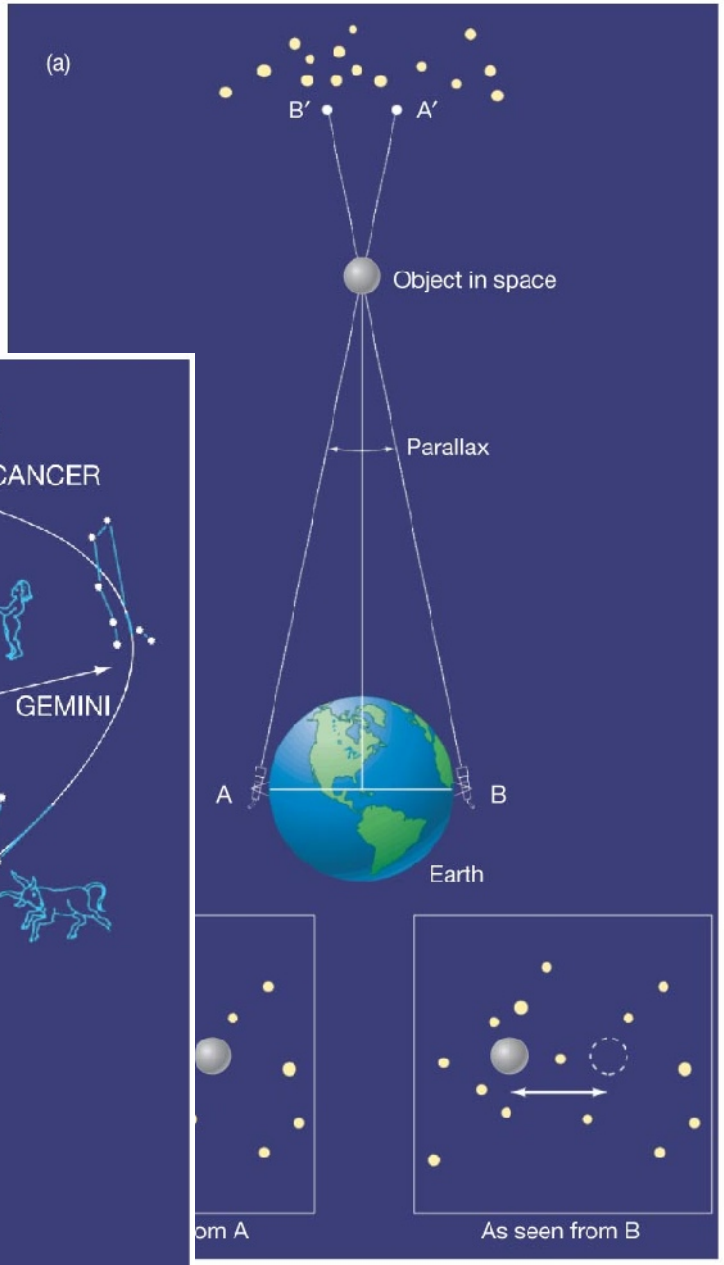
Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley

Knowledge of the Ancient Greeks (cont.)

(4) If Earth is moving, parallax effects sh

Parallax = the apparent motion or shifting o
motion or shifting of the observer.



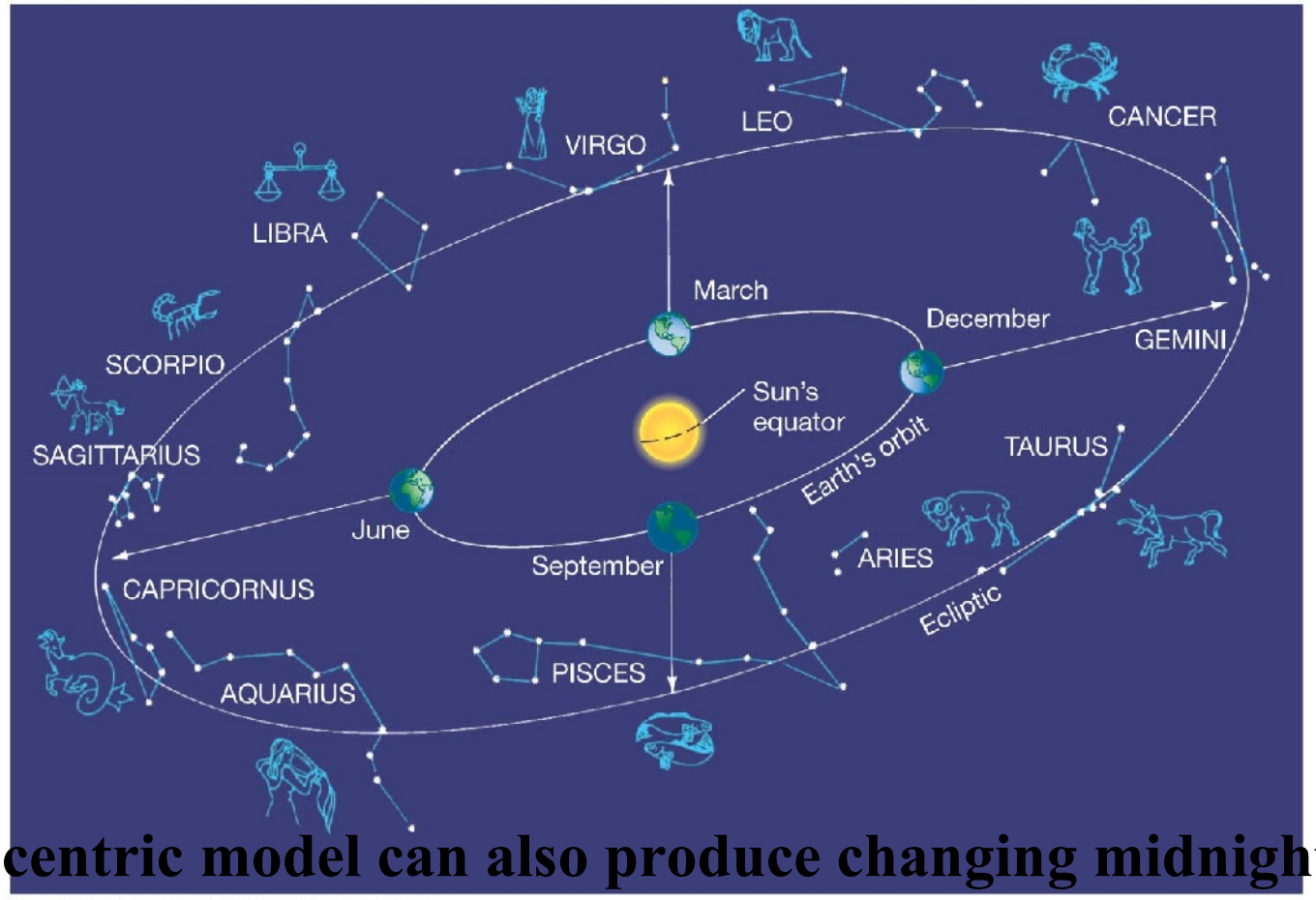


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

Education, Inc., publishing as Pearson Addison-Wesley.

Knowledge of the Ancient Greeks (cont.)

(5) Earth revolves around the Sun (Aristarchus).



Copyright © 2008 Pearson Education, Inc. publishing as Pearson Addison-Wesley.

A geocentric model can also produce changing midnight constellations and seasons. More info about planets was needed to distinguish the two models...

Knowledge of the Ancient Greeks (cont.)

(6) Distance ratios of the Sun and Moon from Earth.

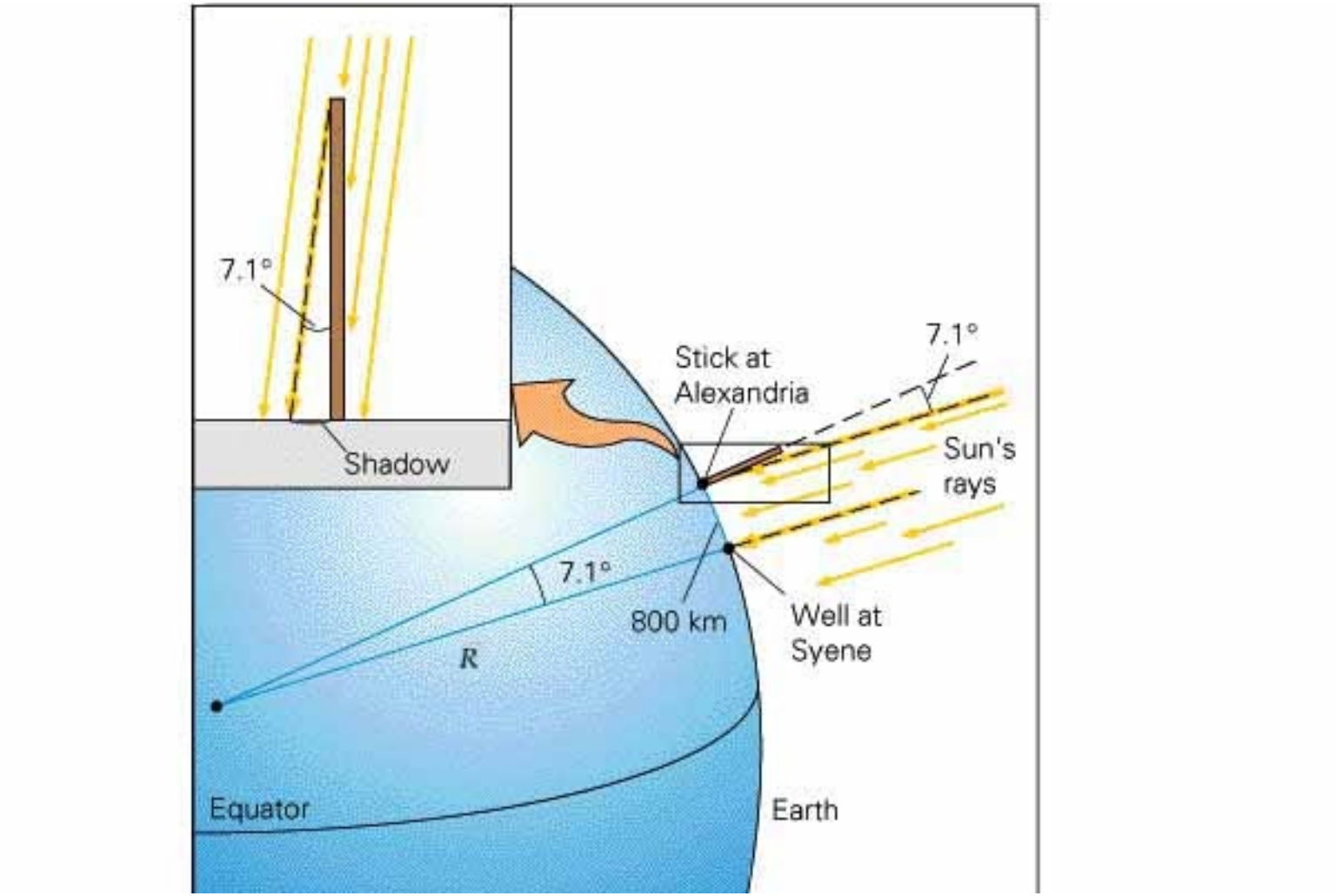
(9) Size ratios of the Sun, Moon and Earth.

(Draw on board.)

Greeks and a Spherical Earth

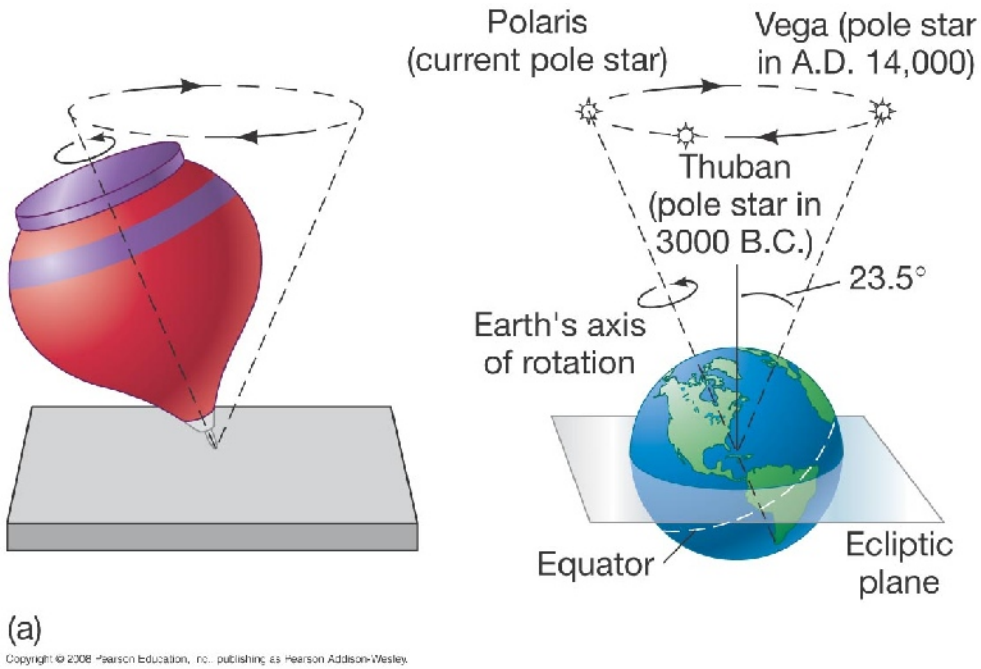
(7) Eratosthenes' radius of Earth (6460 km in 200 B.C.)

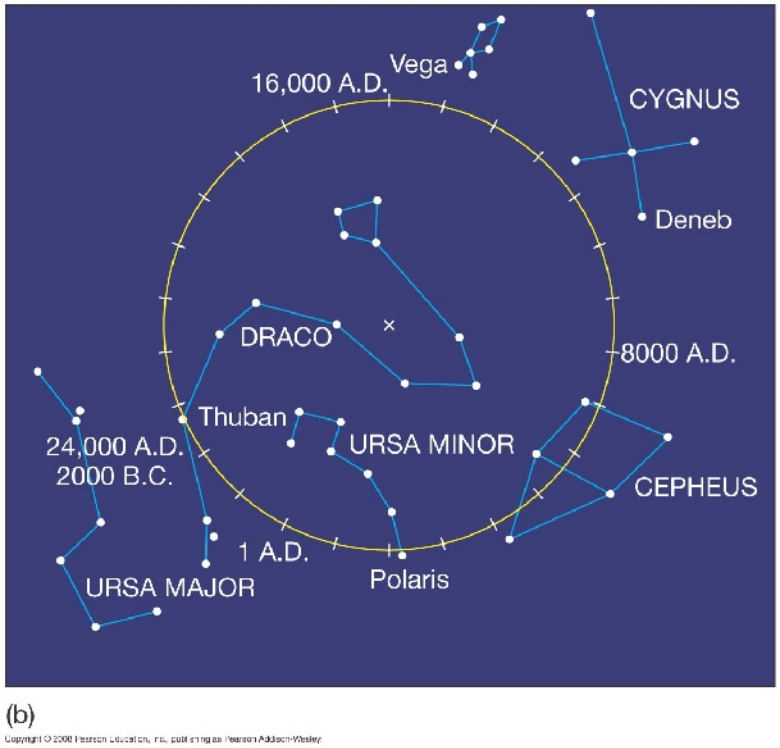
- Modern value is 6378 km



Knowledge of the Ancient Greeks (cont.)

8) Earth's spin axis precesses with 26,000 yr period (Hipparchus 160-127 BC)





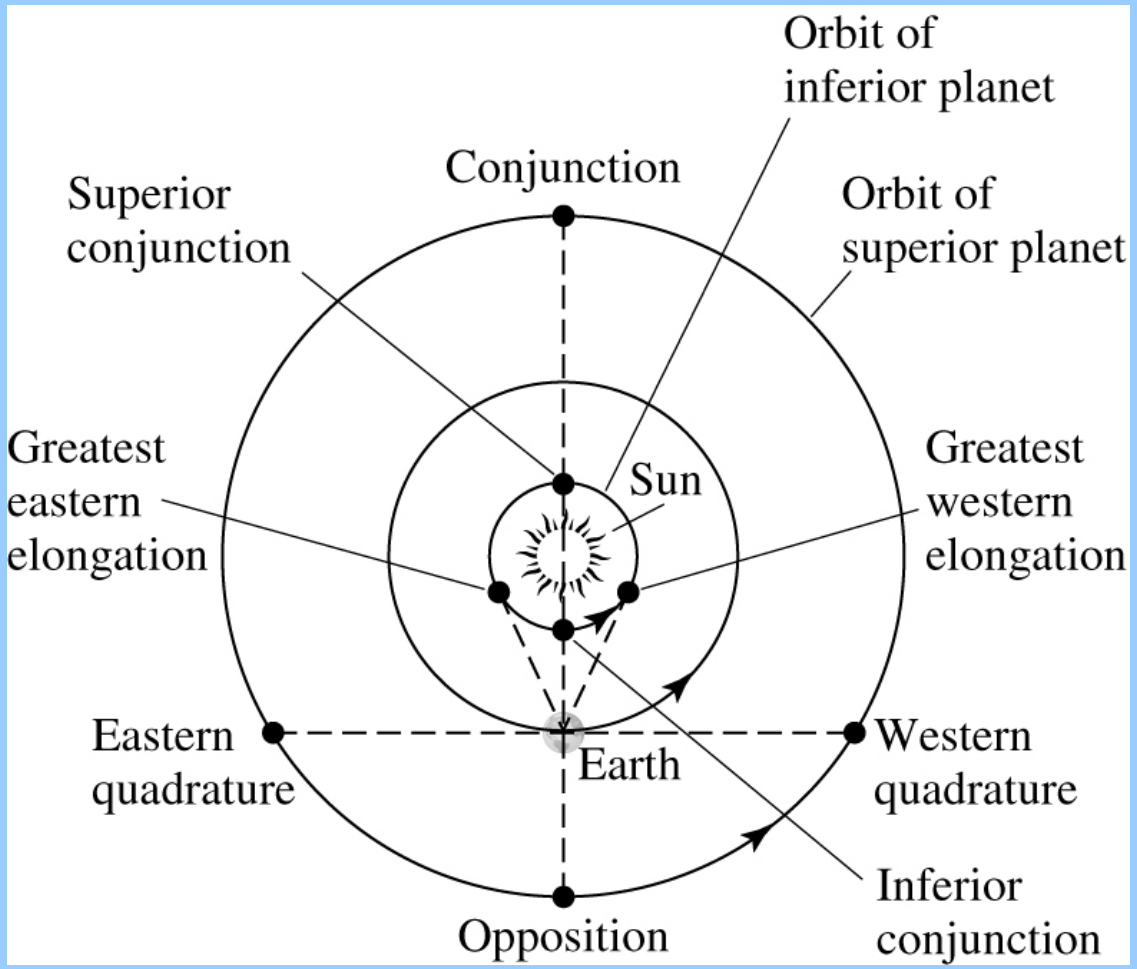
10) Retrograde motion of planets can be modelled with epicycles and deferents (Hipparchus)

The Appearance of the Planets

- Rise and set roughly with stars
- Change brightness, position and angular speed across sky.
- All orbit CCW as seen from "North".
- Usually eastward motion, occasional westward motion
- Modern view
  - Orbits are ellipses with the Sun near one focus
  - It takes 6 numbers to specify an orbit
    - Inclination *i*
    - Longitude of ascending node, Ω
    - Argument of periapsis, ω
    - Eccentricity (or minor axis), ε (or b)
    - Major axis, *a*
    - Mean anomaly at epoch, Mo

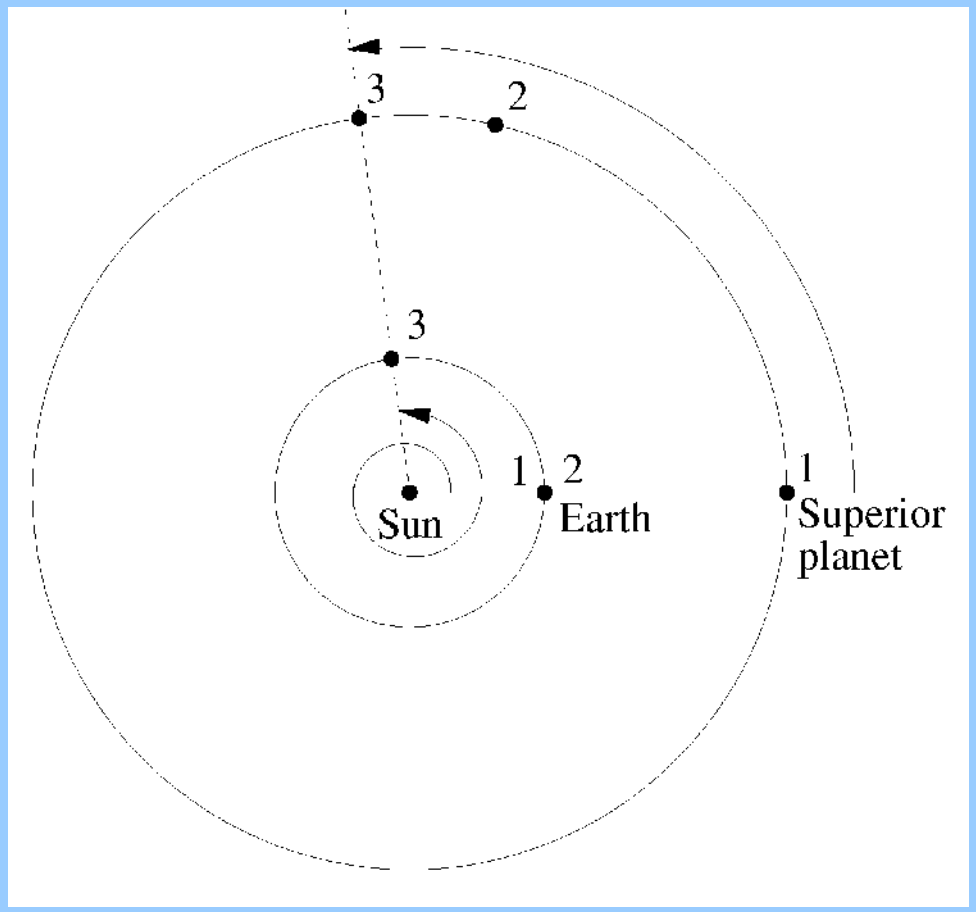
Planetary Configurations

- Inferior planets
  - Inferior conjunction
    - In front of the sun
  - Greatest elongations (morning and evening stars)
- Superior planets
  - Opposition
    - 180 degrees from the sun



Synodic and Sidereal Periods

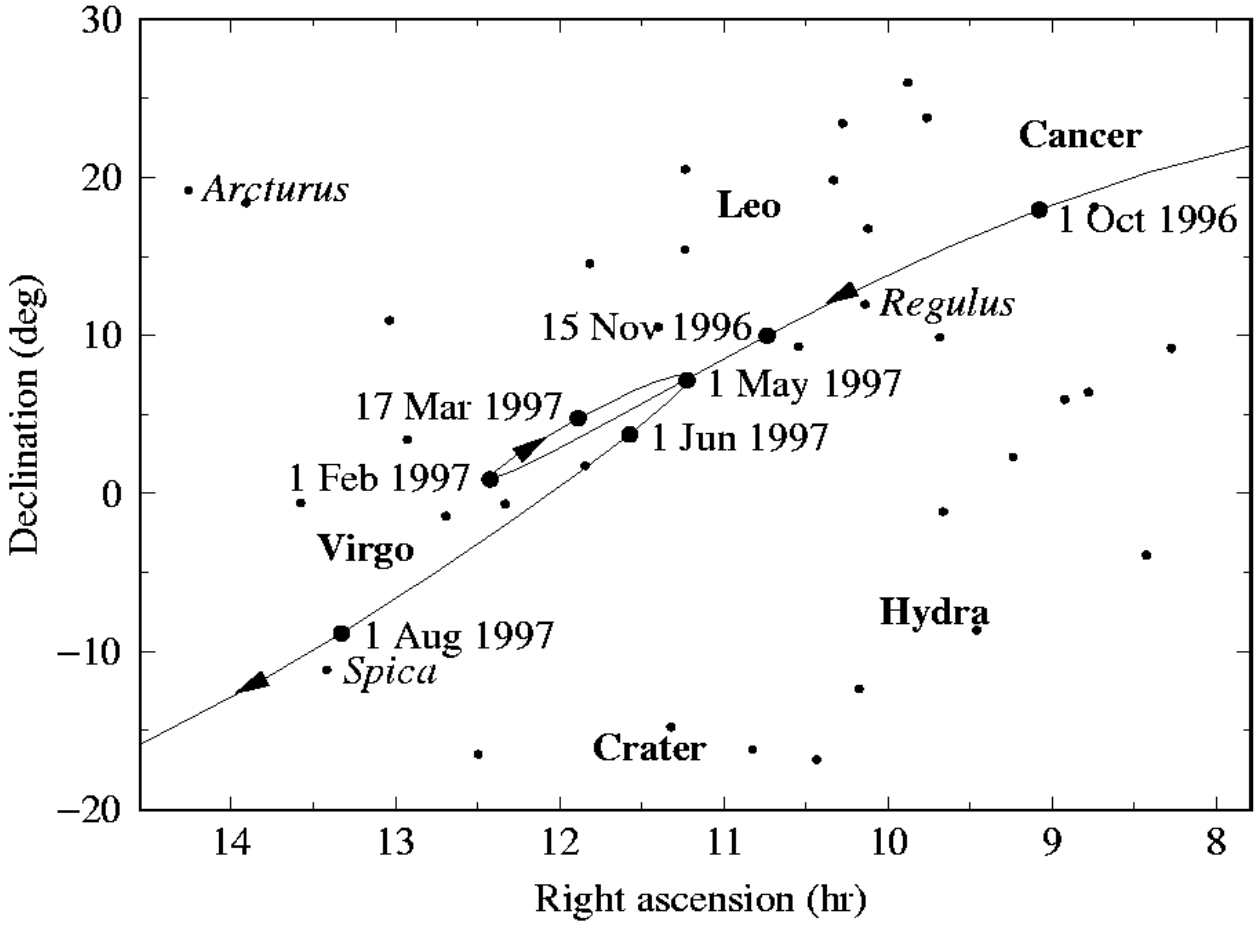
- Synodic period, S
  - time interval between successive conjunctions or oppositions, 1→ 3
- Sidereal period, P
  - Time interval for one complete orbit relative to background stars, 1→2



Relate to Mechanics terms (on board).

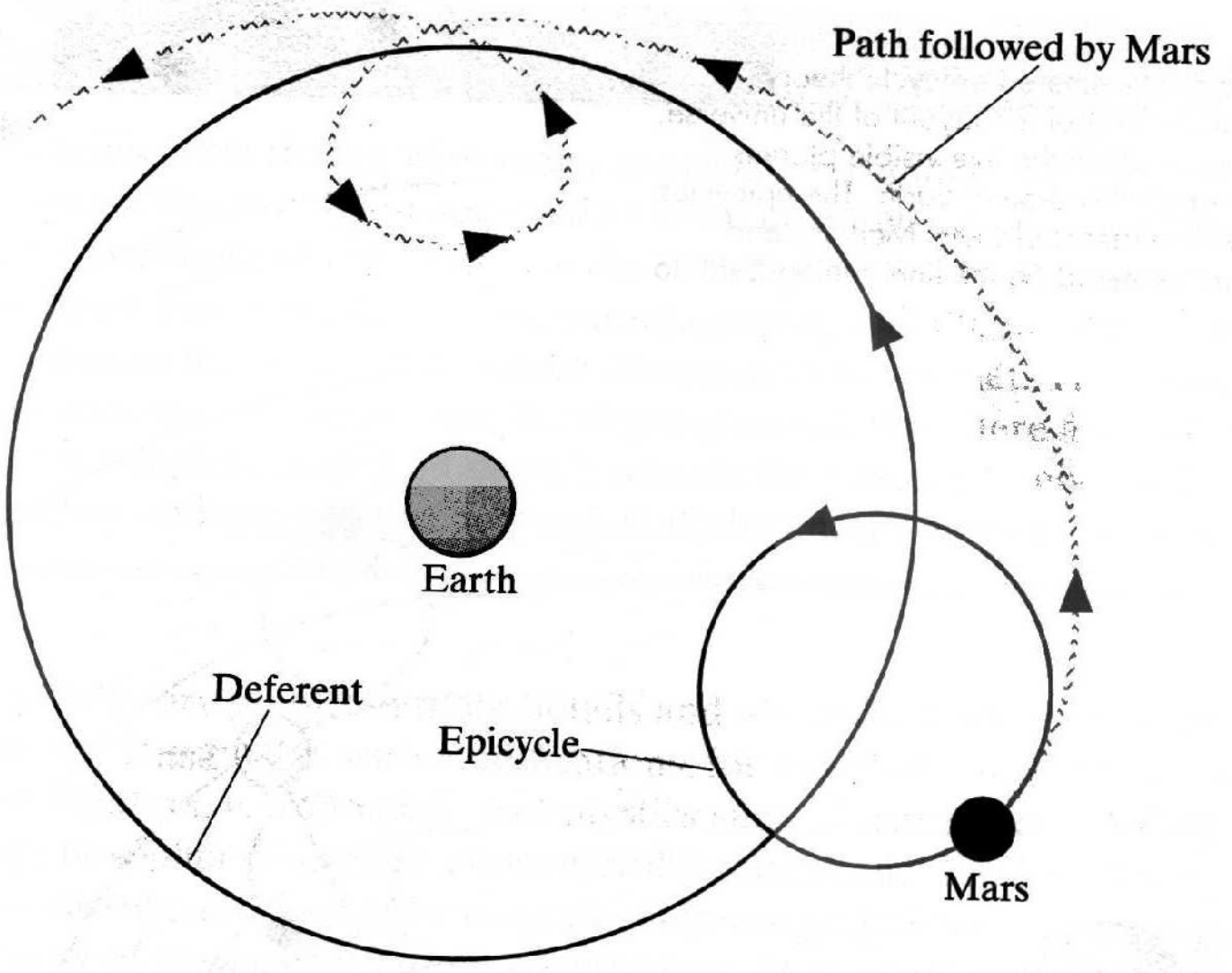
Retrograde Motion

- Planets change speed and brightness
- Example: Mars. Opposition was in May, 1997.
- (See SCIII animation.)



Epicycles on Deferents

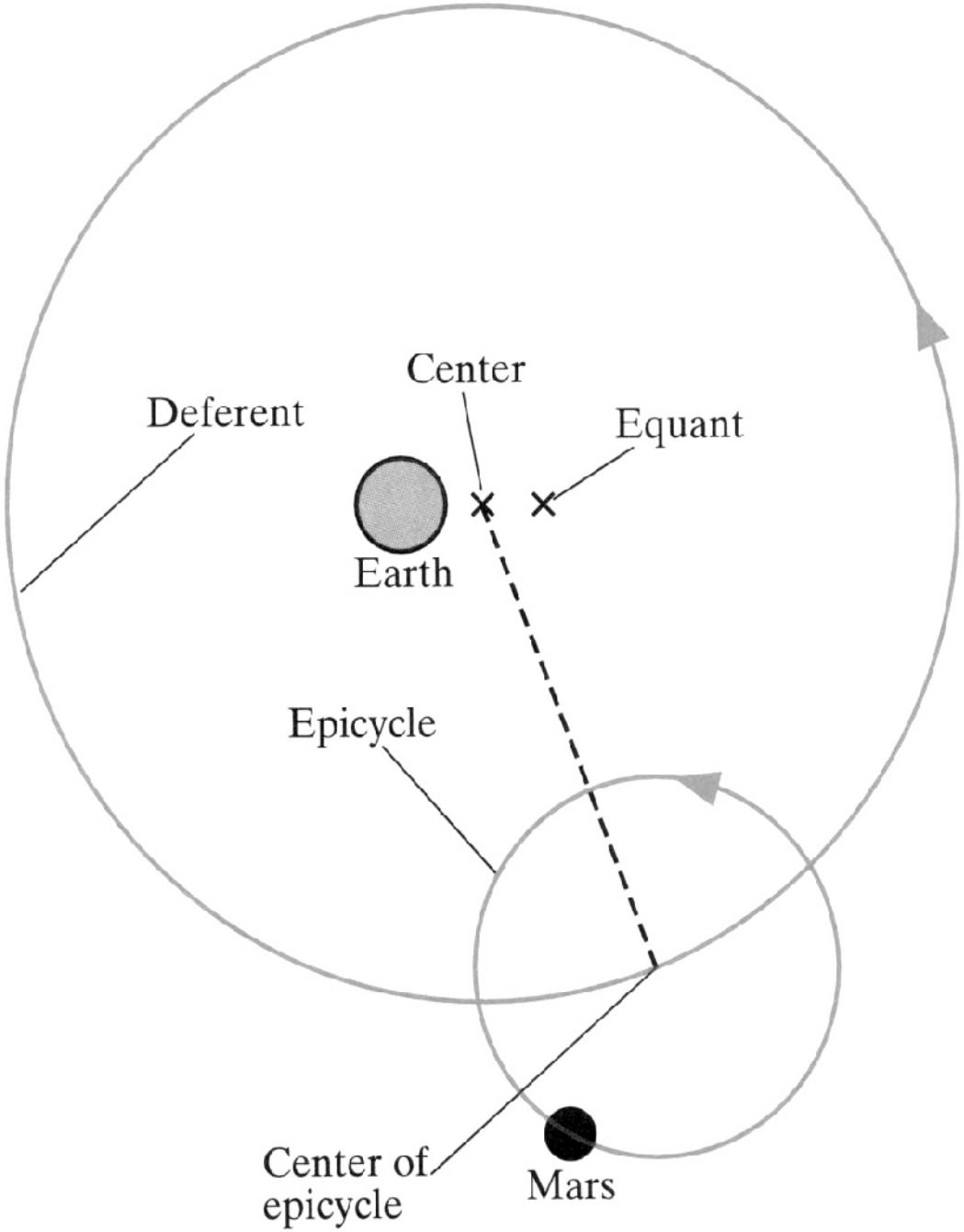
- Keep uniform motion on each circle.



Ptolemy's Model -

- Eccentric - displaces Earth from center
- Equant – center of epicycle has uniform angular speed when viewed from this point
- Period of planet around epicycle is synodic period.
- Period of epicycle center around deferent center is sidereal period.
- 80+ epicycles, Equants, …
- It works pretty well!

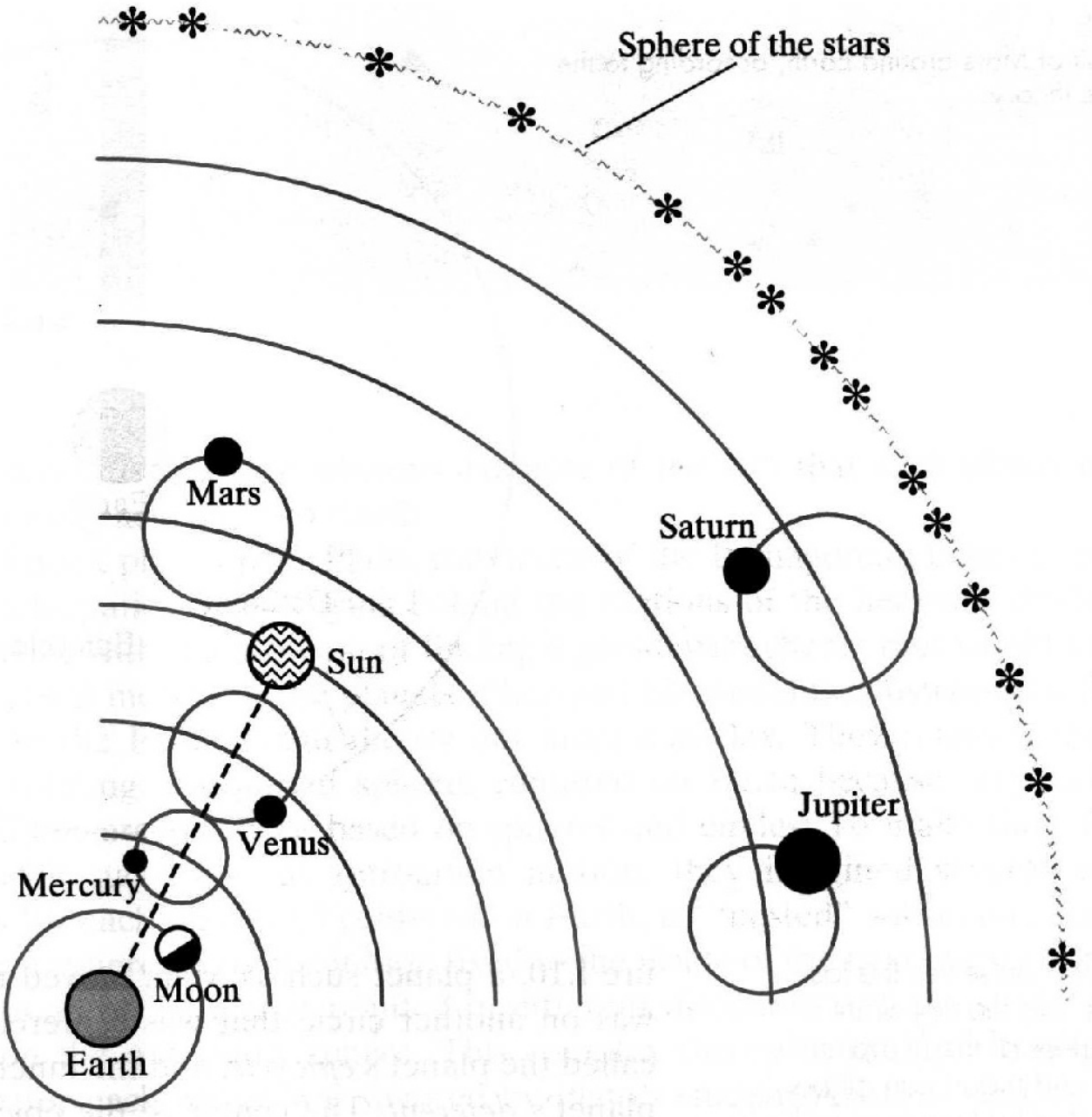
- Occum's Razor (1400?)
  - Accept the simplest explanation



Ptolemy's Model

- Explains retrograde and brightness
- Speed is still a problem

FIGURE 1.12
The ancient astronomer Ptolemy, A.D. 85–165. Using epicycles and many other theoretical devices, he prefected the Earth-centered theory of the layout of the universe.



The Copernican Revolution ... *matching!*

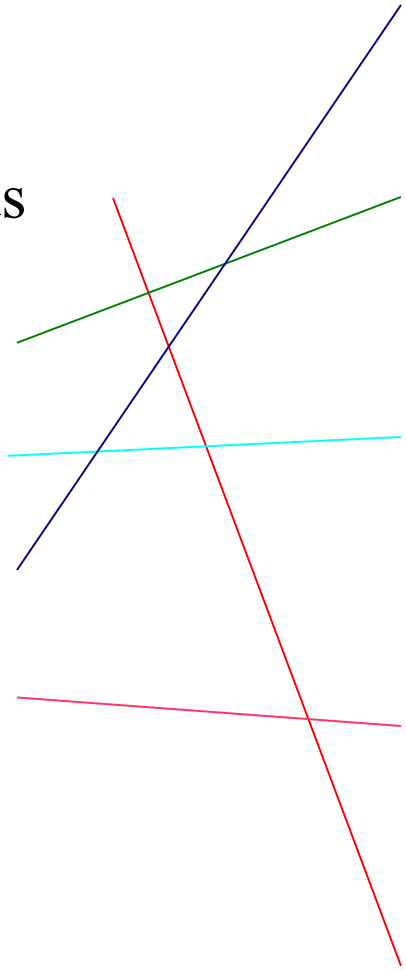
Nicolaus Copernicus

Tycho Brahe

Johannes Kepler

Galileo

Newton



Observed gibbous phase of Venus

Made precision measurements of planets

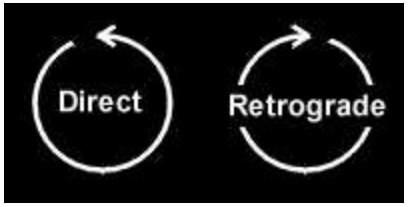
Used ellipses to model solar system

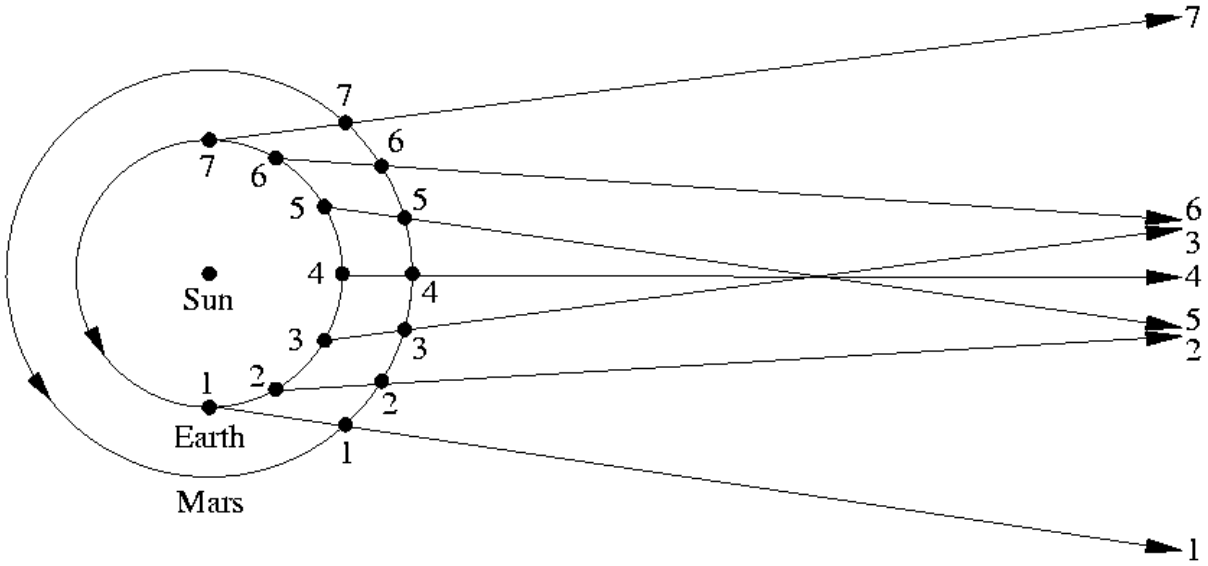
Said gravity accelerates the planets

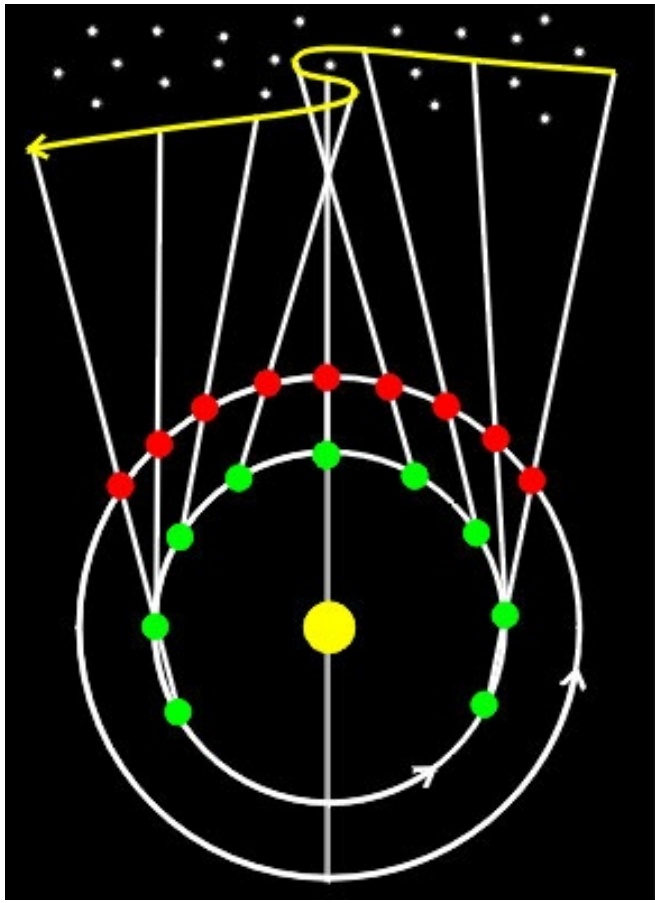
Revived the <u>heliocentric</u> model

Heliocentric Model and Retrograde Motion

- Different orbital speeds
  - More distant planets have lower speeds
  - Slightly different orbital planes







Copernicus

- Predictions of existing observations are not better than Ptolemy's!!
- Slightly simpler
  - No equants
  - Fewer epicycles (still a lot)
    - remove epicycles
      - Copernicus does okay
      - Ptolemy's is a disaster
- Discriminating predictions could not be observed
  - no telescopes
  - Both models survive, Ptolemy's is more widely accepted based on paradigms
  - need better observations

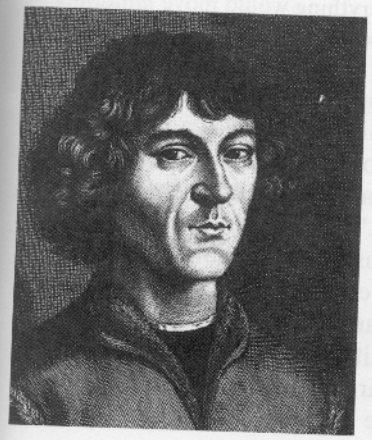


FIGURE 1.14
Renaissance astronomer Nicolaus Copernicus, 1474–1543. Finding Ptolemy's system to be "neither sufficiently absolute nor sufficiently pleasing to the mind," he devised a simpler theory. Copernicus's theory placed the sun at the center of the universe, with Earth moving around it. The odd idea that Earth moved and was a planet like the other planets met with much resistance because it conflicts with the intuitive notion that Earth is at rest at the center of things and because it conflicted with prevailing philosophies.

Tycho Brahe

- Better observations
  - 5x better
    - 2 arc-minutes (1/30 of a degree) compared to 10 arc-minutes (1/6 of a degree)
    - 20 years of data
  - Both Ptolemy and Copernicus's models are wrong!

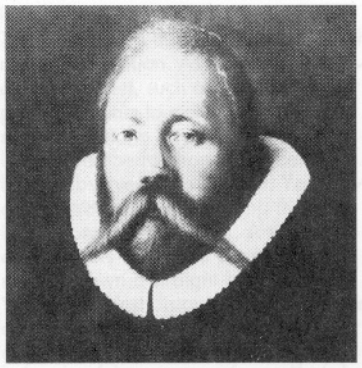


FIGURE 1.18
Tycho Brahe, 1546–1601. By making measurements of the planetary positions that were five times more accurate than were previous measurements, he overthrew two theories of the architecture of the heavens.

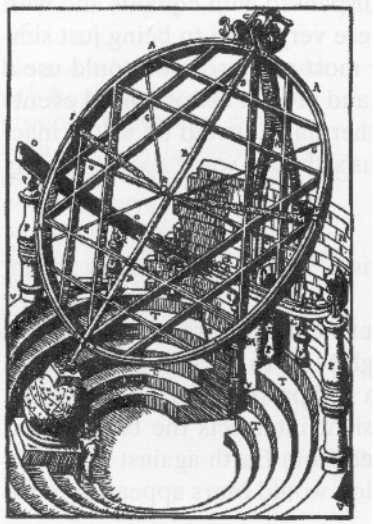


FIGURE 1.19
Brahe's sextant for measuring the positions of the planets. Brahe's work was done without telescopes.

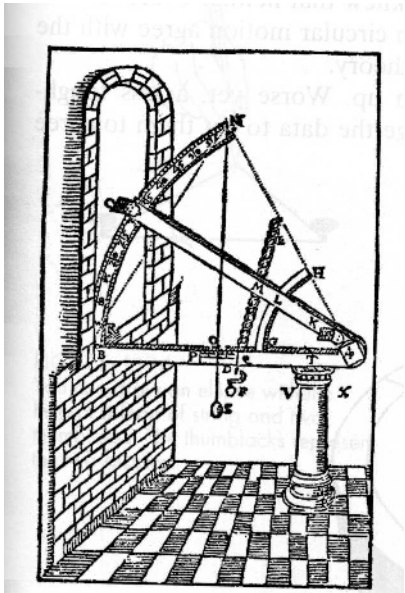


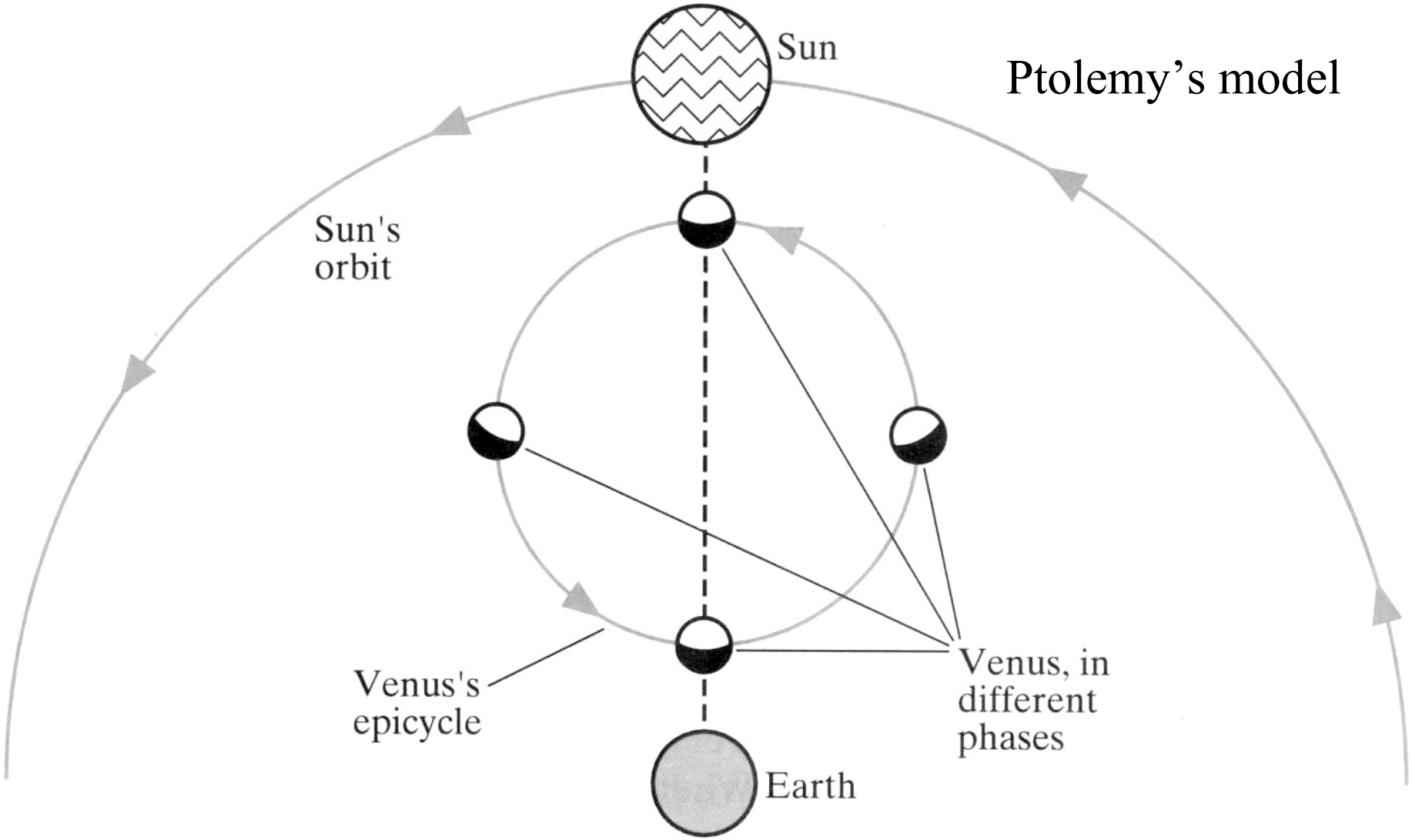
FIGURE 1.20
An instrument that Brahe used for

Galileo

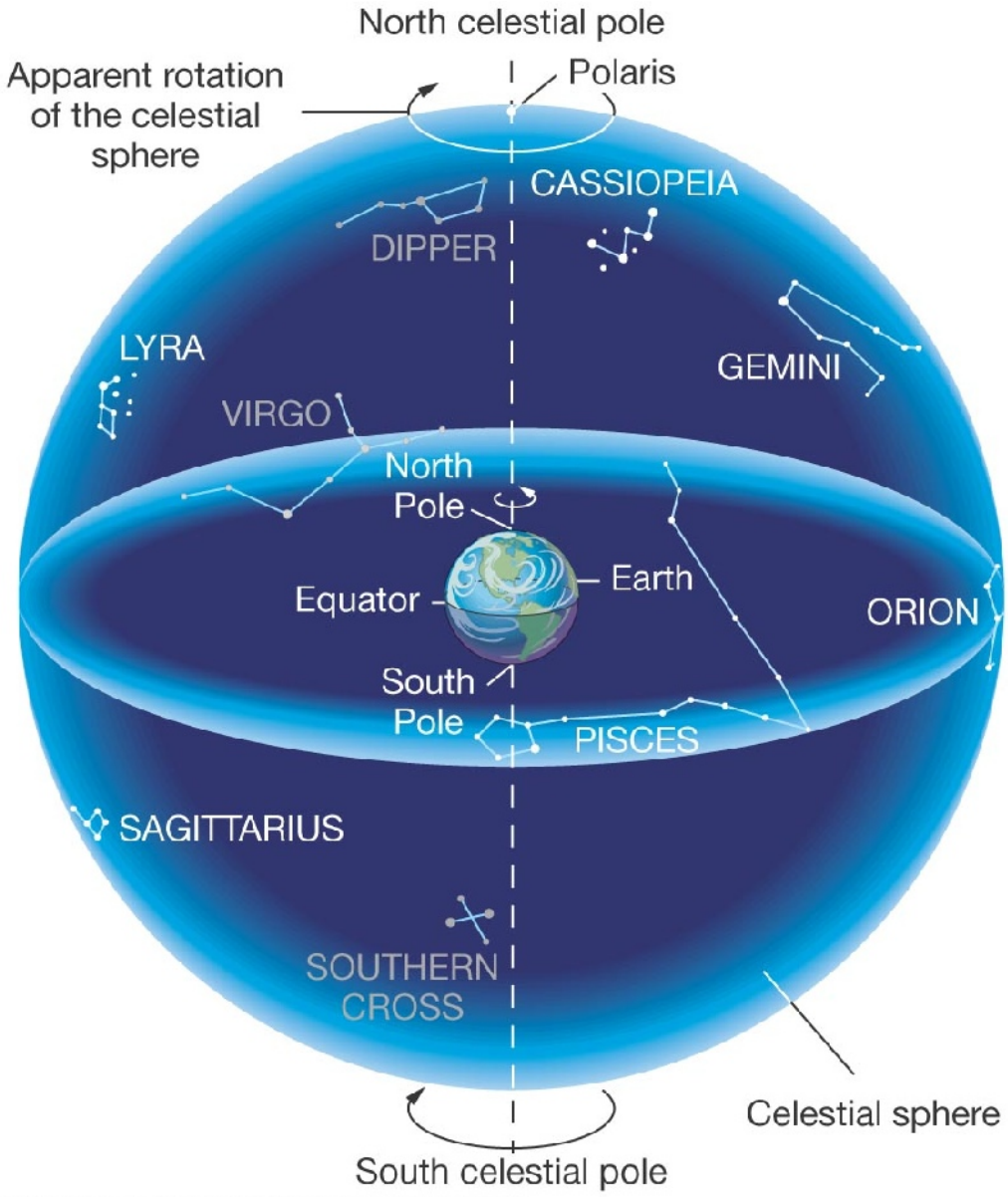
- Used a telescope for astronomical observations
- Strong support for Copernican and Kepler's models (heliocentric)
  - Moons of Jupiter orbit Jupiter!
    - Earth not the center!
  - **Phases of Venus include the gibbous phase!**
    - Not predicted with Ptolemy's model
- Experiments with mechanics
  - Free-fall and incline plane experiments
  - Refutes Aristotelian physics

Phases of Venus

Ptolemy's model

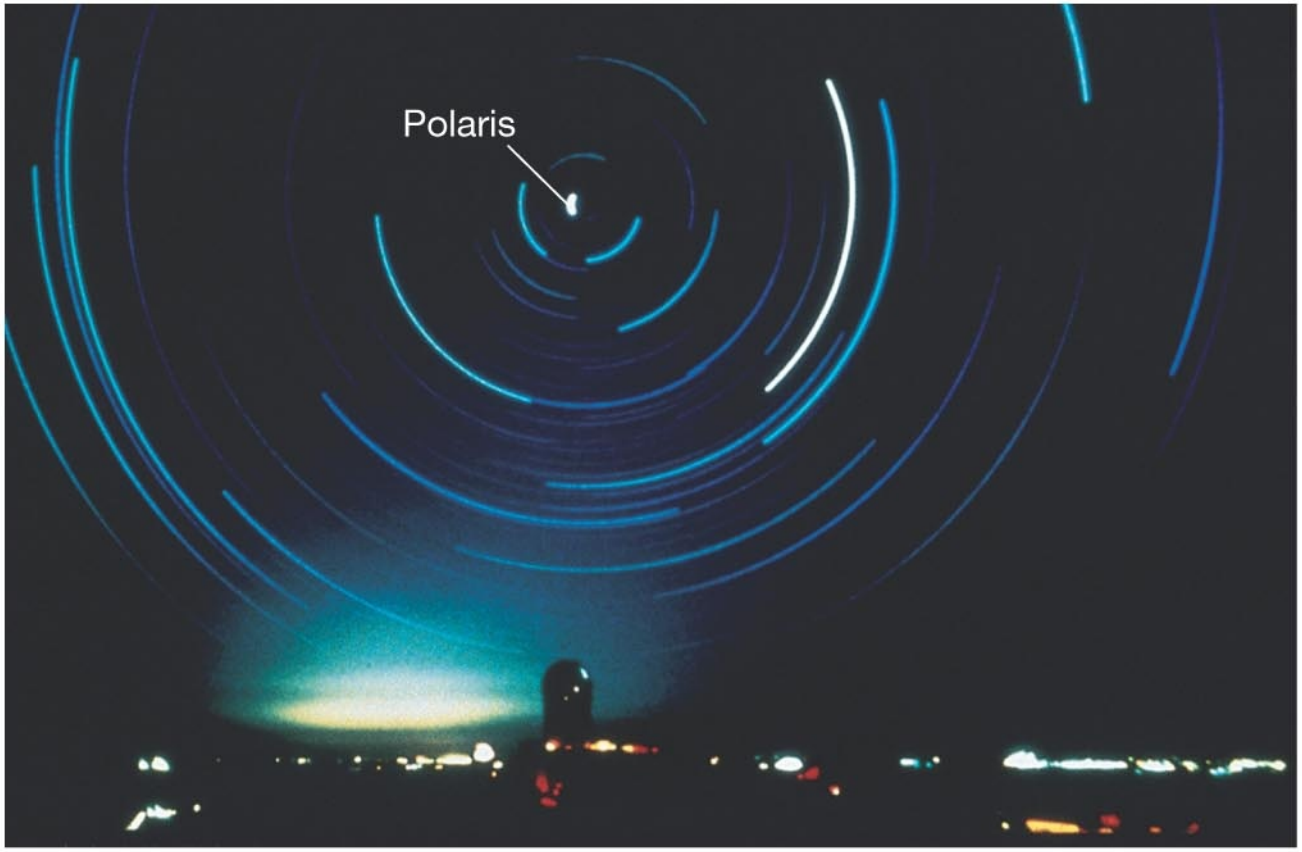


The Celestial Sphere

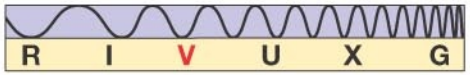


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

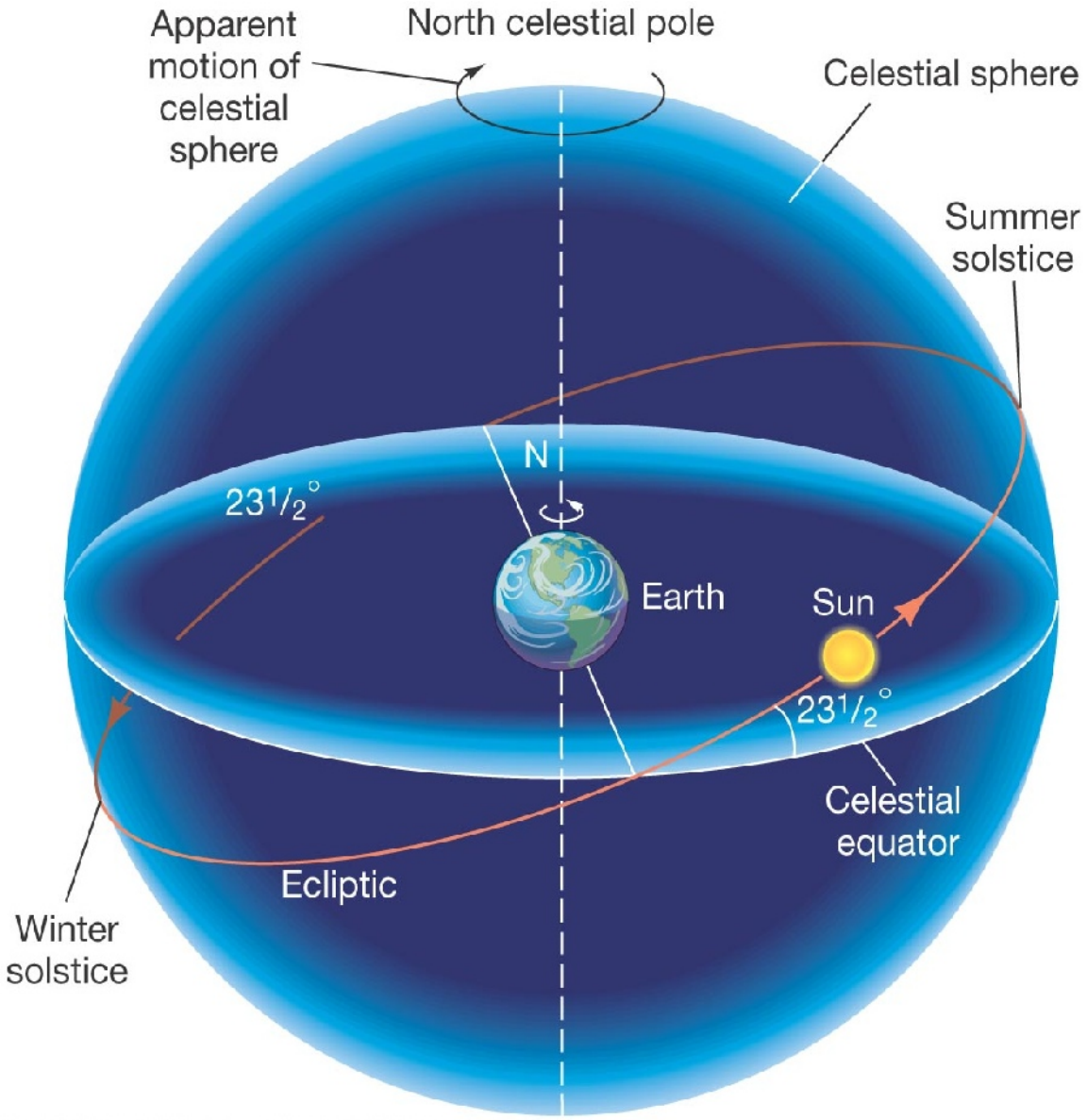
Star Trails



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.



Celestial Sphere and the ecliptic



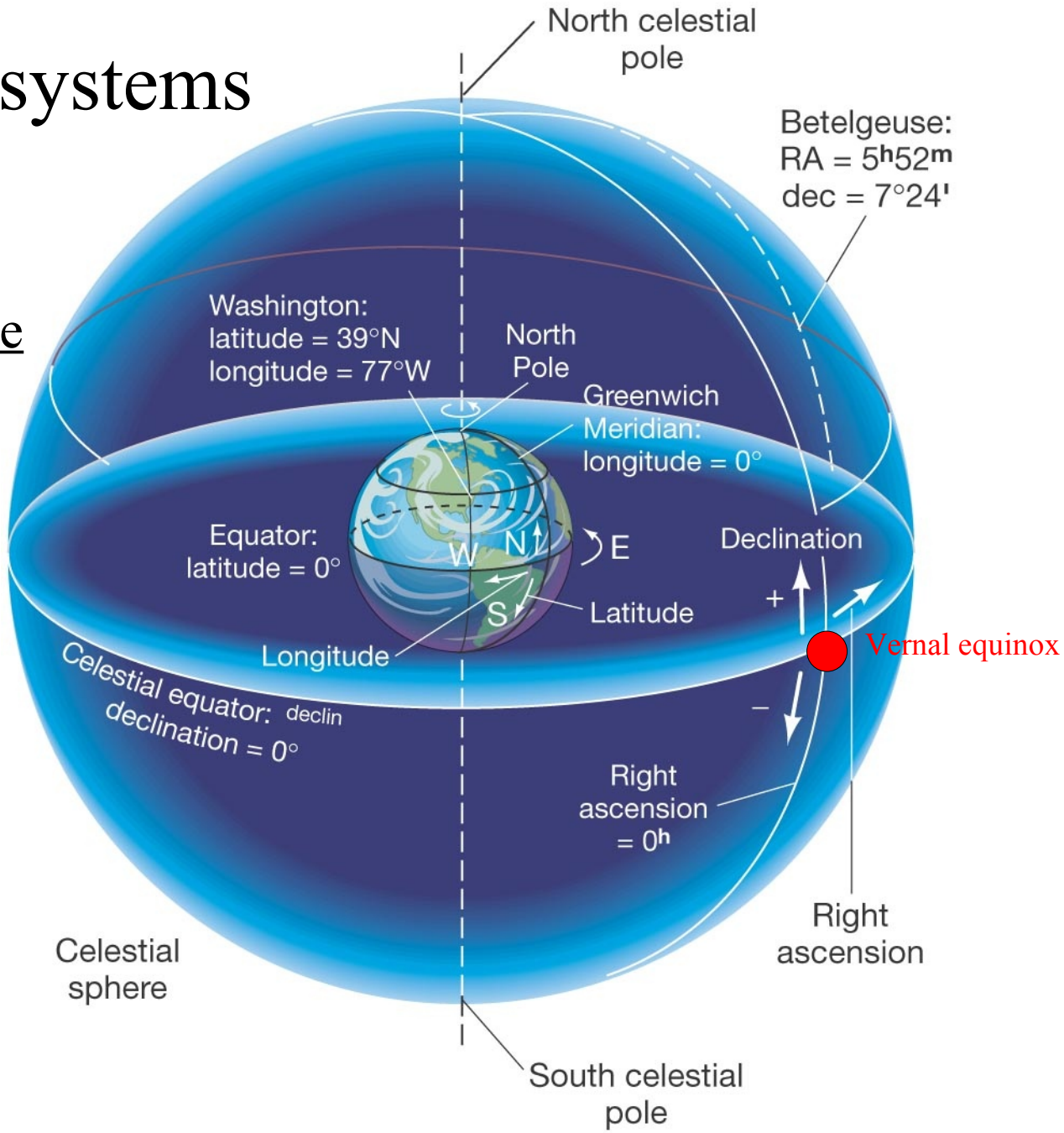
Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

Coordinate systems

Equatorial Coordinate System

Right Ascension

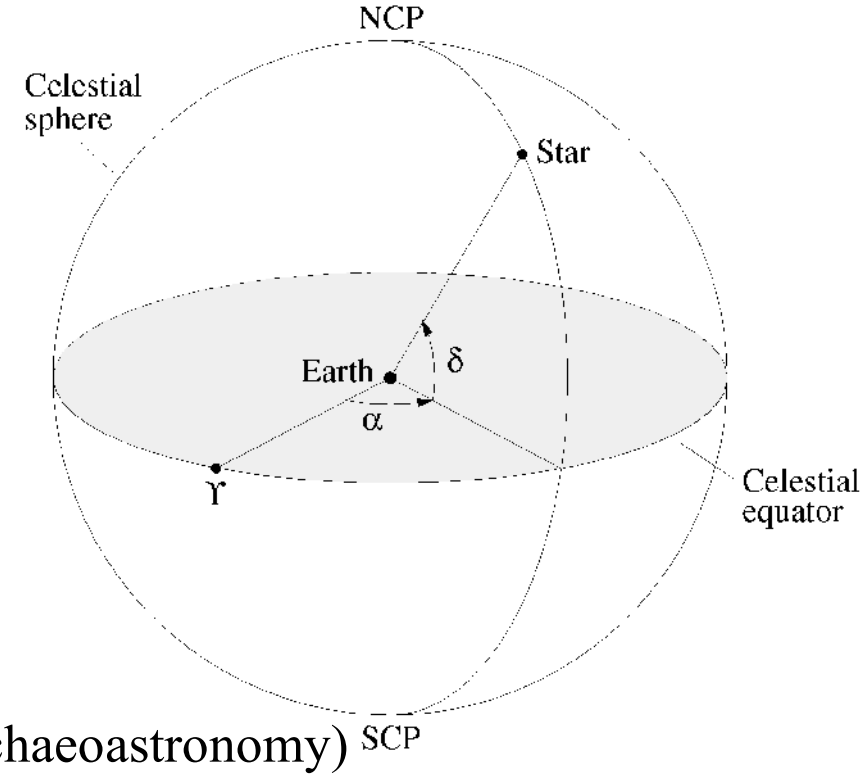
Declination



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

Equatorial Coordinate System

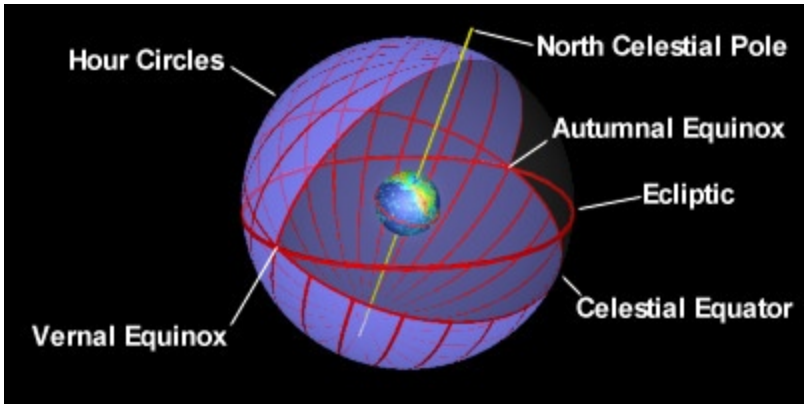
- Overcomes the problems with the diurnal and annual motions

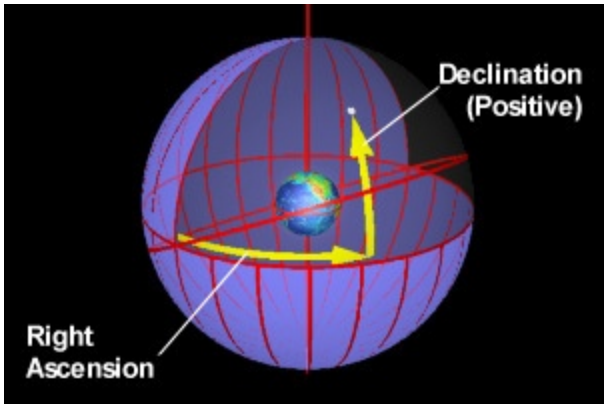


δ – declination (latitude)
α – right ascension (longitude)
ϒ– vernal equinox (origin)

α and δ need corrected for Earth Precession (25,770 year period)

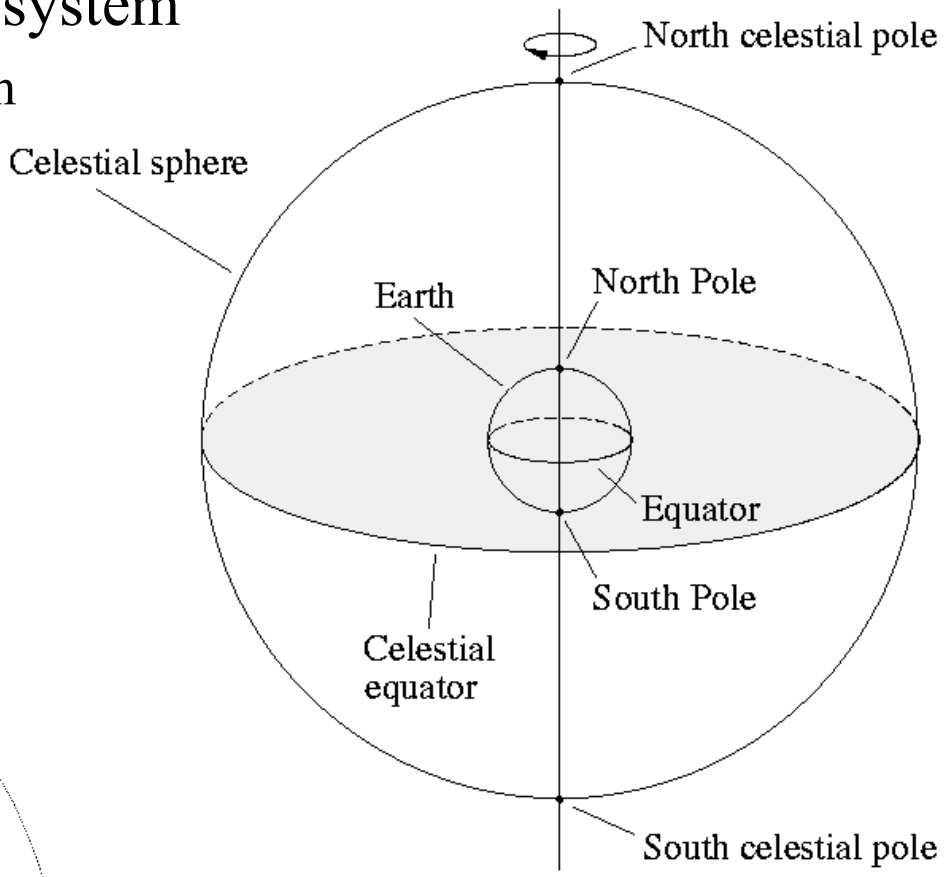
"North Pole" moves 47° in 13,000 years (Archaeoastronomy)

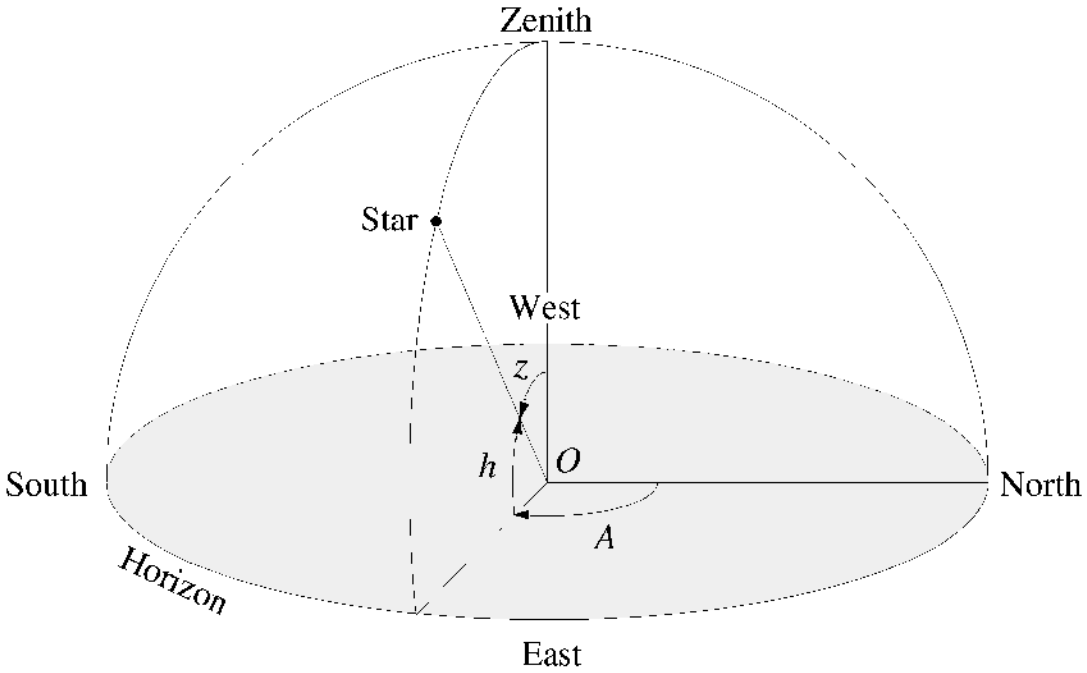




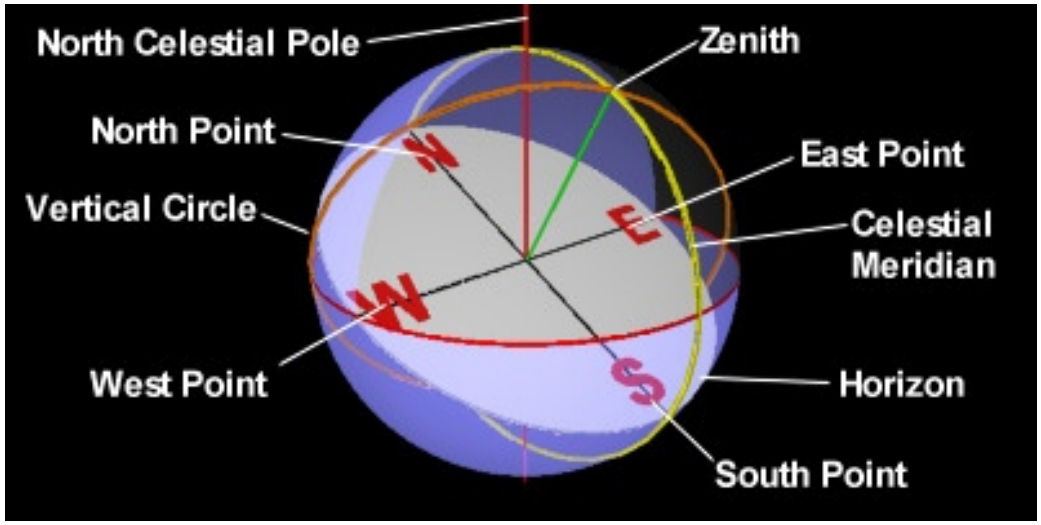
The Celestial Sphere

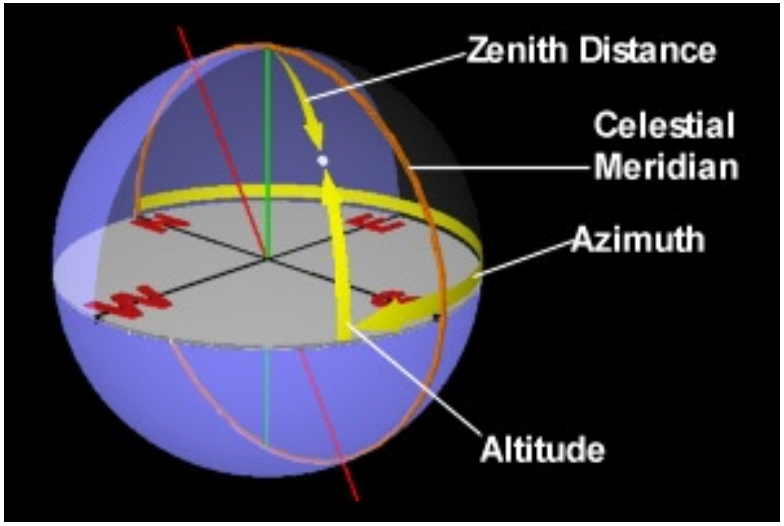
- Location-dependent coordinate system
  - Altitude – azimuth coordinate system
    - A = azimuth
    - z = Altitude (h + z = 90°)





Altitude – azimuth coordinate system

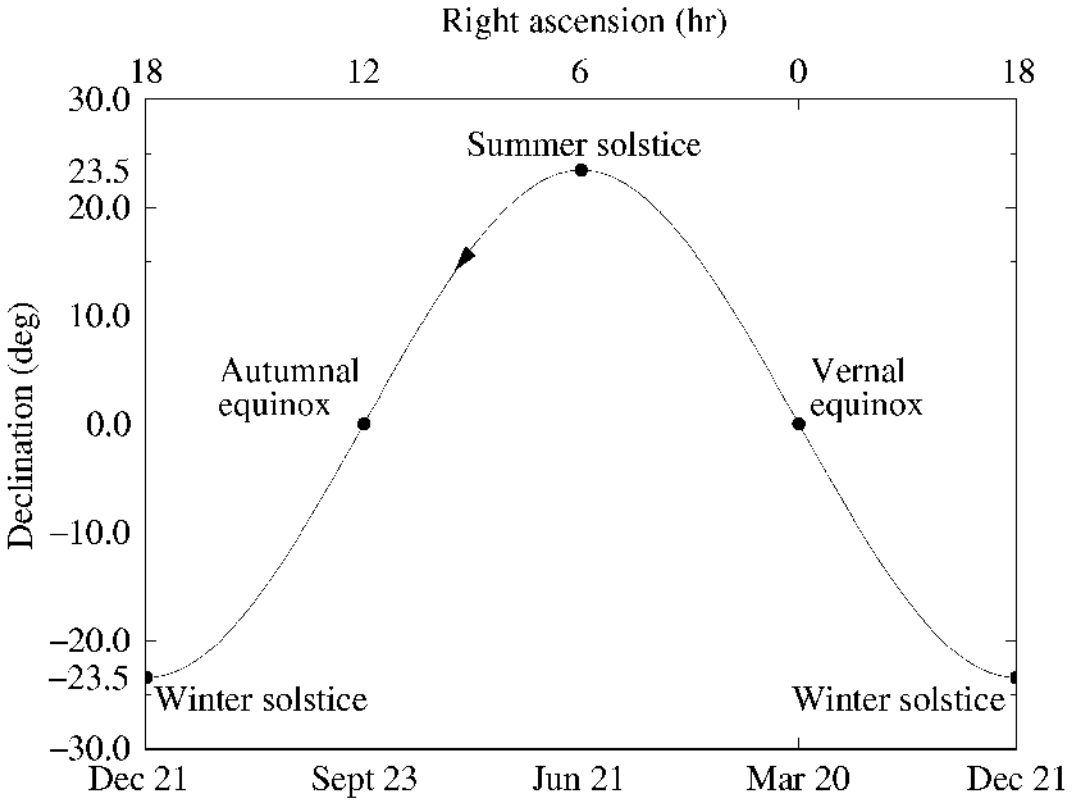


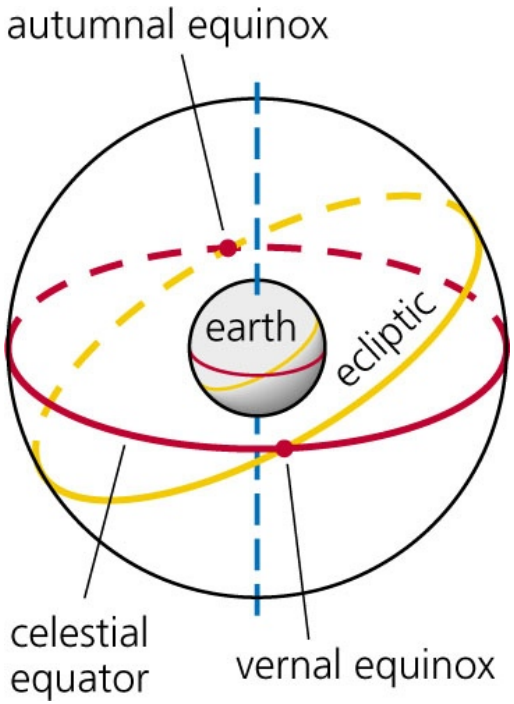


- Problems
  - Observer specific!
  - Diurnal motion (rotation)
  - Orbit around sun
  - Wobble on rotational axis
  - Other relative motions …

Ecliptic

- Seasonal variations due to orbital motion and the 23.5^{o} tilt of Earth's rotational axis





Ecliptic

- Diurnal path the sun takes across the celestial sphere
- Vernal and autumnal equinox
- Summer and winter solstice