
Introductory Astrophysics
Physics 371
Week 1

Outline

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

6.2 Optical Telescopes

- The sky – predictable, yet mysterious
  - Periodicities, Naked eye universe
  - Greek knowledge/models, Ptolemaic system
- Planetary Configurations.
- Copernican Revolution
- Coordinate systems
- Telescope basics

Periodicities in Astronomy

- 24 hours between transits of Sun (solar day)
- 23 h 56m between transits of stars (sidereal day)
- 365.2564 d for Sun to circle celestial sphere (sid. year)
- 365.2422 d for Sun to return to vernal equinox (trop. year)
- " " " for Sun to oscillate about celestial equator
- 29.5 days for Moon to go through phases (phase month)
- Planets have repeatable times between configurations

Many, many more !

Astronomy is mysterious

The *nature* of the Sun, Moon, stars, and planets were completely unknown to ancients.

- Can't touch, smell, hear, or taste them, only see.
- Usually limited to one perspective.
- Our lifetime << astronomical timescales
- Occasional unexpected events:
  - Comets
  - Novae, supernovae
  - Eclipses
- Coincidences ---> astrology

The naked-eye universe

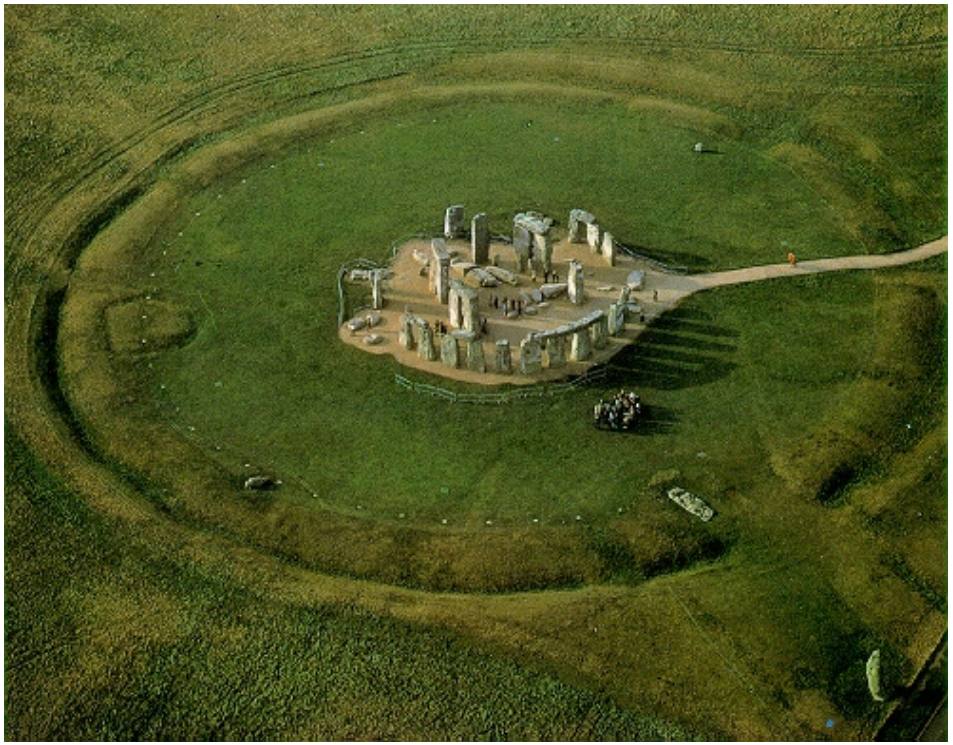
- The Sun
- The Moon (and its phases)
  Eclipses
- 5 Planets (plus the Earth)
  - Mercury, Venus, Mars, Jupiter, Saturn
- 6500 Stars (contained within 88 constellations)
- 3 galaxies
- Occasional novae and supernovae
- Comets
- Aurora, meteors, and other atmospheric phenomena

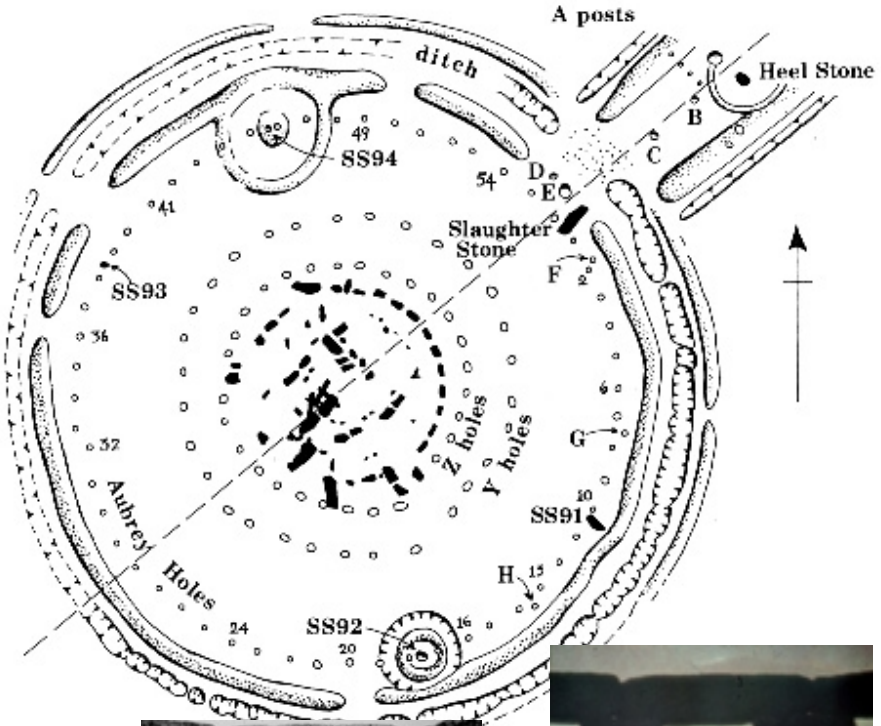
What did the Ancients know?

- 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
  - Islam
  - Greek (more to come)
  - Records of Seasons, lunar cycles, eclipses, comets, novae, star maps, models
- Unknown nature ►superstition► astrology
- Sun provides life
  - Understand seasons for farming
  - Luminaries are deities? - religion

Stonehenge

- Check out: http://witcombe.sbc.edu/earthmysteries/EMStonehenge.html
- 2950 BC – 1600 BC (3 phases)
- Heel stone marks sunrise on Summer Solstice





- 56 Aubrey holes = 3 Saros cycles

(a)

(b)

(c)

Knowledge of the Ancient Greeks

- Ideas and philosophies were rich and varied, some bad for science:
  - Plato: truth through pure thought over observations. Circle – perfect form.
  - Aristotle (and almost everybody): Earth is unmoving, heavens are perfect
  - Ptolemy (AD 140): The Geocentric universe model
- 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) *
  - 4 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 Moon and Sun (Hipparchus)
  - 10 Retrograde motion of planets can be modeled with epicycles and deferents *

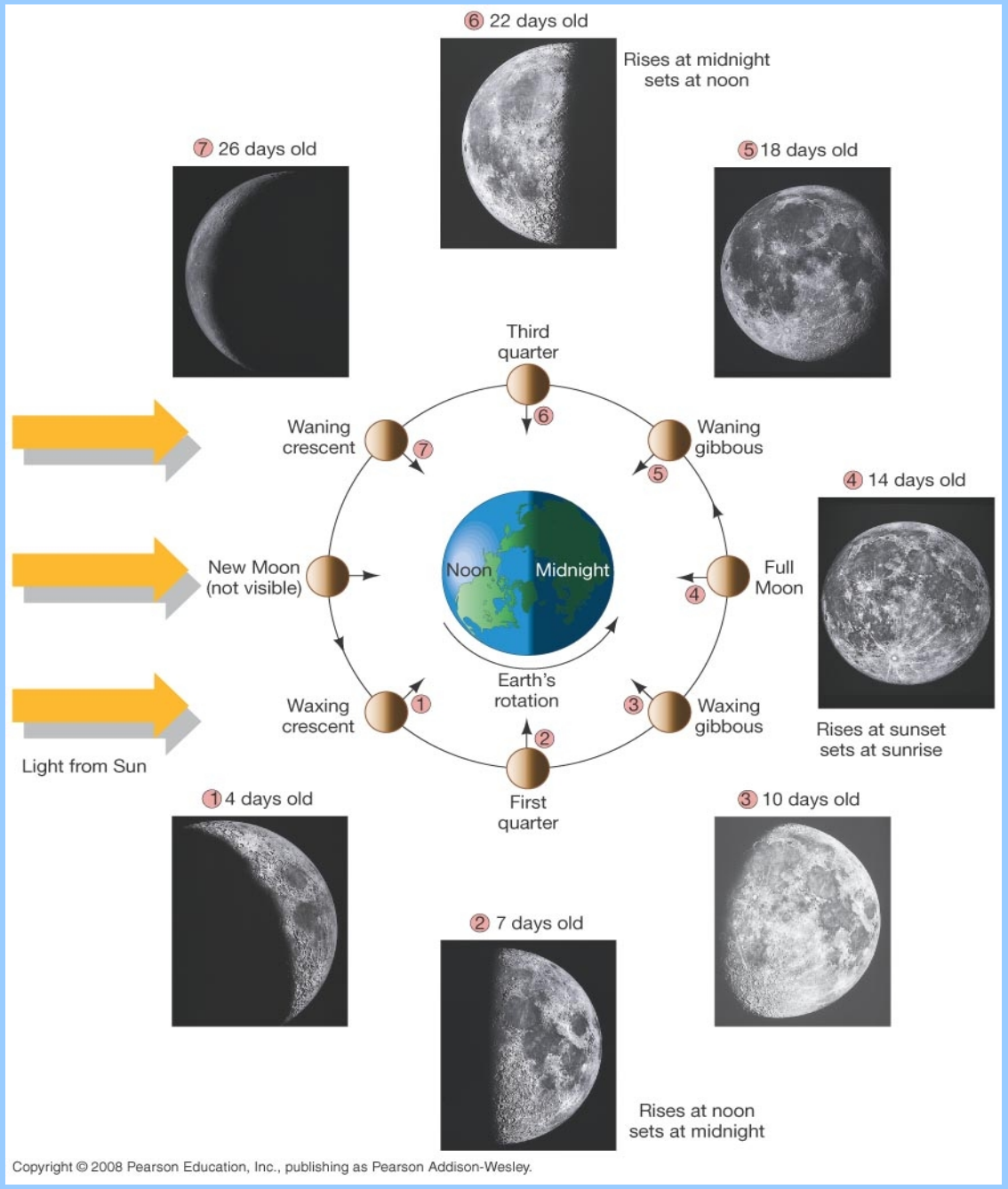
  * = figures to follow.

Knowledge of the Ancient Greeks

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

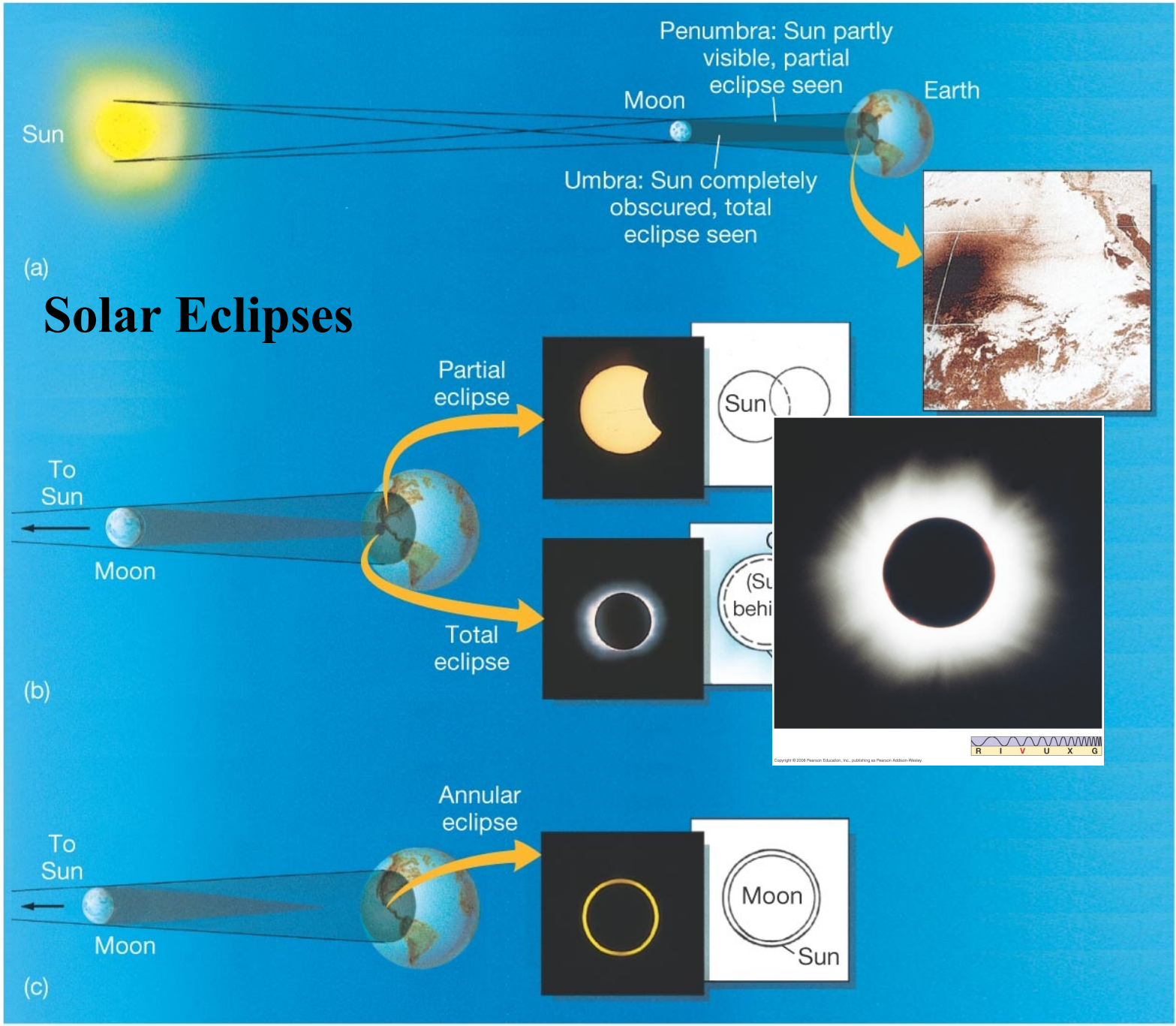
Knowledge of the Ancient Greeks

(2) What causes the phases of the Moon?

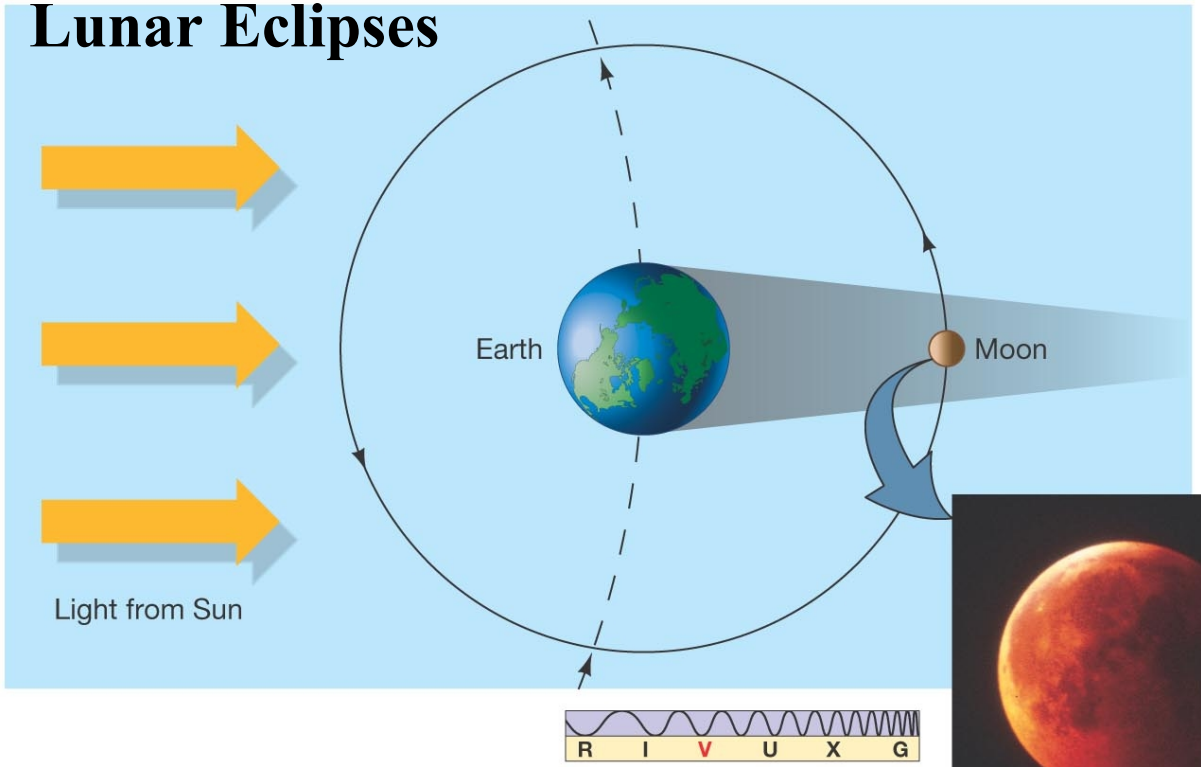


Knowle
Ancient G

(3) E
caused
Moc
align



Knowledge of th Ancient Greeks (cont.)

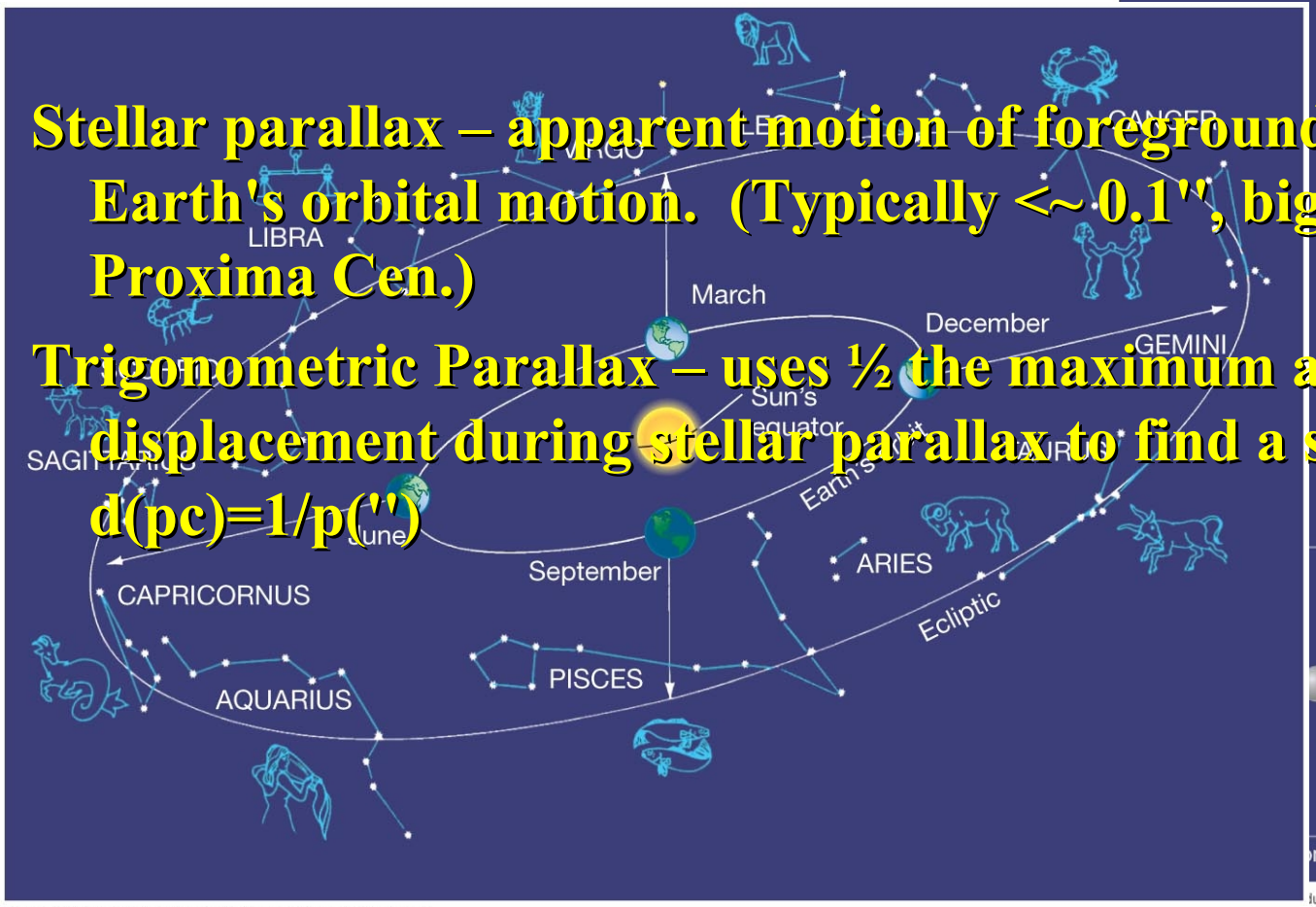


(3) Eclipses caused by Earth-Moon-Sun alignments?

Knowledge of the Ancient Greeks (cont.)

(4) If Earth is moving, parallax effects should occur.

Parallax = the apparent motion or shifting of an object caused by the motion or shifting of the observer.

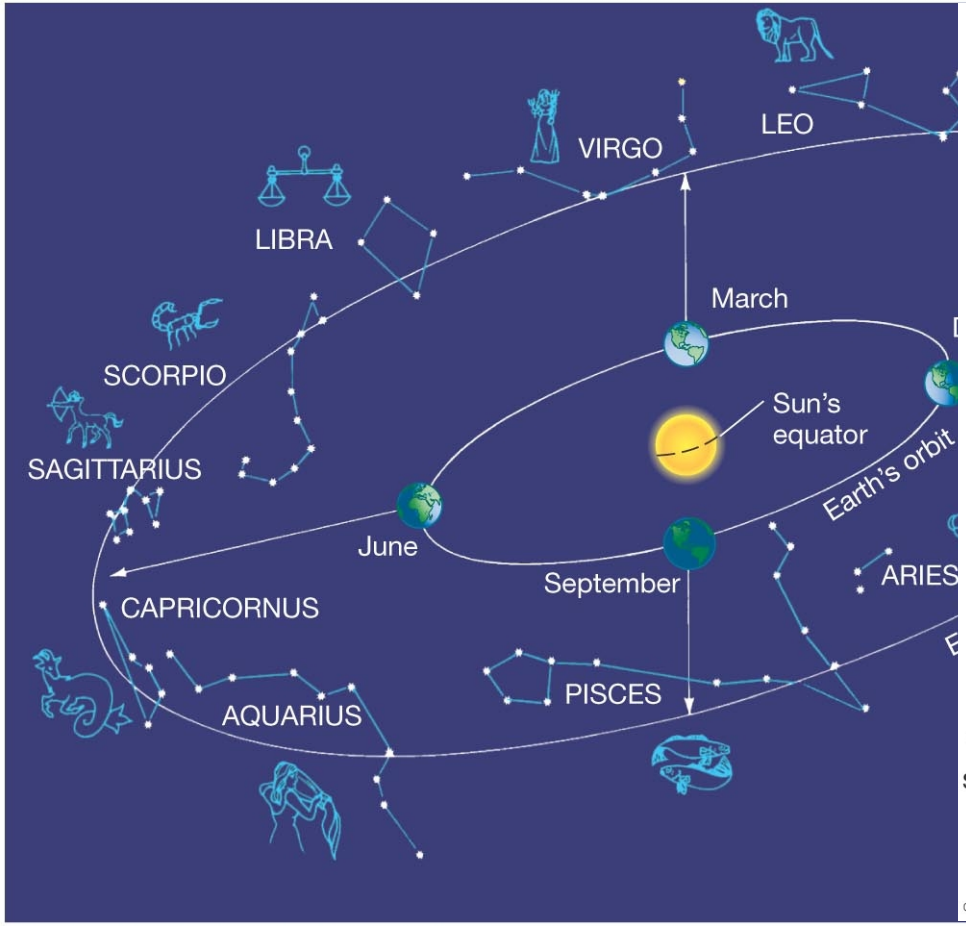


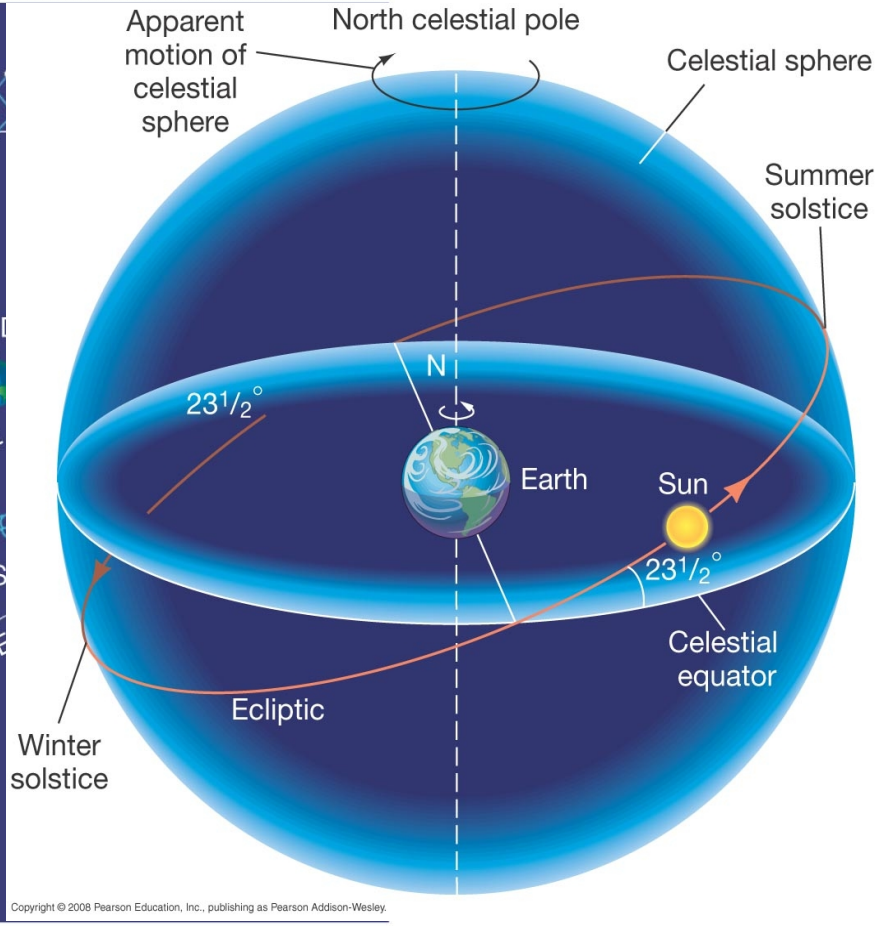
Stellar parallax – apparent motion of foreground stars due to Earth's orbital motion. (Typically <~ 0.1", biggest ~1.0" Proxima Cen.)

Trigonometric Parallax – uses ½ the maximum angular displacement during stellar parallax to find a stars distance. d(pc)=1/p(")

Knowledge of the Ancient Greeks (cont.)

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

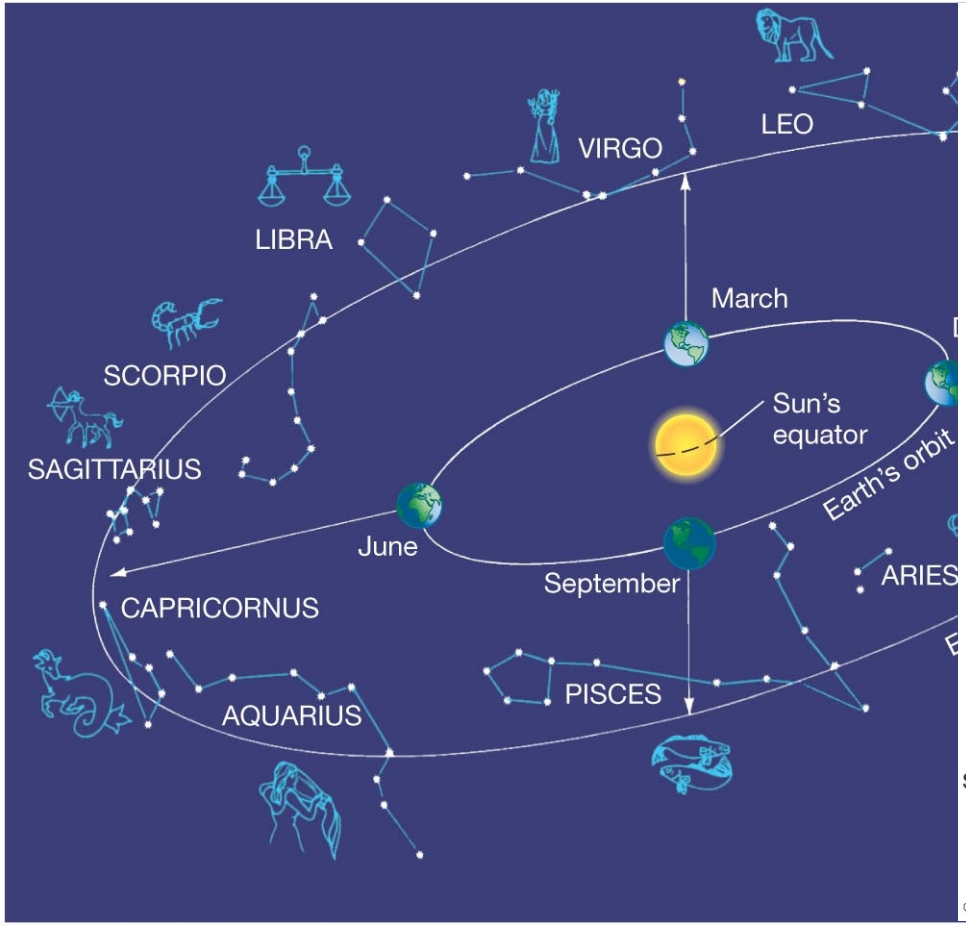


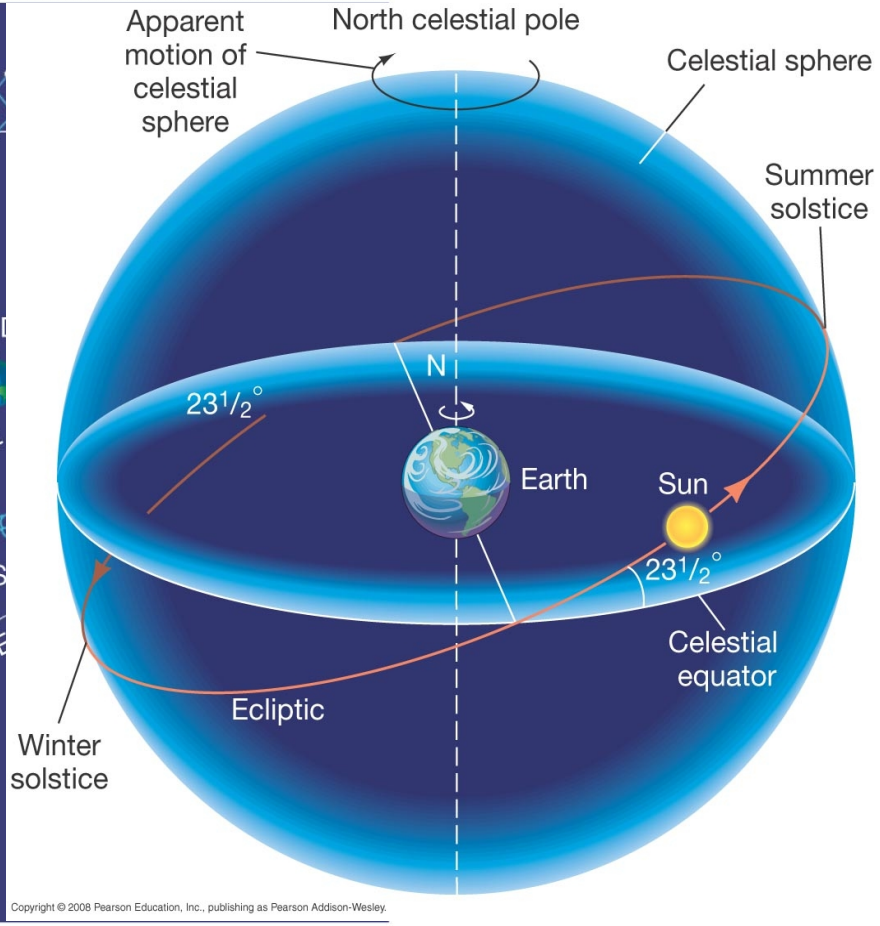


A geocentric model can also produce changing midnight constellations and seasons. More info about planets was needed to distinguish the two models...

Knowledge of the Ancient Greeks (cont.)

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

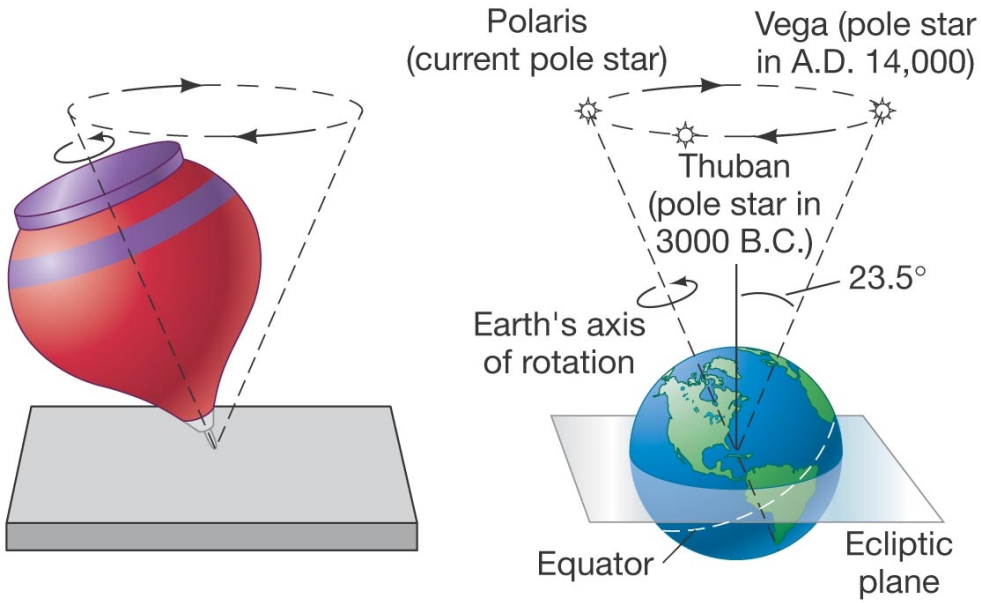


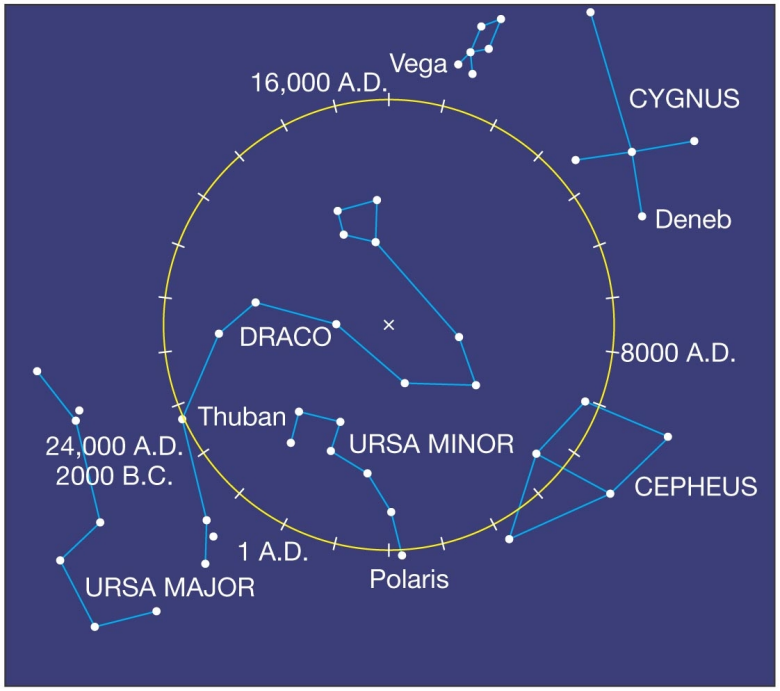


A geocentric model can also produce changing midnight constellations and seasons. More info about planets was needed to distinguish the two models...

Knowledge of the Ancient Greeks (cont.)

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

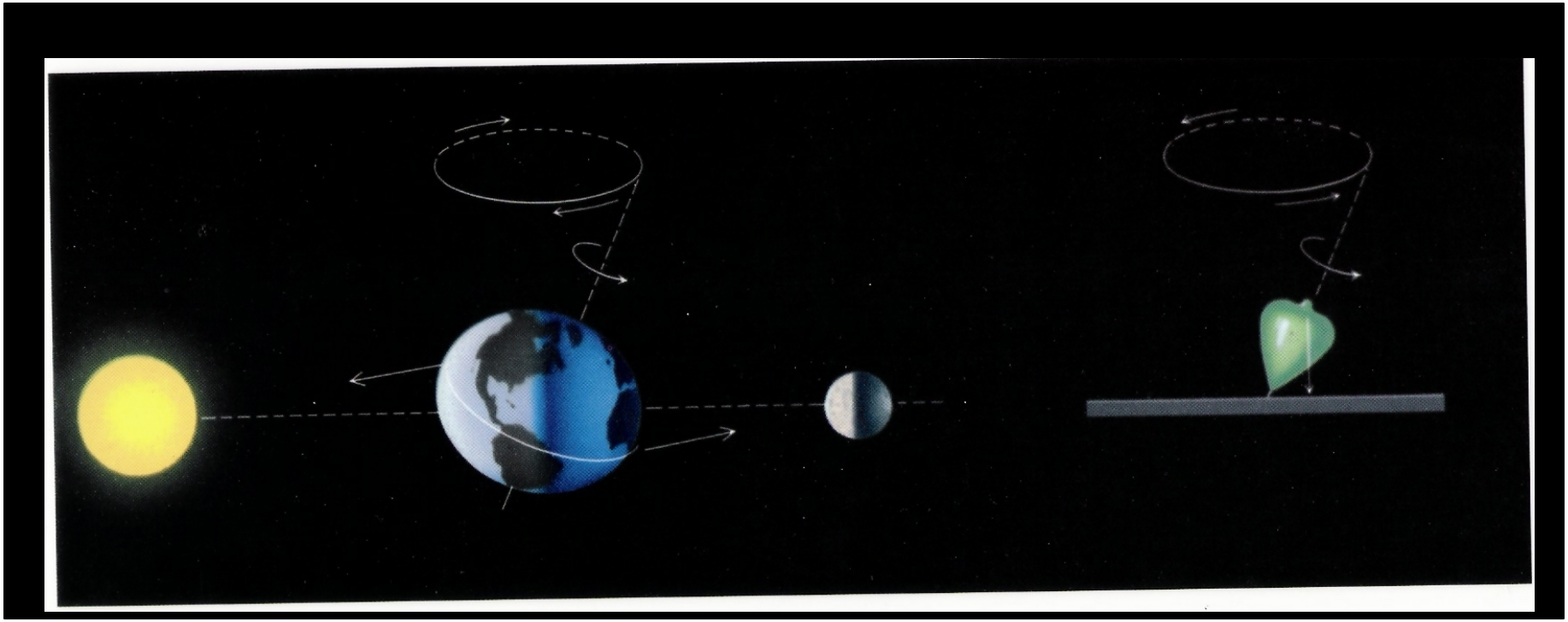




10) Retrograde motion of planets can be modelled with epicycles and deferents (Hipparchus). This requires some background ...

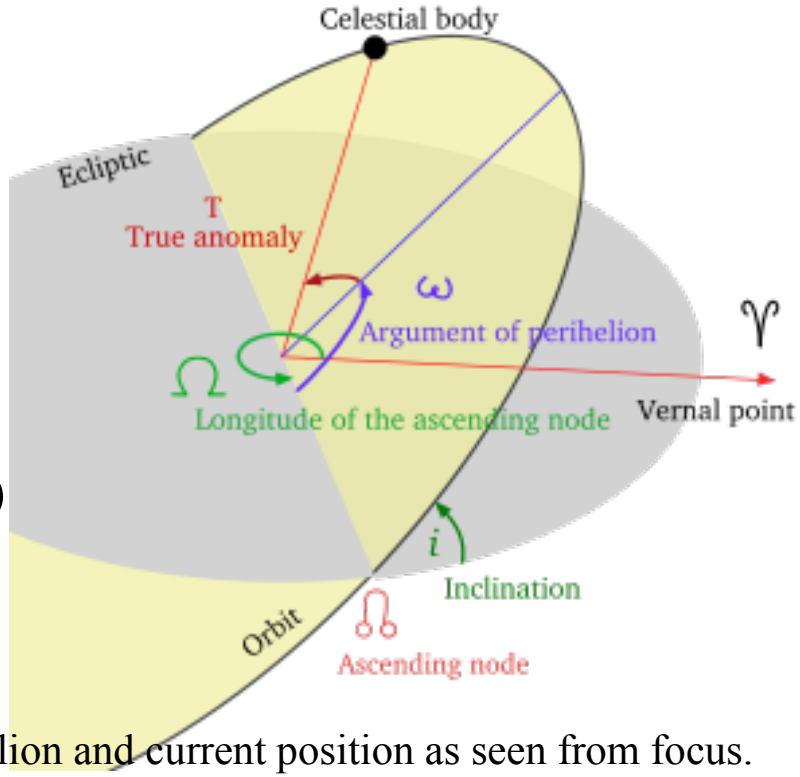
Knowledge of the Ancient Greeks (cont.)

Cause of precession: tidal pulls on Earth's equatorial bulge.



The Appearance of the Planets

- Rise and set roughly with stars
- Change brightness, position and angular speed across sky.
- Usually eastward motion, occasional westward motion
- Modern view
  - All orbit Sun CCW as seen from N
  - Kepler's 3 laws of elliptical orbits
  - 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*
    - True anomaly, T*

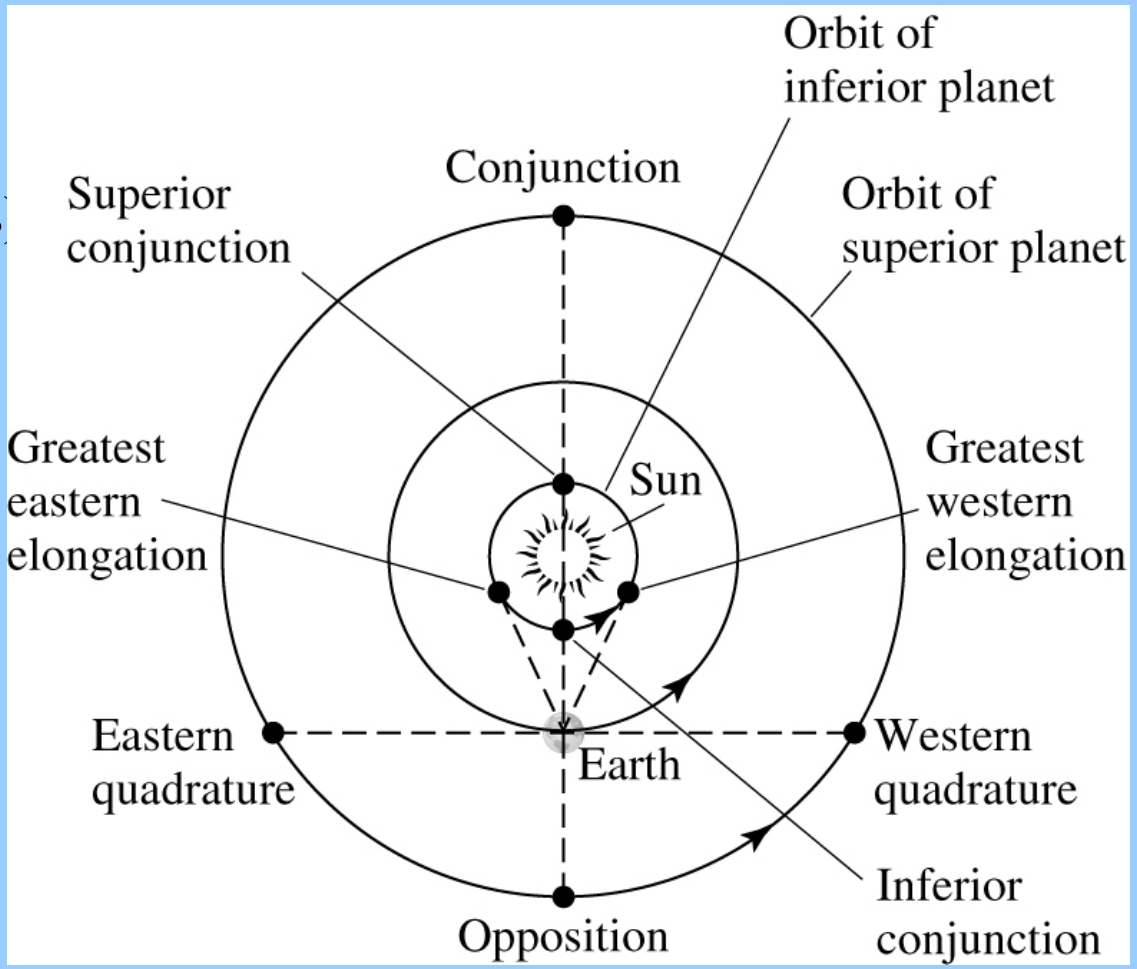


* the angle in radians between perihelion and current position as seen from focus.

Alternatively, *Mean anomaly*, which is 2π(t/P), where t=time since perihelion, P=perio

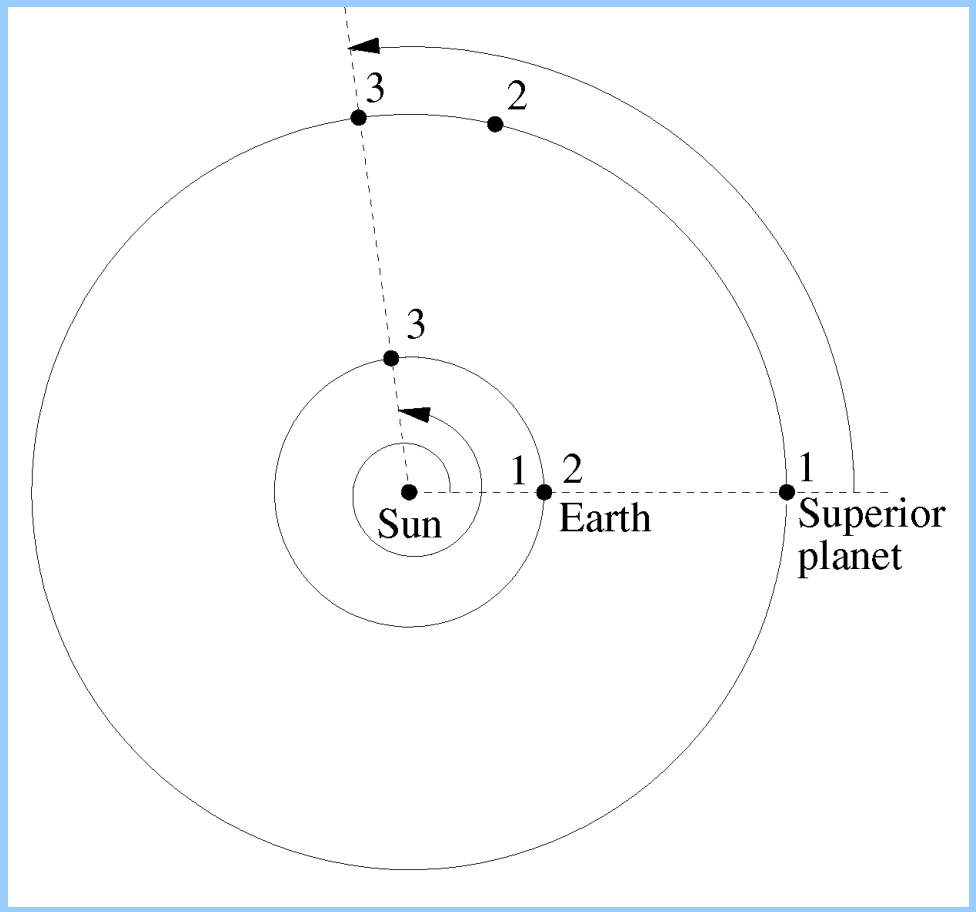
Planetary Configurations

- 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

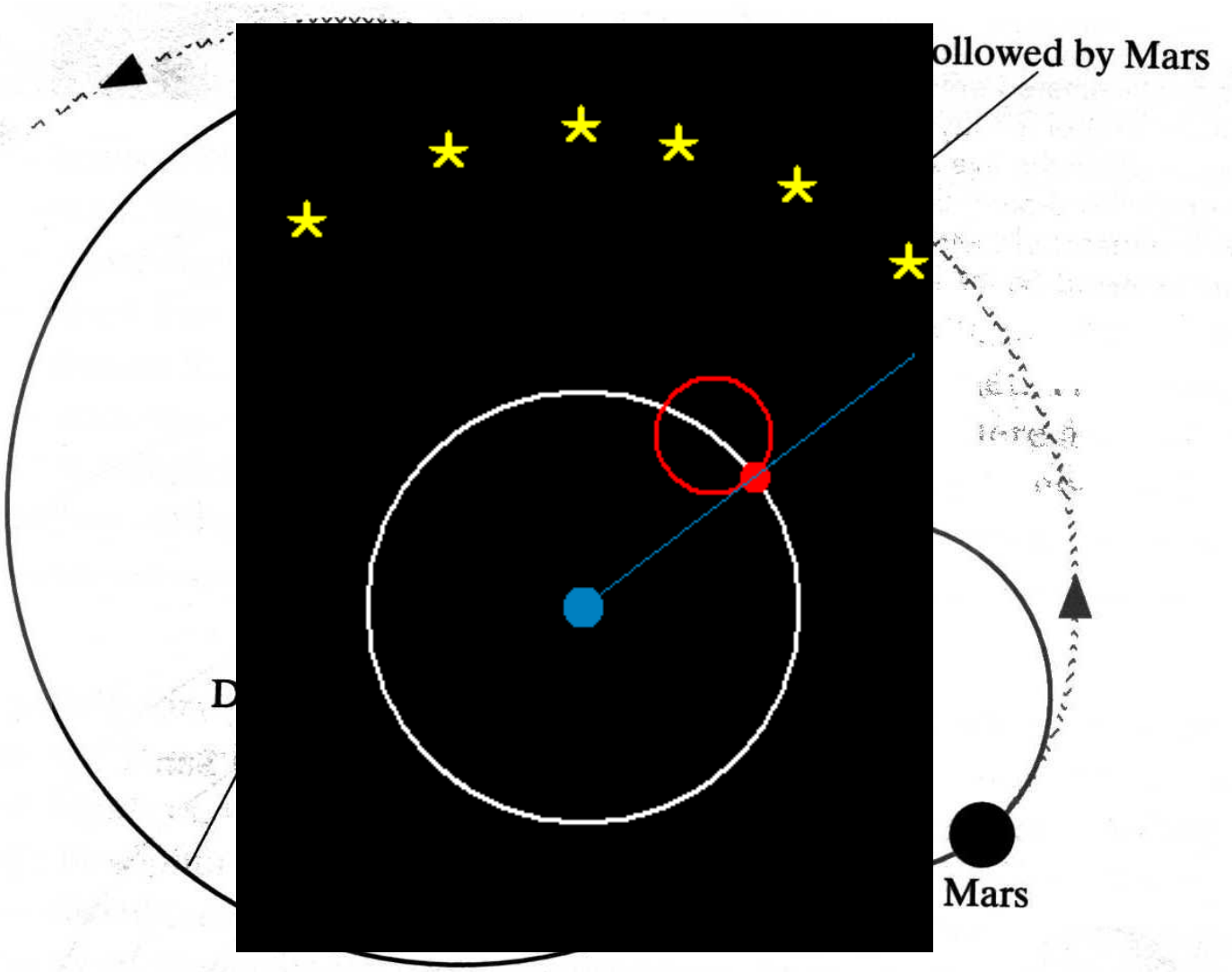
- Synodic period, S
  - time interval between successive conjunctions or oppositions, 1→ 3
- Sidereal period, P
  - Time interval for one complete orbit relative to background stars, 1→2



$$\frac{1}{S} = \frac{1}{P_i} - \frac{1}{P_{out}}$$

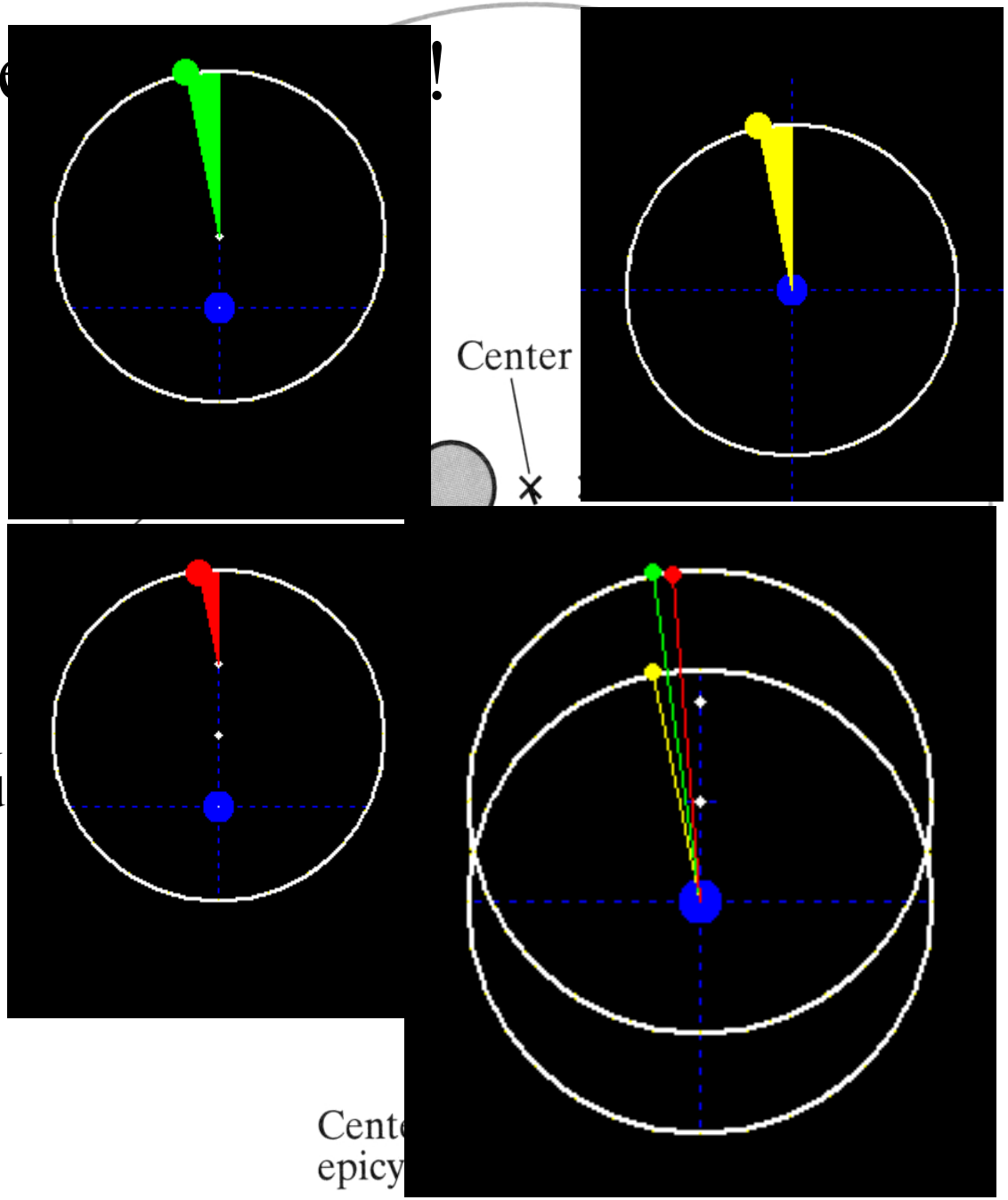
Epicycles on Deferents

- Ptolemy et al. desired uniform circular motions



Ptolemy's Mode!

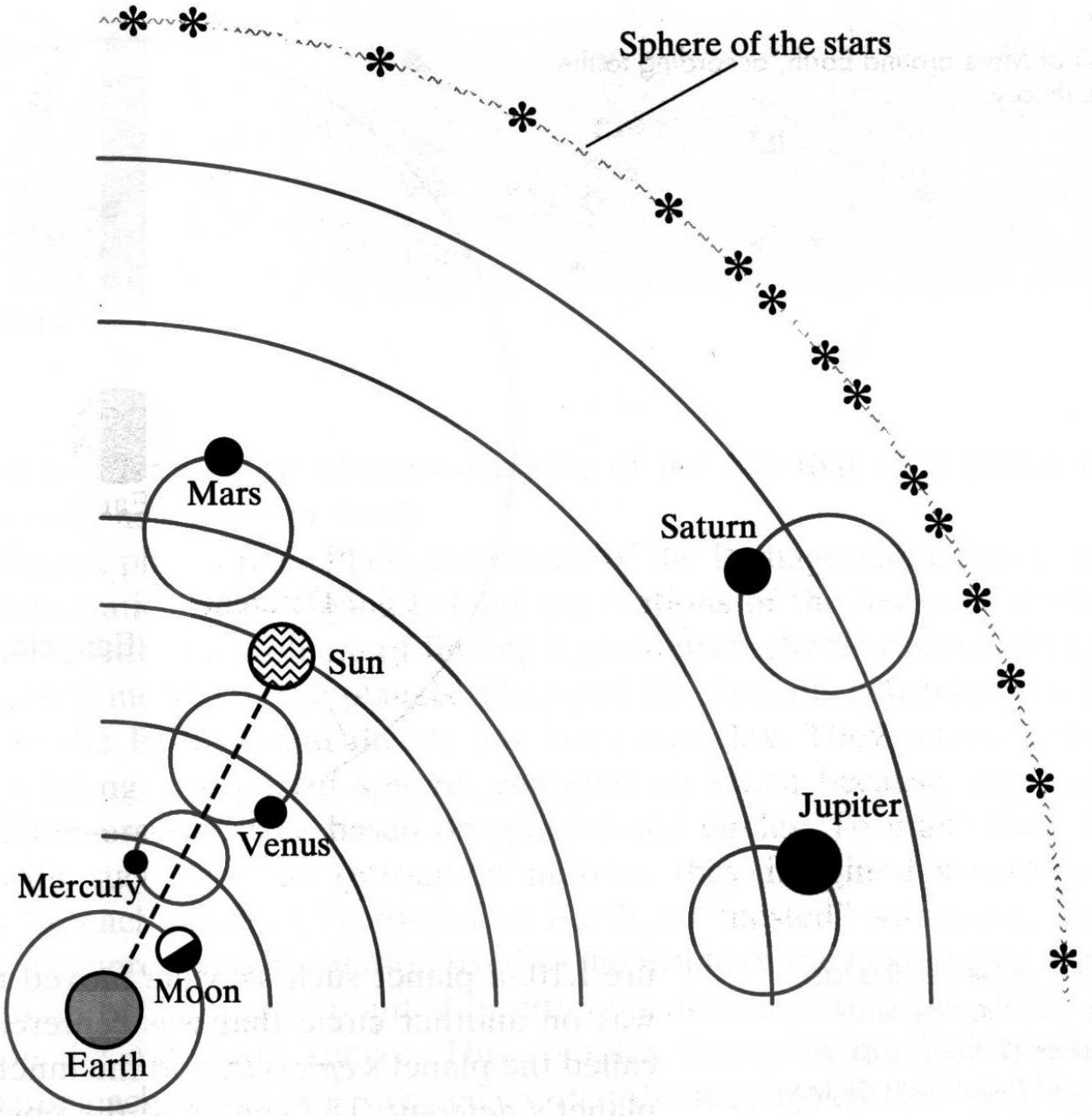
- Eccentric - displaces Earth from center
- Equant – center of epicycle has uniform angular speed when viewed from this point
- For superior planets, the period of planet around epicycle is sidereal period of Earth. For inferior planets, it is the sidereal period of that planet.
- Period of epicycle center around deferent center is sidereal period of the planet for superior planets, of the Earth for inferior planets.
- 80+ epicycles
- Occam's Razor (1348)
  - Accept the simplest explanation



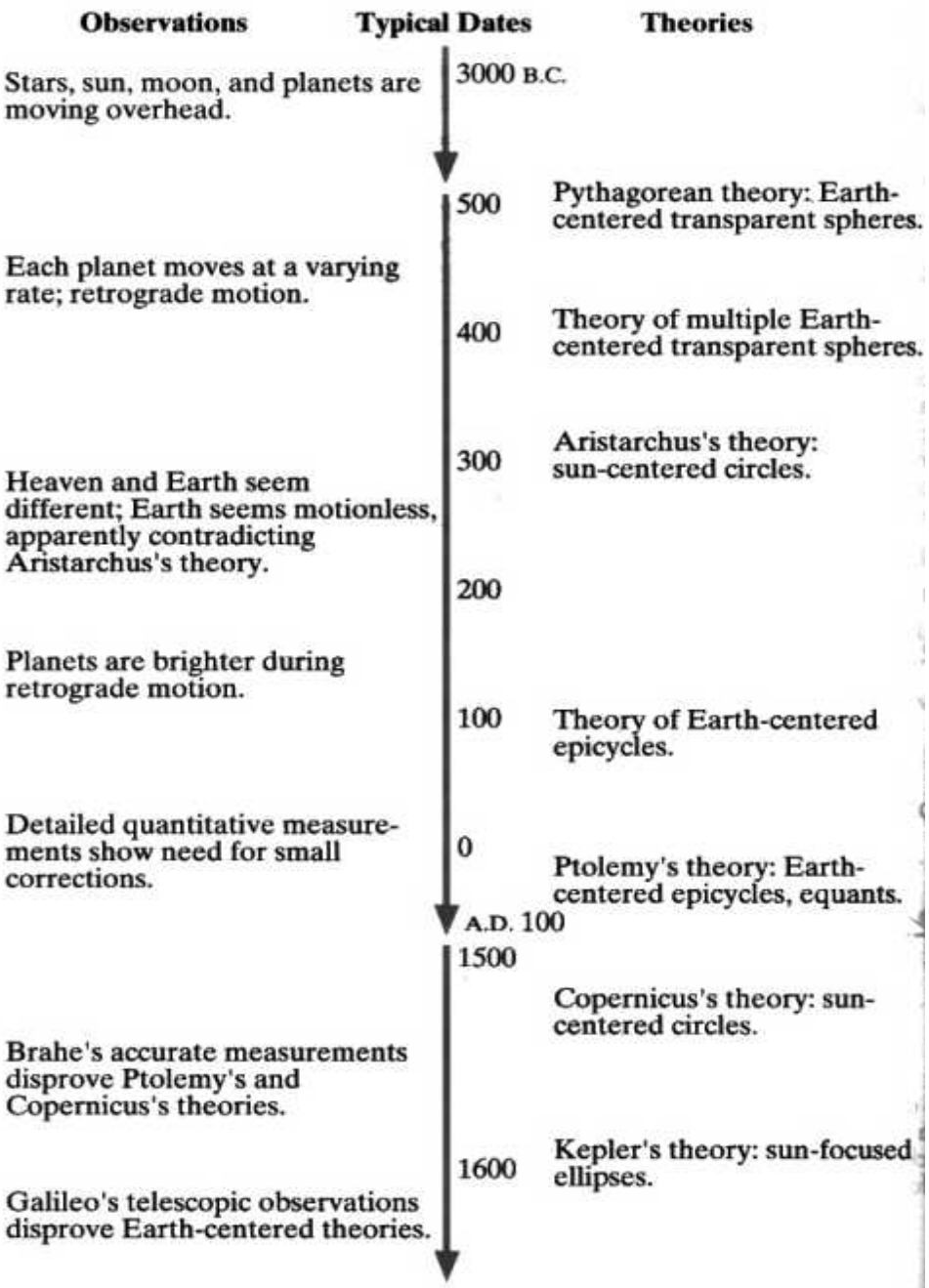
Ptolemy's Model ... of the *Universe*

- Explains retrograde and brightness
- Speed is still a problem

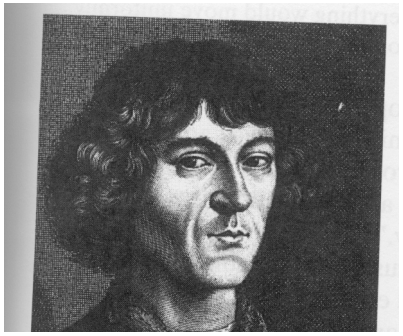
FIGURE 1.12
The ancient astronomer Ptolemy, A.D. 85–165. Using epicycles and many other theoretical devices, he prefected the Earth-centered theory of the layout of the universe.



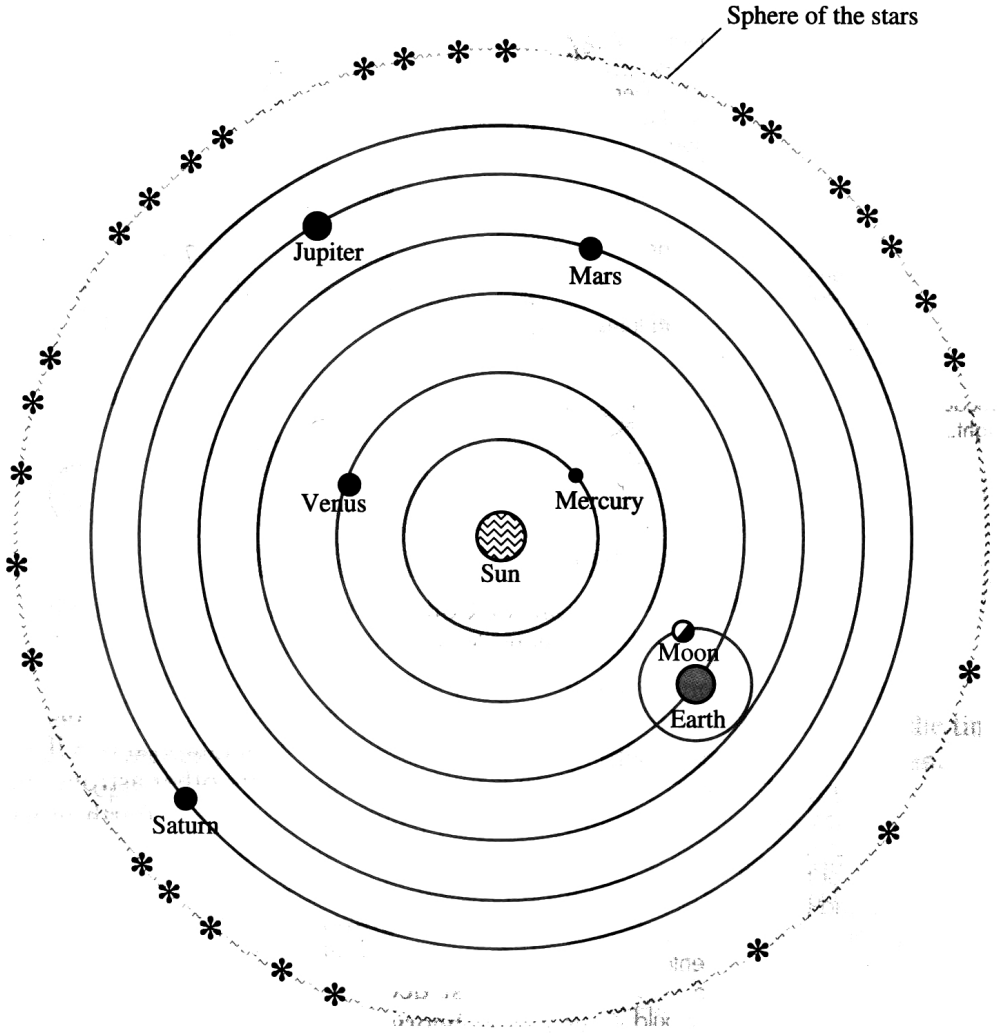
A Summary of the Early History of Astronomy



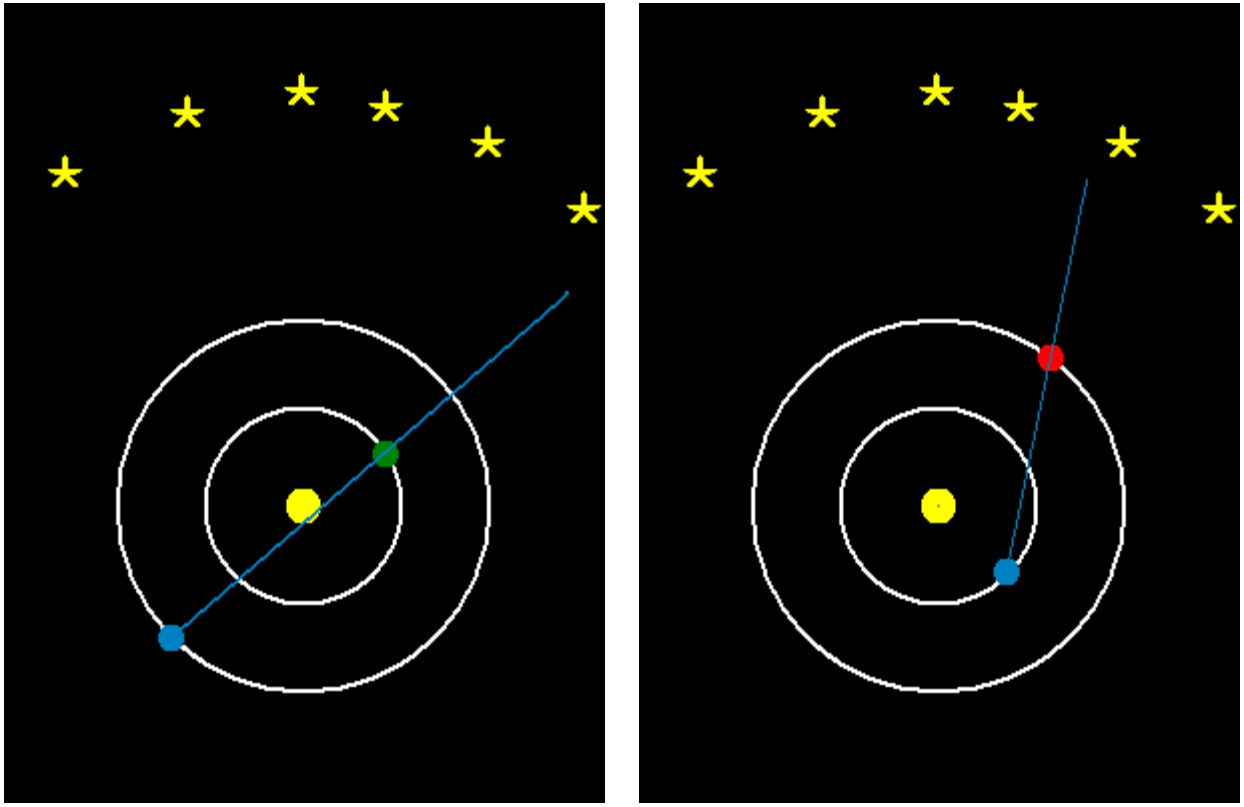
Copernicus (1473-1543)



- Is there something simpler?
- How about Aristarchus' ideas:
  - Earth centered (heliocentric)
  - Earth rotates
  - Earth is no different from the other planets and stars!
- Keeps some Pythagorean ideas:
  - spheres (circles)
  - uniform motion
- Established order of the planets
  - Inferior (Mercury and Venus)
  - Superior (Mars, Jupiter, Saturn)
- A natural explanation for retrograde motion

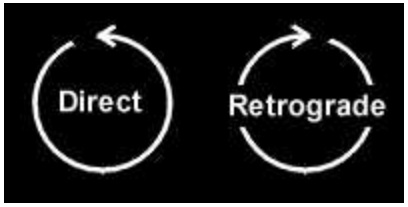


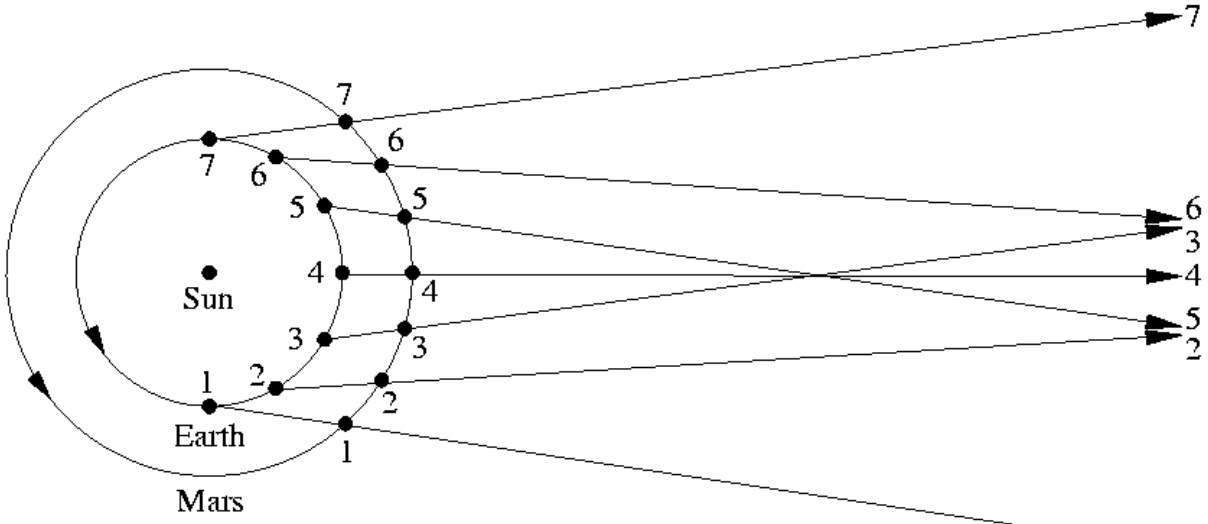
Copernicus' Heliocentric model

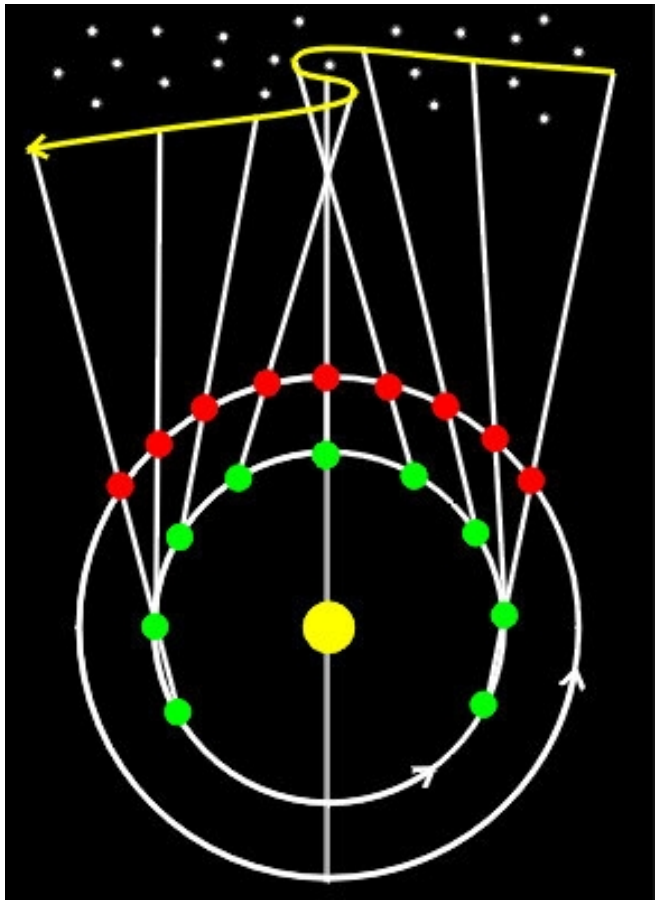


Heliocentric Model and Retrograde Motion

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







Copernicus (cont.)

- Predictions of existing observations are not better than Ptolemy's!!
- Slightly simpler
  - No equants
  - Fewer epicycles (still a lot)
    - If epicycles were removed from the models ...
      - Copernicus does okay
      - Ptolemy's is a disaster
- Discriminating predictions did not exist
  - no telescopes until 1609
  - Ptolemy's was more widely accepted – the official universe of the Catholic church.

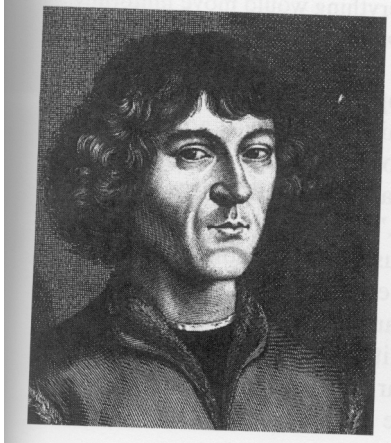


FIGURE 1.14
Renaissance astronomer Nicolaus Copernicus, 1474–1543. Finding Ptolemy's system to be "neither sufficiently absolute nor sufficiently pleasing to the mind," he devised a simpler theory. Copernicus's theory placed the sun at the center of the universe, with Earth moving around it. The odd 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 (1546-1601)

- 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!

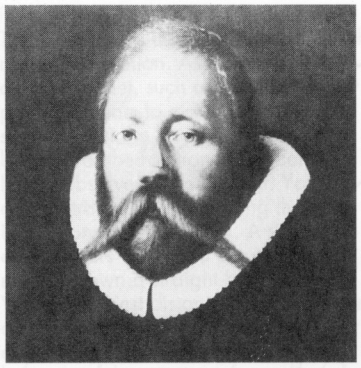


FIGURE 1.18
Tycho Brahe, 1546–1601. By making measurements of the planetary positions that were five times more accurate than were previous measurements, he overthrew two theories of the architecture of the heavens.

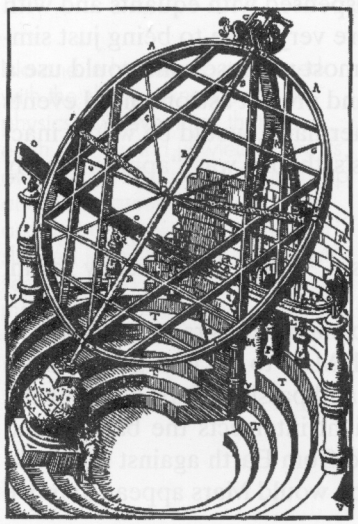


FIGURE 1.19
Brahe's sextant for measuring the positions of the planets. Brahe's work was done without telescopes.

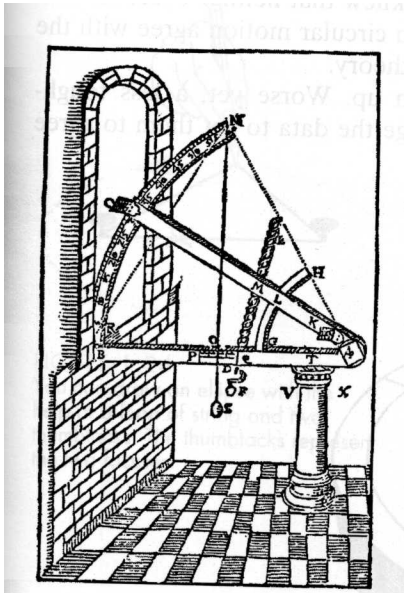
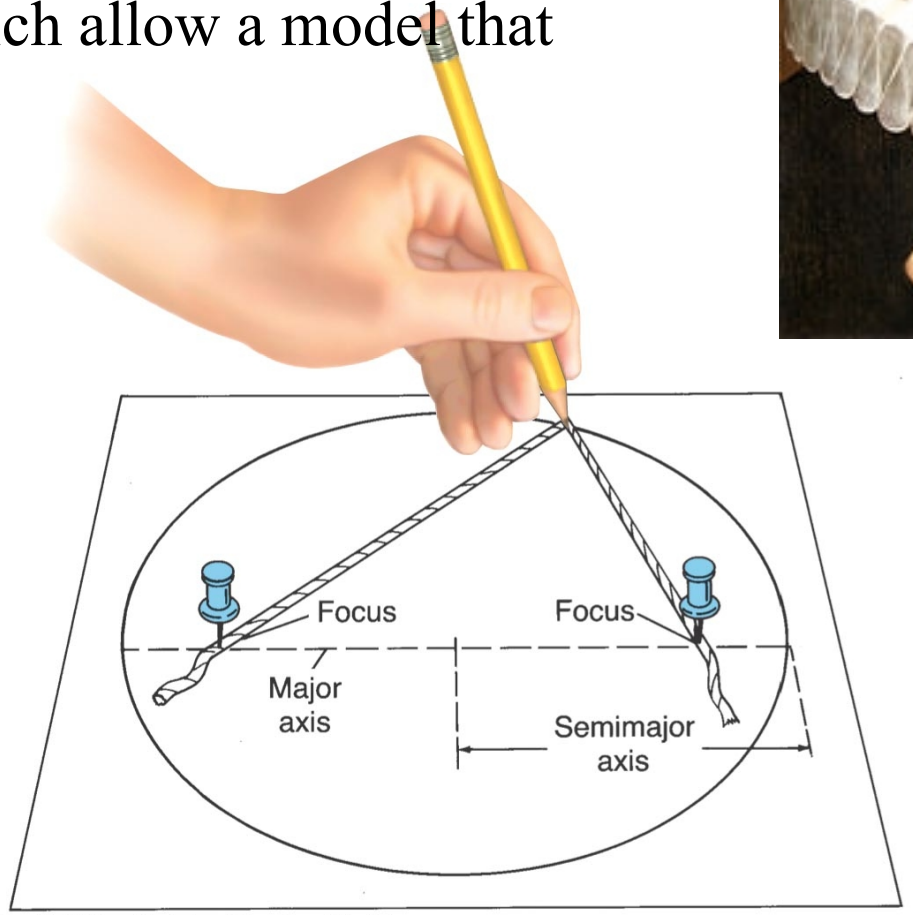


FIGURE 1.20
An instrument that Brahe used for

Johannes Kepler (1571-1630)

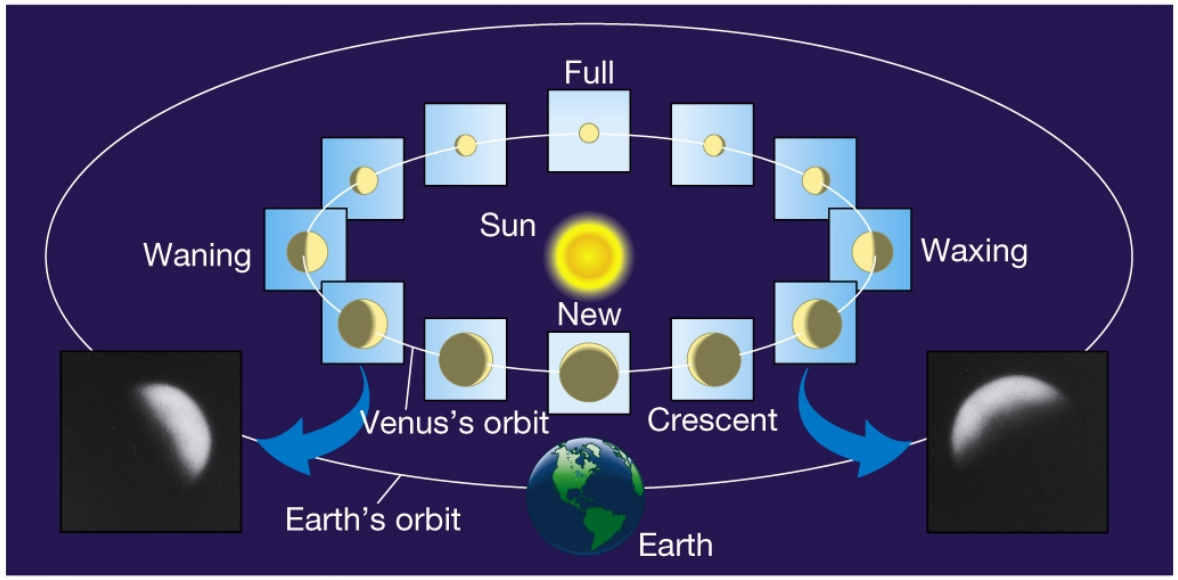
- Brilliant at math and geometry
- Hired by Tycho to work on orbit problem
- Inherits 20 yrs of Tycho's observations
- Develops 3 laws which allow a model that <u>does</u> match the data!



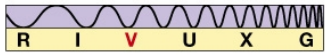
Galileo (1564-1642)

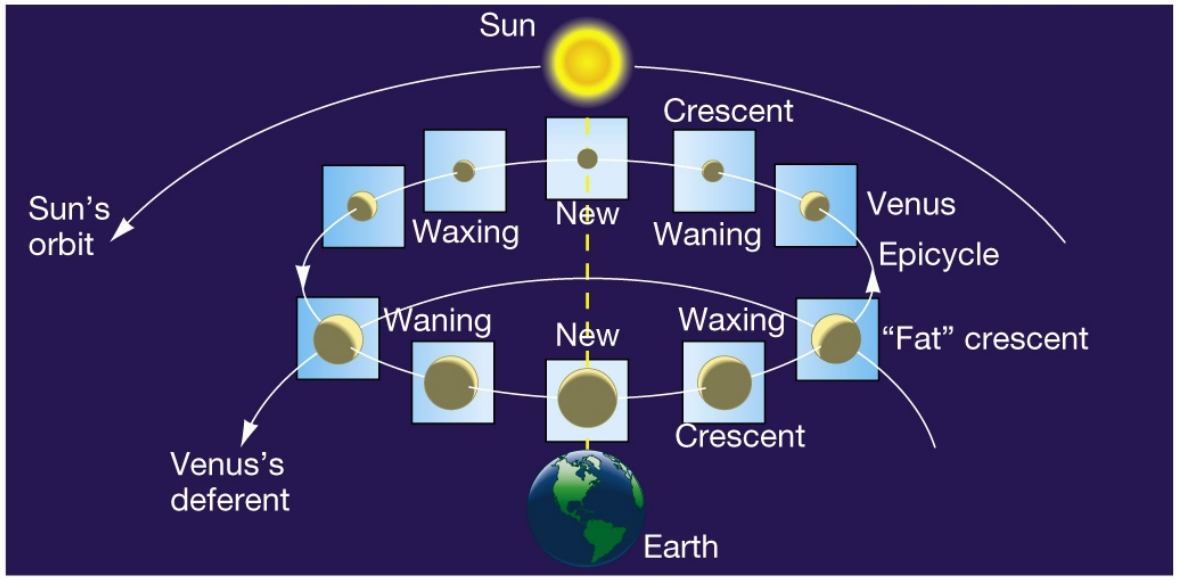
- First used a telescope for astronomy in 1609
- Strong support for Copernican and Kepler's models (heliocentric)
  - Moons of Jupiter orbit Jupiter!
    - Earth not the center!
  - **Phases of Venus include the gibbous phase!**
    - Not predicted with Ptolemy's model
  - The Sun has spots.
  - Other Discoveries: Milky Way made up of stars, Saturn has "ears", Moon has craters.
- Experiments with mechanics refute Aristotelian physics

Ph

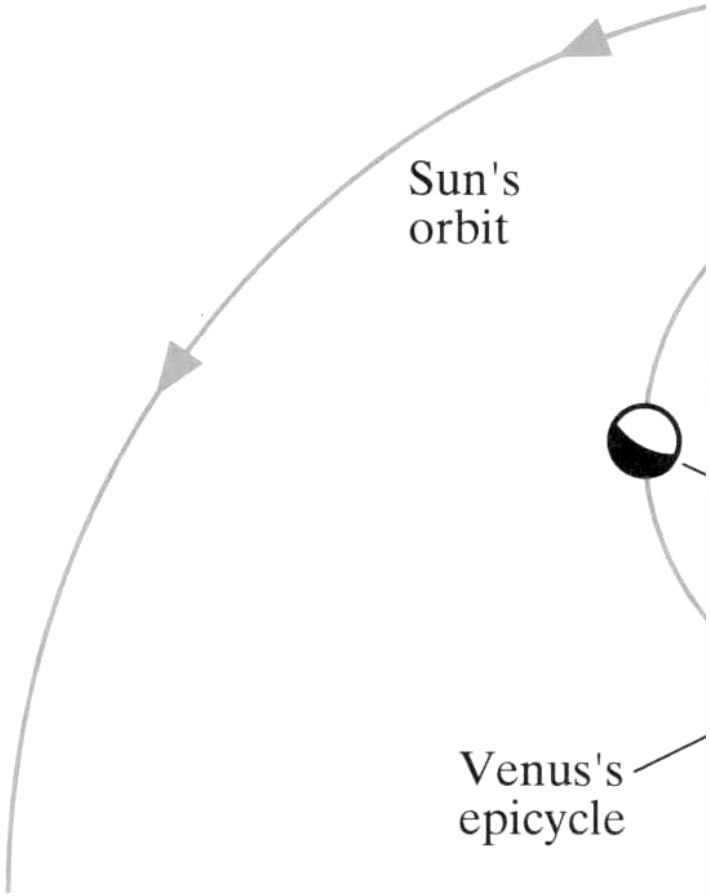


(a) Sun-centered model





(b) Ptolemy's model

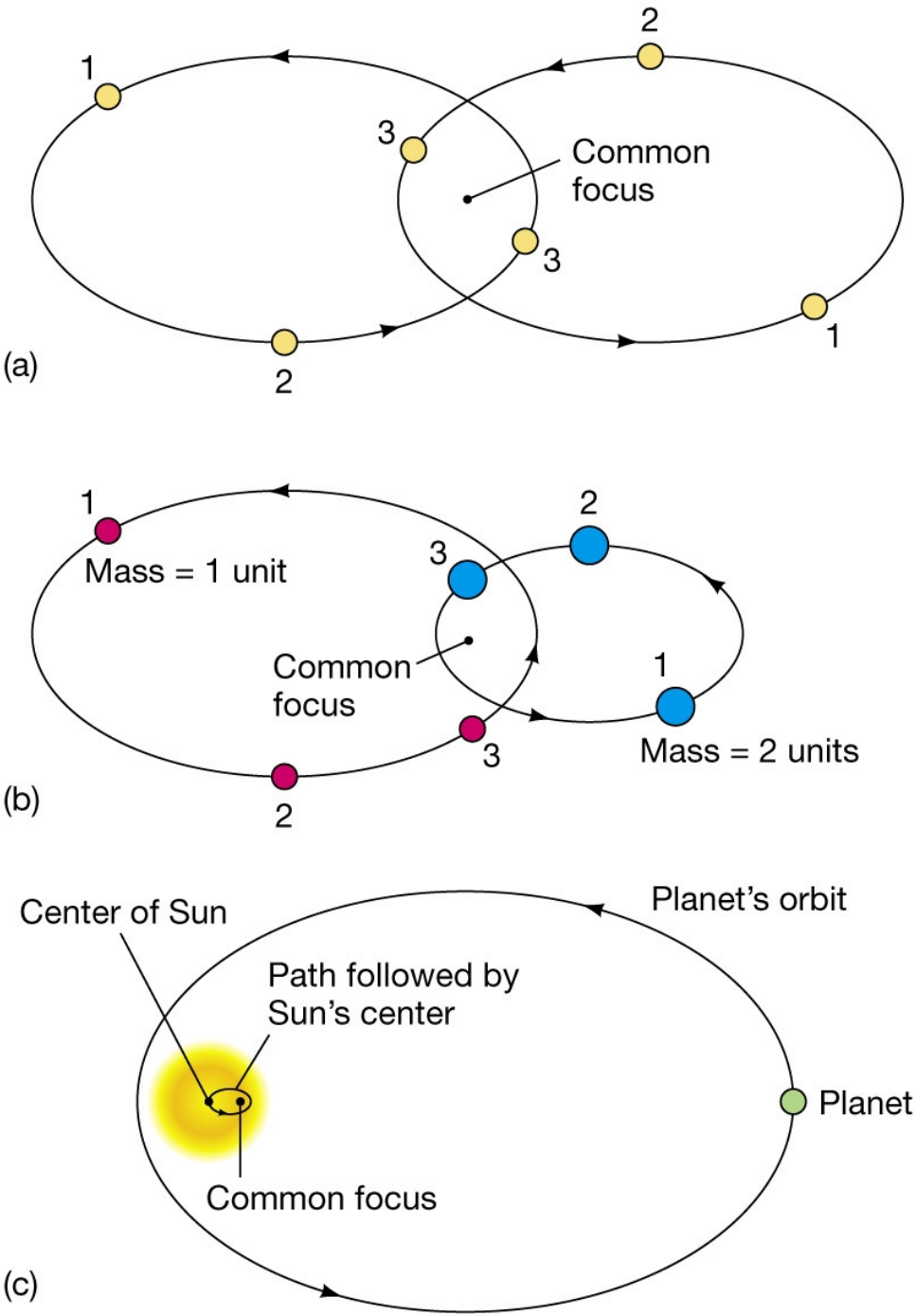


Isaa
t

Kepler I: The planets o
ellipses with the princip
the center of mass of the
system, (not the Sun)

Kepler III: add the total
the system to the denom

$$P^2 = \frac{a^3}{Mtot}$$



Summary of Heliocentric Revolution

- For the 300 years after Copernicus, the heliocentric model gradually gained favor.

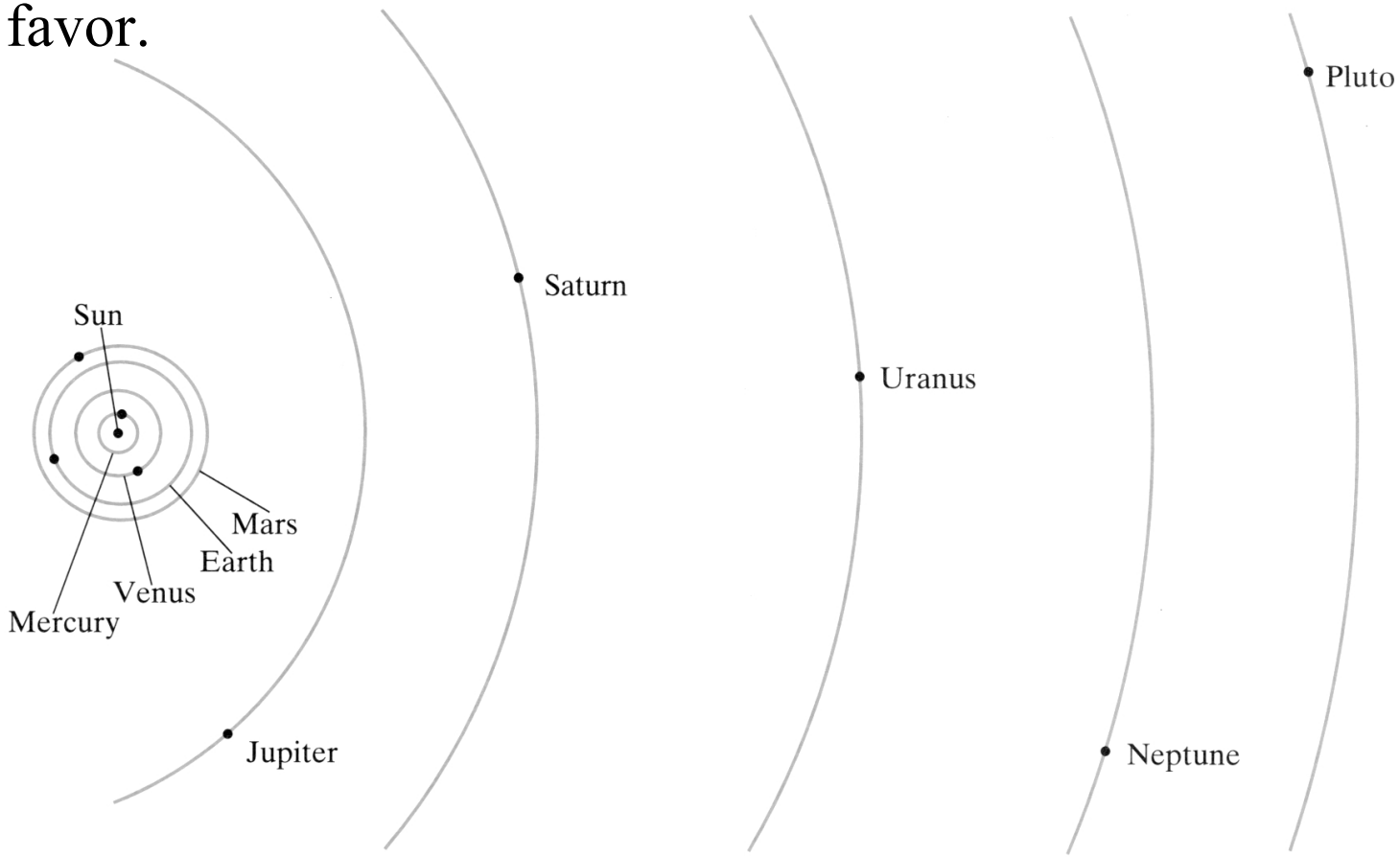


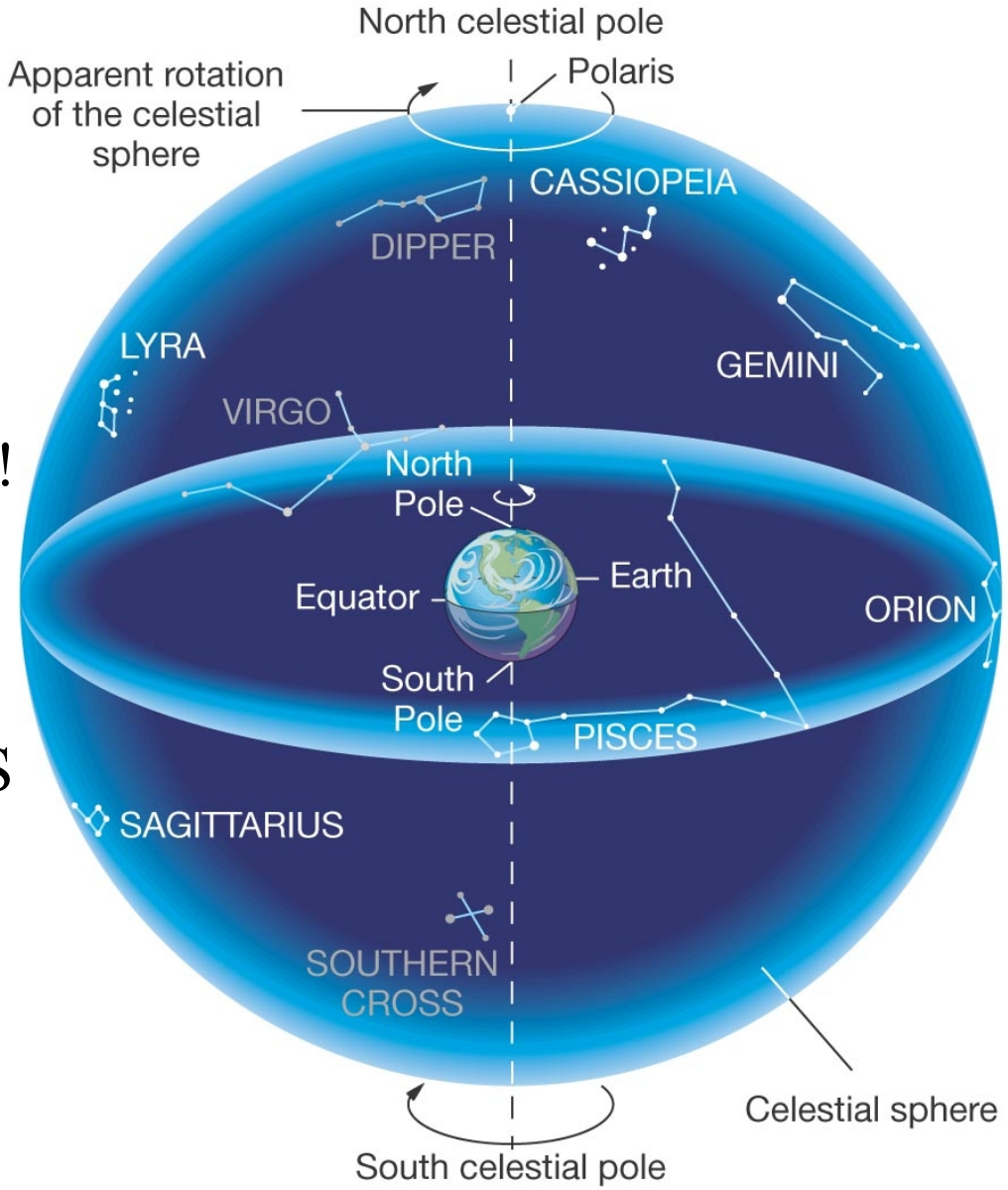
FIGURE 1.26
The arrangement of the solar system as it is now known. Uranus, Neptune, and Pluto are visible only with a telescope. The orbits are elliptical, although their ellipticity is too small to be visible in this diagram.

The Celestial Sphere

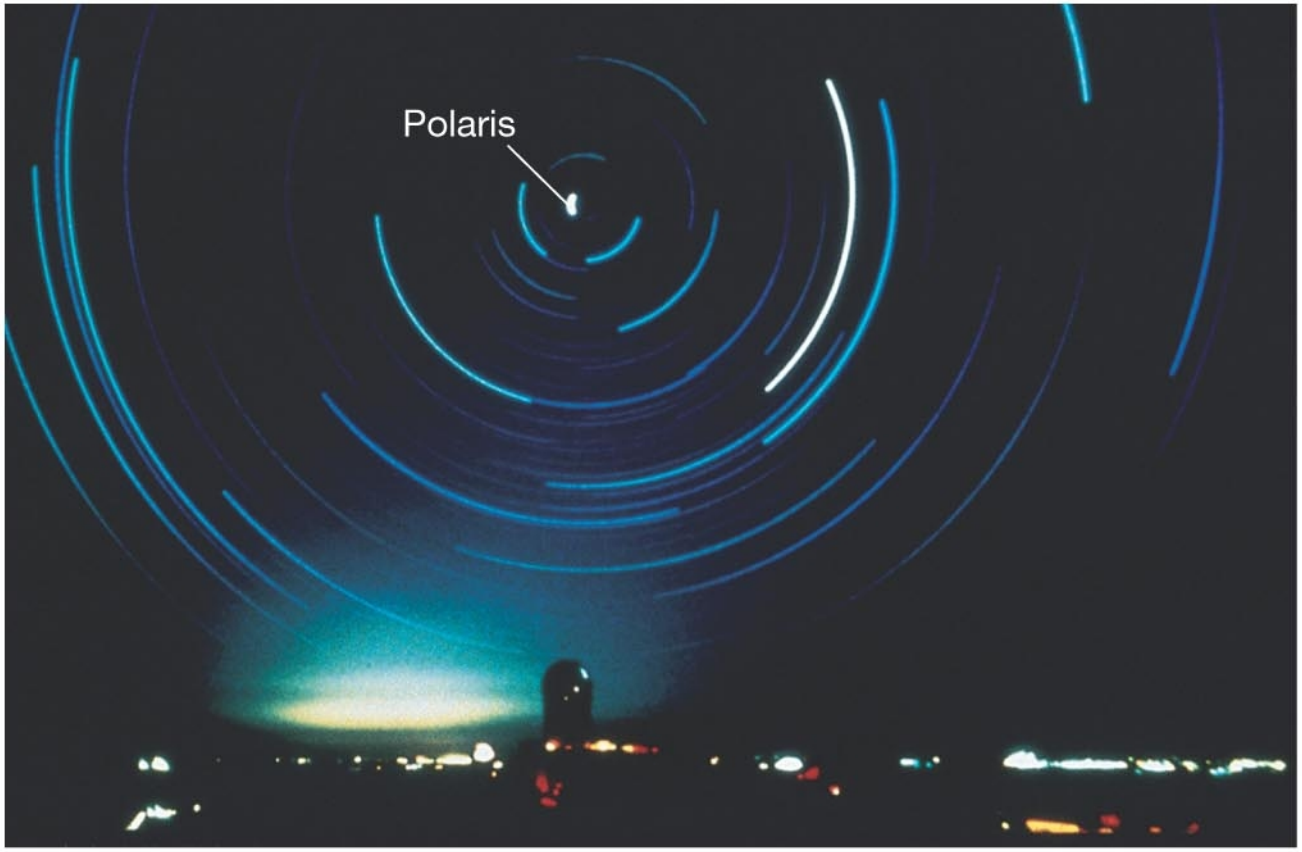
How did the Greeks model daily ("diurnal") motions?

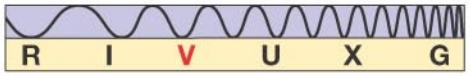
As a celestial sphere (CS)!

- Centered on Earth
- Much bigger than Earth
- Horizons on Earth cut CS in half
- Stars fixed on CS
- CS rotates CW as seen from outside, CCW from inside.

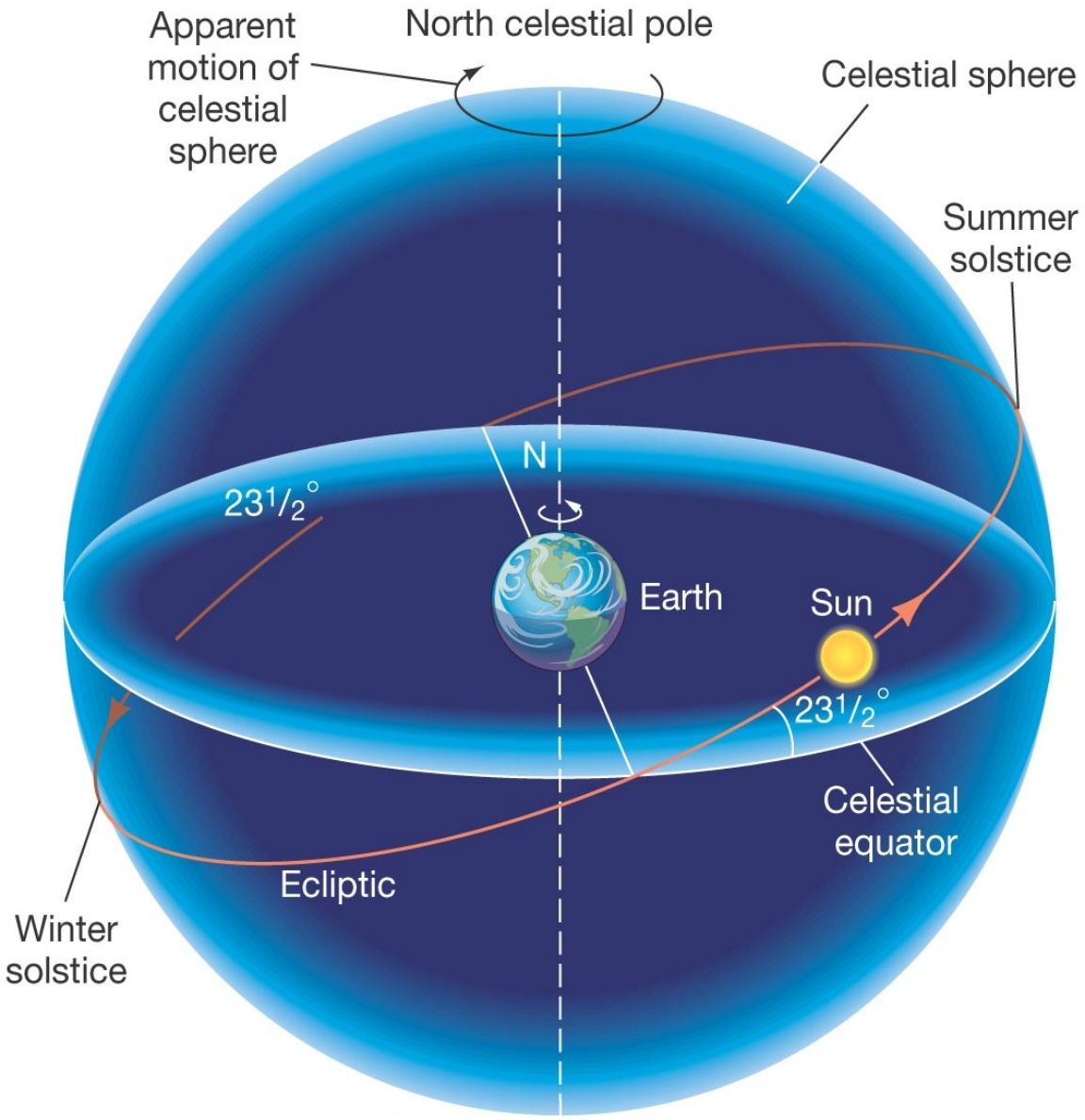


Star Trails



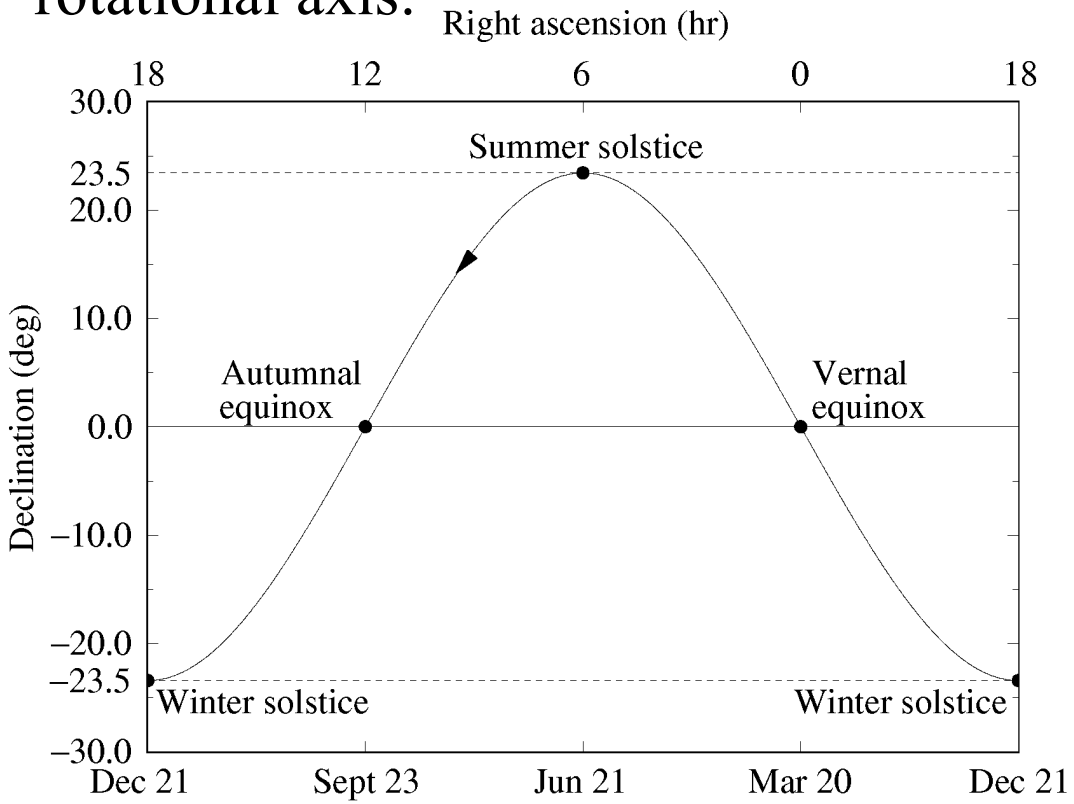


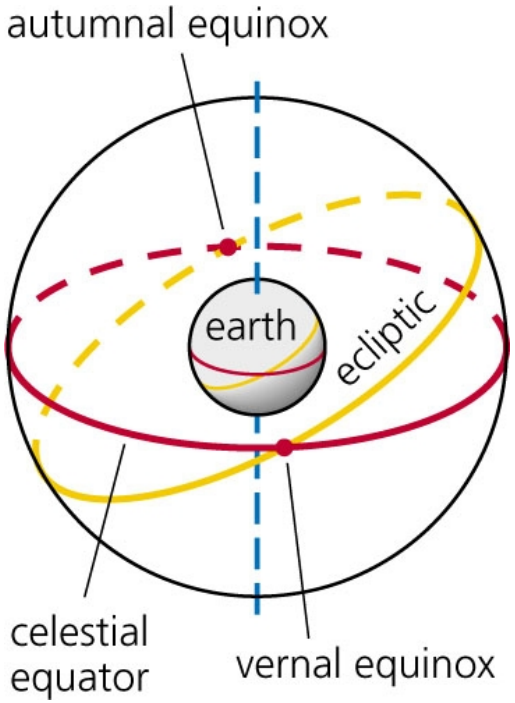
Celestial Sphere and the ecliptic



Ecliptic

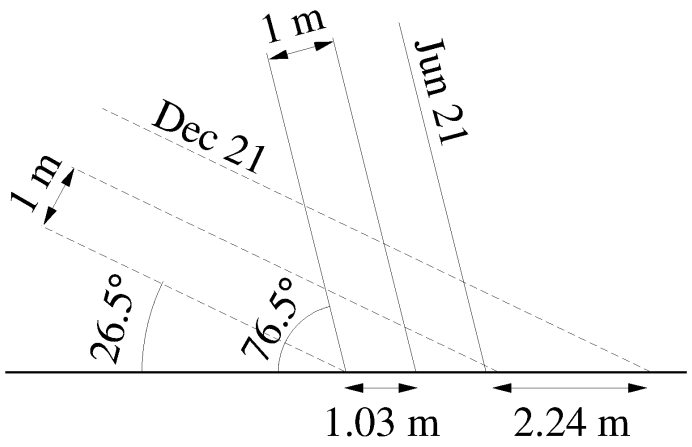
- Ecliptic = Path of the Sun relative to the stars
- Seasonal variations due to orbital motion and the 23.5^0 tilt of Earth's rotational axis:

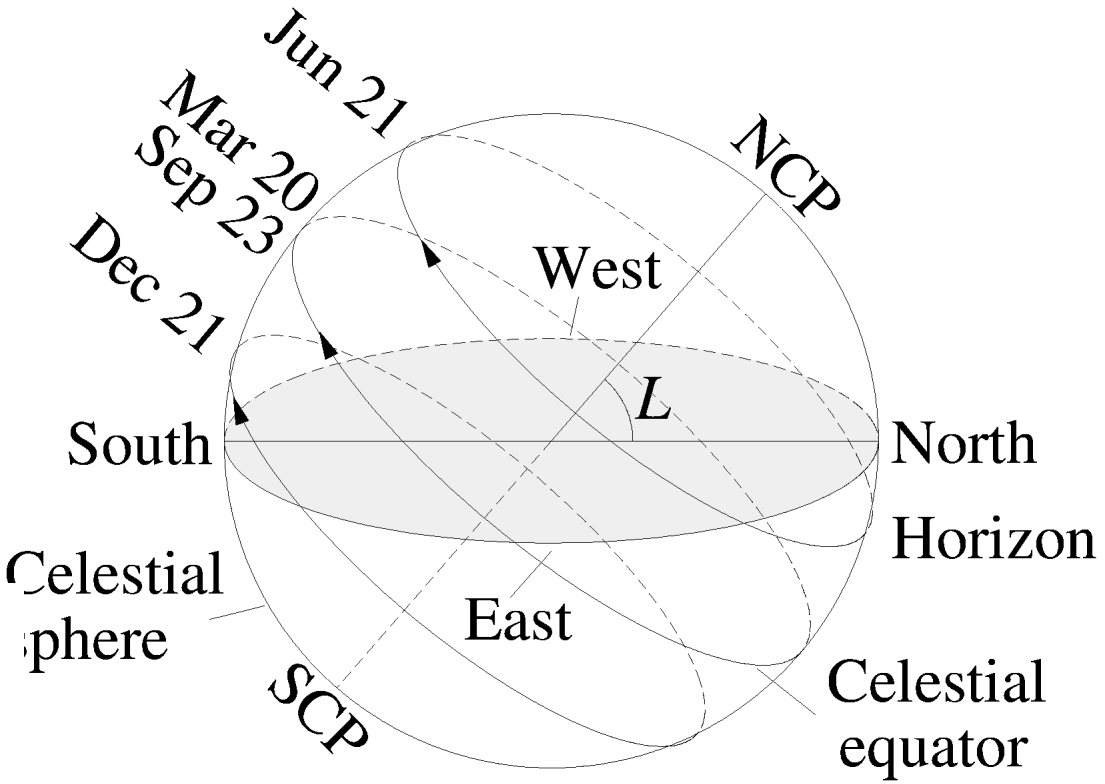




Ecliptic

- Vernal and autumnal equinox
- Summer and winter solstice

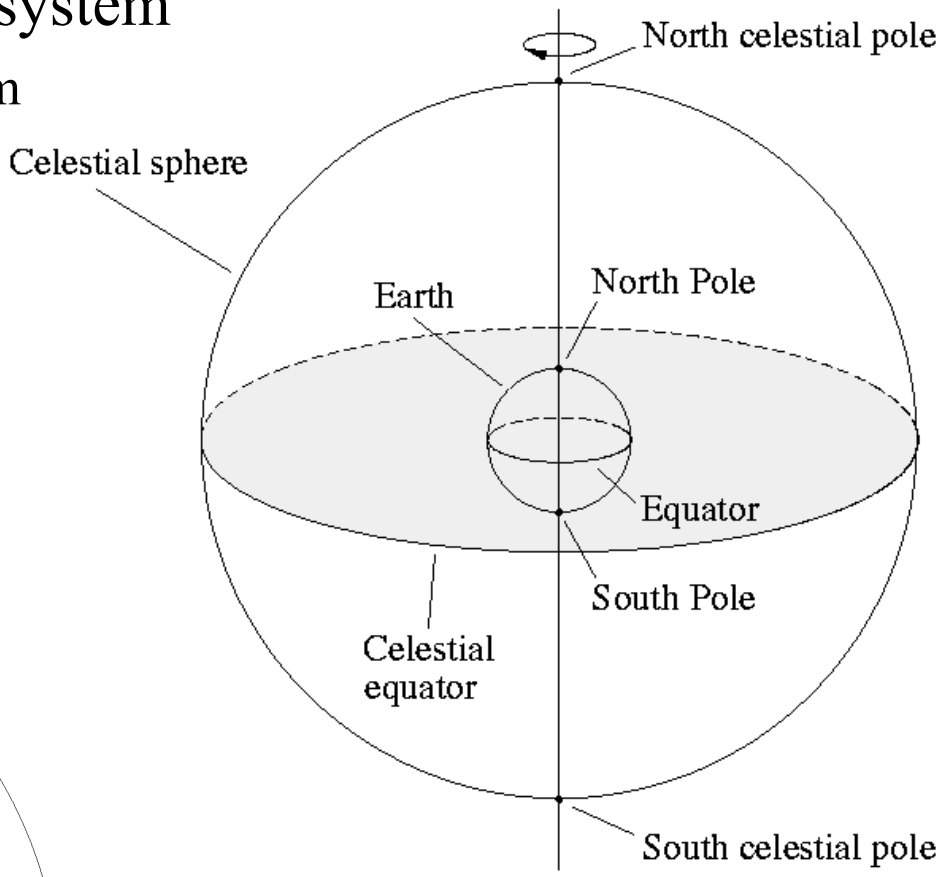


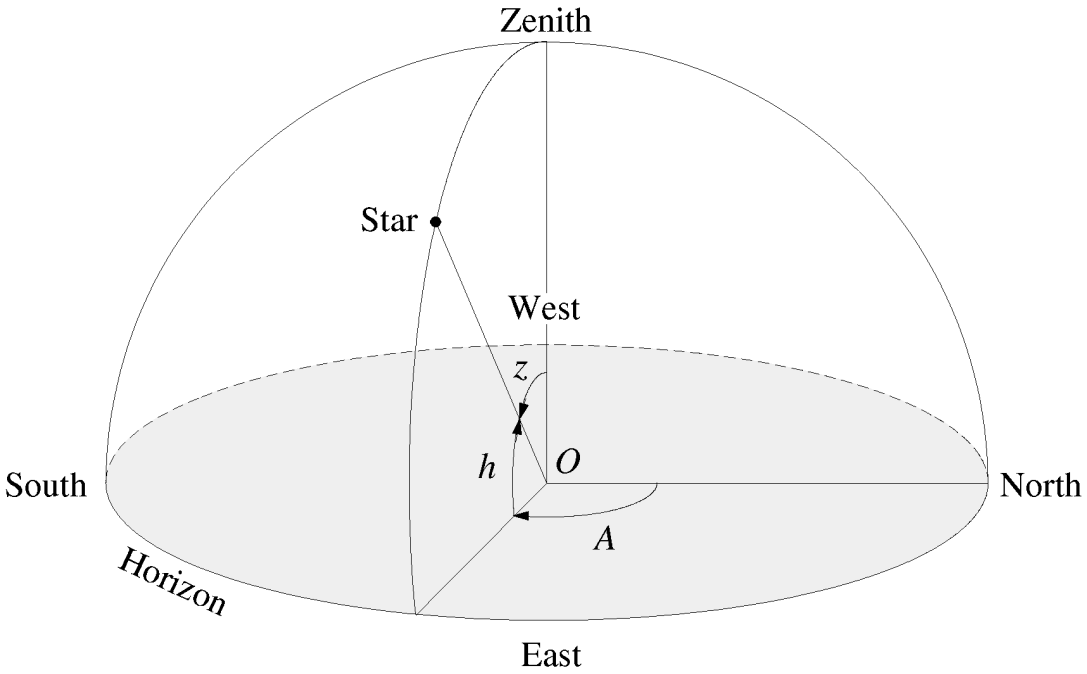


View standing on Earth looking W

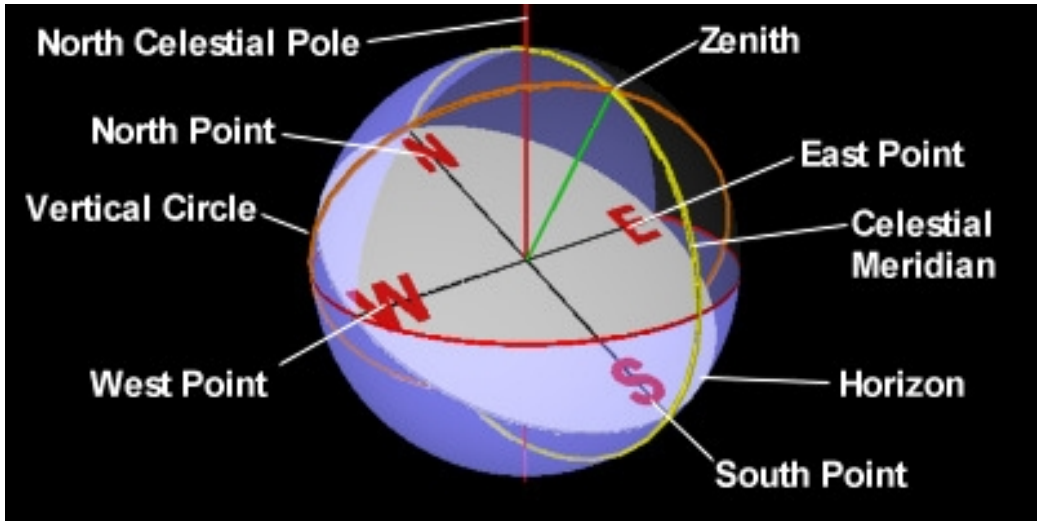
The Celestial Sphere & coordinates

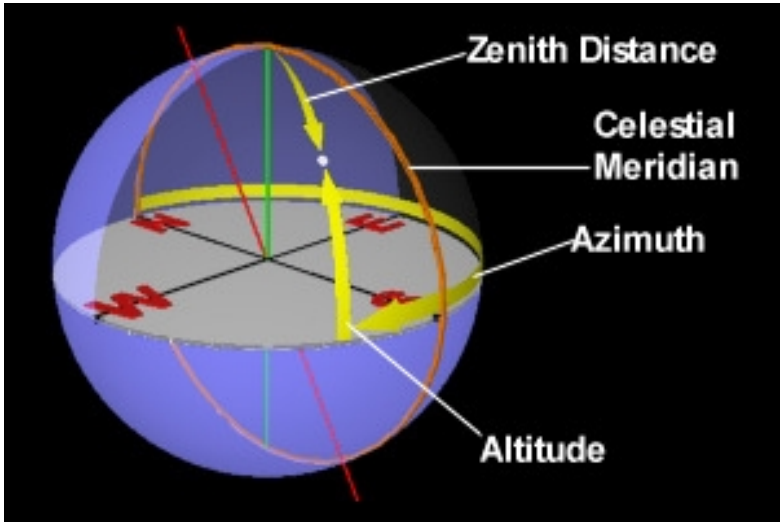
- Location-dependent coordinate system
  - Altitude – azimuth coordinate system
    - A = azimuth
    - h = Altitude (h + z = 90^0)
    - (z= zenith angle)





Altitude – azimuth coordinate system





- Advantages
  - Easy to describe a position to someone near you.
  - Both coordinates are measured in degrees.
- Problems
  - Coordinates of a star depend on your location on Earth.
  - Coordinates of a star change with time.

Coordinate systems

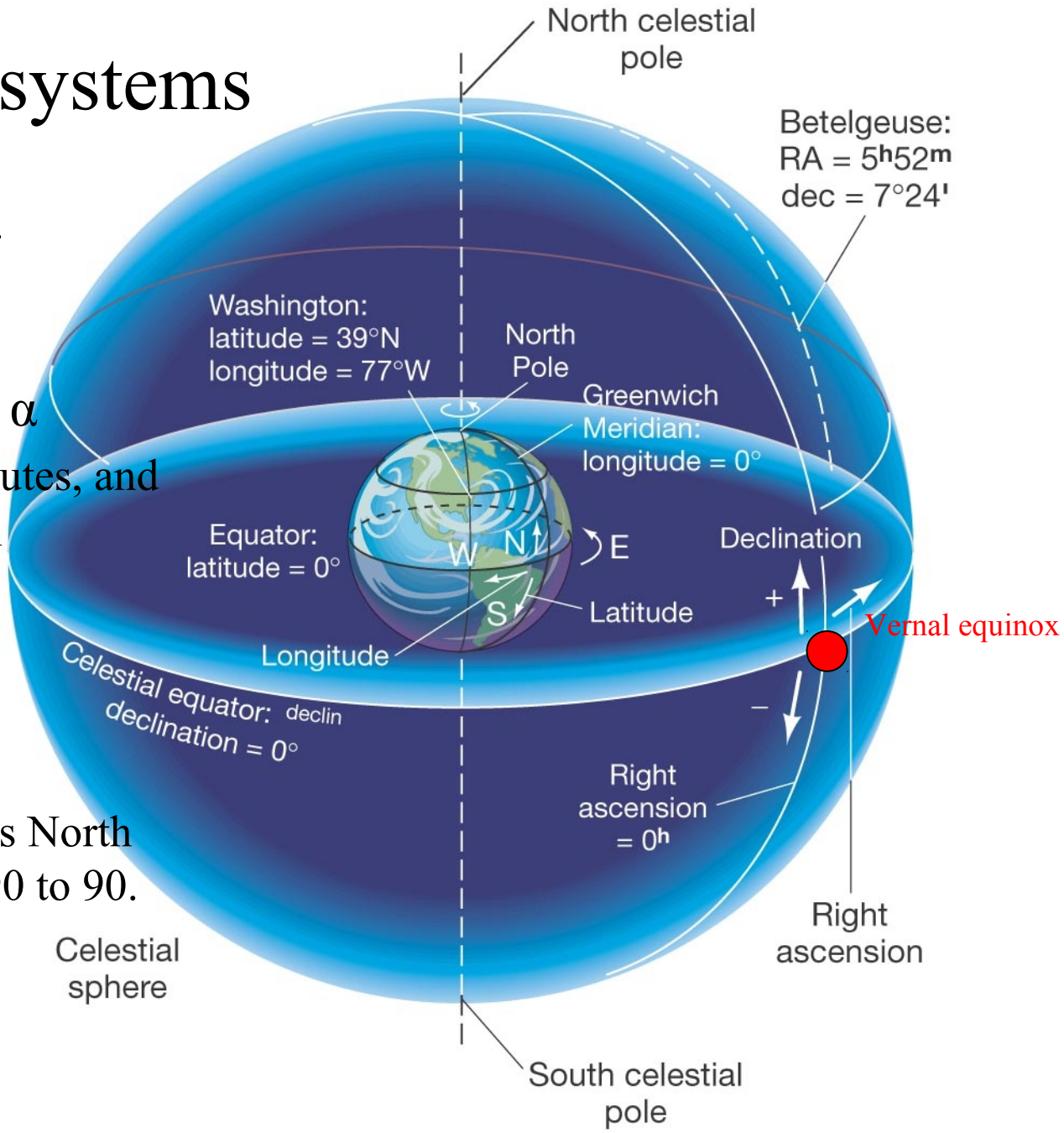
Equatorial Coordinate System

Right Ascension, RA, α

measured in hours, minutes, and seconds East of the Vernal Equinox. 0-24 hrs

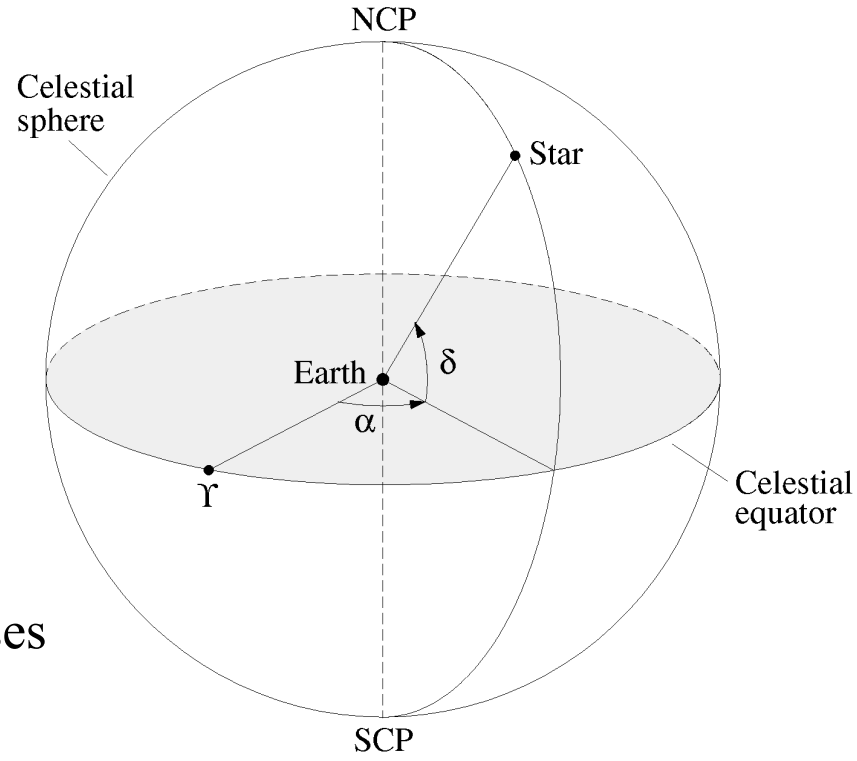
Declination, DEC, δ

measured in degrees, arcminutes, and arcseconds North of the celestial equator. -90 to 90.



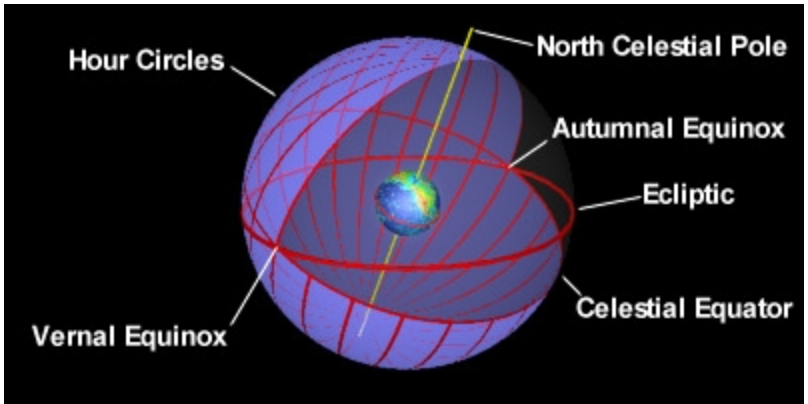
Equatorial Coordinate System

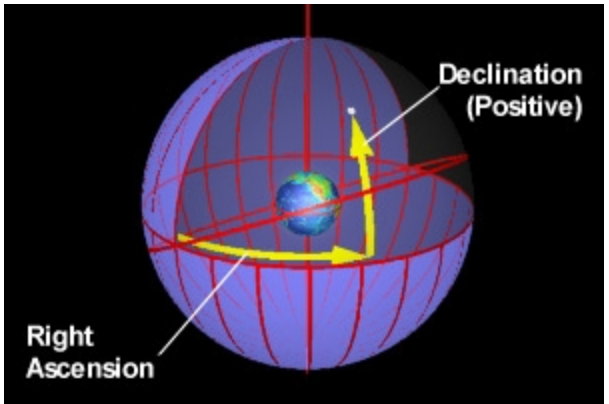
- This system is unaffected by daily and annual motions
- Independent of observer's location



α – right ascension (longitude)
δ – declination (latitude)
γ – vernal equinox (RA=0)

Problems:
1) α and δ gradually change as Earth Precesses
2) RA in measured in Hours, Min, Seconds

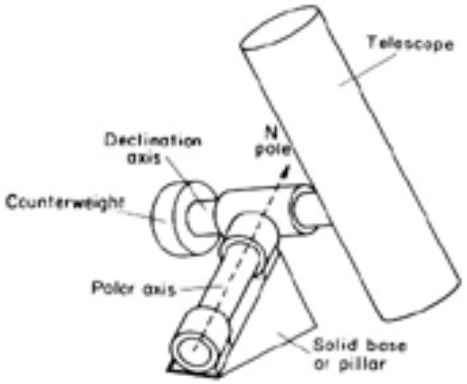




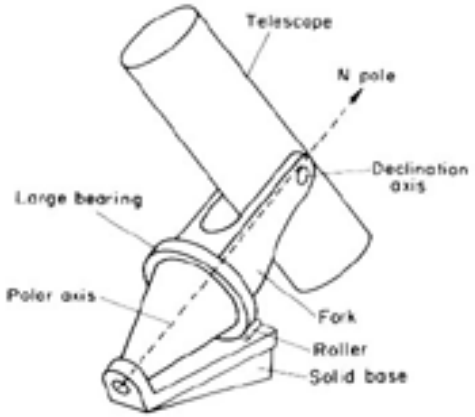
Telescopes - mounts

Equatorial:

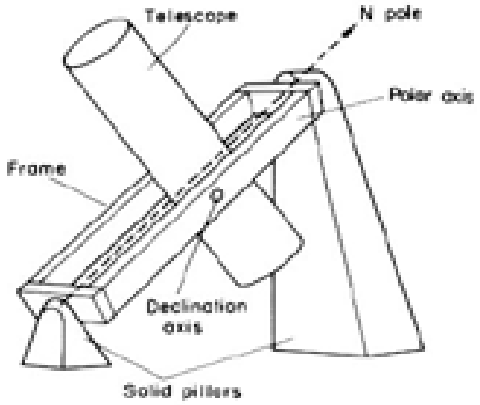
German Equatorial



Fork mount

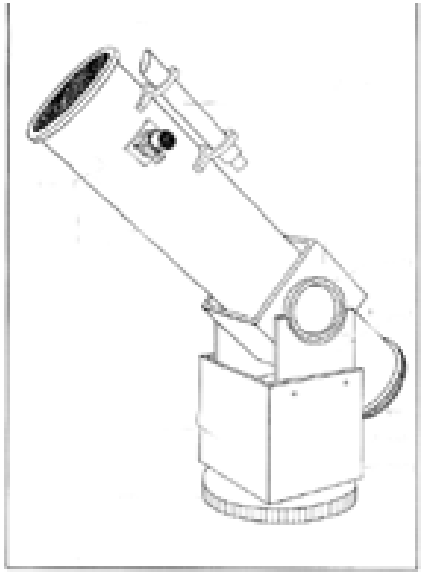


English yoke



Alt-Az:

Dobsonian



The Copernican Revolution ... *matching!*

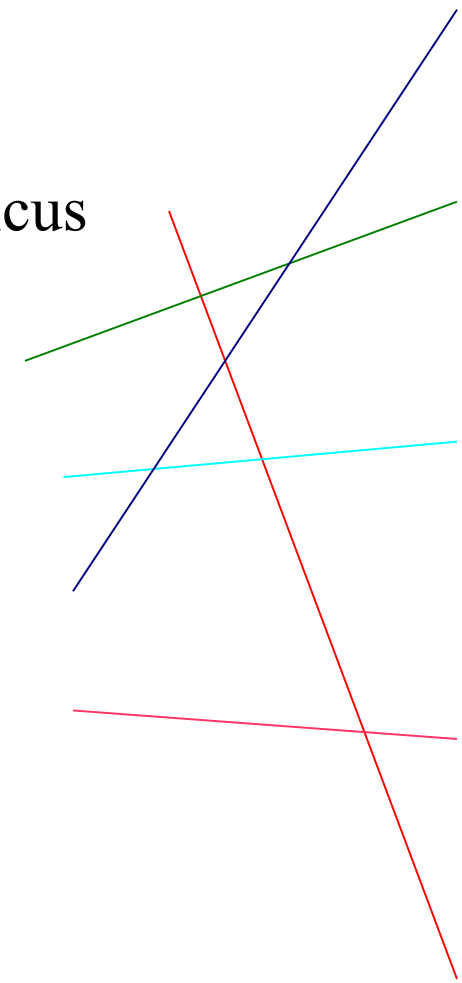
Nicolaus Copernicus

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