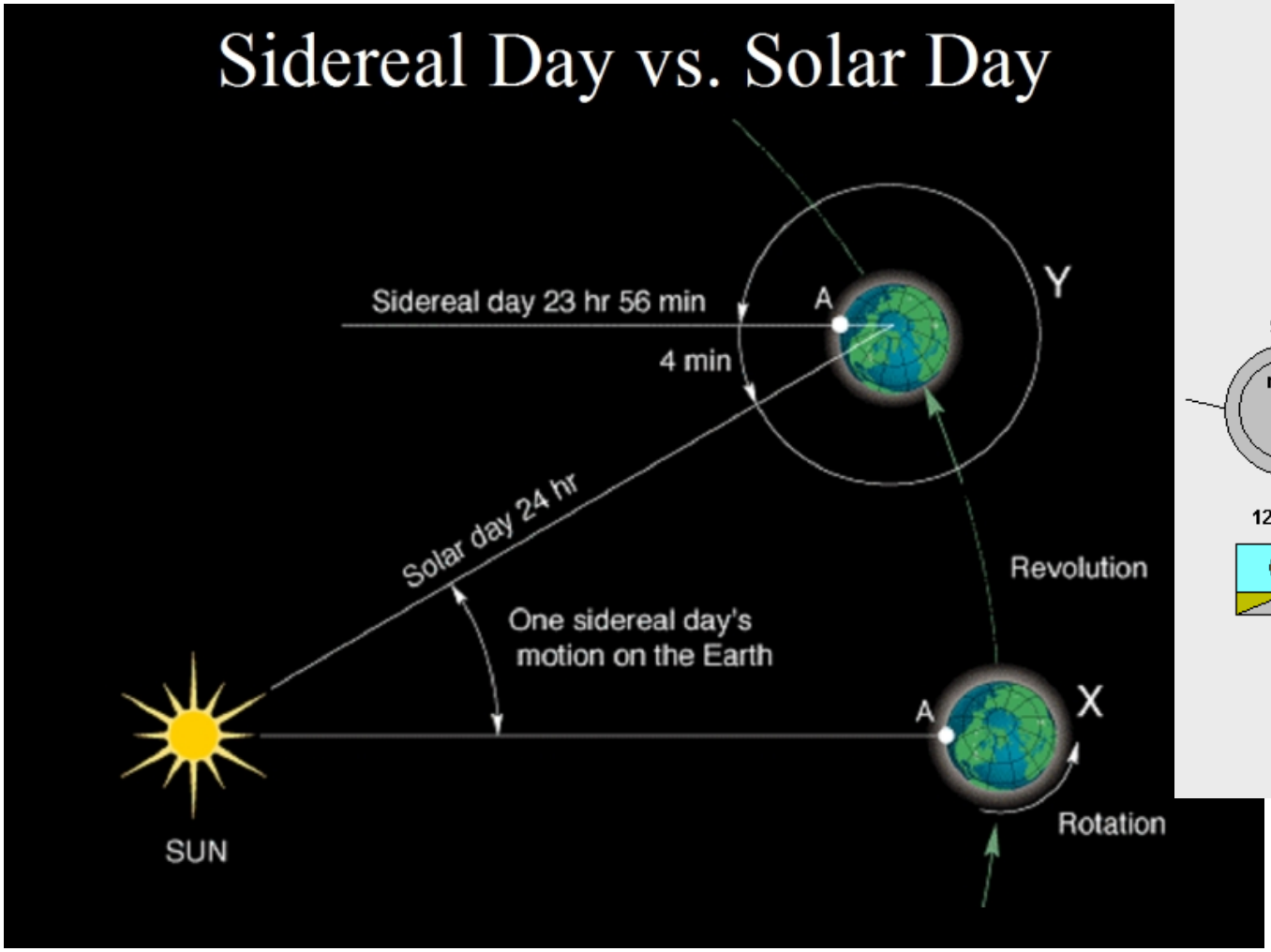
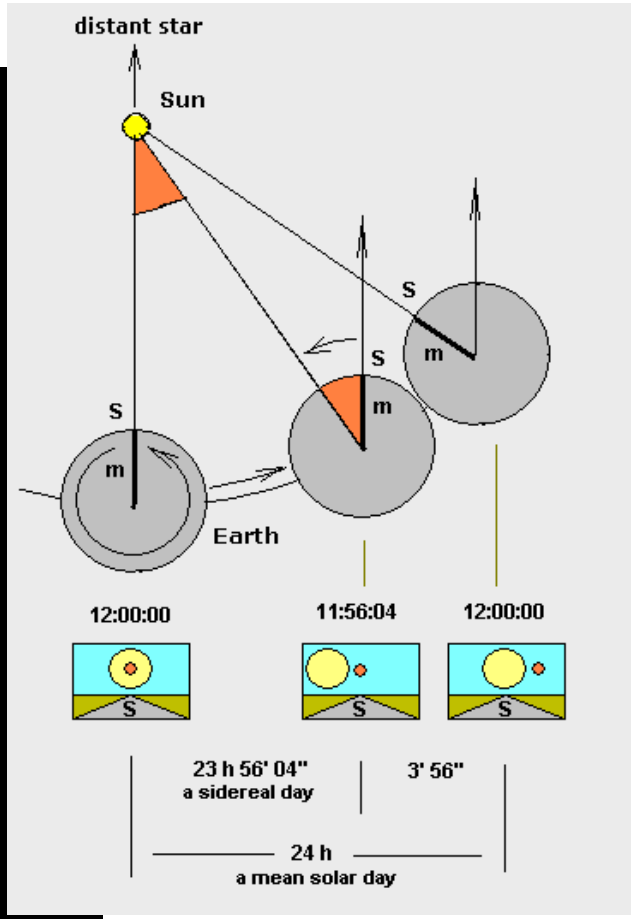
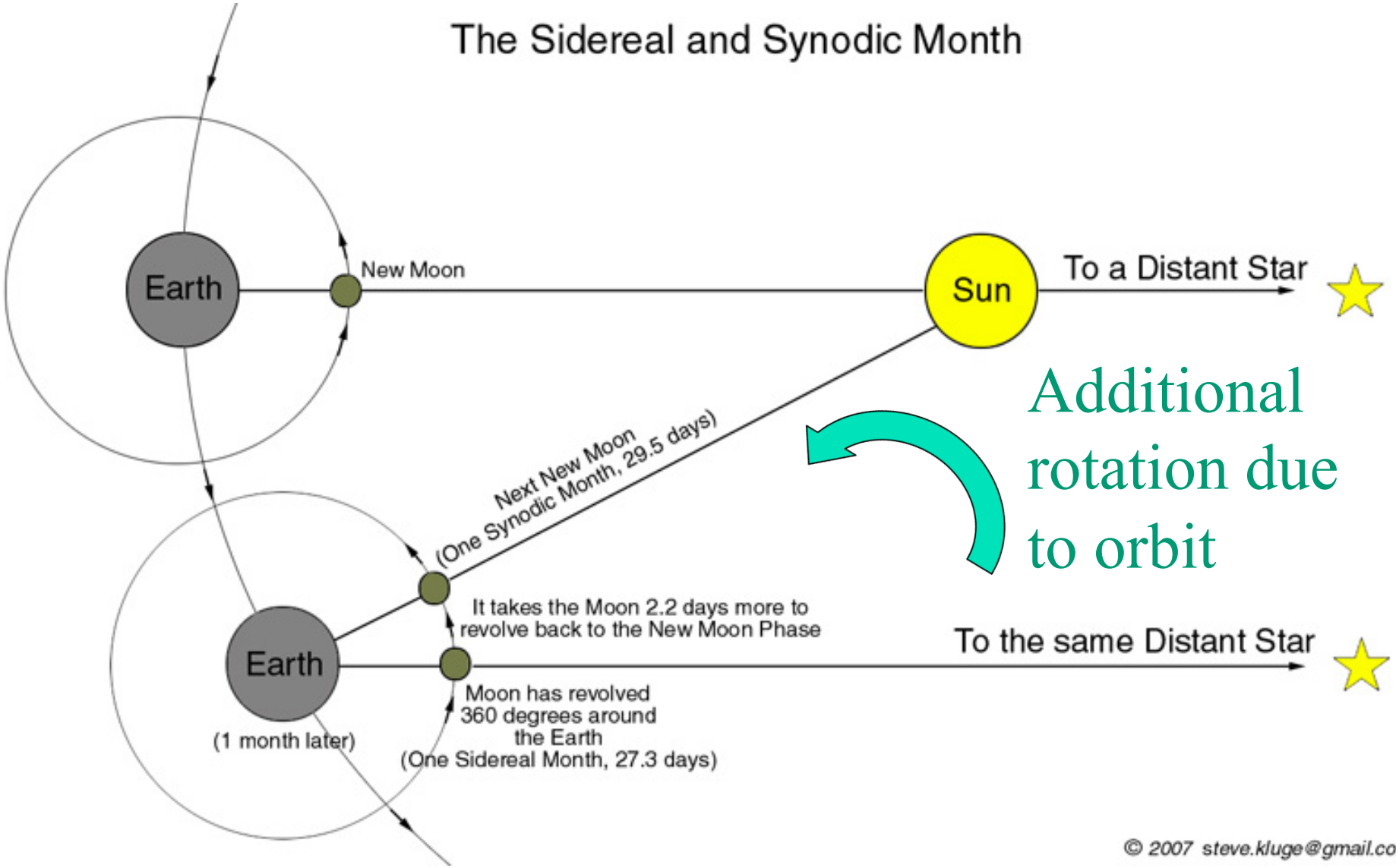
Review of previous concepts !!

- Earth's orbit: Year, seasons, observed constellations, Polaris (North star), day/night lengths, equinoxes
  - Celestial poles, celestial equator, ecliptic, ecliptic plane (Fig 1-13 through 1-15 in Comins), precession, solar and sidereal day
- Moon's orbit: Phases of the moon, sidereal month, synodic (lunar) month
- Eclipses: (Fig 1-22 through 1-24, Comins)
  - Lunar: penumbral, partial, total
  - Solar: annular, partial, total
- Scales of the Universe: Proton ($\sim 10^{-15}$) meters, size of observable universe: ($\sim 10^{26}$) meters.
  - AU (Astronomical Unit) and LY (Light Year)





- Why the stars move West – East 4 mins/night


The Sidereal and Synodic Month
Earth
New Moon
Sun
To a Distant Star
Additional rotation due to orbit
Next New Moon
(One Synodic Month, 29.5 days)
It takes the Moon 2.2 days more to revolve back to the New Moon Phase
Earth
(1 month later)
To the same Distant Star
Moon has revolved 360 degrees around the Earth
(One Sidereal Month, 27.3 days)
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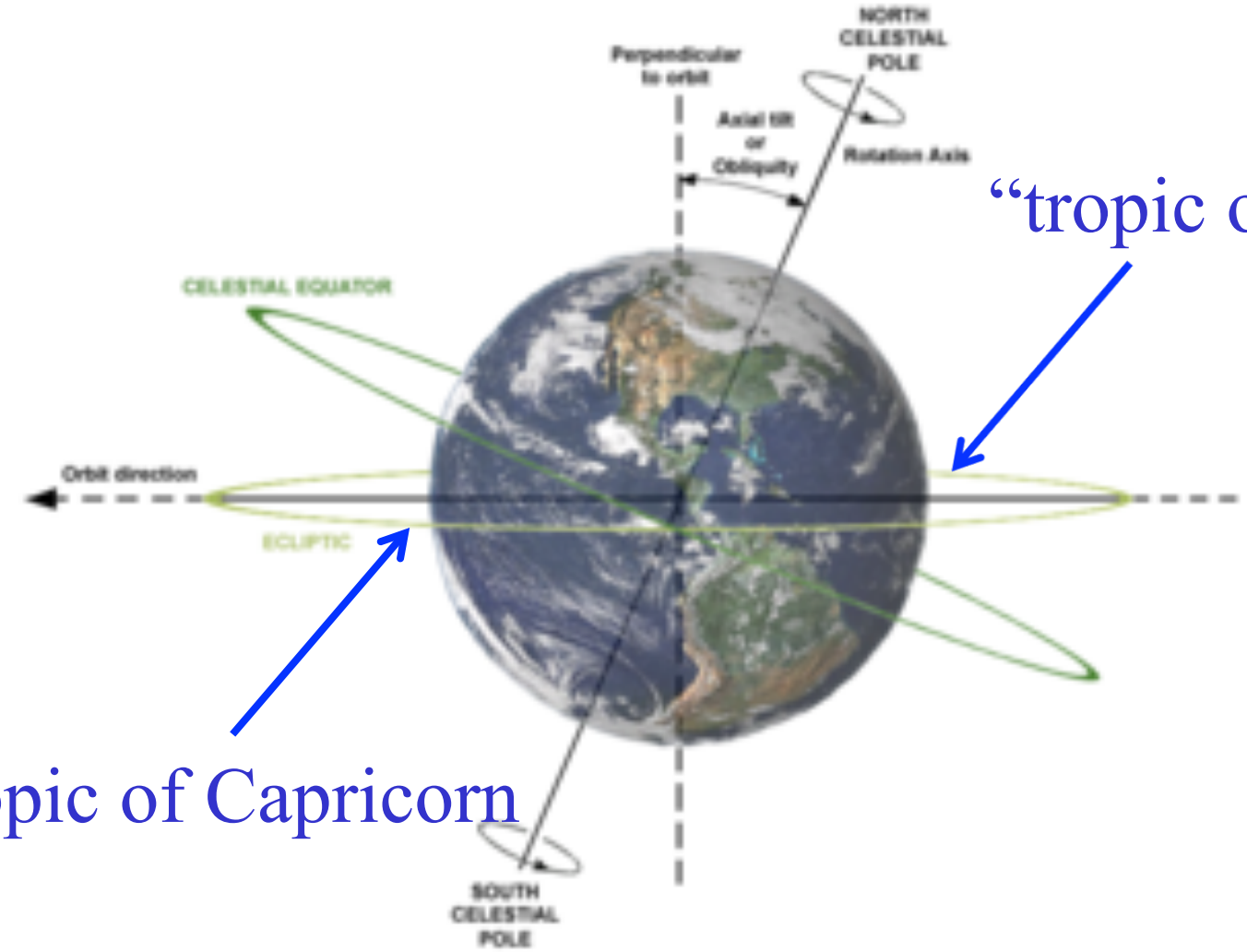
Celestial Equator and Ecliptic

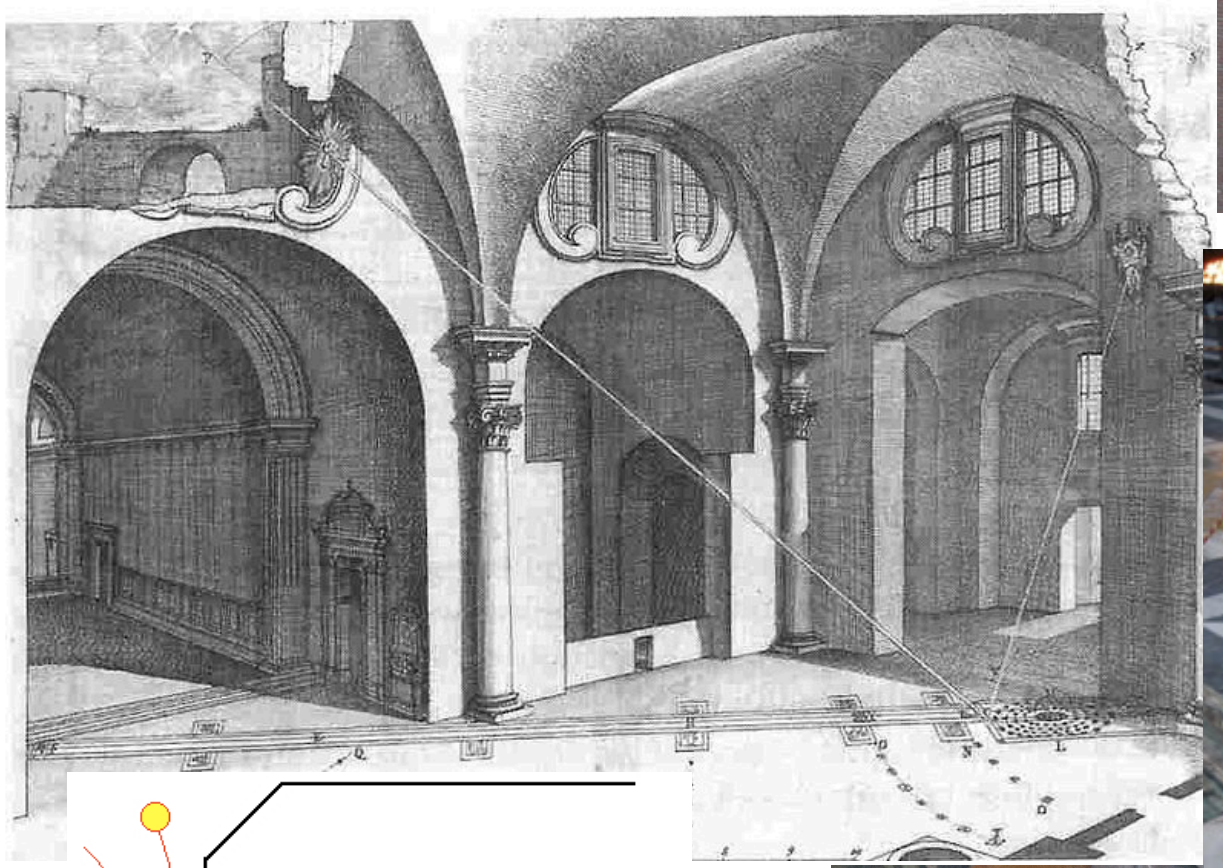


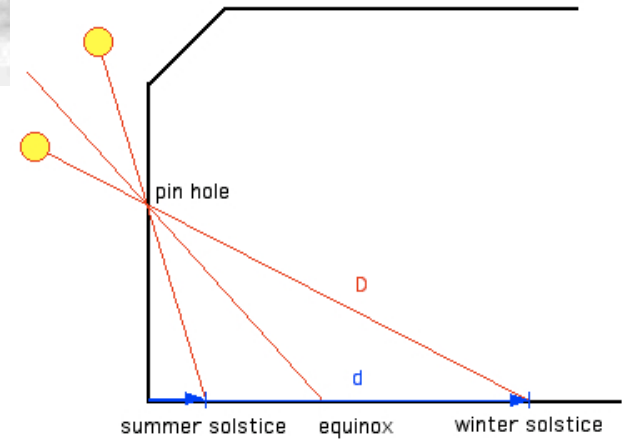
"tropic of Cancer

"tropic of Capricorn

Tracking of the sun over a year

- Santa Maria degli Angeli e dei Martiri

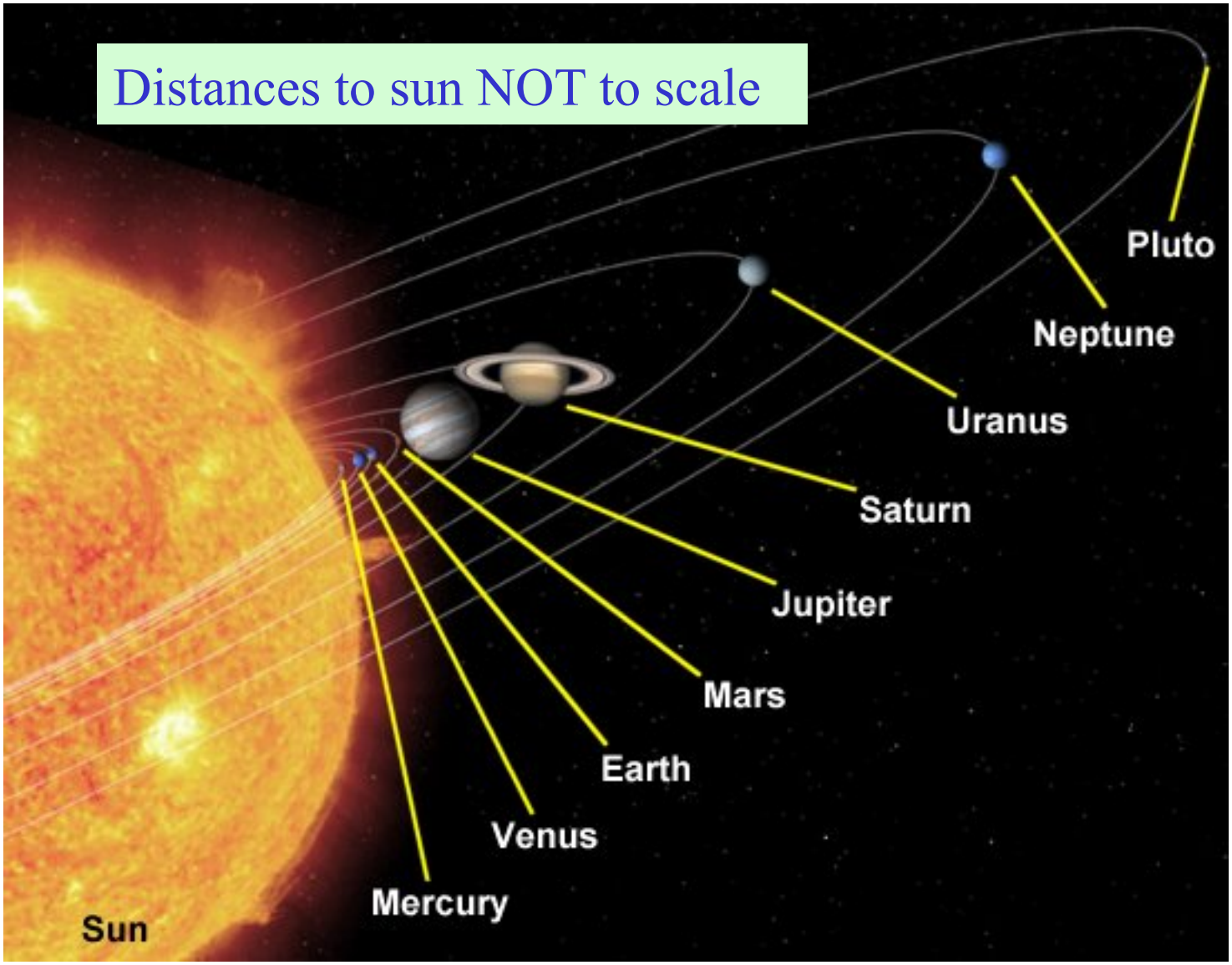




Solar System

- Sun plus 8 (or 9 with Pluto) planets many of which have moons
- Plus “debris”: comets, asteroids, meteors, etc
- Outer debris: Ort cloud, Kuiper belt, scattered disc…
- We’ll go over historical understanding of motion (which is “complicated” when viewed from the Earth) and later look at Solar System formation, planetary atmospheres, and planets discovered in other star systems

Solar System

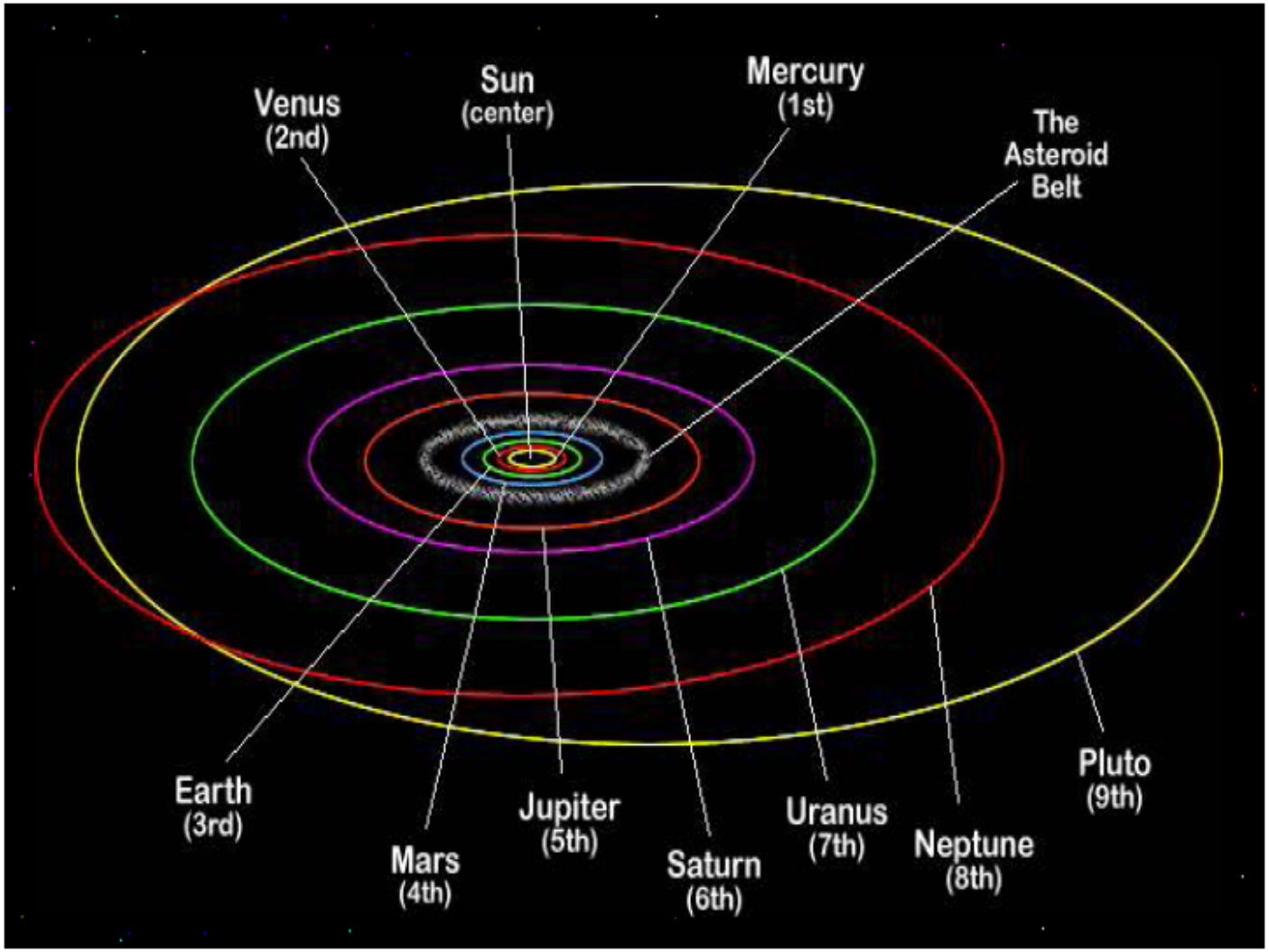


	Planet	Mass (kg)	Radius (km)	Density (g/cm^3)	Rotation Period (days)
1.	Sun	1.991×10^{30}	695,950	1.410	24.66
2.	Mercury	3.181×10^{23}	2,433	5.431	58.82
3.	Venus	4.883×10^{24}	6,053	5.256	244.59
4.	Earth	5.979×10^{24}	6,371	5.519	1.00
5.	Moon	7.354×10^{22}	1,738	3.342	27.40
6.	Mars	6.418×10^{23}	3,380	3.907	1.03
7.	Jupiter	1.901×10^{27}	69,758	1.337	0.41
8.	Saturn	5.684×10^{26}	58,219	0.688	0.43
9	Uranus	8.682×10^{25}	23,470	1.603	0.45
10.	Neptune	1.027×10^{26}	22,716	2.272	0.66
11.	Pluto	1.08×10^{24}	5,700	1.65	6.41

Sun vs Earth.

100 times larger radius → 1,000,000 times larger volume and 300,000 times larger mass

Solar System - Orbits



ics

	Mean Distance from Sun	Sidereal Orbital Period	Mass
	AU	P_e	M_e
Mercury	0.387	0.241	0.055
Venus	0.723	0.615	0.815
Earth	1.000	1.000	1.000
Mars	1.524	1.881	0.107
Jupiter	5.203	11.857	317.828
Saturn	9.537	29.424	95.161
Uranus	19.191	83.749	14.536
Neptune	30.069	163.727	17.148

Planets before telescopes

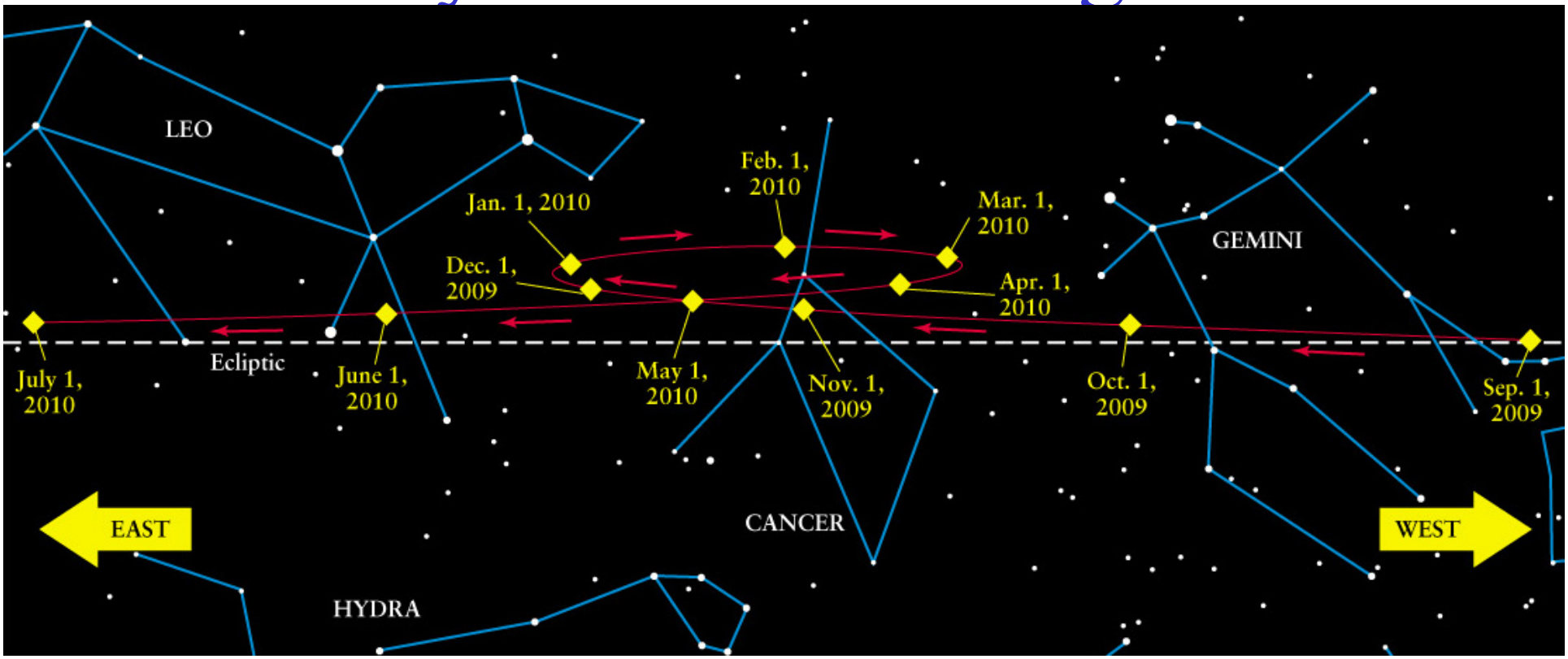
- Five planets can be seen without a telescope.
- Ancients (Babylonia, Egypt) included Sun and Moon as "planets" → gave names to days of week

	FRENCH	ENGLISH
Sun	Dimanche	Sunday
Moon	Lundi	Monday
Mars	Mardi	Tuesday (Germanic)
Mercury	Mercredi	Wednesday (Germanic)
Jupiter	Jeudi	Thursday (Germanic)
Venus	Vendredi	Friday (Germanic)
Saturn	Samedi	Saturday

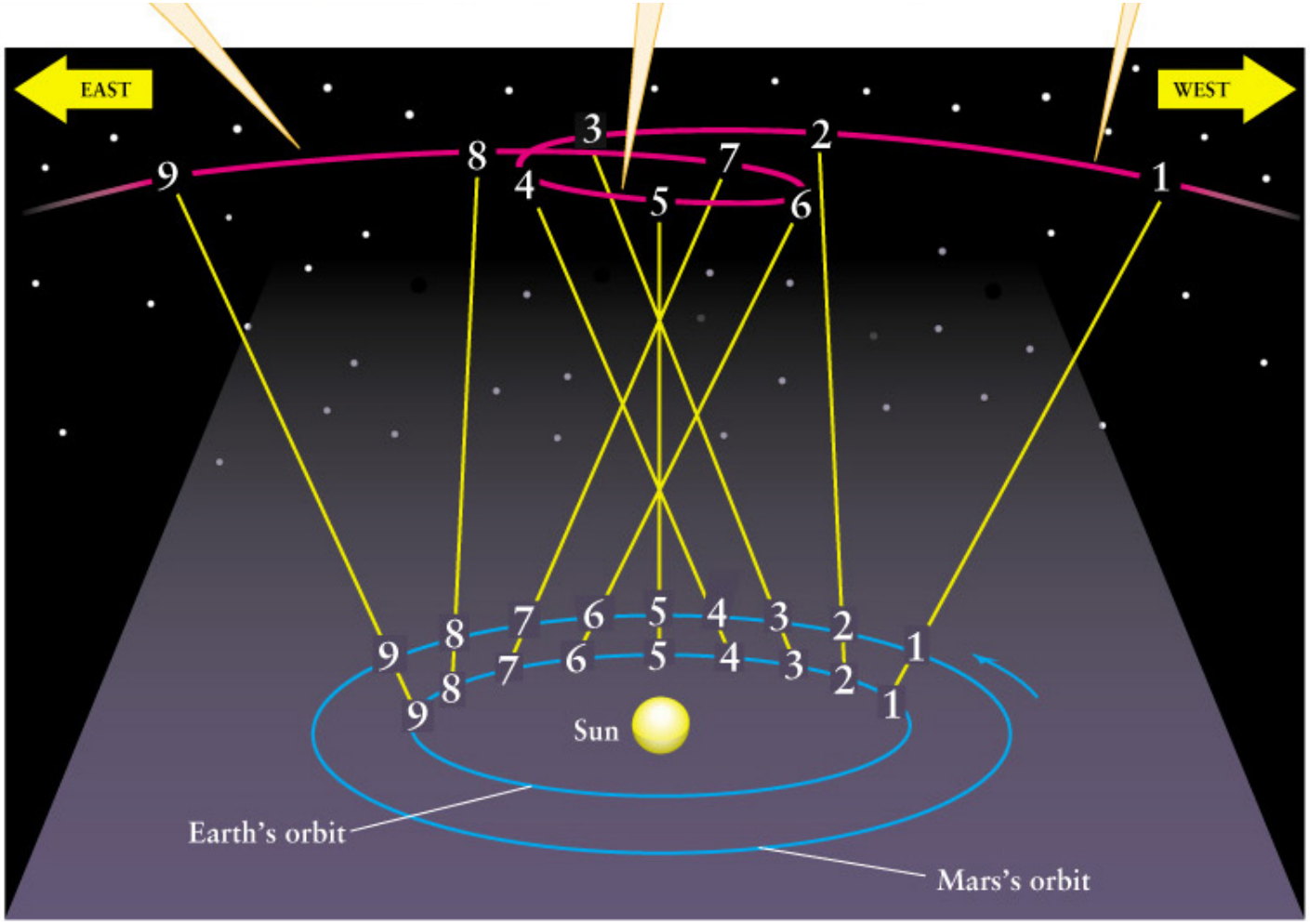
Planetary Motion

- Planets "move" relative to stars
- motion is "odd" as sometimes East to West but mostly West to East against the background of stars (E to W called retrograde motion)
- Historically large problem explaining planets' motion

Planetary Motion - Retrograde



- Mars: Sept 2009 through June 2010



- If we assume Earth and Mars orbit Sun, easy to explain as it takes Earth 1 year to orbit but Mars 1.9 years → sometimes Mars is "ahead" and sometimes "behind" Earth

Models of the Solar System

Ptolemaic – Geocentric – Earth centered

- Earth at center and motionless
- Sun and other planets orbit the Earth on circles within circles.

Copernican - Heliocentric – Sun centered

- Sun at center and motionless
- Earth and other planets orbit Sun (Kepler found later the orbits are ellipses)

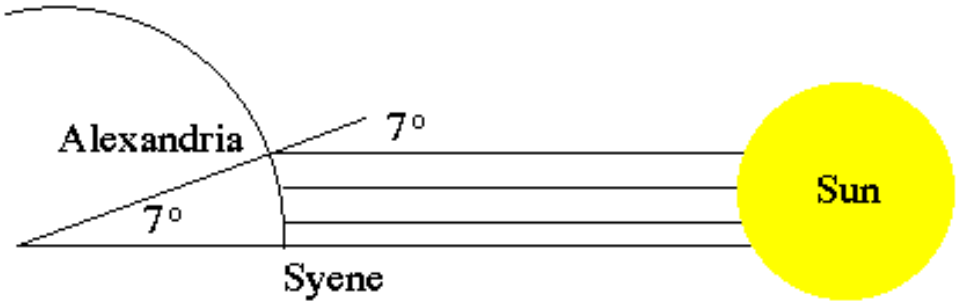
Both models were considered by Greeks 2200 years ago. Use of experimental observations to resolve about 400 years ago helped start modern science

Ancient Astronomy

- Hellenistic Culture (~500 B.C.)
  - Inherited astronomical records from Babylonia – constructed a cosmological model, not just practical → natural philosophy
- Thales (~480 B.C.) used data to predict eclipses
- Eratosthenes (220 B.C.)

Greeks knew the Earth was round from shadow on Earth during lunar eclipses.

Eratosthenes measured the circumference of the Earth.



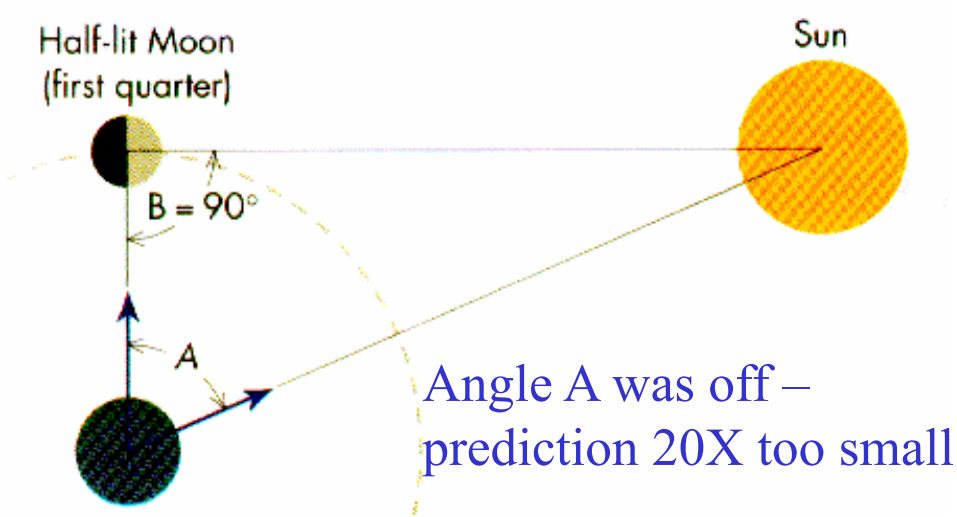
the distance from Alexandria to Syene was 4900 stadia, so the ratio of that distance to the circumference of the Earth, C is given by:

$$\frac{C}{4900 \text{ stadia}} = \frac{360^\circ}{7^\circ}$$

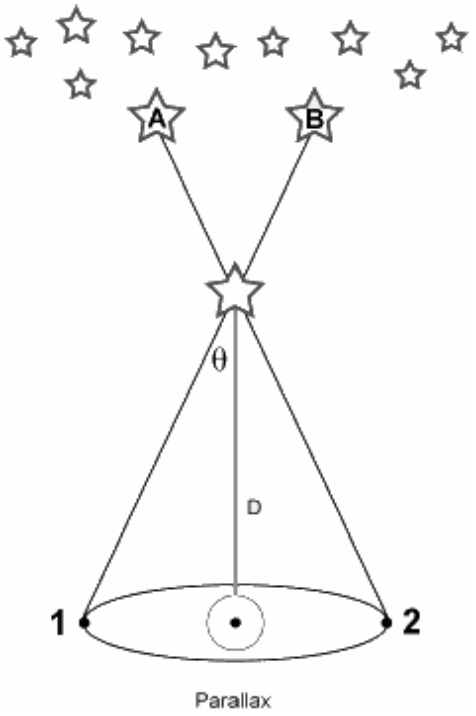
therefore, C = 252,000 stadia (1 stadia = 0.16 km)
= 40,320 km (textbook gives circumference of Earth as 40,030 km)

Ancient Astronomy (con't)

- Heraclides (330 B.C.) developed the first Solar System model, beginning of the Geocentric versus Heliocentric
- Aristarchus (270 B.C.) developed the Heliocentric theory
  - Problems: Earth in motion? Can't feel it
  - Geocentric seemed more "natural"
  - No parallax seen in stars →
  - But made many predictions including relative distance of Moon and Sun from Earth



Angle A was off – prediction 20X too small

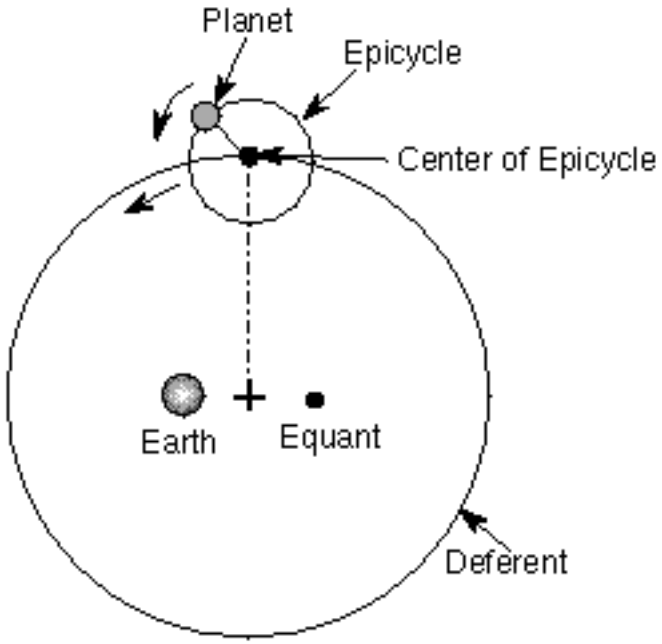


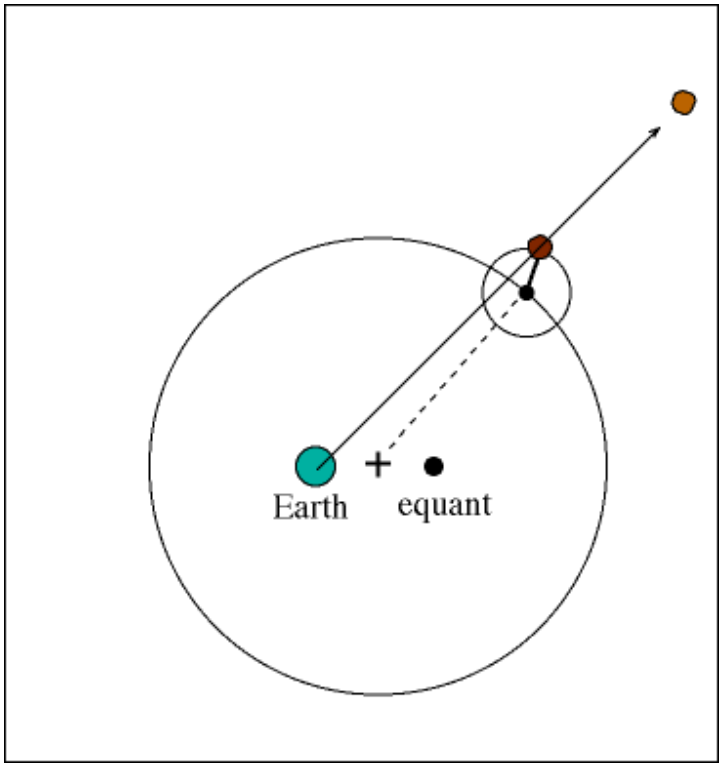
Parallax

Indicated that stars were farther away from Earth than Sun.

Ancient Astronomy (con't)

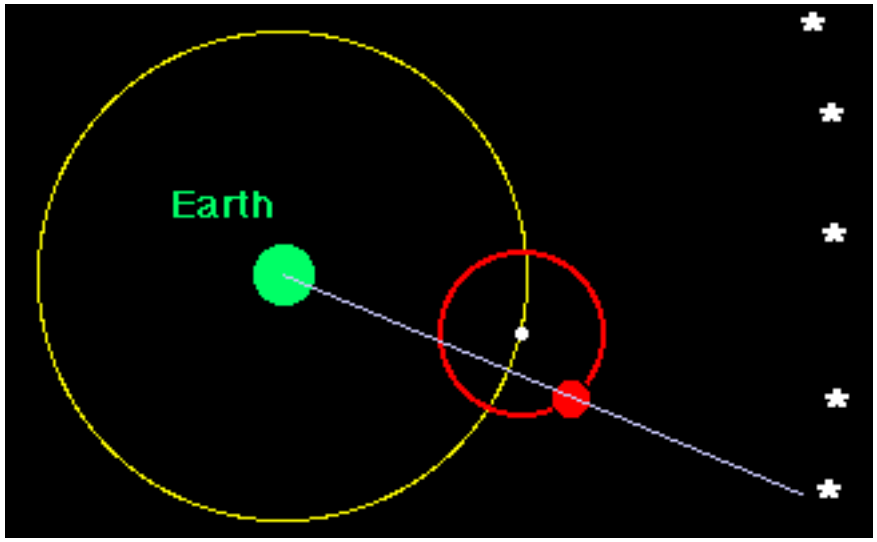
- Ptolemy (220 A.D.)
  - Librarian of Alexandria. Resurrected Heraclides geocentric theory and combined with centuries of data on planetary motions → formulated complete description of the Solar System that explained/predicted the *apparent* motion
  - Unfortunately, the Ptolemy framework was extremely complicated in order to explain retrograde motion.

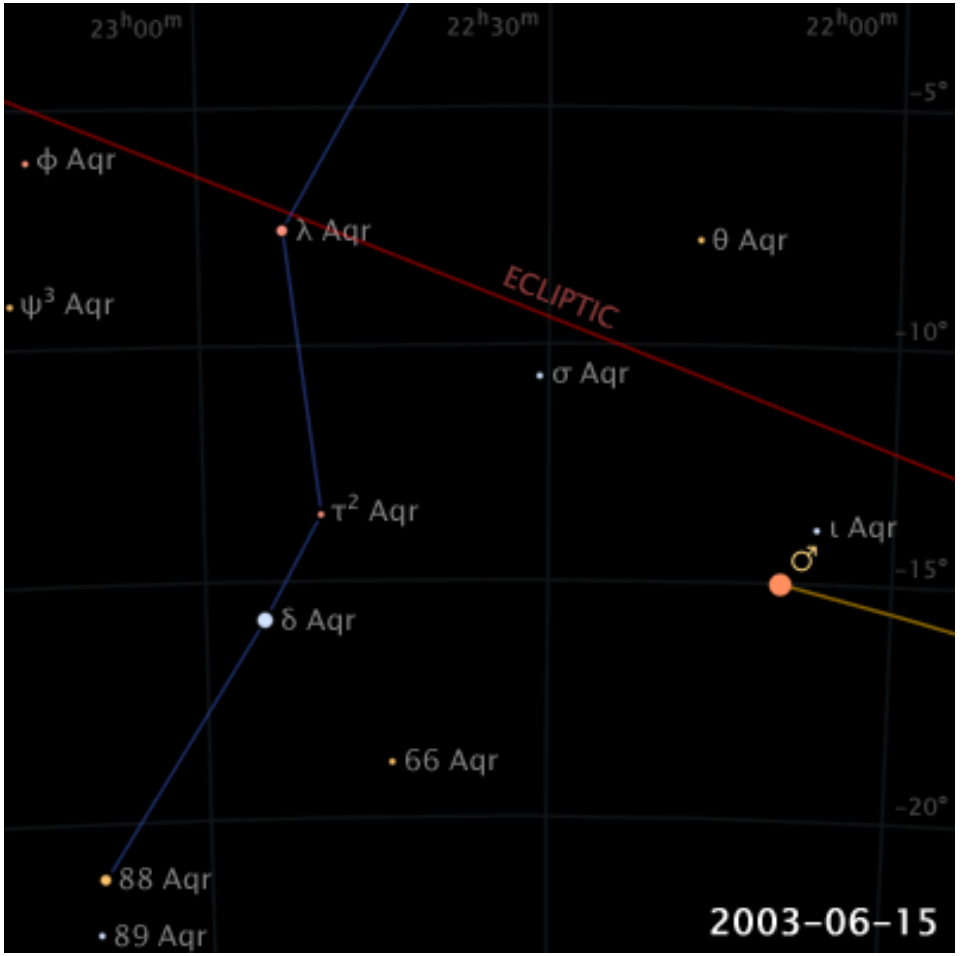




Ancient Astronomy (con't)

- Ptolemy (220 A.D.)
  - Though complicated, worked well enough for the quality of data at the time… prevailed for 1400 years…

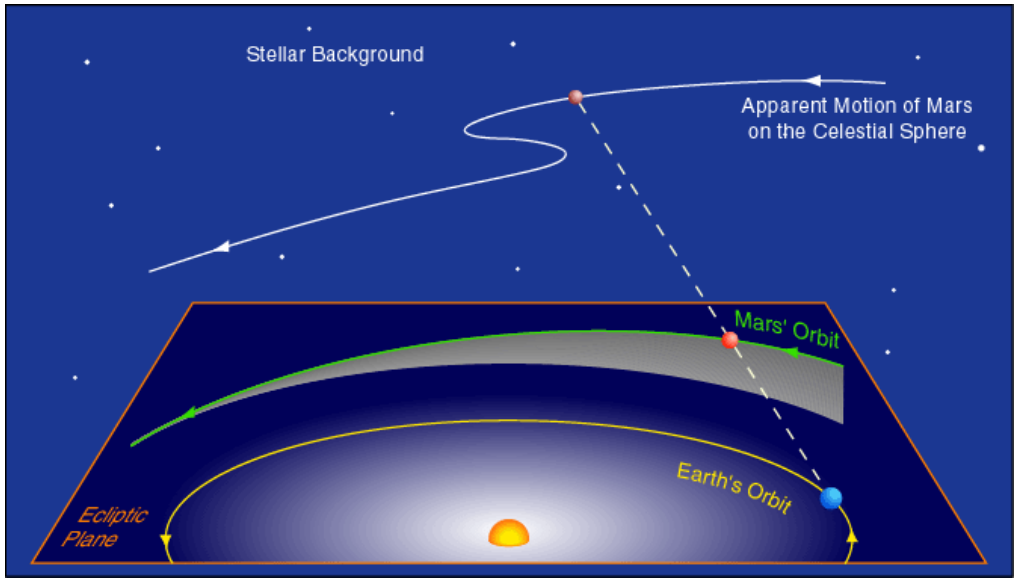


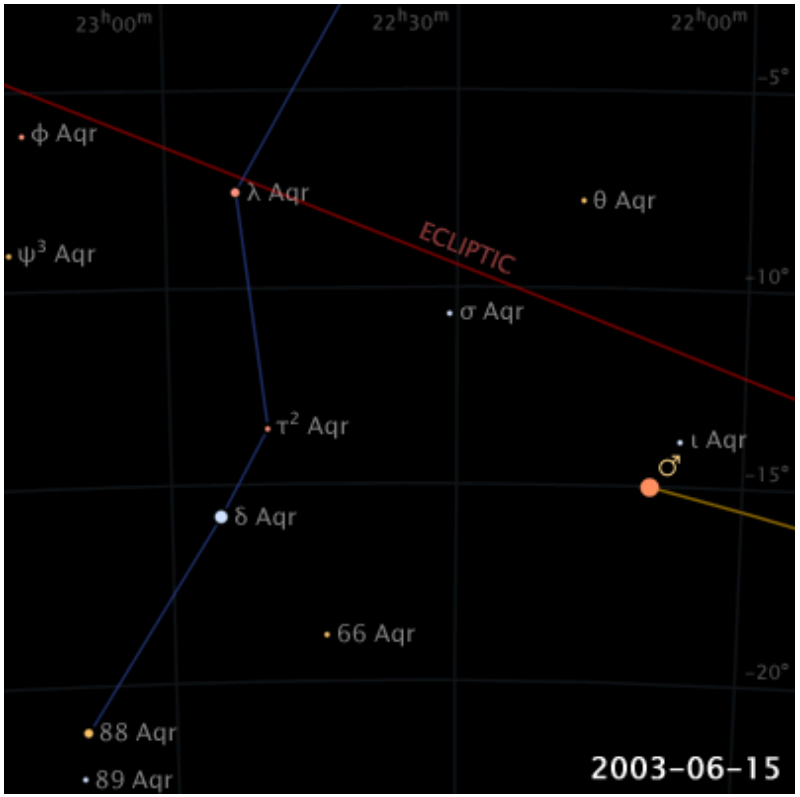


Retrograde motion of Mars

Modern Astronomy

- Copernicus (1500's)
  - Reinvented the heliocentric theory and challenged Church doctrine.
  - However, Copernicus also used circular orbits and had to resort to epicycles and deferents to explain retrograde motions. In fact, Copernicus was forced to use more epicycles than Ptolemy, i.e. a more complicated system of circles on circles.





Retrograde motion of Mars

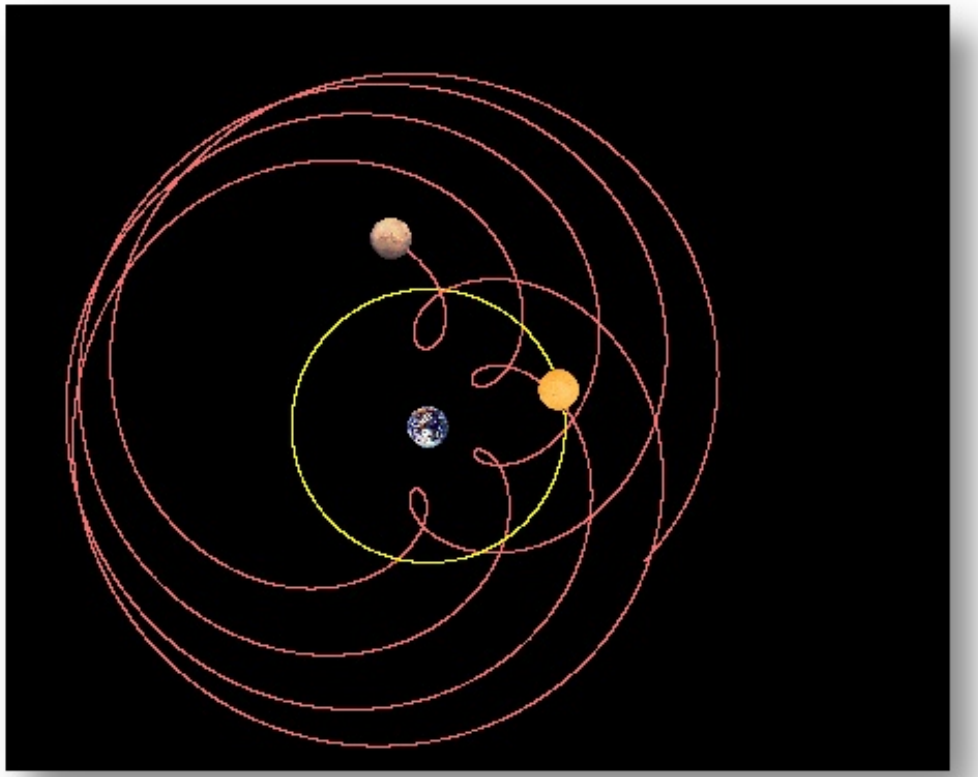
Planetary Motion

- Experimental observations (made prior to telescopes) was used to understand motion of the planets
- Lead to Kepler's 3 laws of planetary motion
- Provided experimental observations which are later explained by physics developed by Galileo, Newton and others

Models of the Solar System

Ptolemaic – Geocentric

- Consistent with Biblical Creation
  - The Church adopted Aristotle's scientific methods and Ptolemy's model into its own doctrine.
- Earth at center and motionless



Sun and other planets orbit the Earth on circles within circles.

Think Tilt-a-Whirl at Cornfest

Copernican - Heliocentric

- Sun at center
- All planets move about Sun on epicycles (circles on circles)
- Earth revolves on axis once per day
- Catholic Church adopts Ptolemaic as "revealed truth" in 13th Century. Copernican model published in 1543 with detailed comparisons to observations (after Copernicus' death so Church would not punish him)

Copernican vs Geocentric vs Catholic Church

- Bruno was burned at the stake in 1600 in Rome for stating Copernicus was correct
- *"Innumerable suns exist; innumerable earths revolve around these suns in a manner similar to the way the seven planets revolve around our sun. Living beings inhabit these worlds."* — Giordano Bruno

Campo d'Fiore Rome

also has farmer's market and 4 nice restaurants

Other Models

- Tycho Brahe's - Earth at center but other planets orbit the Sun (effectively the same as Copernican)
- Kepler's - Sun at center with planets orbitting the Sun in elliptical paths CORRECT

- Differentiate models by comparing predictions with observations

  SCIENTIFIC METHOD

  need best observations as possible

Kepler's Laws of Motion

- Kepler figured out correct orbital shape and determined some relationships between the orbits of different planets
- A big step was realizing that Earth's orbit about the Sun also wasn't a circle – mostly he used relative location of Mars after repeated orbits around the Sun (Mars is close and so has the most accurate measurements)