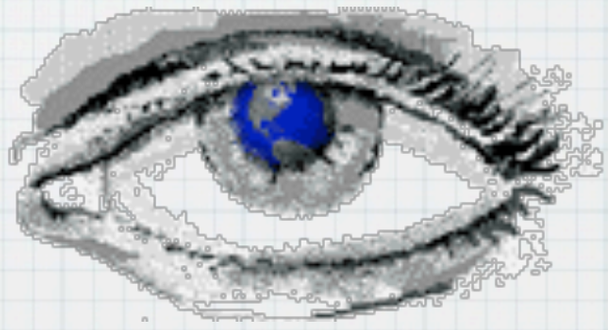
Astronomy 1

Philip de Louraille

pronunciation: duh lure eye



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Practical History & Science Explained

Parts of Chapter 2 & Chapter 3


Galileo
Knowledge
Greeks
heavens
opinion
must
motion
Observed
Mars
times
Jupiter
Aristotle
Universe
modern
test
Greek
Principles
new
Moon
Earth
laws
orbit
make
model
Law
orbiting
Kepler
prediction
moving
telescope
Science
orbits
Sun-centered
Europe
data
parallax
physical
repeated
also
Kepler's
Observations
explain
question
used
Mathematics
Ages
object
nature
planet
Testing
Copernicus
hypothesis
Sun
experimental
speeds
orbital
Observation
evolution
years
predictions
Tycho
phenomena
Ellipse
planetary
models
much
Stars
center
distance
around
Darwin's
validity
Venus
planets
Ptolemaic
heliocentric
Church
seasons
Library
BC
theory
Saw
first
equal
period
predict
natural
challenge
work
phases
stellar
Islamic
distant
three
means
seen
Meaning
rst

Some definitions from Chapter 2

* Celestial sphere
* The local sky
* Motions in the sky
* The ecliptic
* Why do we have seasons?
* Solar & lunar eclipses

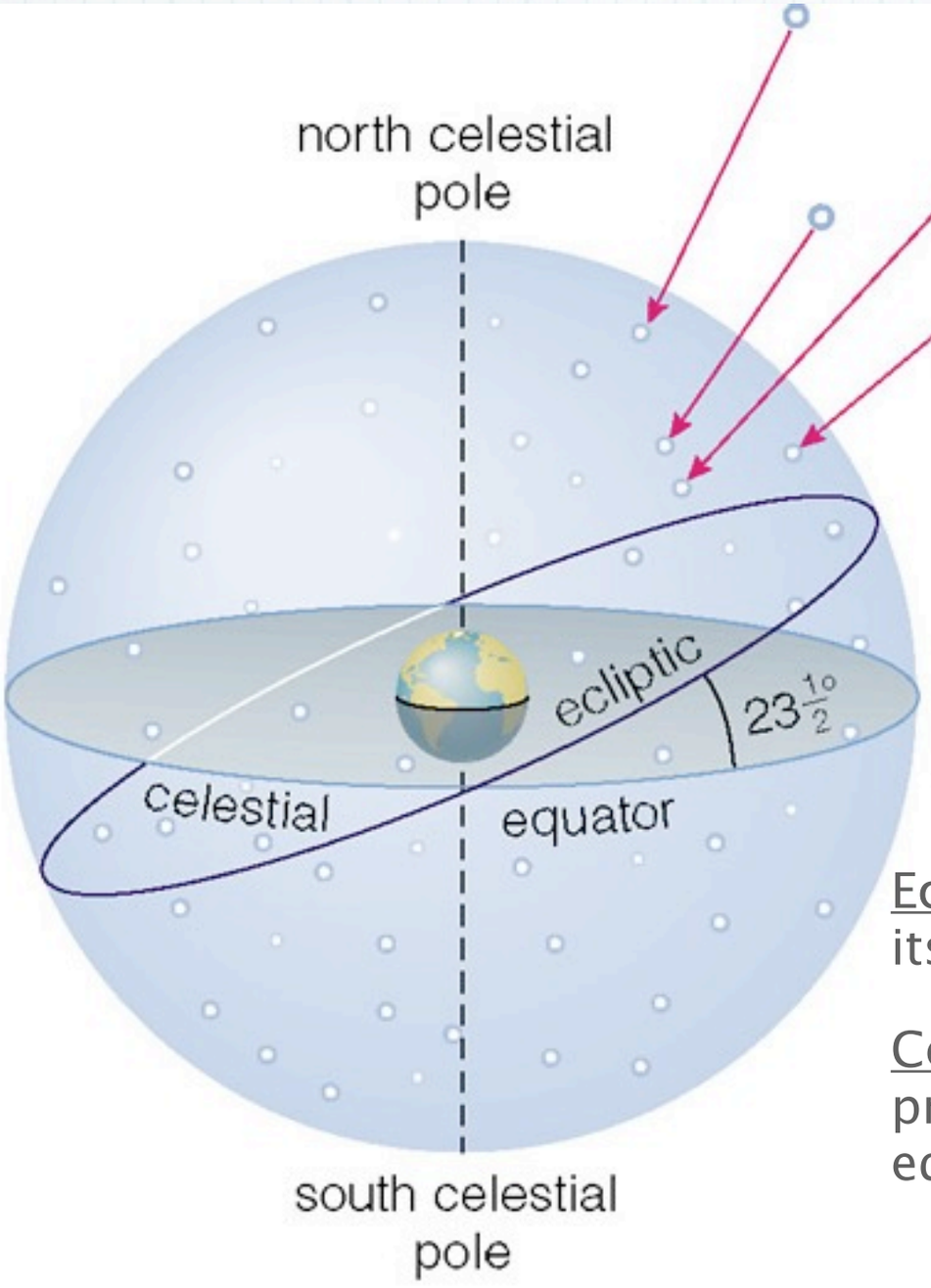
Astronomy, not Astrology!

Aquarius was Jan 21 - Feb 19
now Feb 16 - Mar 11 (for 13 signs)
or Feb 20 - Mar 19 (for 12 signs)

Your belief that all life's problems can be solved with a heart-to-heart talk and a good night's sleep will be severely challenged this week when you are introduced to logical reasoning

The Celestial Sphere

Celestial Sphere



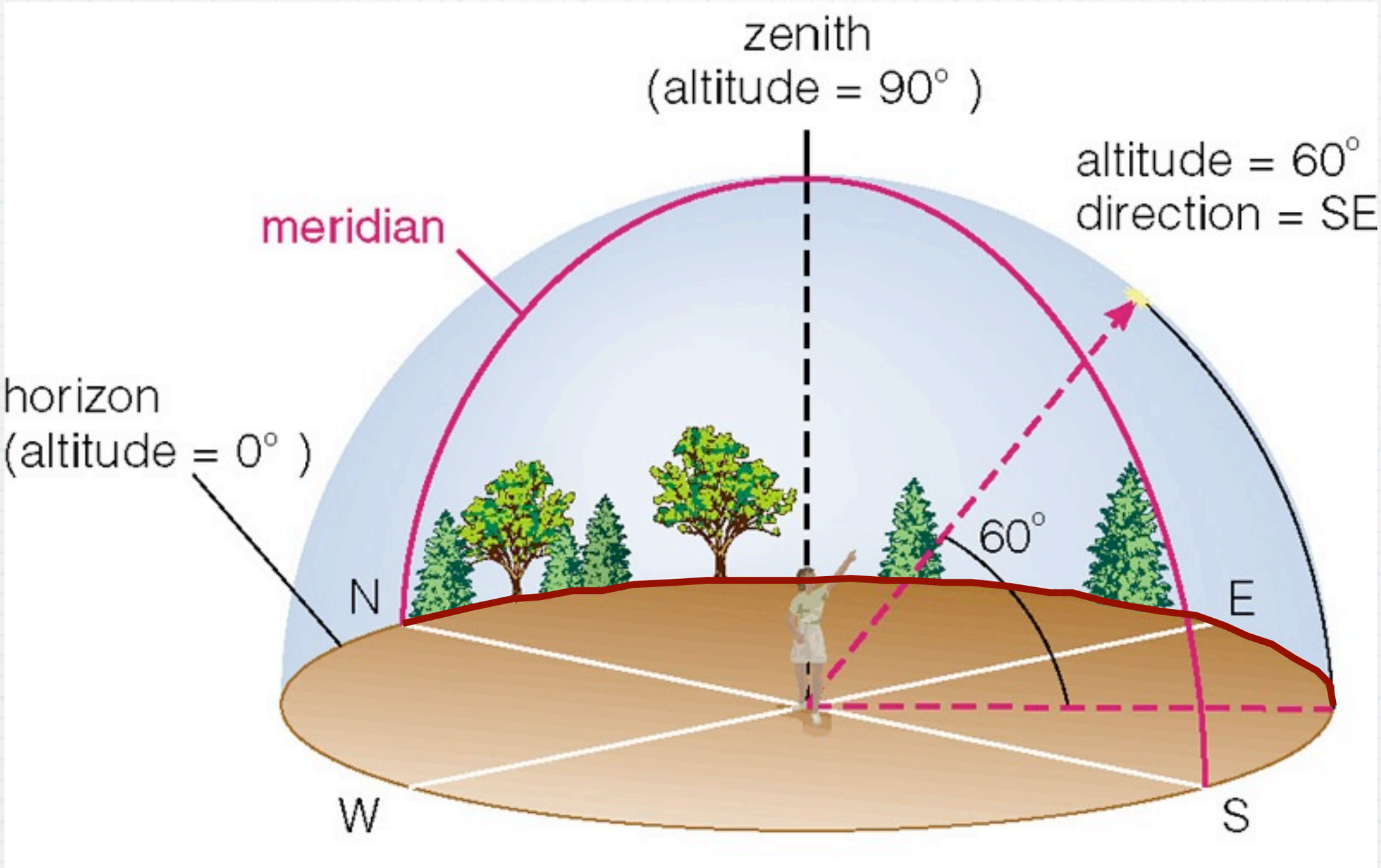
Stars actually lie at different distances; arrows indicate where they *appear* to be located on the celestial sphere.

Ecliptic: Earth's tilt wrt its orbital plane

Celestial equator: projection of Earth's equator

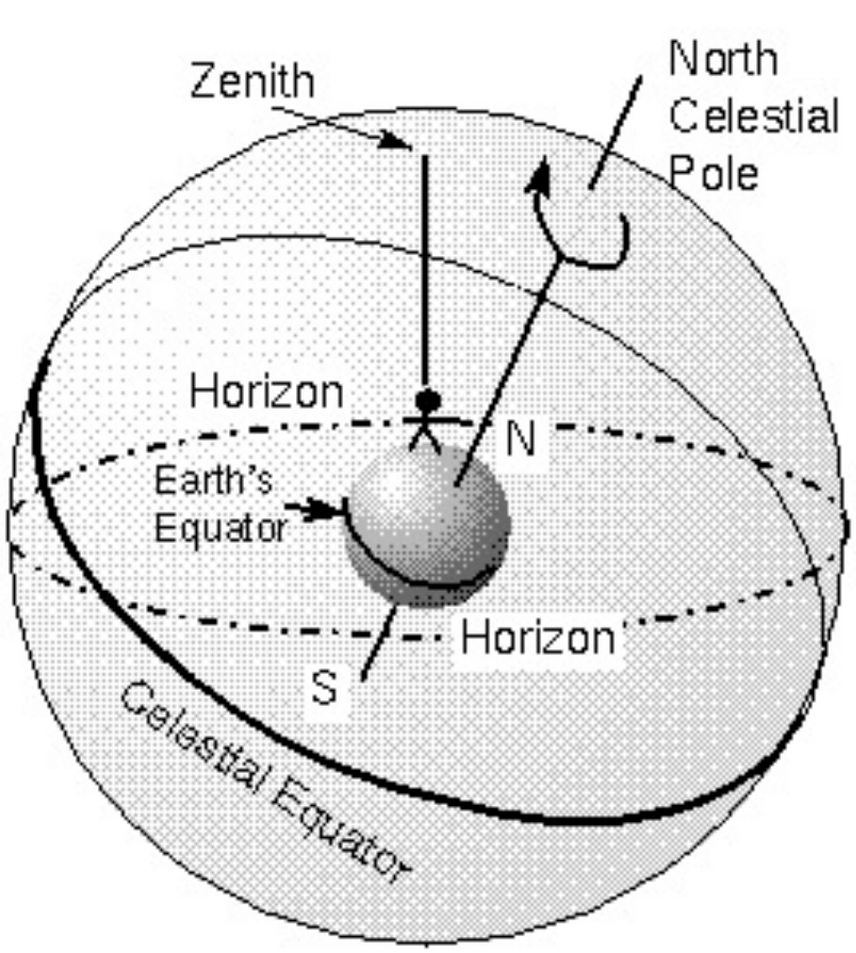
Note: stars forming a constellation are not at the same distance to us

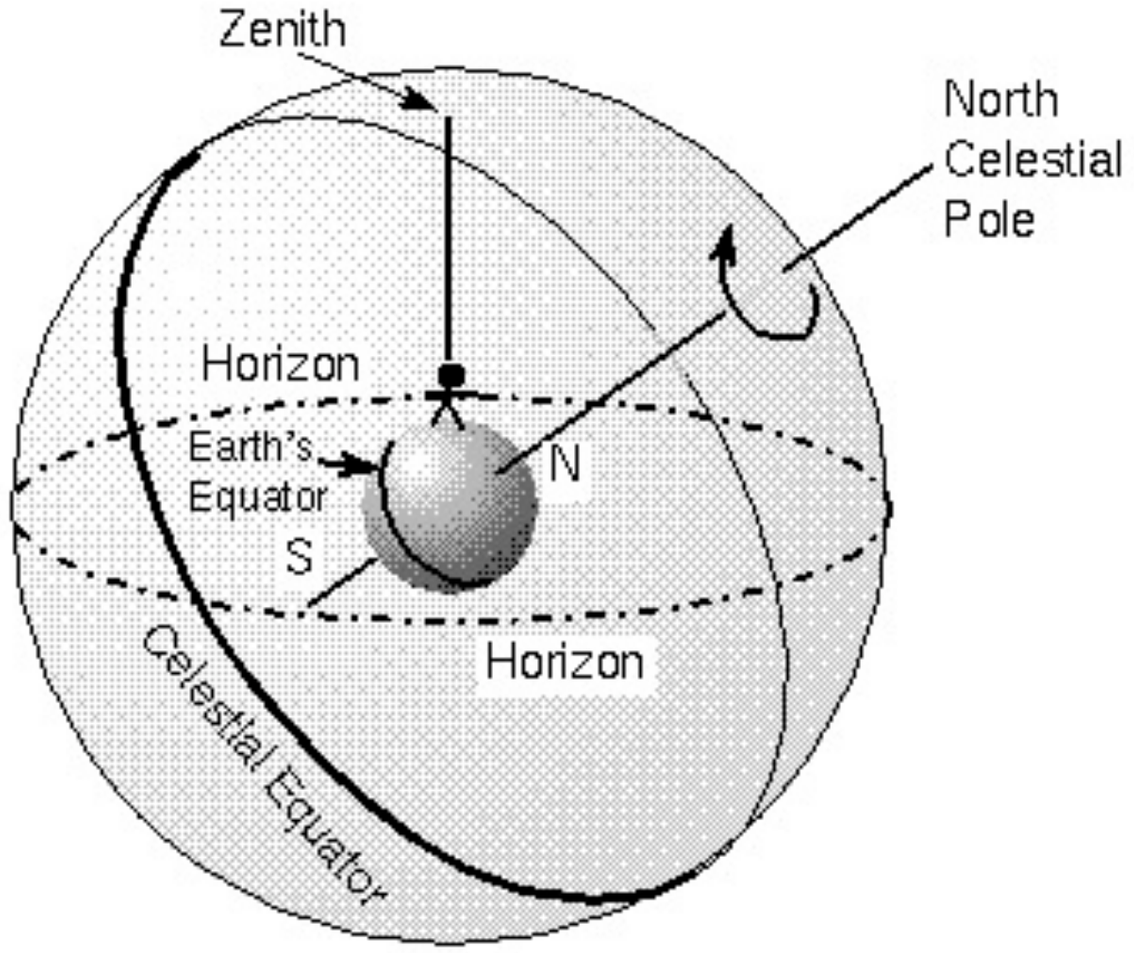
The Local Sky



Changing skies

The local sky from 2 locations on Earth



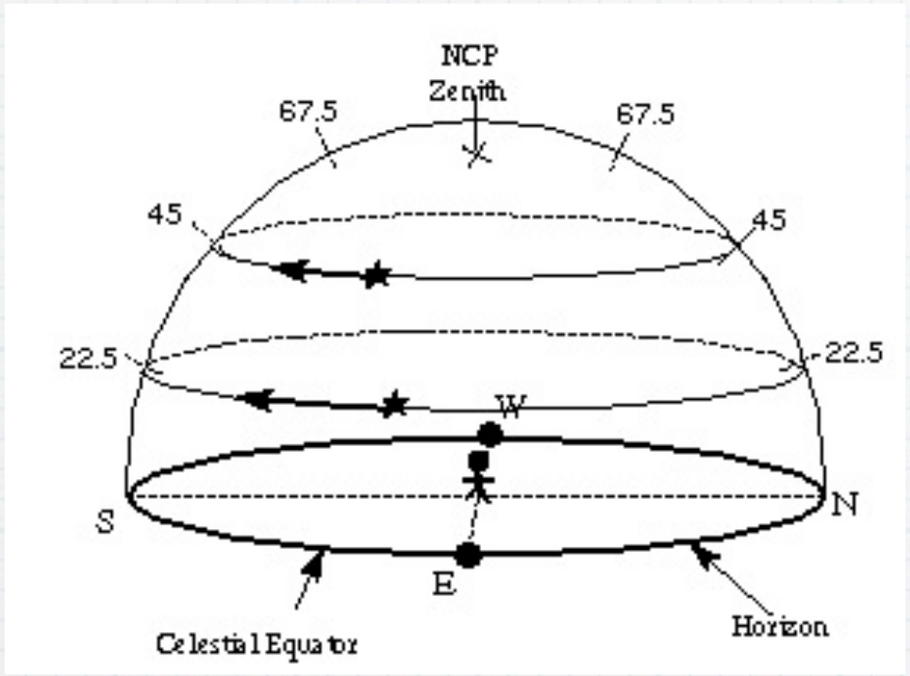


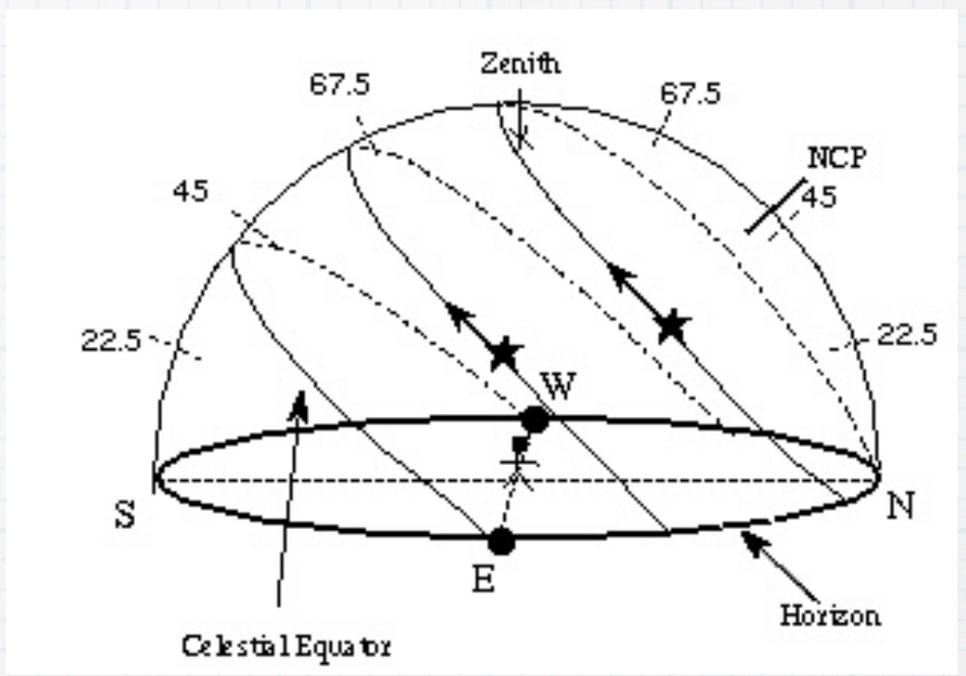
Note: the same star will not appear at the same place in the sky for observers located at different locations on Earth

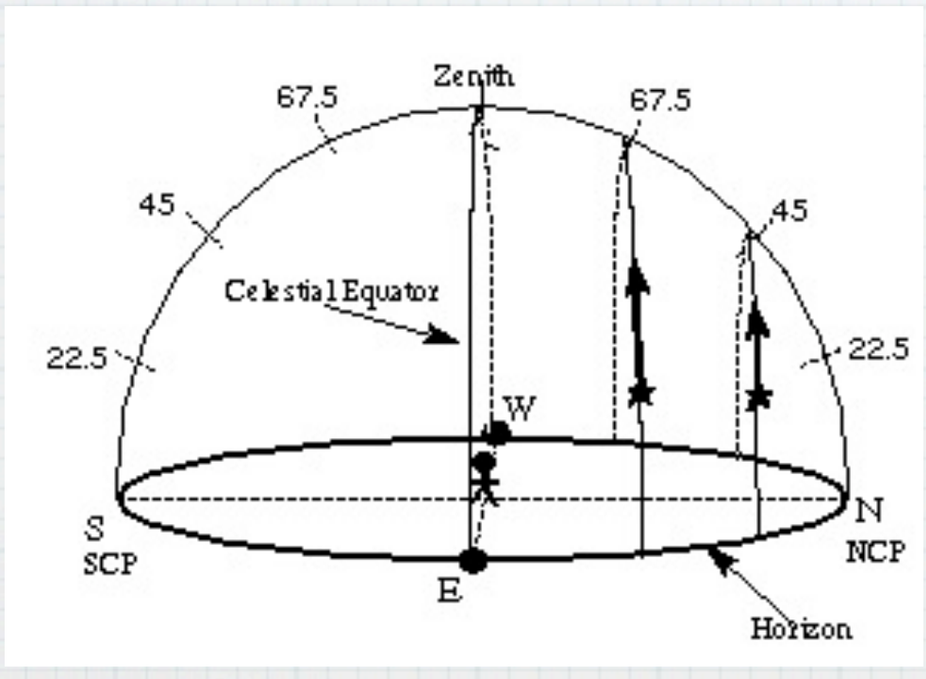
Motions in the Sky

- Stars, the Sun & the Moon and the planets rise and set because of the Earth's daily rotation
- They rise from the East and set in the West
- The apparent path they take depends on one's location on Earth

Star motion at different latitudes



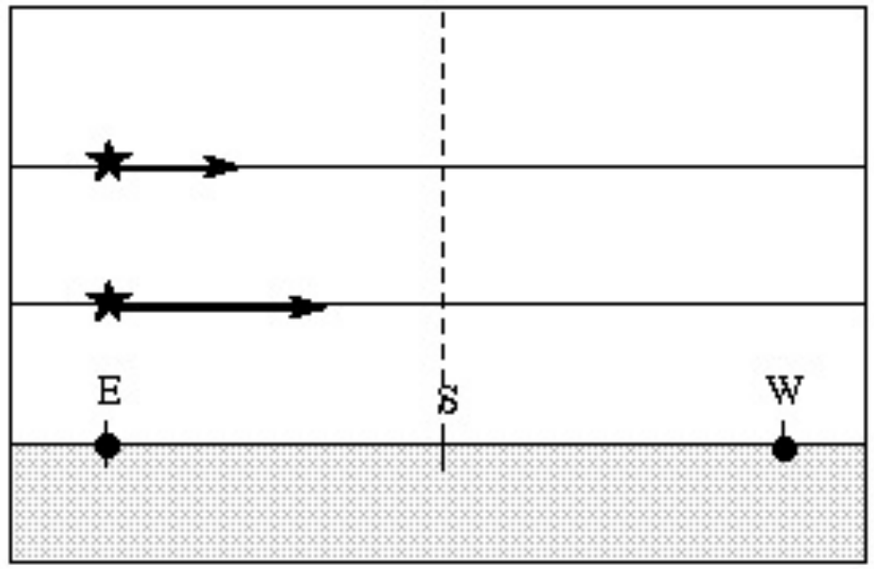




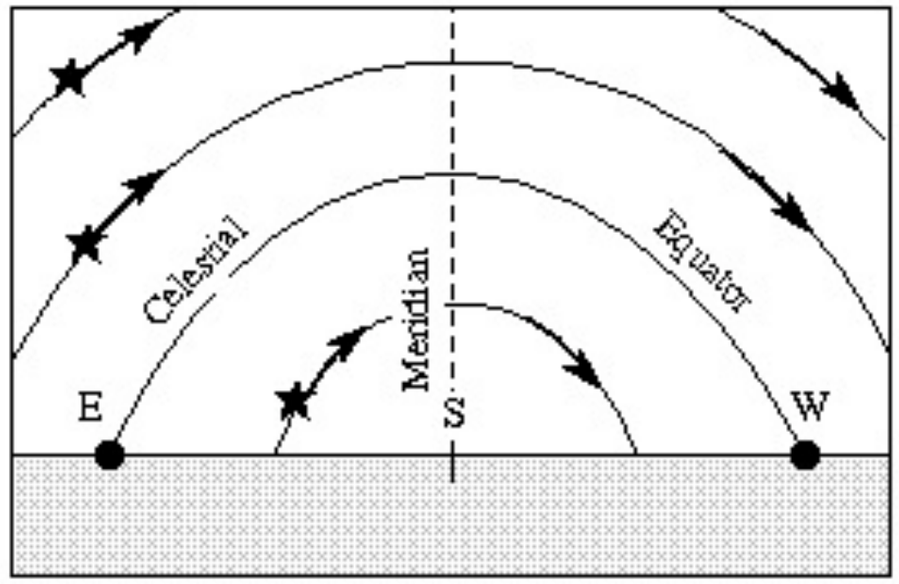
Important fact: the altitude of the celestial pole in your sky is equal to your latitude

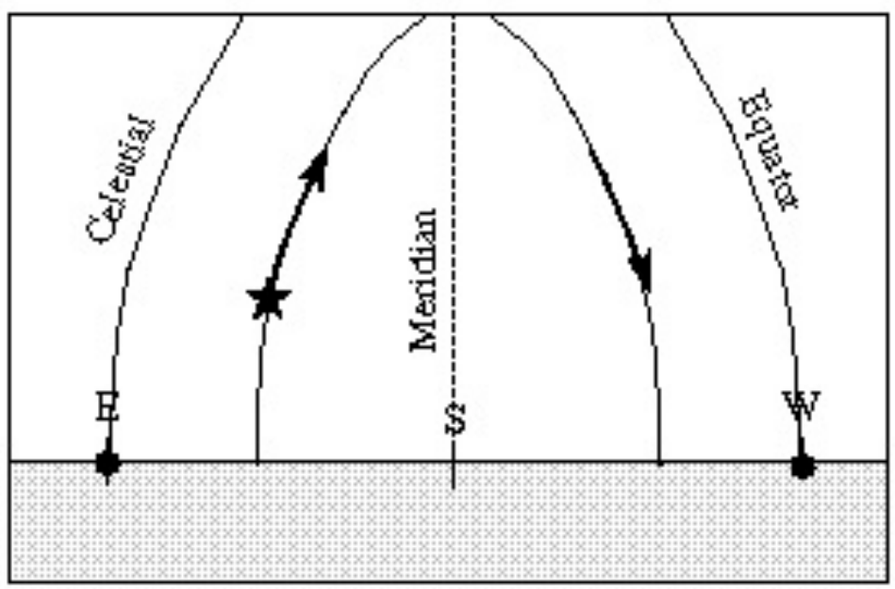
Star motion from your point of view

At the poles



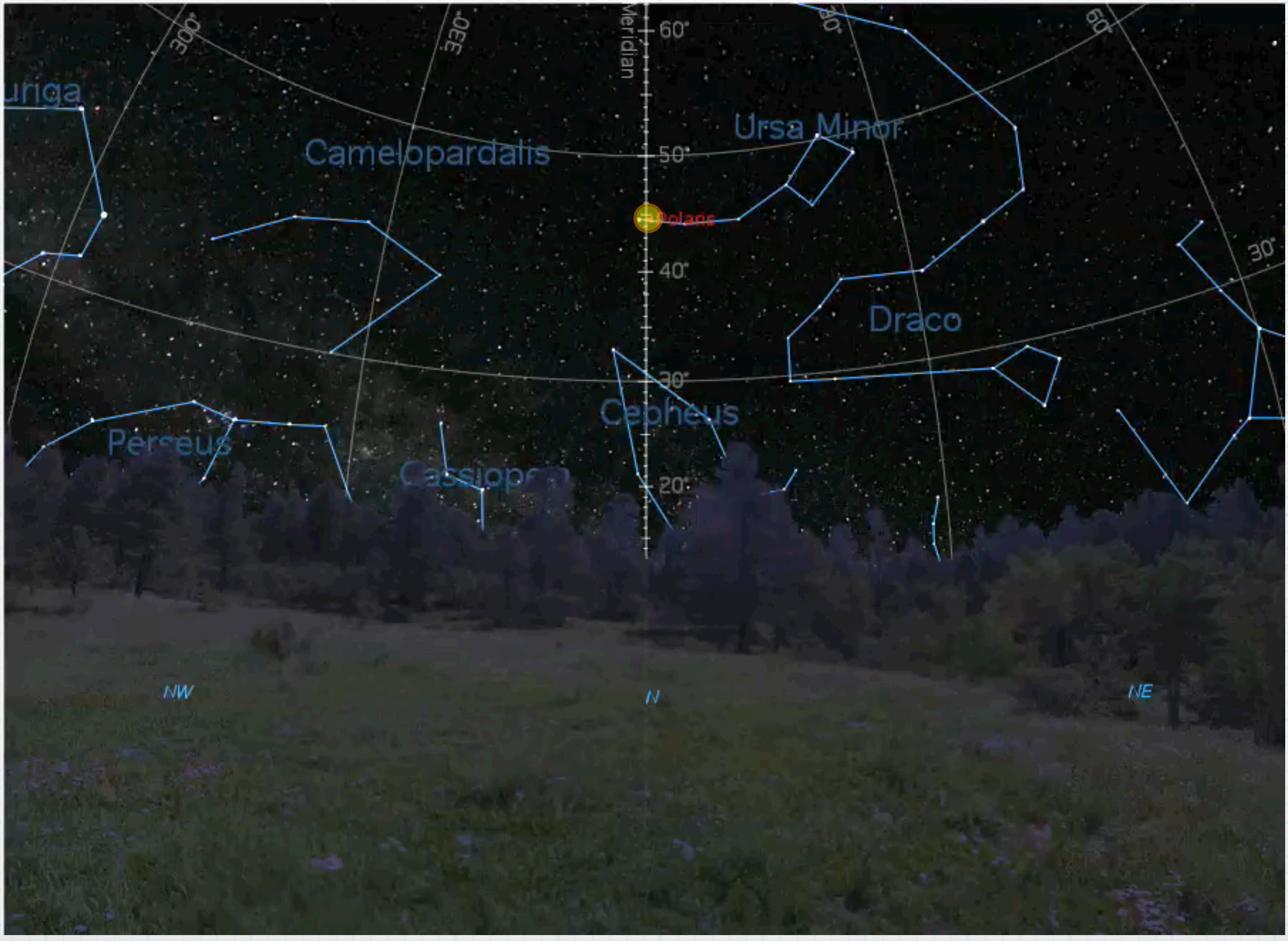
At the equator



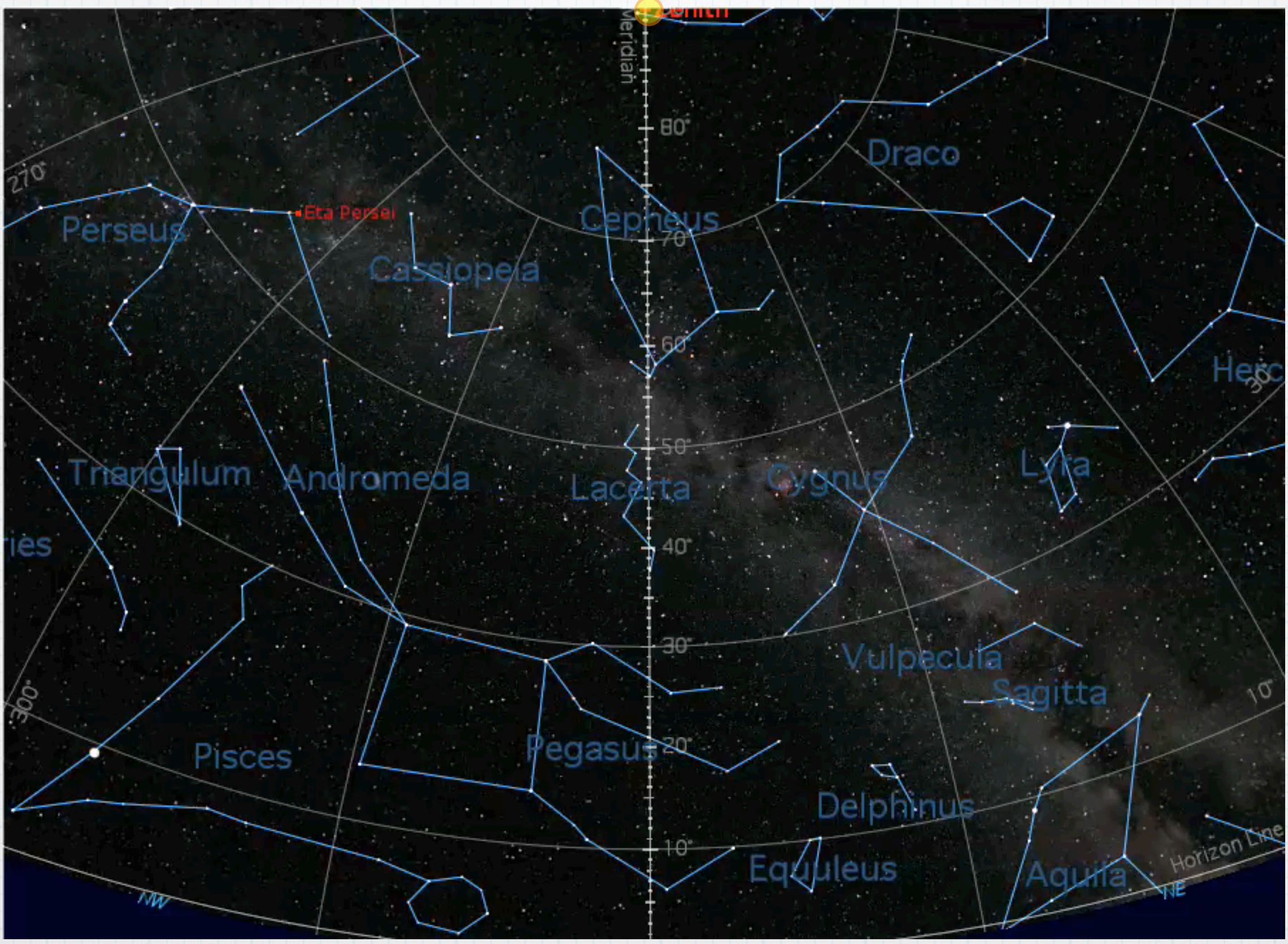


At mid-latitudes

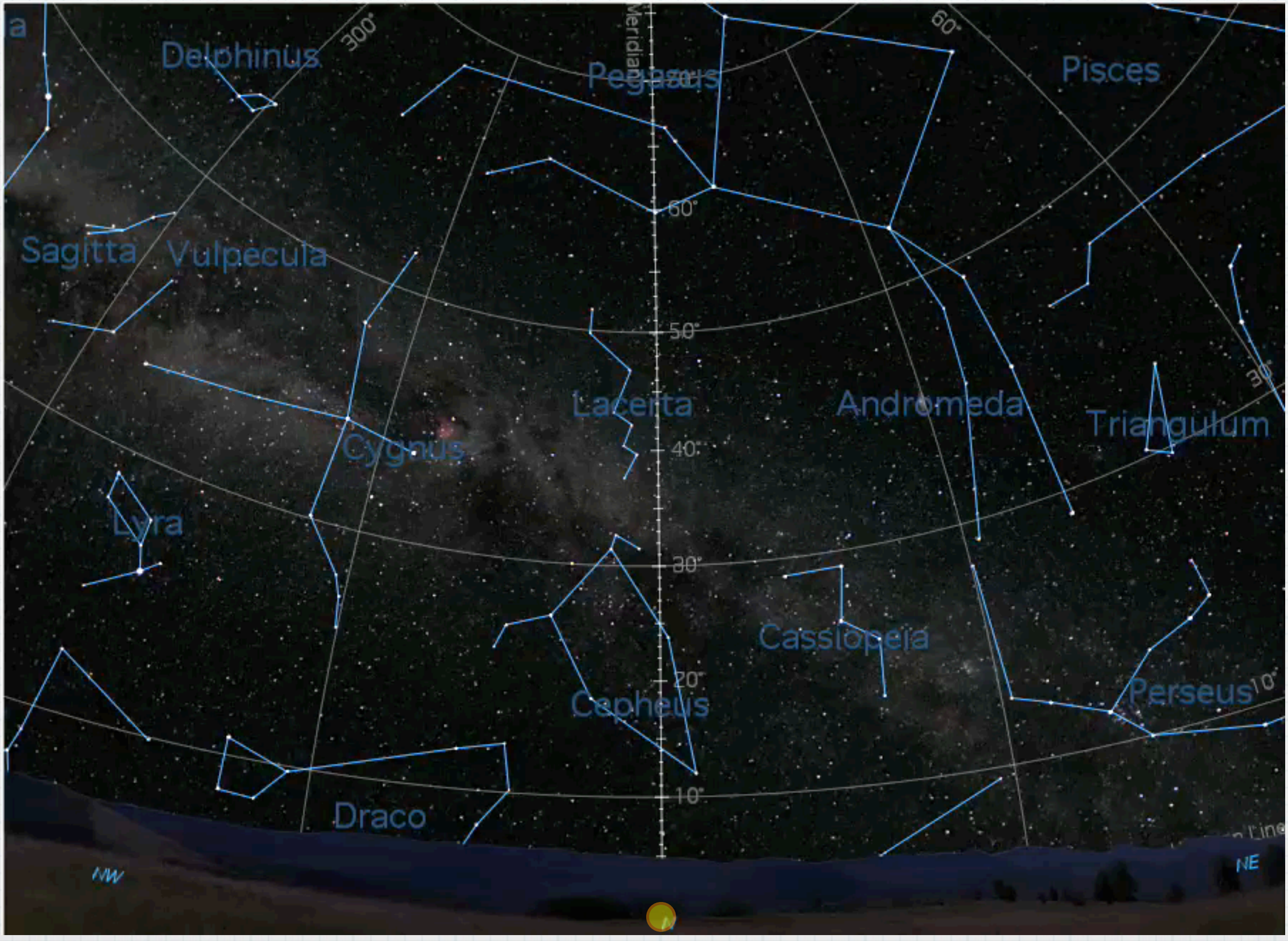
North Star at 45°N altitude



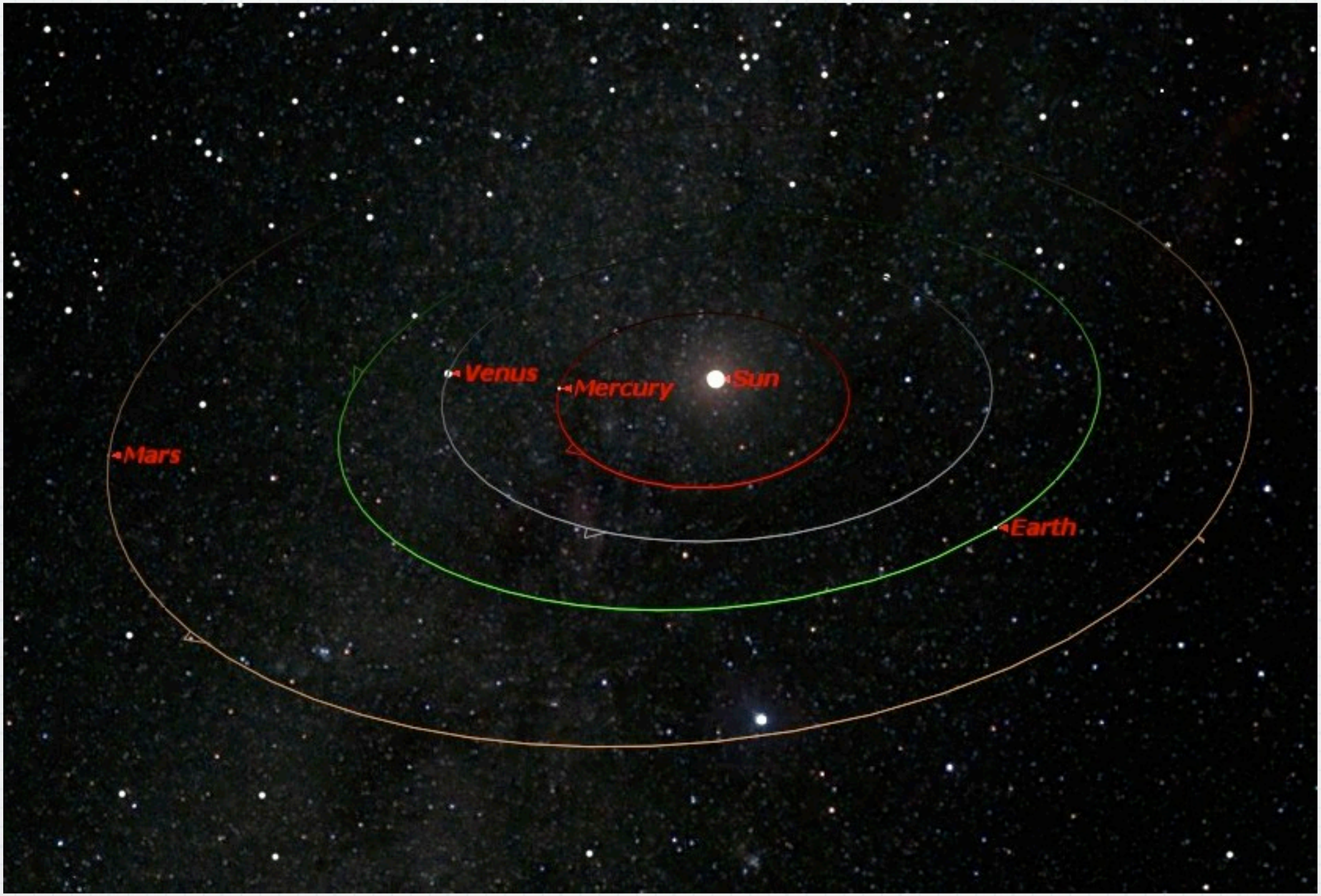
North Star at 90°N altitude (North Pole)



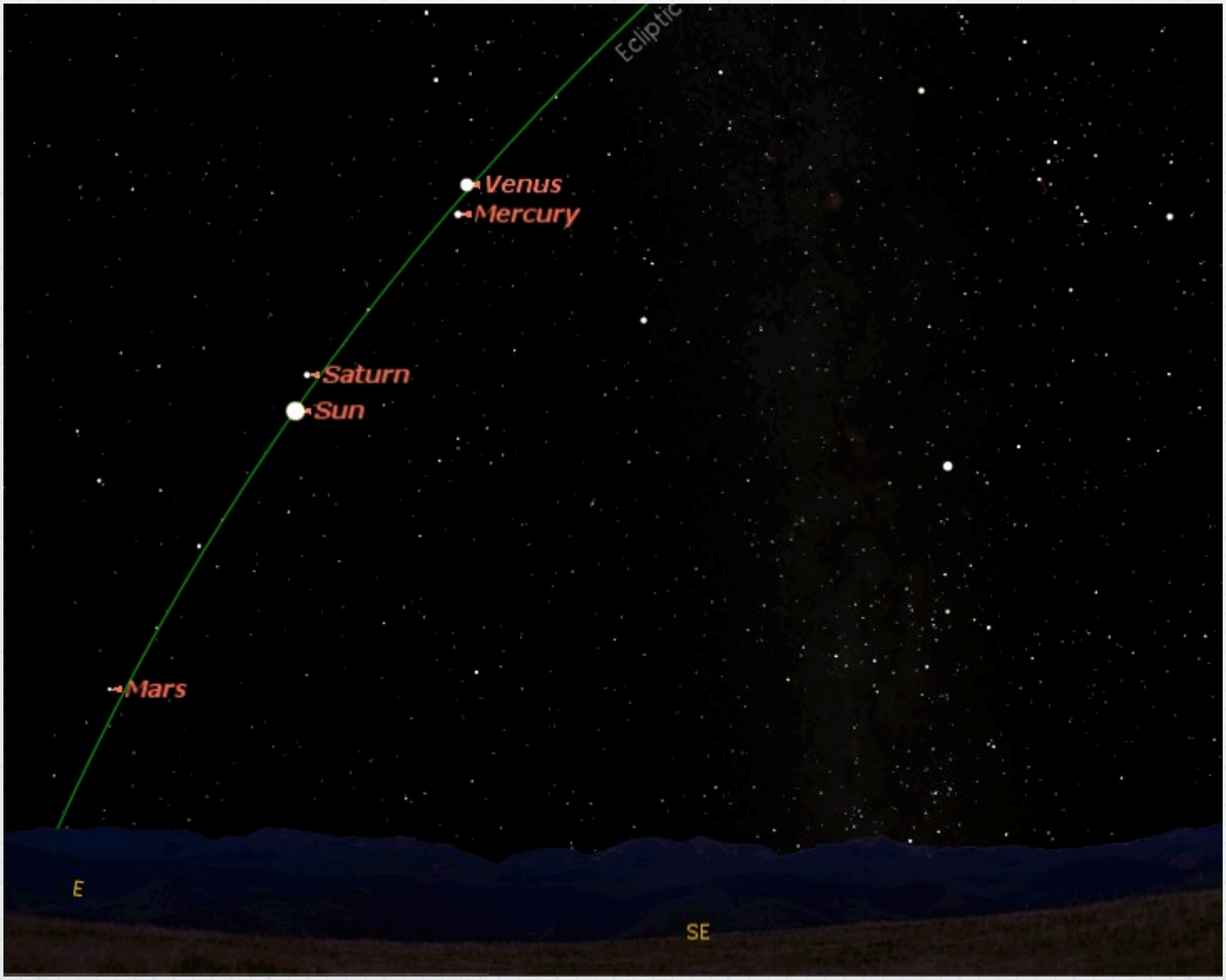
North Star at 0°N altitude (Equator)



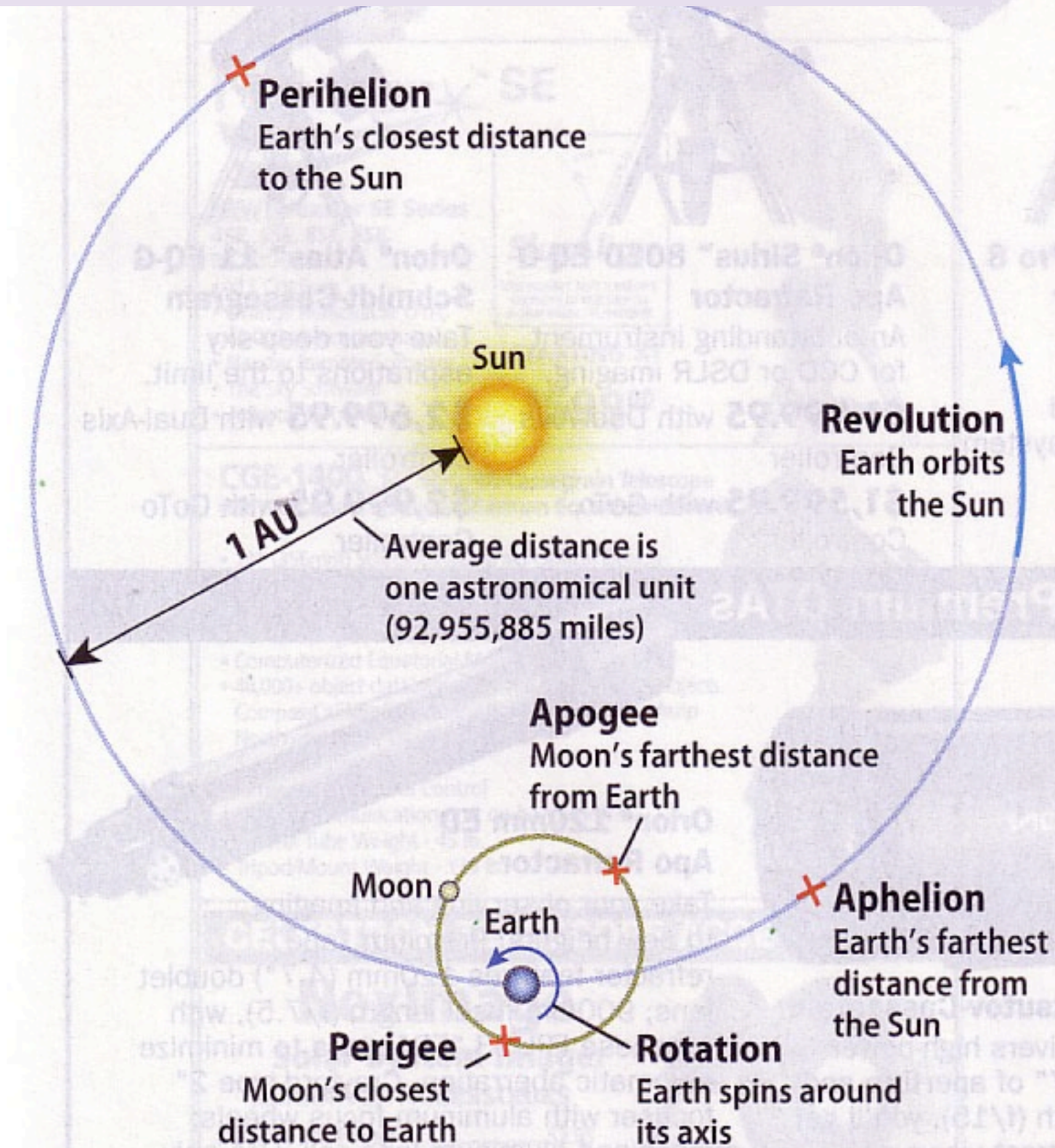
Ecliptic plane: inner view of the Solar System



Ecliptic as seen from a local spot



Sun, Earth & Moon and some definitions



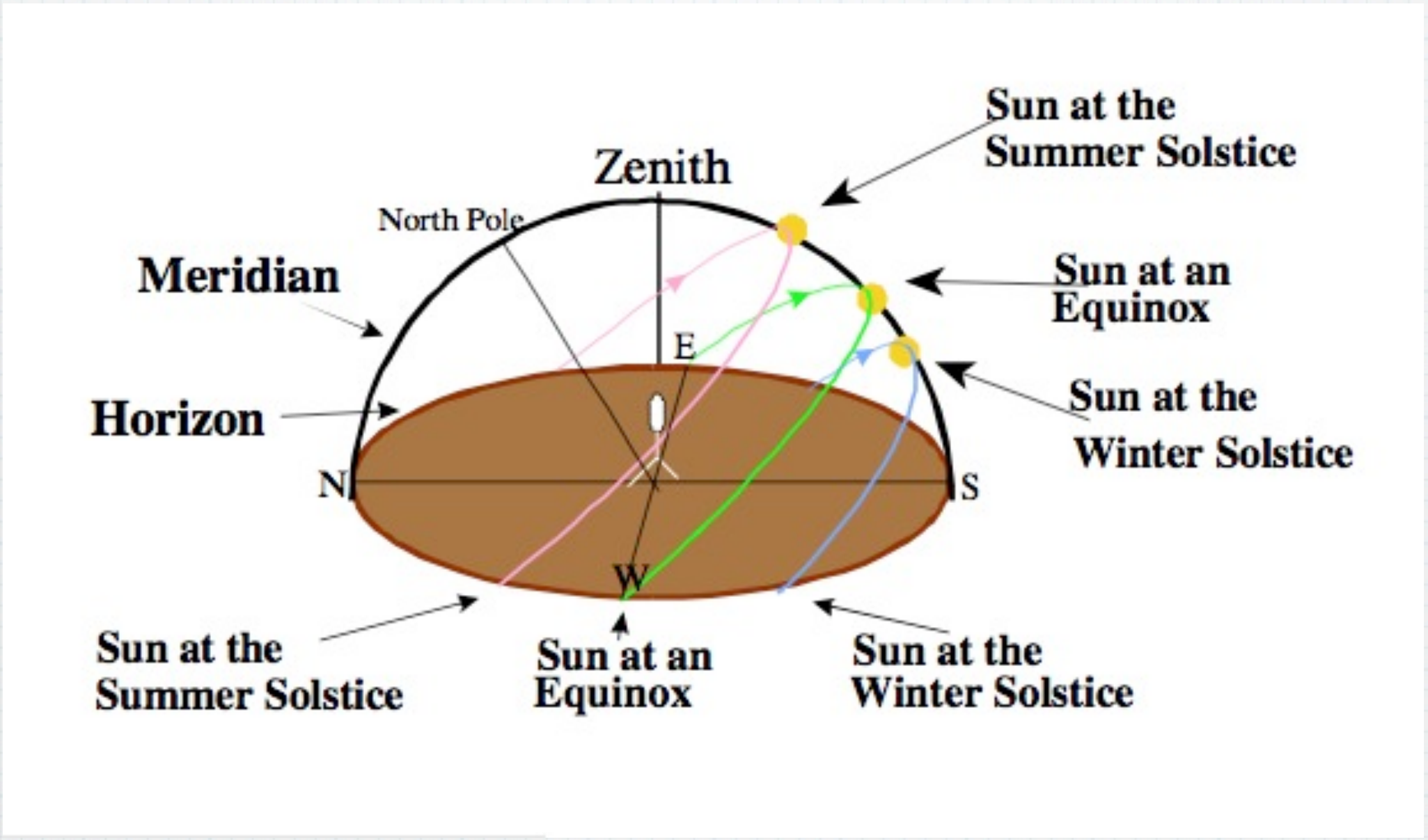
PLANET MOTIONS and positions include similar-sounding terms. **Rotation** means spinning. Earth rotates once a day. **Revolution** means orbiting another object. Earth revolves around the Sun once a year. The average Earth-Sun distance is an astronomical unit (92,955,885 miles, or 149,598,871 km).

For other terms, remember "peri" means "near" and "ap" means "far." An object's closest approach to the Sun is **perihelion**, and its farthest point is **aphelion**. **Perigee** is an object's closest approach to Earth. **Apogee** is the point where it lies farthest from Earth.

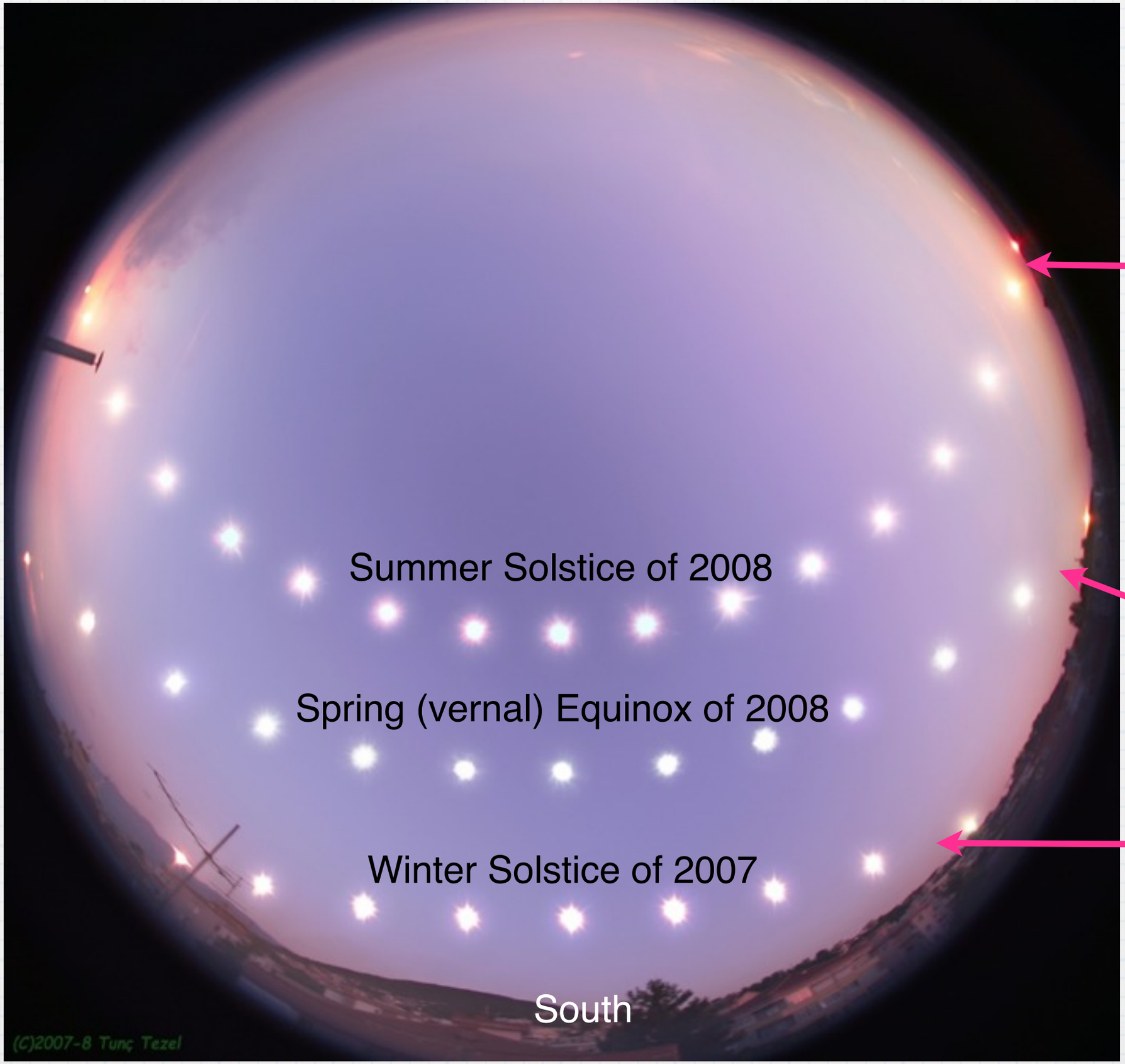
Introducing Seasons

* Longer warmer days in Summer
* Shorter colder days in Winter
* All due to the Earth's axis tilt
* Not due to the change of distance between Earth & Sun during a year

Seasonal changes: Sun path changes in the sky

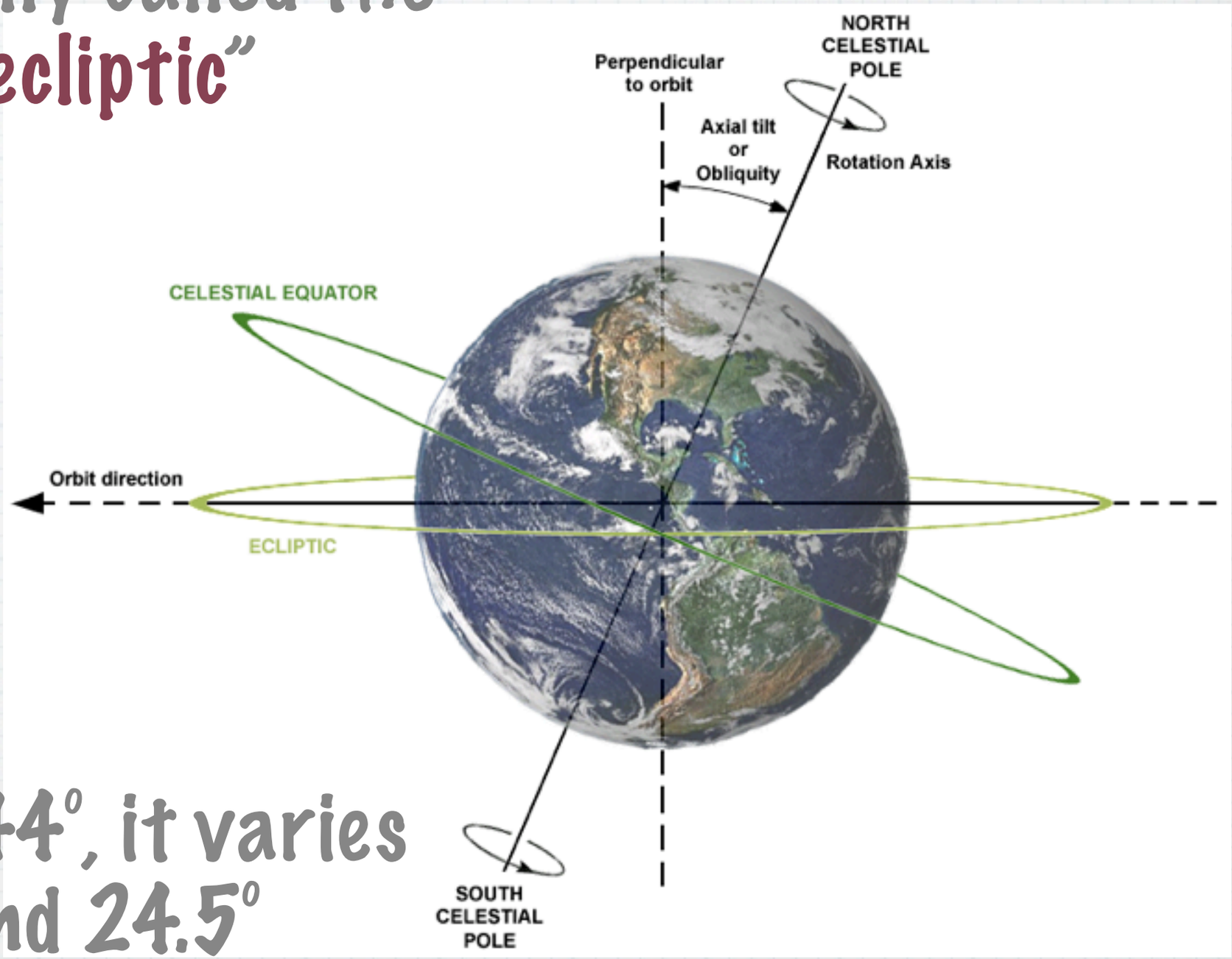


Hourly images of the Sun taken near Bursa, Turkey



The Earth is tilted

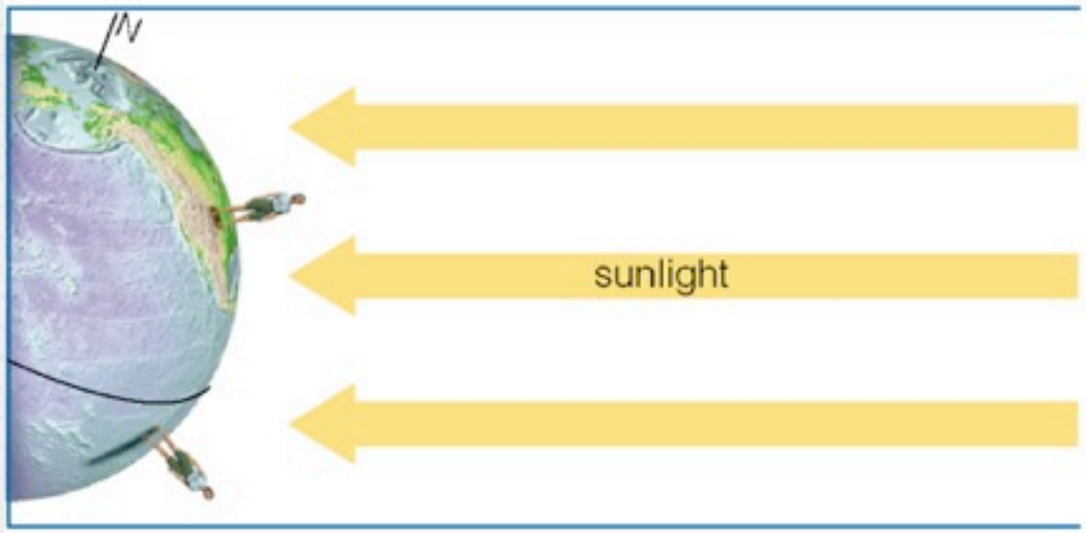
The tilt is officially called the "obliquity of the ecliptic"



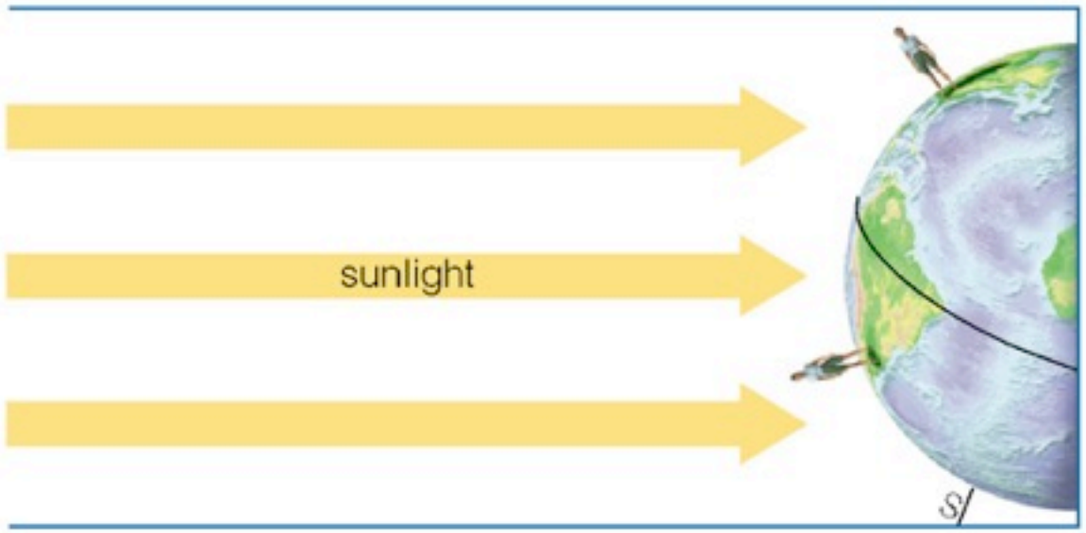
Currently at 23.44°, it varies between 22.1° and 24.5° with a 42,000-year period

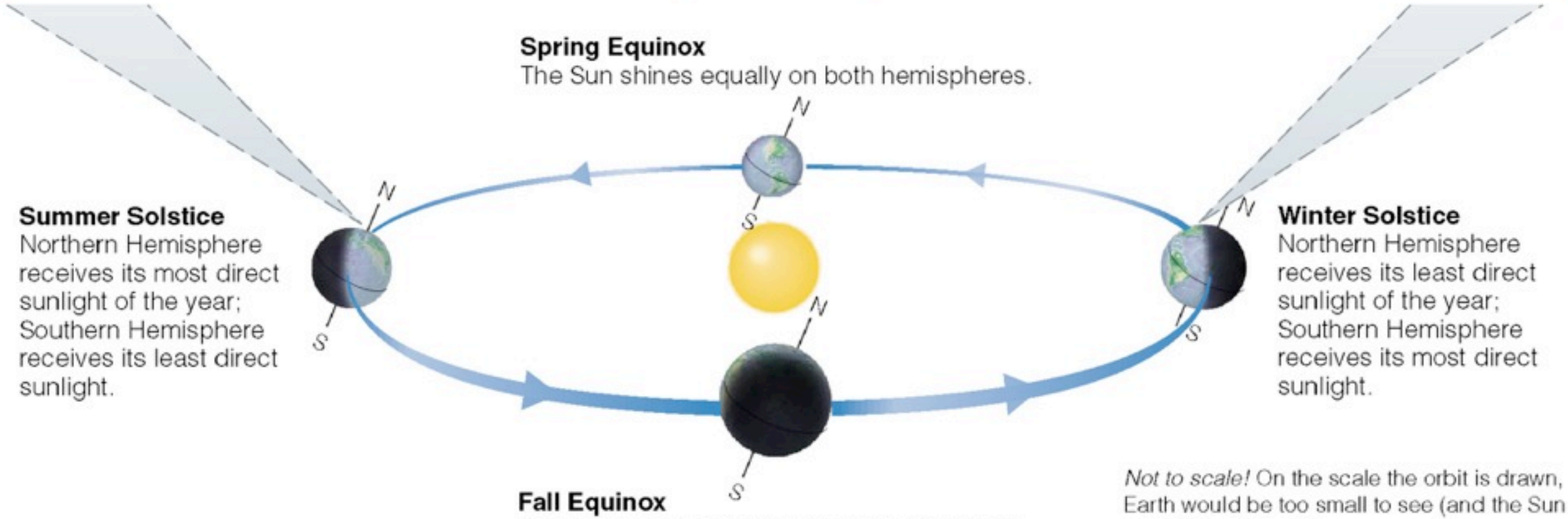
Solstices & Equinoxes

Summer Solstice: Sunlight falls more directly on the Northern Hemisphere, making solar energy more concentrated (notice the smaller shadows) and making the Sun's path longer and higher through the sky.



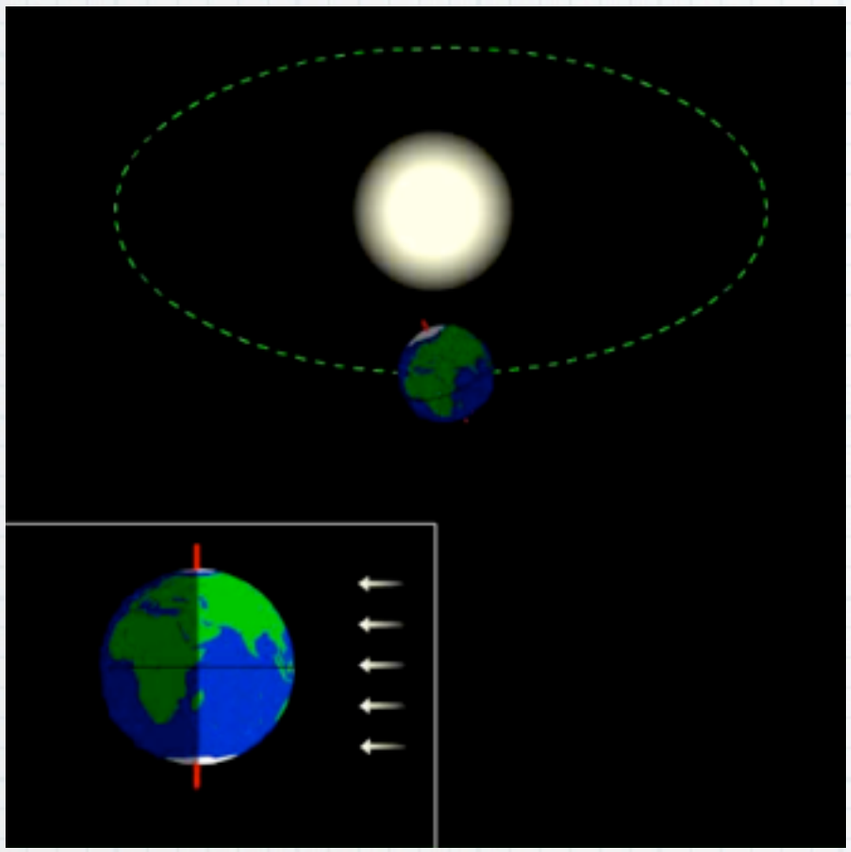
Winter Solstice: The situation is reversed from the summer solstice, with sunlight falling more directly on the Southern Hemisphere than the Northern Hemisphere.



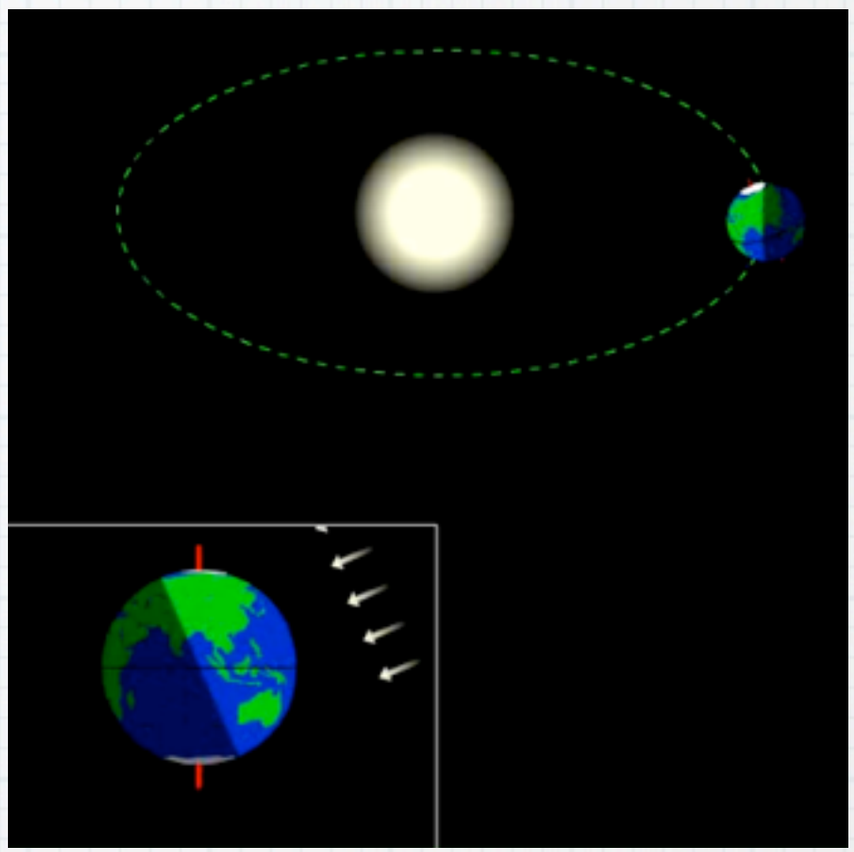


Not to scale! On the scale the orbit is drawn, Earth would be too small to see (and the Sun would be a tiny dot).

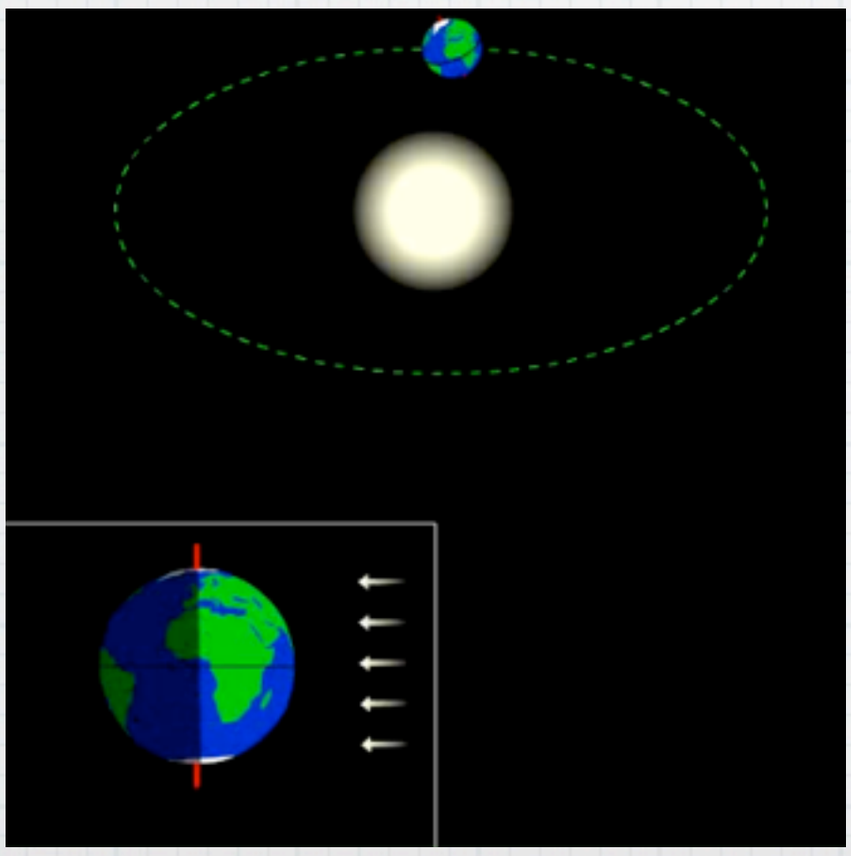
The Earth axis tilt and the angle of sunlight



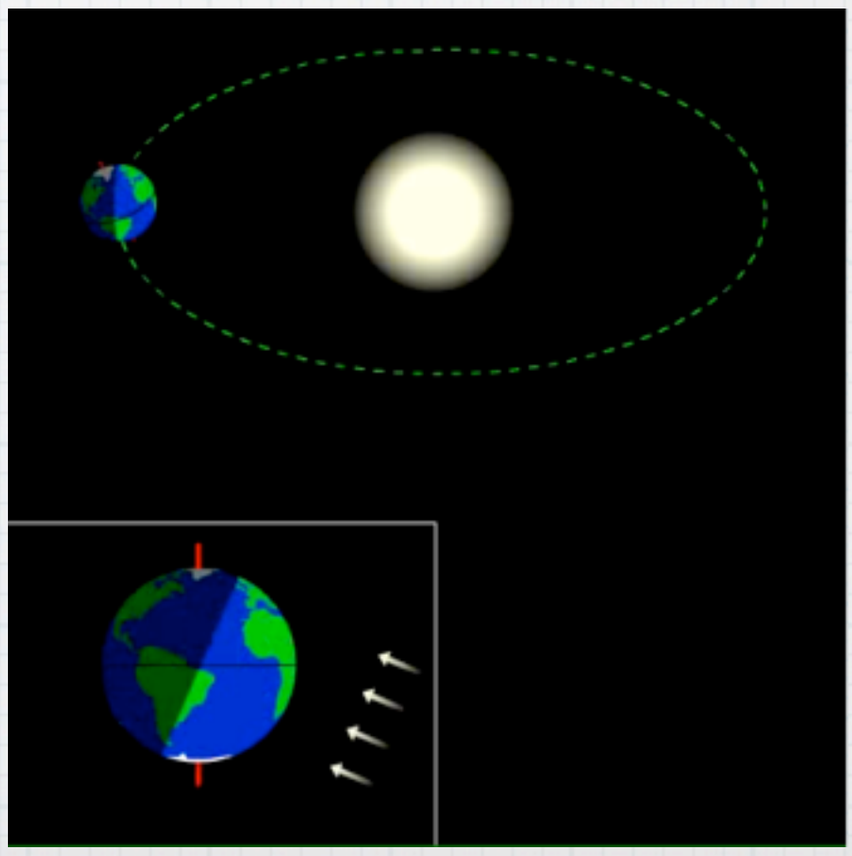
Spring equinox



Summer solstice



Fall equinox



Winter solstice

More Season factoids

* The four seasons we know are mostly felt in mid-latitude regions
* Equatorial regions only have 2 type of seasons: rainy & dry!
* Polar regions only have 2 seasons as well: 6 months of light and 6 months of darkness

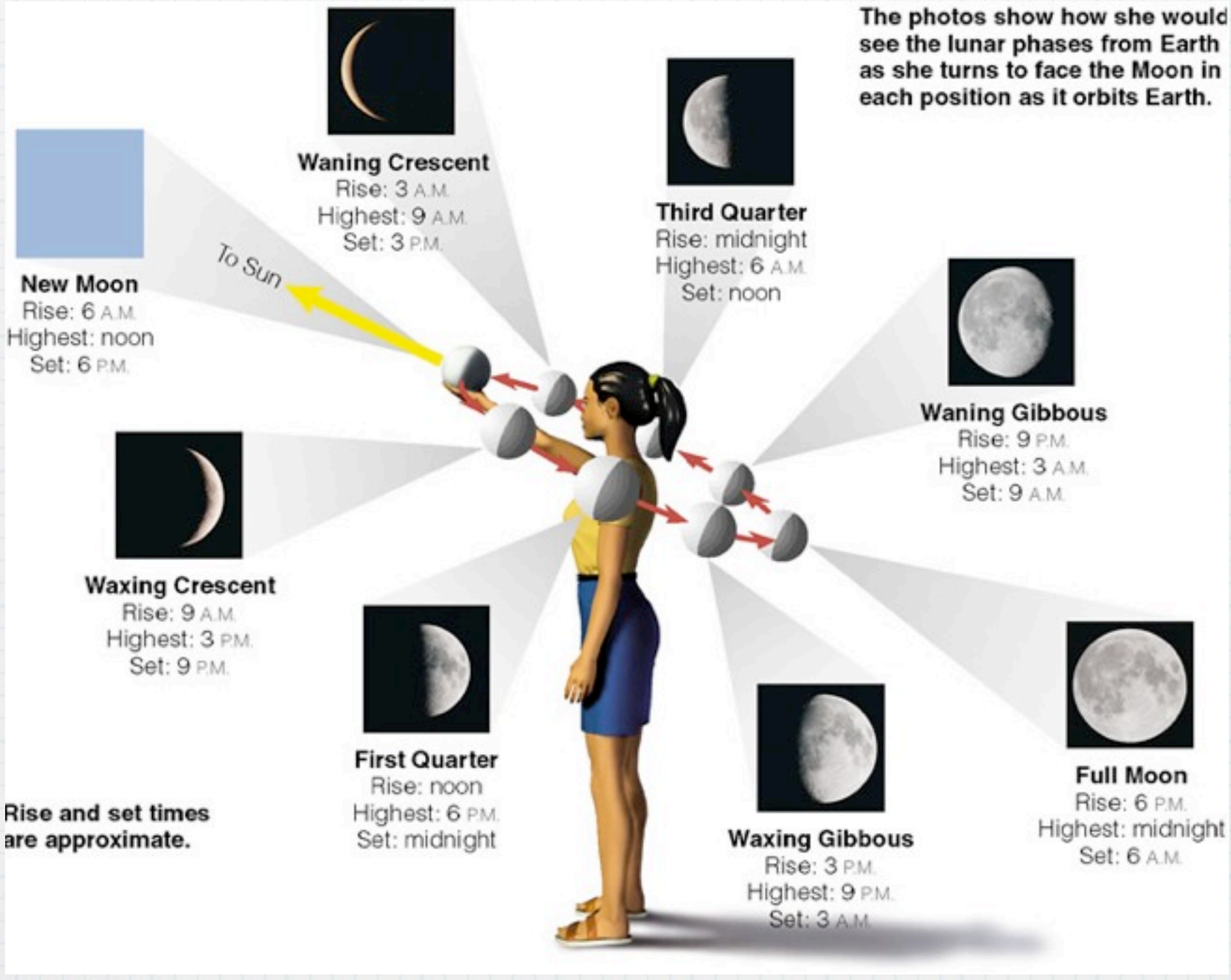
Phases of the Moon

* The Moon orbits the Earth while the Earth orbits the Sun
* A lunar orbit takes 27.33 days
* The Moon spins on its axis in one lunar month: we always see the same face (synchronous rotation)

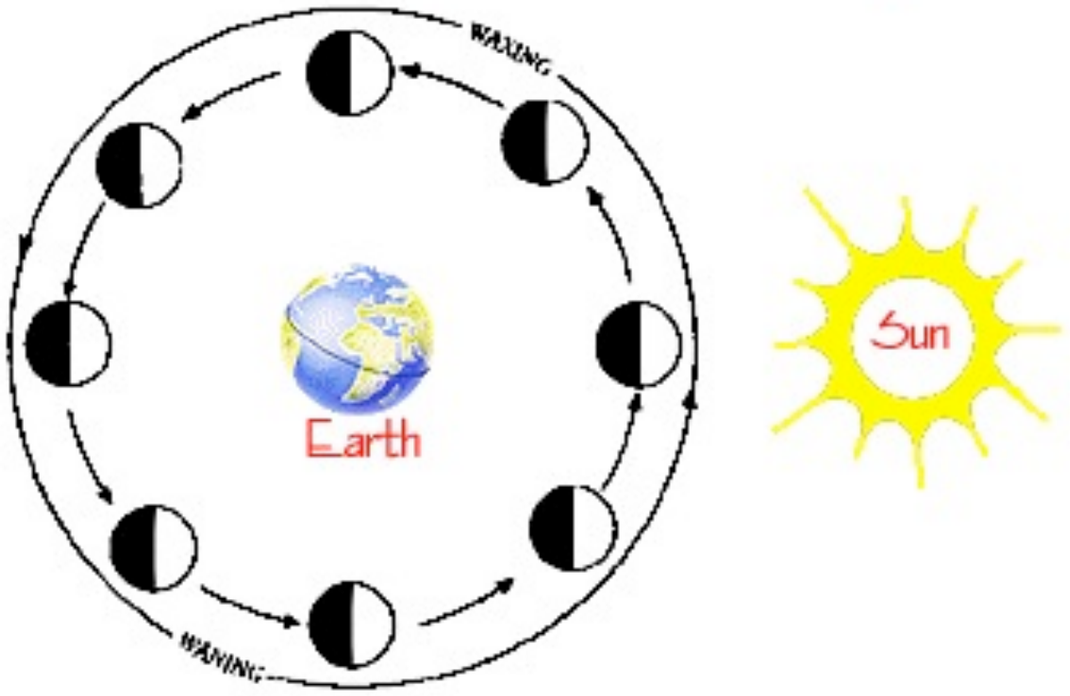
➡ There is no dark side! Only a far side

Moon phases

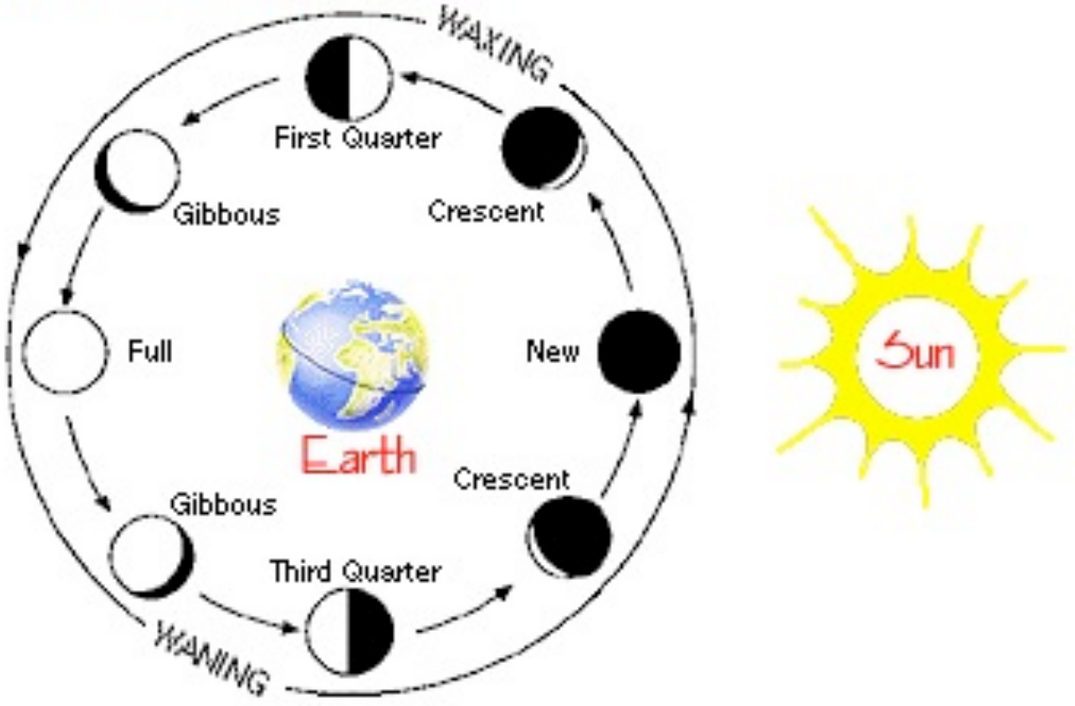
A full Moon is always overhead around midnight
It will rise at sunset and set at sunrise



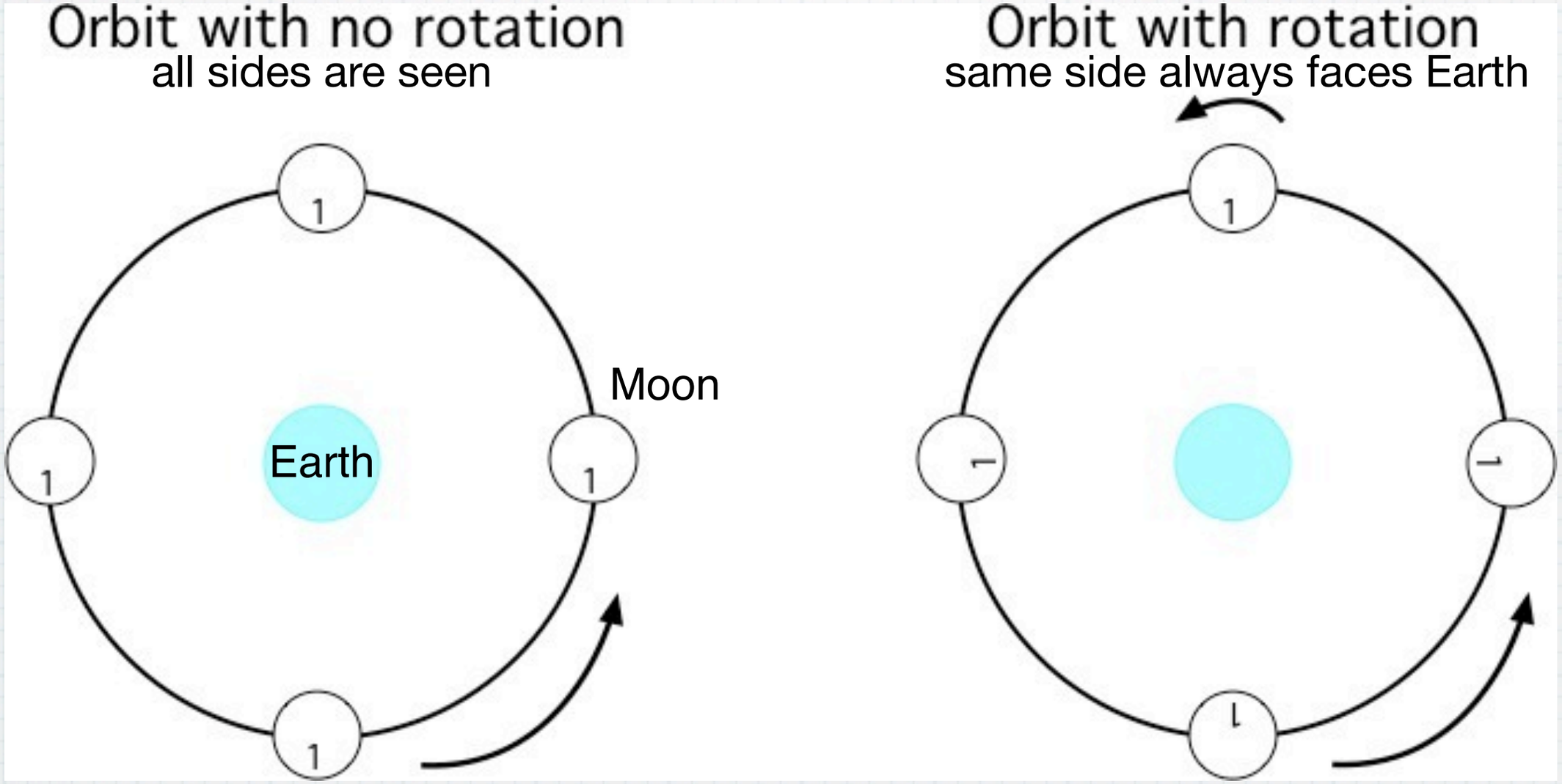
Moon, Earth, Sun as viewed from above our Solar System



The Moon as seen from Earth



Synchronous Rotation of the Moon (also known as tidal-locking)

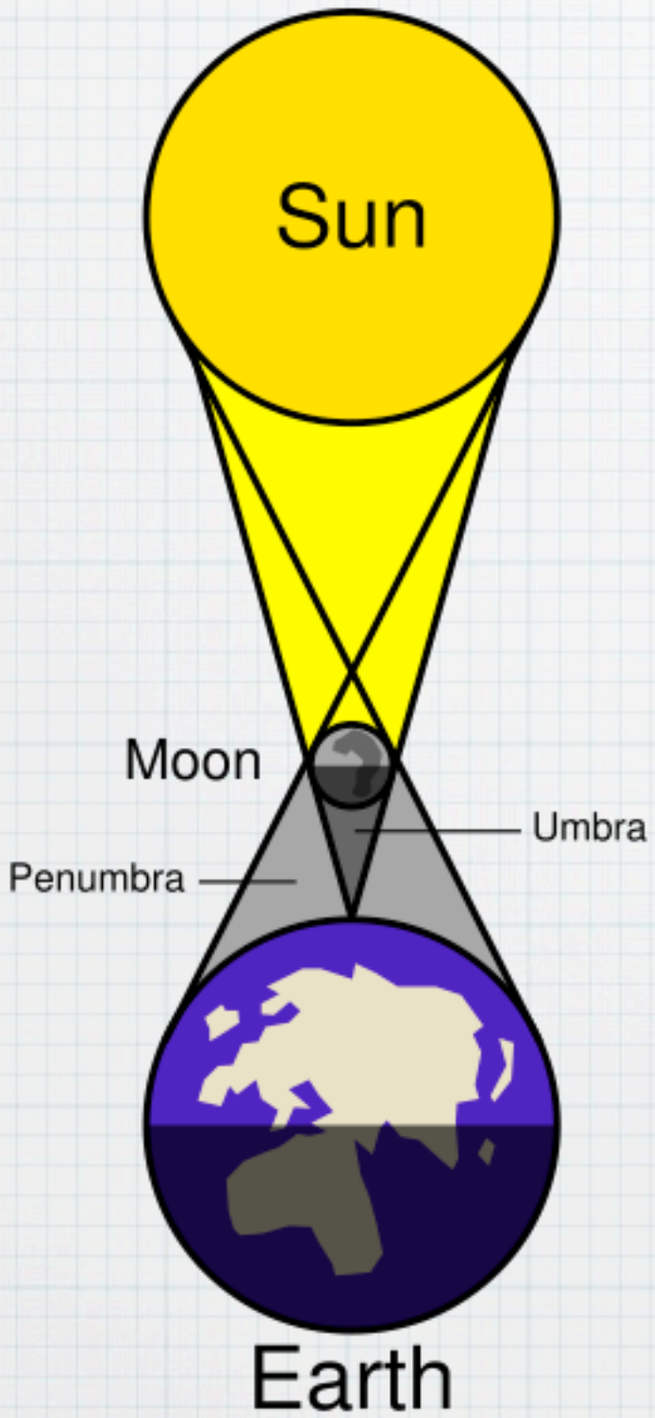


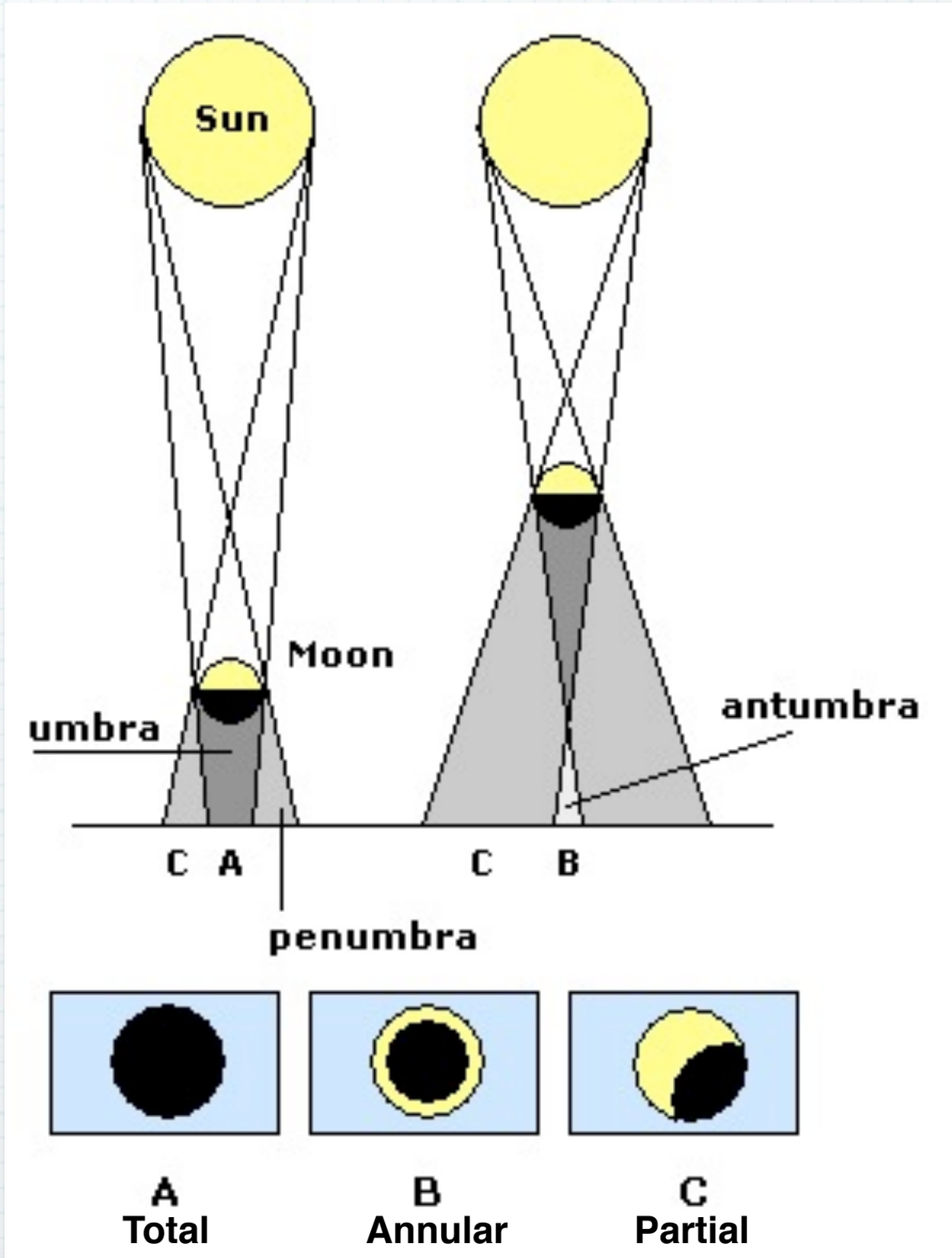
Eclipses

* Due to Earth & Moon shadows
* Solar eclipse needs an alignment of
  * Sun → Moon → Earth
* Lunar eclipse needs an alignment of
  * Sun → Earth → Moon

- These alignments force the Moon to be either new or full for an eclipse to occur
- Lucky shot: angular size of Sun & Moon are similar
- Solar eclipses can be (new Moon)
  - total, annular, partial
- Lunar eclipses can be (full Moon)
  - total, partial, penumbral

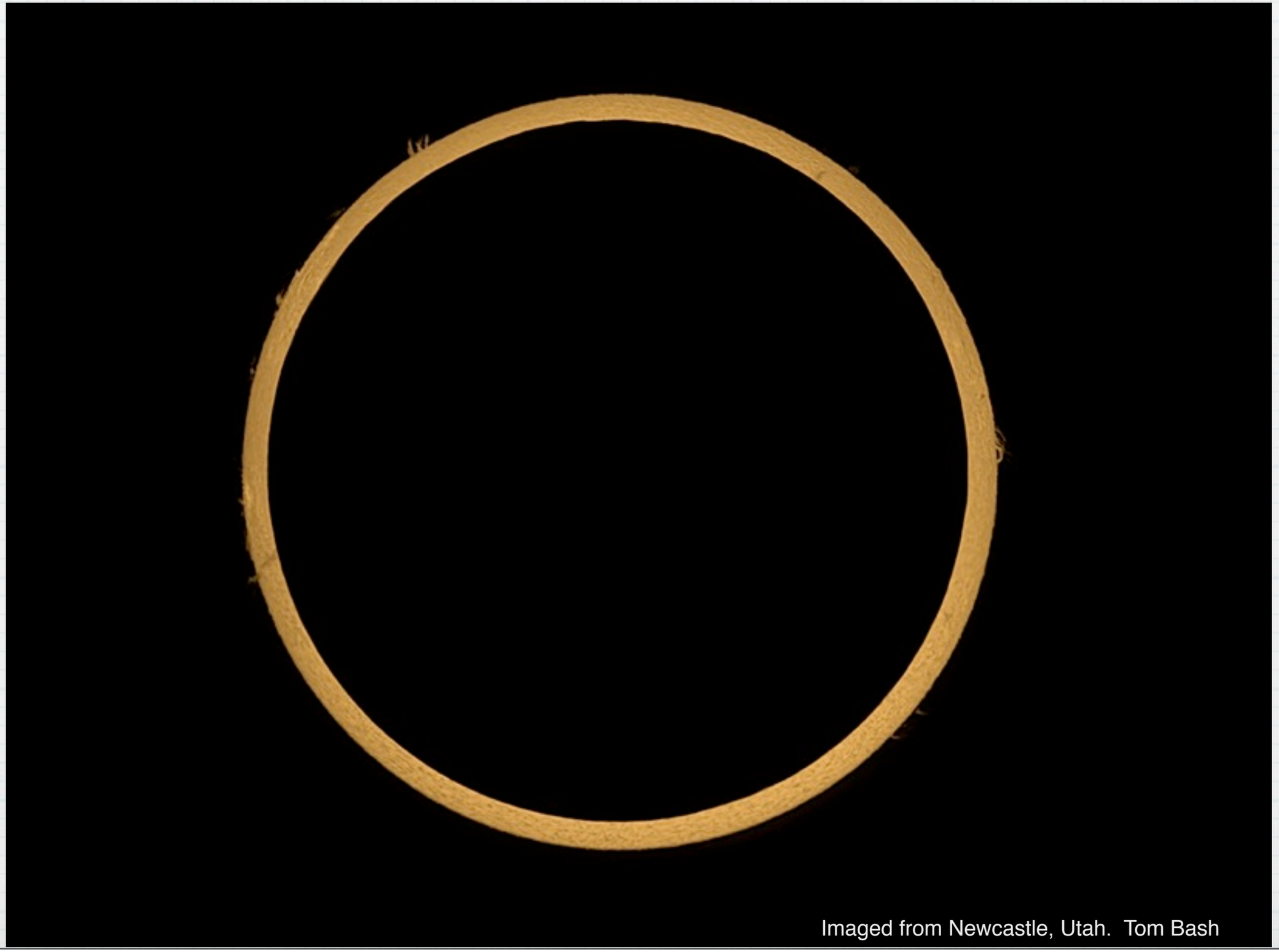
Solar Eclipses





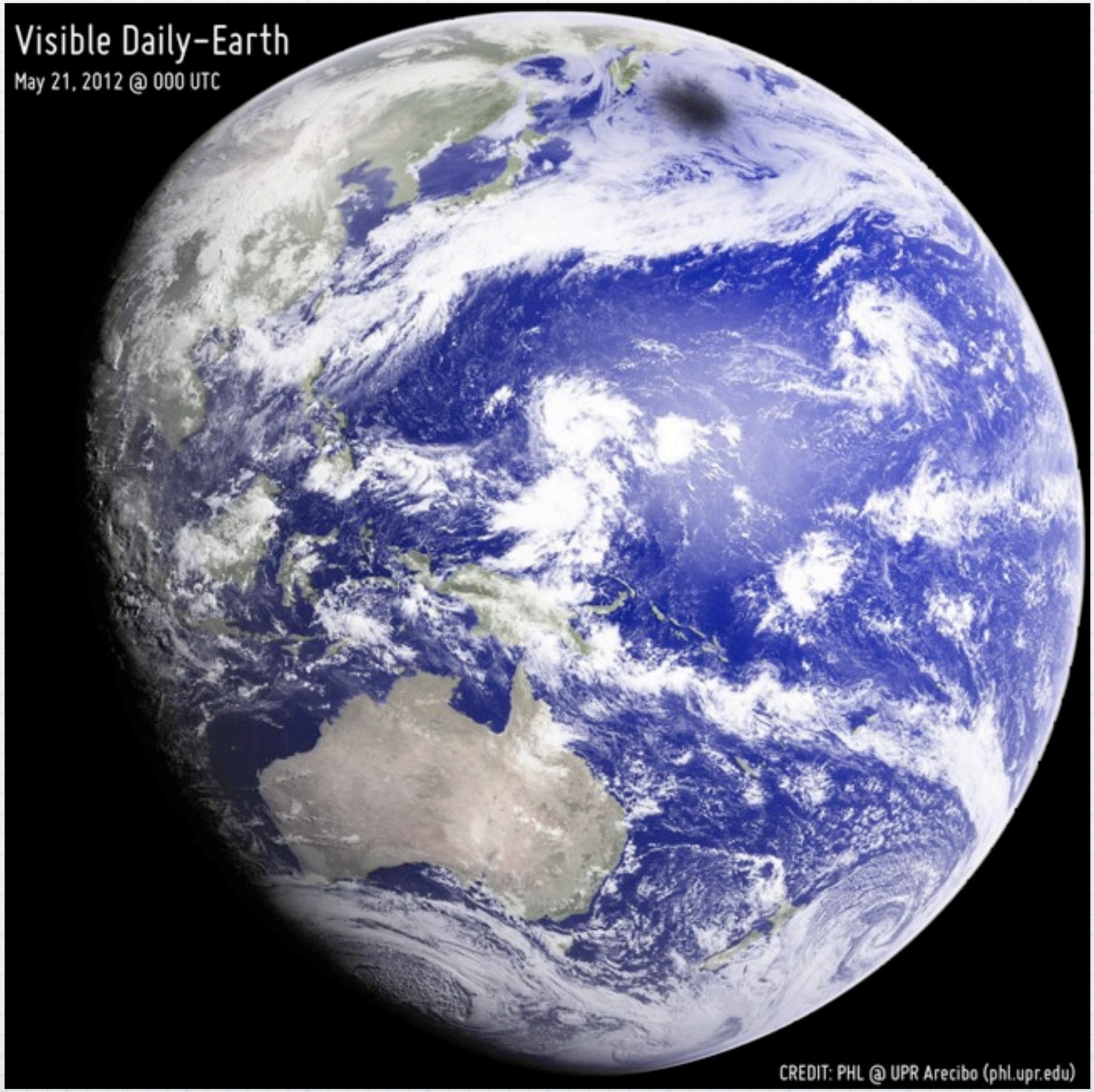
The Moon orbits the Earth in an ellipse, not a circle

Annular Eclipse



Imaged from Newcastle, Utah. Tom Bash

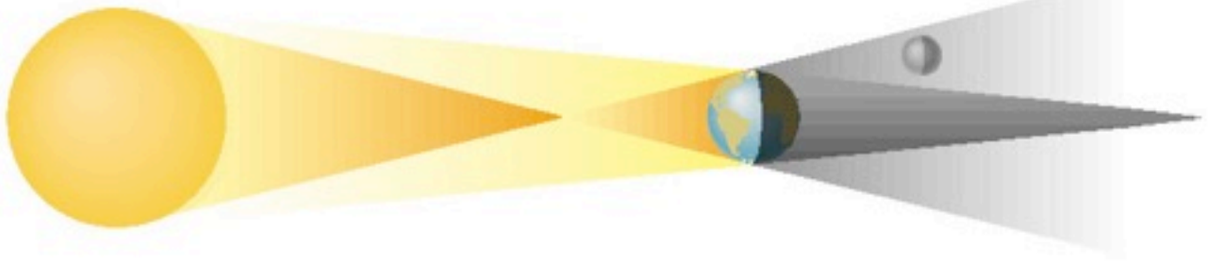
Moon Shadow...


Visible Daily-Earth
May 21, 2012 @ 000 UTC
CREDIT: PHL @ UPR Arecibo (phl.upr.edu)

Lunar Eclipses

Penumbral Lunar Eclipse

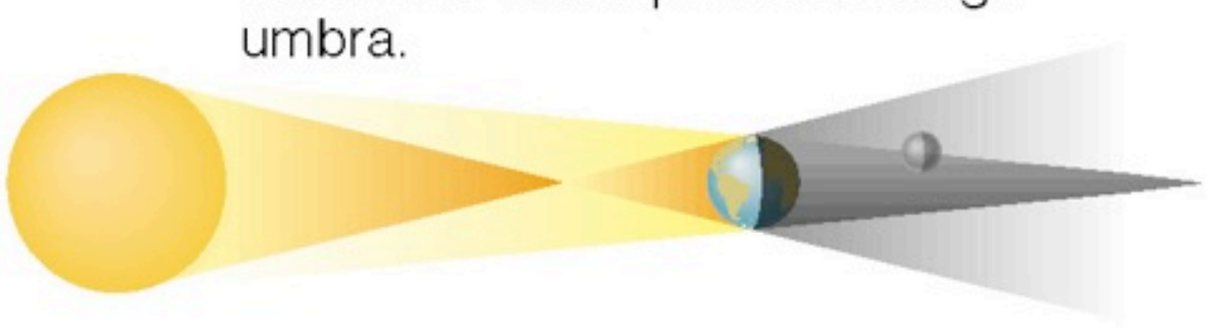
Moon passes through penumbra.



note:
eclipse
is hardly
noticeable

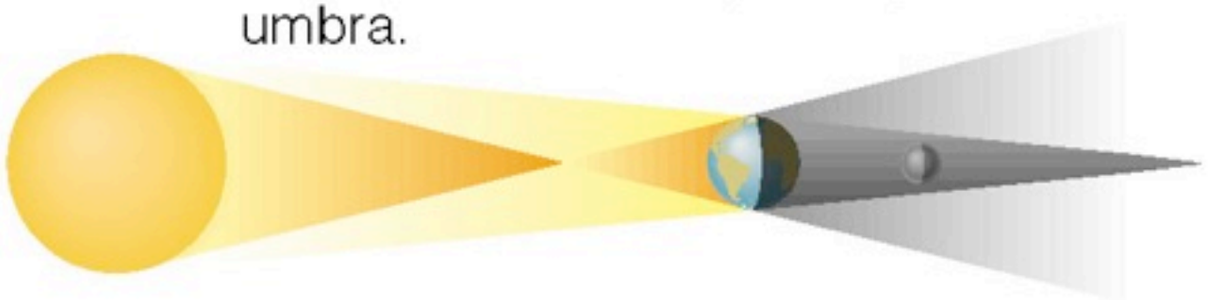
Partial Lunar Eclipse

Part of the Moon passes through umbra.



Total Lunar Eclipse

Moon passes entirely through umbra.



note:
Moon is lit by
Earth
atmosphere

Size of the Earth Shadow

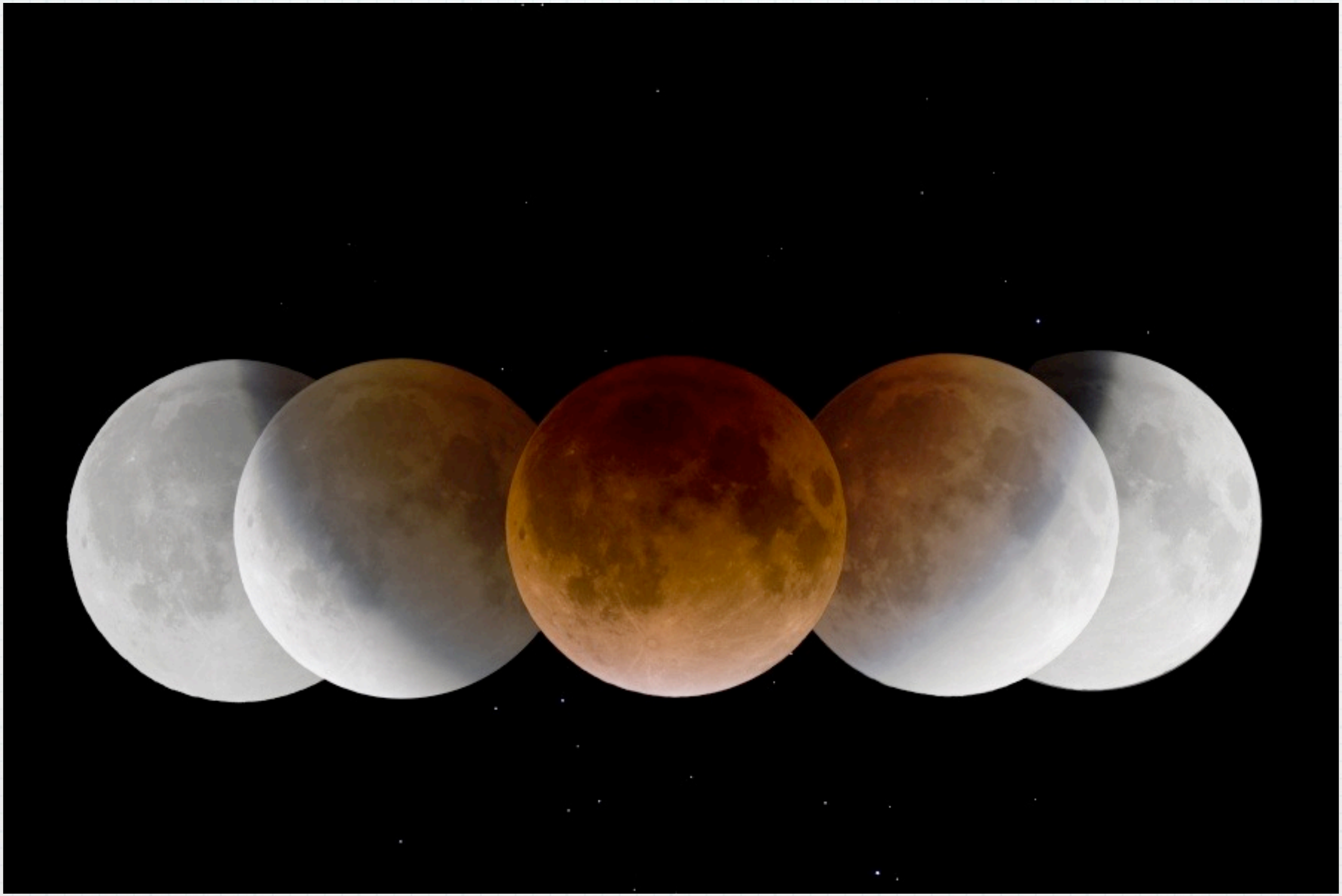
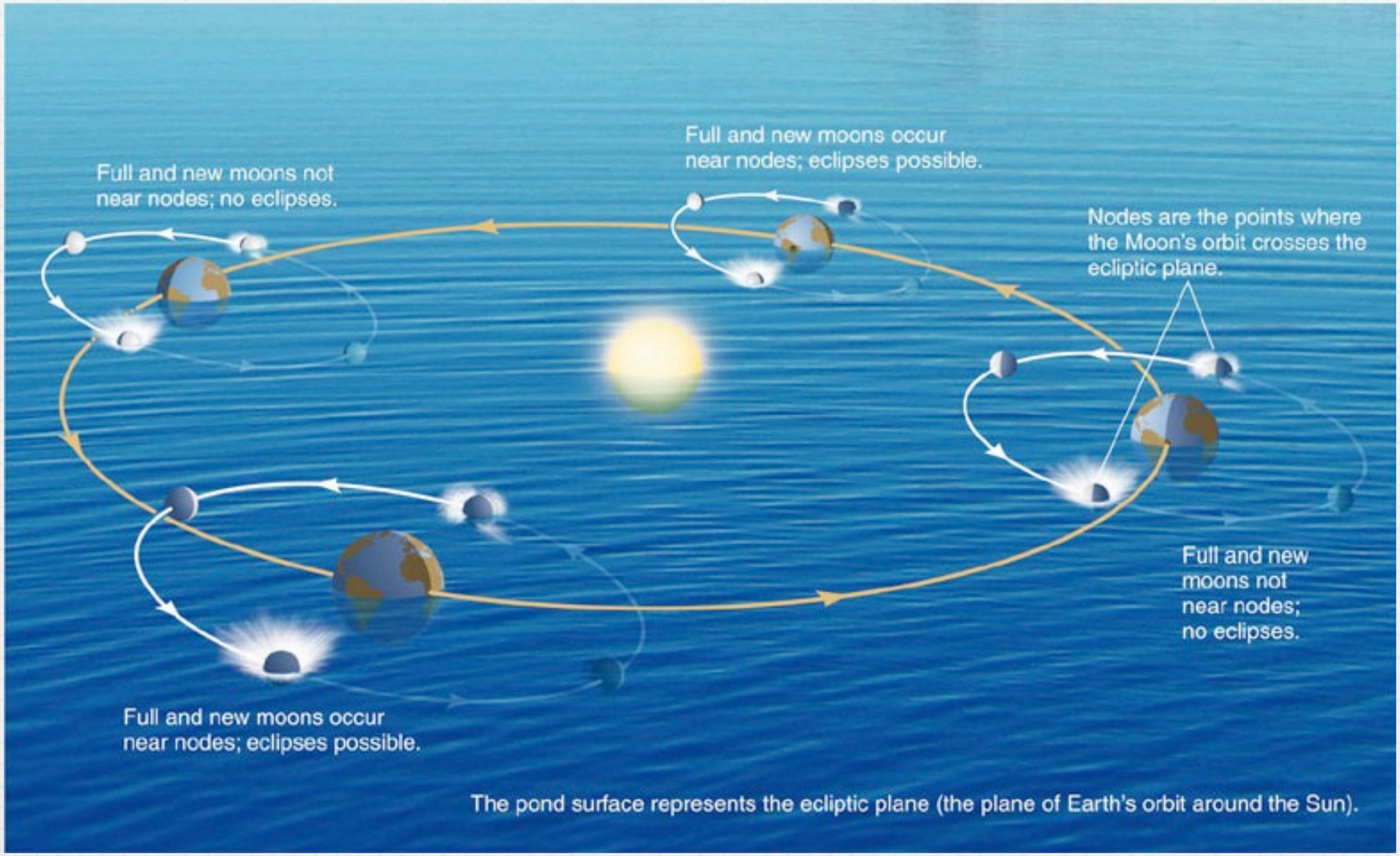


Image Credit & Copyright: Wang, Letian

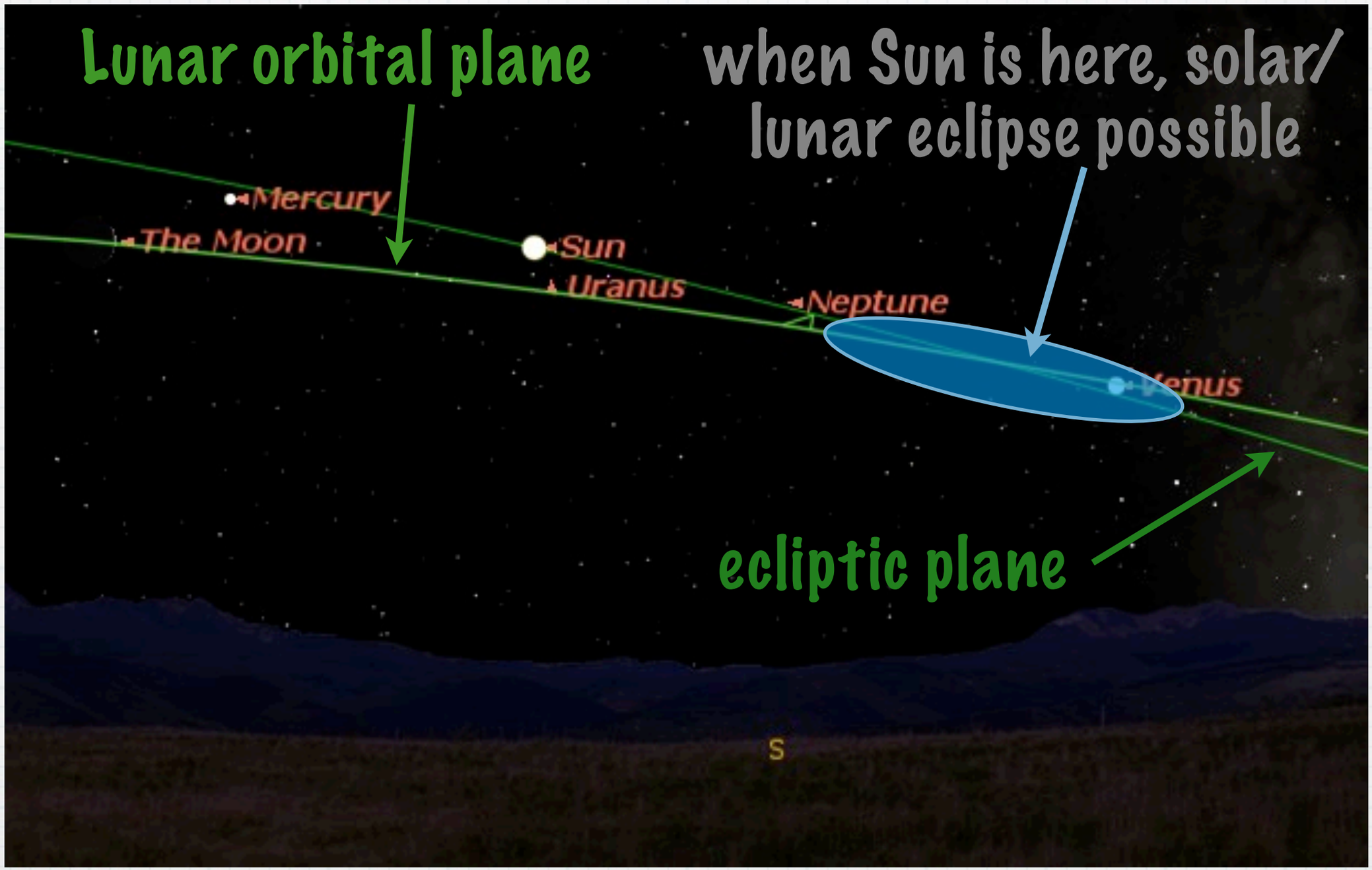
The crossing of 2 planes causes eclipses:

The Moon's orbit (1) is tilted 5° wrt the ecliptic (2)

There are 2 eclipse "seasons" every year



Lunar & ecliptic orbital planes crossing



Moving on to Chapter 3

Power of Observation

* Weather patterns
  * seasons, rainy & dry periods, storms, ...
  * migrating animals, tides, ...
* Sky patterns
  * lunar cycles, constellation movements, ...
  * longer & shorter days, Sun movement,
* Were they linked?

* Season prediction important for agriculture, hunting, best time to travel, shelter
* Daytime could be derived from tree shadows
  ➡ Sundial -> Egyptians (obelisk)
* Season prediction from sun rise/set
  ➡ Stonehenge, Templo Mayor, ...
* Stars & constellations helpful for direction
  ➡ Polynesians & ocean navigation

Some Obelisks

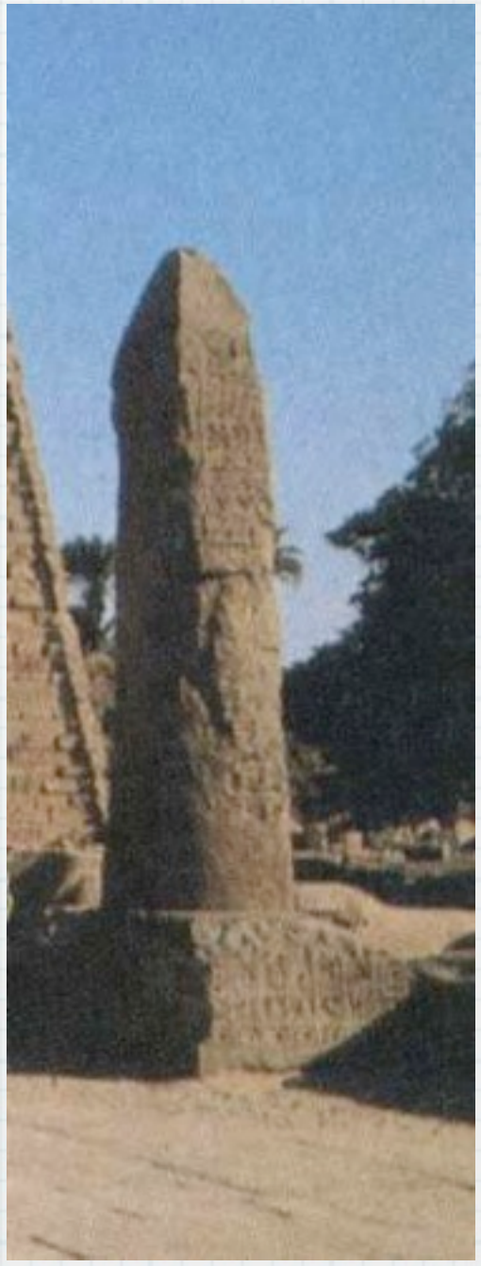
120 tons
20.5 m (67 ft)

Heliopolis, 1950 BC

254 tons
25.0 m (82 ft)

Luxor, 1250 BC

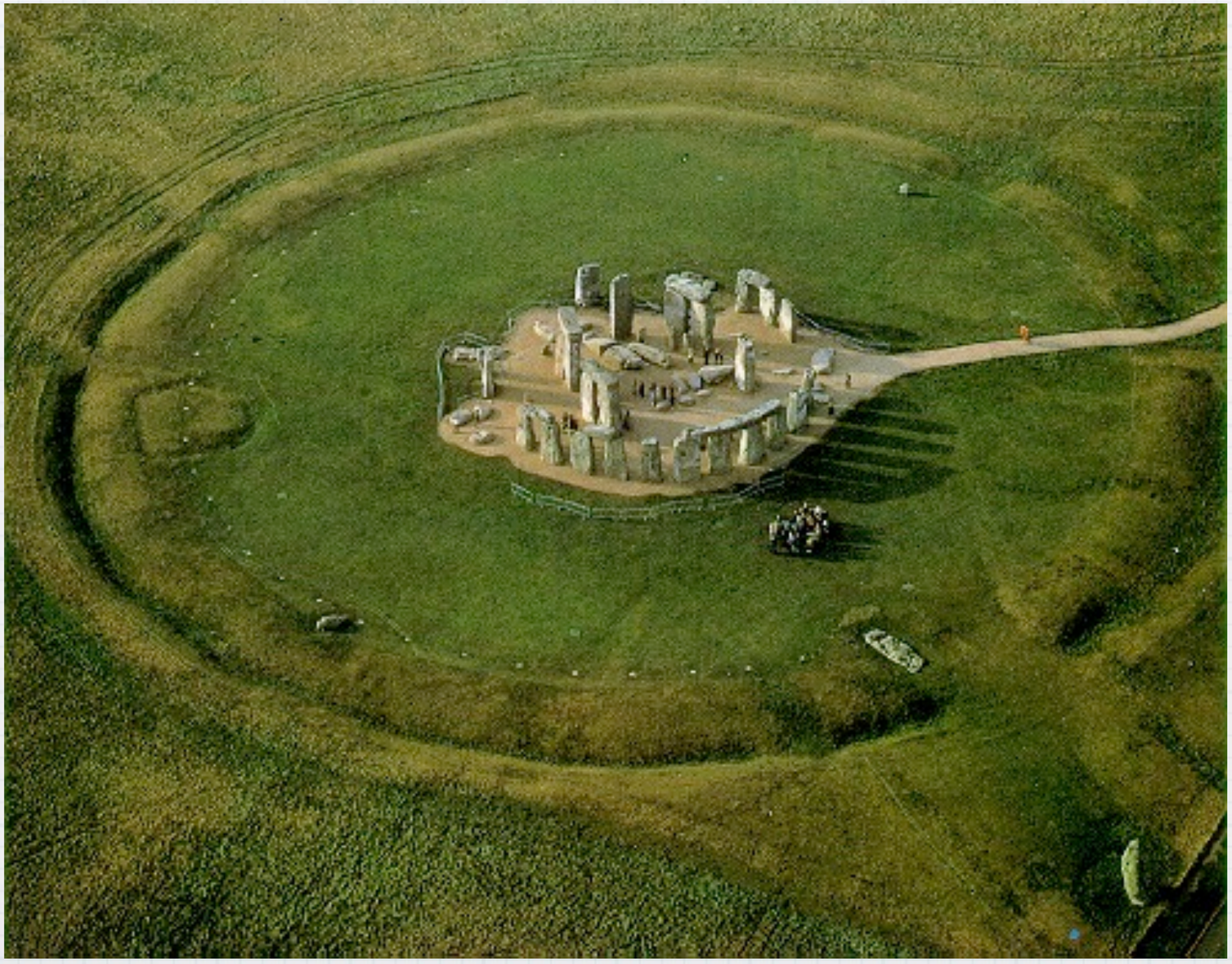
7 tons
7.0 m (23 ft)



Karnak, 1200 BC

Stonehenge

Built in several cycles by the Celts, to help predict seasons



Lunar calendar

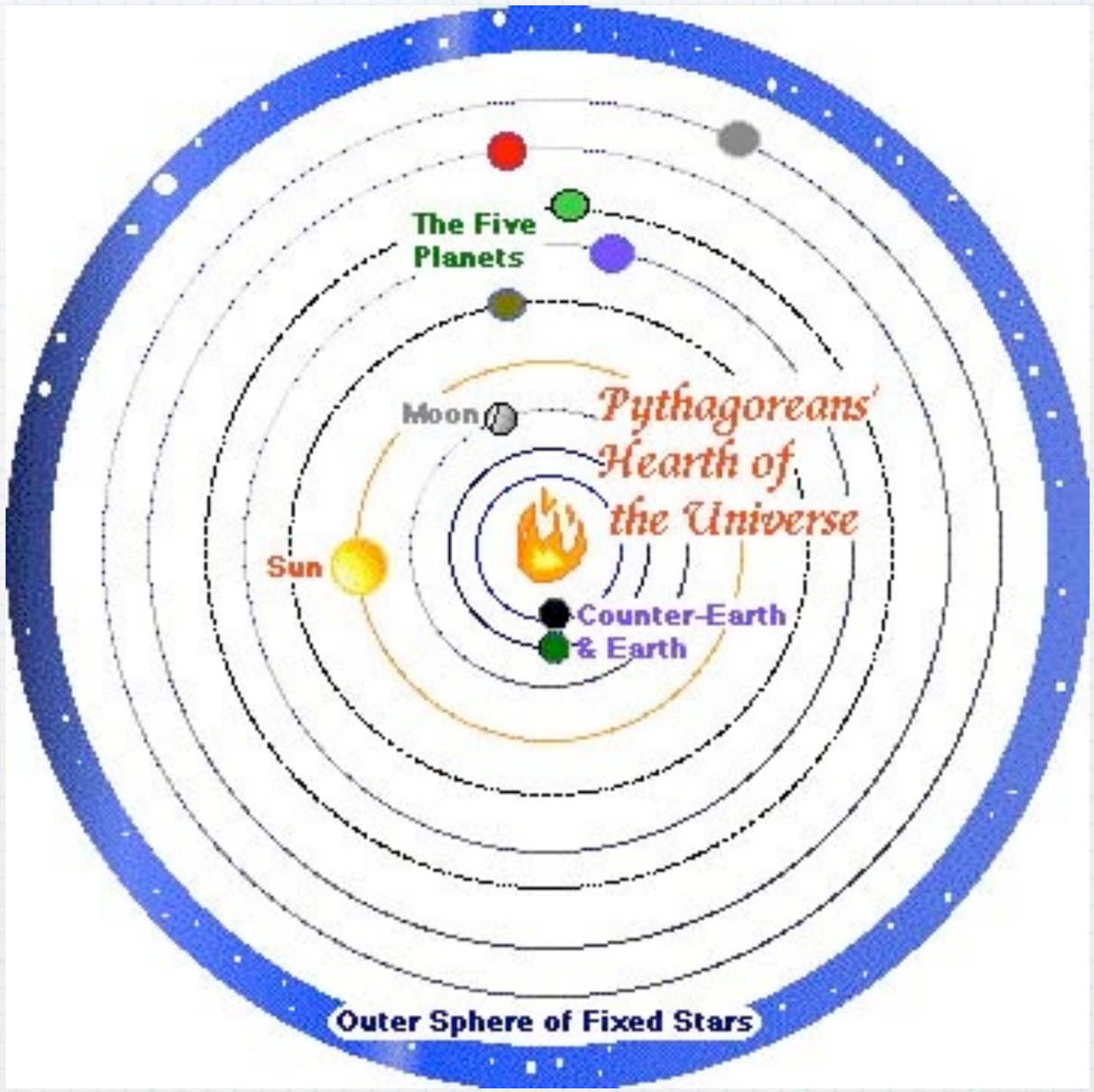
* The Moon was also used to help predict seasons by several ancient civilizations
* Currently still used in the Muslim culture (Islamic lunar calendar)

The Greeks

First culture to try to make models of the "heavens"

from center out

Hearth
Counter-Earth
Earth
Moon
Sun
Mercury
Venus
Mars
Jupiter
Saturn
stars



Geocentricity & "Perfection"

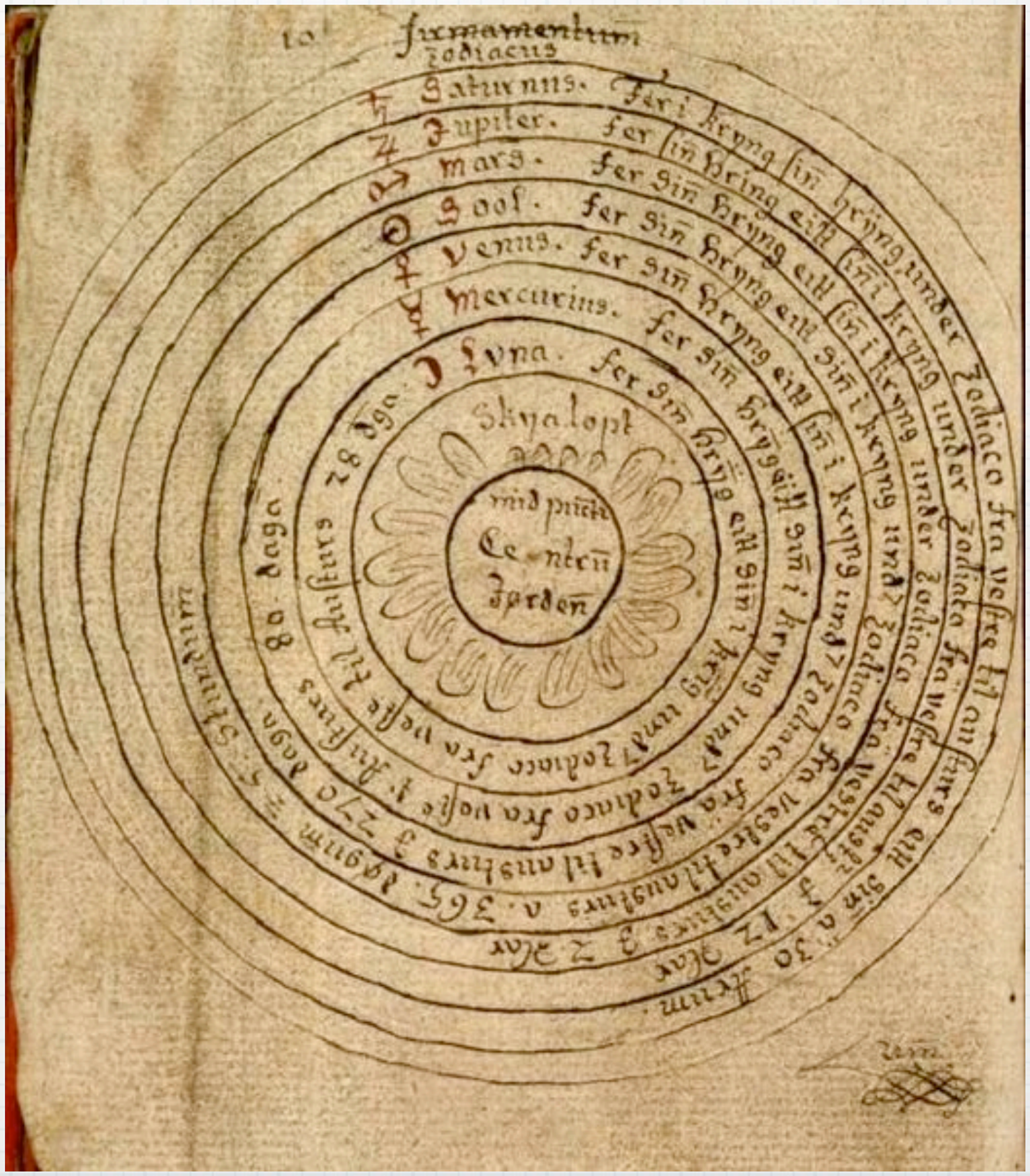
* About 400 years BC, Plato & Aristotle came up with the first recorded model of the Heavens. The characteristics:

1. perfect circular orbits
2. speeds are perfectly uniforms
3. Earth at the center of everything

The Greek Geocentric Model

from center out

Earth
Moon
Mercury
Venus
Sun
Mars
Jupiter
Saturn
sphere of stars



More Observations

✓ the Earth's curved shadow during lunar eclipses -> Earth is spherical

≈ width of Earth's shadow is that of 2 Moons (it is 3)

✓ angular size of Sun and Moon is 1/2°

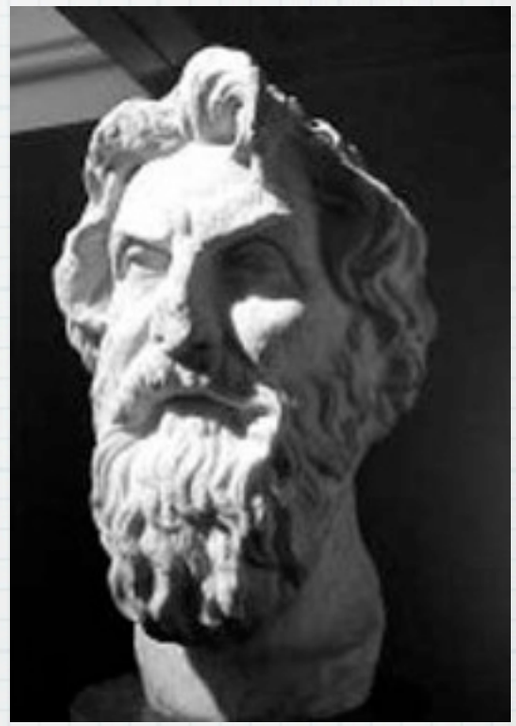
✗ distance Sun-Earth is at least 18 times distance Earth-Moon (it is 400)

An early Sun-Centered Model

* Aristarchus of Samos (310 to 230 BC)

1. proposes a Sun-centered model, and

2. suggests stars are very far away



  * but model is rejected (for lack of evidence)

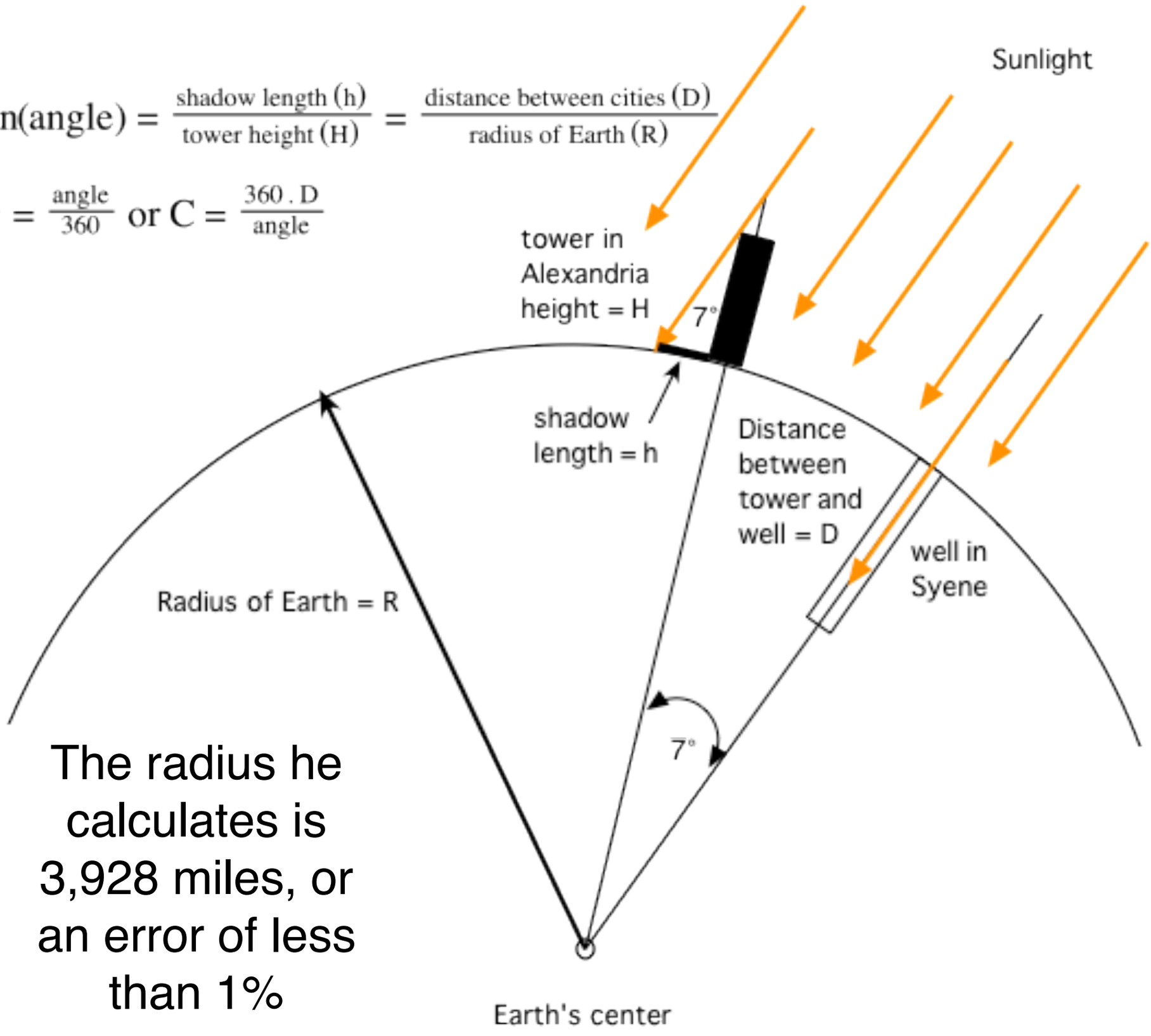
* worked to determine the sizes and distances of the Sun and Moon via geometry

Eratosthenes of Cyrene
(276 - 194 BC)

* Used geometry to estimate the Earth circumference (240 BC)
* Also determined the obliquity of the Ecliptic (the Earth tilt)
* Develops a method for finding prime numbers

$$\tan(\text{angle}) = \frac{\text{shadow length (h)}}{\text{tower height (H)}} = \frac{\text{distance between cities (D)}}{\text{radius of Earth (R)}}$$

$$\frac{D}{C} = \frac{\text{angle}}{360} \text{ or } C = \frac{360 \cdot D}{\text{angle}}$$

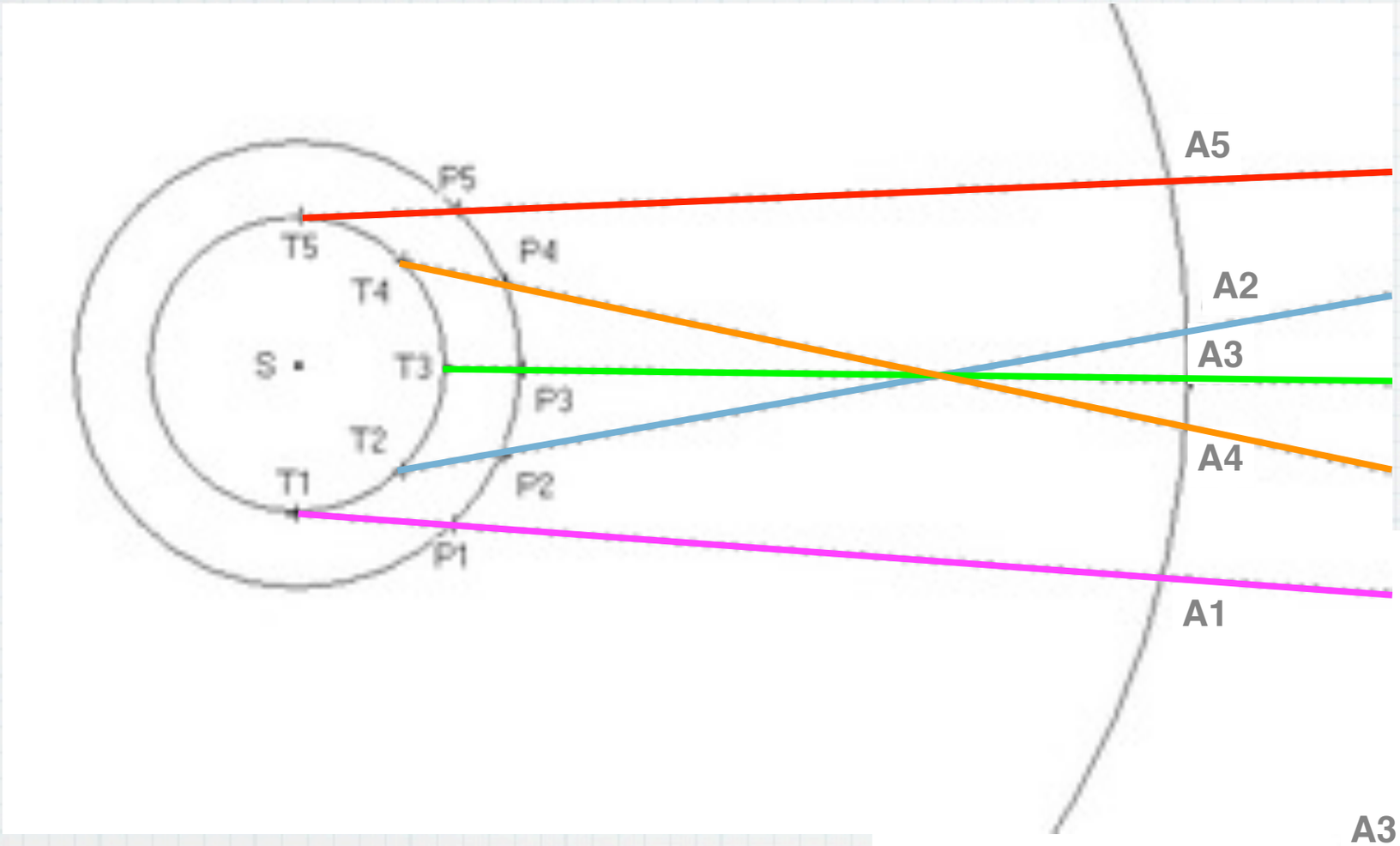


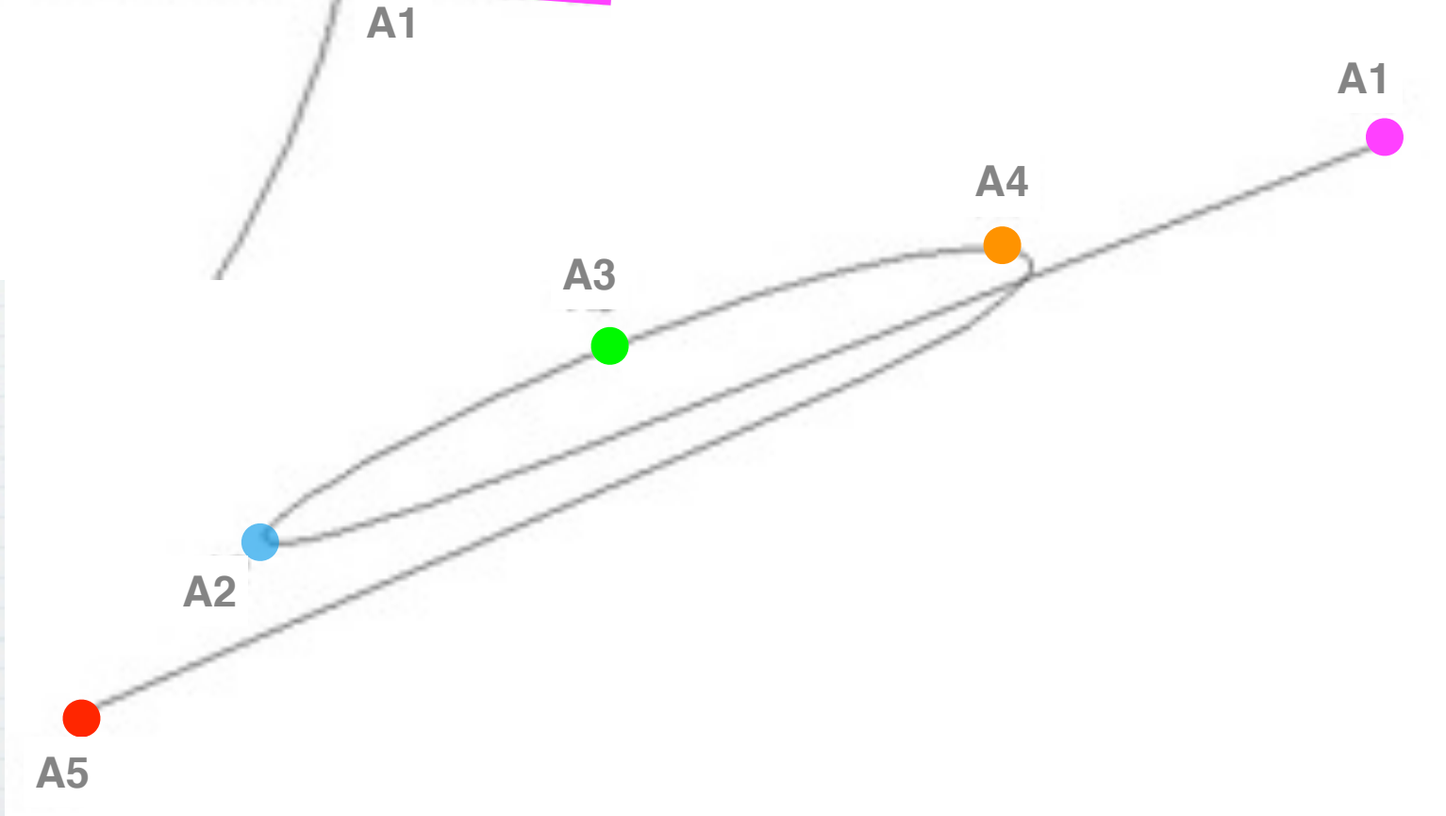
The radius he calculates is 3,928 miles, or an error of less than 1%

Ptolemy
(85 - 165)

* Extended the Plato & Aristotle model
* Writes a book called the Almagest
* (Wrongly) explained planetary retrograde motions
* Finds the length of the seasons
* His model prevailed for the next 1400 years (unfortunately)

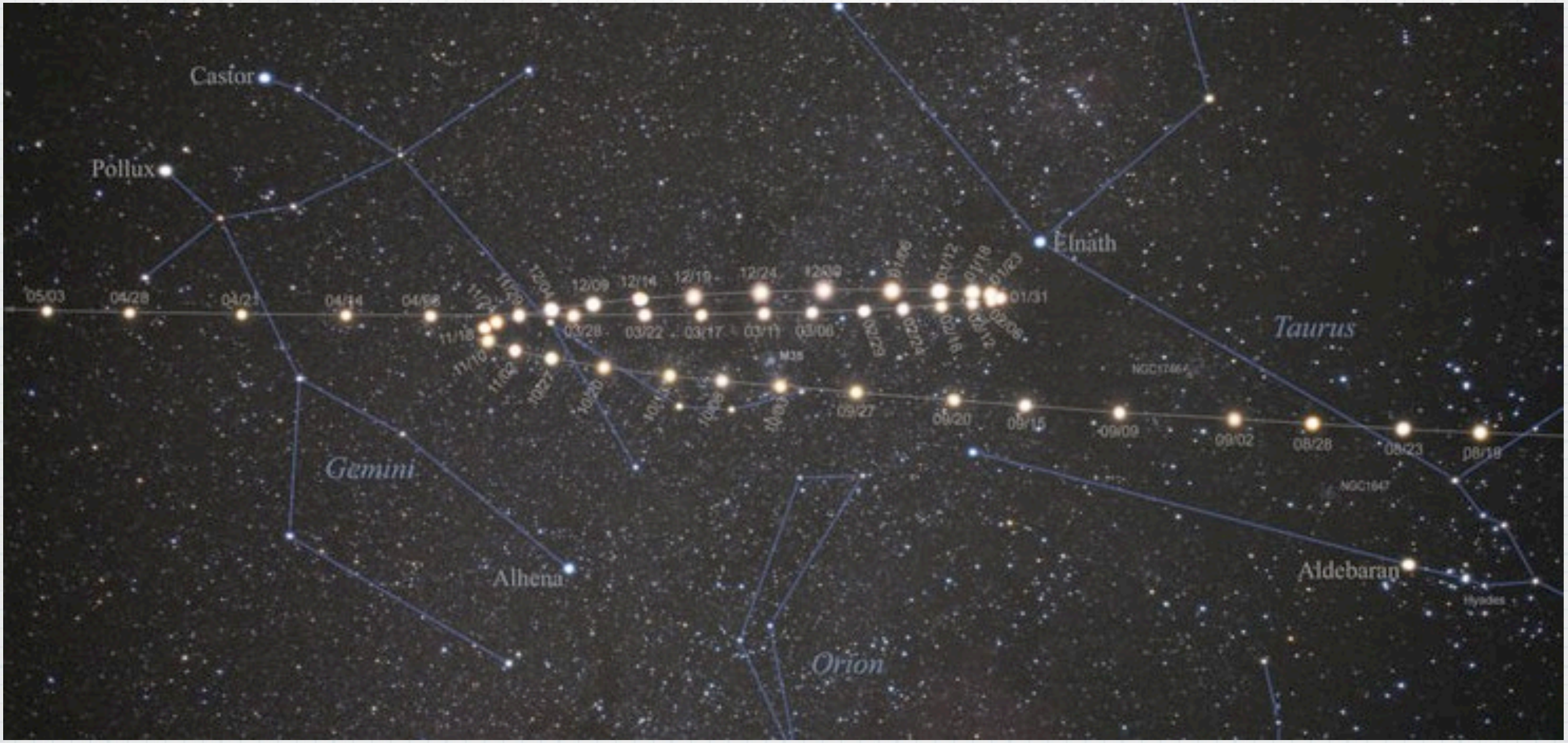
Retrograde motion explained the right way



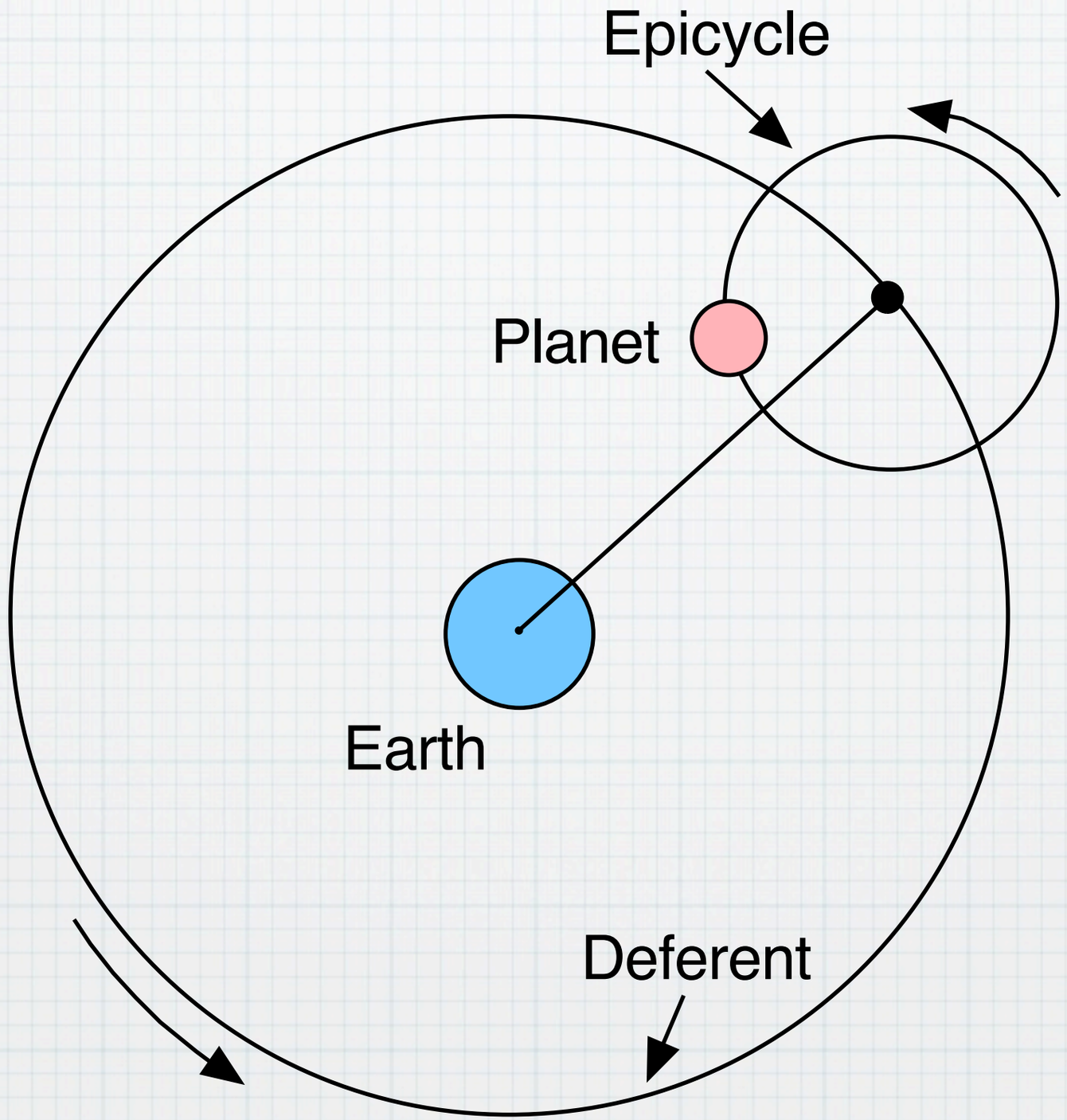


We see apparent retrograde motion when the Earth passes by a planet in its orbit

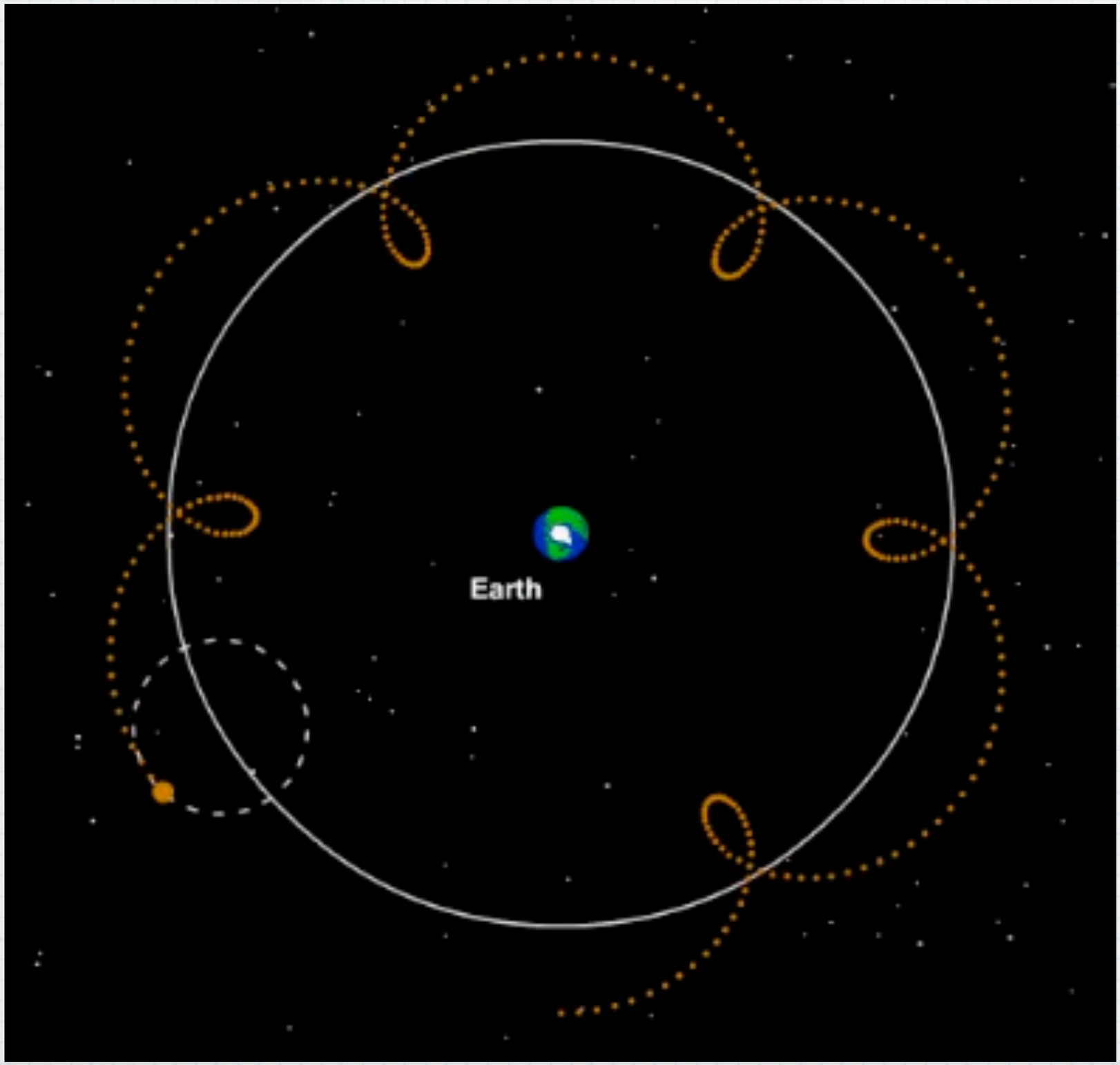
Planetary retrograde motion



Early Greek model (Ptolemy)



This model explains retrograde motion via a deferent and an epicycle



It is not a simple model:
it does not explain why the (yellow) planet orbits around a non-existent object while orbiting the Earth at the same time

Knowledge Transfer

* The Library of Alexandria is destroyed (391 AD?)
* Contents may have been seen as pagan
* Around 800 AD a similar library is built in Baghdad
* Muslims, Christians & Jews all work together in the "House of Wisdom", a new library
* Also had Indian and Chinese knowledge

More Knowledge Transfer

* This knowledge spreads to the Byzantine empire

* But Constantinople falls to the Turks in 1453

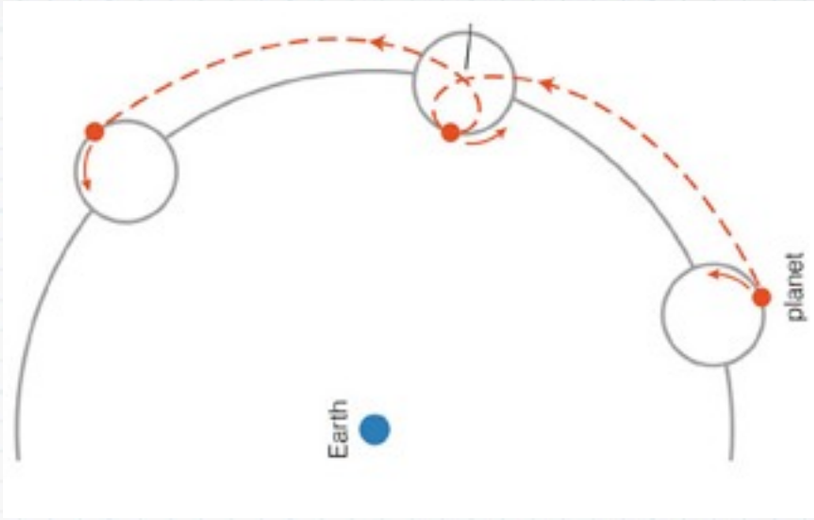
* Many scholars head west to Europe

* This knowledge sparks the Renaissance period (it helps that the printing press has just been invented by Gutenberg)

The Dark Ages

* In the meantime in Europe, non-Christian work is heresy
* The Earth is flat and at the center of the Universe
* If you question that knowledge, you are flammable material
* Back then, being curious is a curse...

Snapshot



* Why does modern science trace its roots to the Greeks?
* The Greeks developed models of nature and emphasized that the predictions of those models should agree with observations
* How did the Greeks explain planetary motion?
* The Ptolemaic model had each planet move on a small circle whose center moves around the Earth on a larger circle

Snapshot

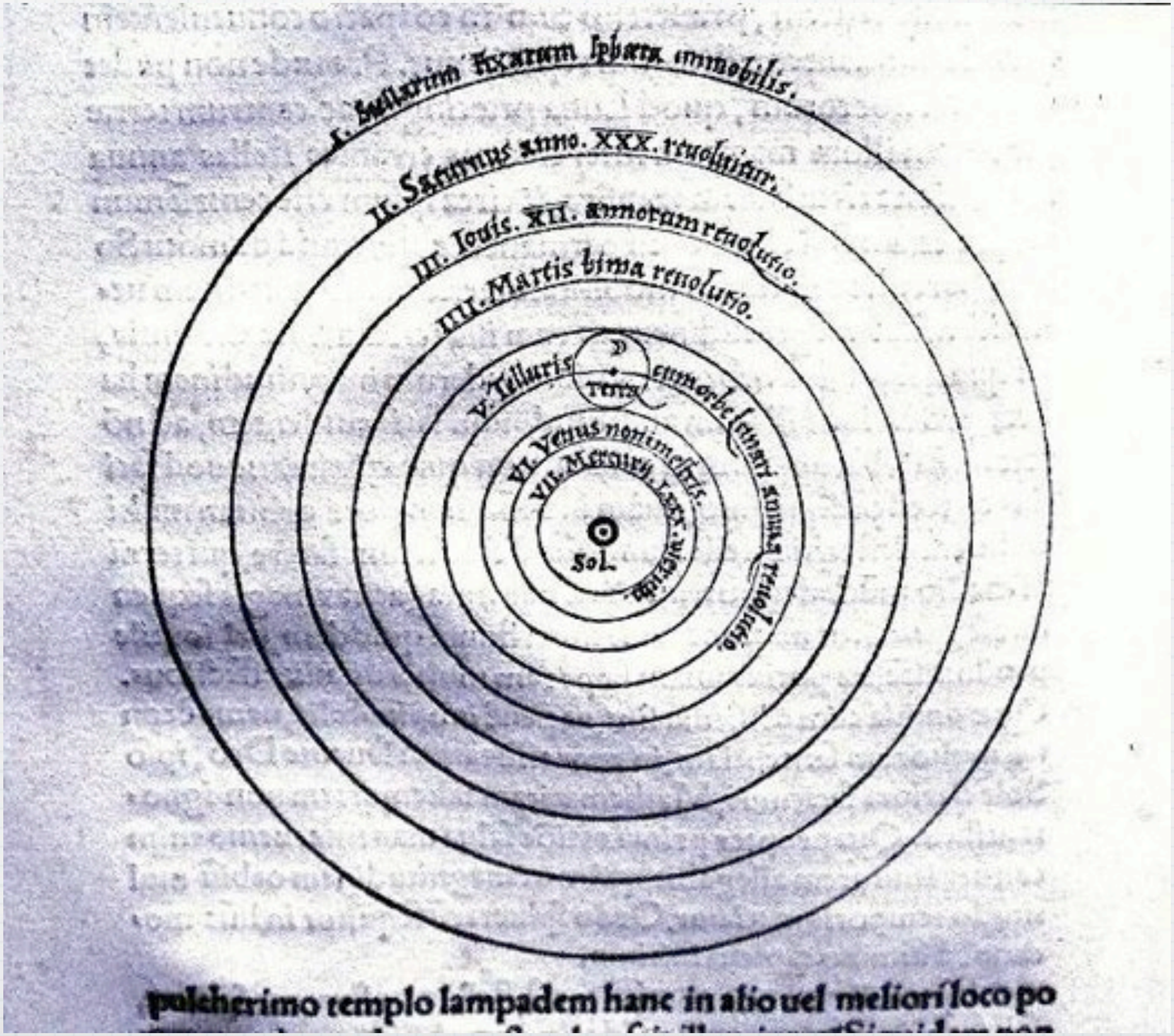
* What contributions did the Islamic scientists add to the Greek science?
* While Europe was in its Dark Ages, the Islamic scientists preserved and extended Greek science. This material later helped ignite the European Renaissance

Copernicus
(1473 - 1543)

* Polish
* Begins the work that will overturn (a century later...) the Ptolemaic model
* Adopts Aristarchus' Sun-centered idea
* Calculates each planet's orbital period around the Sun & their distance from the Sun (in AUs)
* His work is published on the day he dies

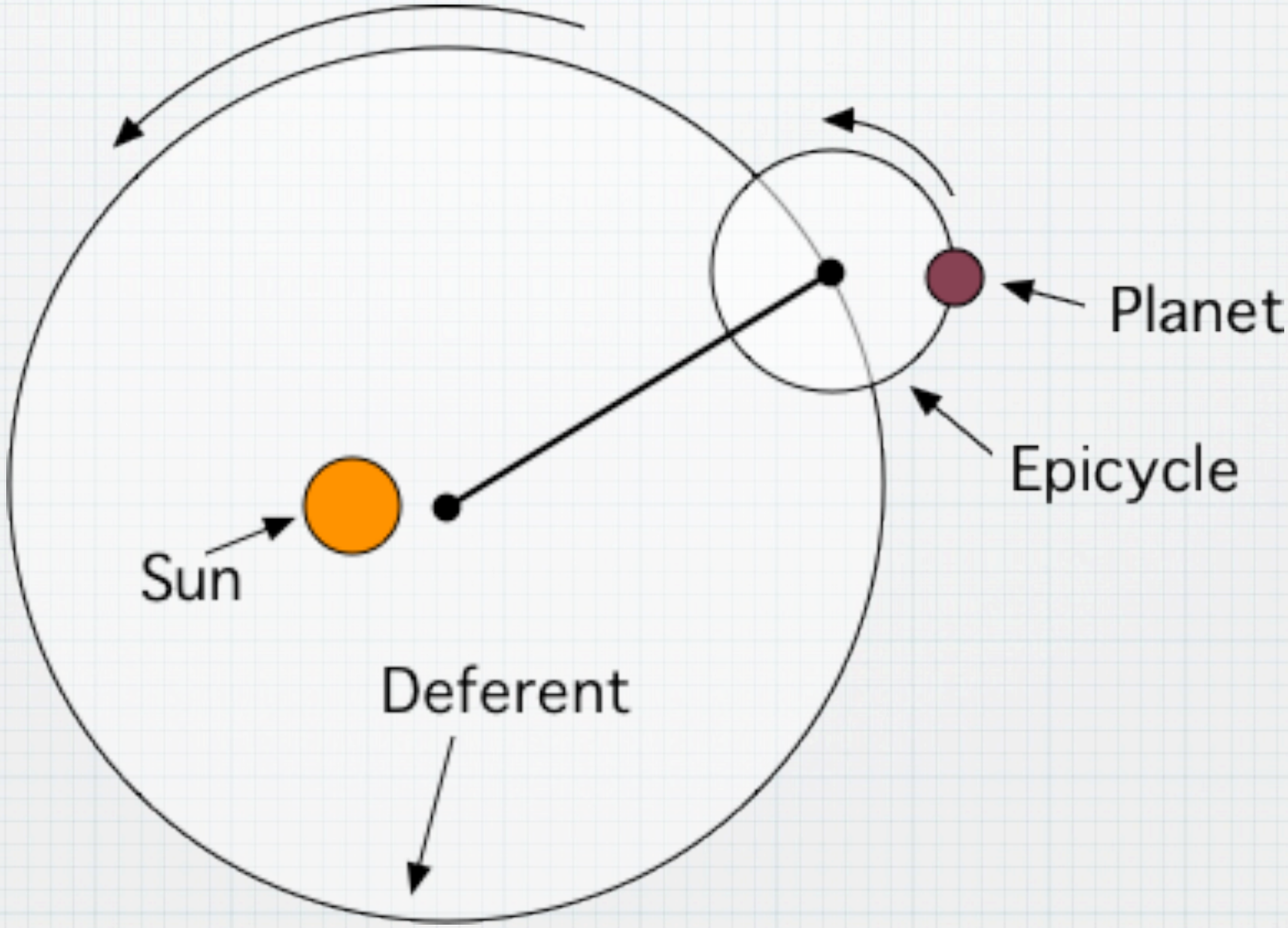
* Copernicus misses an important point: his orbits are still circulars
* His predictions are not better than the Ptolemaic system
* He still needs to add epicycles & deferents, though off-centered
* His system is as complicated as Ptolemy

Copernicus Heliocentric model

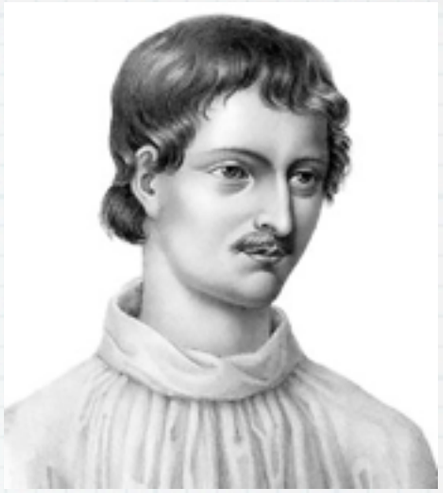


pulcherimo templo lampadem hanc in alio uel meliori loco po

Copernicus' model does not explain retrograde motion as he keeps circular orbits



Giordano Bruno
(1548 - 1600)



* He maintained that the Earth moved around the Sun, the Sun moved through the cosmos, the Universe was infinite, and the stars were suns with their own planetary systems
* He was not found of Catholic dogma -> heretic!
* He was burnt at the stake by the Inquisition

Tycho Brahe
(1546 - 1601)

* Danish
* Did not believe in Copernicus' heliocentric model
* Observed and noted the positions of planets for over 30 years
* Observes a supernova (an exploding star) in 1572
* Determines that comets are not atmospheric phenomena

Tycho Brahe's Model

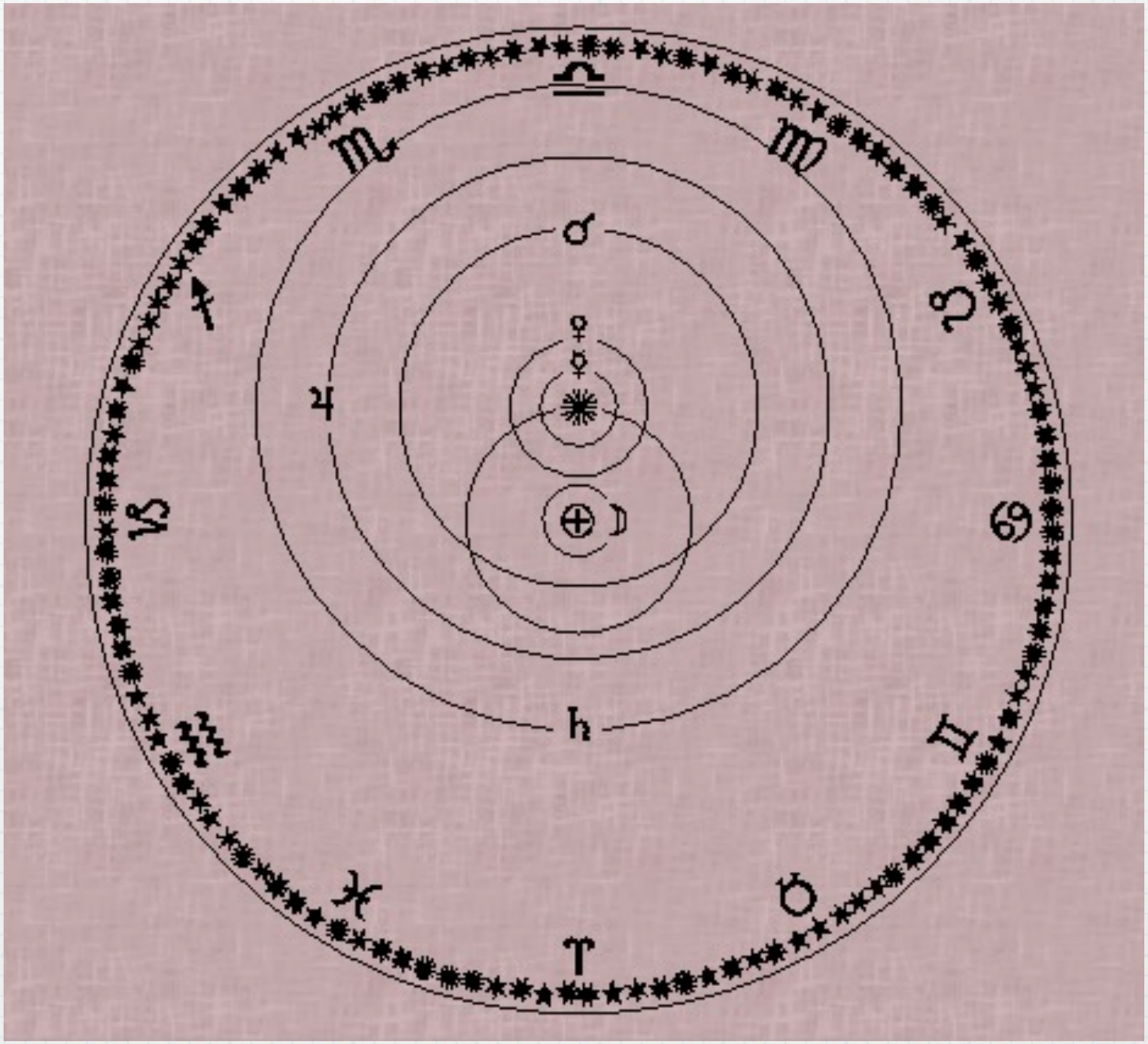
* His model has the Earth at the center (because he could not detect stellar parallax)
    * The Sun and the Moon orbits the Earth
        * The other planets orbit the Sun
* His observations are very accurate
* His assistant is Johannes Kepler
* Tycho dies of a ruptured bladder (ouch!)

Tycho Brahe's Geocentric Model

Earth at the center

Sun & Moon orbit the Earth

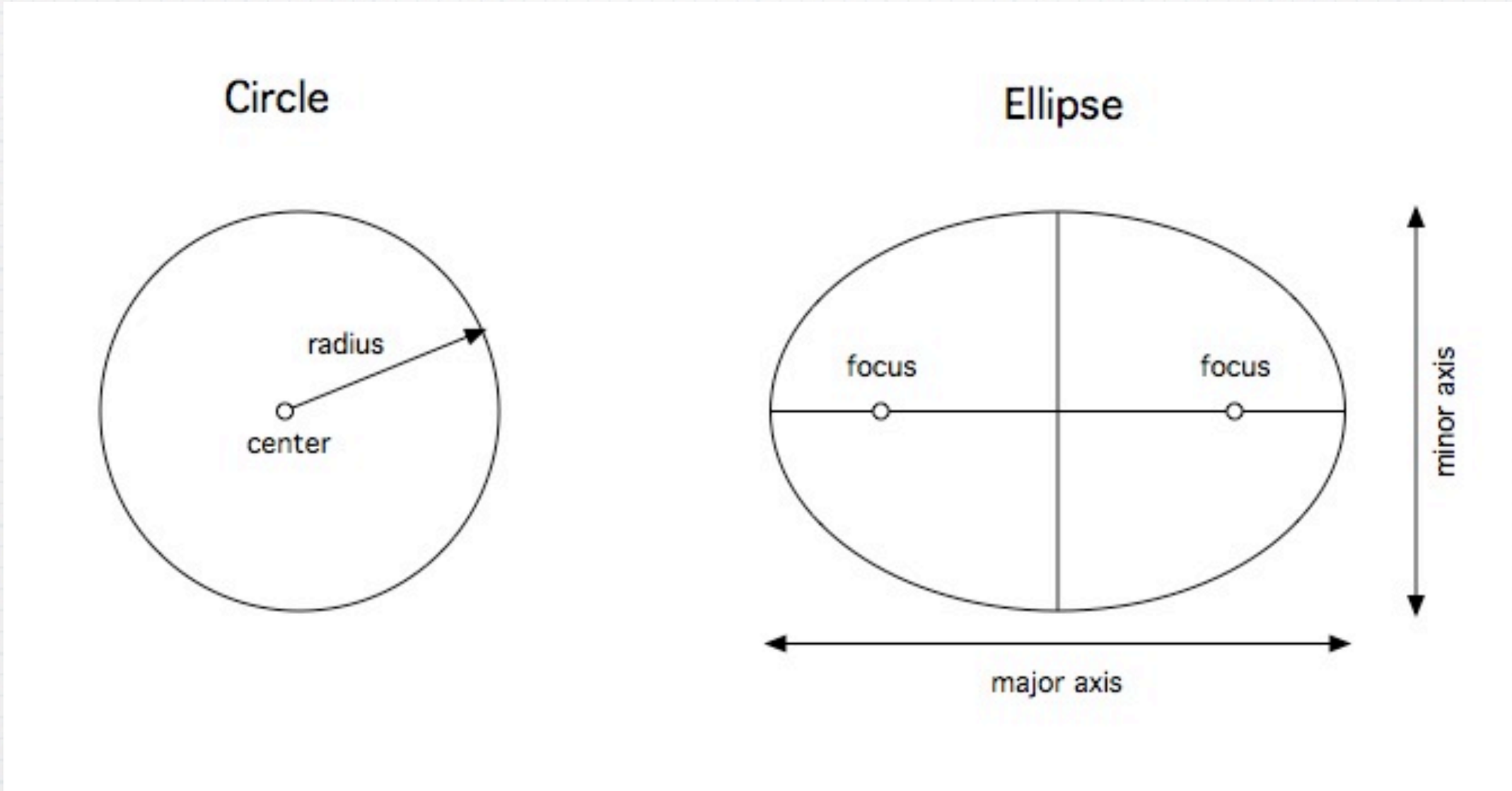
Mercury, Venus, Mars, Jupiter & Saturn orbit the Sun



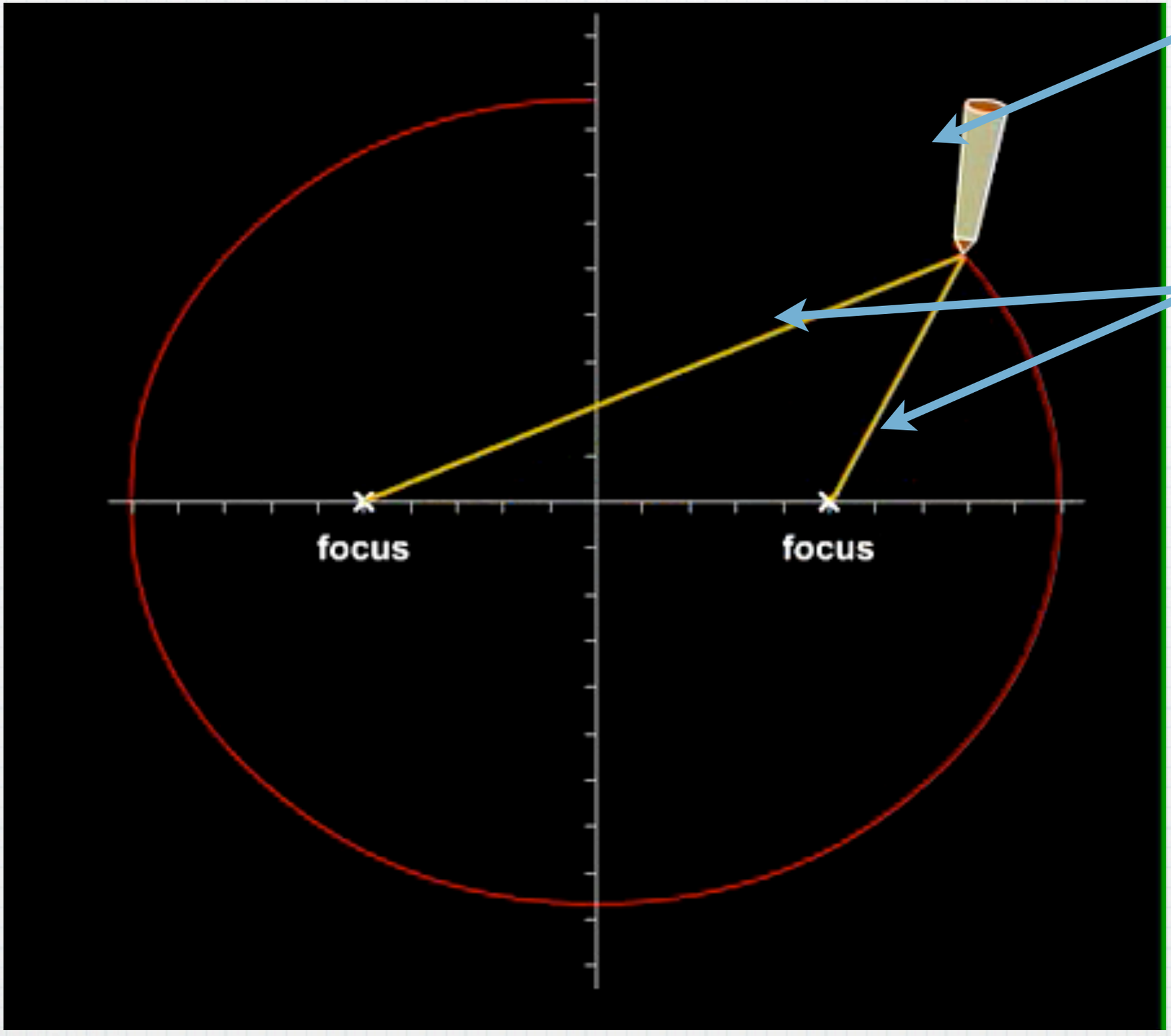
Johannes Kepler
(1571 - 1630)

* German
* Thinks the heliocentric model is correct
* Because of the precise observation data he and Tycho obtained he concluded three (empirical) planetary motion laws
* Saw a supernova (with Brahe), documented it as a star that had "changed", something that was unconceivable in those time

Circle versus Ellipse

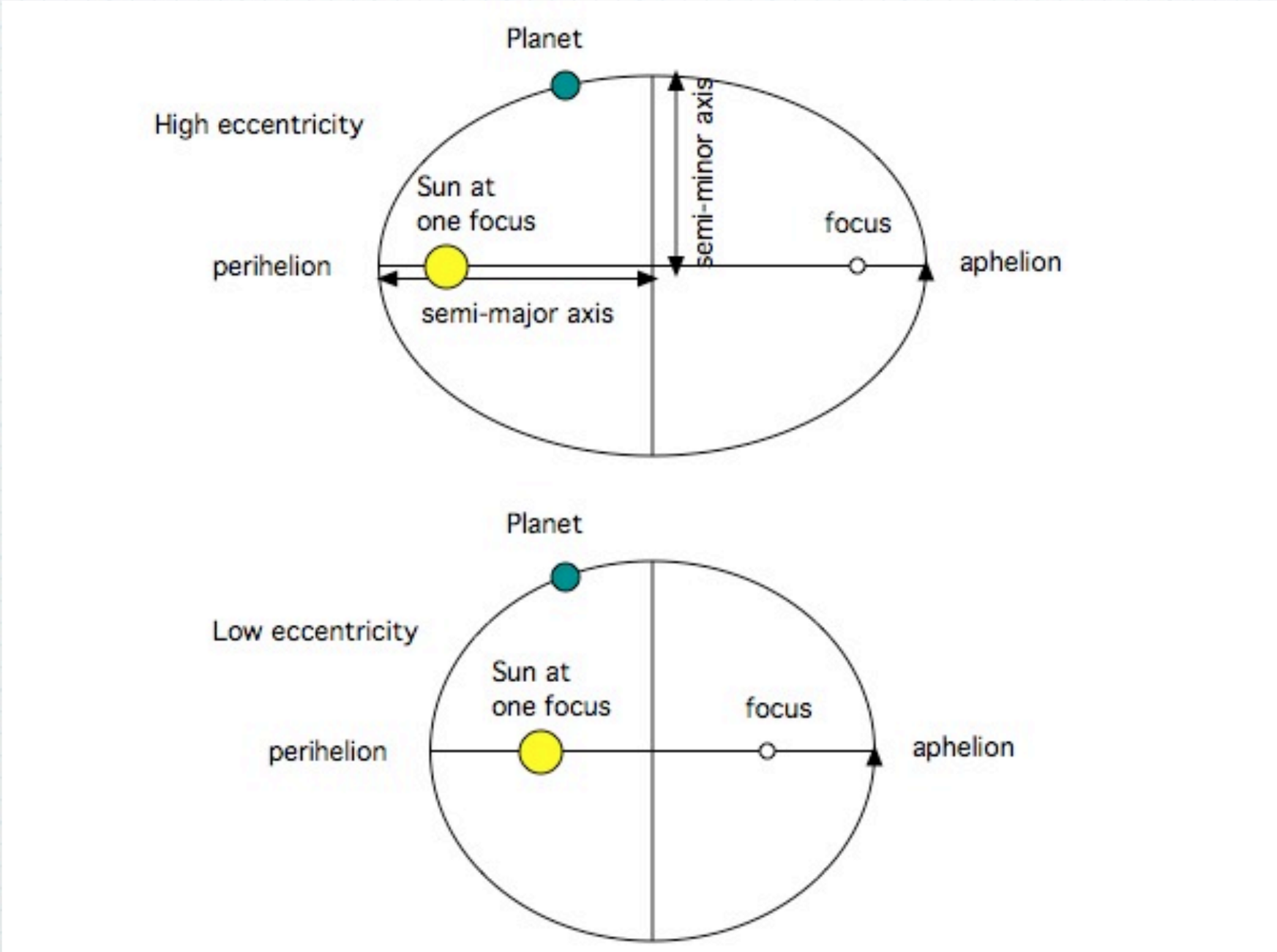


Making an Ellipse



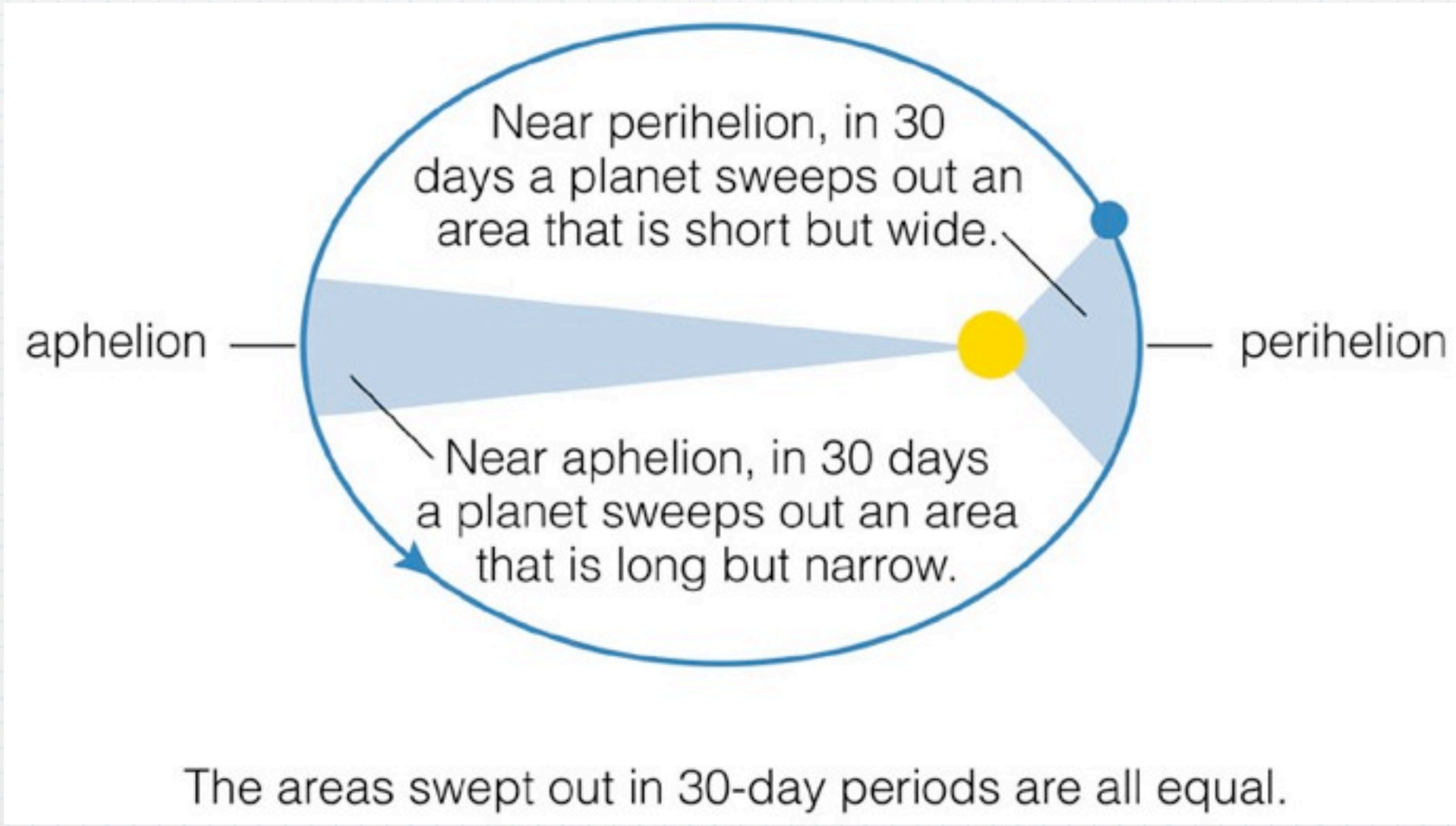
Kepler's First Law of Planetary Motion (1610)

* A planet orbits the Sun in an ellipse with the Sun located at one focus



Kepler's Second Law of Planetary Motion (1610)

* A planet orbiting the Sun sweeps out equal areas in equal times => the planet does not have a constant speed!

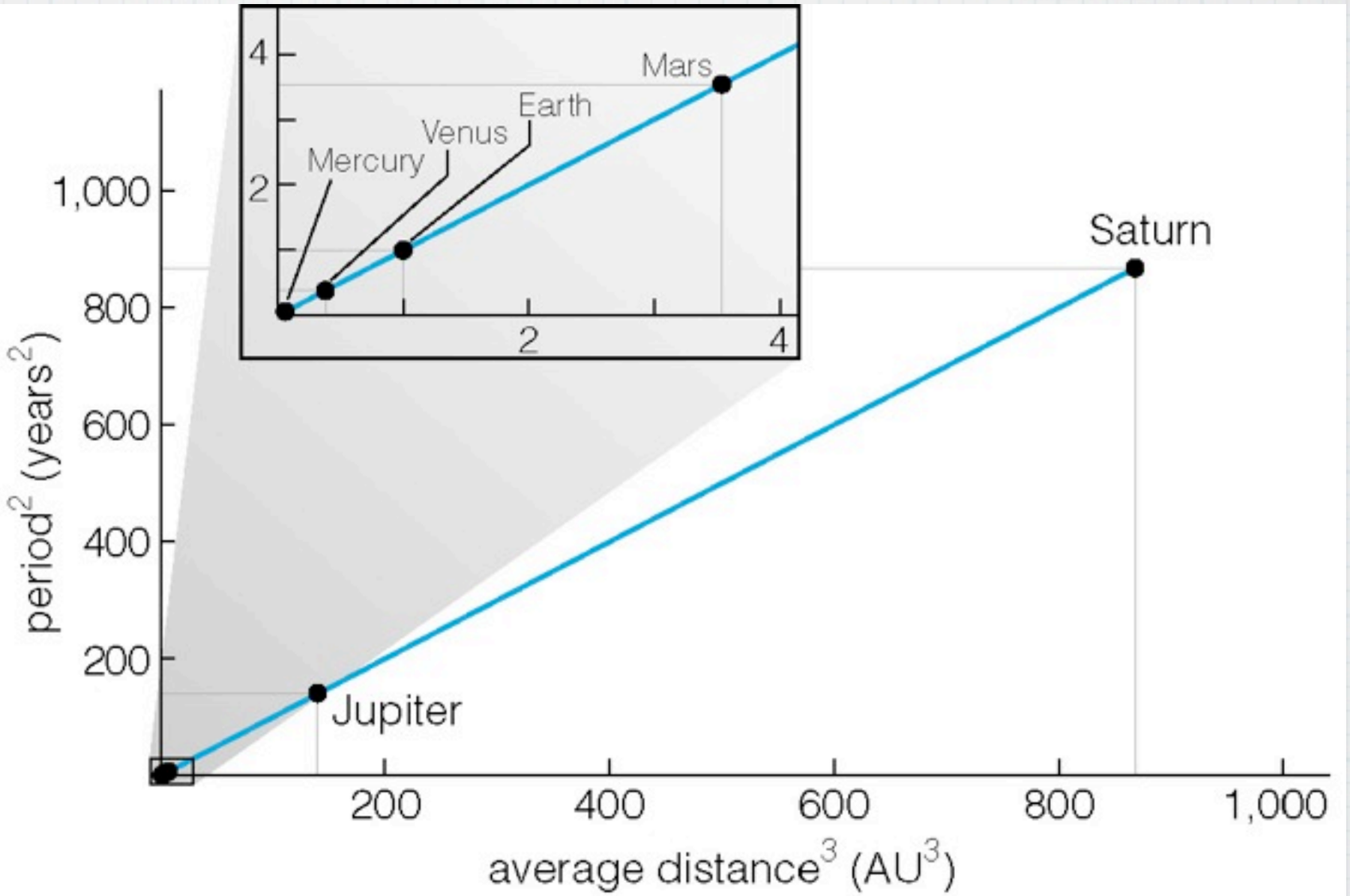


The areas swept out in 30-day periods are all equal.

Kepler's Third Law of Planetary Motion (1618)

* The square of a planet's orbital period (in years) is equal to the cube of its average distance from the Sun (in AUs)
* More distant planets orbit the Sun with slower average speeds, obeying this relationship:
* $p^2 = a^3$
  * For instance, Mars' orbital period is 1.88 Earth years, so $a = p^{2/3} = 1.88^{2/3} = 1.52$ AU
* Mars' average distance to the Sun is 1.52 AU

Graphical representation of Kepler's Third Law



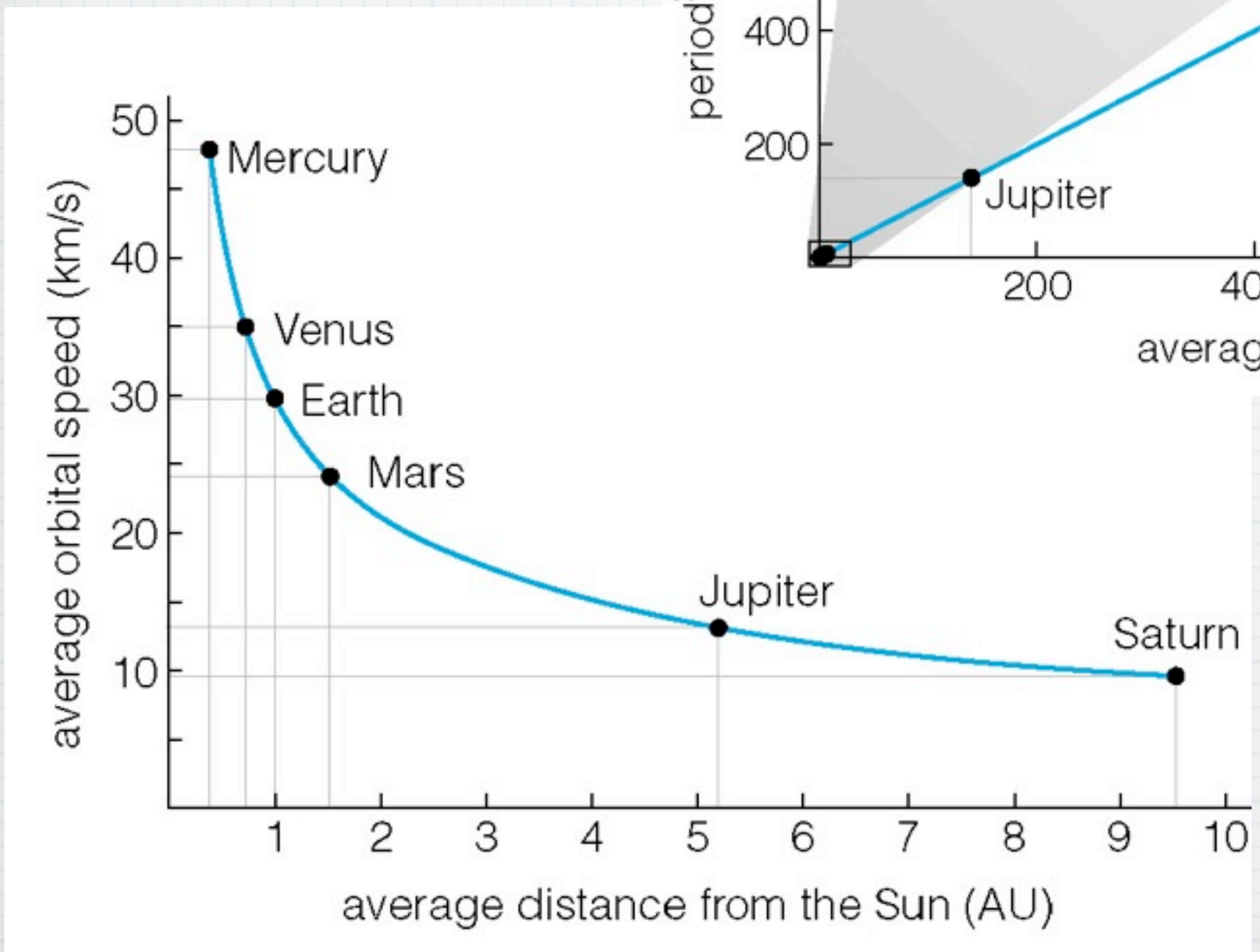
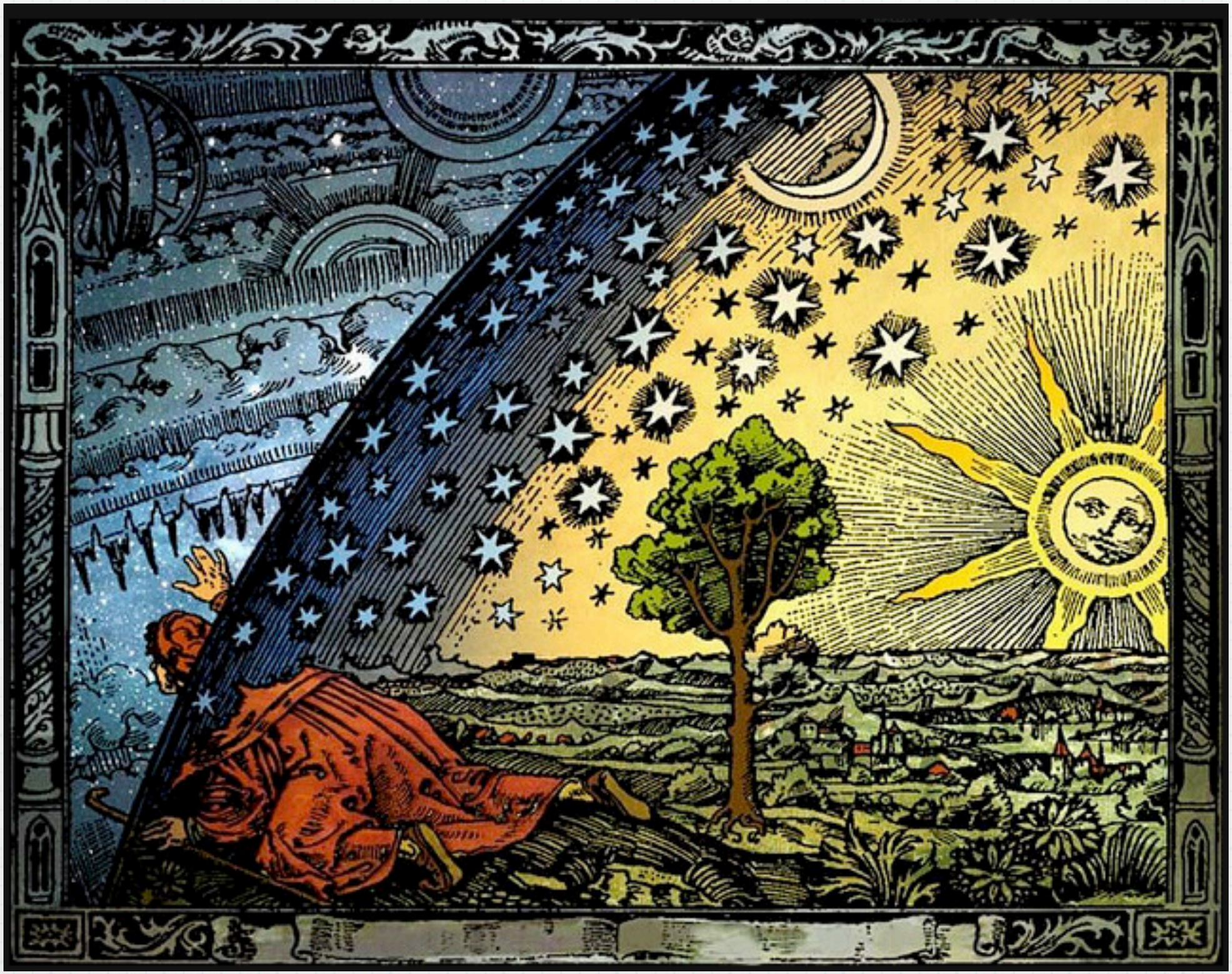


Illustration from Camille Flammarion



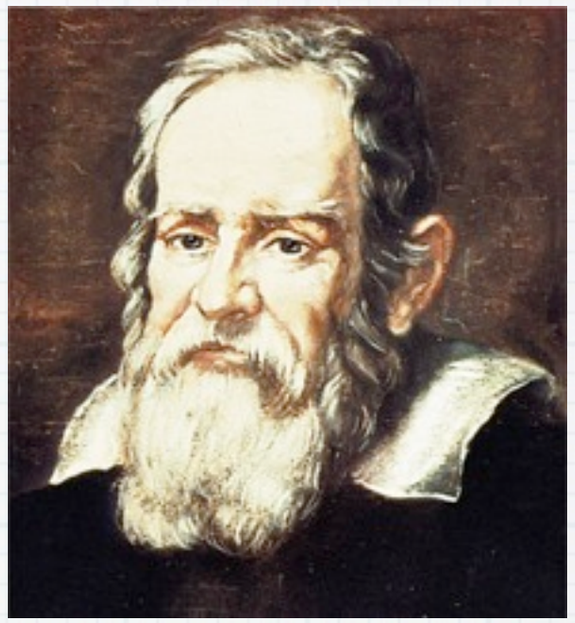
More on Kepler:

* known as the father of celestial mechanics
* first to state modern "natural laws", or "empirical laws"

➡ universal, verifiable, precise

* first to explain how a telescope works
* first to explain that the Moon causes the tides
* first to suggest that the Sun spins on its axis
* and much more firsts in the world of optics

Galileo Galilei
(1564 - 1642)



* Italian
* Lived too close to the Vatican...
* First to use a telescope as a scientific instrument, which he re-invents (1608)
* As a physicist, he overturned the Aristotelian interpretations of the world

* Three key objections rooted in Aristotelian views were:
  * Earth could not be moving else objects in air (not to mention the atmosphere itself!) would be left behind
  * Non-circular orbits are not "perfect", hence they do not belong in the Heavens
  * If Earth were orbiting the Sun, we would detect parallax

* Aristotle claimed that any object in motion will come to rest naturally
* Galileo's experiments demonstrated that a moving object remains in uniform motion unless a force acts on it
* He discovered that free falling bodies (heavy or light) have the same constant acceleration

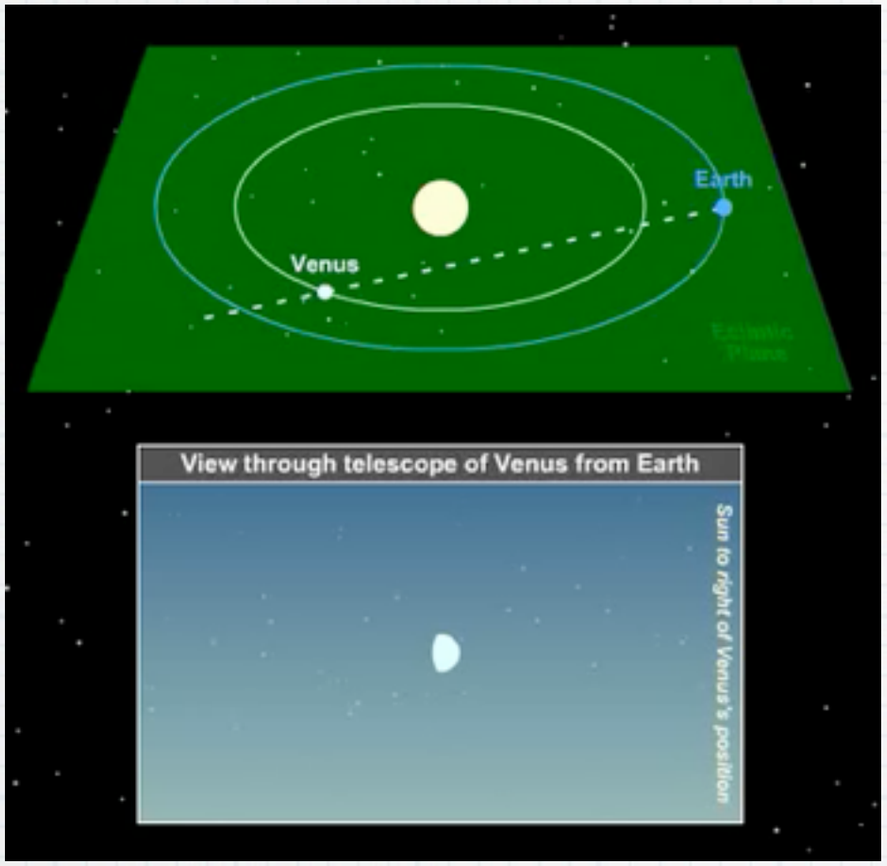
Hammer & Feather drop on the Moon

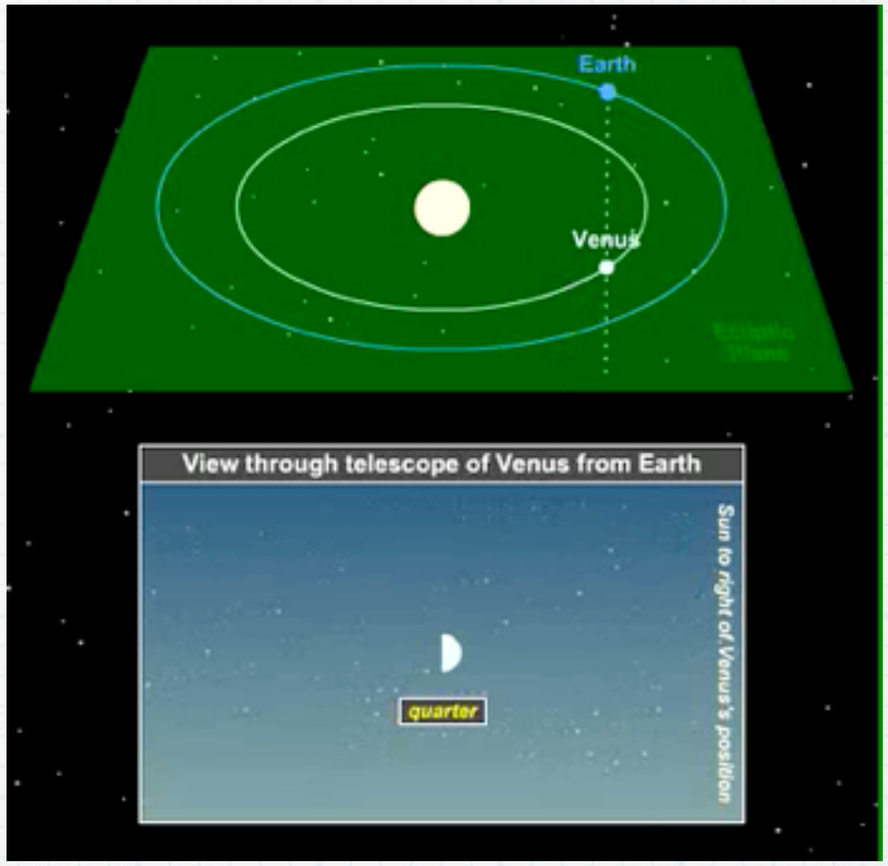
Hammer & Feather drop on the Moon

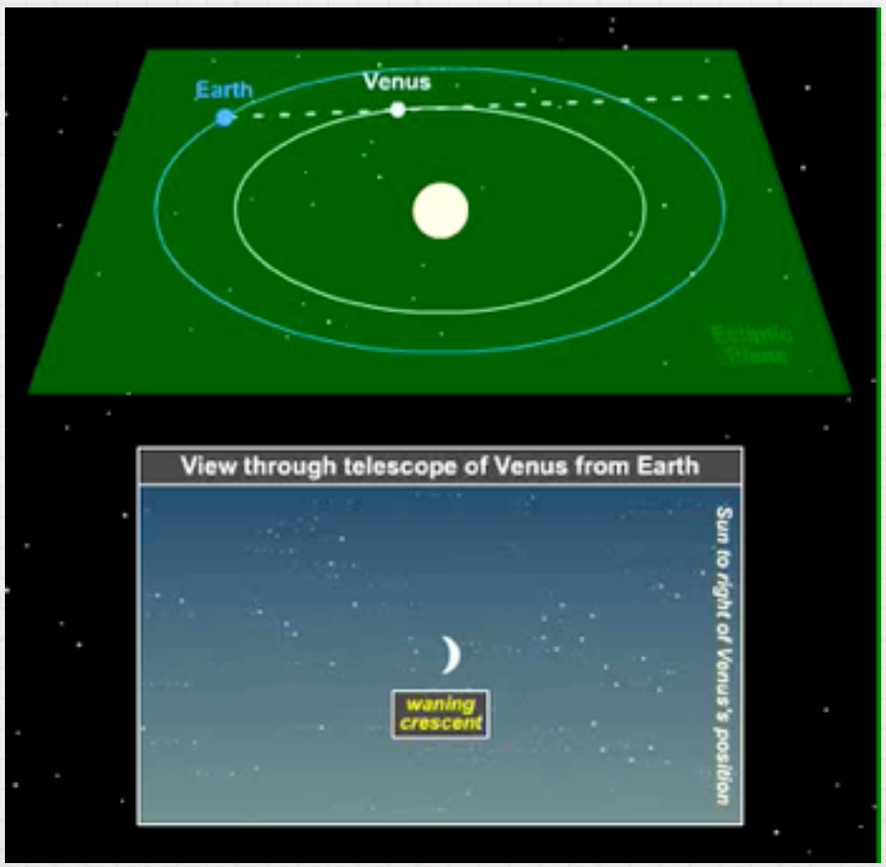
* By observing Venus with a telescope, Galileo saw that **Venus went through phases just like the Moon**
* **Since Venus went through full phases, it meant it orbited the Sun directly** and did not orbit the Earth on a deferent/epicycle model
* He saw points of lights orbiting **Jupiter** and reasoned they were **satellites**. The Earth was not special after all in this regard

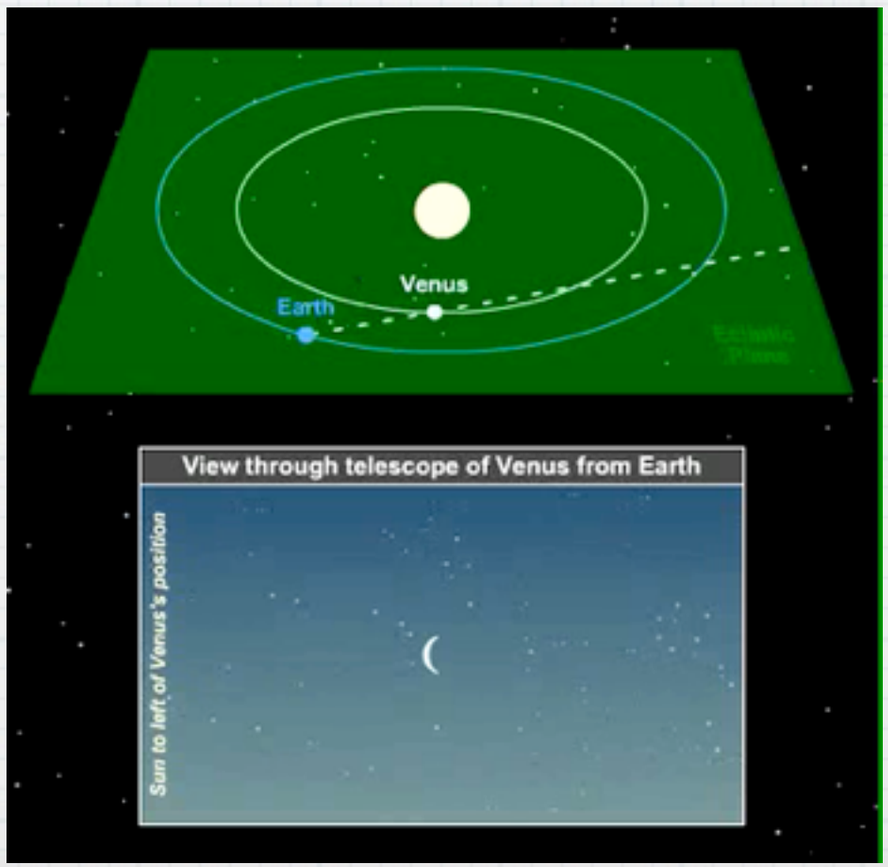
Galileo drawing of Jupiter and its satellites

The Phases of Venus seen from Earth





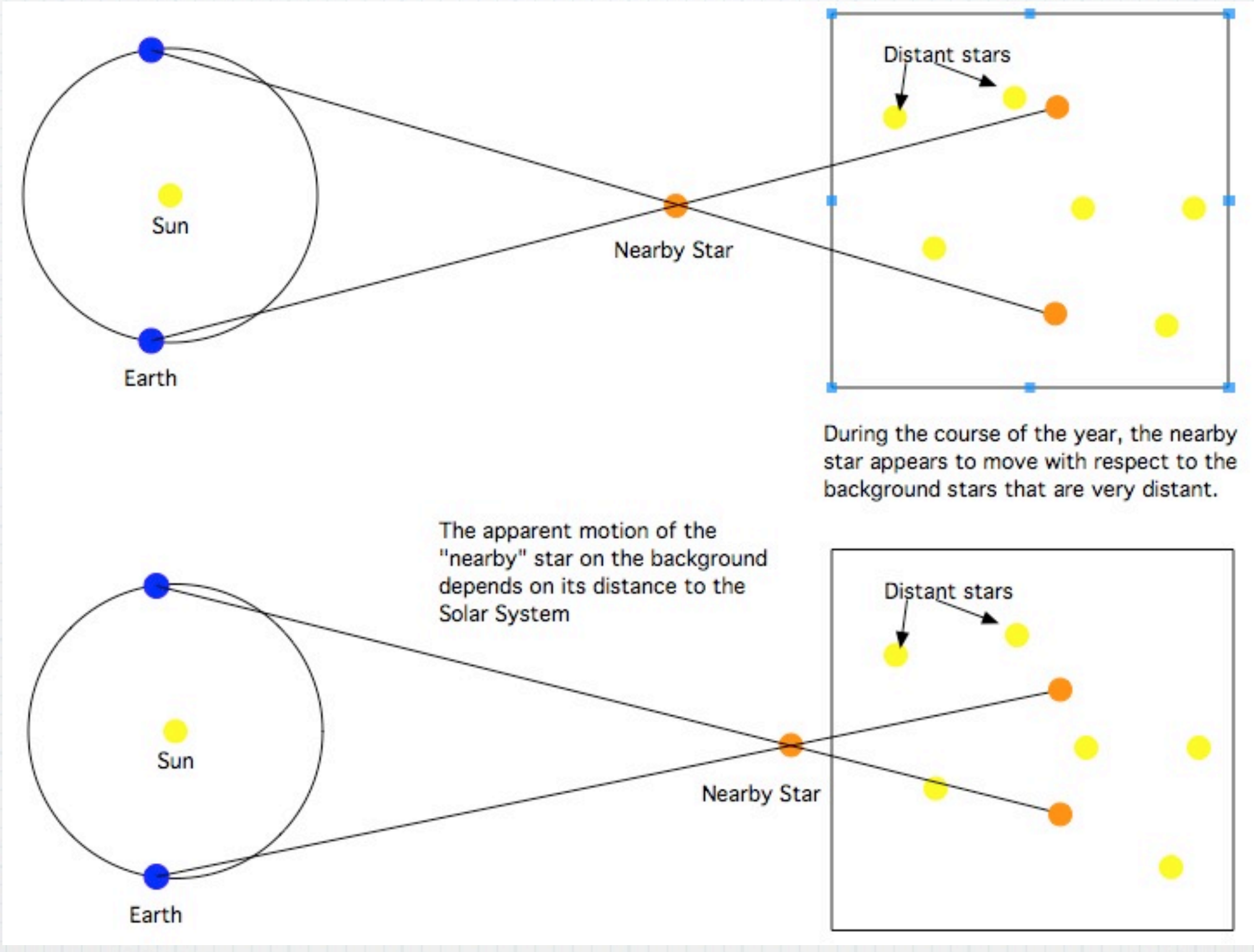




* With his telescope he saw mountains and valleys on the Moon
* He saw spots on the surface of the Sun (imperfections! And they were moving)
* The Heavens were not perfect! And they could change! (The Church had problems with this view...)
* So non-circular orbits were not objectionable after all...

* Galileo also provided strong evidence that the stars were very distant. He saw that the "milky" substance in the sky was composed of innumerable stars that seemed much more distant that the ones that could be seen individually with the naked eye
* Hence the non-detectable stellar parallax was due to those huge distances
* Stellar parallax was eventually observed in 1838 by Friedrich Bessel, a German mathematician and astronomer

Stellar Parallax



The Church and Galileo

* The Church was not happy with Galileo
  * It saw its influence challenged
  * It saw its knowledge compromised
  * It saw itself ridiculed
* At the same time, knowledge was no longer tightly controlled - thanks to Gutenberg's invention of the printing press, nearly 150 years before

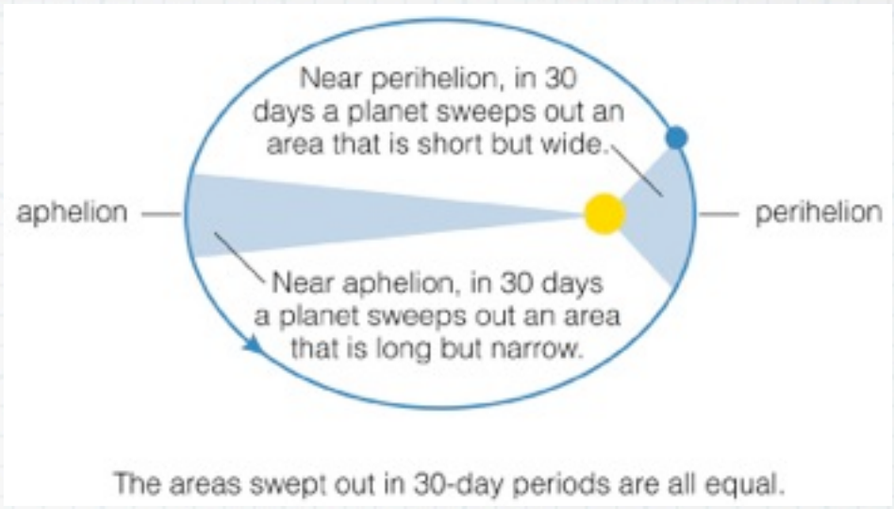
When to hold them and when to fold them...

* An inquisition sent after Galileo made him recant his claims that the Universe was heliocentric in 1633
  * He was in house arrest until the day he died, 9 years later
  * In 1992, the Catholic church apologized about this mis-treatment and Dec. 21, 2008, it (finally) paid tribute to Galileo
  * The Catholic church as yet to apologize for the burning of Giordano Bruno (a sad episode, they said)

Snapshot

* How did Copernicus, Tycho and Kepler challenge the Earth-centered idea?
* Copernicus created a sun-centered model
* Tycho provided the data needed to improve this model
* Kepler found a model that fit Tycho's data

Snapshot

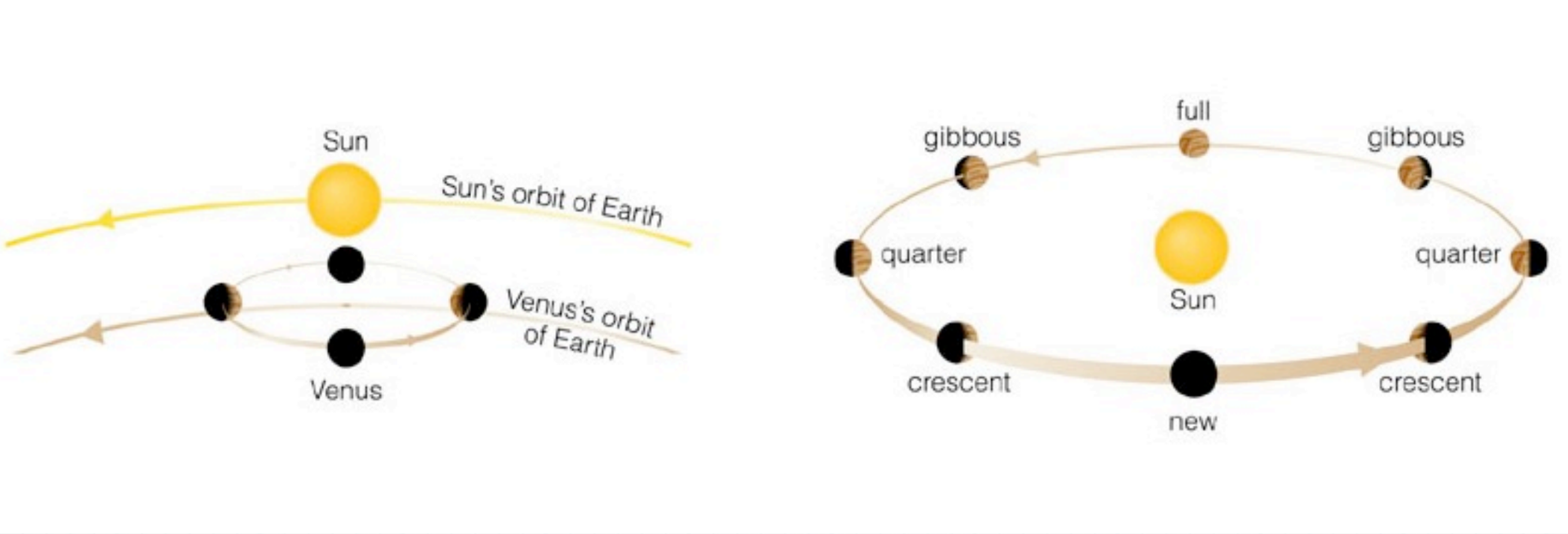


The areas swept out in 30-day periods are all equal.

What are Kepler's three laws of planetary motion?

1. The orbit of each planet is an ellipse with the Sun at one focus
2. As a planet moves around its orbit, it sweeps out equal areas in equal times
3. More distant planets orbit the Sun at slower speeds according to $p^2 = a^3$

Snapshot



- What was Galileo's role in the Copernican revolution?
- His experiments and observations overcame the remaining objections to the Sun-centered solar system

What is Science?

Some definitions:

* A process for evaluating empirical knowledge
* A branch of knowledge based on objectivity and involving observation and experimentation
* Systematically acquired knowledge that is derived from observed results of repeated experimentations which can be verified by others

What is Science?...

* Branches of study relating to the phenomena of the physical universe and its laws
* A connected body of demonstrated truths with observed facts systematically classified under general laws
* The study of relative, modified Principles which can be proven through physical measurements and through physical senses

How do we go from beliefs to physical laws?

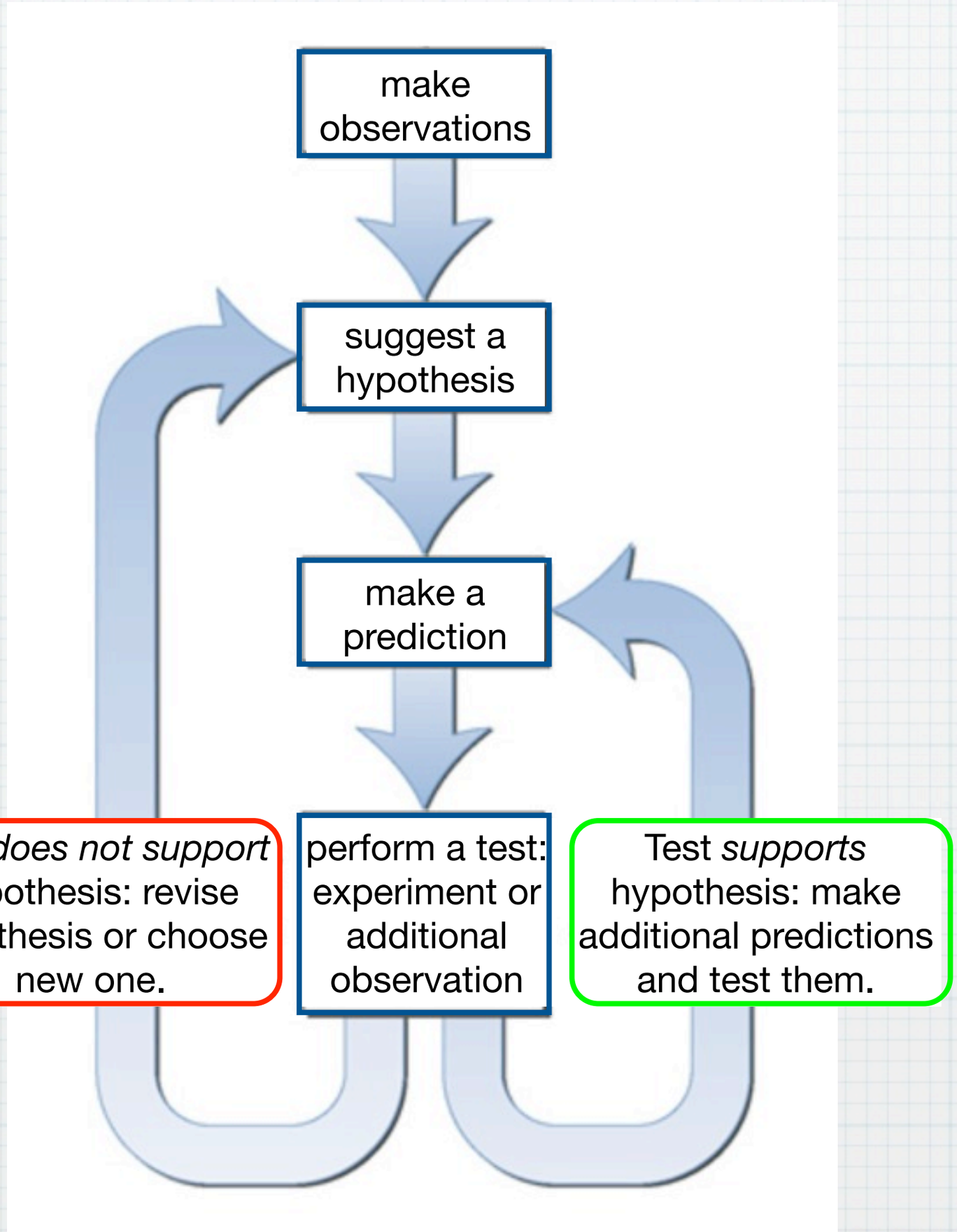
* By applying logical reasoning on acquired knowledge
  * Question Everything:
    * How do we know what we know?
  * Take nothing for granted
  * Common sense is uncommon
  * Simplicity is Key (Occam's razor)
    * Complexity is inefficient

Do Scientists "believe"?

* Wrong question
* Scientists do not believe in this or that theory. It is not a matter of faith in Sciences
* Scientists have **confidence** that the accepted theories represent, or model, "reality" within the accuracy of our instruments

The Four Steps of the Scientific Method

1. **Observation** and description of a phenomenon
2. **Formulation** of an hypothesis to explain the phenomenon
3. **Prediction**: Use of the hypothesis to predict the existence of other phenomena or to predict quantitatively the results of new observations
4. **Repeatability**: properly performed experimental tests of the predictions by several independent experimenters


make observations
suggest a hypothesis
make a prediction
perform a test: experiment or additional observation
Test *does not support* hypothesis: revise hypothesis or choose new one.
Test *supports* hypothesis: make additional predictions and test them.

Testing the hypothesis

* Experiment and repeatability are supreme
* Rule out or modify if predictions fail to match the experiment
* Account for experimental errors
  * set-up, measurements, sensitivity, noise
  * and ... experimenter's personal biases

Definitions

* **An hypothesis** is a limited statement regarding cause and effect in specific situations
* **A model** is a situation where the hypothesis has validity
* **A scientific theory** or law represents a set of hypotheses which have been confirmed via repeated experimental tests

Meaning of "Theory"

* The word "theory" has a different meaning in the common public
* It usually means a speculation
* However gravity is a theory too
  * But will you test it by walking off a roof?
* In Science, "theory" is a reserved word

Meaning of "Theory"

* Newton's theory of gravity, Darwin's theory of evolution & Einstein's theories of relativity (simple & general)
* They are not speculations, they are not suppositions, they are not choices
* They are objective reasoned conclusions and represent the way Nature work in specified environments

Snapshot

What are the hallmarks of Science?

1. Modern science seeks explanations for observed phenomena that rely solely on natural causes

2. Science progresses through the creation and testing of models of nature that explain the observations as simply as possible

3. A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations

Snapshot What is a scientific theory?

* The word theory has a different meaning in science than in everyday life
* In science, a theory is NOT the same as a hypothesis, rather:
* A scientific theory must:
  * Explain a wide variety of observations with a few simple principles, AND
  * Must be supported by a large, compelling body of evidence, AND
  * Must NOT have failed any crucial test of its validity

Snapshot

* How can we distinguish science from non-science?

➡ Science: seeks explanations that rely solely on natural causes; progresses through the creation and testing of models of nature; models must make testable predictions

* What is a scientific theory?

➡ A model that explains a wide variety of observations in terms of a few general principles and that has survived repeated and varied testing

Mathematics

* It is a language, based on abstraction, agreed-on conventions and logical reasoning
* Mathematics are used to express scientific models with extreme precision
* Mathematics is our language of choice to explain Nature
* It is both an invented and discovered language
* Theorems are human logical thoughts

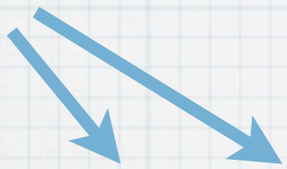
+ a simple operation?

+ and = means "in specific conditions"

operators

+ means "and"

= means "observe"



* 2 + 1 = 3

these pure numbers do not impact each others

* 2 atoms of H + 1 atom of O = 1 molecule of water, not 3 atoms these atoms affect each others

* a + b = b + a (is this always the case?)

* 1 left turn (LT) + 1 right turn (RT) ≠ 1 RT + 1 LT

13 Must See Stargazing Events in 2013

1) January 21 — Very Close Moon/Jupiter Conjunction
2) February 2-23 — Best Evening View of Mercury
3) March 10-24 — Comet PANSTARRS at its best
4) April 25 — Partial Lunar Eclipse
5) May 9 — Annular Eclipse of the Sun ("Ring of Fire" Eclipse)
6) May 24-30 — Dance of the Planets
7) June 23 — Biggest Full Moon of 2013
8) August 12 — Perseid Meteor Shower
9) October 18 — Penumbral Eclipse of the Moon
10) November 3 — Hybrid Eclipse of the Sun
11) Mid-November through December — Comet ISON
12) All of December — Dazzling Venus
13) December 13-14 — Geminid Meteor Shower

More Stuff to Access

* http://www.youtube.com/watch?v=KDEmtWLwMOM
* http://www.youtube.com/watch?v=ev9oPUNaqXE

* http://space.jpl.nasa.gov/
* And because I care:
  * https://www.facebook.com/video/embed?video_id=10150090284287761