Today's Topics
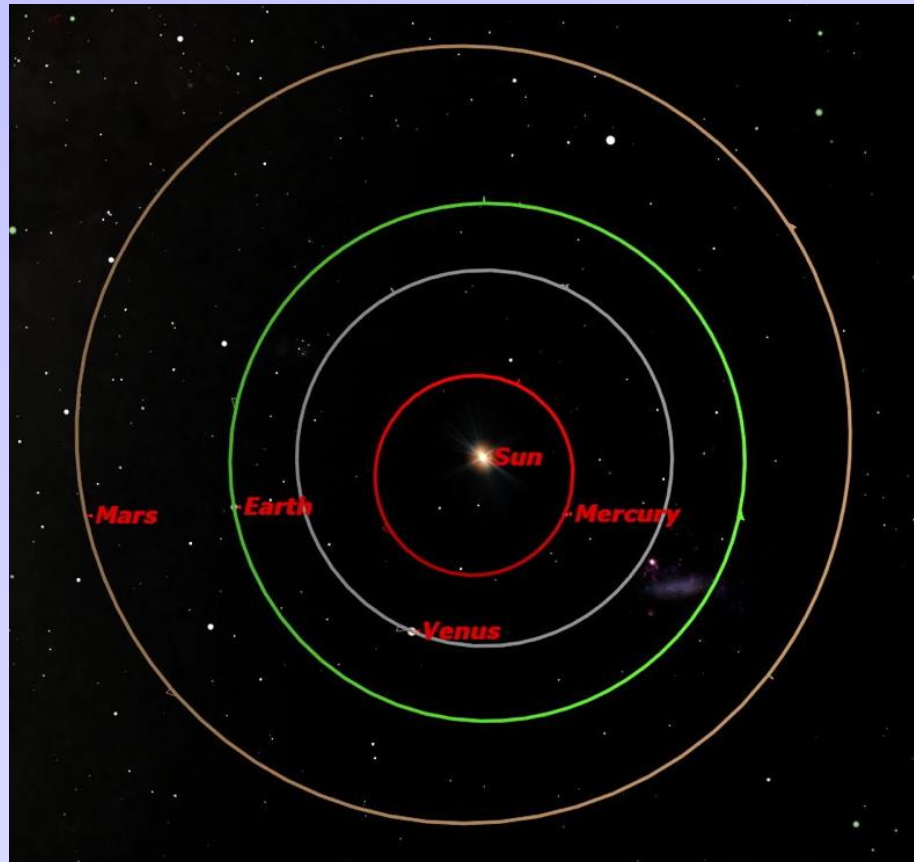
Monday, August 24, 2020 (Week 1, lecture 3) – Chapters 2 & 3.

A. Orbits & retrograde motion of planets

B. Earth's axis tilt, seasons, precession

C. Stellar parallax

D. Kepler's laws

Planetary Orbit Basics

➢ The planets orbit the Sun following roughly "circular path."

➢ These "circular paths" are actually somewhat elliptical.

➢ The orbits all lie in more or less the same plane.

Inner Solar System planetary orbits

Retrograde Motion of Mars

➤ If you map out the motion of the planet Mars against the background stars (celestial sphere), it follows a "line."

➤ But, <u>roughly every 2 years</u> Mars appears to go **backwards**.

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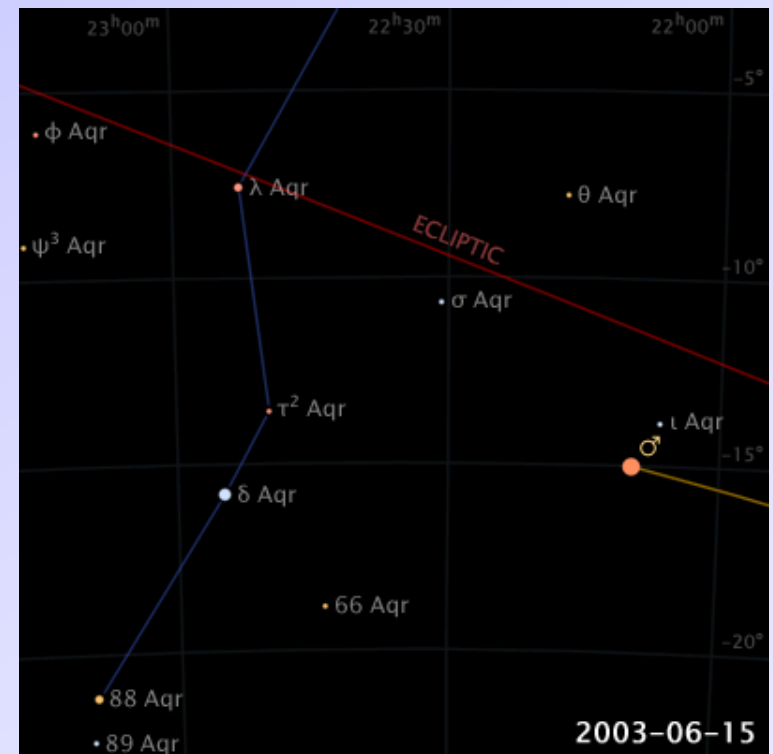➢ But, <u>roughly every 2 years</u> Mars appears to go **backwards**.
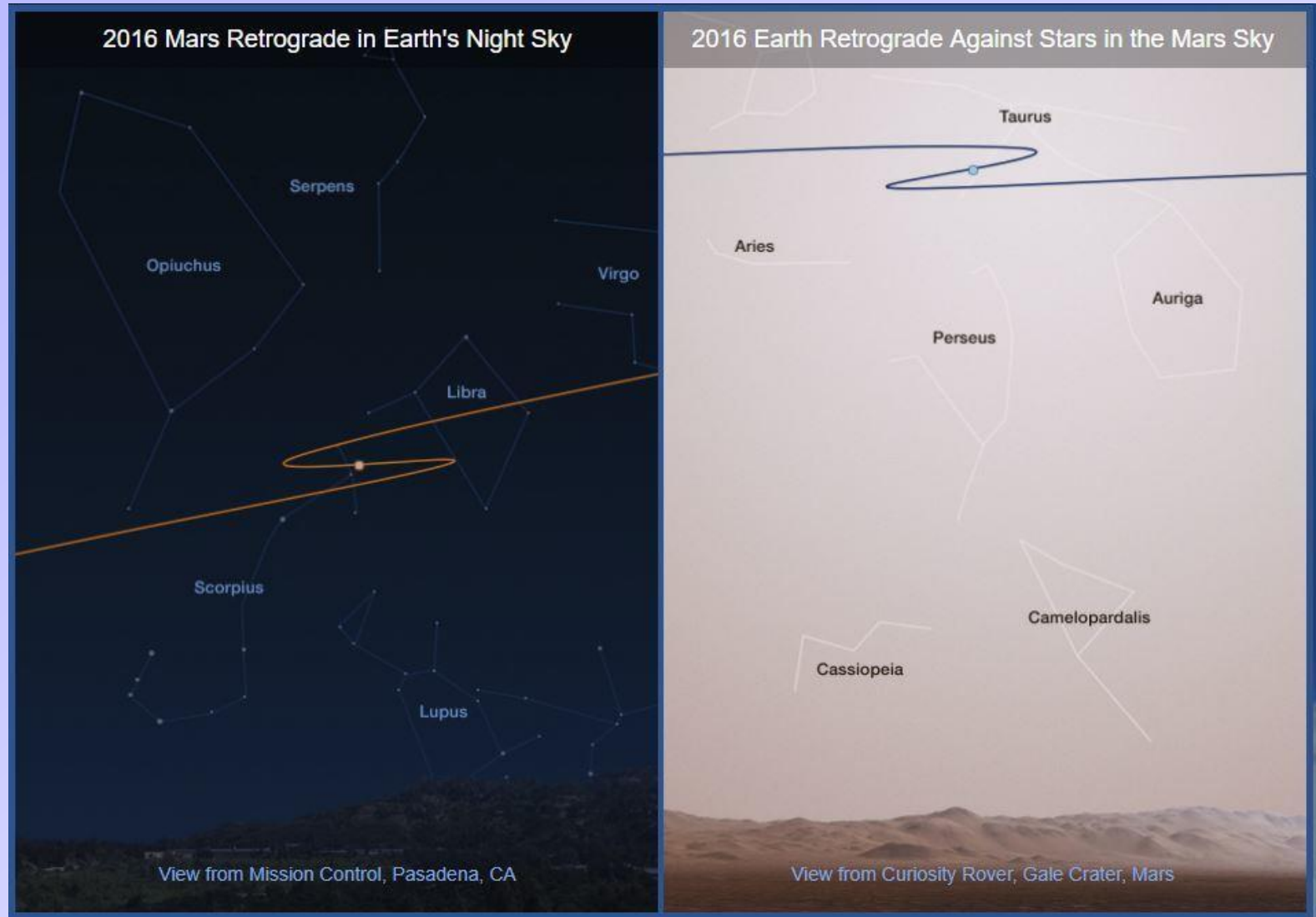
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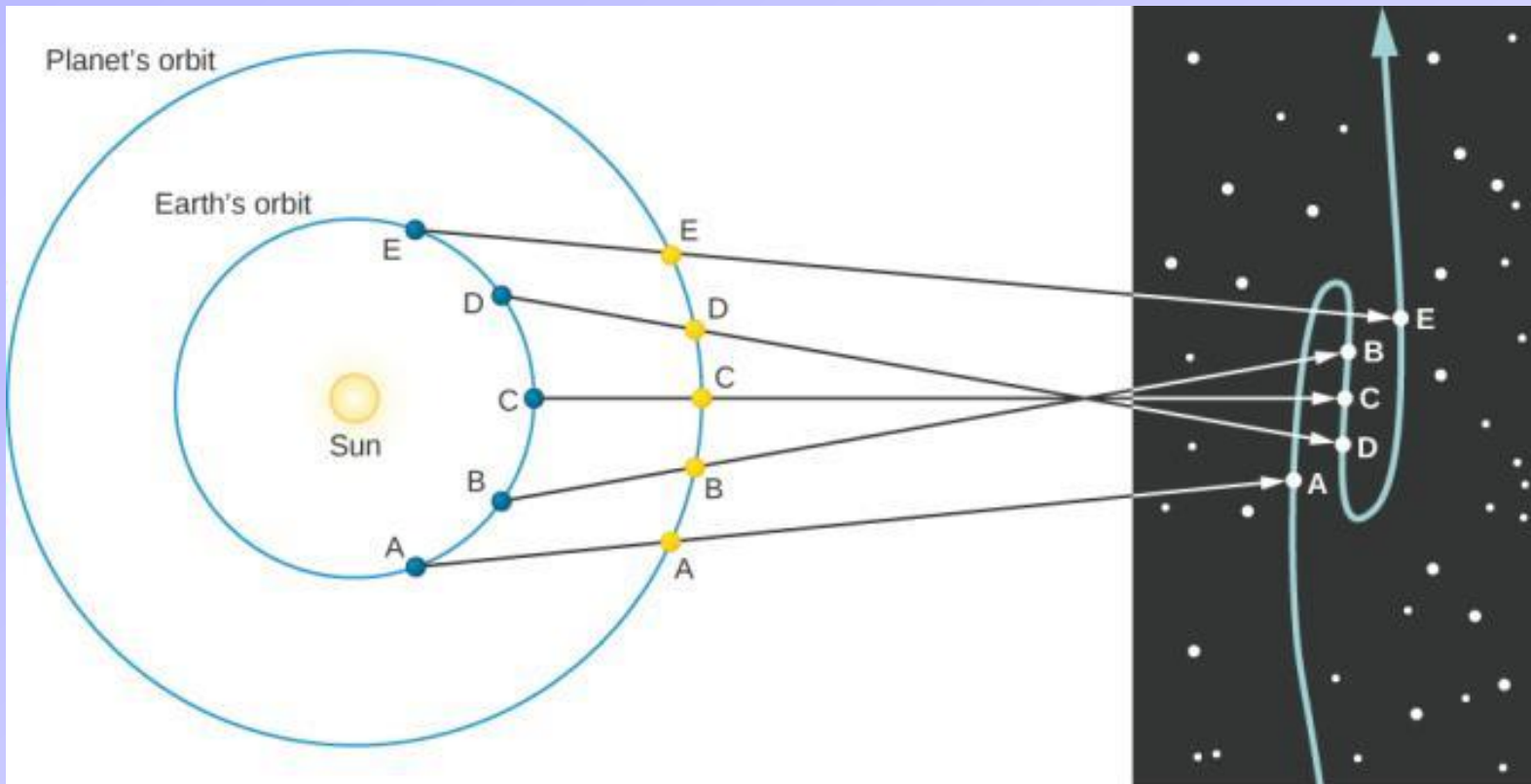[source: NASA, https://mars.nasa.gov/all-about-mars/night-sky/retrograde/]

By Eugene Alvin Villar (seav) - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=4662202

Retrograde Motion of Earth (from Mars)

2016 Mars Retrograde in Earth's Night Sky

Serpens

Opiuchus

Virgo

Libra

Scorpius

Lupus

View from Mission Control, Pasadena, CA

2016 Earth Retrograde Against Stars in the Mars Sky

Taurus

Aries

Auriga

Perseus

Camelopardalis

Cassiopeia

View from Curiosity Rover, Gale Crater, Mars

[source: NASA, https://mars.nasa.gov/all-about-mars/night-sky/retrograde/]
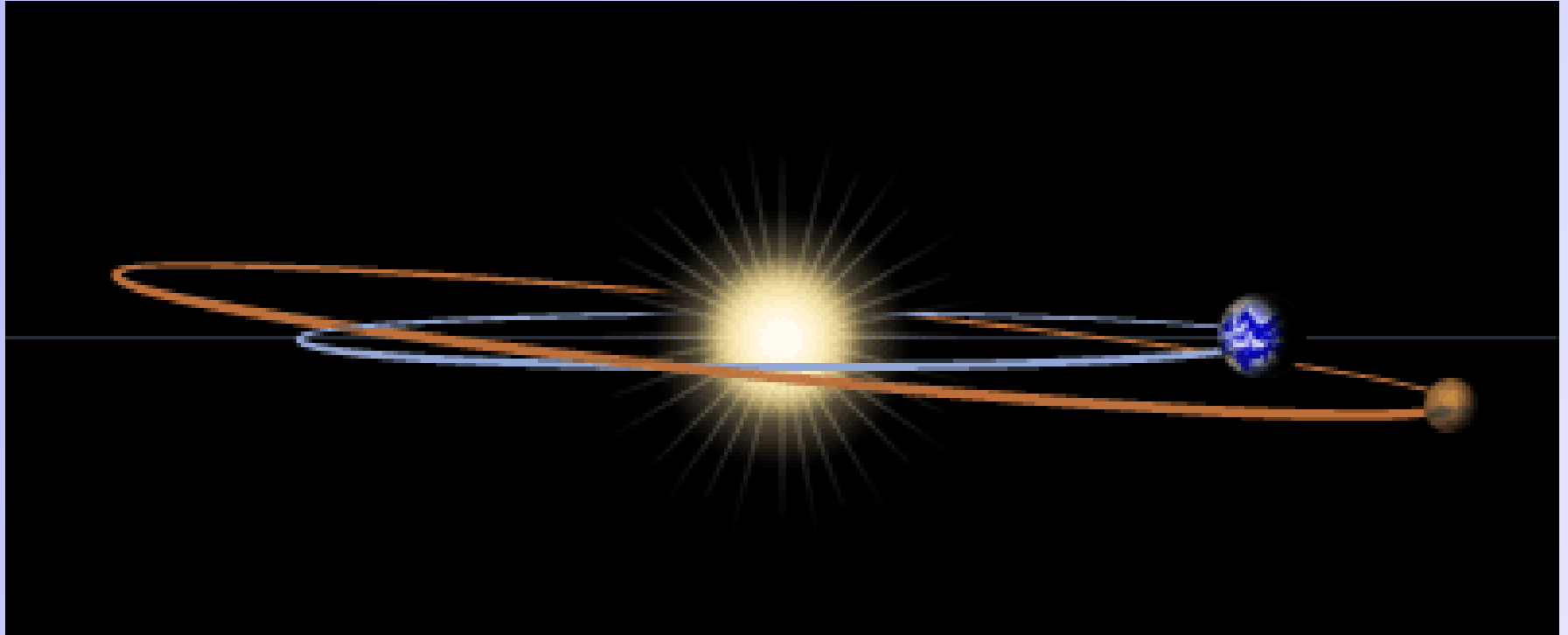
What's going on?

[OpenStax: Astronomy]

- The Earth orbits faster than Mars and passes it every 26 months.

- While Earth is passing Mars, then Mars appears to go backwards.

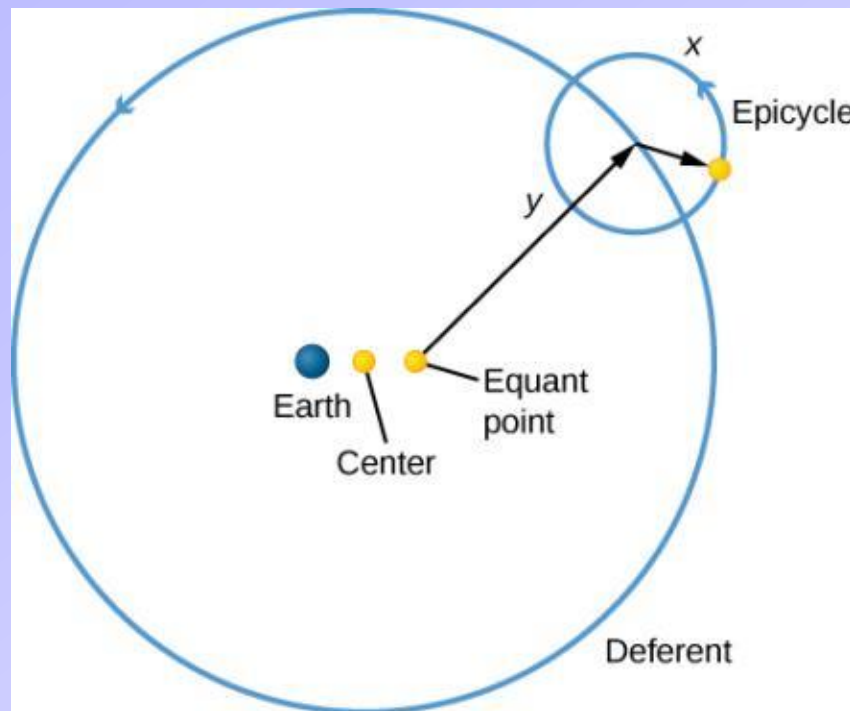- "Loop-de-loop" behavior is because Earth and Mars orbital planes are angled.

Inclination of Mars Orbit

[source: NASA, https://mars.nasa.gov/all-about-mars/night-sky/retrograde/]

Inclination of orbit (relative to ecliptic) = 1.85°

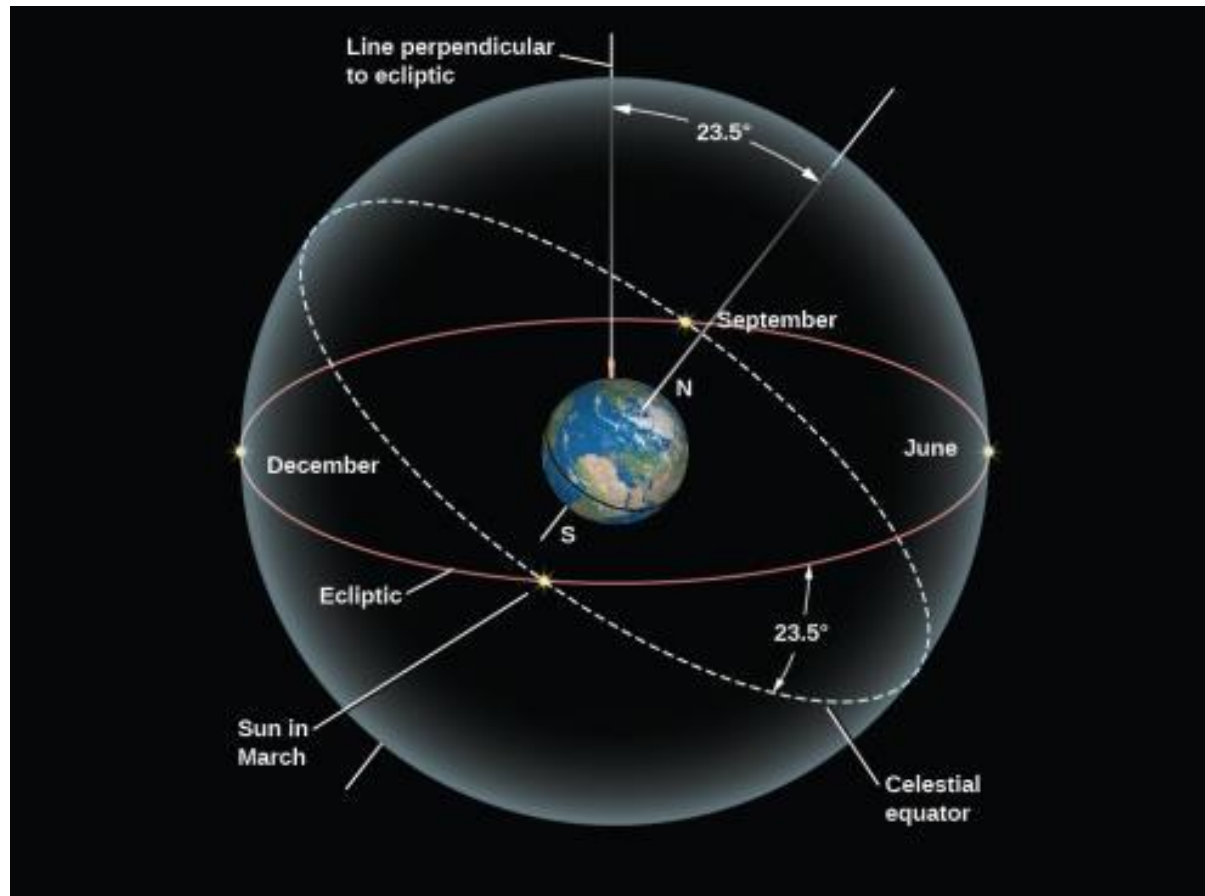# Ancient Geocentric View: Epicycles

[OpenStax: Astronomy]

Ptolemy (Alexandria, c."100-168" AD) explained retrograde motion using **epicycles**.

➢ Planets travel on an **epicycle circle** attached to their main orbit circle (**deferent**).

➢ The **deferent circle also moves** around the equant point.

➢ Epicycle model could **predict** apparent motion of planets.

➢ Replaced by Copernicus's (Poland, 1473-1543 AD) heliocentric model.
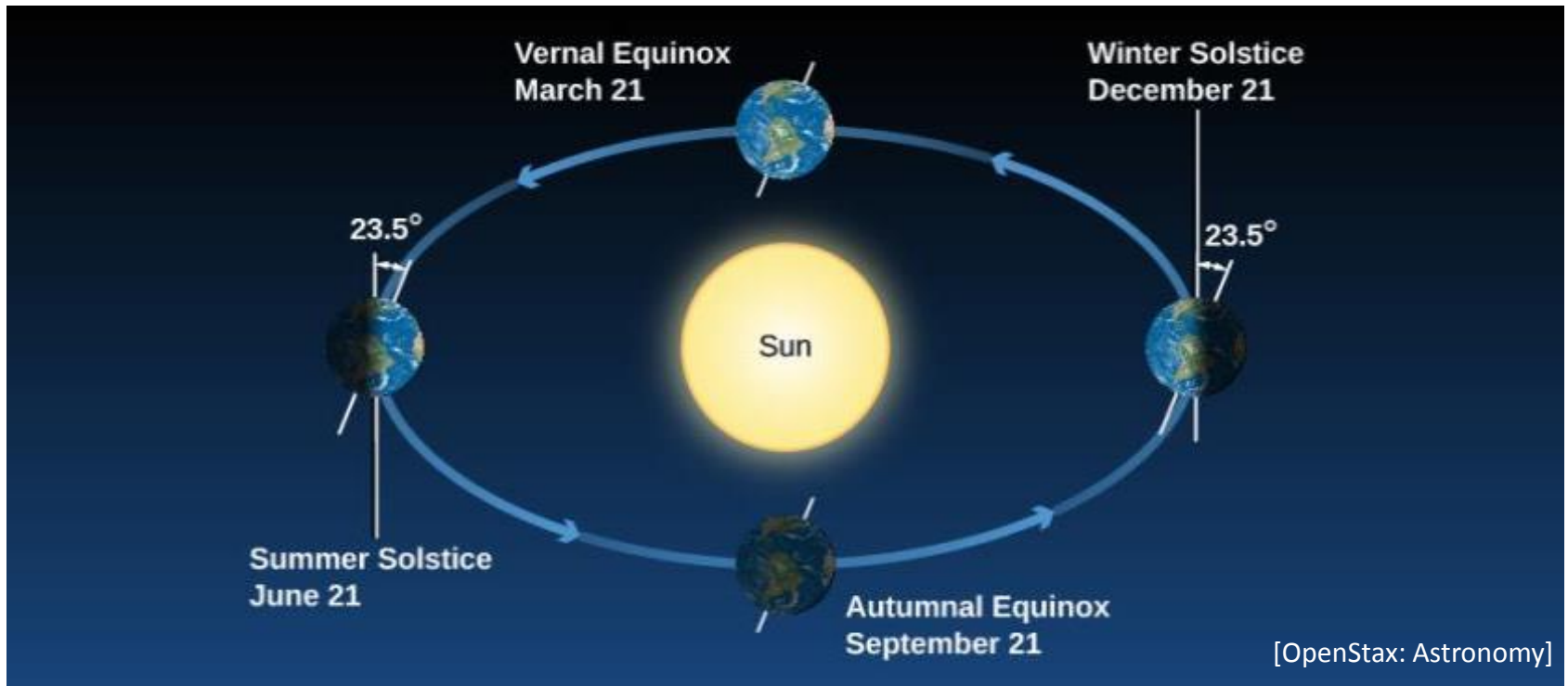
Tilt of Earth's Rotation Axis

Line perpendicular to ecliptic

23.5°

September

December

June

N

S

Ecliptic

23.5°

Sun in March

Celestial equator

[OpenStax: Astronomy]

- The **Ecliptic plane** is the plane in which the Earth orbits the Sun.

- The **orbital axis** is perpendicular to the Ecliptic plane.

- The **Earth rotation axis is inclined by** θ **= 23.5°** from the orbital axis.

Earth's tilt direction is constant

Earth's rotation axis always points in the same direction with respect to Sun and celestial sphere

Earth's tilt direction is constant

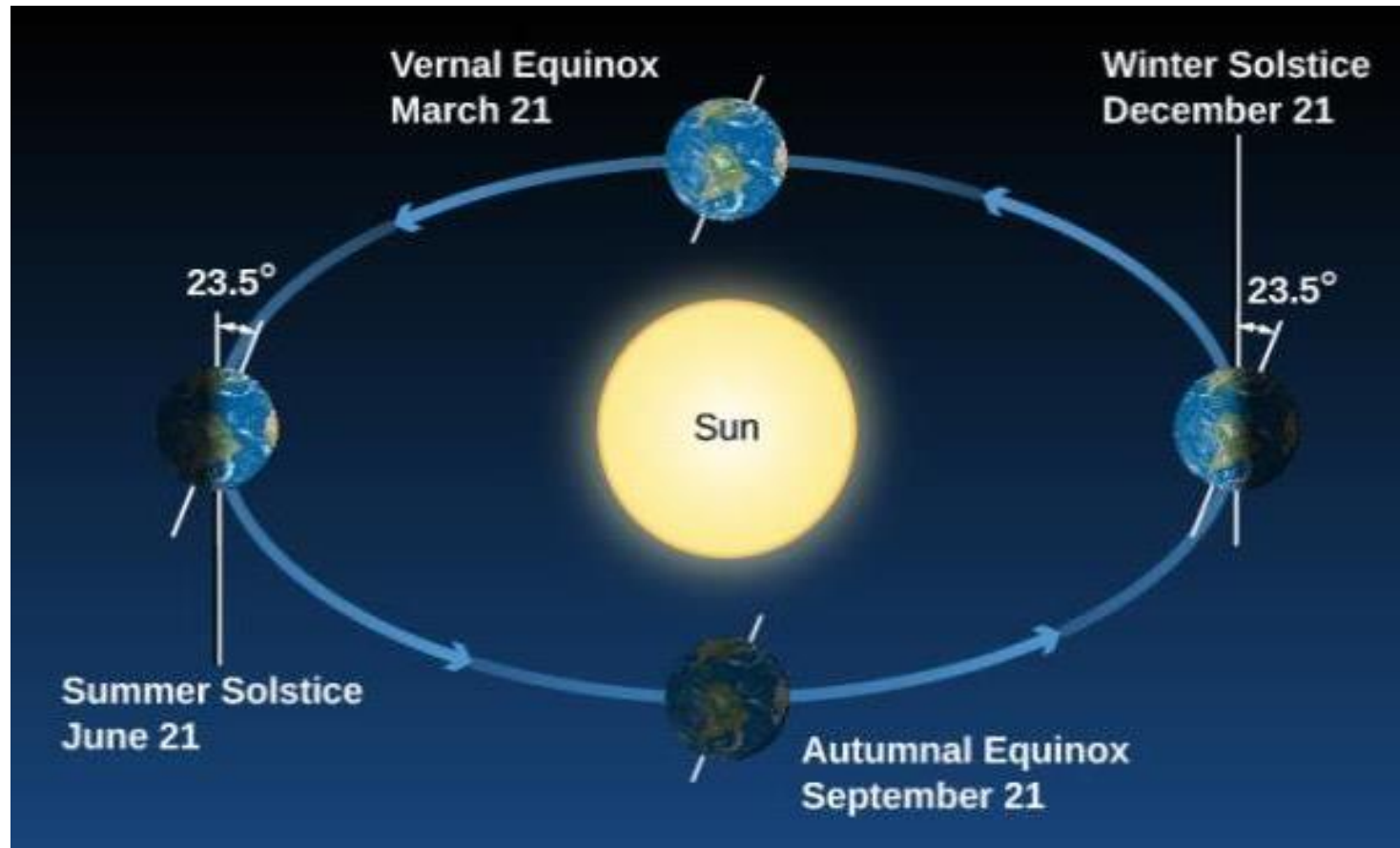The celestial sphere always "rotates" around the star **Polaris**.

[Source: https://epod.usra.edu/blog/2013/05/earths-rotation-and-polaris.html]

Earth's tilt direction is constant

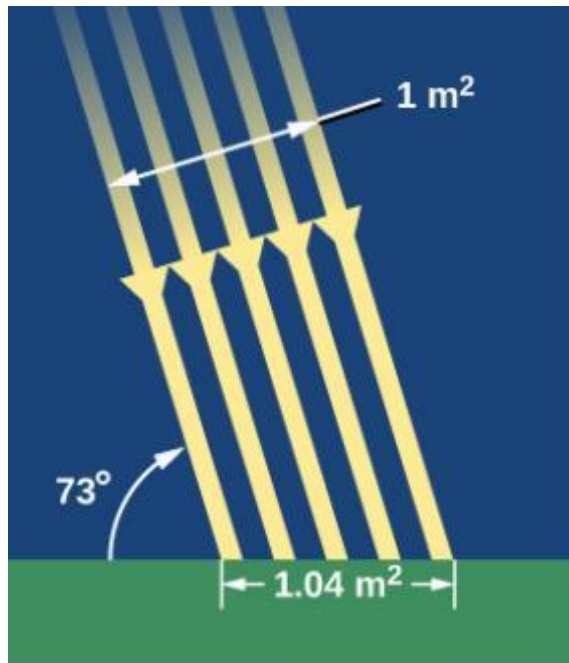The celestial sphere always "rotates" around the star **Polaris**.
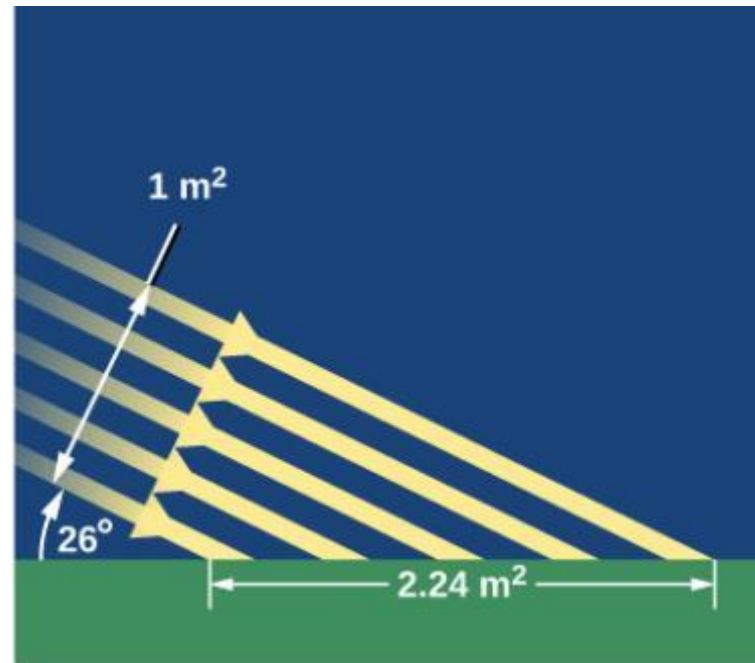

Polaris

Earth's tilt & the Seasons

➢ The summer and winter seasons are determined by the **amount of sunlight** that fall in a given location on Earth.

➢ Amount of sunlight = light power per unit area

Recall: power = energy per time

Earth's tilt & the Seasons

(a) Summer   (b) Winter
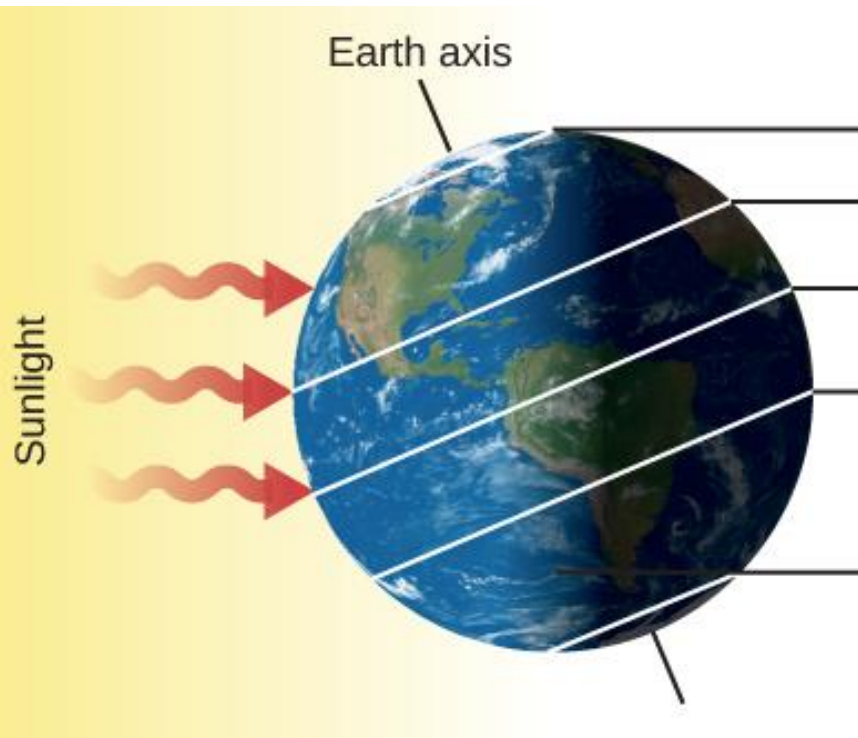
(a) In **summer**, the Sun appears high in the sky and its rays hit Earth more directly, spreading out less.

(b) In **winter**, the Sun is low in the sky and its rays spread out over a much wider area, becoming less effective at heating the ground.
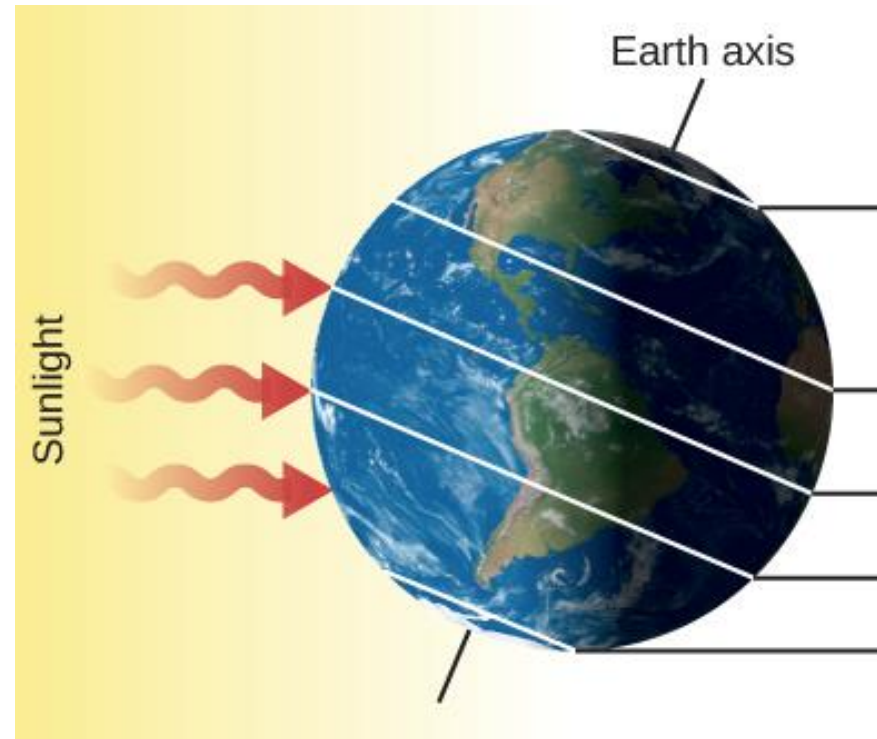
Sun's light intensity on Earth $\approx$ 1 KiloWatt per square meter = 1 kW/m^2
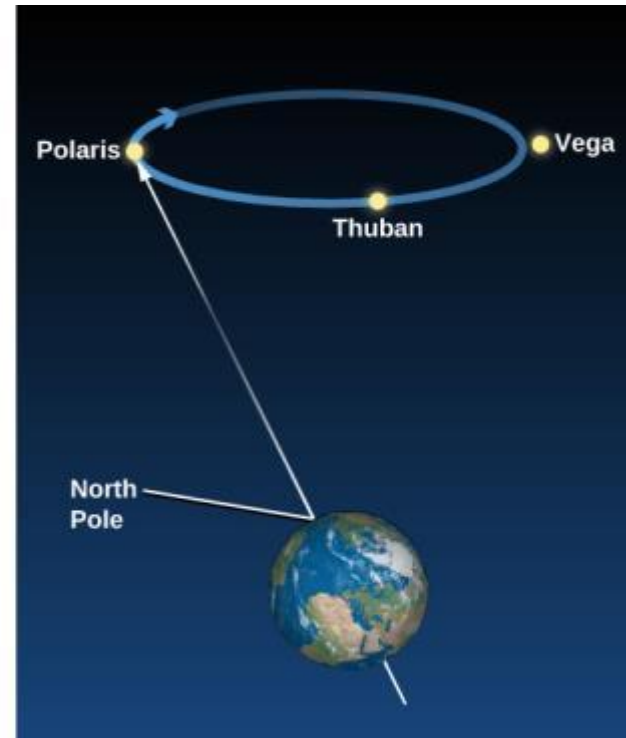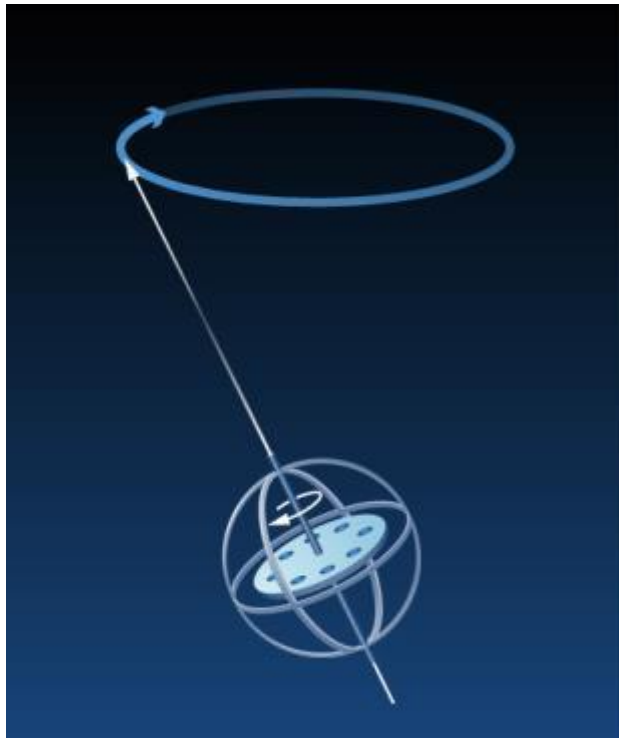
Orientation #1

Winter ?
Summer ?

Orientation #2

Winter ?
Summer ?

Classify diagrams by season for <u>North America</u>

Precession of Earth's Axis

The direction of Earth's rotation axis is slowly changing.
→ The axis is precessing over a 26,000 year period.

- Today the north celestial pole is near the star Polaris
- About 5000 years ago it was close to a star called Thuban
- In 14,000 years it will be closest to the star Vega.

Precession of Earth's Axis
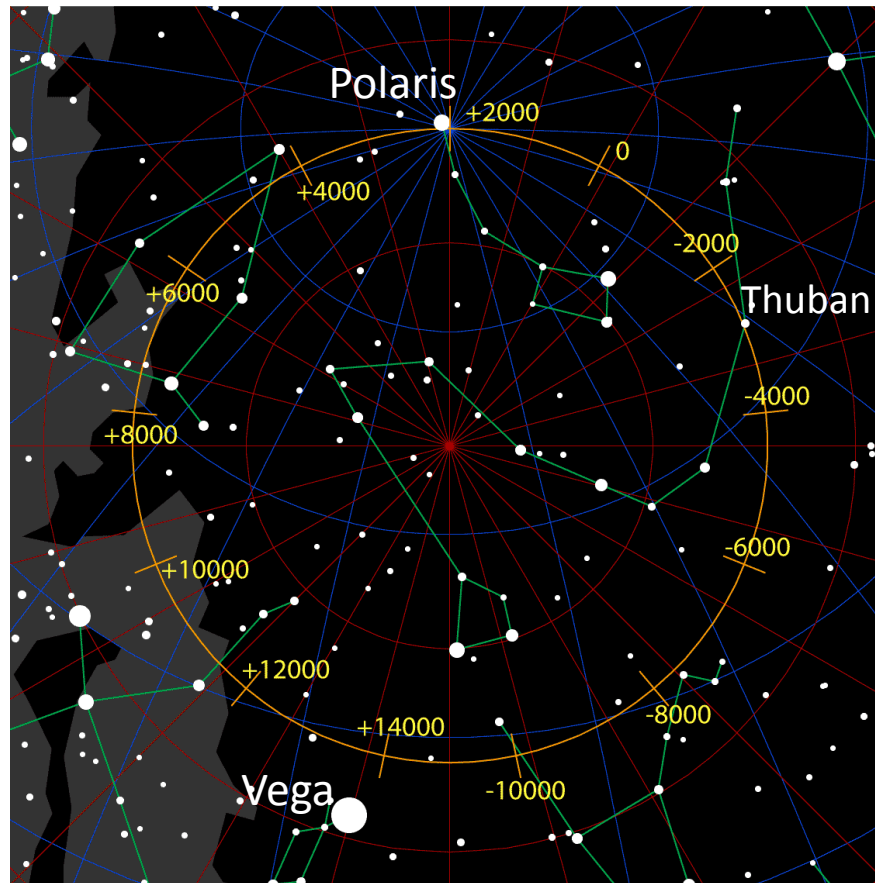
By Tauʻolunga - self, 4 bit GIF, CC BY-SA 2.5,
https://commons.wikimedia.org/w/index.php?curid=891838

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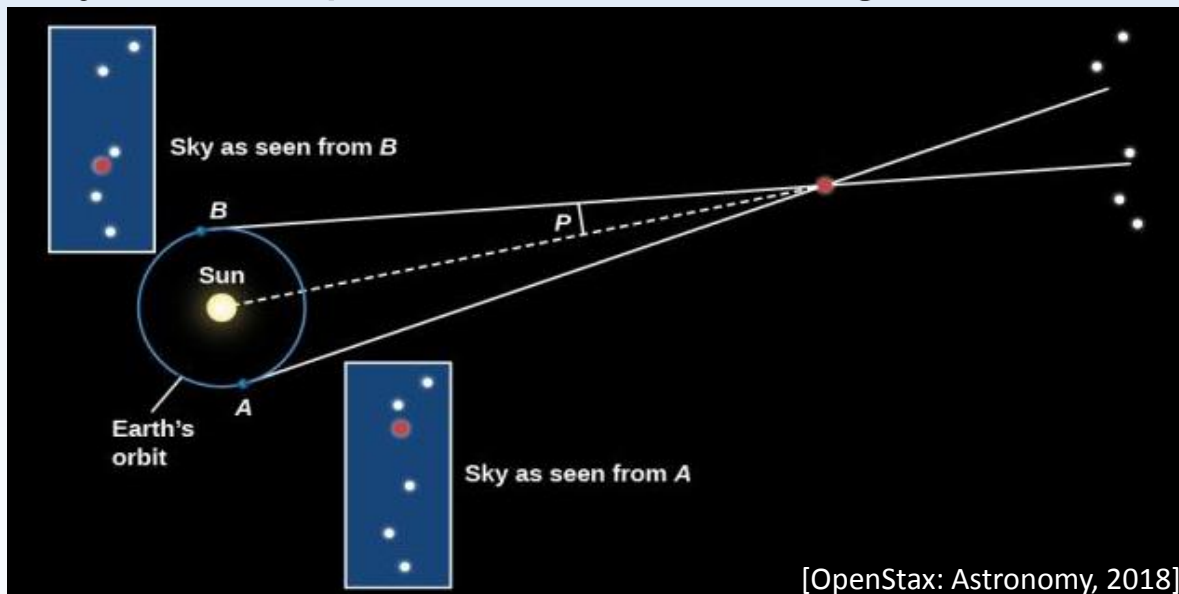
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As the Earth orbits the Sun, the direction (position) of a nearby star should vary with respect to distant "background stars."

[OpenStax: Astronomy, 2018]

Stellar Parallax → Stellar Distances

➢ Stellar parallax is really small, because even nearby stars are very far away.

➢ Requires a powerful telescope
   → First observation in 19th century (Bessel).

➢ Most accurate method for measuring stellar distances.

   → Only works for nearby stars.

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→ The New Horizons spacecraft to Pluto (and beyond) measured a large parallax for <u>Proxima Centauri</u>.

Earth

[NASA: New Horizons mission, 2020]

Stellar Parallax
Geocentrism vs Heliocentrism

➢ **Aristarchus** (310-230 BC) proposed a heliocentric model of the universe.

 → Rejected in part because the ancient Greeks were never able to observe **stellar parallax**.

 → Geocentric models by **Ptolemy, Aristotle**, and others gained favor for the next 18 centuries.
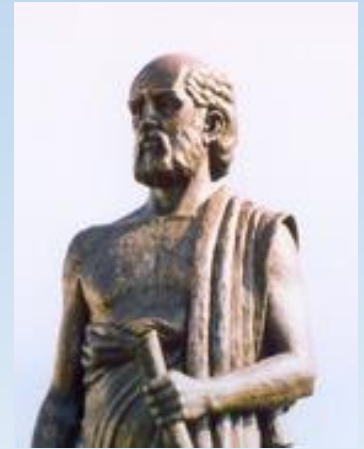
Aristarchus of Samos
[Wikipedia, modern statue at Aristotle U. of Thessaloniki]

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➢ **Copernicus** (1473-1543 BC) re-introduced the heliocentric model.

    → Same predictive power as Ptolemaic epicycle model, but simpler.

    → Simple explanation for the retrograde motion of planets.

    → Criticized because stellar parallax was not yet observed.
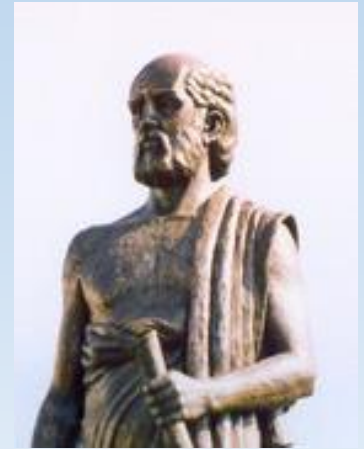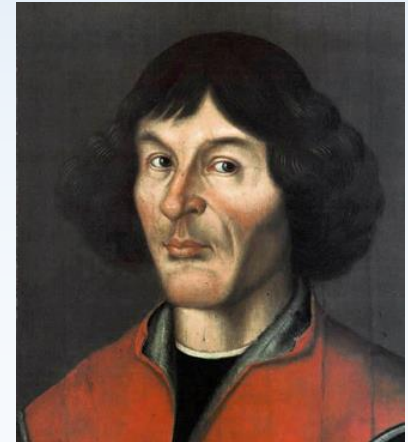
Nicolaus Copernicus
[anonymous, c. 1580]

Kepler's Laws

of Planetary Motion
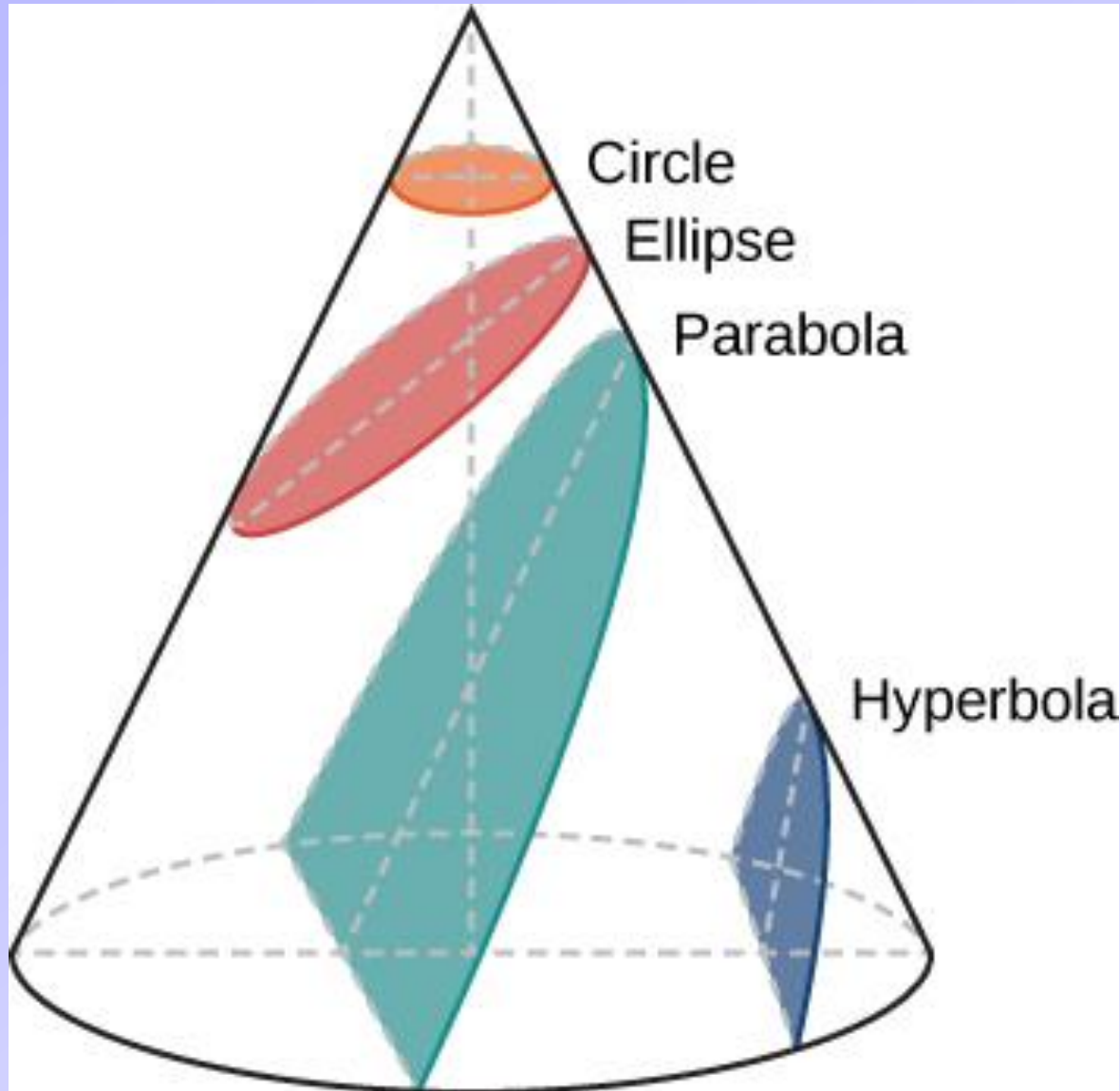
1st Law: The orbits of all planets are **ellipses**.

2nd Law: Law of **equal areas**.

3rd Law: (orbital period)^2 = (semimajor axis)^3

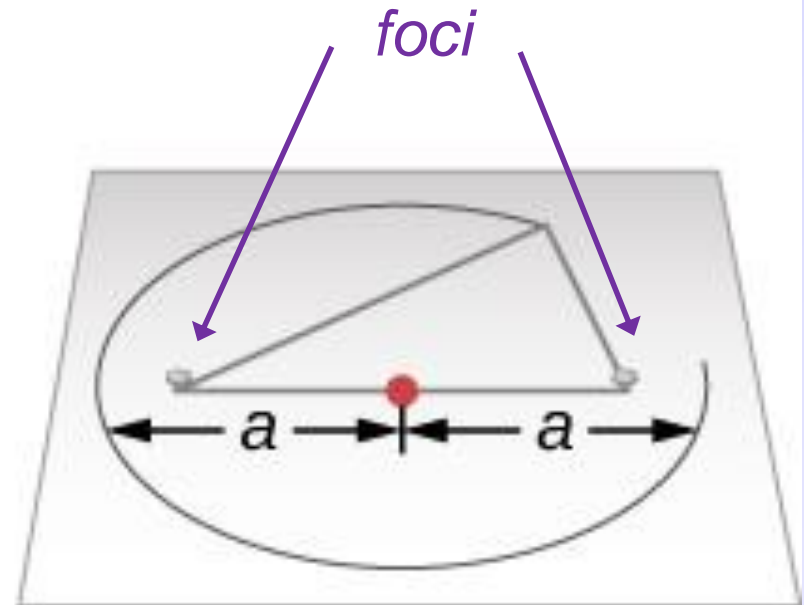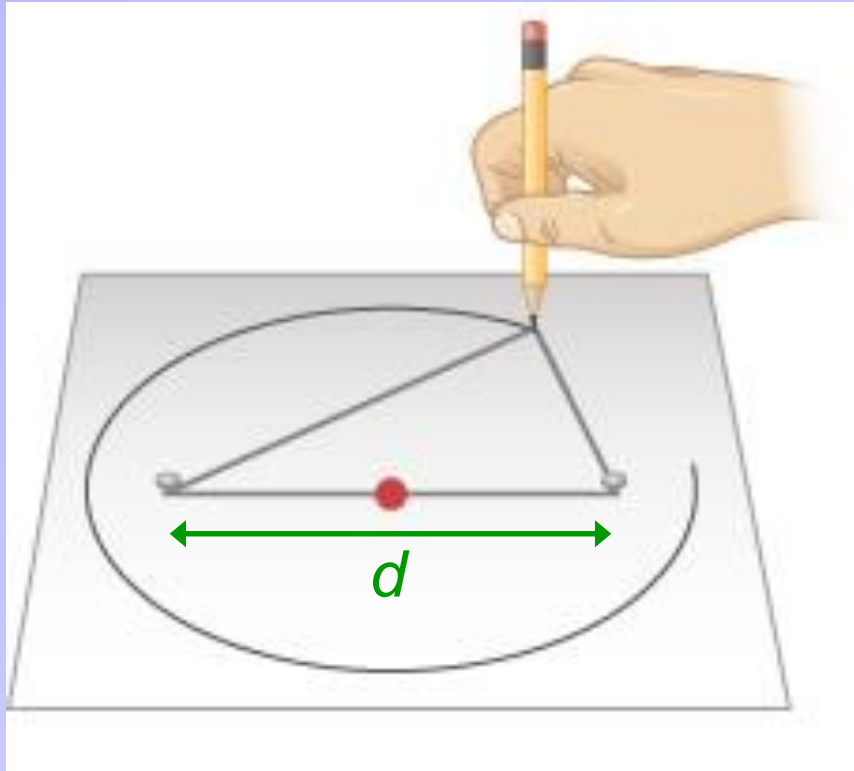[**fine print:** the "=" depends on units used]

Kepler's 1st Law – Conic Sections

The **circle**, **ellipse**, **parabola**, and **hyperbola** are all formed by the intersection of a plane with a cone.

Note: Unbound orbits can be parabolic or hyperbolic.

d

$foci$

a a

a = semimajor axis
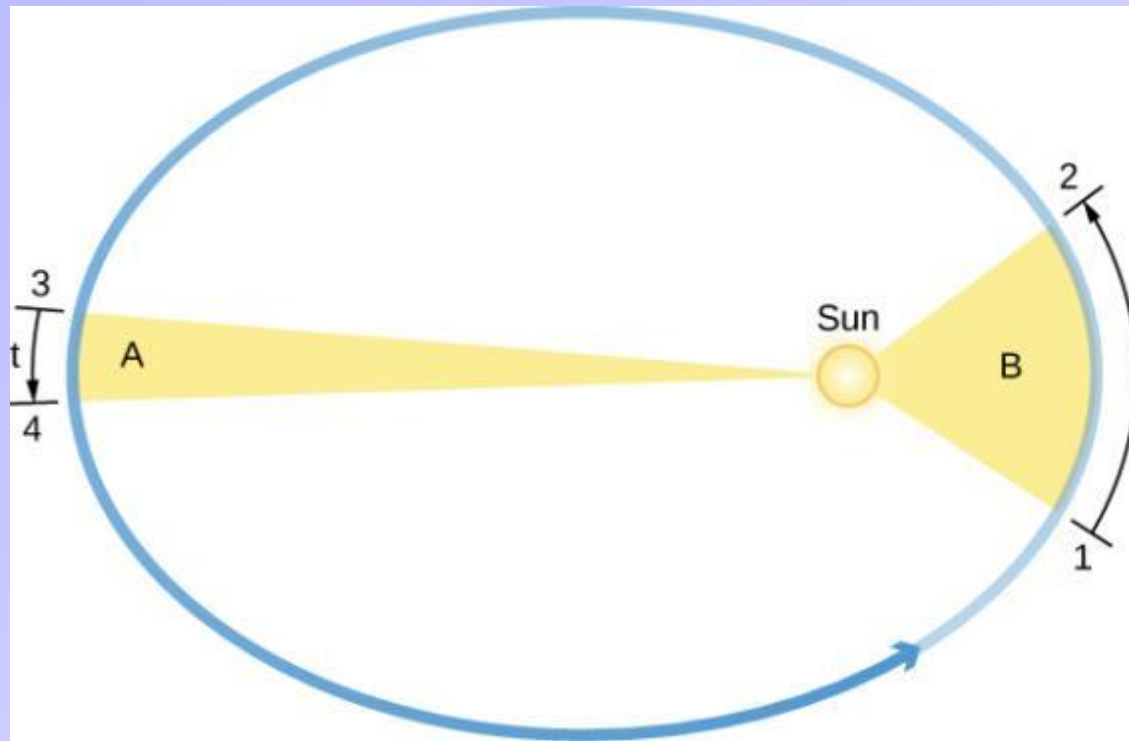
- Sun sits at one of the foci.
- Other focus is empty.

$$\text{Eccentricity} = \varepsilon = \frac{d}{2a}$$

Kepler's 2nd Law

The Law of Equal Areas. The orbital speed of a planet traveling around the Sun varies such that in equal intervals of time t, a line between the Sun and a planet sweeps out equal areas (area A = area B).

Kepler's 3rd Law

T = orbital period in units of Earth years

a = semimajor axis in AU

$$T^2 = a^3$$