Today’s Topics

Wednesday, January 29, 2025 (Week 1, lecture 3) – Chapters 2 & 3.

A. Planetary orbit basics

B. Earth’s axis tilt, seasons, precession

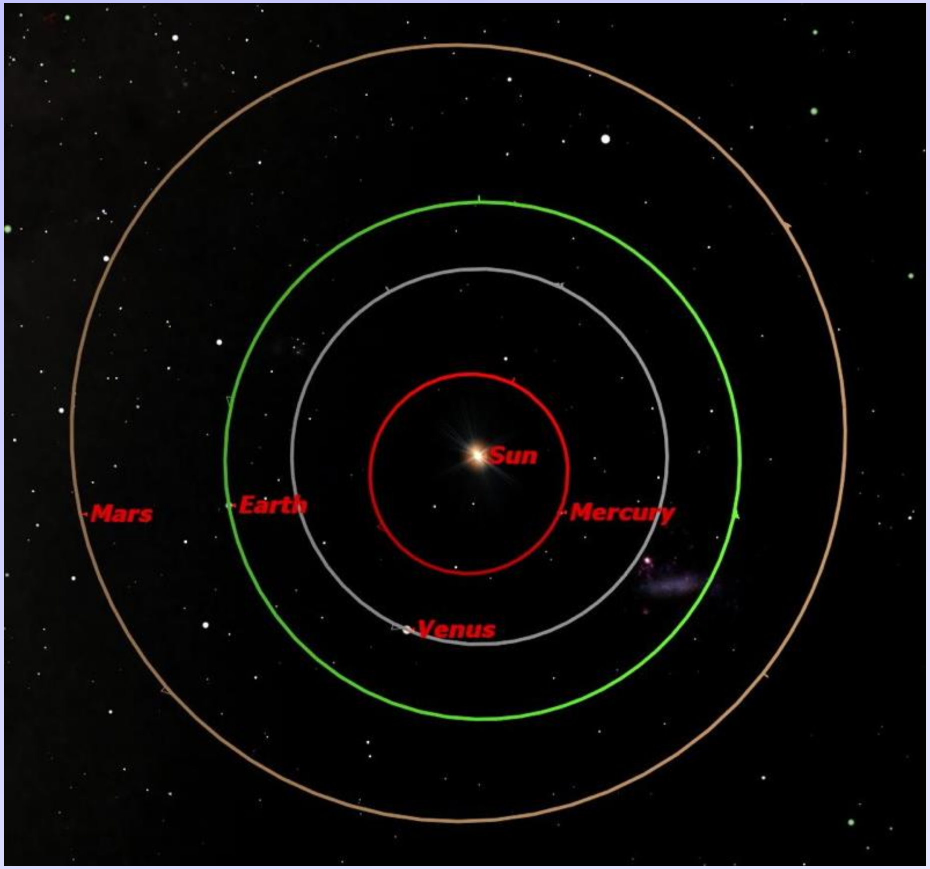
C. Stellar parallax

D. Kepler’s laws

Planetary Orbit Basics

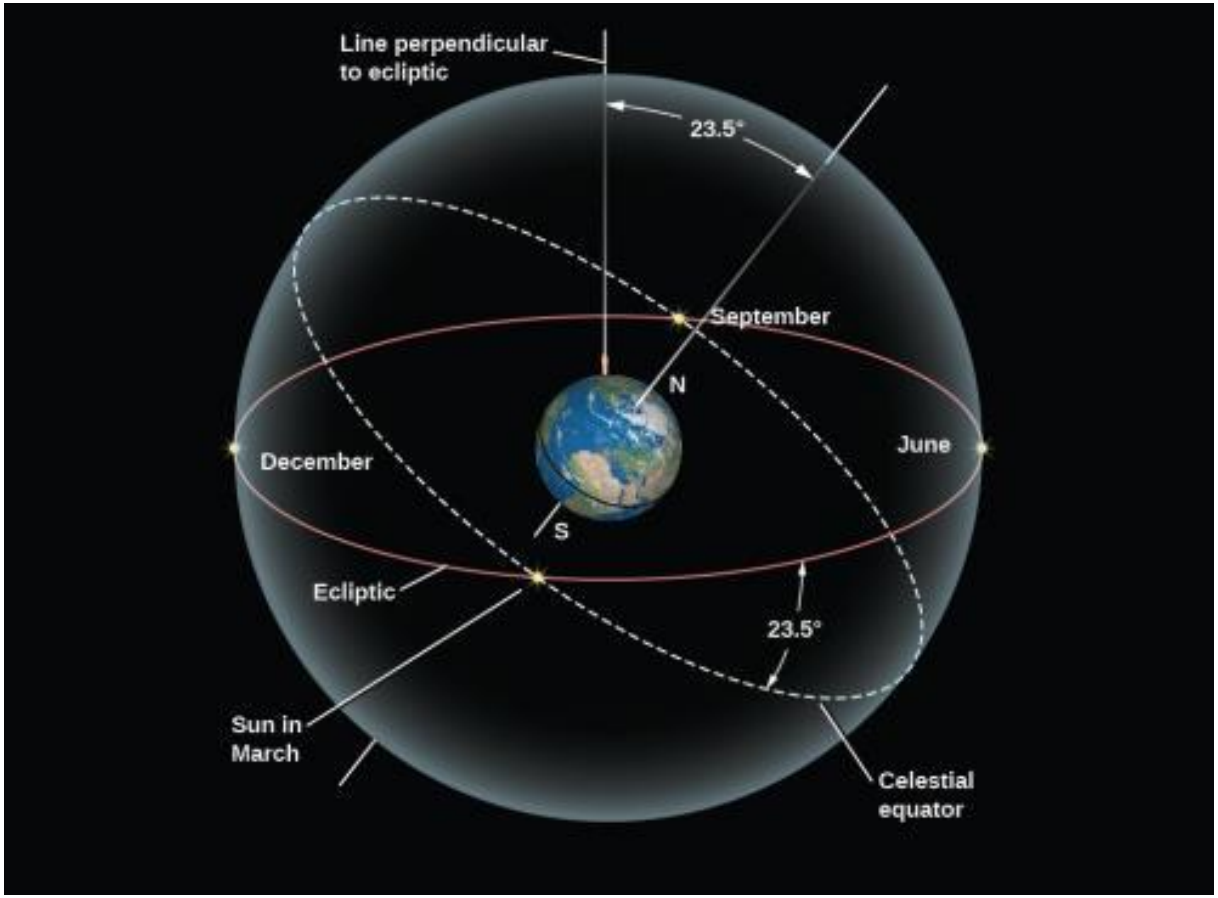
- The planets orbit the Sun following roughly "circular path."
- These "circular paths" are actually somewhat elliptical.
- The orbits all lie in more or less the same plane.

Inner Solar System planetary orbits



[Source: www.space.com/25367-mars-opposition-next-week-video.html, Starry Night software]

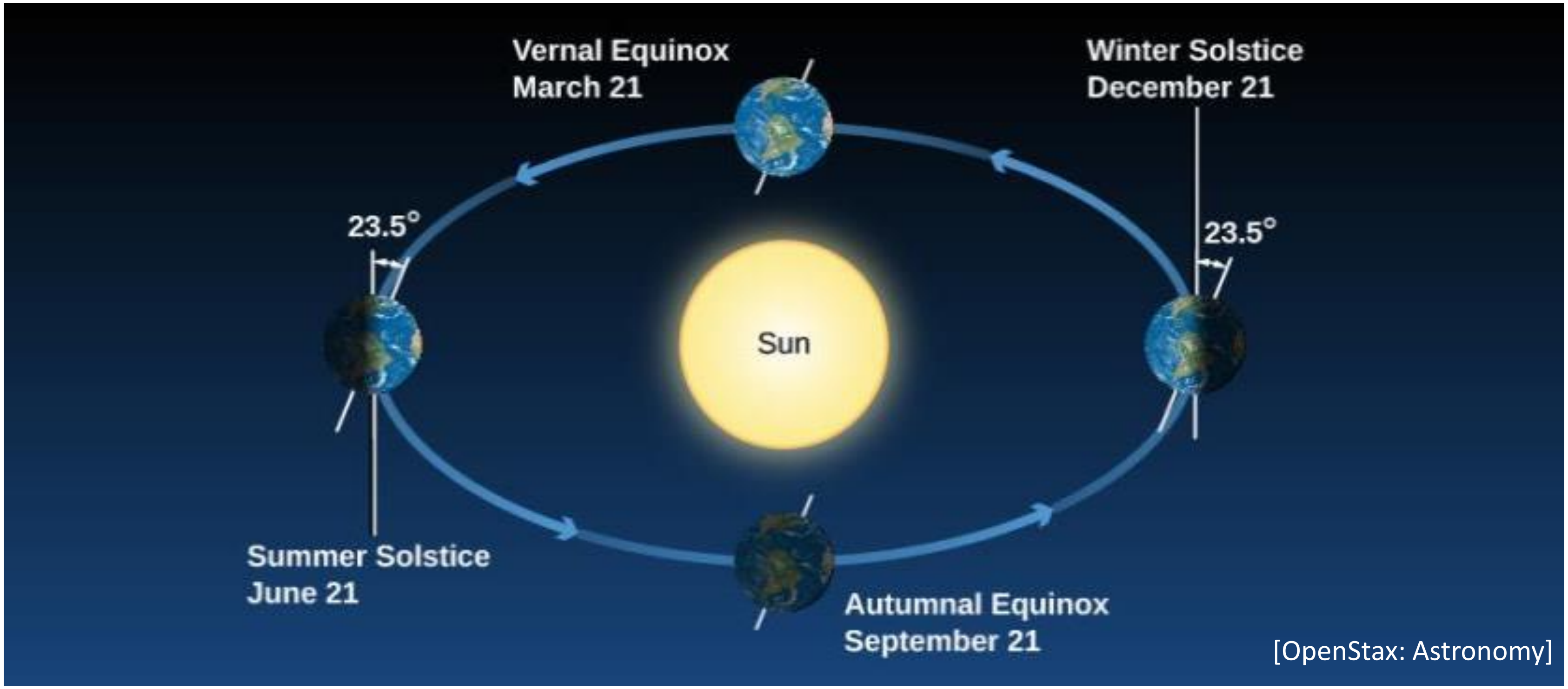
Tilt of Earth's Rotation Axis



[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]

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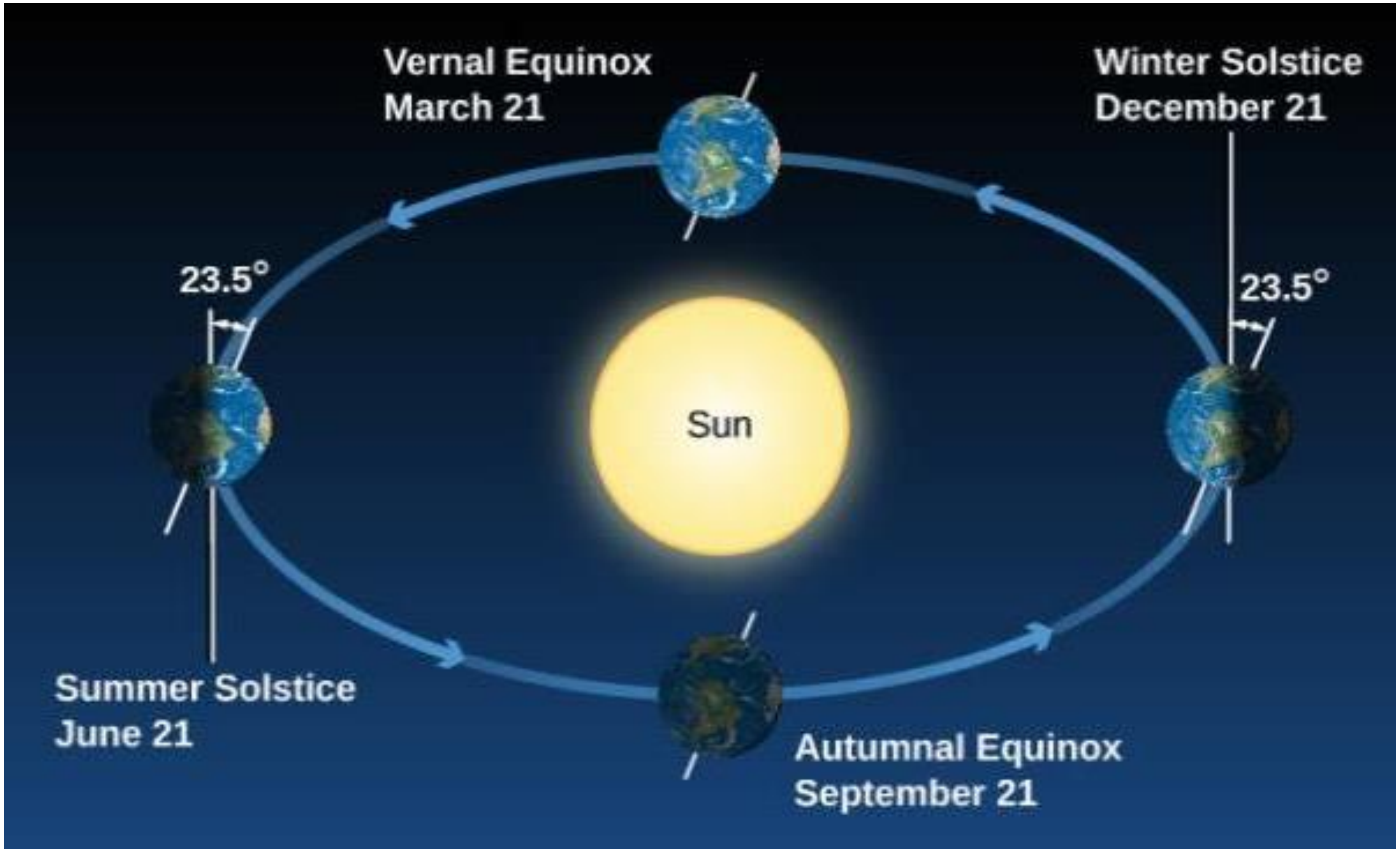
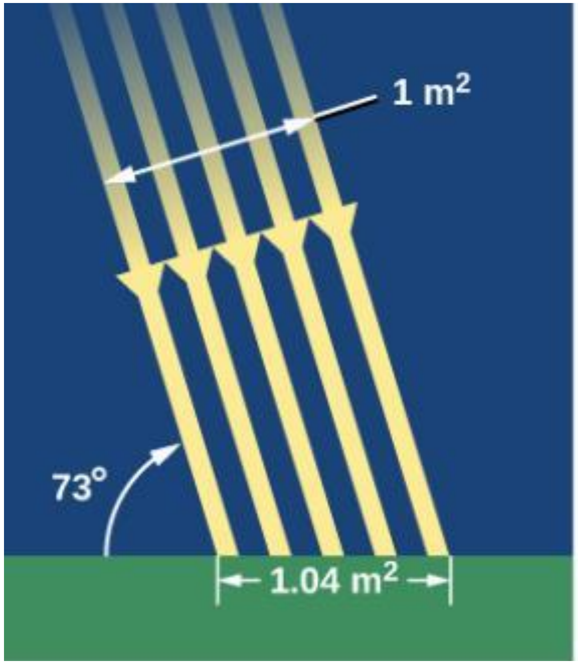
Earth’s tilt & the Seasons



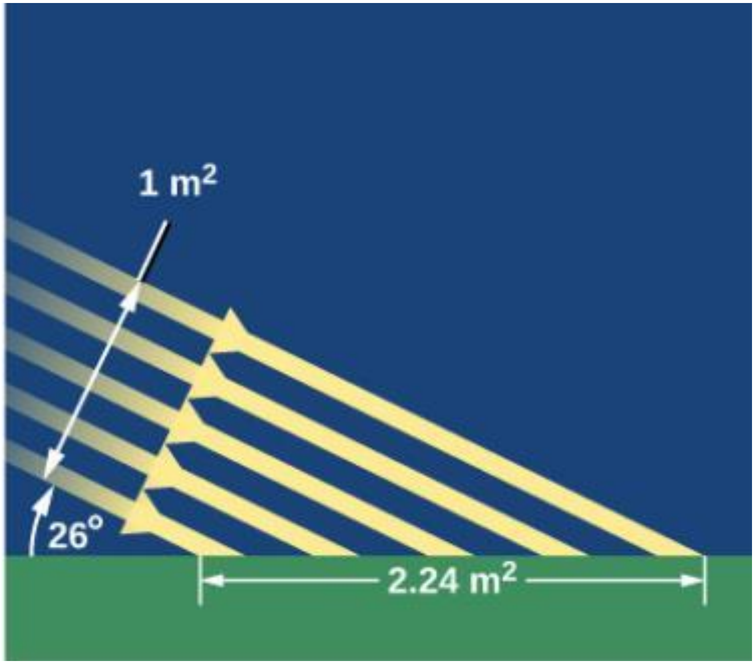
- The summer and winter seasons are determined by the **amount of sunlight** that fall in a given location on Earth.
- Amount of sunlight = light power per unit area

Recall: power = energy per time

Earth's tilt & the Seasons



(a) Summer



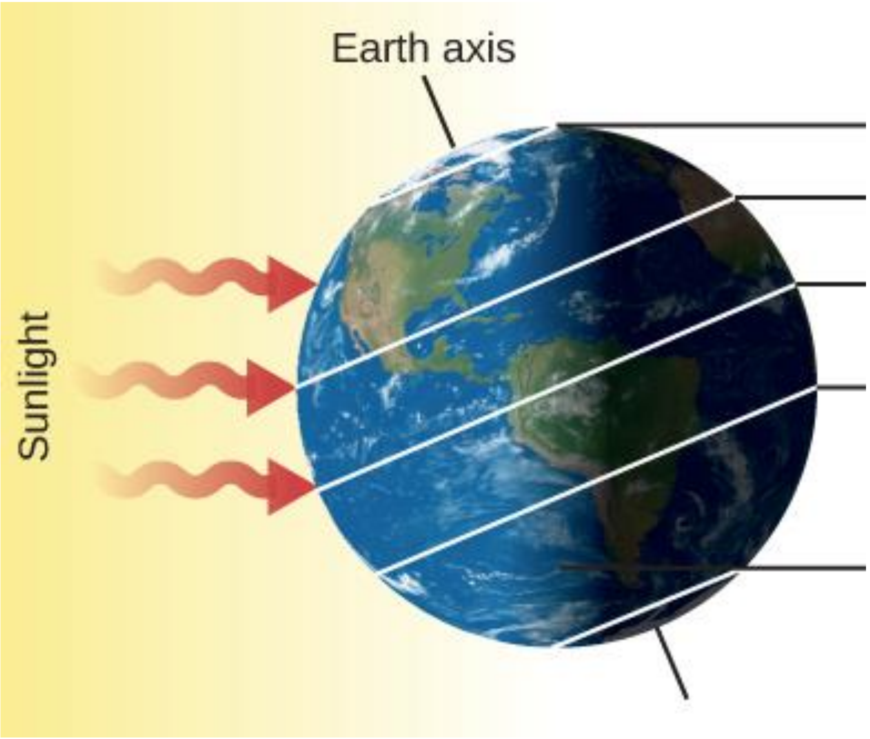
(b) Winter

(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.

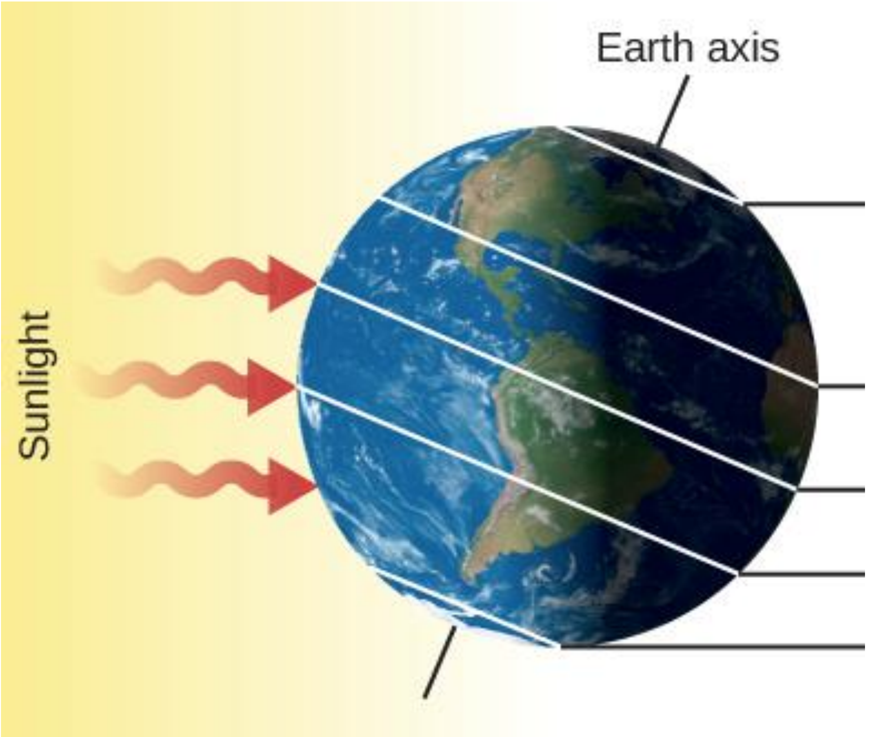
Sun's light intensity on Earth ≈ 1 KiloWatt per square meter = 1 kW/m^2

Participation Question



Orientation #1

Winter ?
Summer ?



Orientation #2

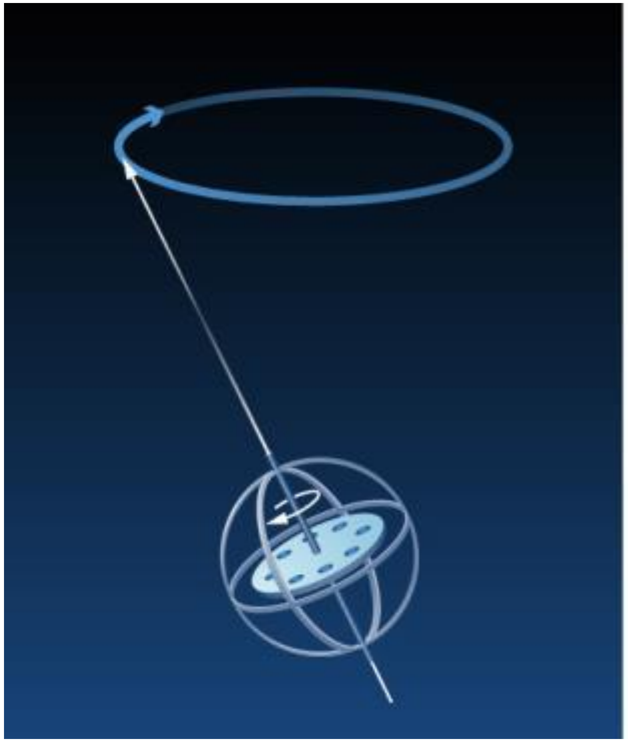
Winter ?
Summer ?

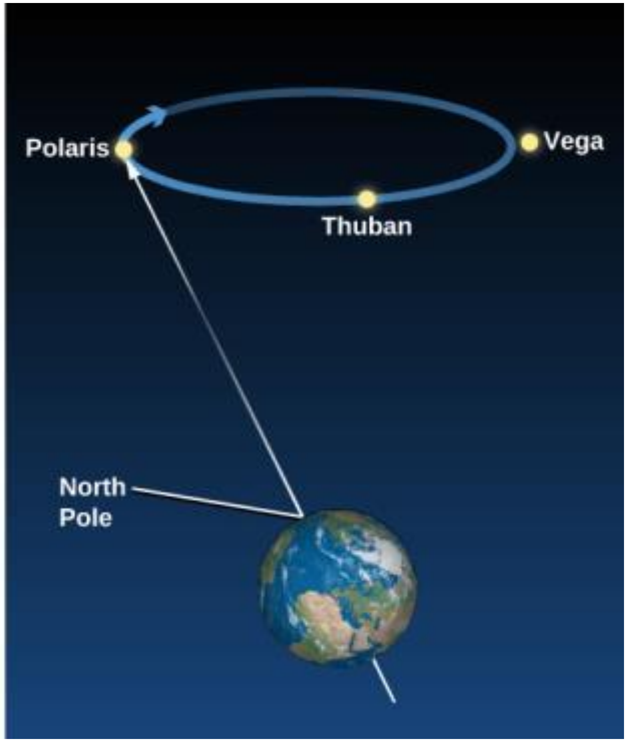
Classify diagrams by season for North America

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.

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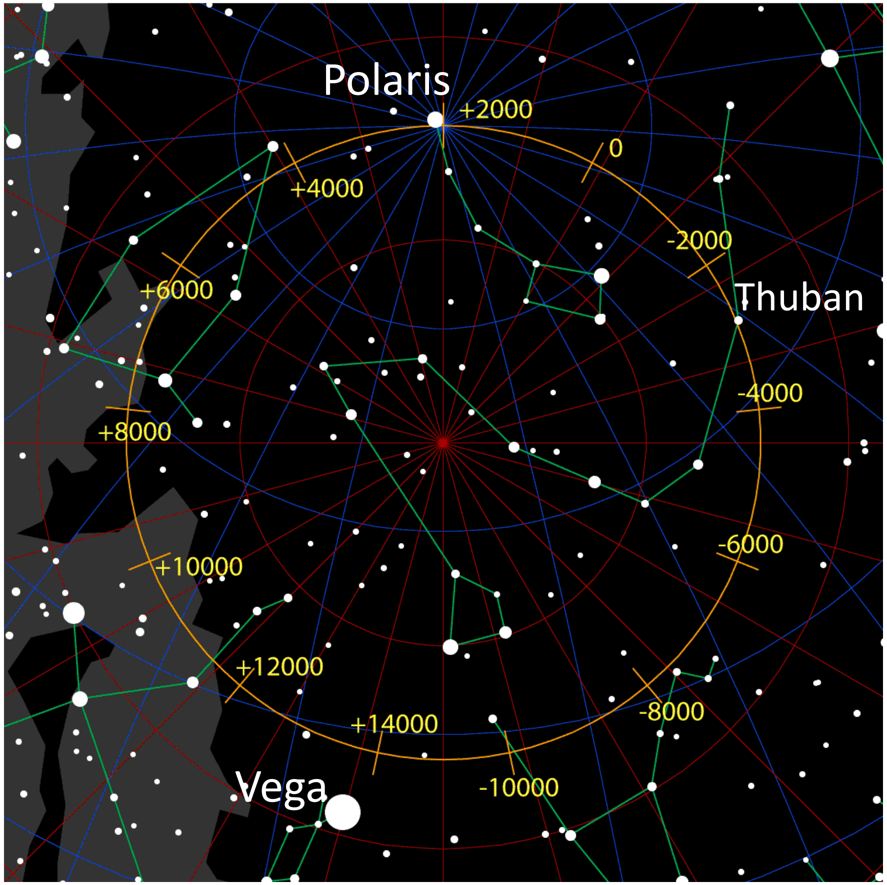

By Tau'olunga - self, 4 bit GIF, CC BY-SA 2.5,
https://commons.wikimedia.org/w/index.php?curid=891838

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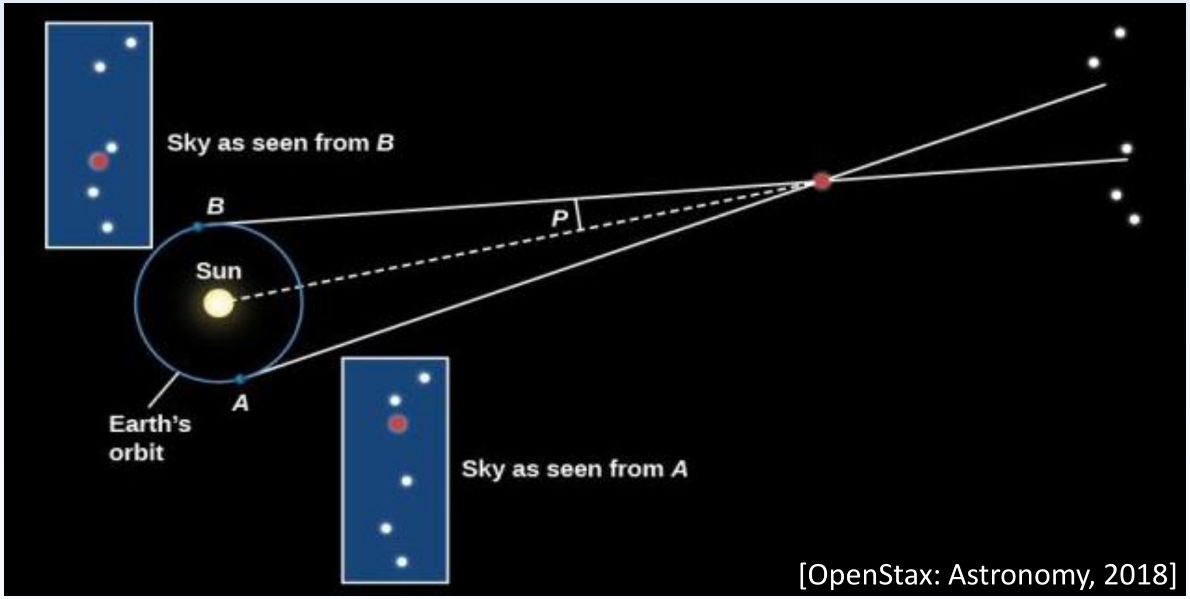
Stellar Parallax

As the Earth orbits the Sun, the direction (position) of a nearby star should vary with respect to very 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.
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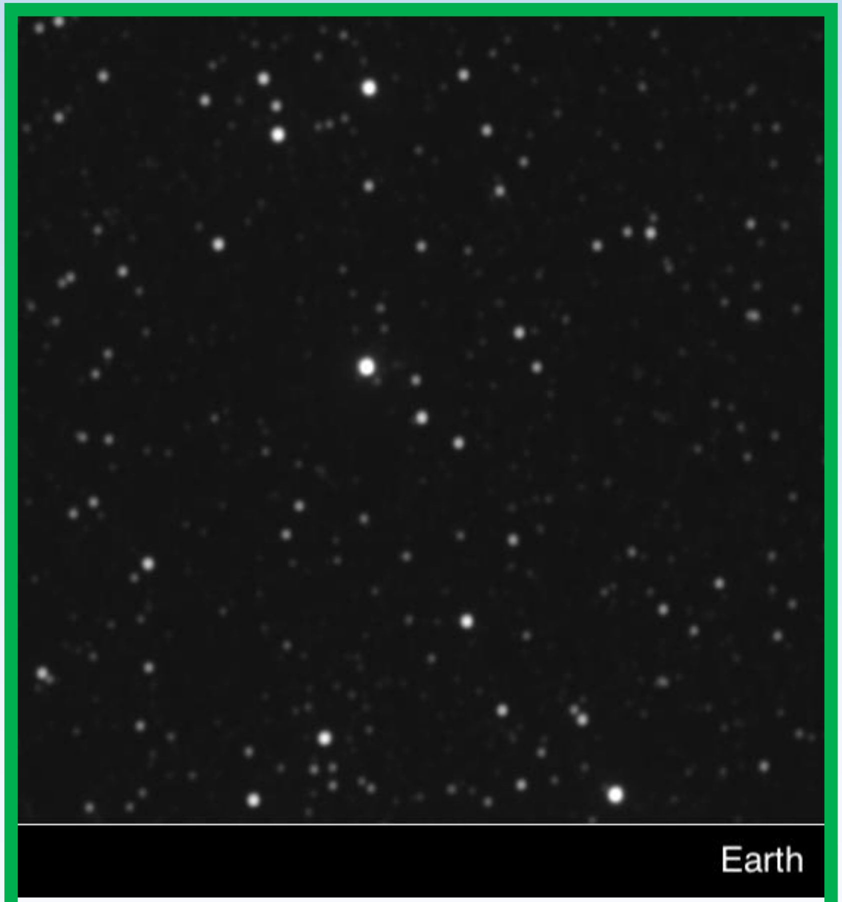
→ The New Horizons spacecraft to Pluto (and beyond) measured a large parallax for Proxima Centauri.



[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**.
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Aristarchus of Samos
[Wikipedia, modern statue at Aristotle U. of Thessaloniki]

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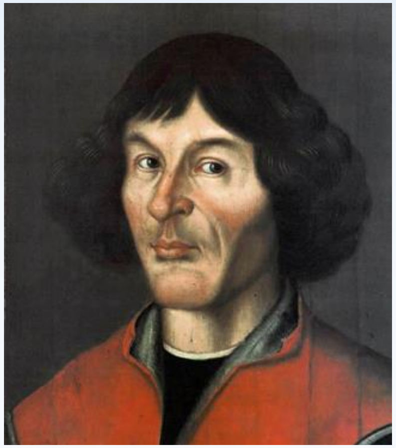
- **Copernicus** (1473-1543 BC) re-introduced the heliocentric model.
  - → Same predictive power as Ptolemaic epicycle model, but simpler.
  - → Simple explanation for the retrograde motion of planets.
  - → Criticized because stellar parallax was not yet observed.



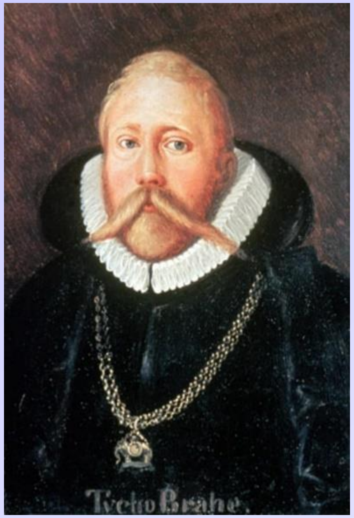
Nicolaus Copernicus
[anonymous, c. 1580]

Kepler and Brahe

- **Tycho Brahe** (1546-1601) collected extensive precision observational data (pre-telescope) on the motion of the planets.

- **Johannes Kepler** (1571-1630) worked for Tycho Brahe.

- Kepler **analyzed 20+ years of data** to understand the motion of the planets.



Tycho Brahe


Johannes Kepler

Kepler's Laws of Planetary Motion

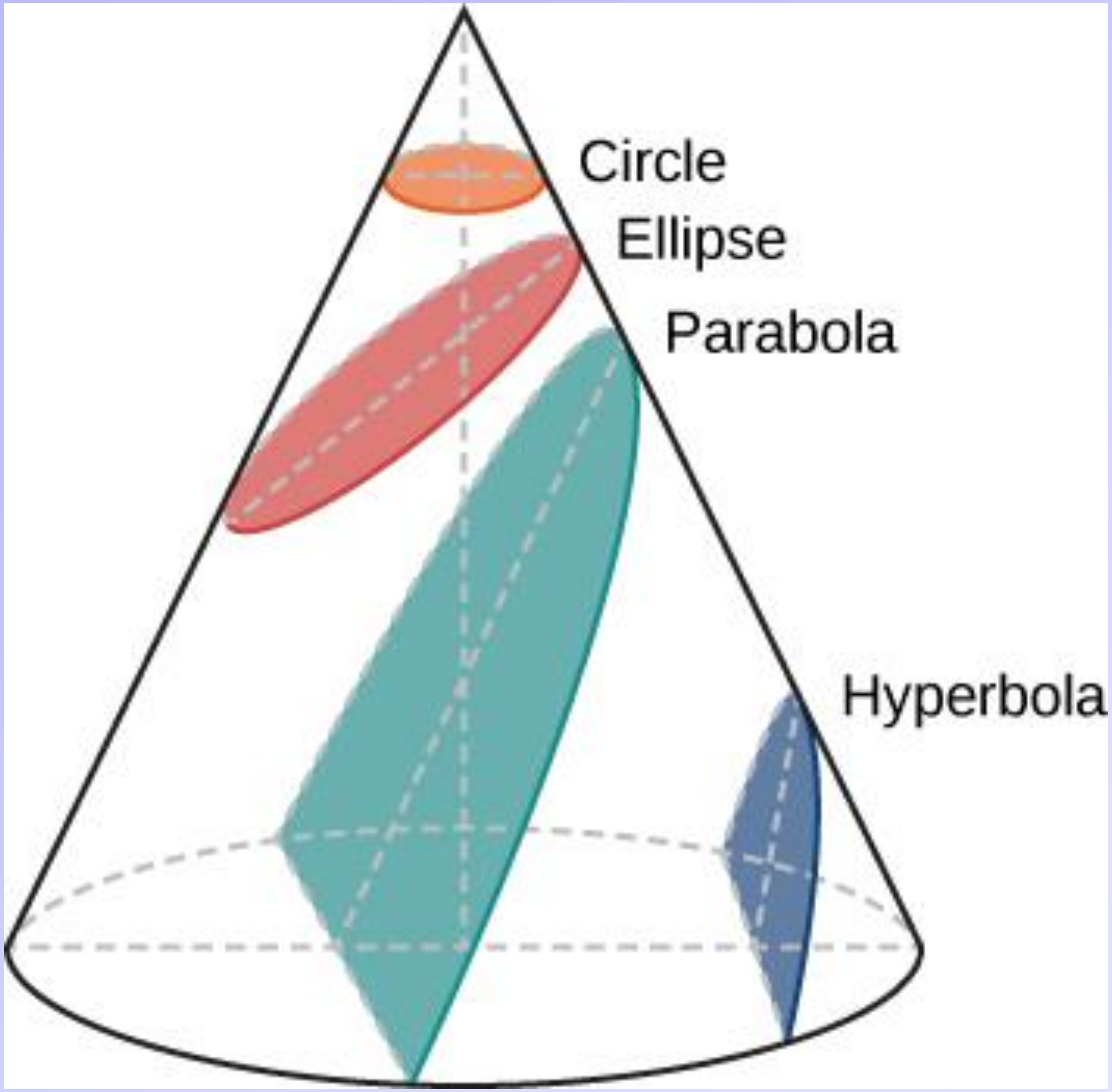
1st Law: The orbits of all planets are **ellipses**.

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

3rd Law: $(\text{orbital period})^2 = (\text{semimajor axis})^3$

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

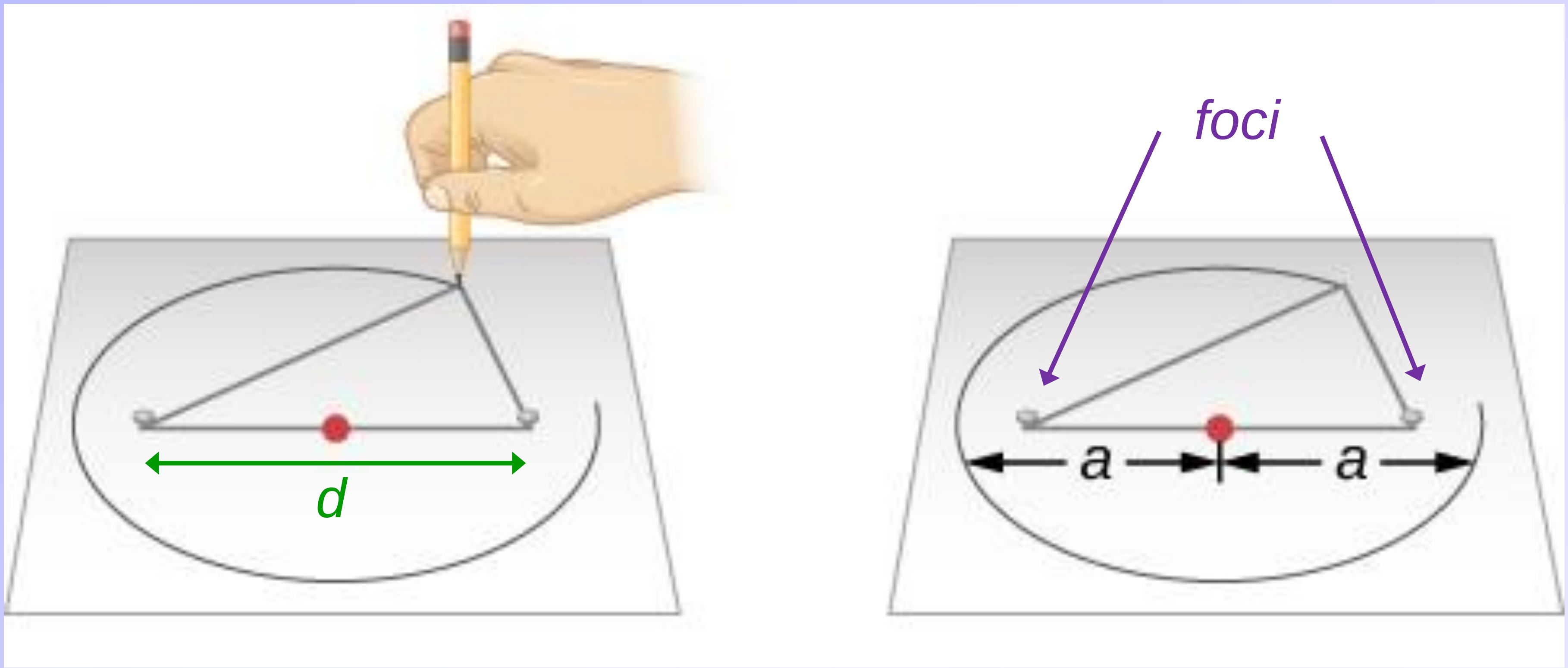
Kepler’s 1st Law – Conic Sections



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.

Kepler's 1st Law -- Ellipses

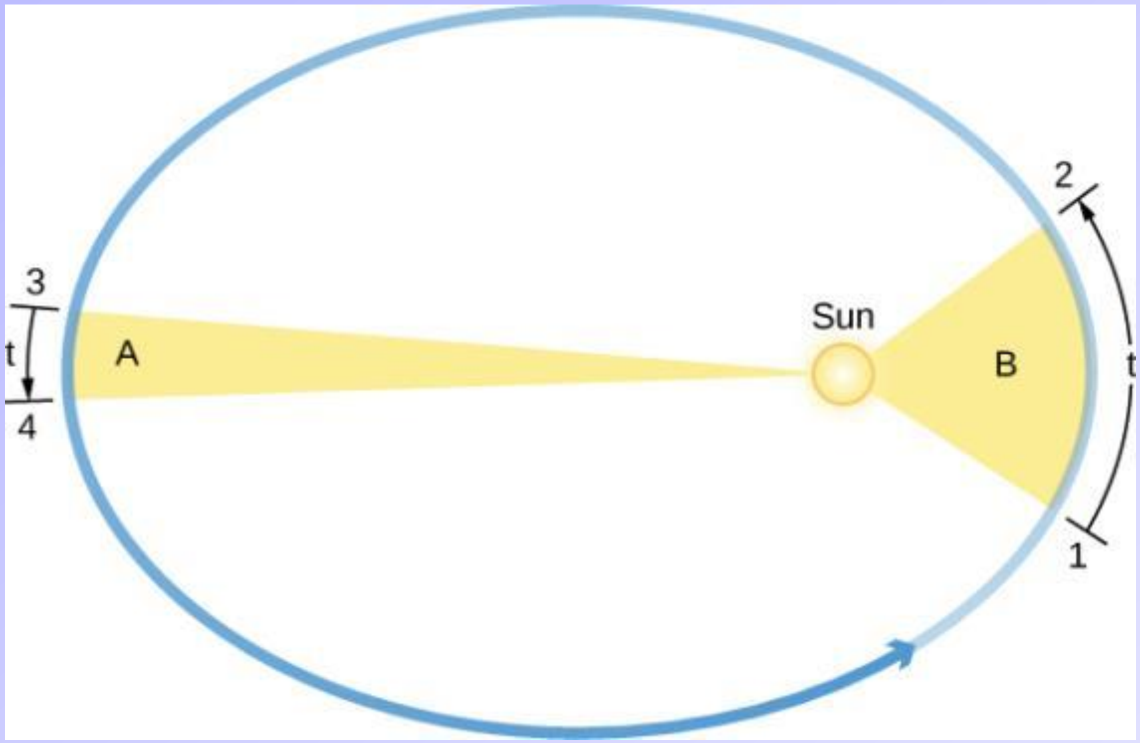


- Sun sits at one of the foci.
- Other focus is empty.

a = semimajor axis

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

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).

PollEv Quiz: PollEv.com/sethaubin

Kepler's 3rd Law

T = orbital period in units of Earth years

a = semimajor axis in AU

$$T^2 = a^3$$

Kepler's 3rd Law

Example: Martian Orbit

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Given T_{Mars} = 1.88 yr,

what is the average distance of **Mars** from the **Sun** ?

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$$\Rightarrow \quad a = (1.88)^{2/3} \simeq 1.52 \text{ AU}$$

On average, Mars is $a = 1.52$ AU from the Sun.