

Today's Topics

Wednesday, January 28, 2026 (Week 1, lecture 3) – Chapters 2 & 3.

A. Ancient Greek physics: radius of the Earth

B. Planetary orbit basics

C. Earth's axis tilt, seasons, precession

D. Stellar parallax

E. Kepler's laws

Reminder: *Problem Set #1 due in class (hard copy) this Friday (Jan. 30).*

Problem Set Resources

➤ **Seth Aubin**

Open office hours and Tuesday & Thursday noon-1pm (room 255).

➤ **Russell Tanner, TA**

Office hours on Thursdays 2-3pm (room 220 ... knock on door for access).

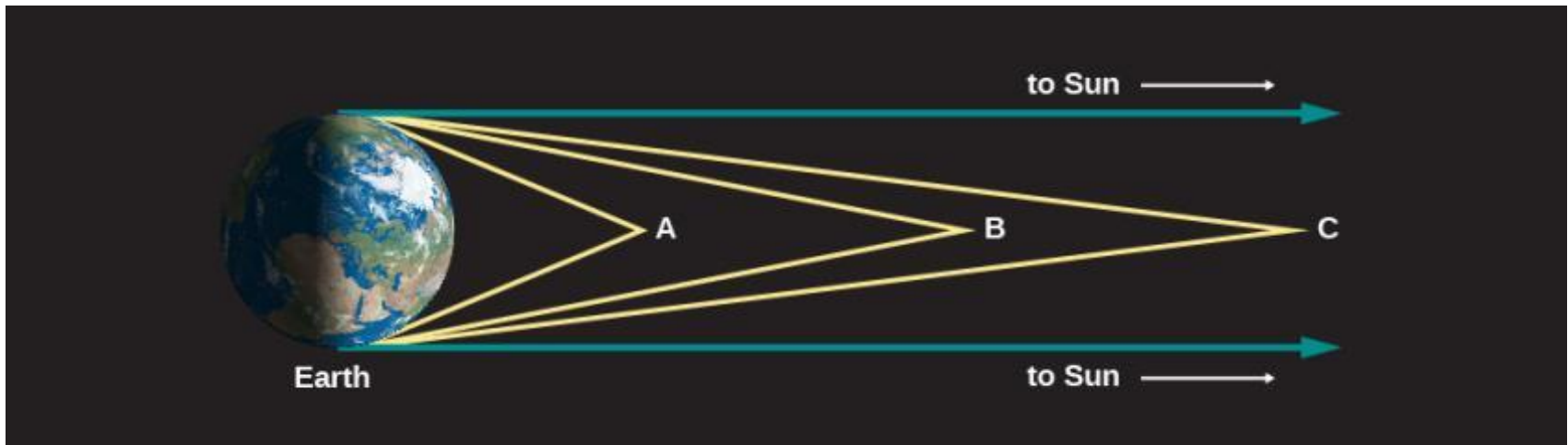
➤ **Free Physics Tutoring** (Society of Physics Students)

Thursdays 6-8 pm in room 122.

Ancient Greek Physics

Determining the Radius of the Earth

Parallel light rays from the sun



[OpenStax: Astronomy]

Light Rays from Space. The more distant an object, the more nearly parallel the rays of light coming from it are.

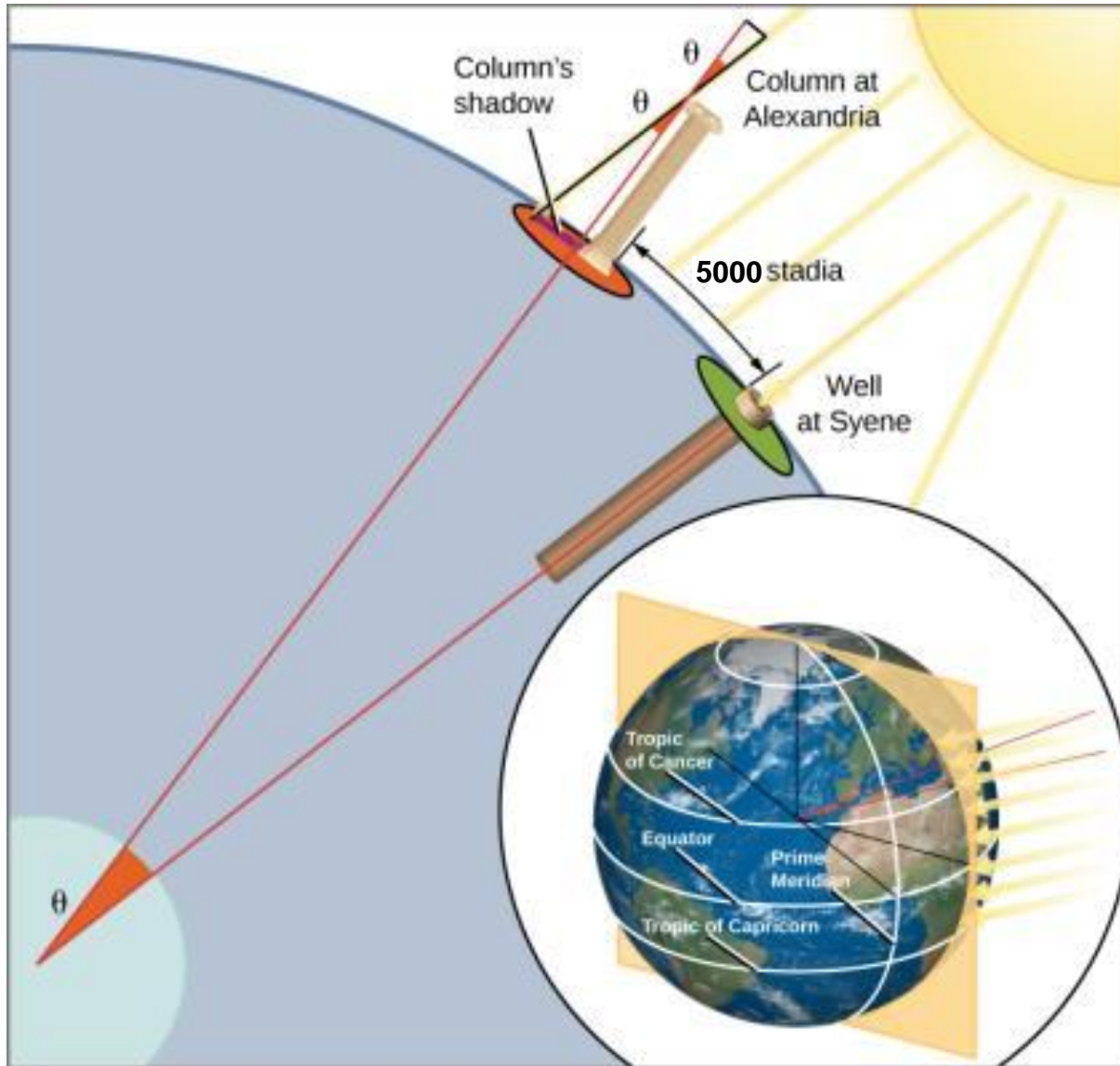
→ Light rays from Sun are quite parallel.

→ Light rays from stars are very parallel.

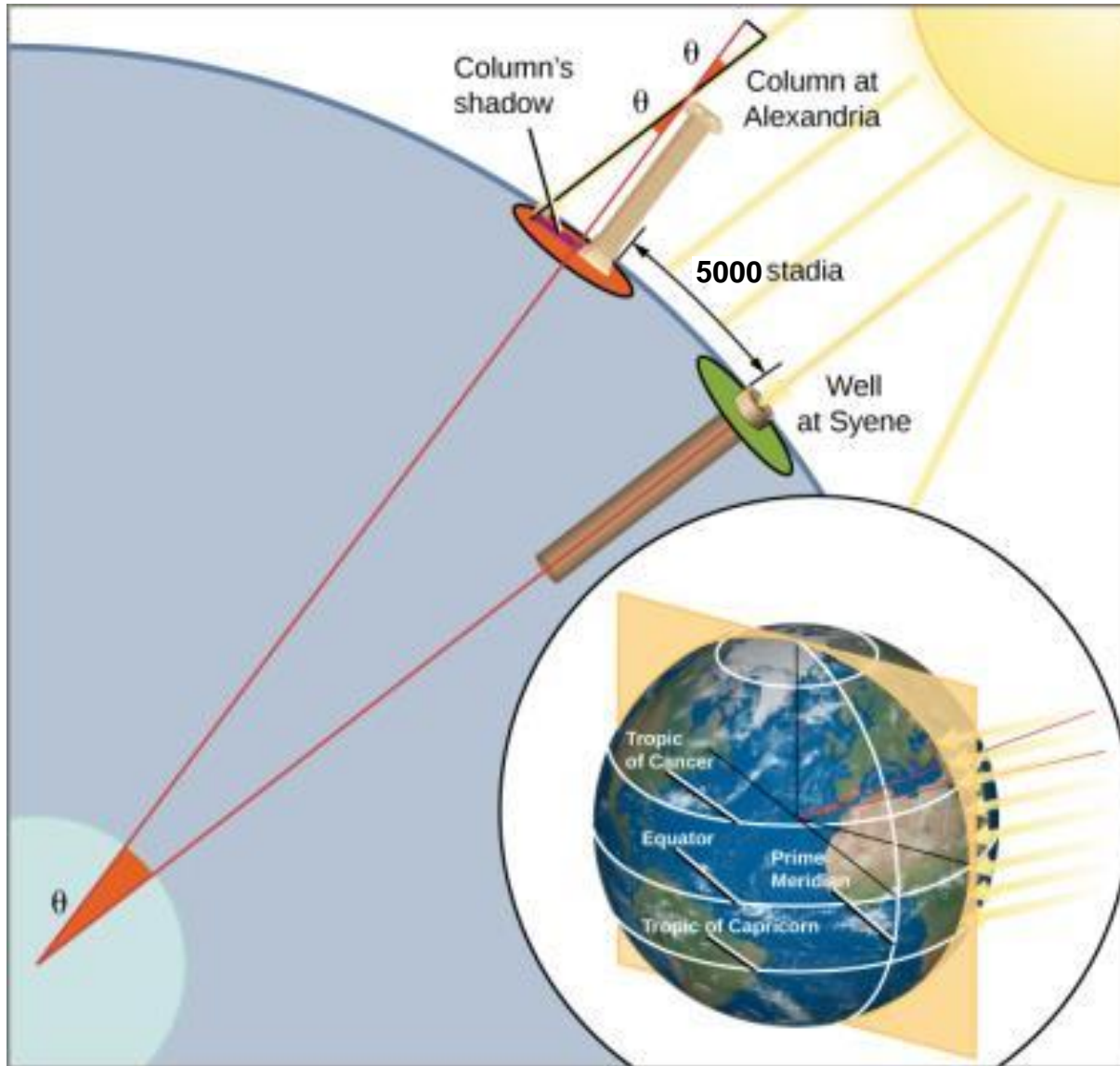
How Eratosthenes Measured the Size of Earth

Eratosthenes (276-194 BC) observed that:

1. A Sun's ray at Syene comes straight down whereas a ray at Alexandria makes an **angle of 7° with the vertical**.



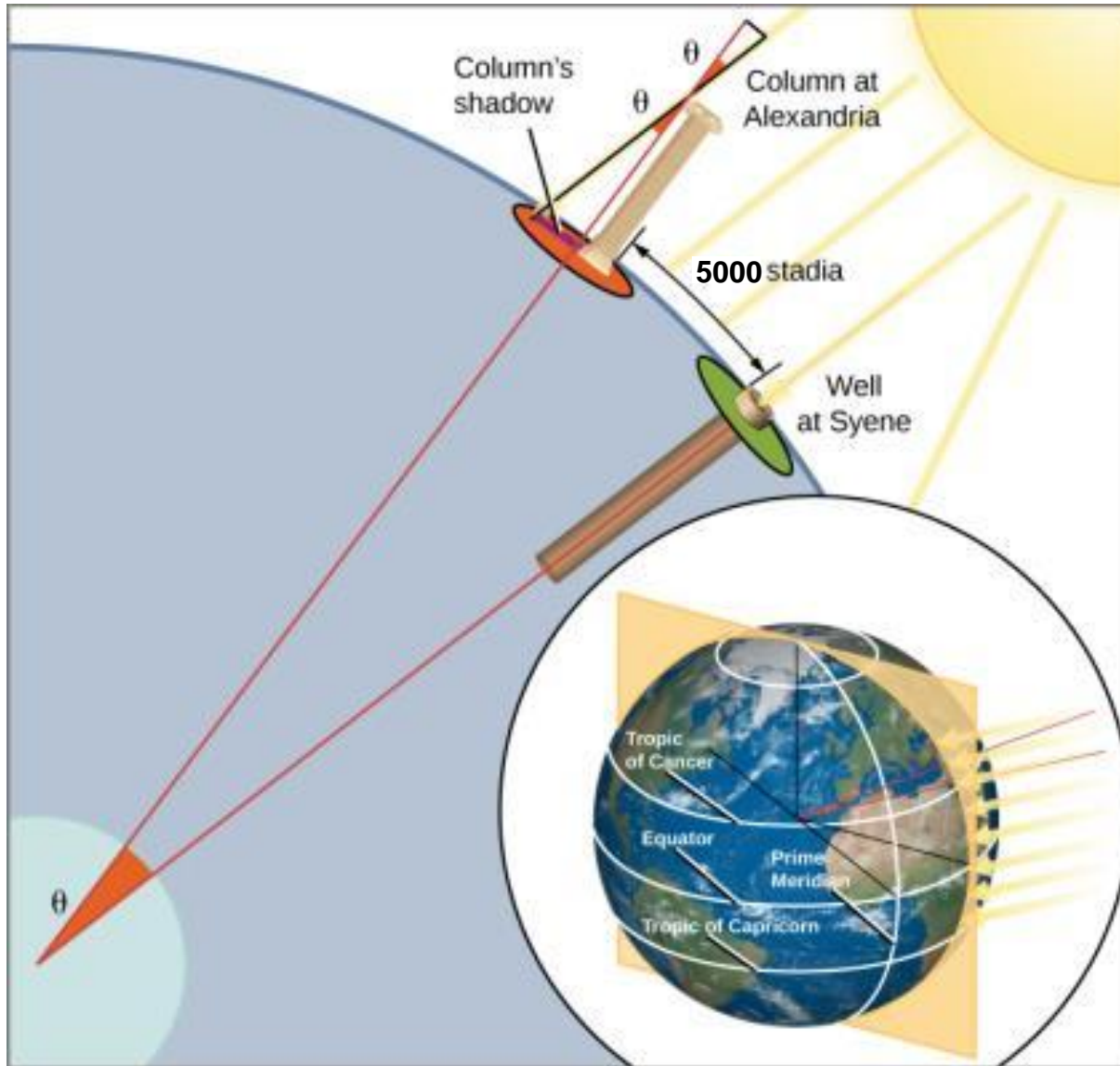
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3. The distance between the two cities, i.e. 5000 stadia, must be **$1/50$ the circumference** of Earth.

How Eratosthenes Measured the Size of Earth

$$\begin{aligned}\text{Circumference of Earth} &= 50 \times 5000 \text{ stadia} \\ &= 250,000 \text{ stadia} \quad (1 \text{ stadia} \sim 180 \text{ m}) \\ &\approx 45,000 \text{ km}\end{aligned}$$

Actual circumference of Earth = 40,000 km

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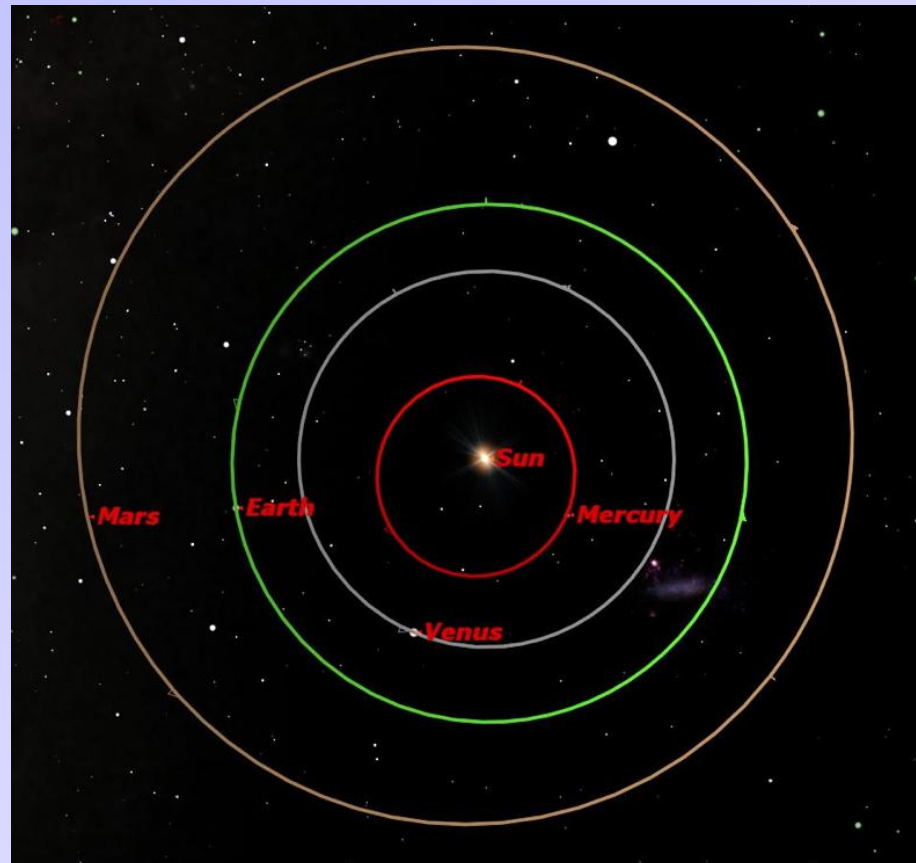
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$$\begin{aligned}\text{Actual circumference of Earth} &= 40,000 \text{ km} \\ \rightarrow \text{Radius} &= 40,000 / 2\pi \approx 6,400 \text{ km}\end{aligned}$$

Planetary Orbit Basics

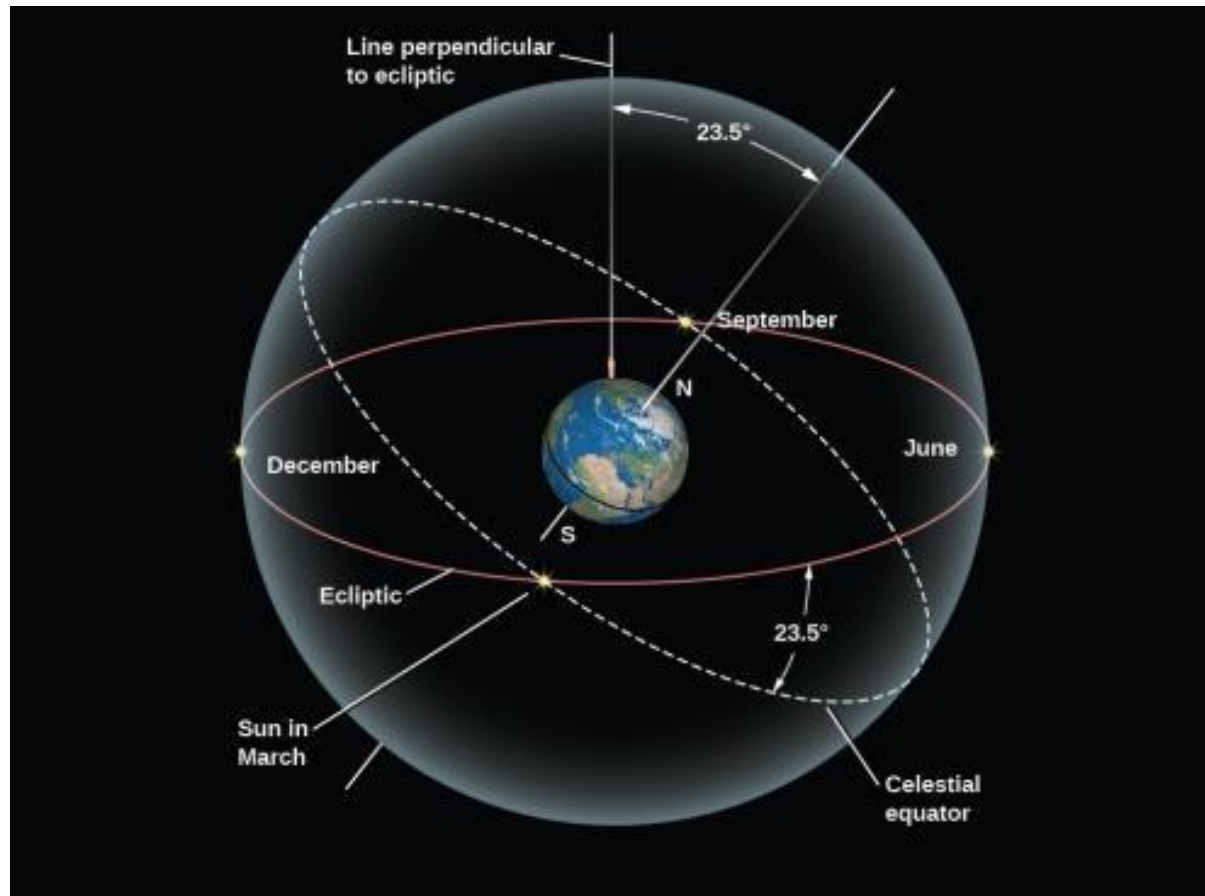
- The planets orbit the Sun following a roughly “circular path.”
- These “circular paths” are actually somewhat elliptical.
- The orbits all lie in more or less in the same plane.

Inner Solar System
planetary orbits



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

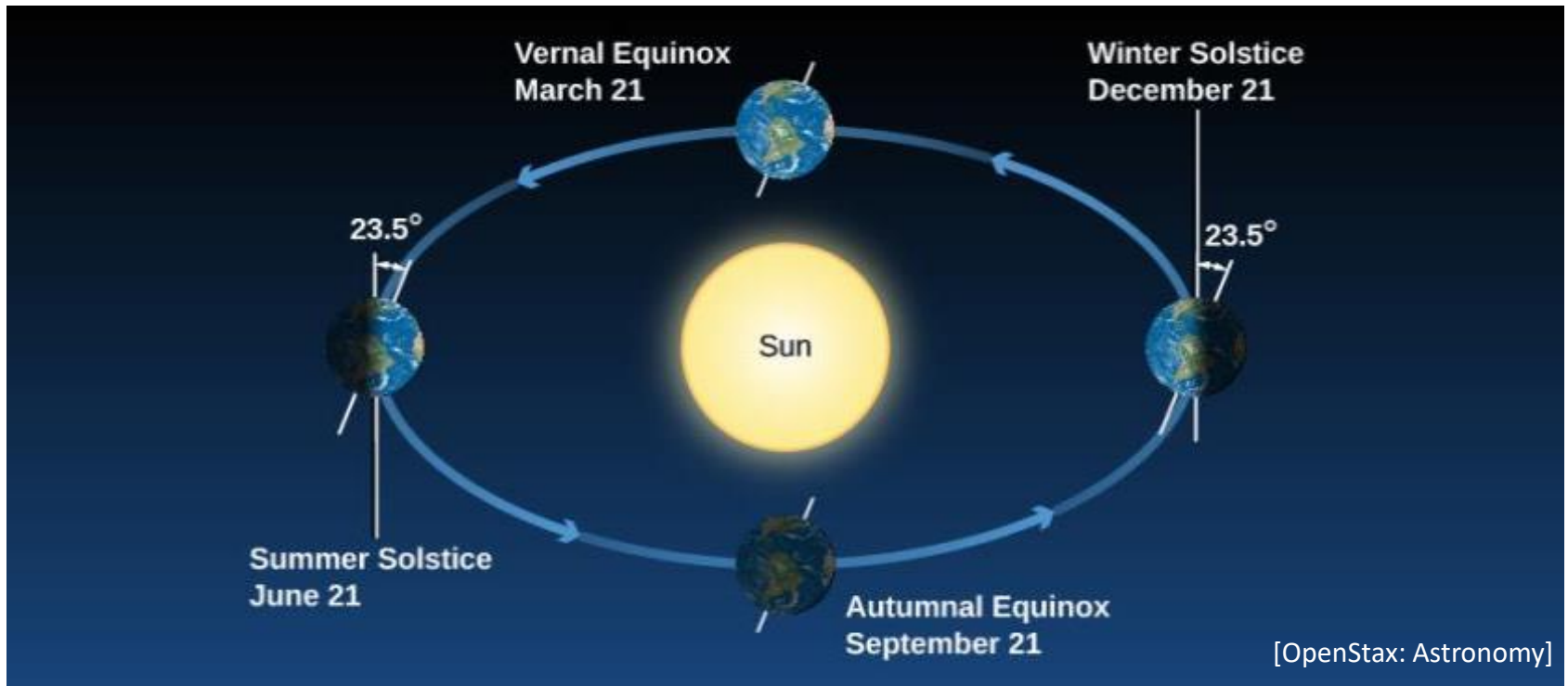
Tilt of Earth's Rotation Axis



[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 $\theta = 23.5^\circ$** 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>]

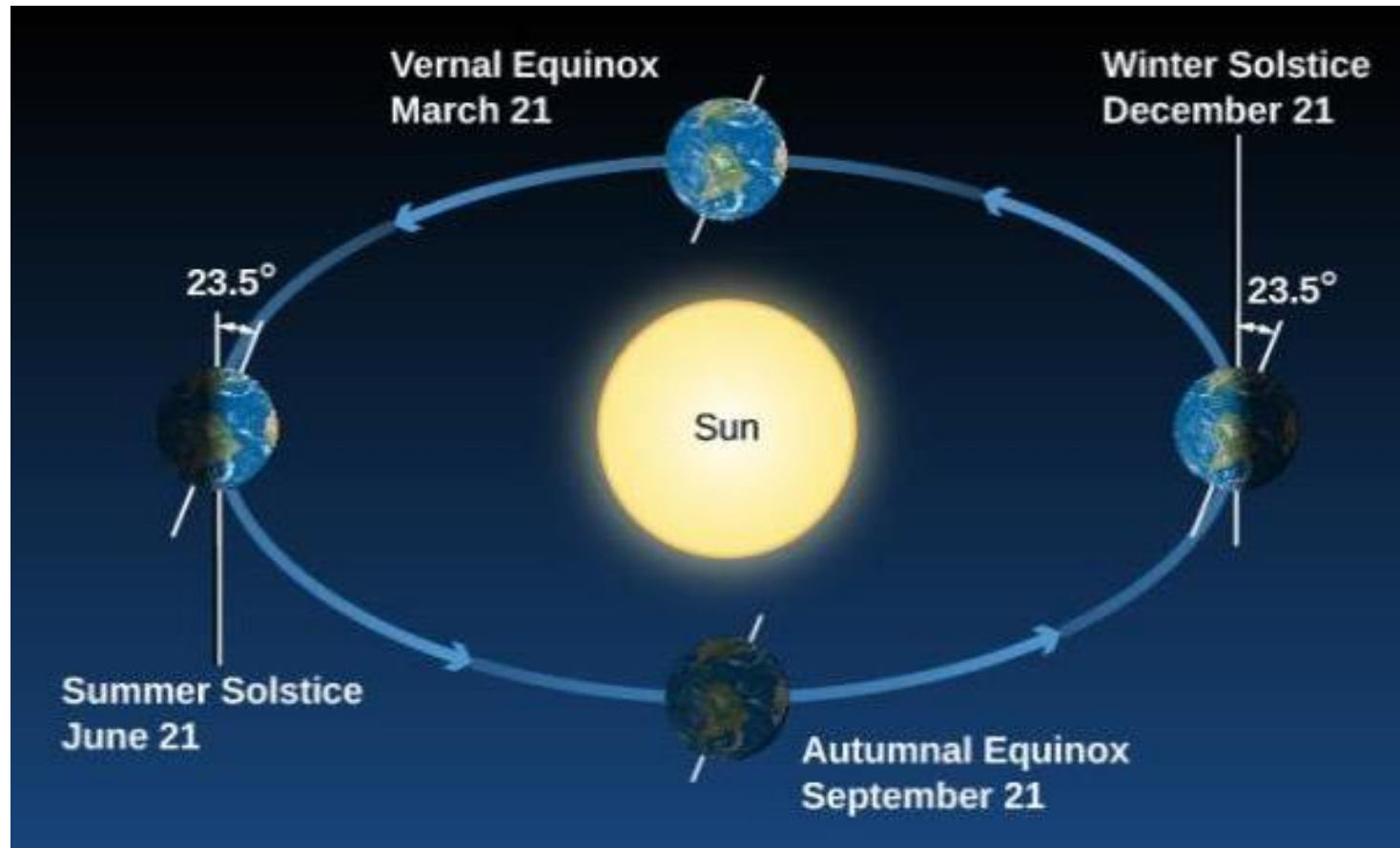
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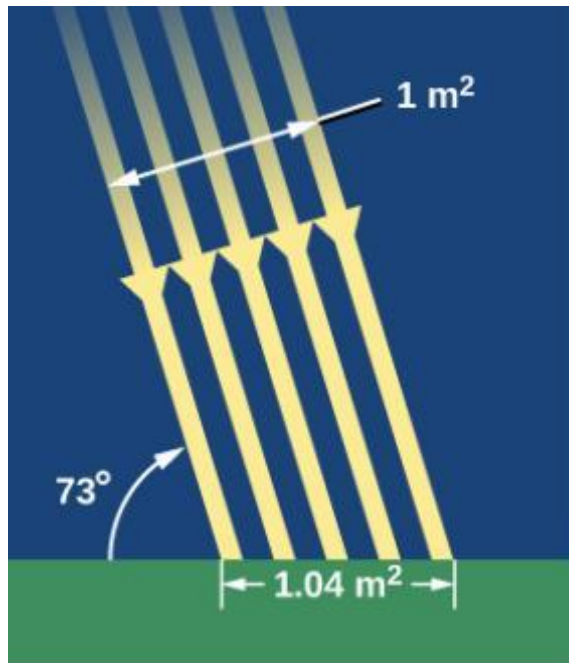
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Earth's tilt & the Seasons

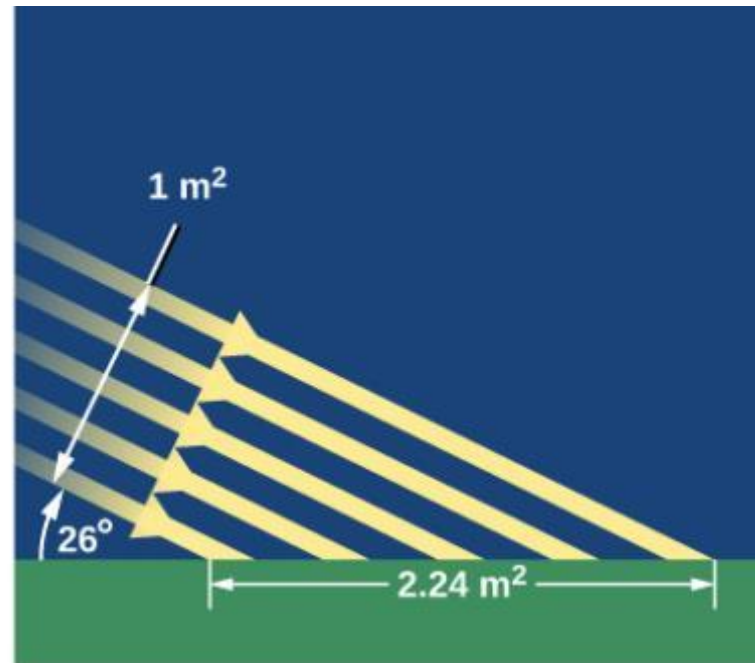


- The summer and winter seasons are determined by the **amount of sunlight** that fall in a given location on Earth.
- Amount of sunlight = light power per unit area
Recall: power = energy per time

Earth's tilt & the Seasons



(a) Summer



(b) Winter

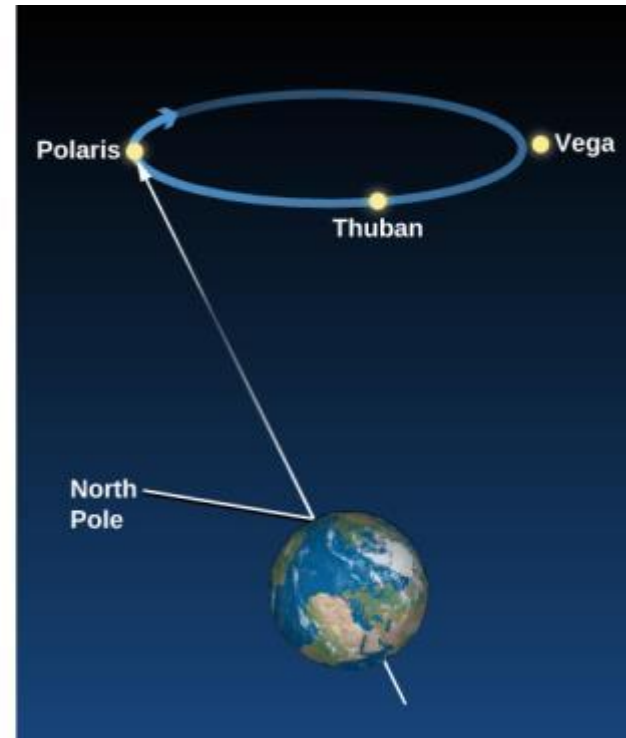
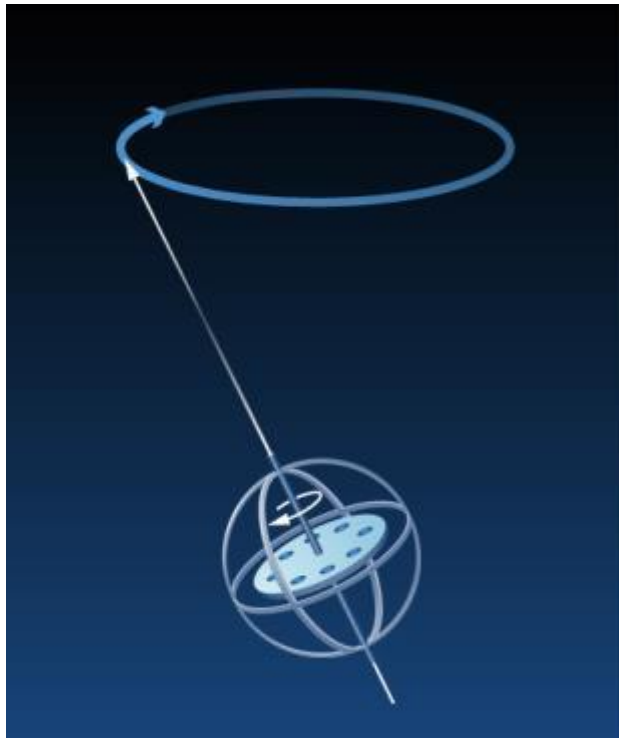
- (a) In **summer**, the Sun appears high in the sky and its rays hit Earth more directly, spreading out less.
- (b) In **winter**, the Sun is low in the sky and its rays spread out over a much wider area, becoming less effective at heating the ground.

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

PollEv Quiz: PollEv.com/sethaubin

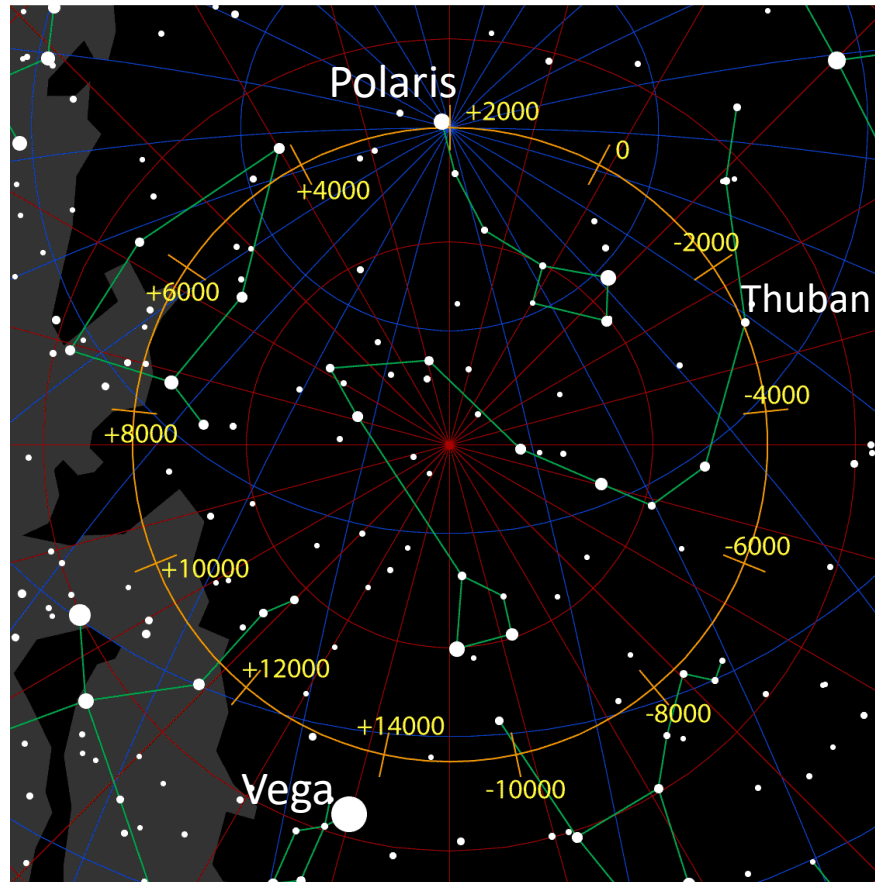
Precession of Earth's Axis

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

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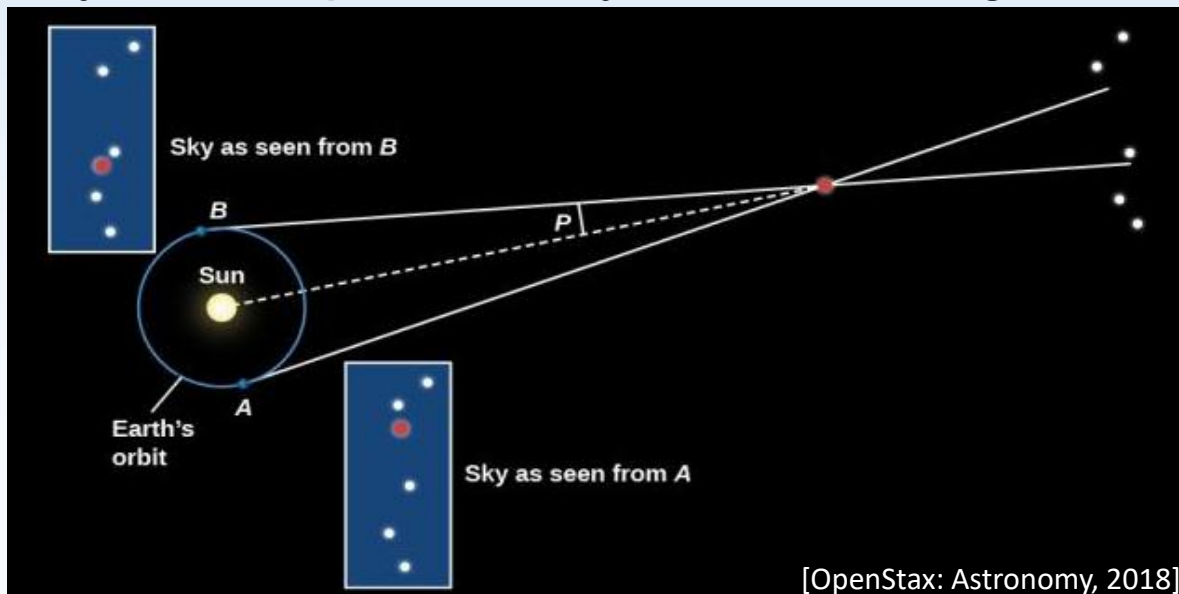
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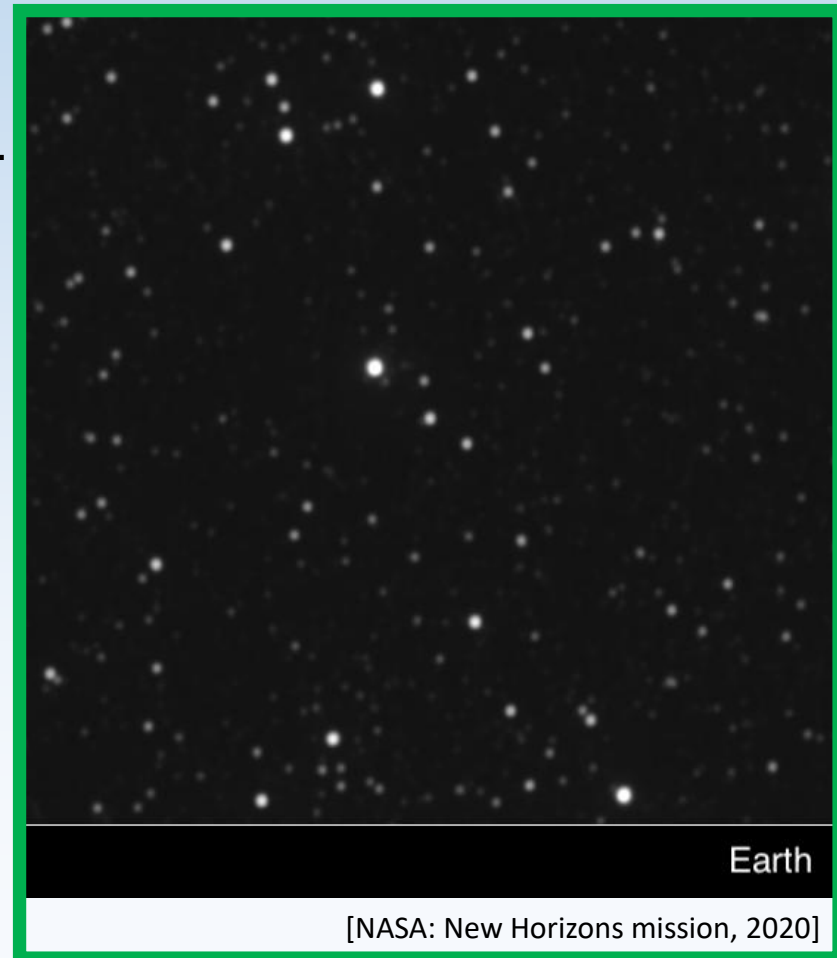


Stellar Parallax → Stellar Distances

- 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.
- With a large baseline, the effect is much larger.

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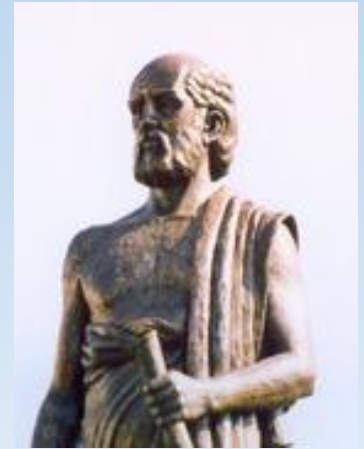
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- Most accurate method for measuring stellar distances.
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 - The **New Horizons** spacecraft to **Pluto** (and beyond) measured a large parallax for Proxima Centauri.



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.

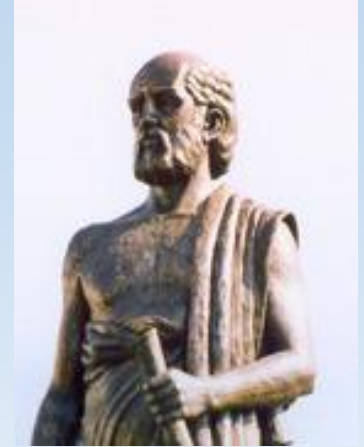


Aristarchus of Samos
[Wikipedia, modern statue at
Aristotle U. of Thessaloniki]

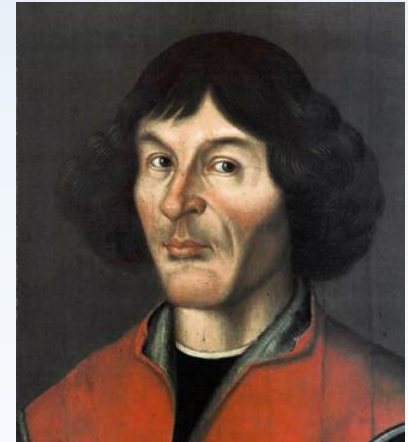
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- **Copernicus** (1473-1543 BC) re-introduced the heliocentric model.
 - Same predictive power as Ptolemaic epicycle model, but simpler.
 - Simple explanation for the retrograde motion of planets.
 - Criticized because stellar parallax was not yet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



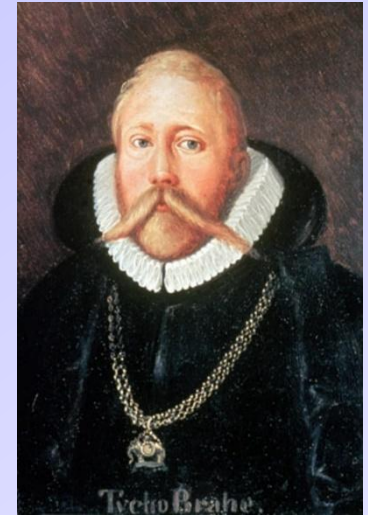
Aristarchus of Samos
[Wikipedia, modern statue at Aristotle U. of Thessaloniki]



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

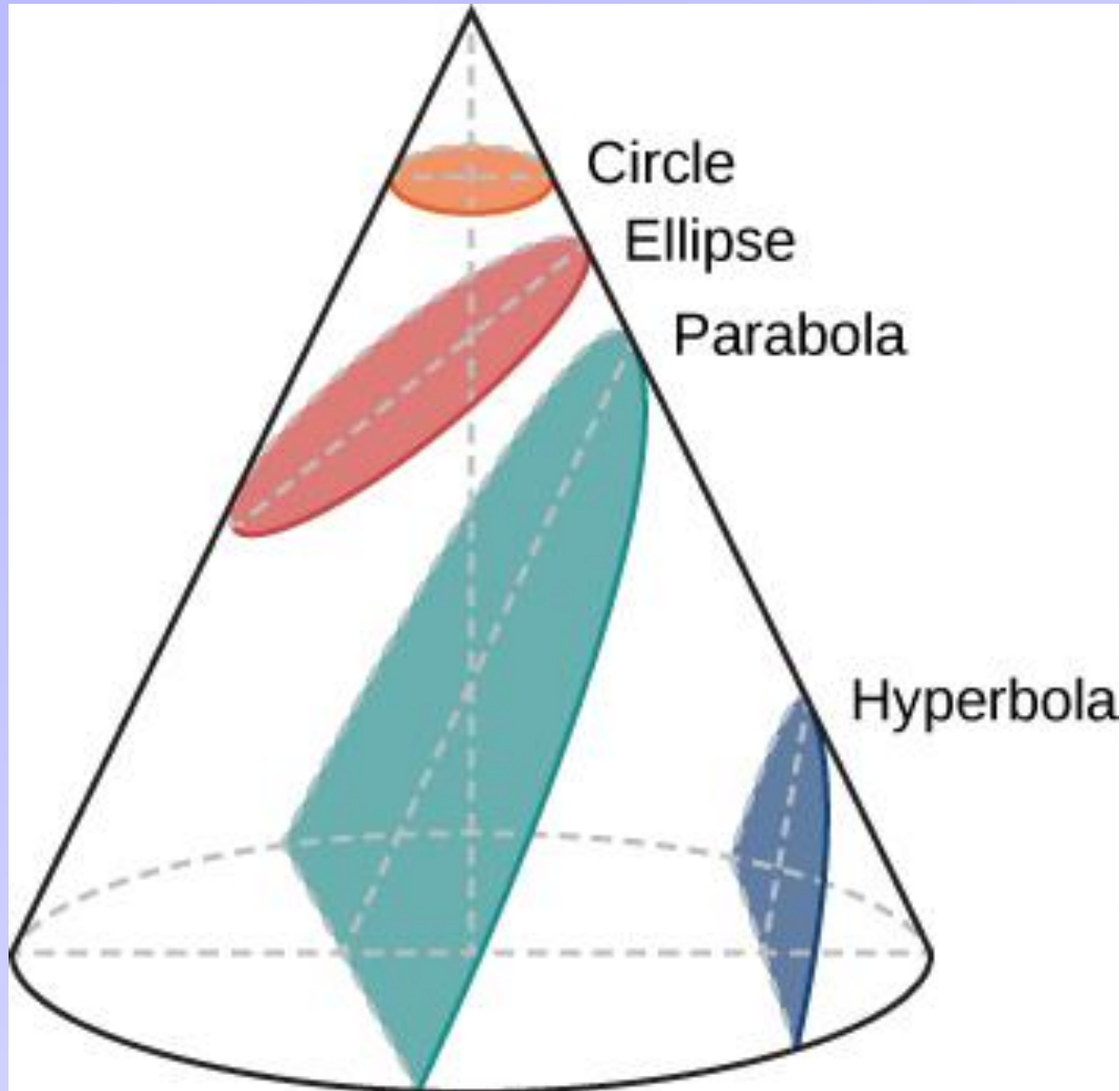
1st Law: The orbits of all planets are **ellipses**.

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

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

[fine print: the “=” depends on units used]

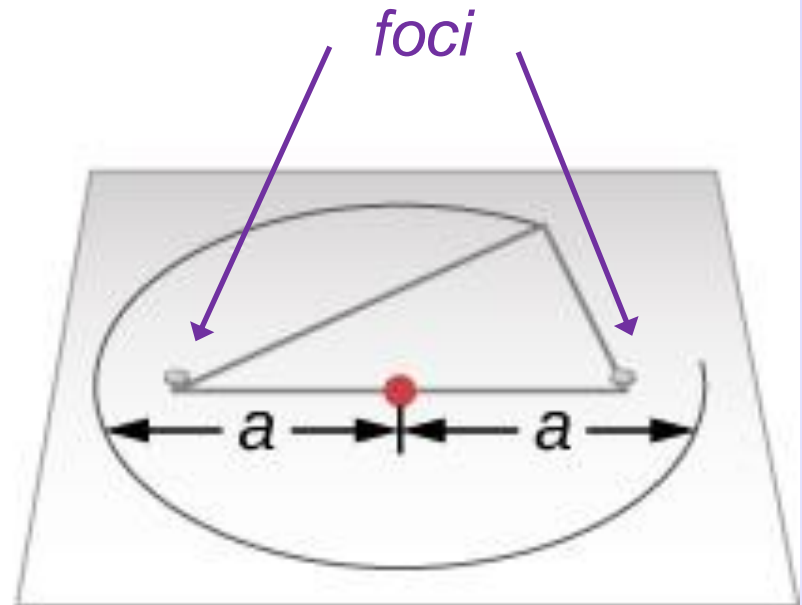
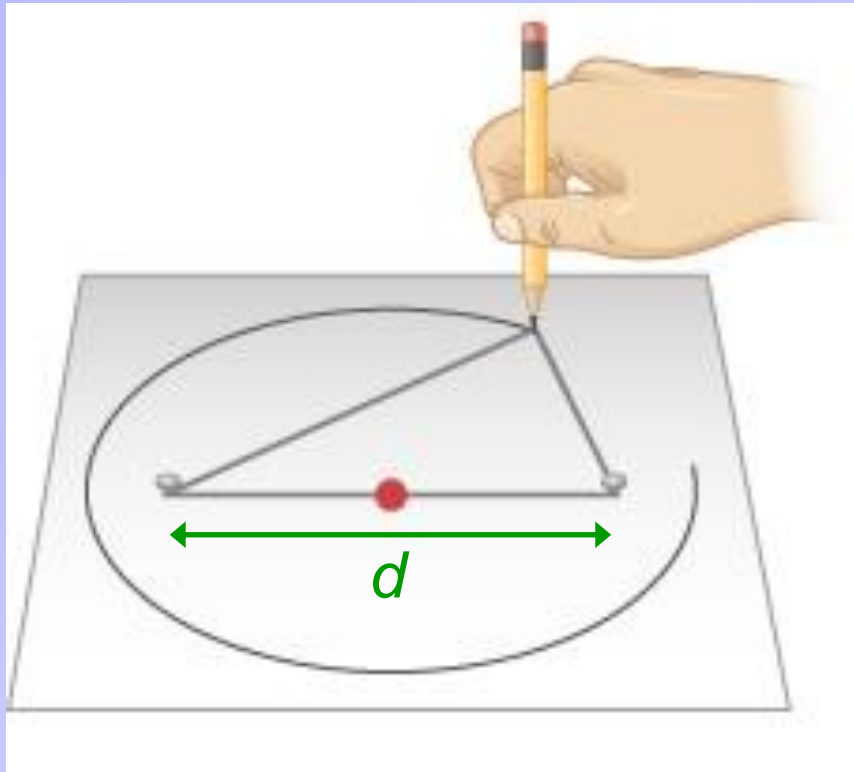
Kepler's 1st Law – Conic Sections



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

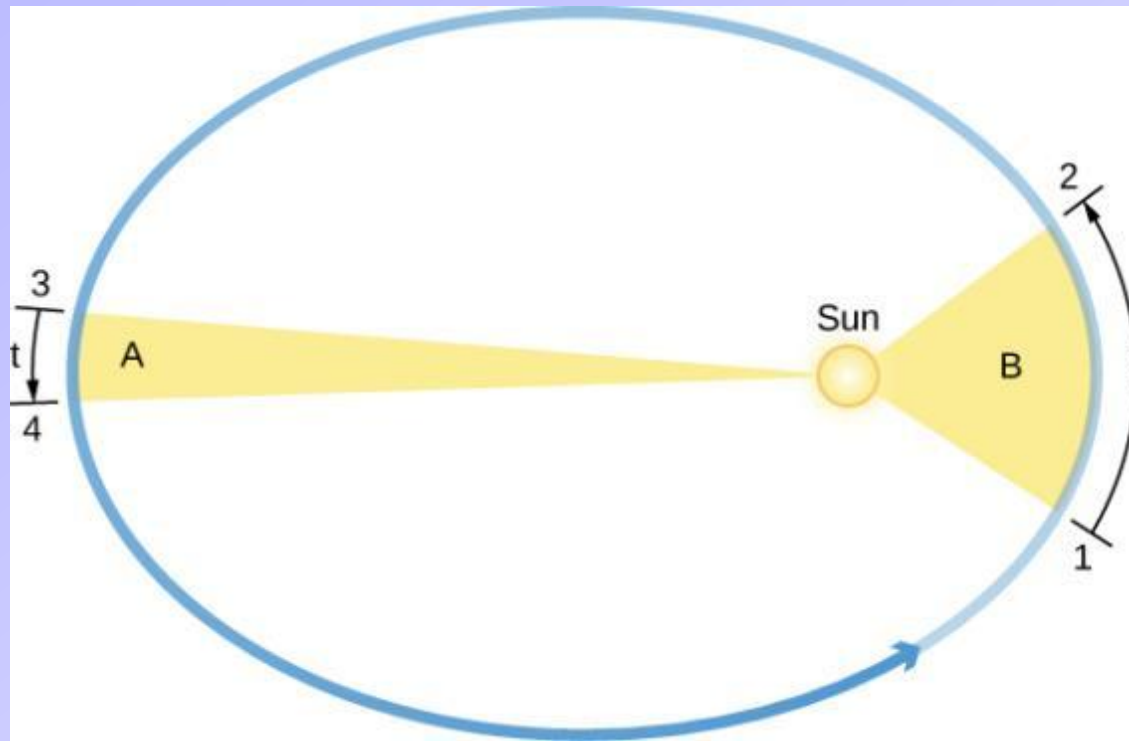


- Sun sits at one of the foci.
- Other focus is empty.

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).

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

$$T^2 = a^3$$

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Given $T_{\text{Mars}} = 1.88 \text{ yr}$,

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

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

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