

# 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).

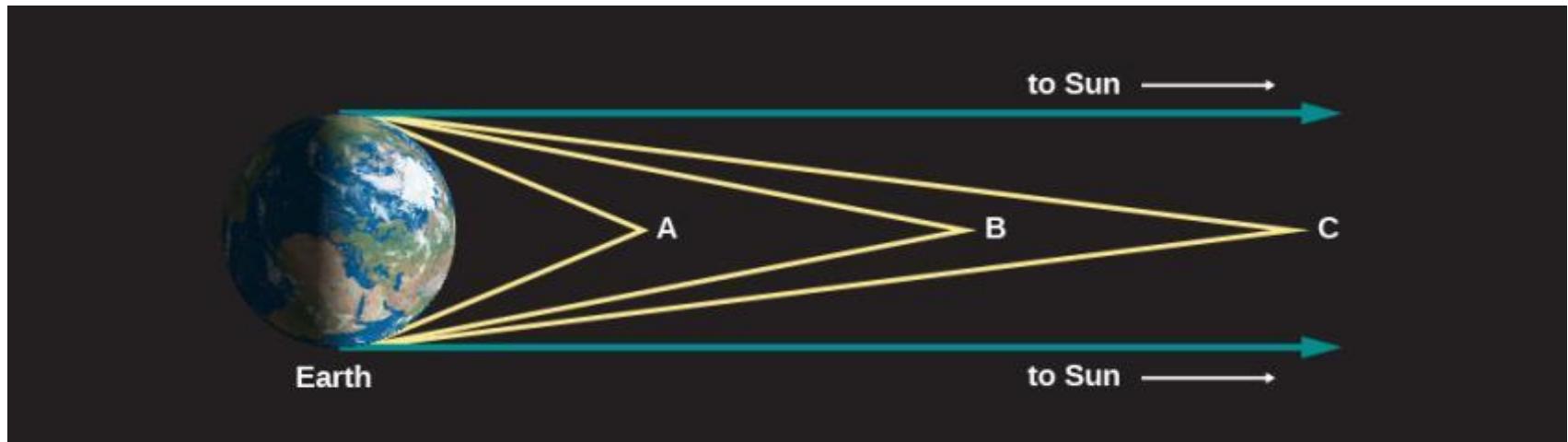
- **Free Physics Tutoring** (Society of Physics Students)

Thursdays 6-8 pm in room 122.

# **Ancient Greek Physics**

## **Determining the Radius of the Earth**

# Parallel light rays from the sun



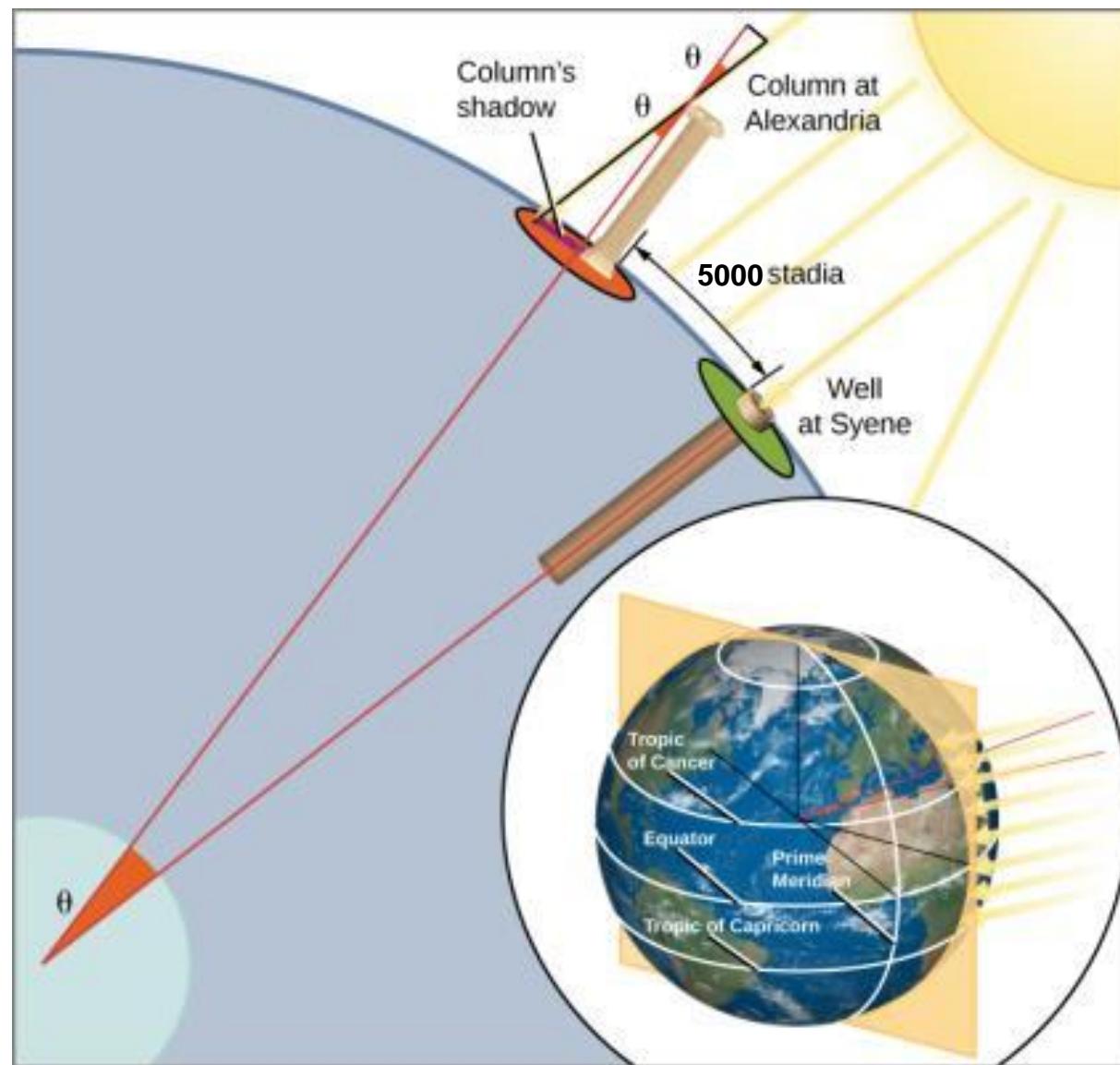
[OpenStax: Astronomy]

**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.

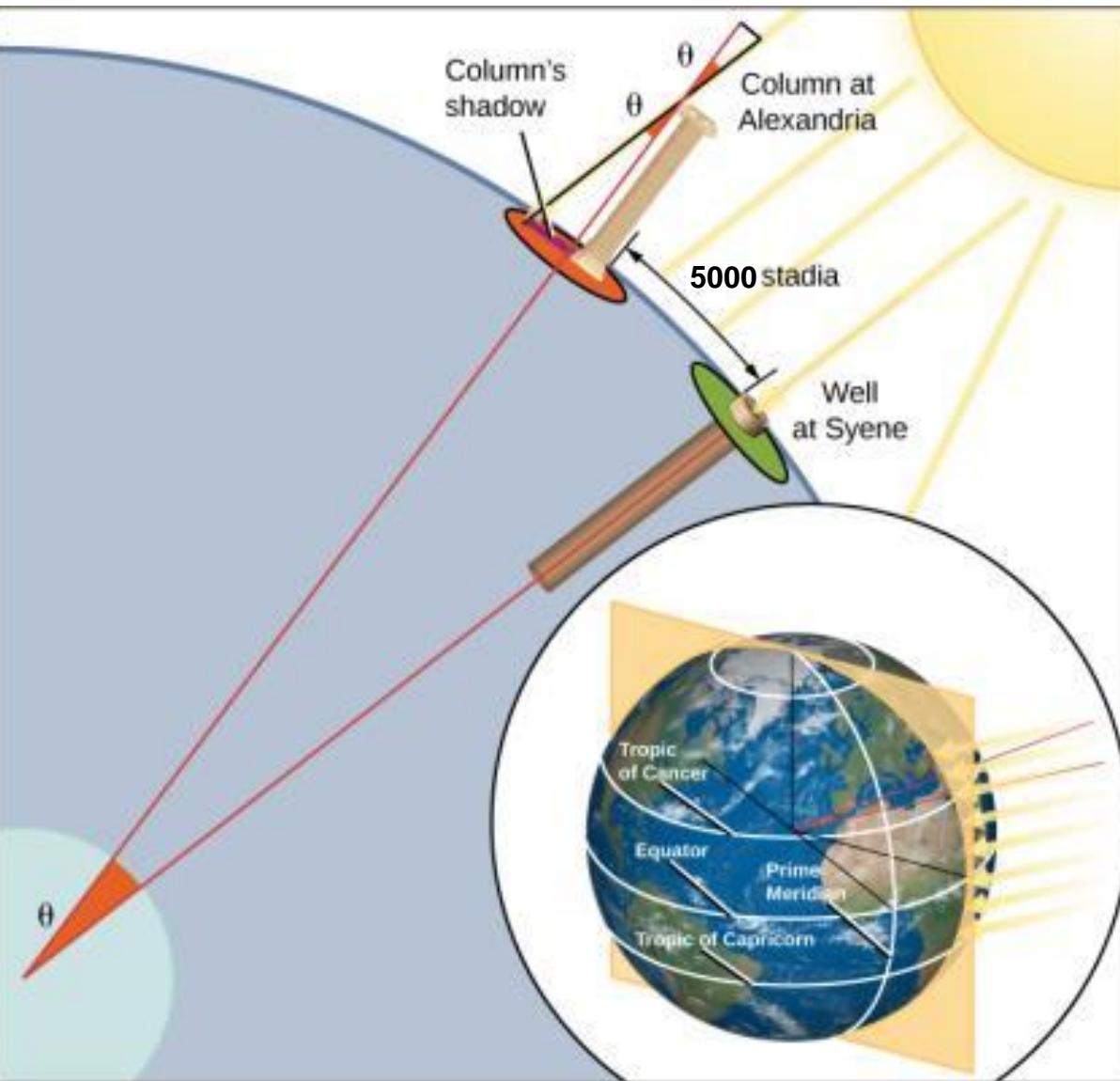
# How Eratosthenes Measured the Size of Earth



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  $7^\circ$  with the vertical.**

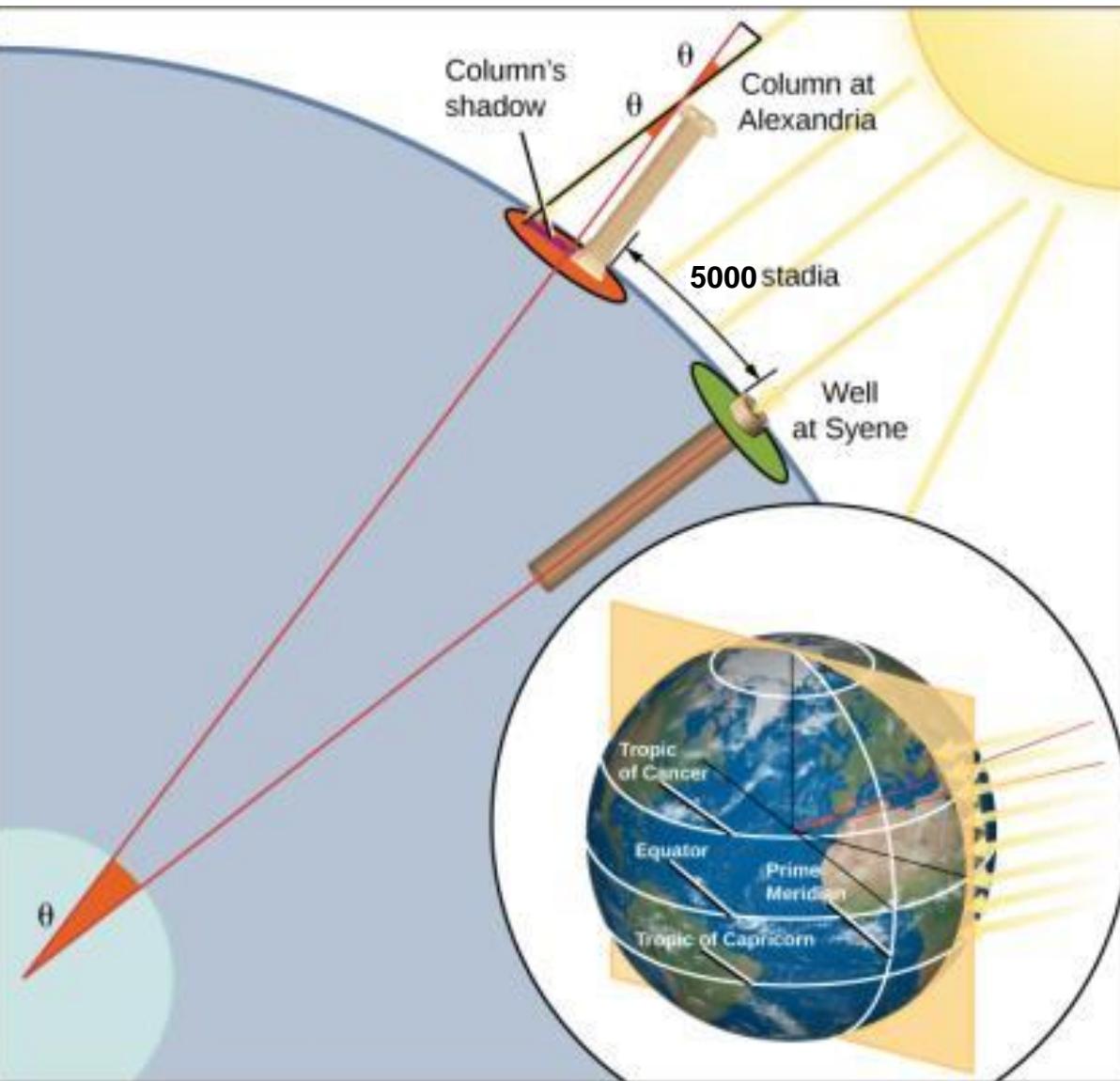
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3. The distance between the two cities, i.e. 5000 stadia, must be  **$1/50$  the circumference** of Earth.

# How Eratosthenes Measured the Size of Earth

Circumference of Earth =  $50 \times 5000$  stadia

= 250,000 stadia      (*1 stadia ~ 180 m*)

≈ 45,000 km

Actual circumference of Earth = 40,000 km

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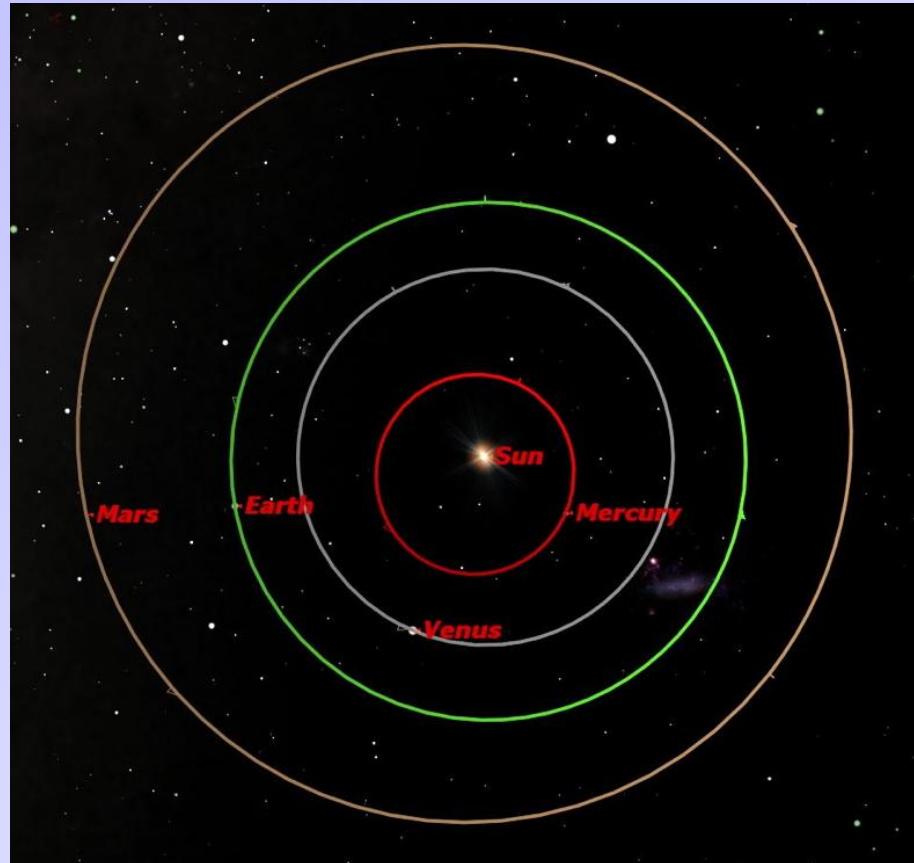
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→ Radius =  $40,000/2\pi \approx 6,400$  km

# Planetary Orbit Basics

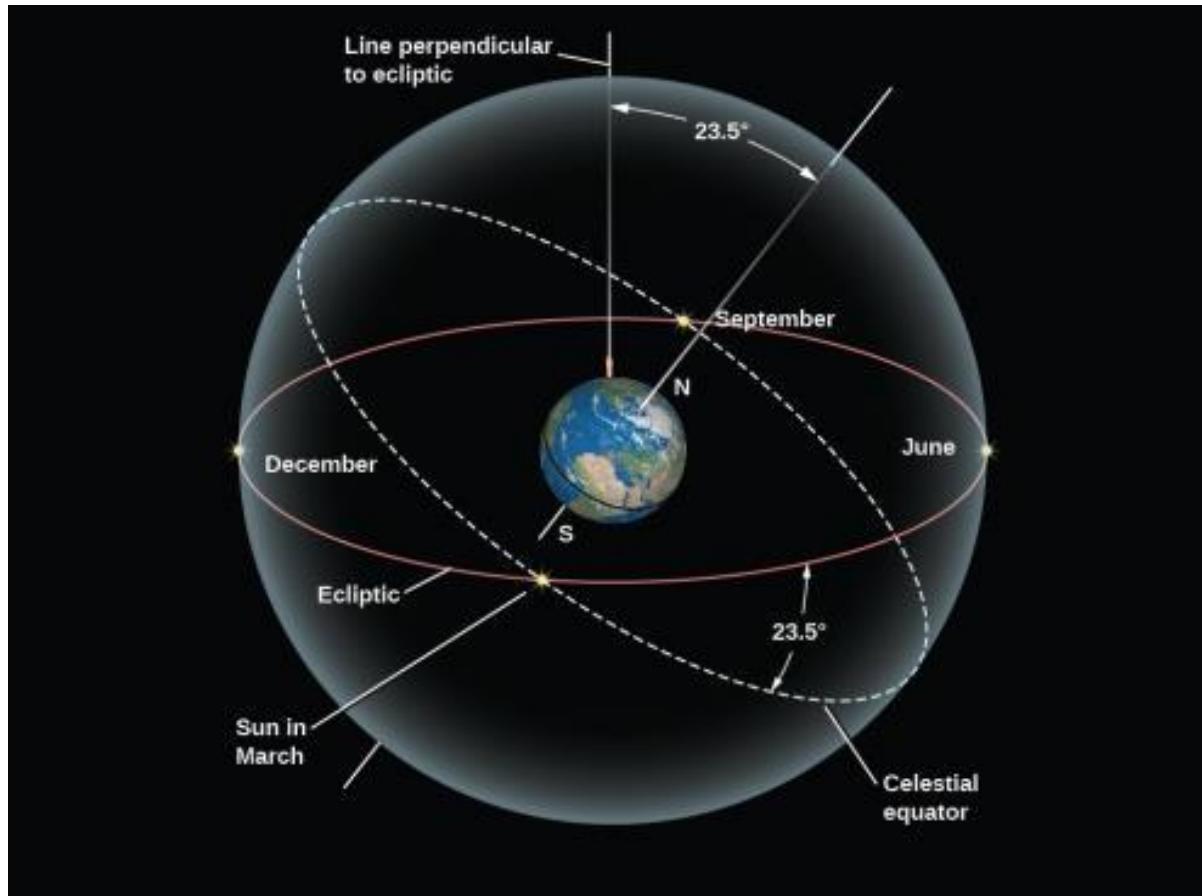
- The planets orbit the Sun following a roughly “circular path.”
- These “circular paths” are actually somewhat elliptical.
- The orbits all lie in more or less in the same plane.

Inner Solar System  
planetary orbits



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

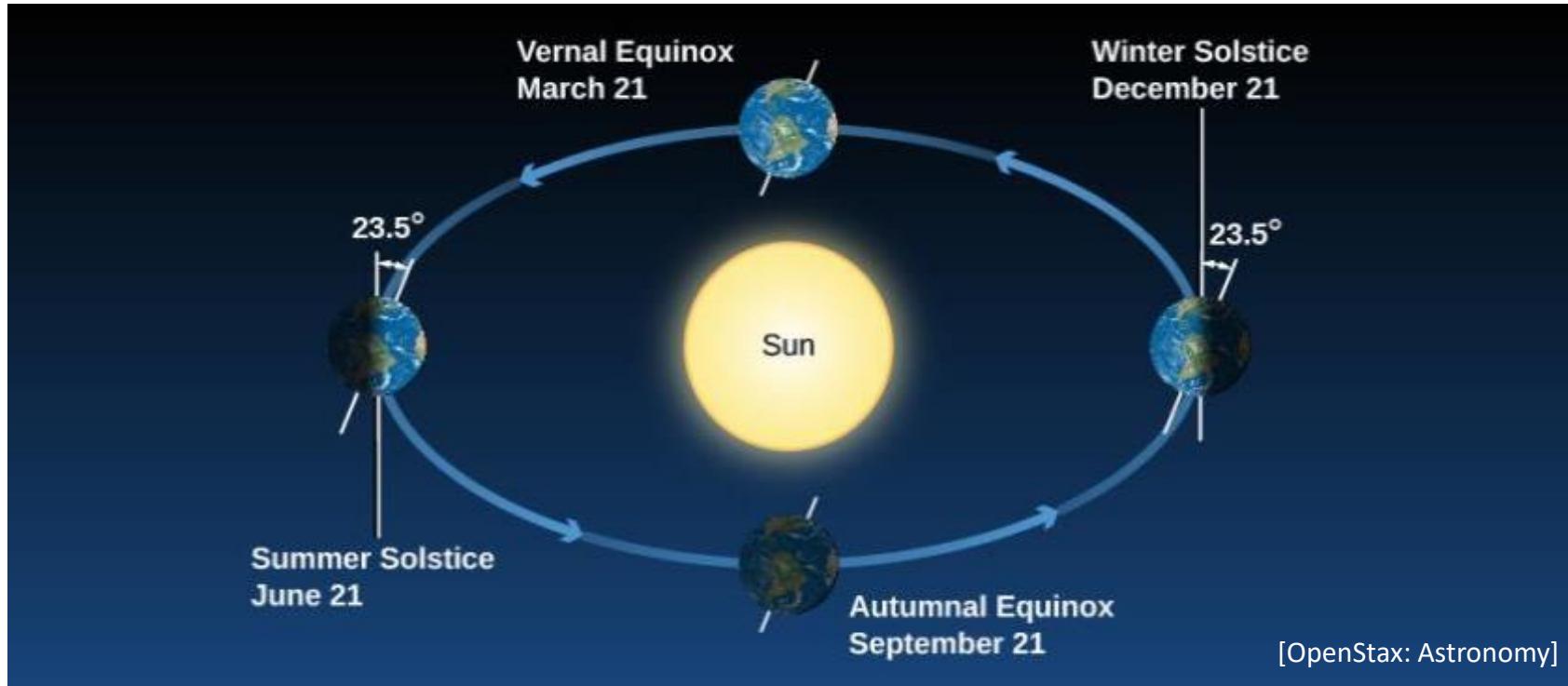
# Tilt of Earth's Rotation Axis



[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



[OpenStax: Astronomy]

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> ]

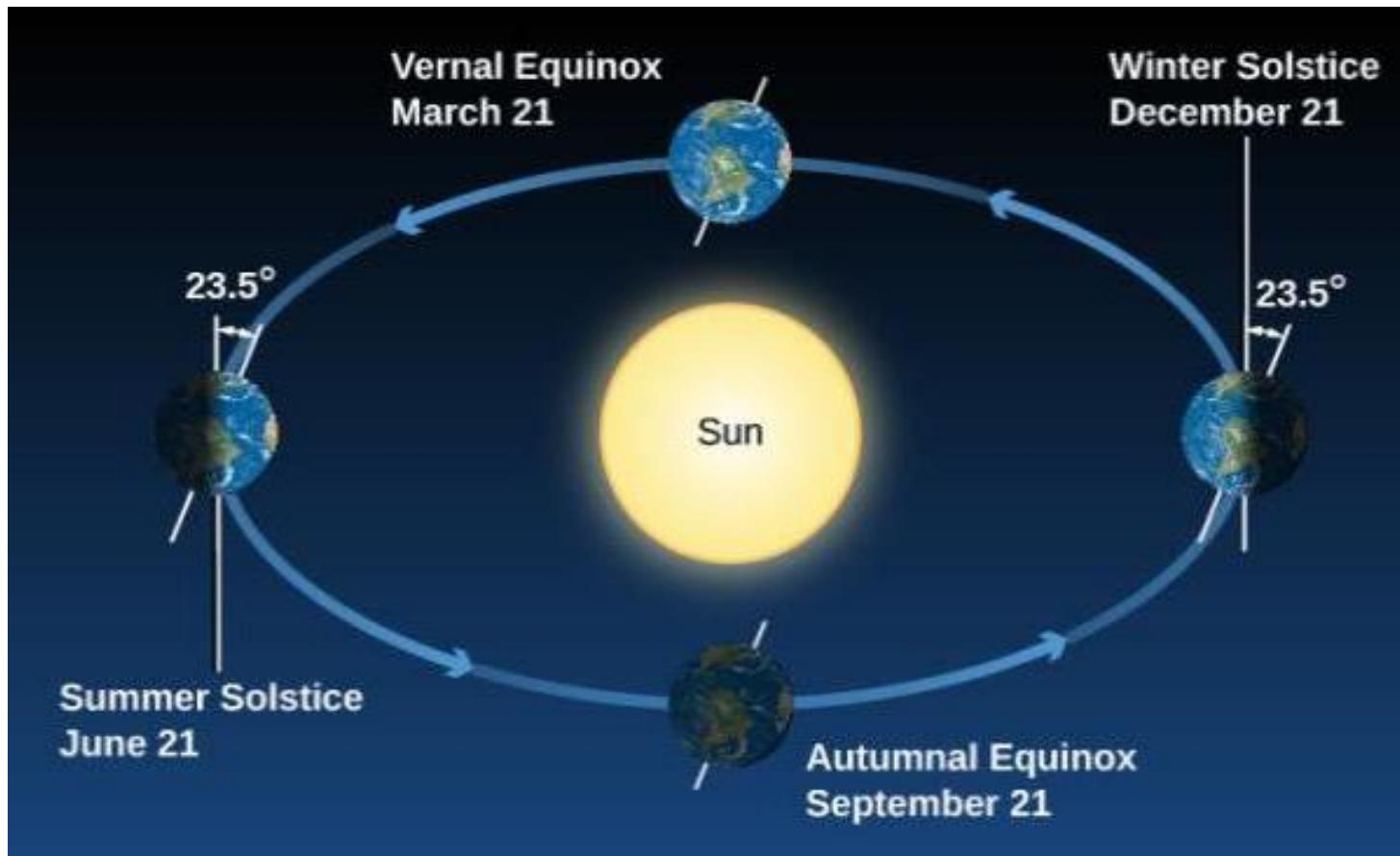
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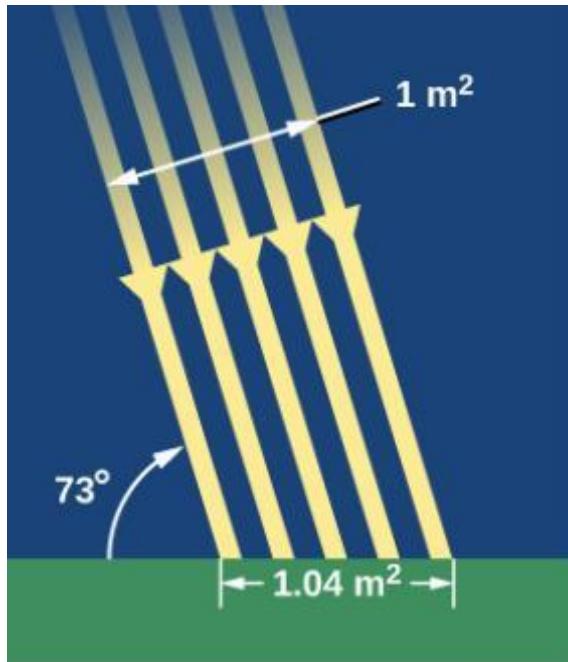
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# Earth's tilt & the Seasons

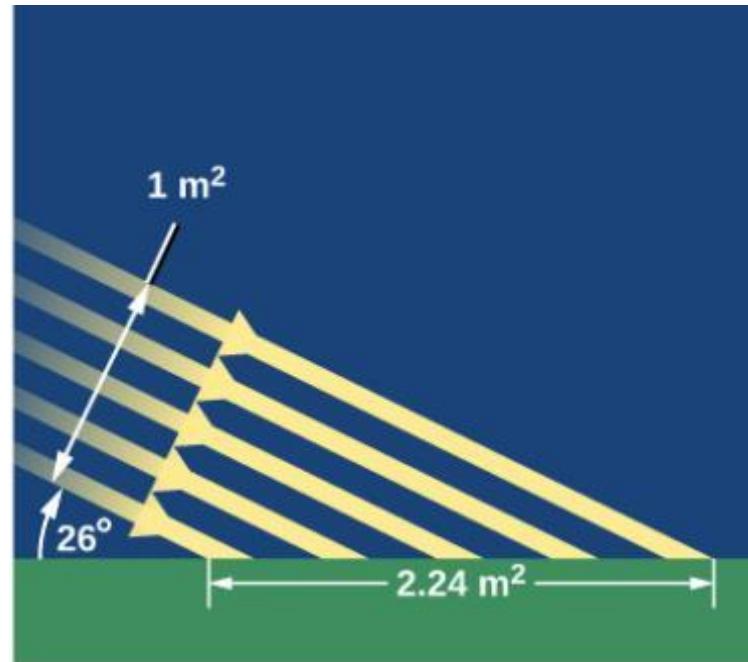


- The summer and winter seasons are determined by the **amount of sunlight** that fall in a given location on Earth.
- Amount of sunlight = light power per unit area  
Recall: power = energy per time

# Earth's tilt & the Seasons



(a) Summer



(b) Winter

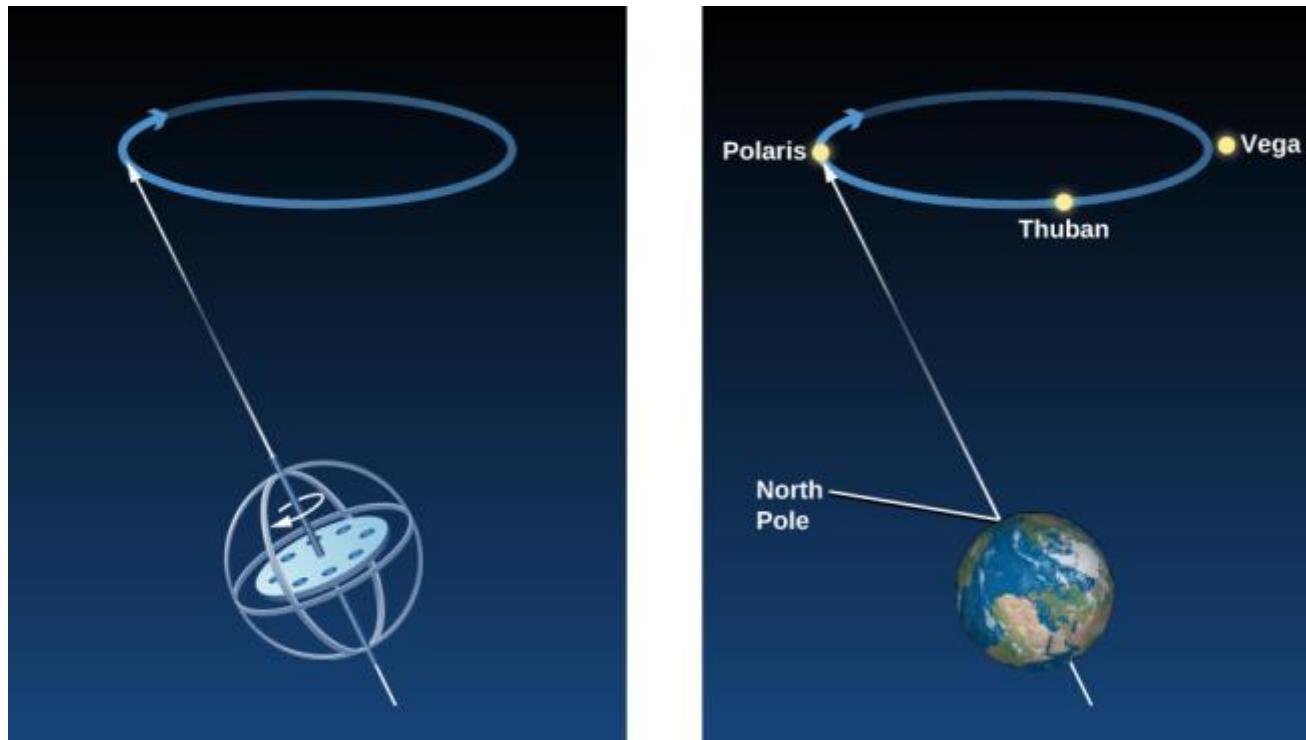
- (a) In **summer**, the Sun appears high in the sky and its rays hit Earth more directly, spreading out less.
- (b) In **winter**, the Sun is low in the sky and its rays spread out over a much wider area, becoming less effective at heating the ground.

Sun's light intensity on Earth  $\approx 1$  Kilowatt per square meter =  $1 \text{ kW/m}^2$

**PollEv Quiz: [PollEv.com/sethaubin](https://PollEv.com/sethaubin)**

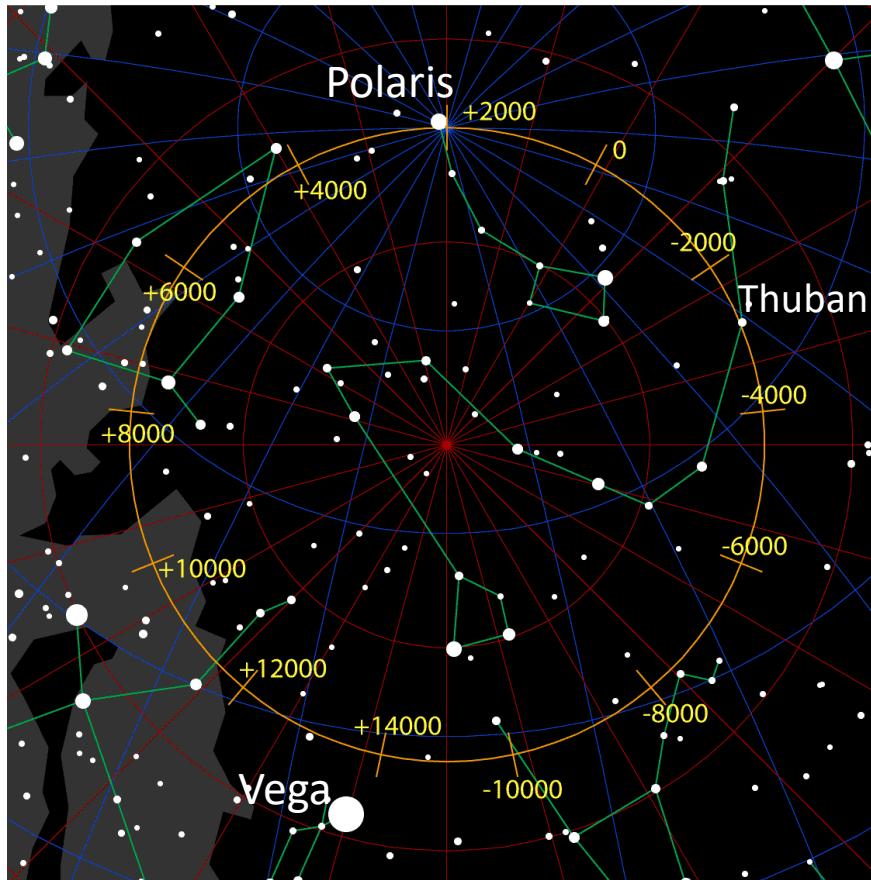
# Precession of Earth's Axis

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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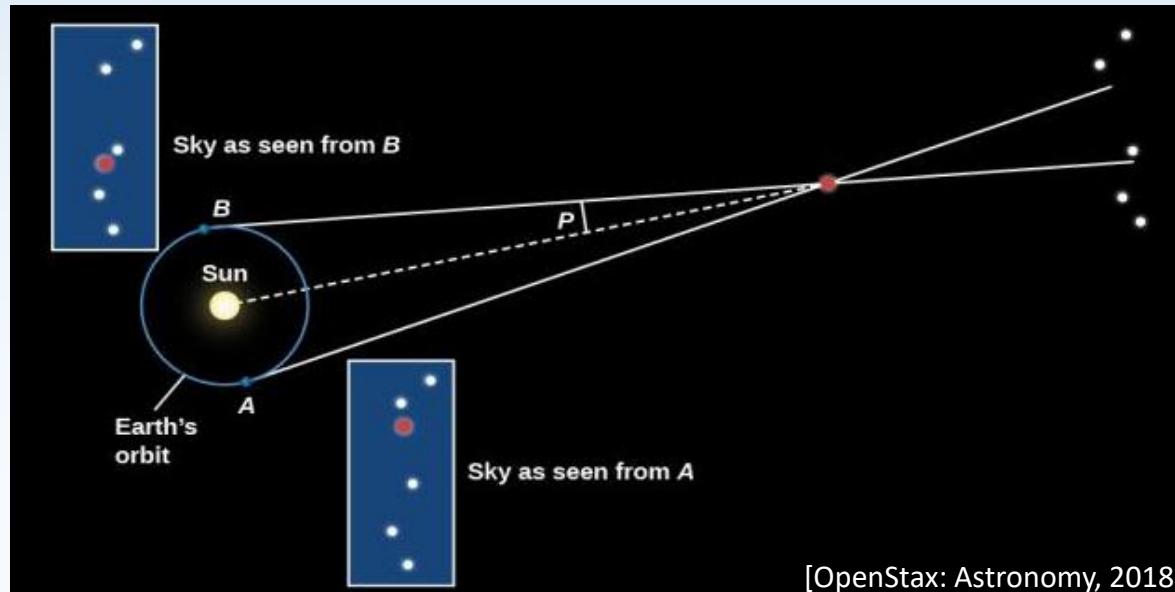
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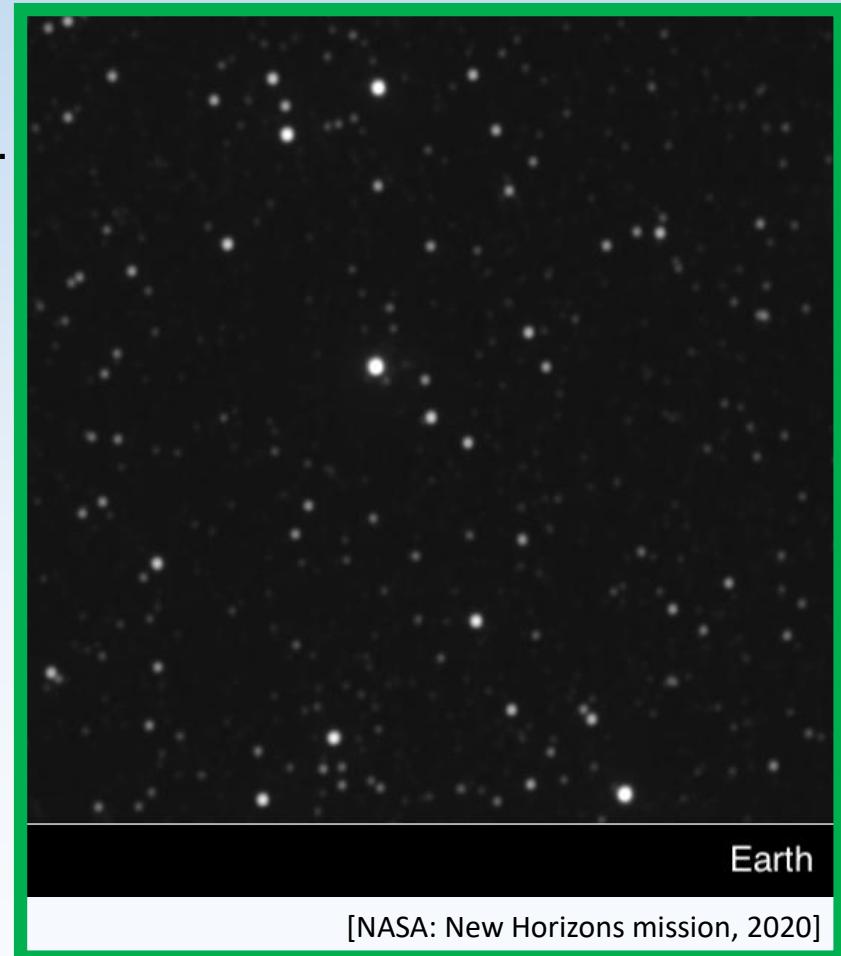


## Stellar Parallax → Stellar Distances

- Stellar parallax is really small, because even nearby stars are very far away.
- Requires a powerful telescope
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- Most accurate method for measuring stellar distances.
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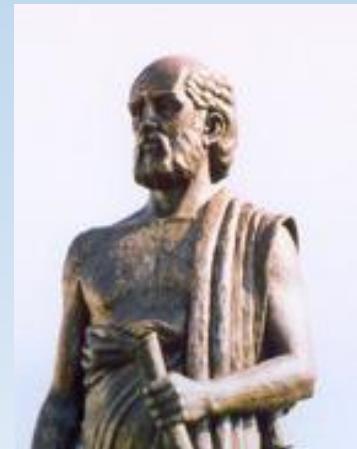
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  - The [New Horizons](#) spacecraft to [Pluto](#) (and beyond) measured a large parallax for [Proxima Centauri](#).



# 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**.
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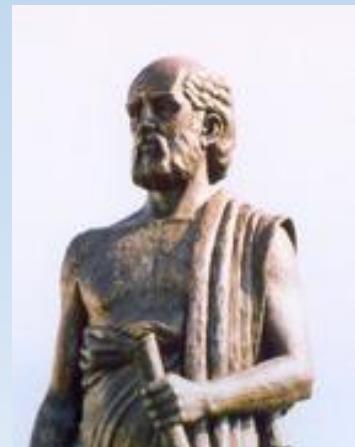


Aristarchus of Samos  
[Wikipedia, modern statue at Aristotle U. of Thessaloniki]

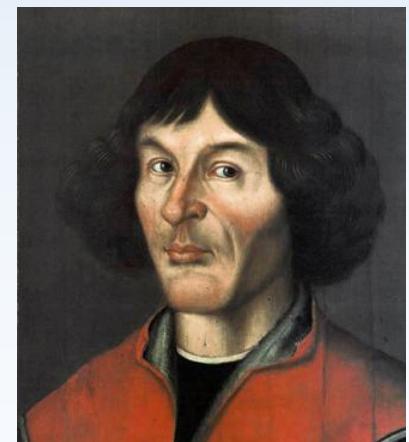
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- **Copernicus** (1473-1543 BC) re-introduced the heliocentric model.
  - Same predictive power as Ptolemaic epicycle model, but simpler.
  - Simple explanation for the retrograde motion of planets.
  - Criticized because stellar parallax was not yet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



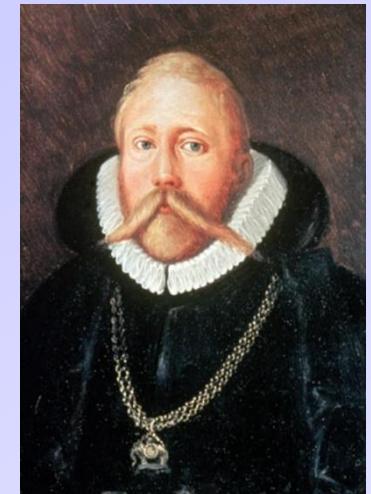
Aristarchus of Samos  
[Wikipedia, modern statue at Aristotle U. of Thessaloniki]



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

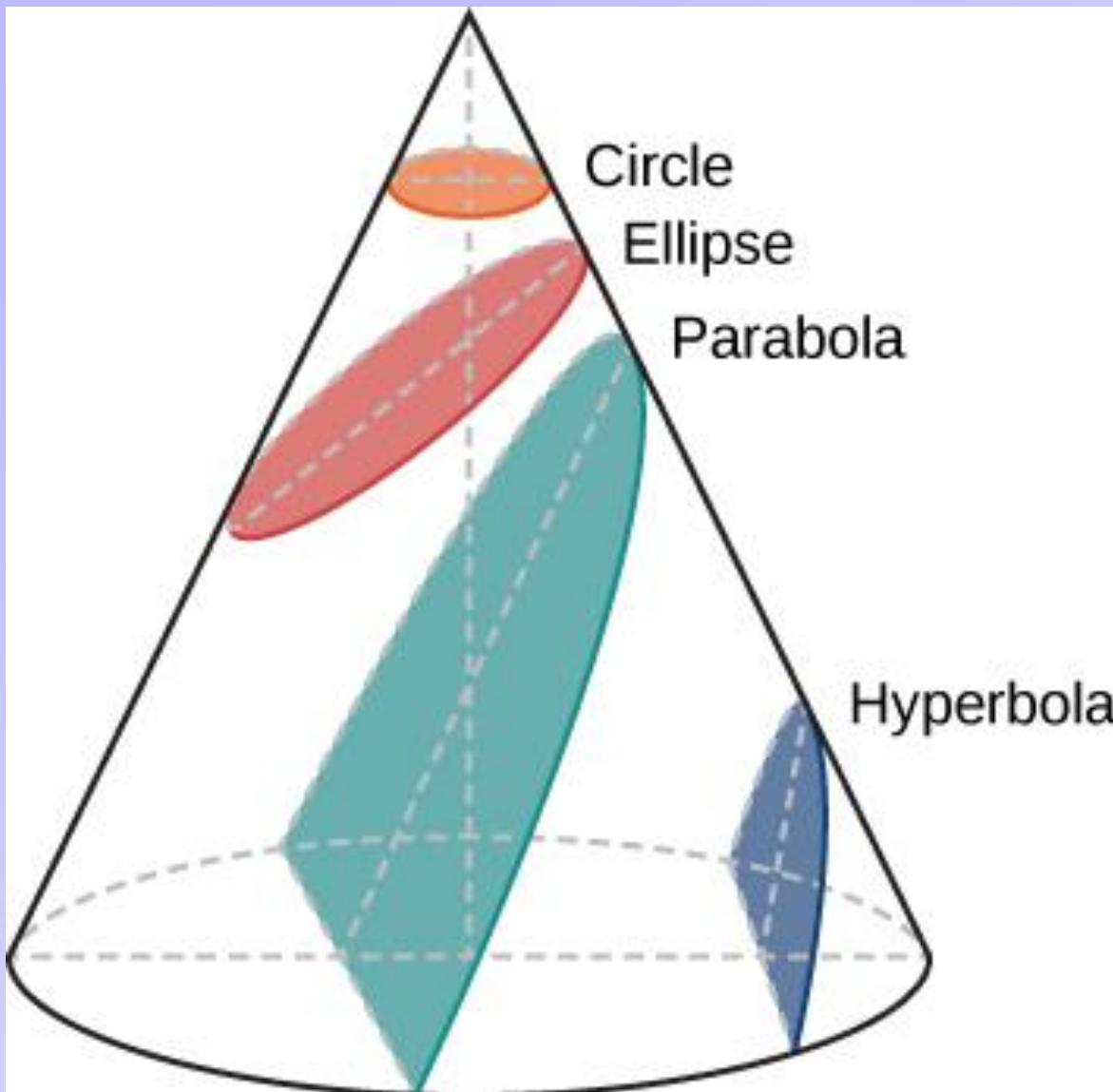
1st Law: The orbits of all planets are **ellipses**.

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

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

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

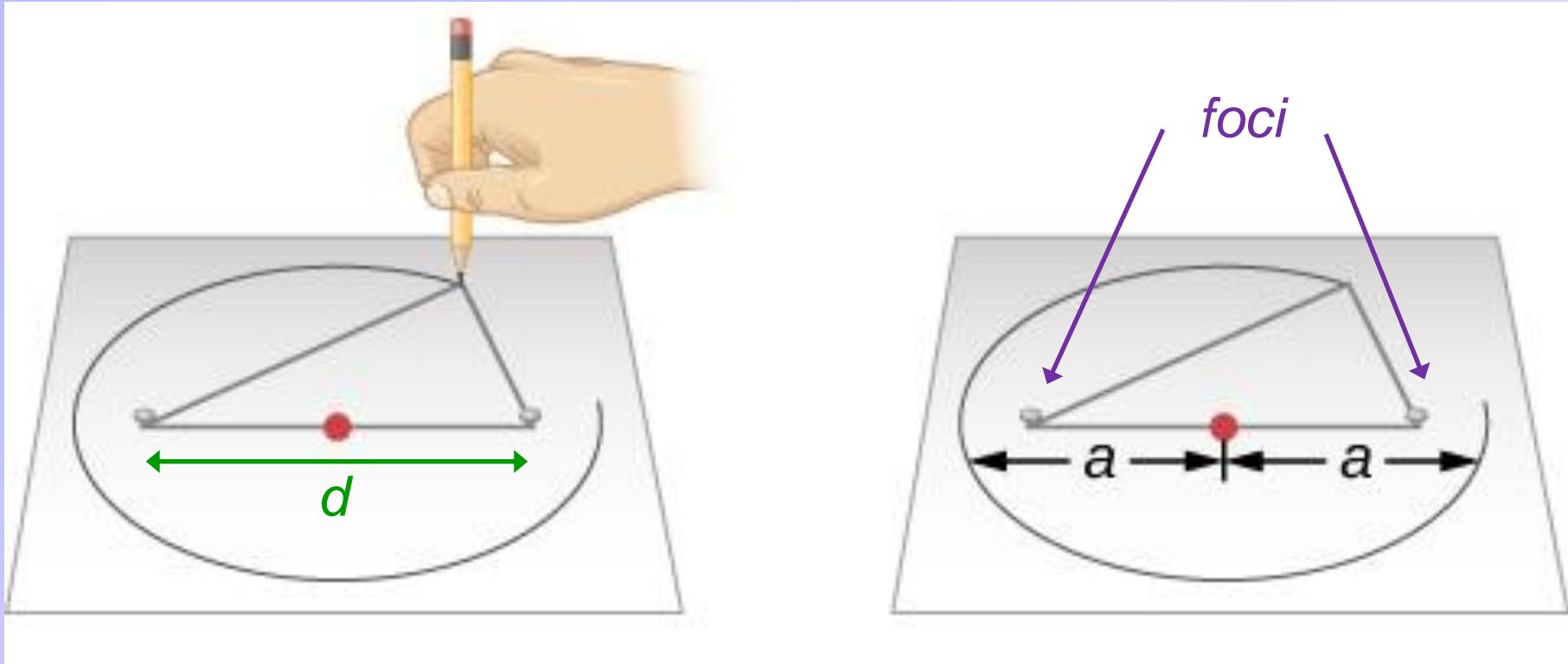
# Kepler's 1st Law – Conic Sections



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

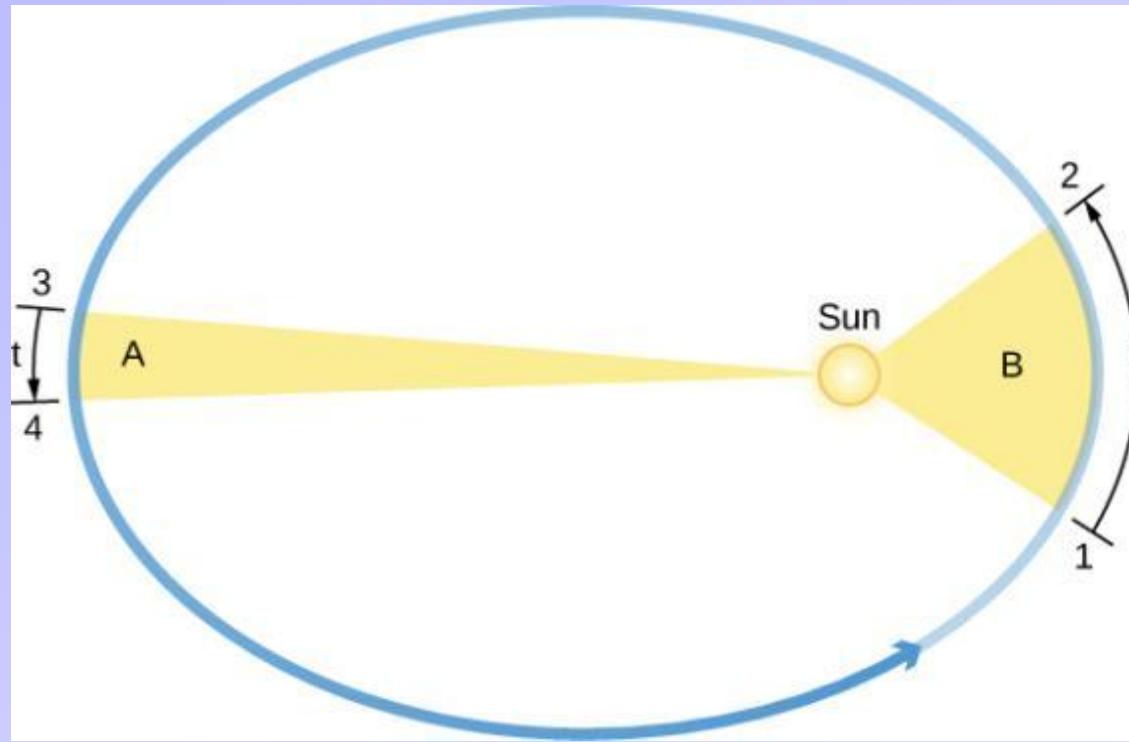


- Sun sits at one of the foci.
- Other focus is empty.

$a$  = 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

$$T^2 = a^3$$

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## Example: Martian Orbit

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

On average, Mars is  $a = 1.52 \text{ AU}$  from the Sun.