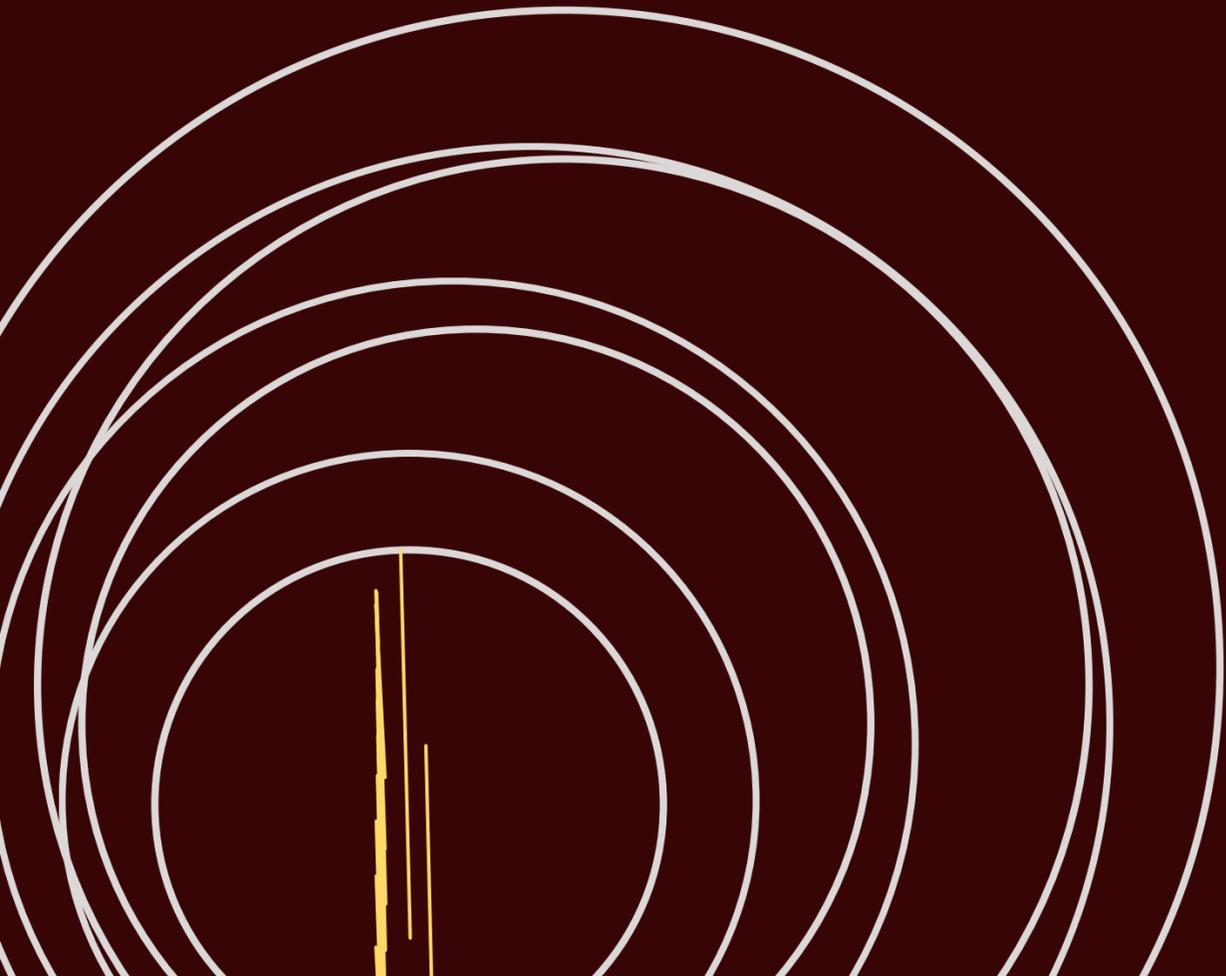


# Kepler's Laws

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Of planetary motion

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# 01 History

# About Kepler

- Johannes Kepler was a German mathematician and astronomer who discovered Kepler's 3 Laws of Planetary Motion
- He was born in 1571 and died in 1630 in Germany
- He was employed by Danish astronomer Tycho Brahe and worked for him until his death, and Kepler took over his work
- He wrote "Somnium," a science fiction story about a journey to the Moon, which is considered one of the earliest examples of the genre



Johannes Kepler 1571-1630

# History

- Tycho Brahe, who had been doing detailed observations of the planets, discovered that the orbits are not perfectly circular.

1619

Kepler's 3rd law was published

- He employed Kepler, who inherited his work after his death

1

1609

Kepler published his first 2 law having found them by analysing the astronomical observations of Tycho Brahe.

2

This helped to provide evidence for the idea of the heliocentric model

← most likely discovered from analysing Tycho Brahe's observations for Mar's orbit (it has the highest eccentricity)

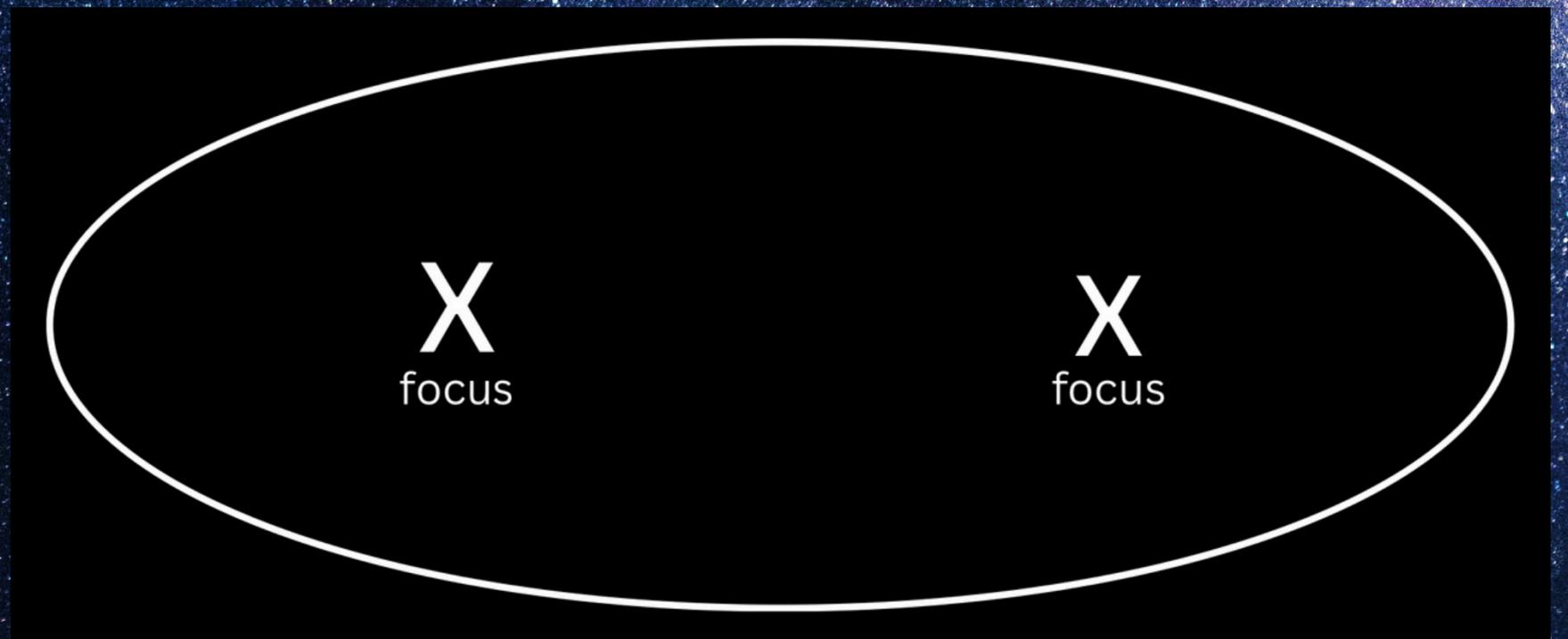


# 02 Kepler's Laws

# 1st Law: Law of orbits

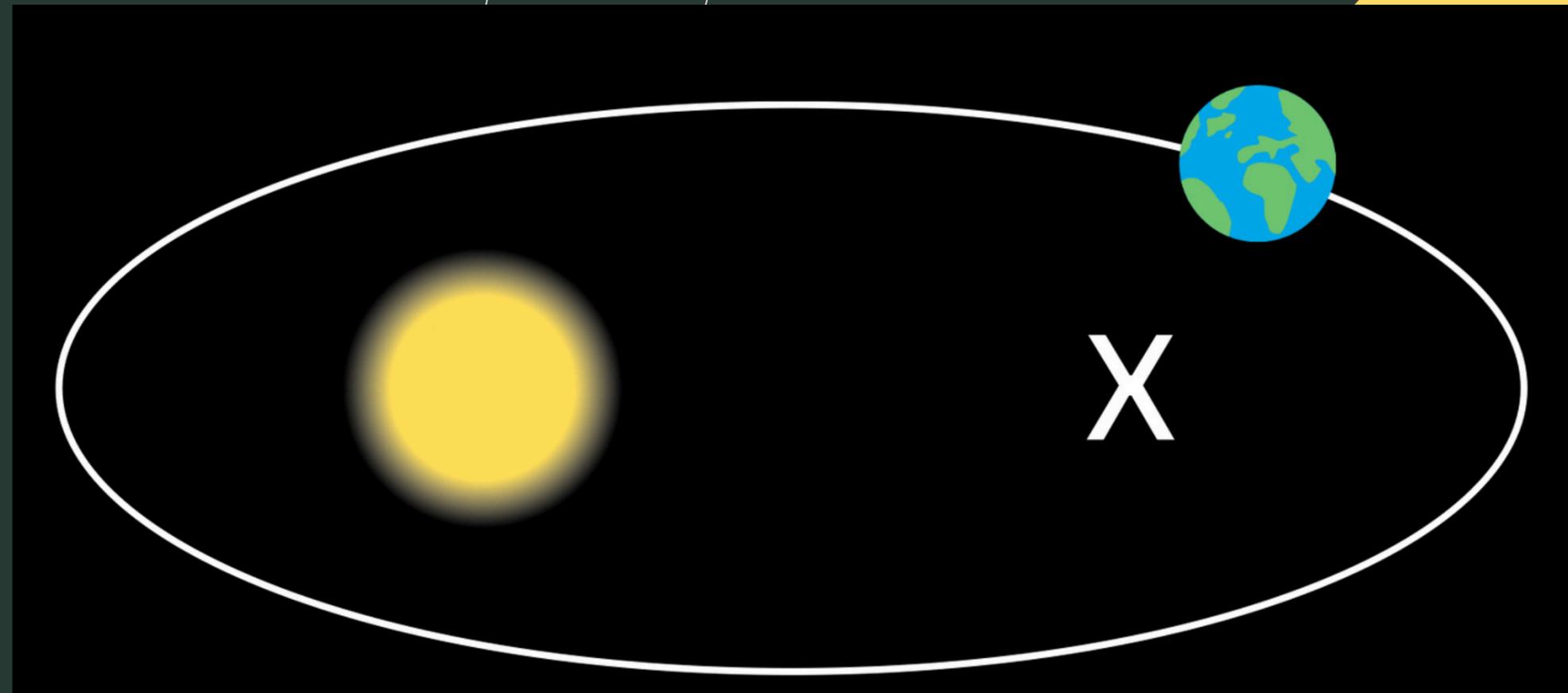
Each planet's orbit about the sun is an ellipse. The Sun is located at one focus of the ellipse.

The ellipse is an elongated or flattened circular shape. There are two points on the ellipse, marked by the two crosses here on the diagram. Each point is called a focus, the plural form would be foci.



# 1st Law: Law of orbits

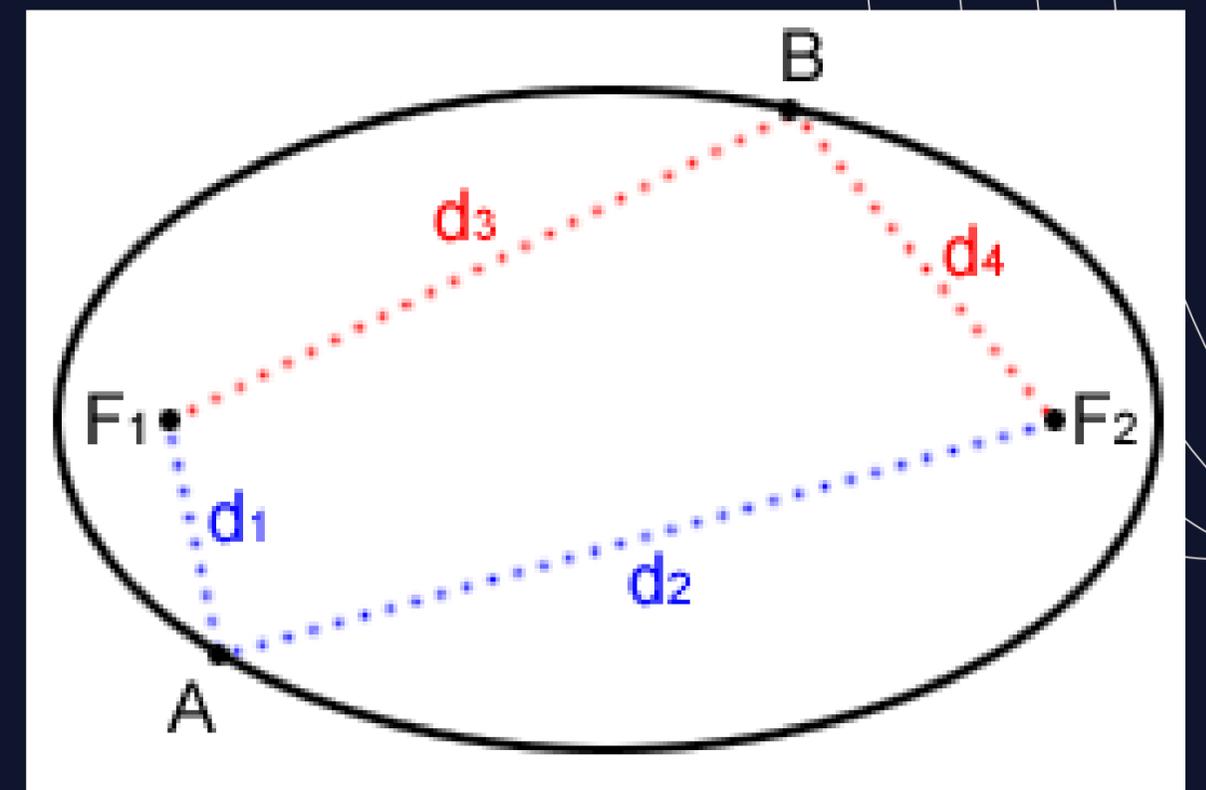
In the case of planetary orbits, the Sun is located at one of the focus and not the centre of the ellipse. Planets travel along this oval-shaped path, which is called the elliptical orbit.



# Properties of Ellipses

1. The sum of the distances from any point on the ellipse to the foci is always a constant.

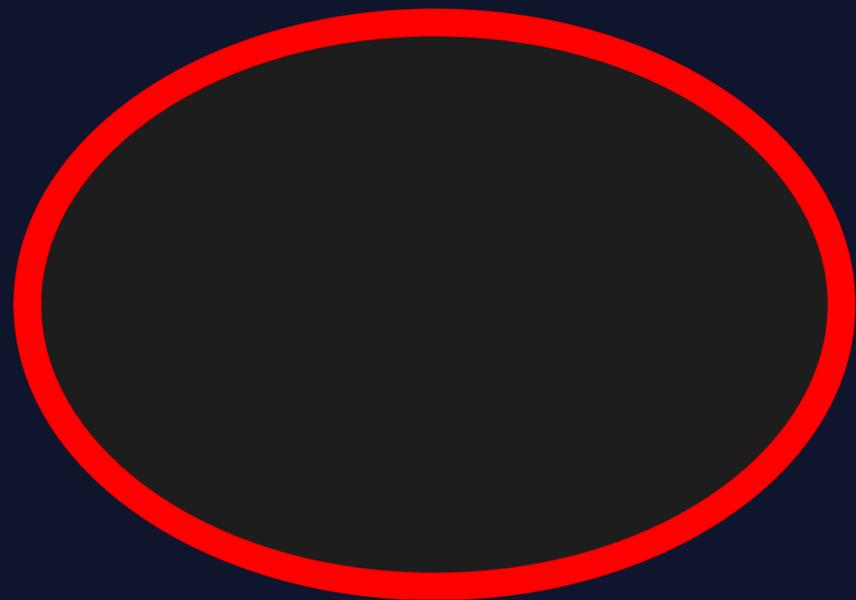
Take for example point A on this diagram. The total distance from point A to the foci,  $F_1$  and  $F_2$  will be  $d_1$  plus  $d_2$ , which is indicated by the blue lines. Similarly, the total distance from point B to the foci is  $d_3$  plus  $d_4$ . The total distance of the red lines is equal to that of the blue lines.



# Properties of Ellipses

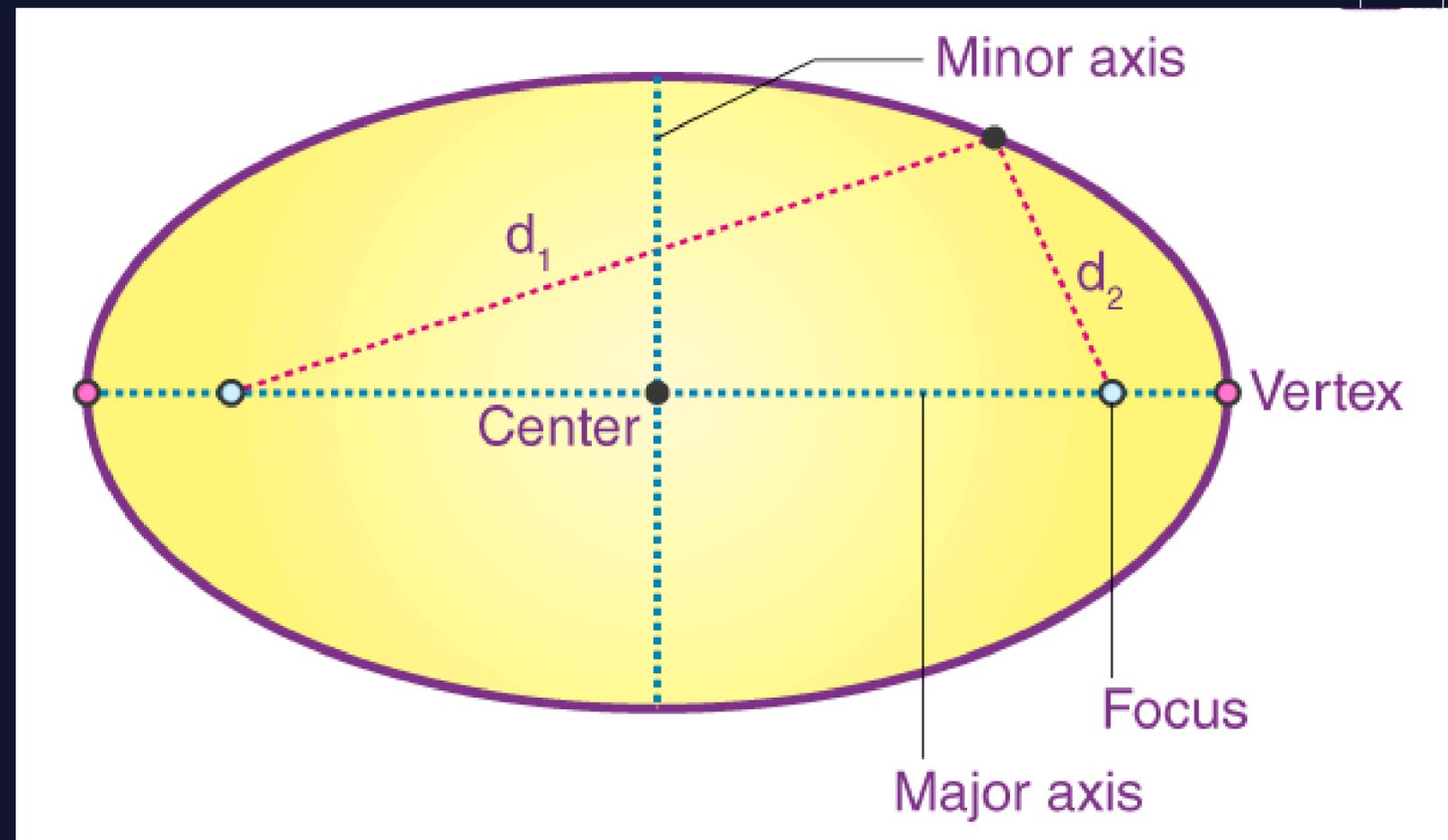
## 2. Eccentricity: The amount of flattening of the ellipse.

The more elongated or flat it is, the higher its eccentricity. The value could be between zero, which is a circle, and one, essentially a flat line. Earth's orbital eccentricity is 0.0167.



# Properties of Ellipses

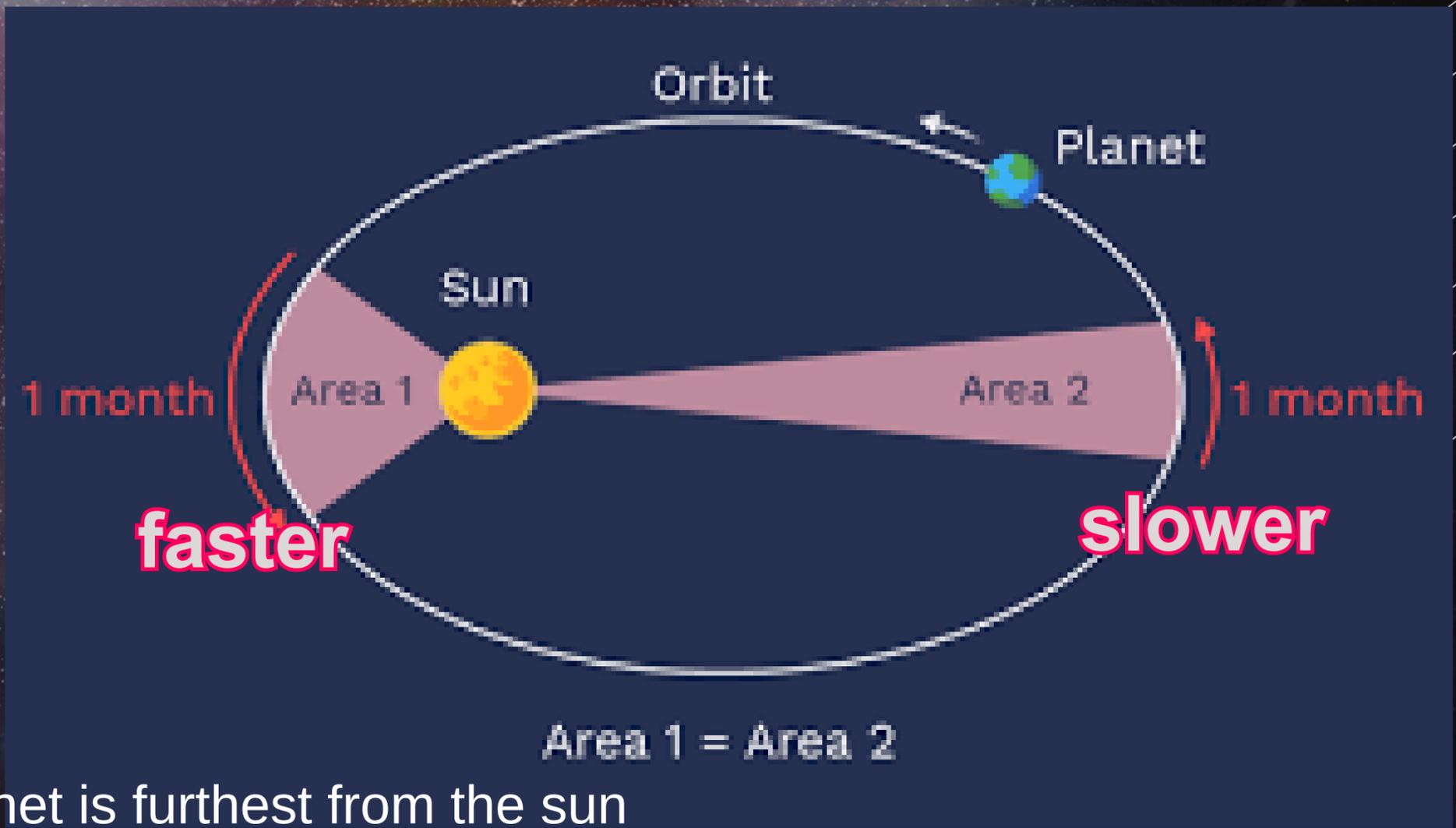
3. Major axis: Longest axis of the ellipse
  - Semi-major axis: Half of Major axis
4. Minor axis: Shortest axis of the ellipse
  - Semi-minor axis: Half of Minor axis



# 2nd Law: Law of equal areas

'A line joining a planet and the Sun sweeps out equal areas during equal intervals of time'

- A planet covers the same area of space, in the same amount of time, no matter where it is in its orbit

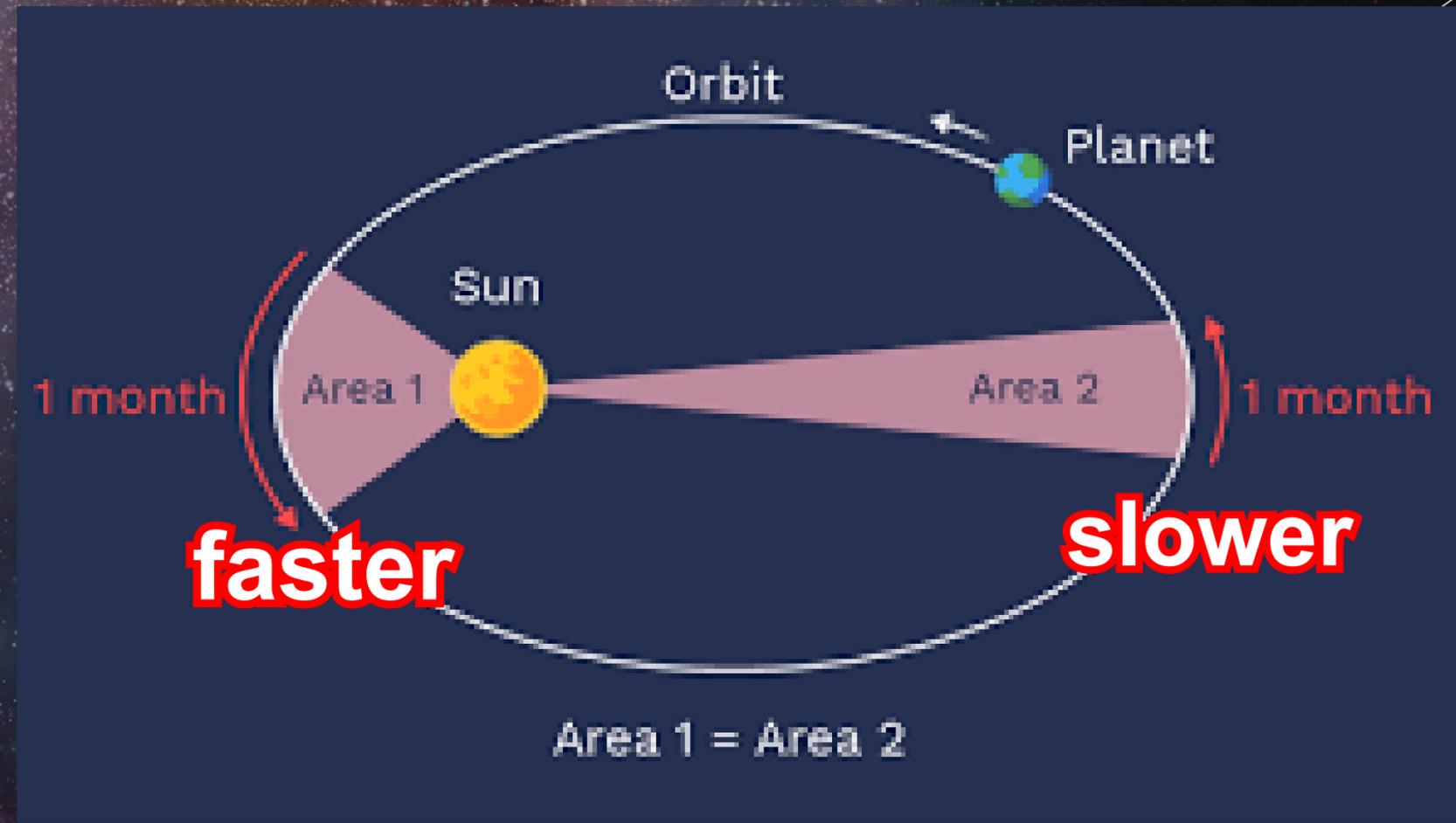


- aphelion: the pt at which a planet is furthest from the sun
- perihelion: the pt at which a planet is closest to the sun

# 2nd Law: Law of equal areas

'A line joining a planet and the Sun sweeps out equal areas during equal intervals of time'

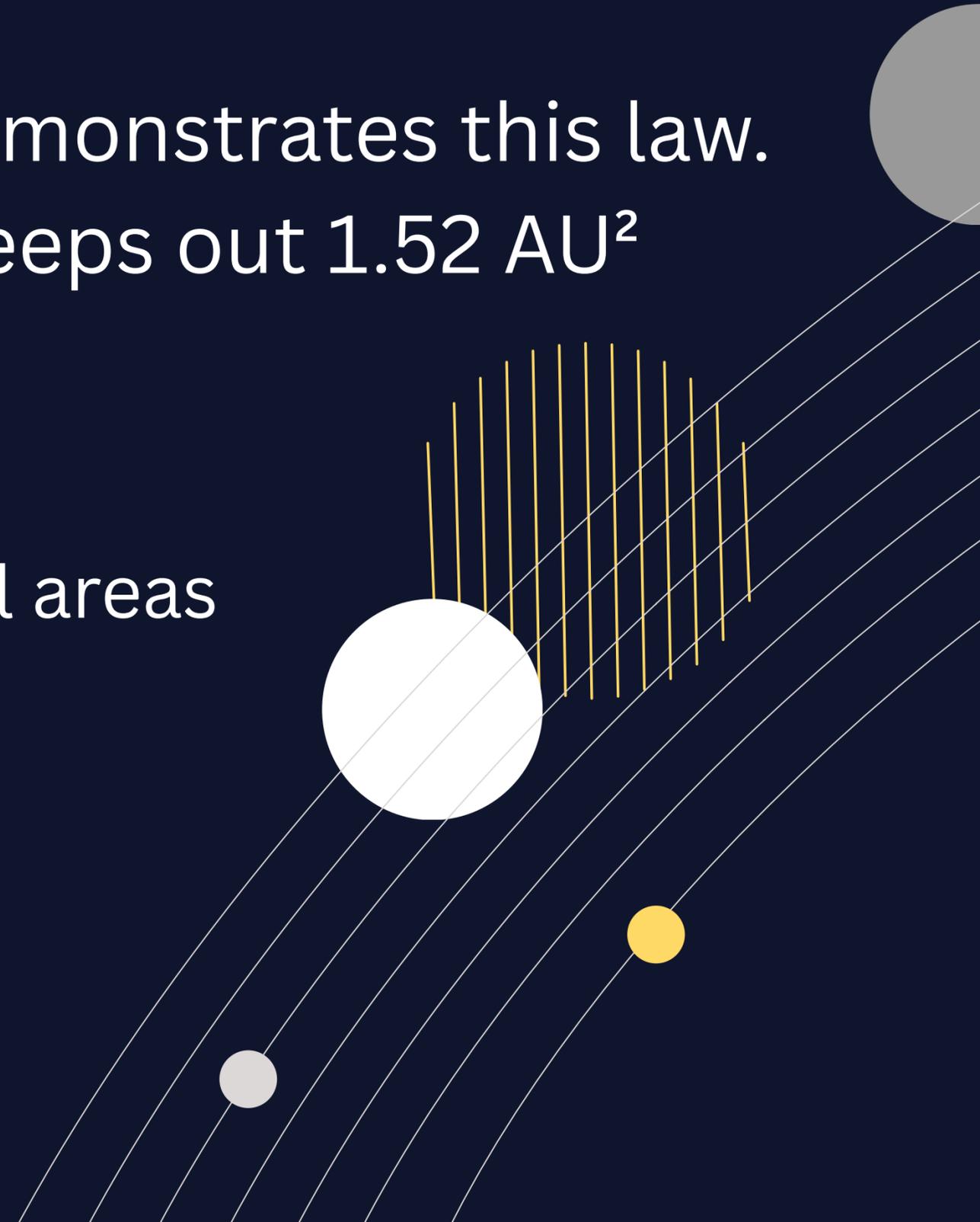
- Planets do not move with constant speed along their orbits, but rather their speed varies.
- So imagine drawing a line from the centre of the sun to the centre of the planet, if you refer to the diagram, the areas that the planet had swept out during a period of 1 month are also equal, so area 1 is equal to area 2. This means that a planet will move faster when it is closer to the Sun, as shown on the left side of the diagram, and slower when it is farther away, ensuring that the area swept out by the line connecting the planet and the Sun remains constant over equal time periods.



# Simulation

Now, let's watch a simulation that demonstrates this law. You will see that for 0.42 years, it sweeps out  $1.52 \text{ AU}^2$

This shows that the sun sweeps out equal areas during equal intervals of time.



# Simulation

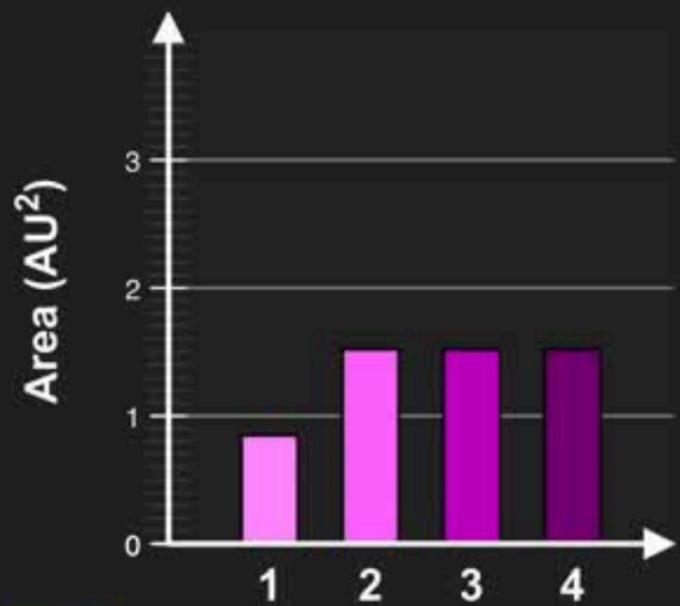
Period Divisions



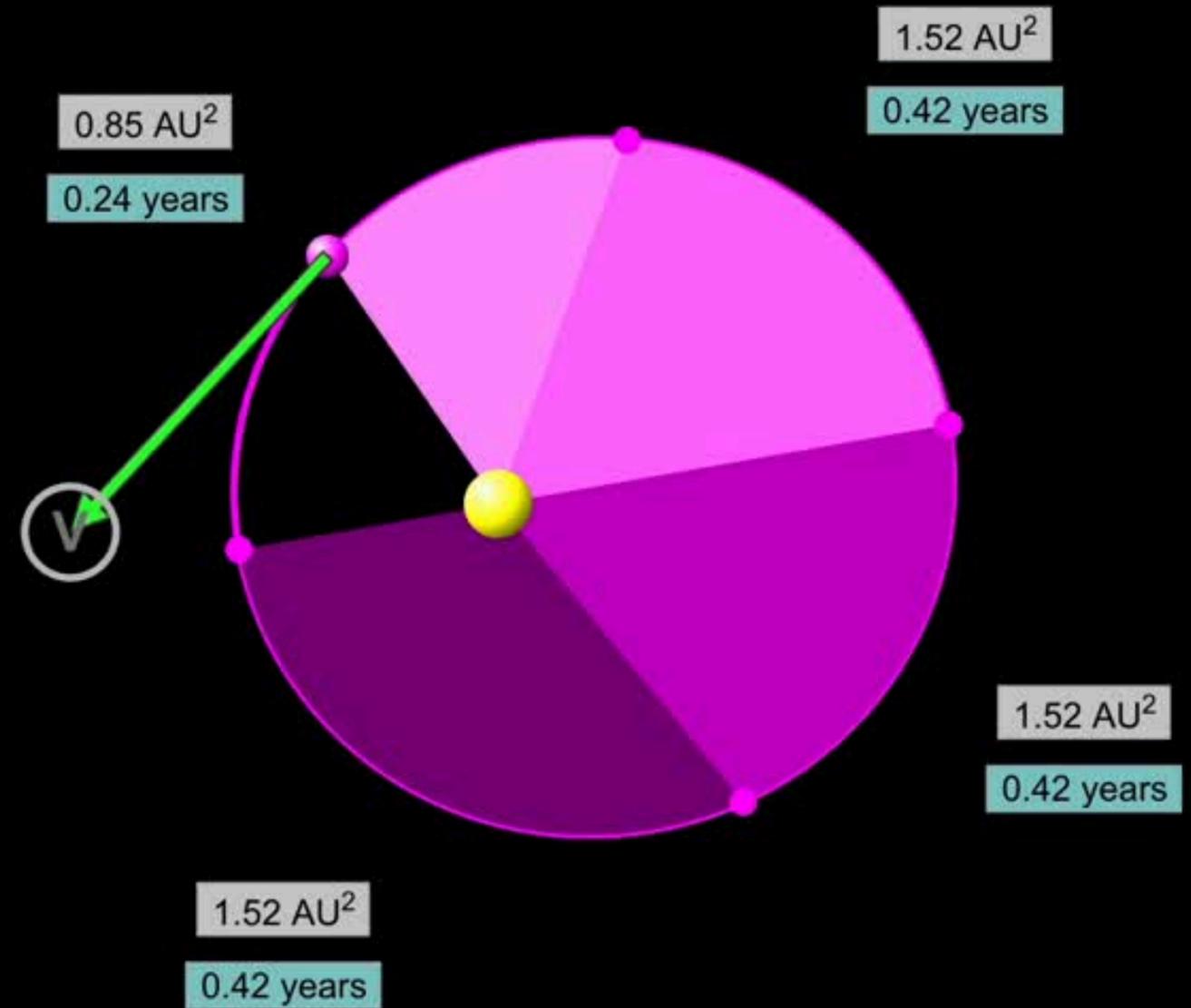
Area Values

Time Values

**Swept Area**



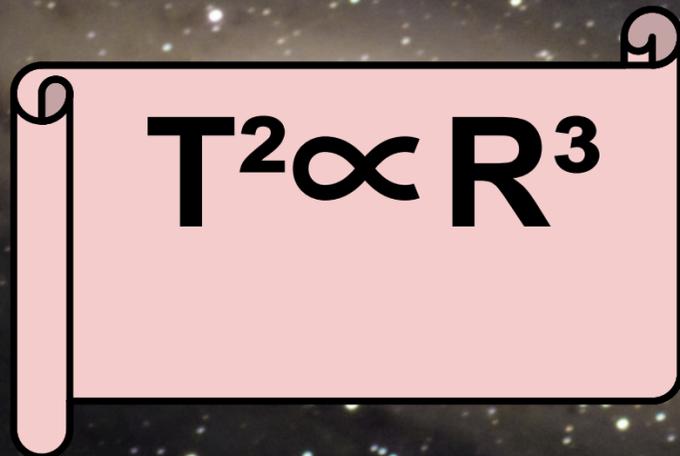
Period Divisions



- Fast
- Normal
- Slow

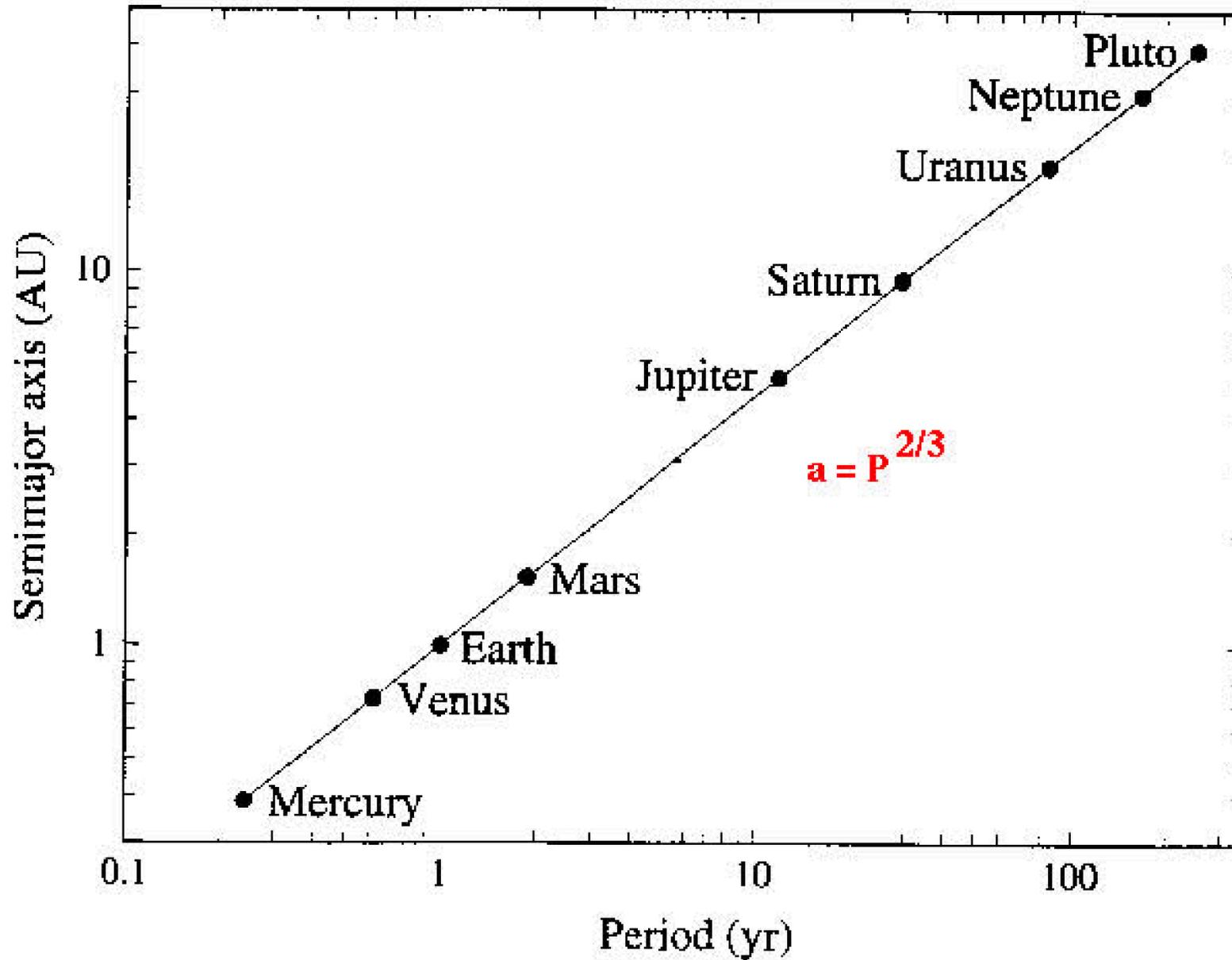
## Law 3: Law of periods/harmonies

The square of the time period of revolution of a planet around the sun in an elliptical orbit (T) is directly proportional to the cube of its semi-major axis (R).


$$T^2 \propto R^3$$

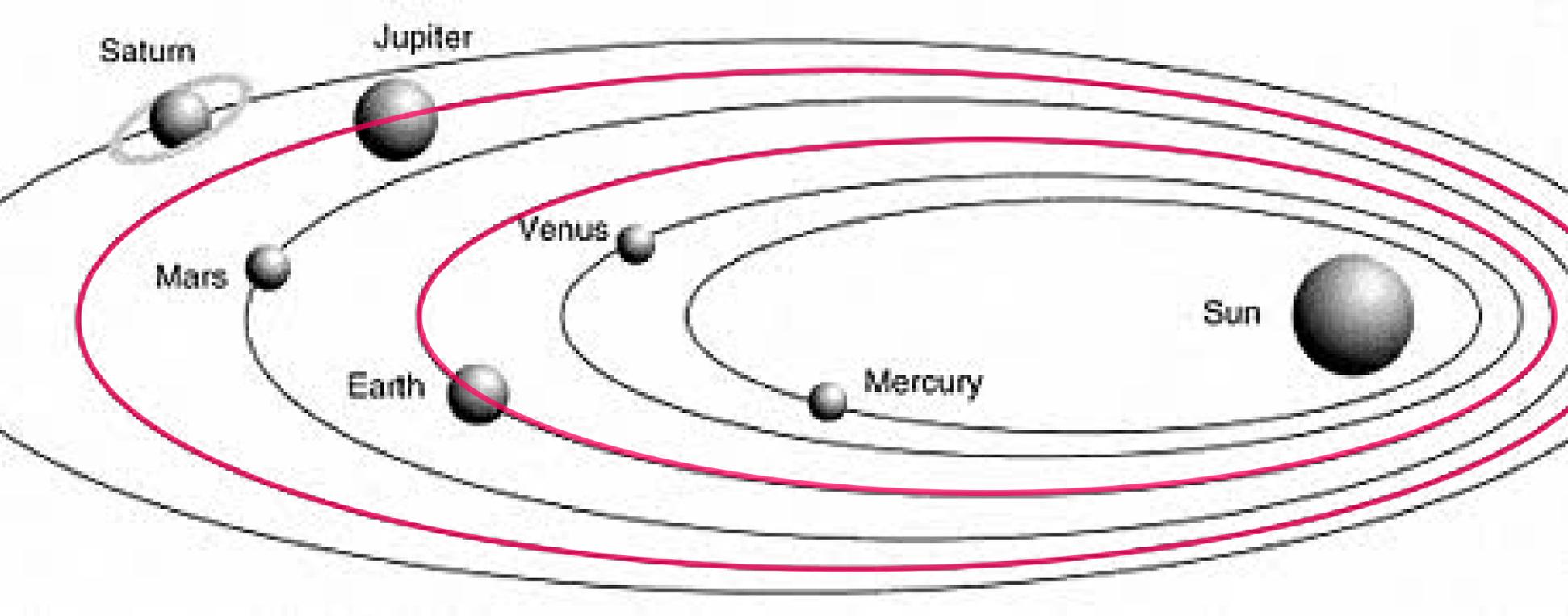
The period for a planet to orbit the Sun increases rapidly with the radius of its orbit.

This means that the farther a planet is from the Sun, the longer its semi-major axis is and the longer it takes to complete one orbit.



$$T^2 \propto R^3$$

This graph shows that the period which is the time taken for one complete revolution shown in the x axis increases as the semi major axis increases (y-axis)



$$T^2 \propto R^3$$

Earth

$T = 1 \text{ year}$   
 $R = 1 \text{ AU}$

Jupiter

$T = 11.8 \text{ years}$   
 $R = 5.2 \text{ AU}$

Take for example, Jupiter and Earth, indicated by the two red ellipses here. The semi-major axis of earth is 1AU (astronomical unit) and Earth takes one year to orbit the Sun. While Jupiter has 5.2 AU, which is much farther away from the sun than earth and it takes a longer time, 11.8 years to complete one revolution.

# Formula

useful for calculations

$$\left(\frac{T_1}{T_2}\right)^2 \propto \left(\frac{r_1}{r_2}\right)^3$$

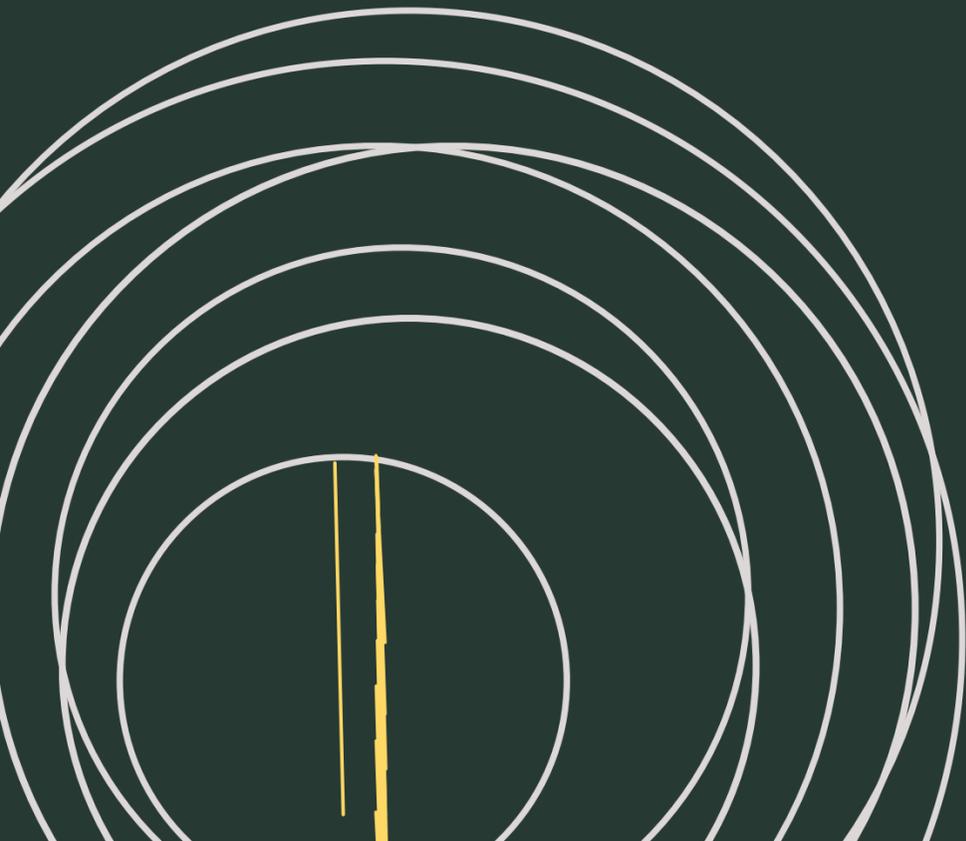
A cosmic background featuring a vibrant nebula with purple, blue, and orange hues, set against a dark field of stars. The scene is framed by several thin white lines and two large white circles, one on the left and one on the right, which appear to be stylized representations of celestial bodies or orbits.

# Common misconception

# Misconception

Seasons are caused by the Earth's distance to the Sun  
(ie. being closer or further from the Sun)

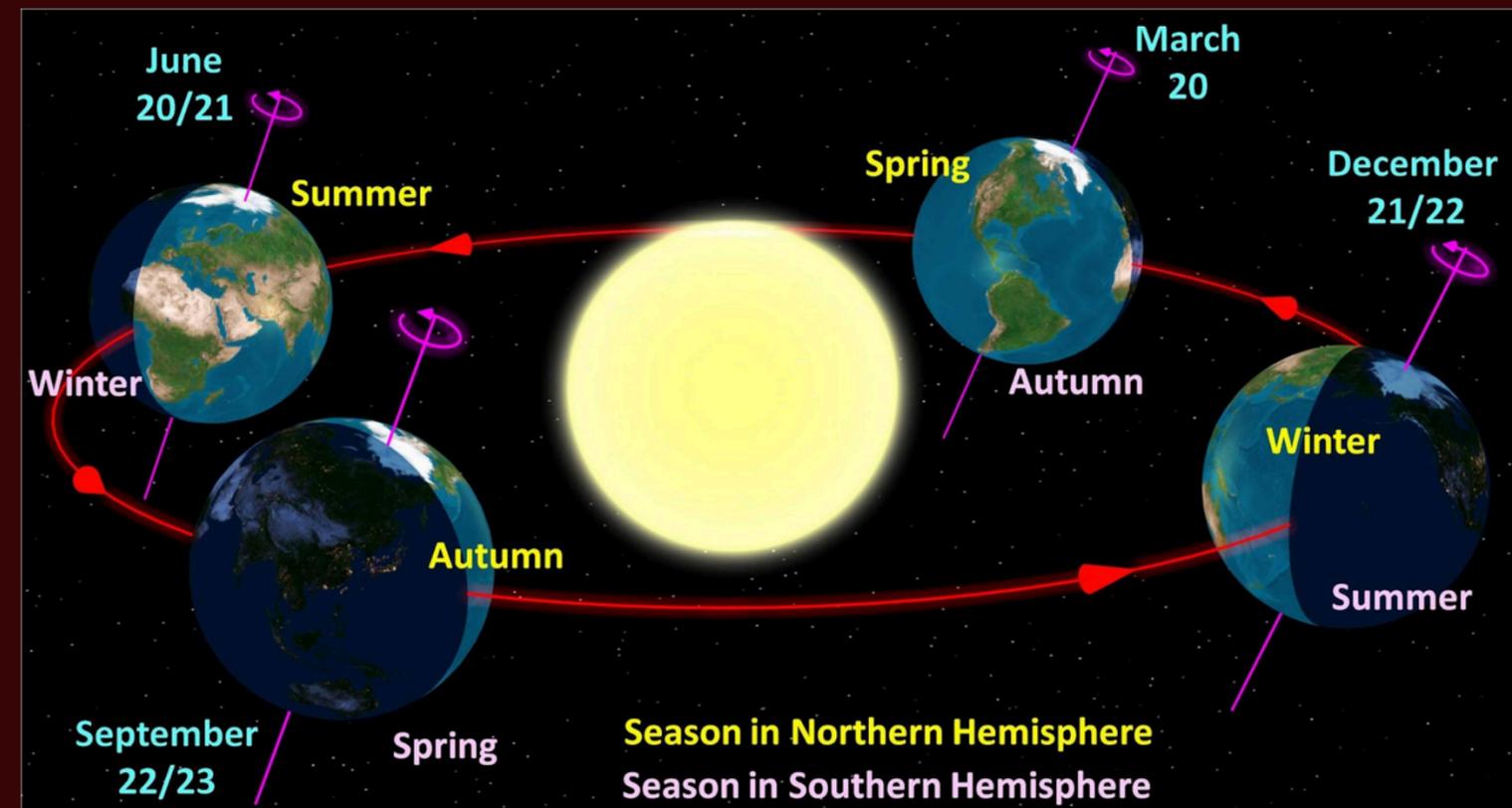
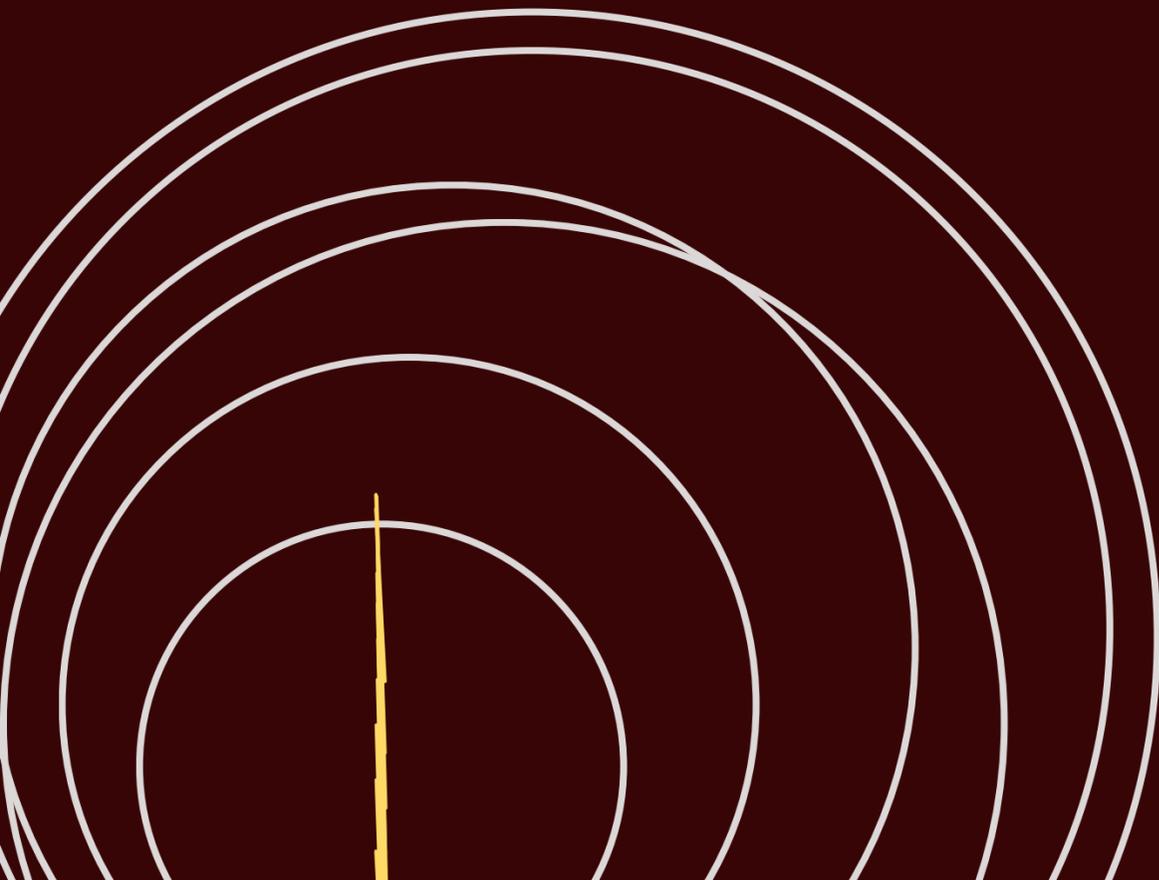
**WRONG**



# Misconception

Seasons are determined by Earth's axial tilt.

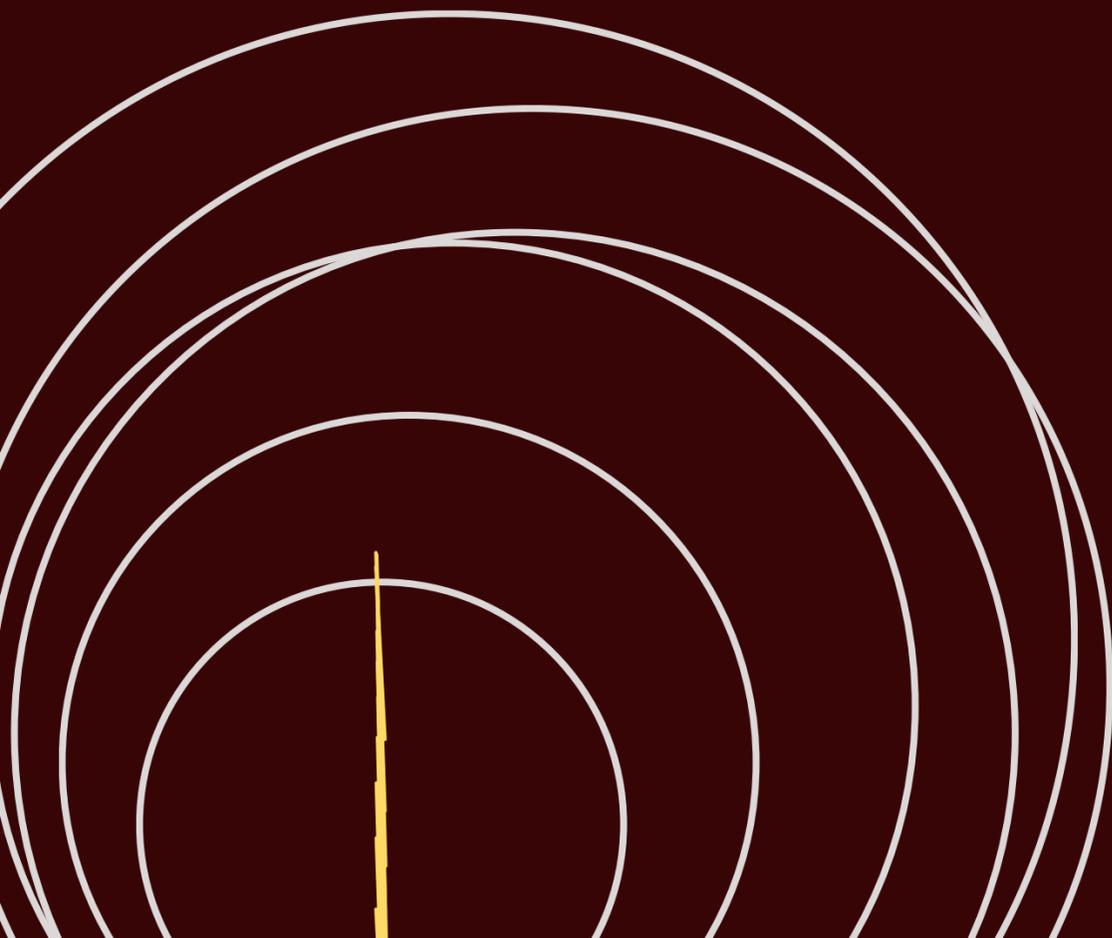
Axial tilt: Earth is tilted at about  $23.5^\circ$  on its axis. Earth's axis is an imaginary pole going right through the centre of Earth from "top" to "bottom." Earth spins around this pole, making one complete turn each day. Its tilted axis always points in the same direction as it orbits around the ellipse.



# Misconception

This tilt causes different hemispheres to receive varying amounts of sunlight throughout the year.

When a hemisphere is tilted toward the Sun, it experiences summer (more direct sunlight, longer daytime hours), and when tilted away, it experiences winter (less direct sunlight, shorter days)

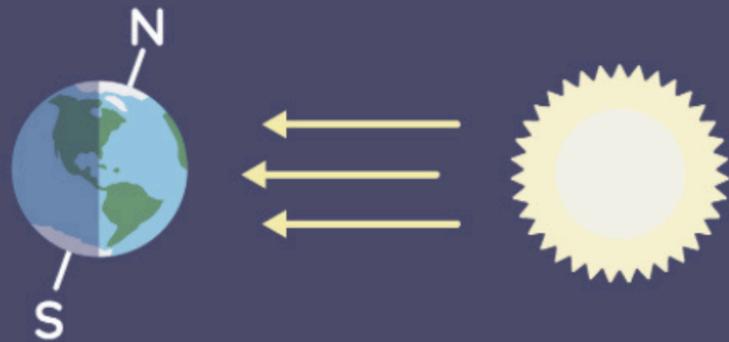


# Misconception

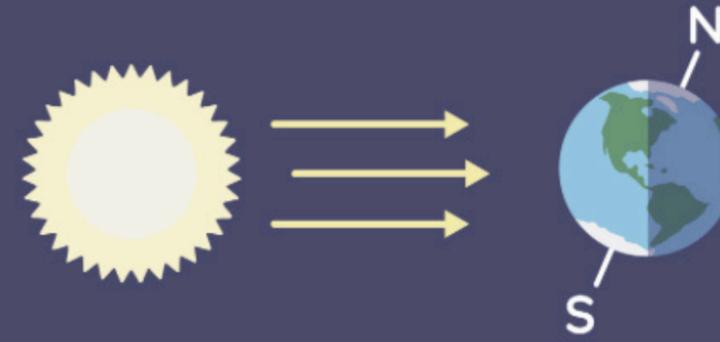
Seasons are determined by Earth's axial tilt.

North pole tilts towards Sun  $\rightarrow$  Summer in Northern Hemisphere  
South pole tilts towards Sun  $\rightarrow$  Summer in Southern Hemisphere

North Pole - Summer 



North Pole - Winter 



South Pole - Winter 

South Pole - Summer 

# Implications

1

## Shift from Geocentric to Heliocentric Model

Kepler's 1st law contradicted the geocentric model

2

## Basis for modern astronomy and astrophysics

These laws are still used today to calculate orbits and predict the movements of celestial objects, including exoplanets and other stars.

3

## Foundation for Newton Law of Universal Gravitation

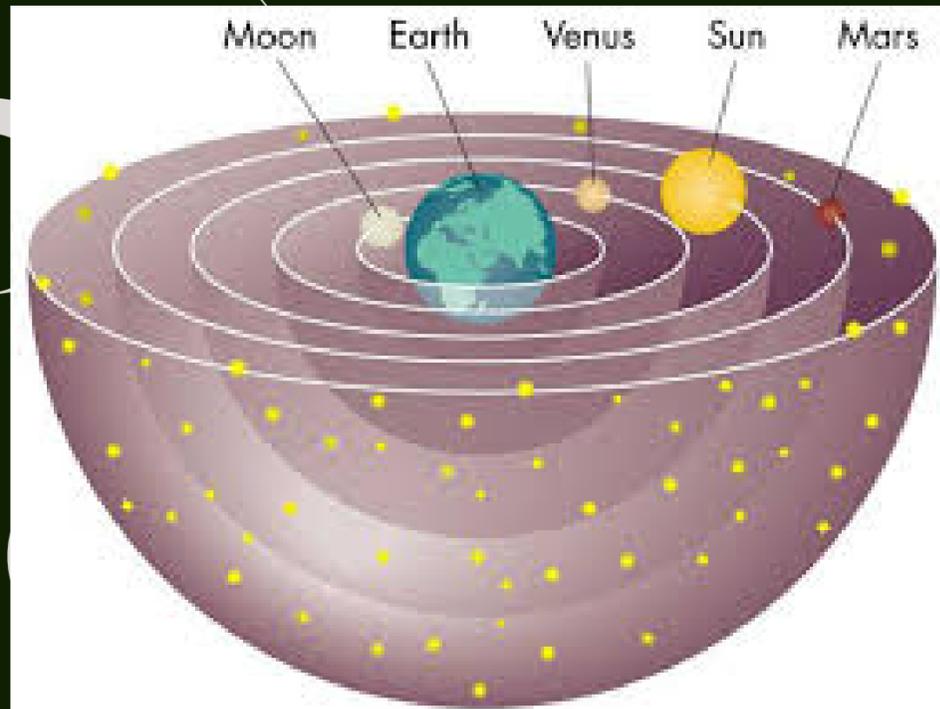
Newton built on his laws to discover his own laws

4

## Applications in space exploration

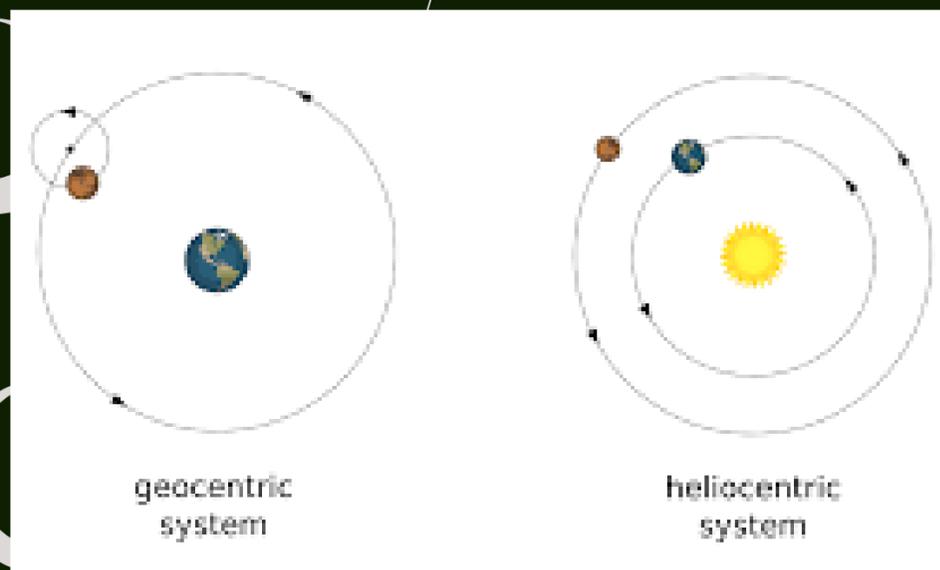
Kepler's laws are essential for planning space missions, calculating trajectories, and understanding orbital dynamics

# Shift from Geocentric to Heliocentric Model



Geocentric -> Heliocentric

- In the past, people believed that the Earth was the centre of the earth and that everything else in our solar system was orbiting us
- This was until the 16th century when Nicolaus Copernicus published his detailed theory on the heliocentric model
- Many people didn't really believe him



Kepler's 1st law contradicted the geocentric model

# Implications

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## Shift from Geocentric to Heliocentric Model

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## Applications in space exploration

Kepler's laws are essential for planning space missions, calculating trajectories, and understanding orbital dynamics

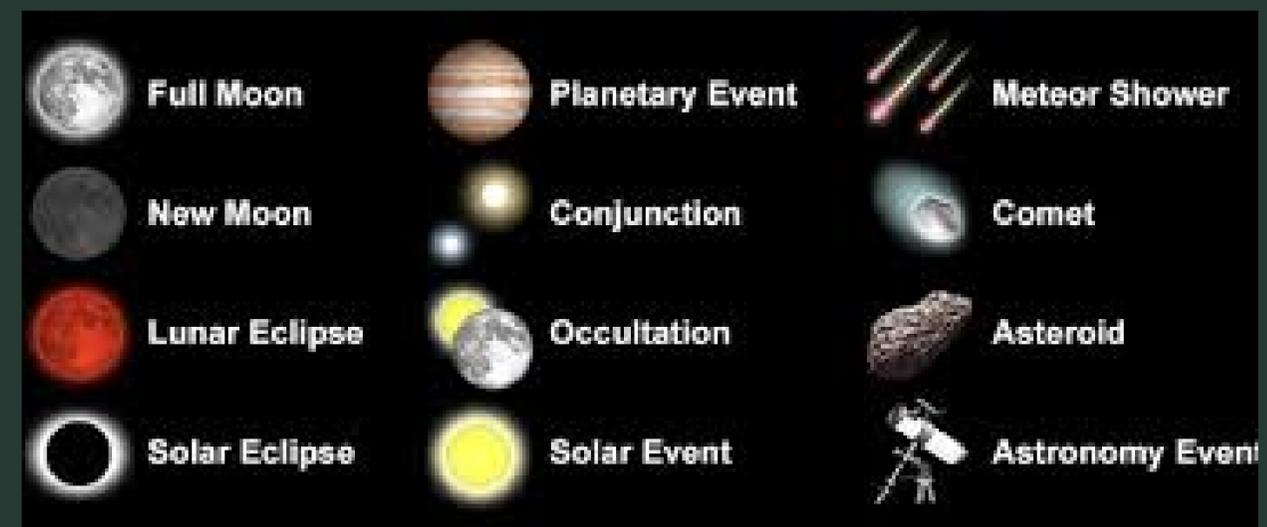


# Applications in space exploration

- Interplanetary Missions
  - Space missions to other planets rely heavily on Kepler's laws for trajectory planning
  - Especially for calculating the necessary velocity changes ( $\Delta v$ ) and orbital maneuvers to reach a target planet

# Applications in space exploration

- Predicting Astronomical Events
  - Kepler's laws enable precise predictions of planetary positions, transits, and conjunctions, as well as the orbits of comets and asteroids



# Applications in space exploration

- Understanding Celestial Mechanics
  - Kepler's laws provide a foundation for understanding the fundamental principles of celestial mechanics, which are vital for studying the motion of all objects in space

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Thank  
You!

