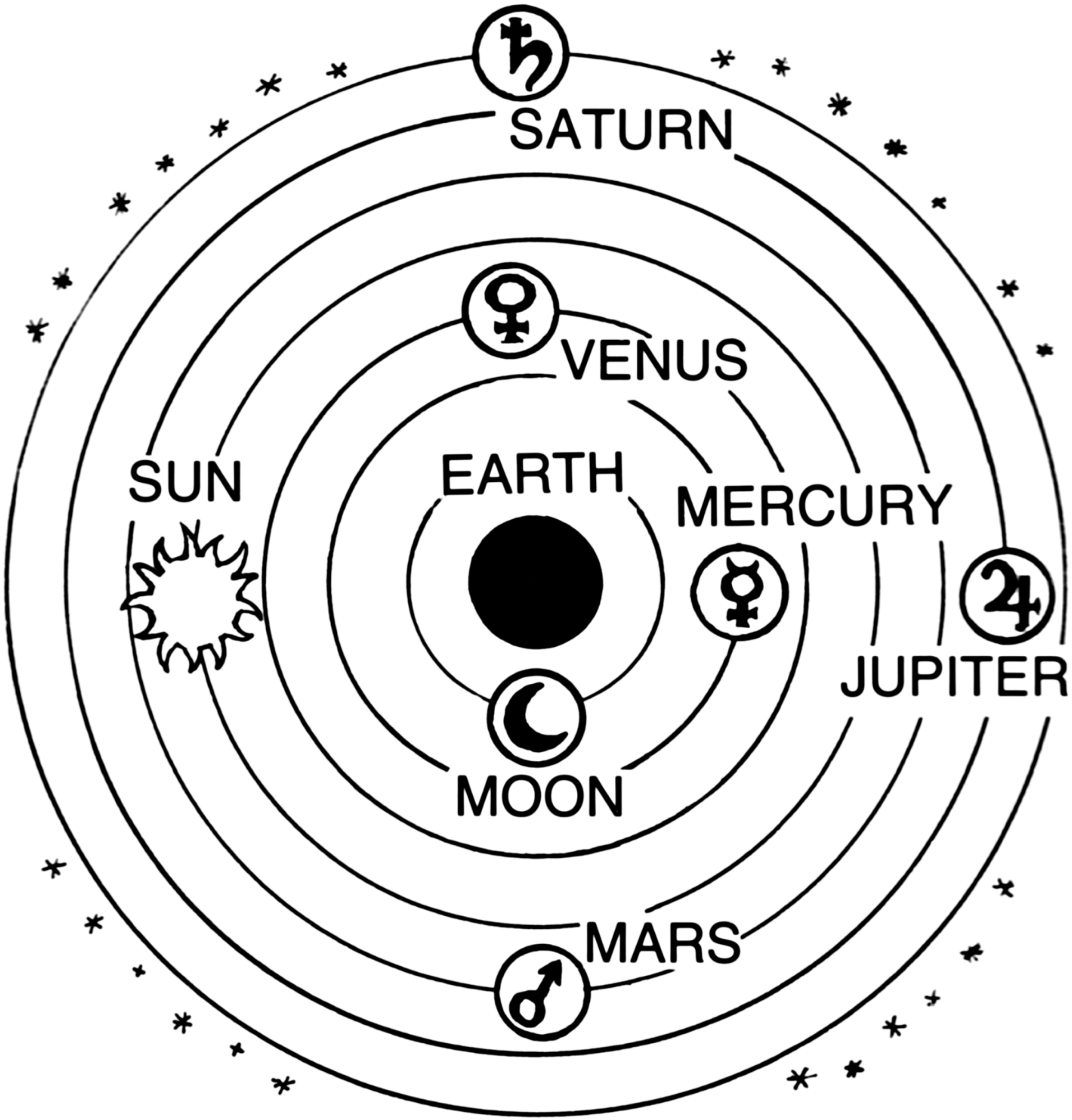
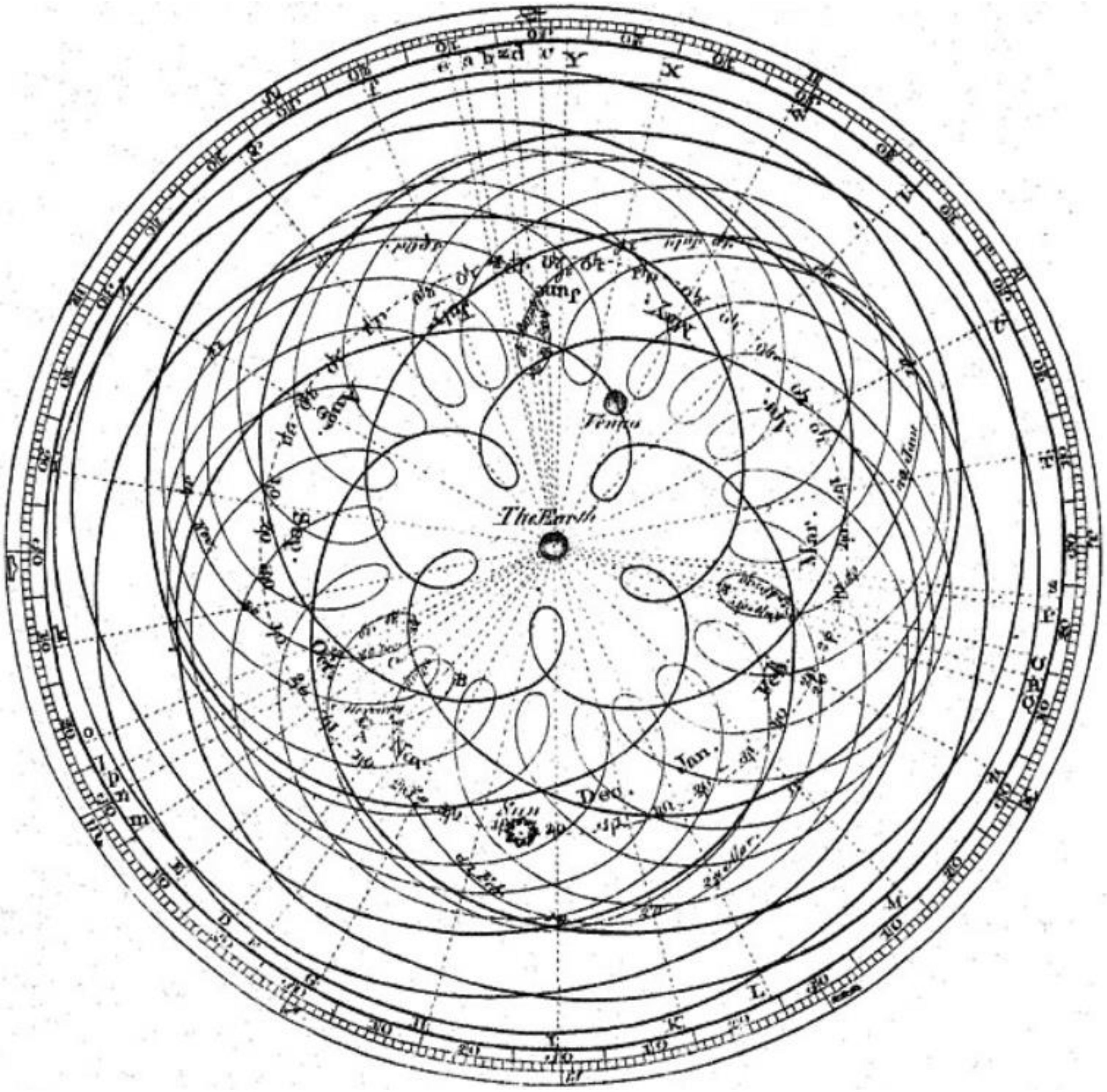
Topic 8: Planetary Motion and Gravity

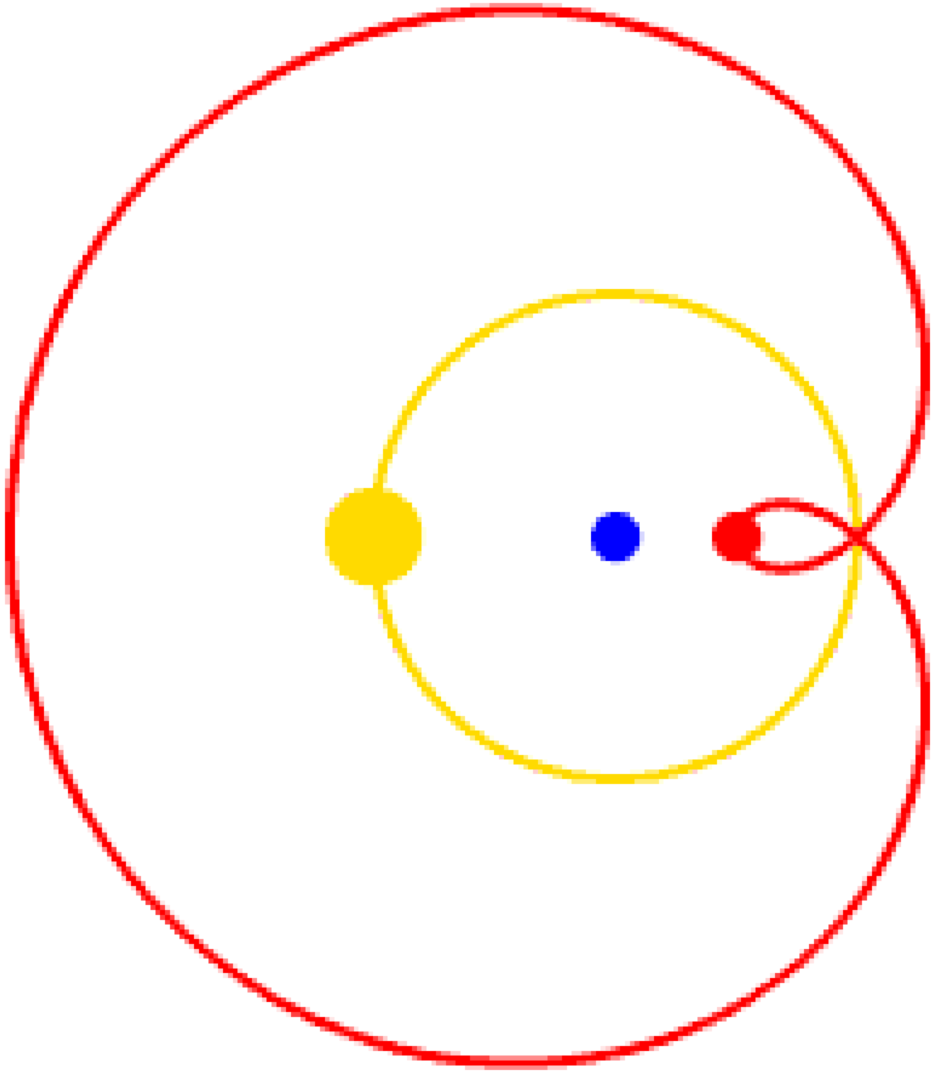


The Ancient Puzzle

For over a millennium, the geocentric model dominated astronomical thought. The Earth was *rightly* placed at the centre of universe. Thanks to development by Ptolemy the Sun, Moon and planets moved in complex 'epicycle' circular orbits.

Whilst elegant, the model required constant adjustment as technology evolved and new observations had to be explained and incorporated.


The Earth
Sun
Jan.
Dec.

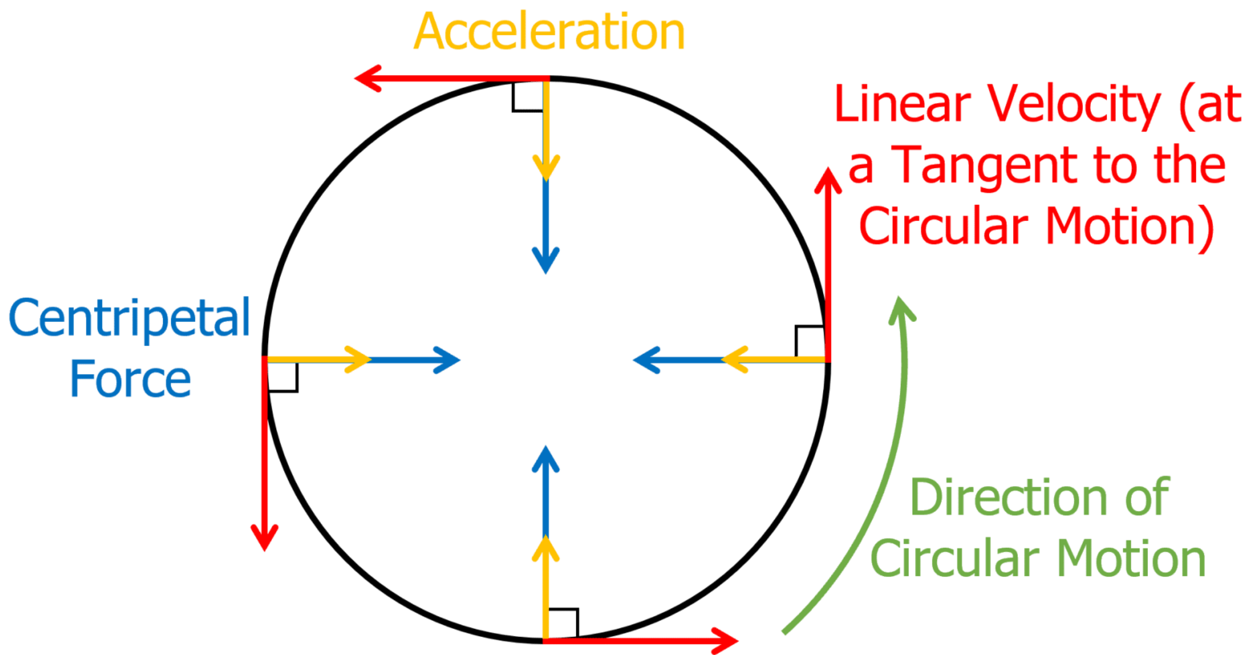


On Circular Orbits

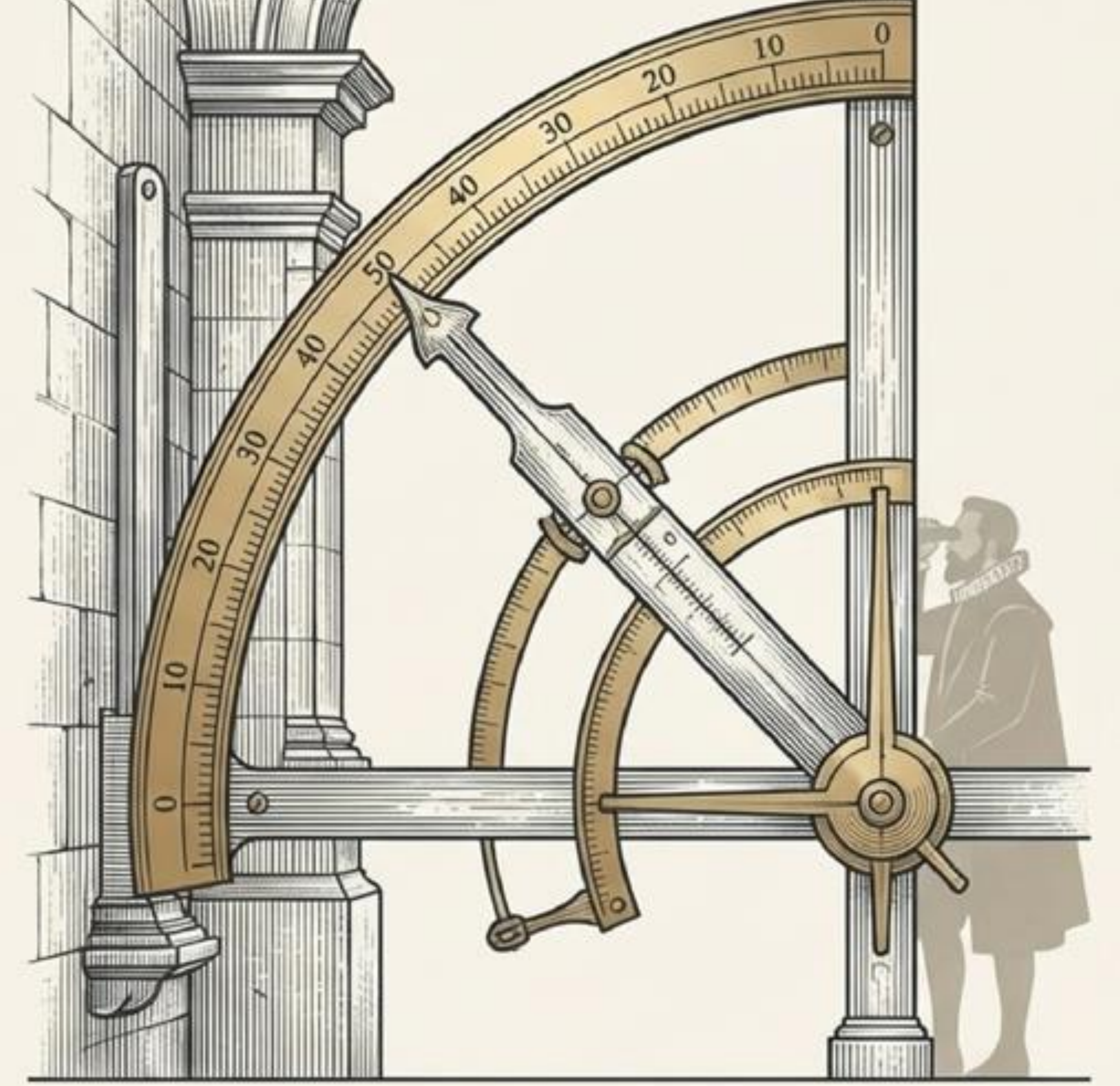
Velocity is speed **in a given direction**.
It is a **vector** quantity, so has **MAGNITUDE** and **DIRECTION**.
When an object changes direction, its **velocity is changing**, even if its speed remains constant.

An object is **accelerating** whenever its velocity is changing.
An accelerating object can be speeding up, slowing down or changing direction.
Objects accelerate when subjected to **a resultant force**.

When an object has a **resultant force** on it (i.e. the forces on it are **unbalanced**), the object will **accelerate** in the **direction** of the resultant force.



A stars **gravitational field** exerts a force of **weight** on each planet.
The weight acts as a **centripetal force**, acting perpendicular to the motion of the planet, pulling planets toward the Sun while their velocity keeps them moving forward.
Without gravity, planets would **move in straight lines** into space.
We can mathematically model orbits as circular using the mathematics of circular motion.



Observations

Tycho Brahe

Brahe made thousands of incredibly precise naked-eye observations of planetary positions over several years.

His data was considered the most accurate in the world. Whilst he was beholden to the Geocentric (and later hybrid Geo-Heliocentric) model his high-quality observations allowed others to pursue their own curiosities.

Johannes Kepler

Using Brahe's data. Kepler sought to refine the heliocentric model which had been proposed by Copernicus (and subsequently vilified). He discovered that a number of radical assumptions were needed to make it work, and that they all centred around on core concept.

Planets do not move in circles.

Planetary Motion

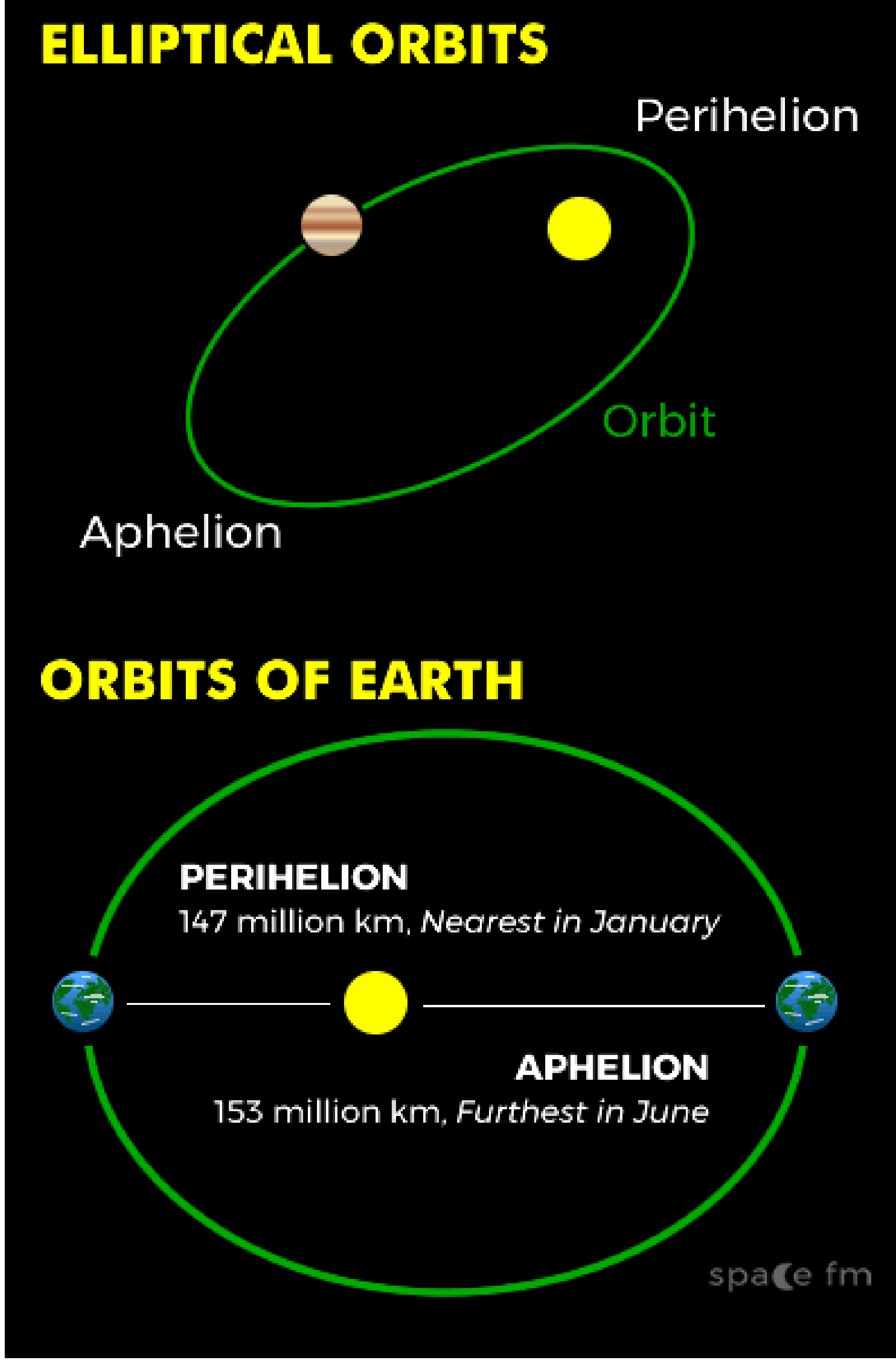
Orbital Terminology

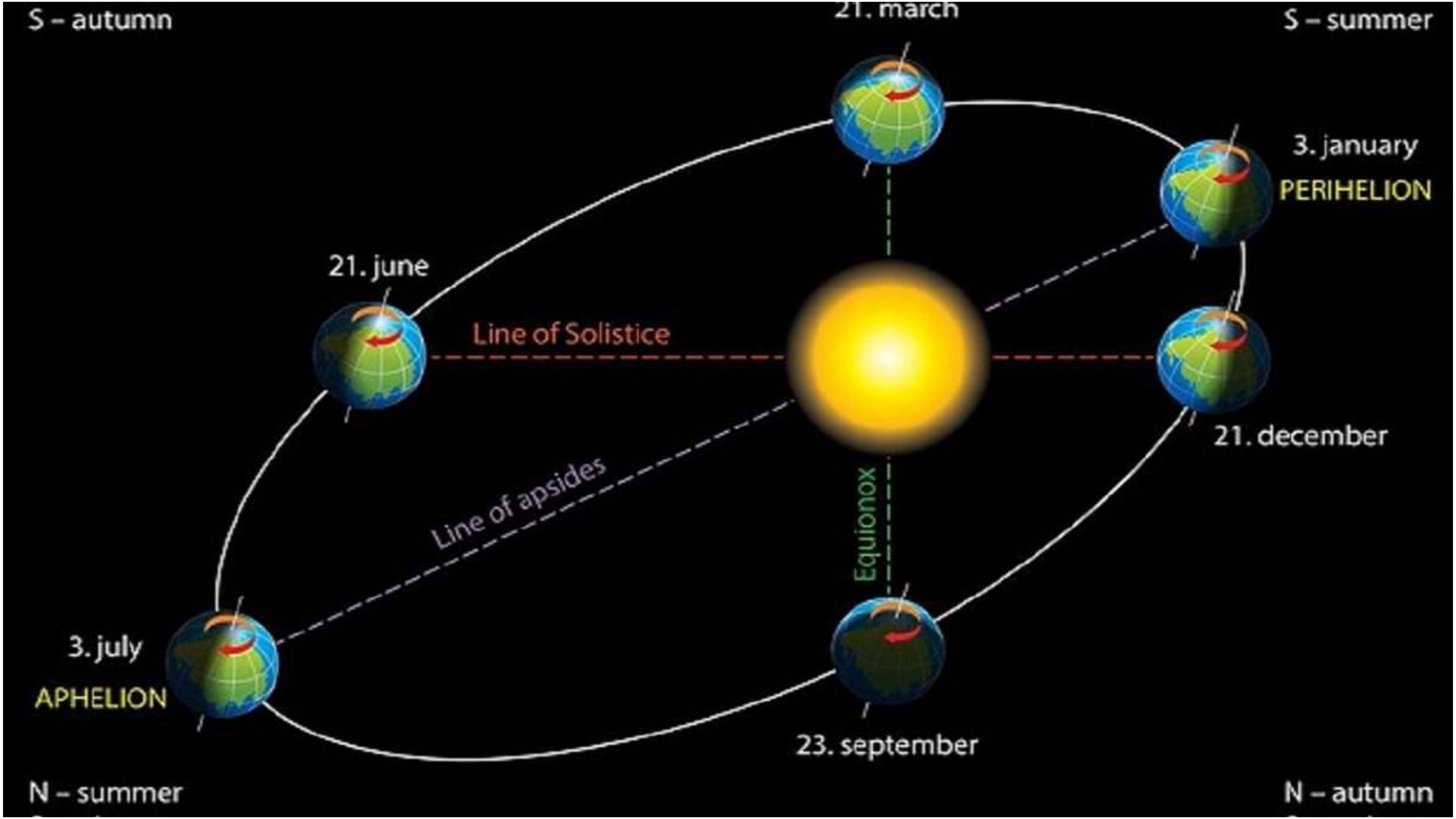
As stated by Kepler, whilst we often model using circular motion, planets and comets do not orbit in perfect circles. They orbit in ellipses.

•When the Earth is nearest to the Sun (in January) it is in PERIHELION or **perigee** and is 147,000,000 km from it.

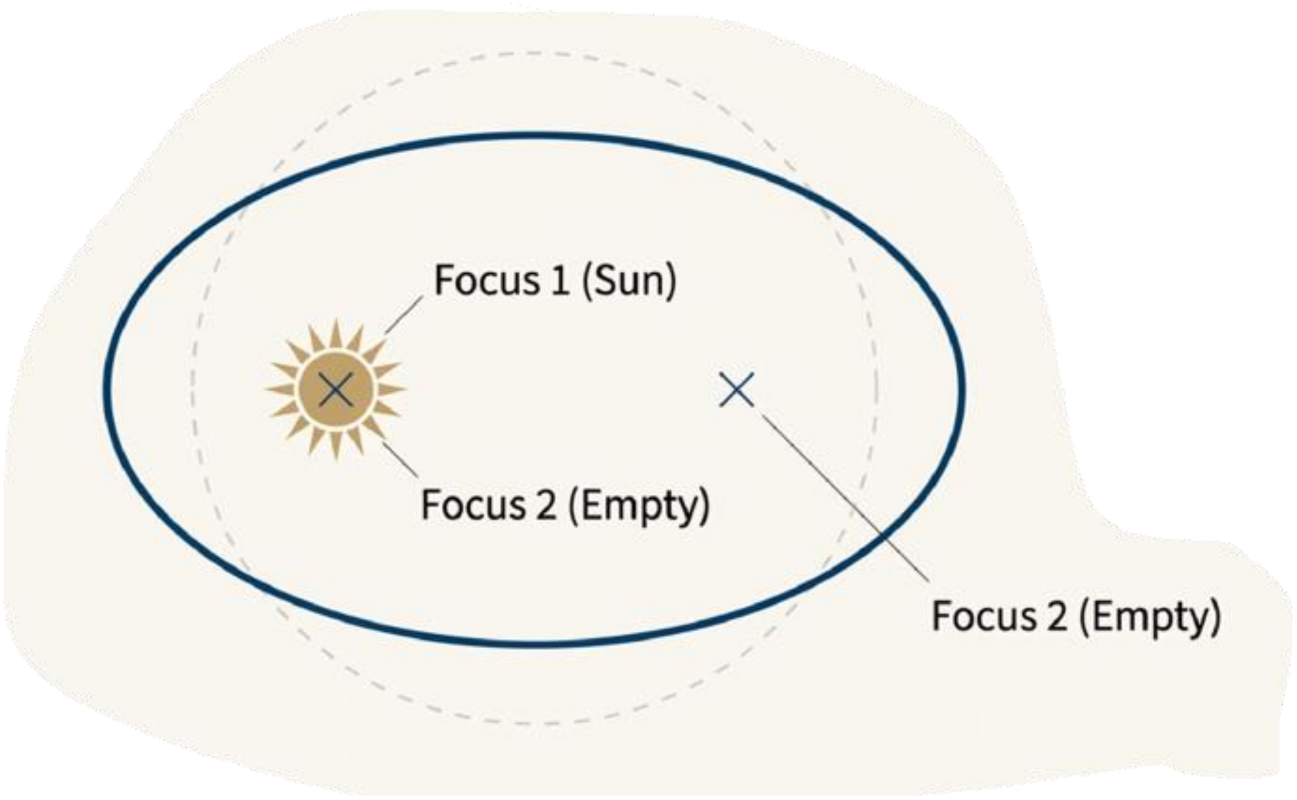
•When it is furthest from the Sun (in July) it is in APHELION or **apogee**. It is then 153,000,000 km from the Sun.

•The mean average distance is approximately 150,000,000 km. This is called the Astronomical Unit, or AU.




S – autumn
21. march
S – summer
3. january
PERIHELION
21. june
Line of Solistice
21. december
Line of apsides
Equionox
3. july
APHELION
23. september
N – summer
N – autumn

Kepler's First Law: The Law of Ellipses



Planets orbit the Sun in elliptical paths, with the Sun at one foci

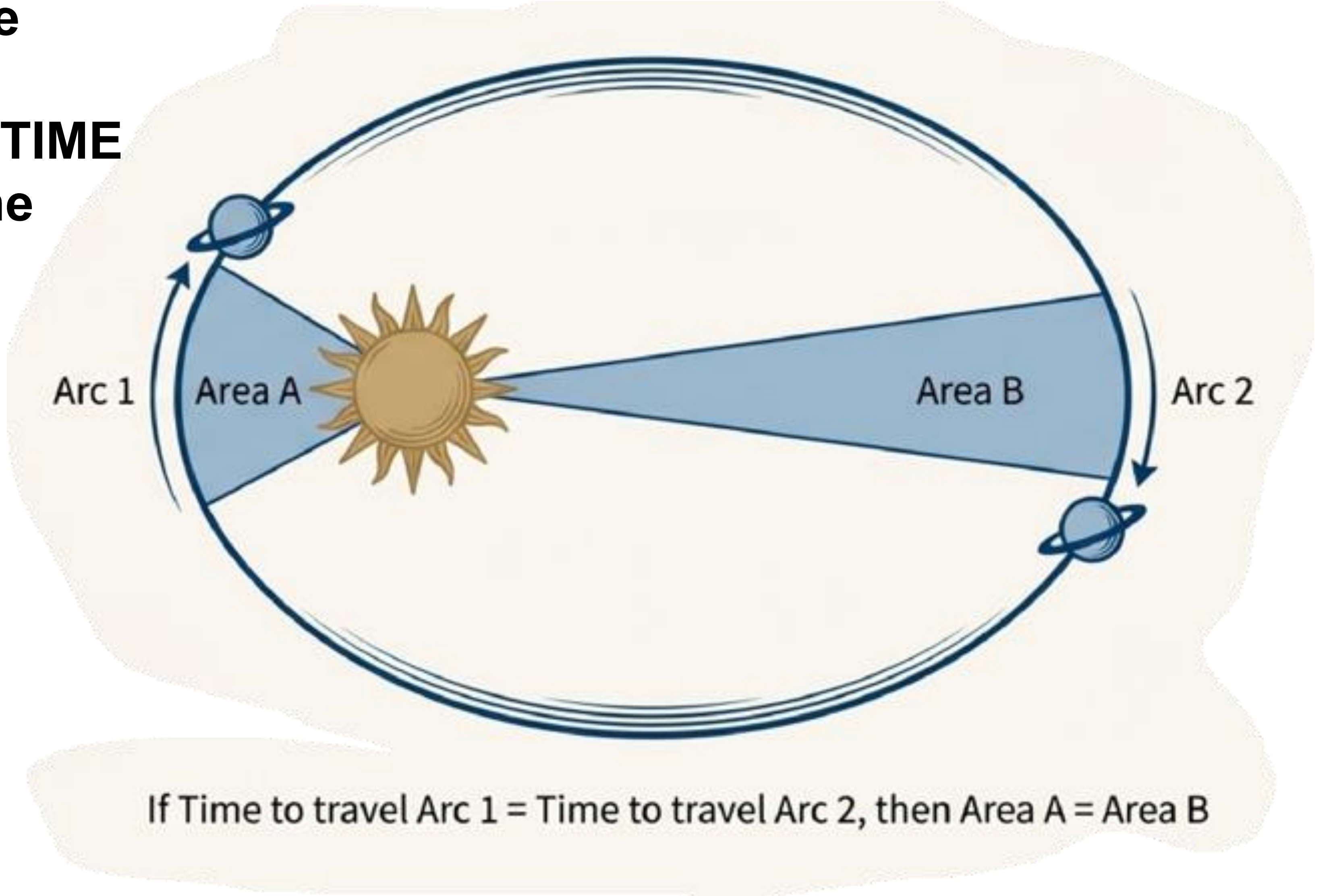
Kepler was able to use elliptical orbits to match Brahe's observations to some tangible theory.

The major body that the object orbits occupies one of two focal points (foci) whilst the other is empty.

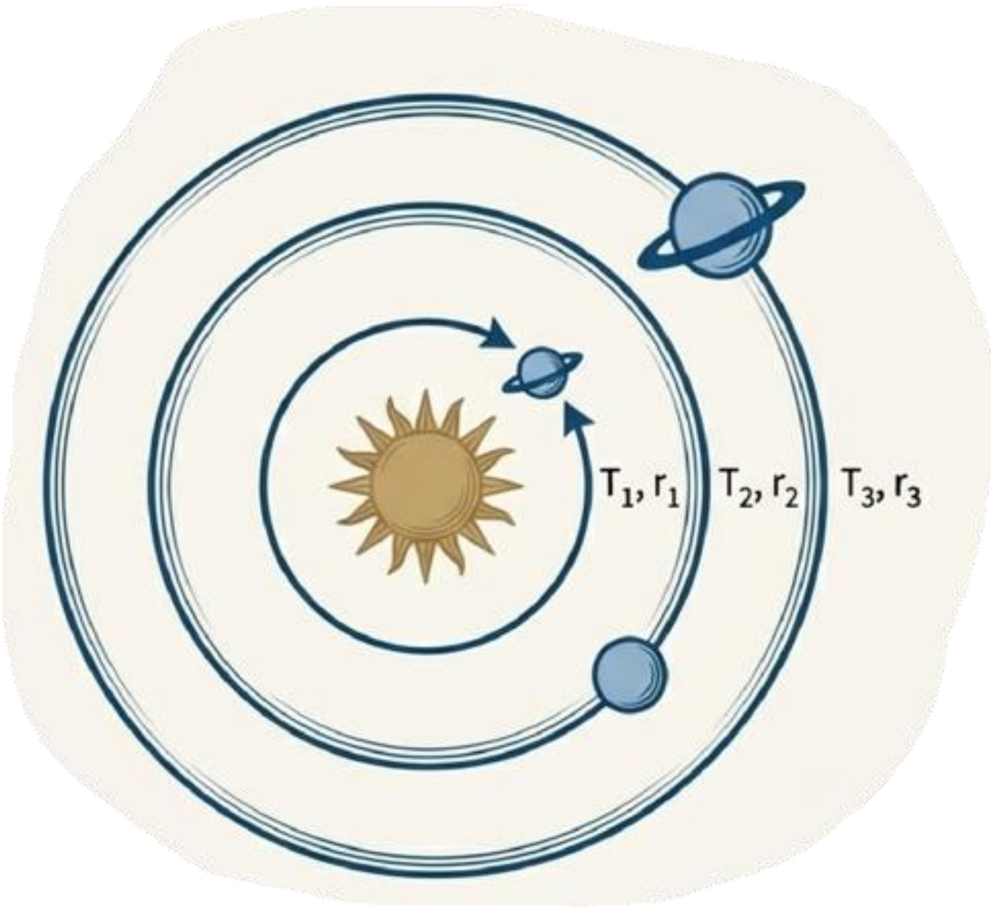
Kepler's Second Law: Law of Equal Areas

A line from the Sun to the planet sweeps out and EQUAL AREA in EQUAL TIME regardless of where in the orbit the planet is.

Planets move closest when they are closest to the Sun (in perigee) and slowest when they are furthest away (in apogee).



Kepler’s Third Law: Law of Harmonies



The square of a planets orbital period (T^2) is directly proportional to cube of its average distance from the Sun (r^3)

$$T^2 \propto r^3$$

If we know how long a planet takes to orbit the Sun we can determine the average distance from the centre of the orbit (modelled as circular mathematically).

It applies to any orbital body. (Such as the moon or satellites)

Isaac Newton

Kepler’s Laws give an accurate picture of planetary motion with incredible accuracy but do not outline the underlying cause or speak full in the language of science.

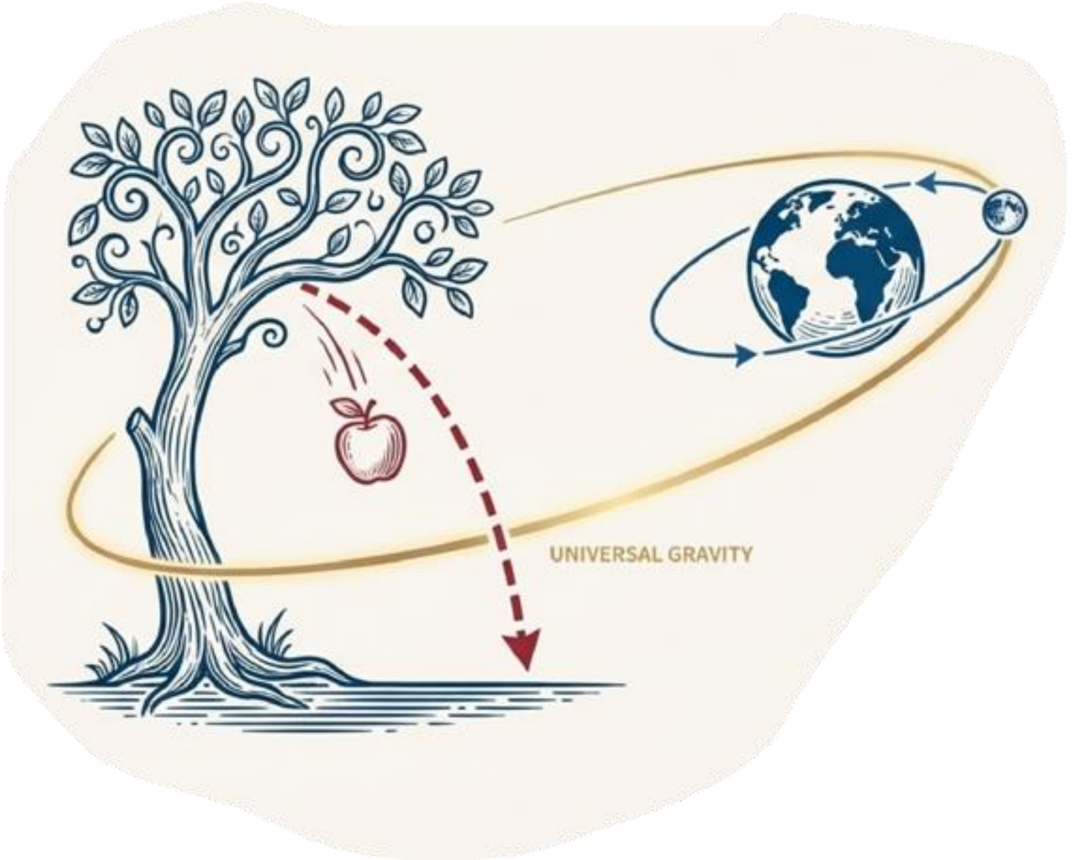
This is where Isaac Newton steps in.
Kepler developed the mathematical arguments to support and verify Kepler’s laws.

He based this on two overall principles:
Inertia: The tendency of an object to resist changes to its motion.

Gravity: A gravitational field is a region of space around a mass where another mass experiences an attractive force.

Gravity is always an **attractive** force.

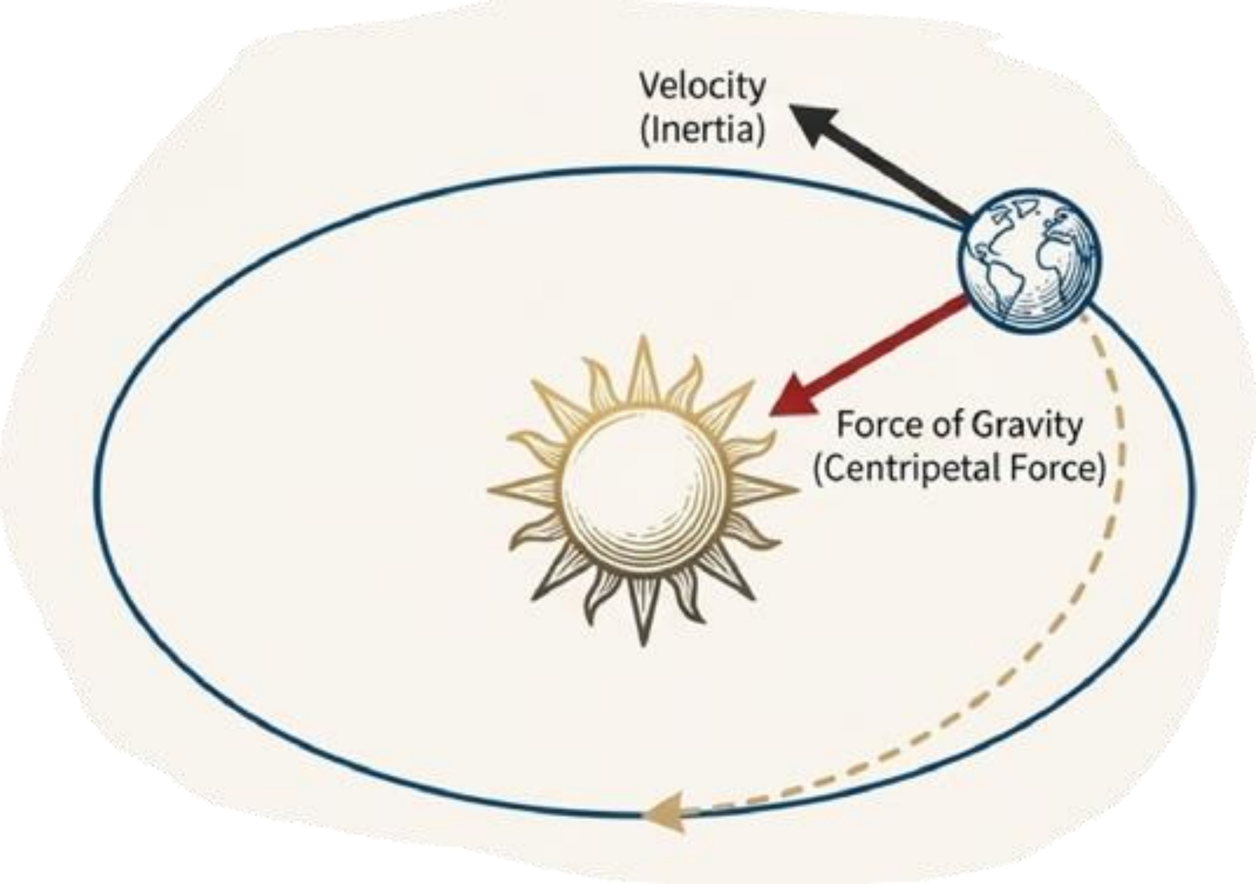
The gravitational field strength is the **FORCE** per **UNIT MASS**.



Universal Gravitation

The force of Gravity between two point objects:

- is proportional to the product of the masses of the objects ($F \propto m_1 m_2$)
- is inversely proportional to the square of the distance between the centre of mass of the objects. ($F \propto 1/r^2$)



It acts to reduce the distance, *r*, between the two masses.

It is in the opposite direction to the displacement from one object to the other.

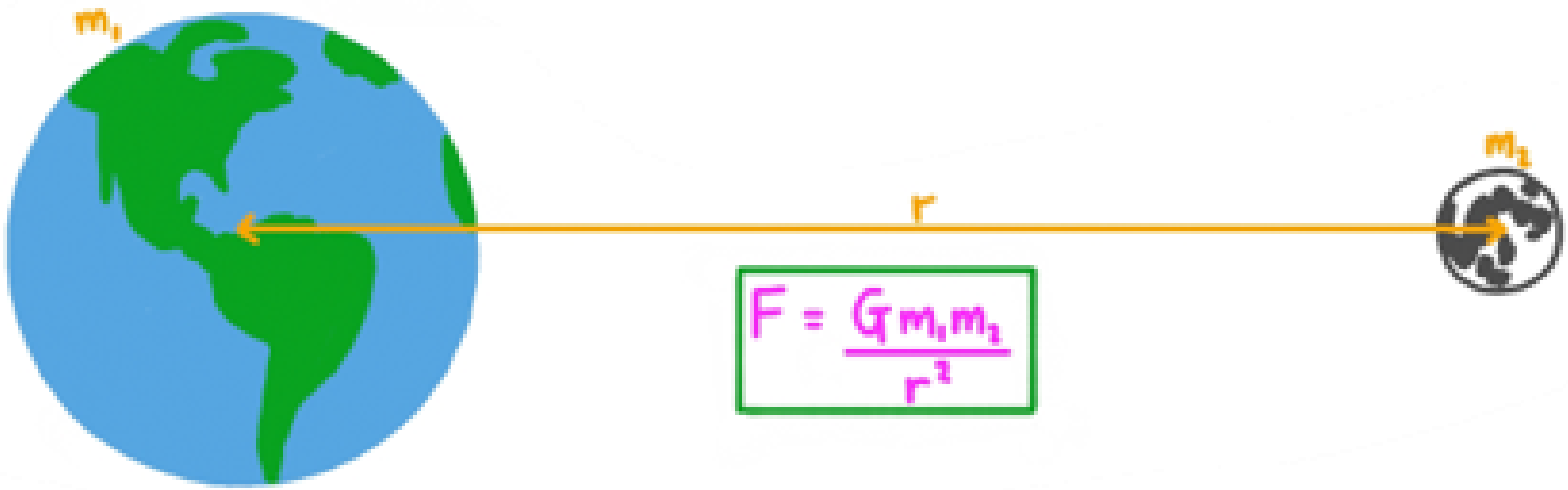
The constant *G* is known as the universal gravitational constant.

This is an example of what we call an **inverse square law.**

Newton’s Law of Gravitation

The force of gravity is a **vector** quantity, where the force act between the two objects.

The two bodies exert a gravitational force on each other, where the direction of the force acts from the centre of mass of the body, and acts towards the centre of mass of the other body.

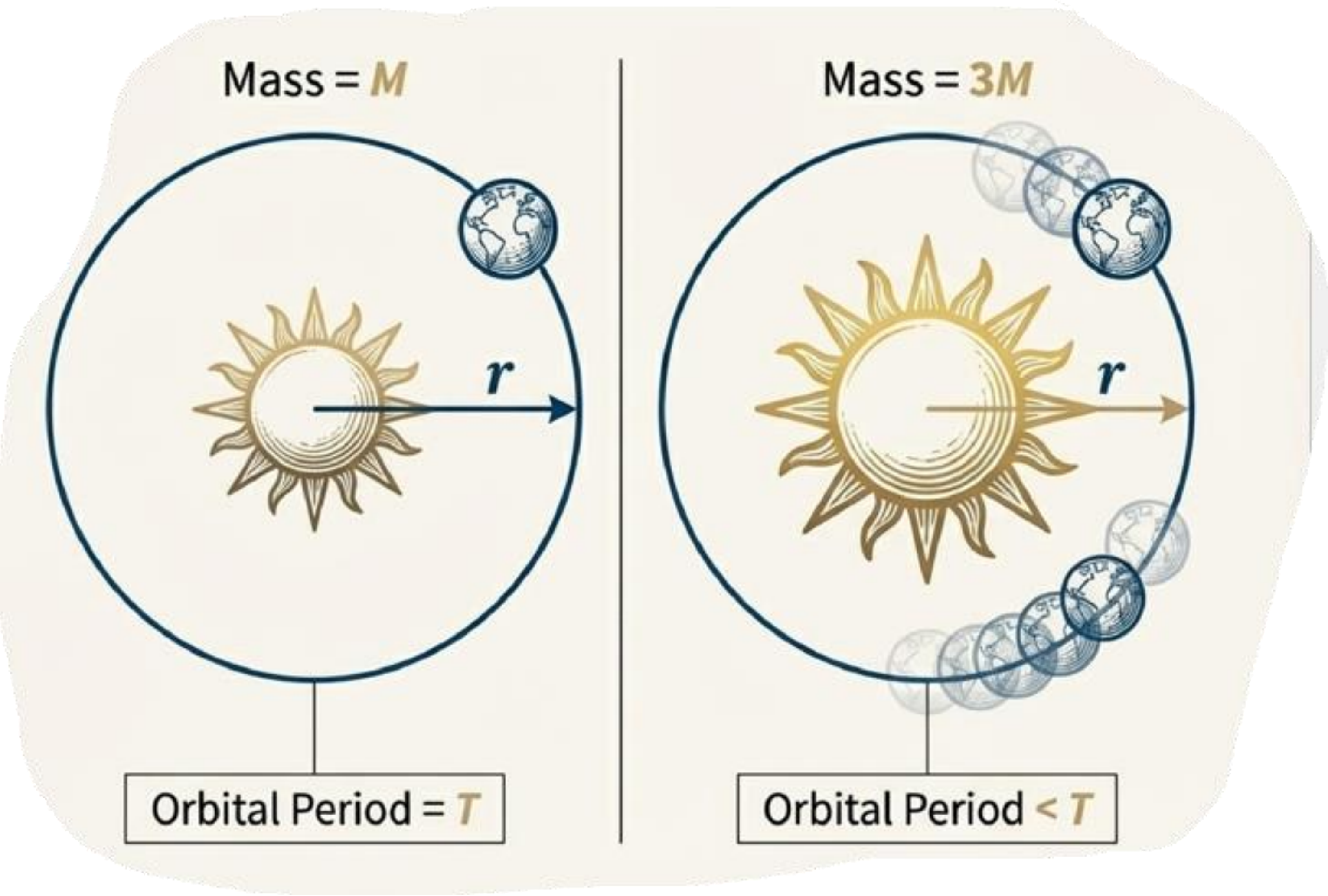


Central Orbital Body

A more massive (not necessarily larger…) central body creates a stronger gravitational field.

For planets at the same average planetary radius we would see a faster orbital speed (and lower orbital period) for the more massive central body.

If the sun was replaced with a more massive central star, a planet at 1AU would have a much shorter year.



DECODING THE COSMOS: A GUIDE TO PLANETARY MOTION

THE PIONEERS OF PLANETARY MODELS

TYCHO BRAHE: THE MASTER OBSERVER

His precise, naked-eye observations of planets were crucial for future breakthroughs.

COPERNICUS: A SUN-CENTRED UNIVERSE

He proposed the first hellocentric model, placing the Sun at the centre.

FROM PERFECT CIRCLES TO ELLIPSES

Keplor refined Cepernicus's model by proving planets move in ellipses, not perfect circles.

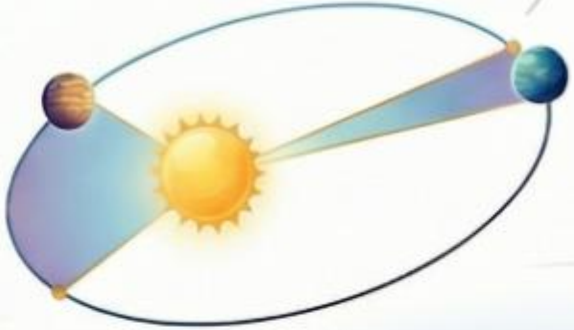
THE LAWS THAT GOVERN ORBITS

KEPLER'S 1ST LAW: THE LAW OF ELLIPSES

Planets travel in elliptical paths with the Sun at one of the two foci.

KEPLER'S 2ND LAW: THE LAW OF EQUAL AREAS

Planets move faster when closer to the Sun and slower when farther away.



NEWTON'S EXPLANATION: GRAVITY & INERTIA

Gravity pulls planets toward the Sun while their inertia keeps them moving forward.