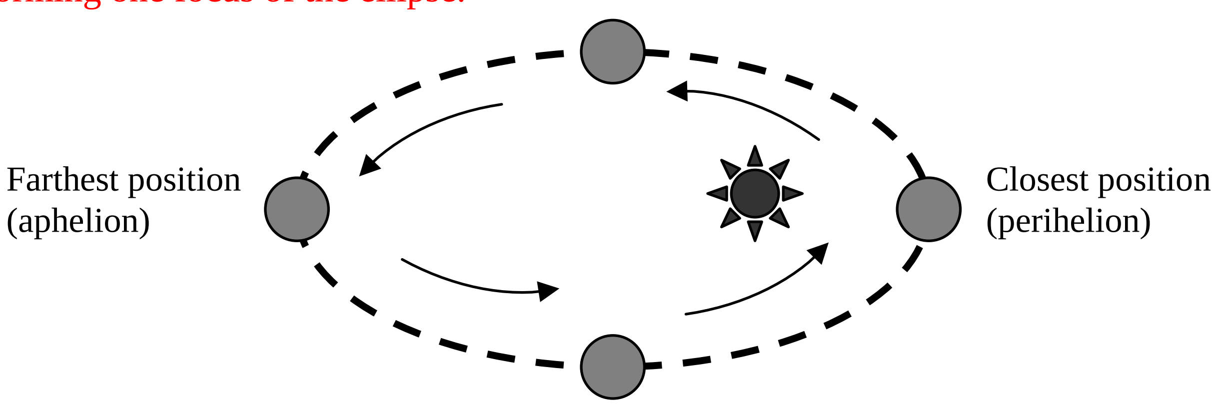
KEPLER'S LAWS OF PLANETARY MOTION

Gravity is one of the four fundamental forces. ***Gravity*** is a mutual attractive force (pull force) where all objects with mass naturally attract all other objects with mass. The motions of bodies (star, moons and planets) in our solar system are direct evidence of gravitational attraction between them.

Johannes Kepler was a German mathematician in the late 1500s and early 1600s who analyzed the motions of planets in our solar system by using recorded astronomical data that was collected over the centuries. Kepler's work predated ***Galileo's*** falling experiments by 10-20 years and predated Sir Isaac Newton's gravity quantifications by 80 years. Kepler had no idea what gravity was, or that gravity was responsible for how the planets in our solar system orbit the sun. Kepler only used numbers and geometry without knowing the "why" it was happening.

Kepler's three laws of planetary motion describe how the planets orbit the sun. Kepler's laws do not explain why the planets orbit the sun they way they do because the gravity force was unknown to him. His laws are based solely on mathematical calculations of their positions according to astronomical data.

Kepler's 1st Law of Planetary Motion: The orbits of planets are ellipses with the sun forming one focus of the ellipse.



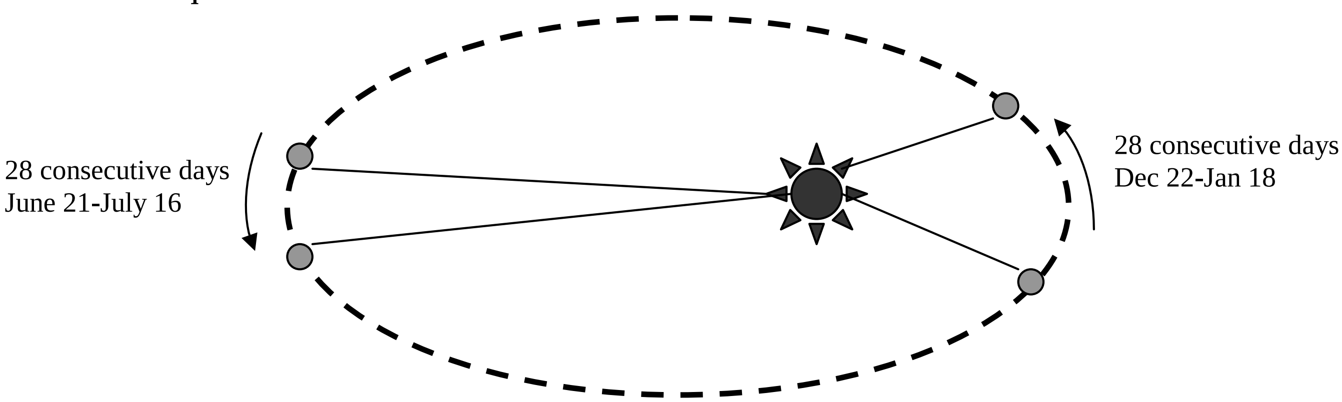
In other words: Orbits of stars are not perfect circles. Orbits are elliptical or oval shaped.

The figure shows a moving planet in orbit around a star at four different times during its revolution. Because the orbits of planets around the sun or star are elliptical in shape, the planet will be physically closer to the star at one point in its orbit and the planet will be physically farther away from the star at another point in its orbit. ***Perihelion*** is the position where the planet is physically closest to the star (sun) in its orbit. ***Aphelion*** is the position where the planet is physically farthest from the star (sun) in its orbit.

Earth's orbit is a very slight ellipse—the orbit only deviates from a perfect circle by ~ 3%. Because of the slight deviation from a perfect circle, Earth's climates are not greatly affected by the "closeness" or "distance" differences between perihelion and aphelion. Earth's perihelion is January 3 and aphelion is July 4. Other planets have more elliptical orbits (more oval shaped).

Kepler's 2nd Law of Planetary Motion: The Law of "Equal Areas". The imaginary line between the sun and the planet sweeps equal areas in equal times.

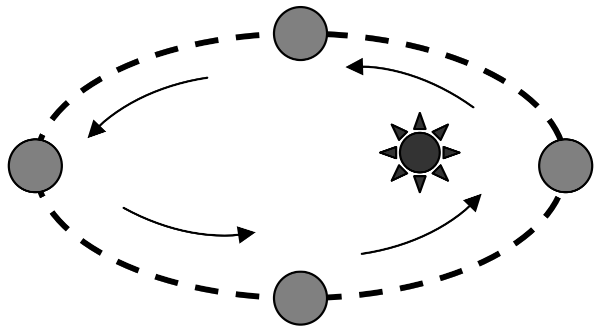
In other words: The "pie wedge" areas between the sun and the planet moving in its orbit are equal for equal times. In the diagram, Earth moves for 28 consecutive days in December-January and 28 consecutive days in June-July. The Earth in its orbit moves a greater distance in its orbit during the 28 days in December-January; the Earth in its orbit moves a lesser distance during the 28 days inJune-July. Despite the differences in how fast the Earth moved in its orbit, the areas of the pie wedges between the sun and the Earth's orbit are equal.



This observation is directly related to how fast the Earth moves in its orbit. When the Earth is physically closest to the Sun (at perihelion), gravitational attraction force between Earth and Sun is the greatest, therefore the Earth is moving the fastest in its orbit—the Earth experiences a greater acceleration with the sun as it is closer. As a result, the Earth moves a greatest distance in its orbit in those 28 days (moves faster). Conversely, when the Earth is physically farthest from the Sun (at aphelion), gravitational attraction force between Earth and Sun is the weakest, therefore the Earth is moving the slowest in its orbit—the Earth experiences a lesser acceleration with the sun as it is farther away. As a result, the Earth moves a very short distance in its orbit in 28 days from late June to mid July.

- Moving away from the star
- Gravitational attraction decreasing
- Orbit speed getting slower

- Farthest distance
- Weakest gravitational attraction
- Orbit speed the slowest



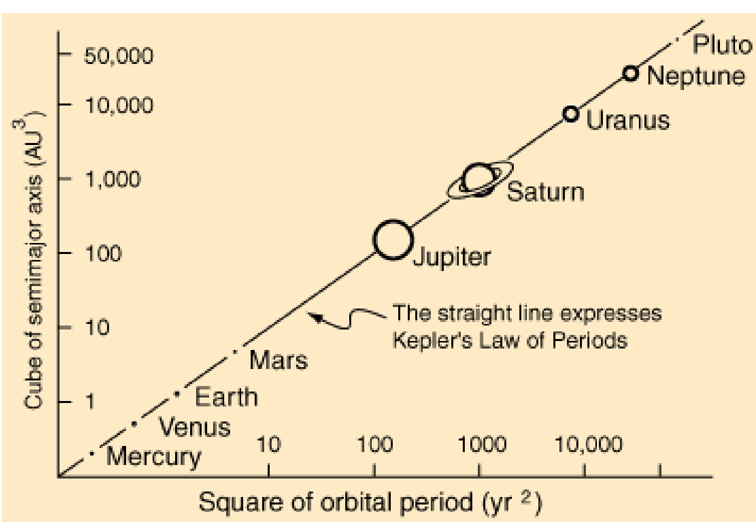
- Closest distance
- Strongest gravitational attraction
- Orbit speed the fastest

- Moving closer to the star
- Gravitational attraction increasing
- Orbit speed getting faster

Kepler's 2nd Law indirectly relates to orbit speed as controlled by gravitational attraction and acceleration of the planet in the star's gravity field because of the planet's changing distance to the star.

- The closer a planet is in its orbit to its star, the stronger the gravitational attraction, the greater the acceleration, the greater the orbit speed.
- The farther away a planet is in its orbit to its star, the weaker the gravitational attraction, the lesser the acceleration, the lesser the orbit speed.

Kepler's 3rd Law of Planetary Motion: The square of the planet's orbital period **(Period)^2** is proportional to the cube of the semi-major axis of the planet's orbit **(Distance)^3**.



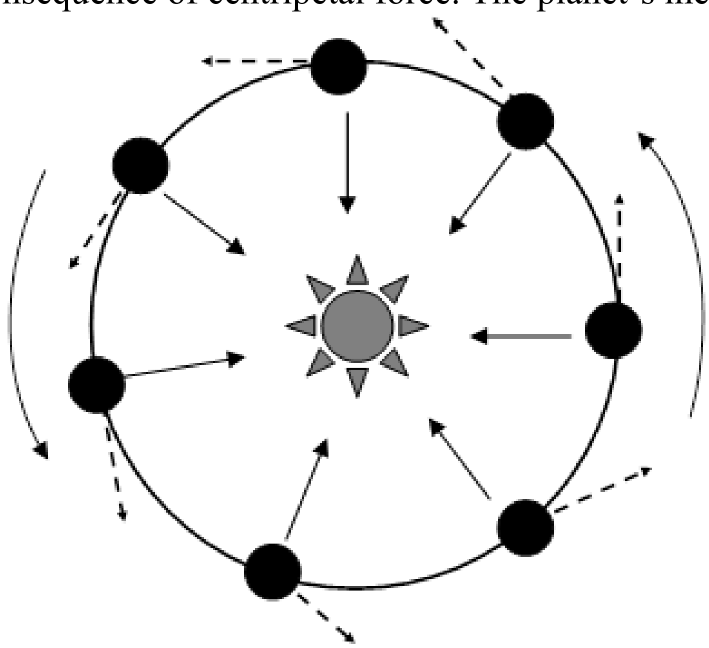
In other words: Kepler's 3rd Law relates how long it takes for a planet to make one orbit around the star based on how far away the planet's orbit lies from the star.

- The farther a planet's orbit distance is away from the star, the longer it takes for the planet to orbit the star.
- The closer a planet's orbit distance is away from the star, the shorter the time it takes for the planet to orbit the star.

Mercury's orbit is the closest to the Sun. Mercury's orbit period is 88 Earth days. In contrast, Neptune's orbit is farthest from the Sun. Neptune's orbit period is 164 years. Kepler's 3rd Law of planetary motion relates to the average orbital speed that the planet must travel to balance out the gravitational pull of the Sun on the planet. Mercury must orbit the sun very fast to maintain a stable orbit because the gravitational attraction between Mercury and the Sun is very strong due to their close proximity. Neptune, in contrast, orbits the Sun very slowly because the gravitational attraction between Neptune and the Sun is much weaker because of their greater distance apart.

STABILITY OF ORBITS

The orbits of planets, albeit ellipses, remain stable because of the push-and-pull of (1) gravitational attraction between the star and the planet and (2) centripetal force and inertia of the planet moving in its curving orbit around the star. The dashed arrows represent the motion component of the orbiting planet if allowed to move under its inertia—a consequence of centripetal force. The planet's inertia wants to continue moving in a straight line at constant velocity (tangential velocity). The solid arrows represent the "falling" of the planet toward the star because of gravitational attraction force between the planet and the star.



So, as the planet moves outward in a straight line, it simultaneously falls toward the star. This continuous moving outward-falling combination results in a curved path of motion (and centripetal force)—resulting in the orbit. The orbit will remain stable as long as gravitational attraction force between the planet and star equals centripetal force affecting the planet as it moves around the star.

GRAVITATIONAL ATTRACTION FORCE = CENTRIPETAL FORCE

If gravitational attraction was stronger than centripetal force, the planet would spiral inward toward the star and eventually crash into the star. If gravitational attraction were weaker than centripetal force, the planet would spiral outward away from the star and eventually leave the gravity field of the star.