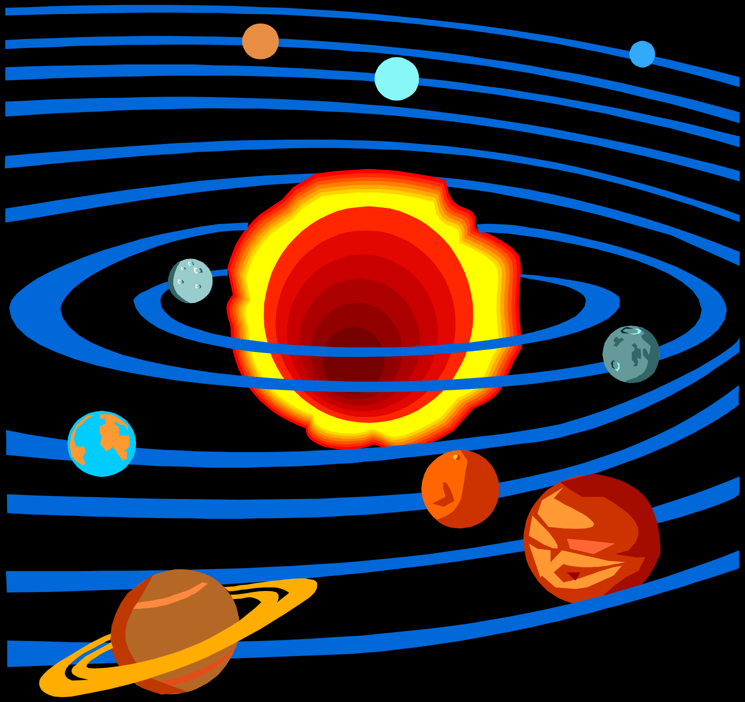
Kepler’s Laws of Planetary Motion

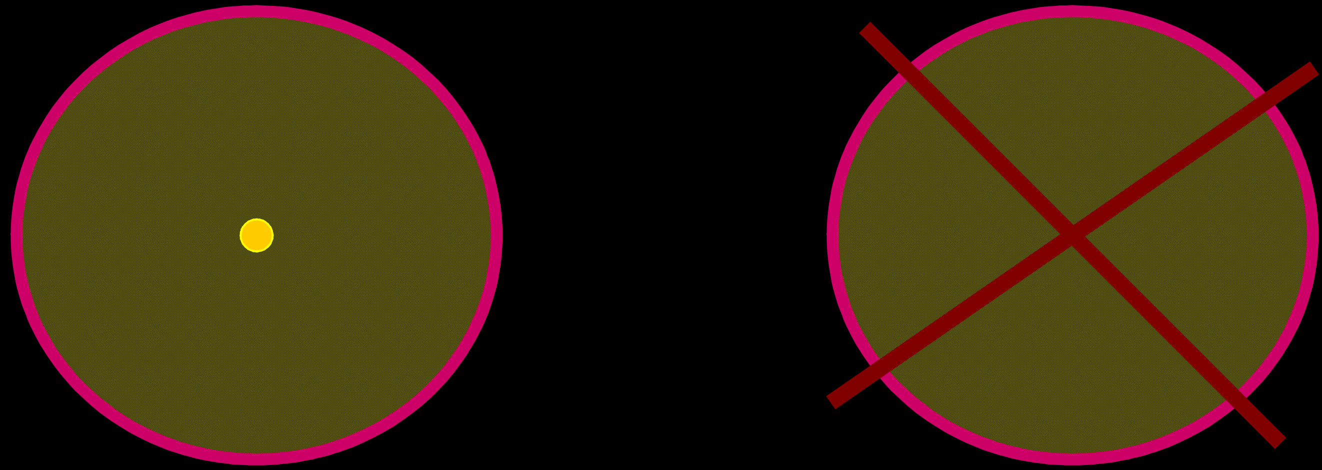


Tyco Brahe (1546-1601)

- Danish astronomer
- Had an island observatory and the best measurements of the positions for all know planets and the moon
- Mercury, Venus, Mars, Jupiter, Saturn

Johannes Kepler (1571-1630)

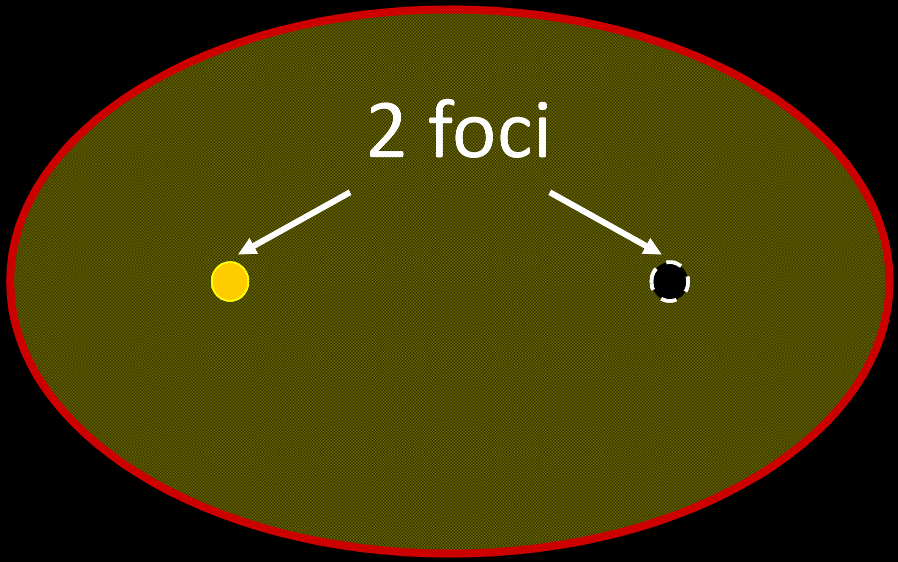
- Austrian mathematician
- Interested in how the planets move around the sun
- When to Tyco’s island to get these accurate measurements



- At that time, many astronomers believed that planets orbited around the sun in **perfect circles**
- Tyco’s accurate measurements for Mars didn’t fit a **circle**
- Kepler found that the orbit of Mars fit an **ellipse** the best

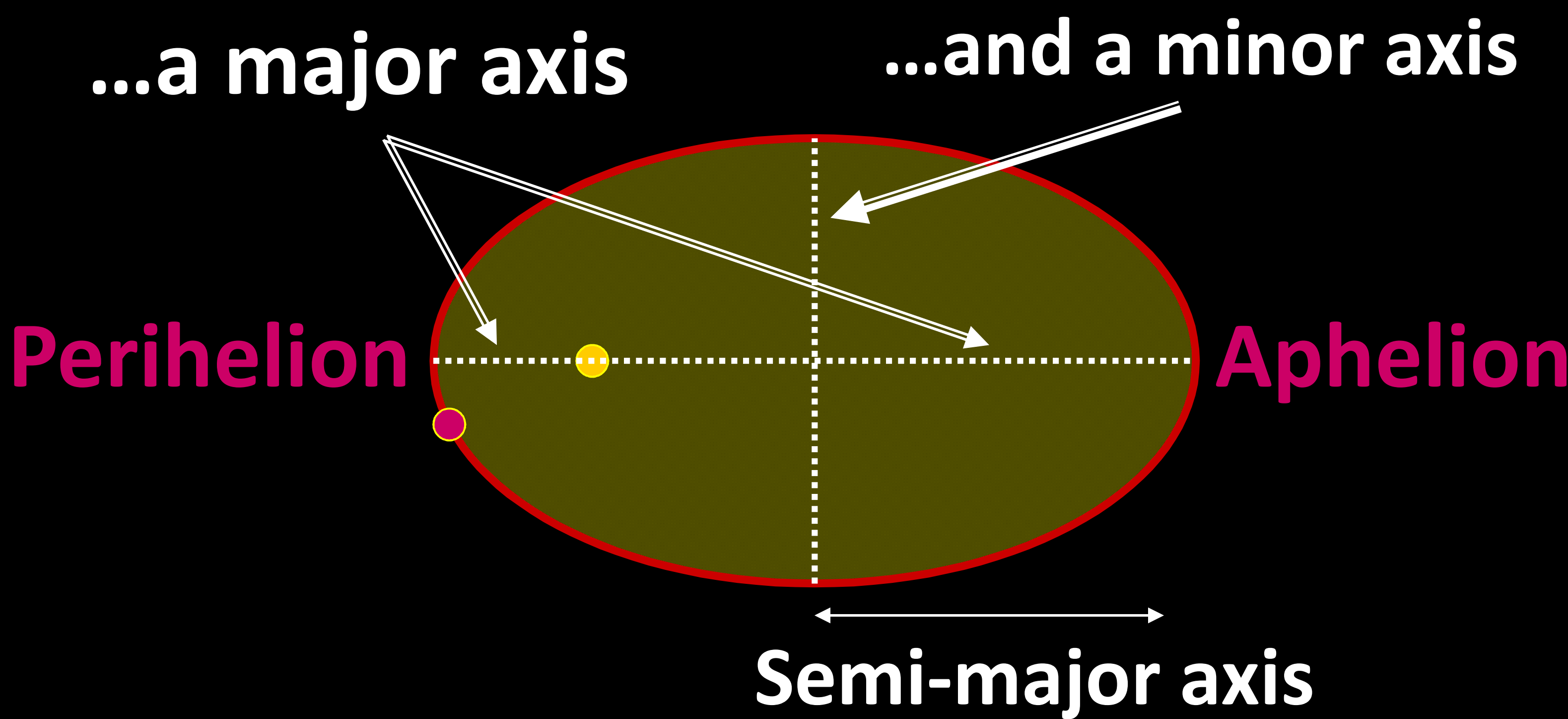
<u>First Law of Planetary Motion</u>: A planet's orbit is an ellipse with the sun at one focus and nothing at the other focus

What is an ellipse?



- An ellipse is a geometric shape with 2 foci
- A circle has 1 central focus

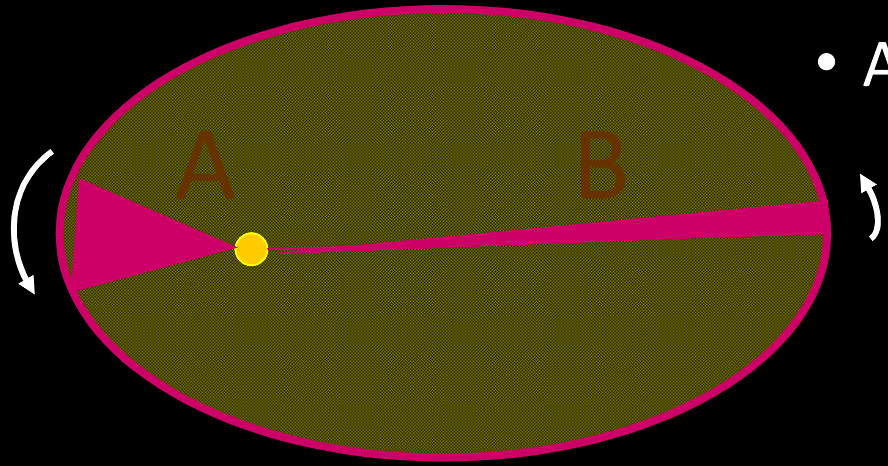
An ellipse also has…



- **Perihelion**: When Mars or any other planet is closest to the sun
- **Aphelion**: When Mars or any other planet is farthest from the sun

Second Law of Planetary Motion: the line joining the planets to the Sun sweeps out "equal areas in equal times" as the planet travels around the ellipse

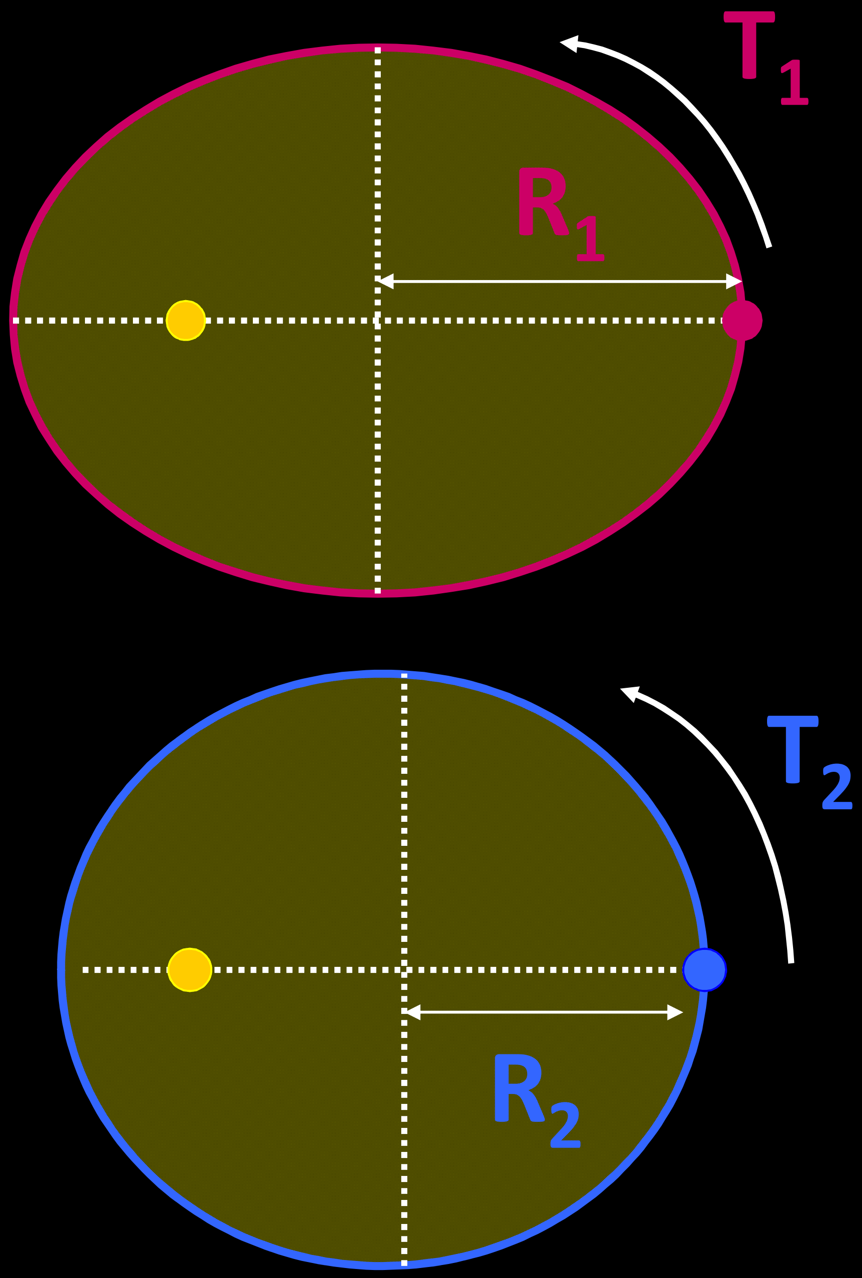
- Kepler also found that Mars changed speed as it orbited around the sun
  - **Faster** when **closer** to the sun
  - **Slower** when **farther** from the sun



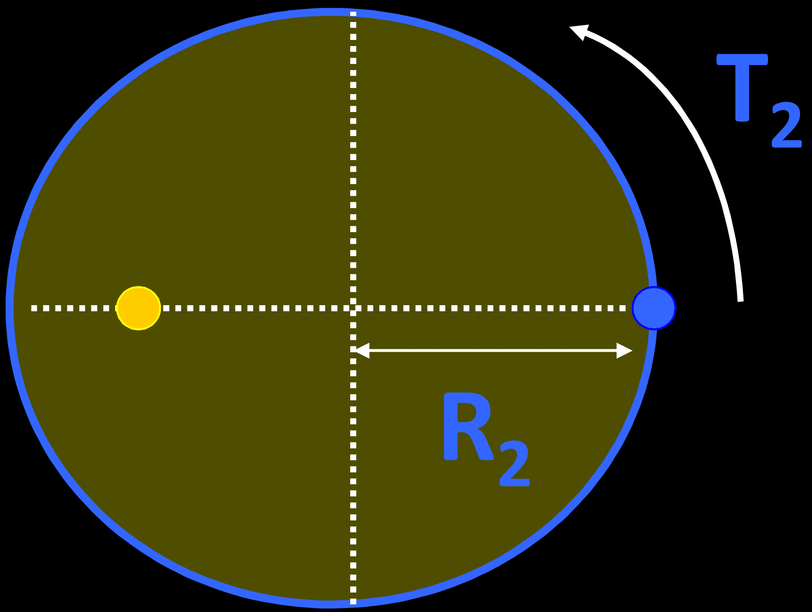
- Areas A and B swept out by a line from the sun to Mars, were equal over the same amount of time

- Kepler found a relationship between the time it took a planet to go completely around the sun (T, year) and the average distance from the sun (R, semi-major axis)

$$\frac{T_1^{\ 2}}{T_2^{\ 2}} = \frac{R_1^{\ 3}}{R_2^{\ 3}}$$



Third Law of Planetary Motion: the ratio of the square of the revolution time for two planets is equal to the ratio of the cubes of their semi-major axes



- Earth's year (T) is 1 year
- Earth's semi-major axis (R), the distance from the Earth to the Sun, is 1 astronomical unit (AU)

$$\frac{T_1^{\,2}}{T_2^{\,2}} = \frac{R_1^{\,3}}{R_2^{\,3}} \text{ or } \frac{T_1^{\,2}}{1} = \frac{R_1^{\,3}}{1} \text{ or } T_1^{\,2} = R_1^{\,3}$$

WHAT DOES THIS MEAN?!?

- If you know the distance from the sun and year of planet A, and you know the distance from the sun for planet B you can find the year of planet B.

OR

- If you know the distance from the sun and year of planet A, and you know the year of planet B you can find the distance from the sun for planet B

When we compare the orbits of the planets…

Planet	T(yrs)	R(au)	T^2	R^3
Venus	0.62	0.72	0.38	0.37
Earth	1.00	1.00	1.00	1.00
Mars	1.88	1.52	3.53	3.51
Jupiter	11.86	5.20	141	141

We find that T^2 and R^3 are essentially equal.

Kepler’s Laws apply to any celestial body orbiting any other celestial body

- Any planet around a sun
- The moon around the Earth
- Any satellite around the Earth
- The International Space Station
- Any rings around any planet