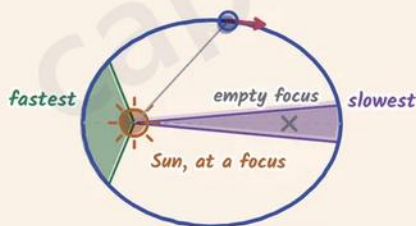


one law pulls every mass toward every other, from an apple to a satellite

Kepler's laws

- law of orbits: every planet moves in an ellipse with the Sun at one focus
- law of areas: the line from the Sun sweeps equal areas in equal times
- so a planet is fastest nearest the Sun, slowest farthest away
- equal areas is angular momentum conservation: the Sun's pull is central, no torque



equal areas, equal times

equal times sweep equal areas: short and wide near the Sun, long and thin far away

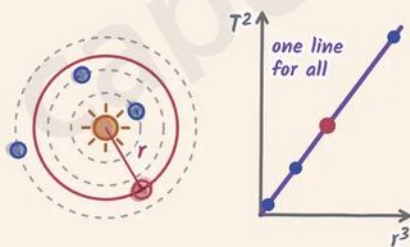
Kepler's law of periods

every planet of one Sun, same constant

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

for a circular orbit of radius r

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$



farther out means slower and a longer year; all planets lie on one straight line of T^2 over r^3

for an ellipse, r is the semi-major axis; the constant depends only on the Sun's mass

The universal law of gravitation *

force between two point masses

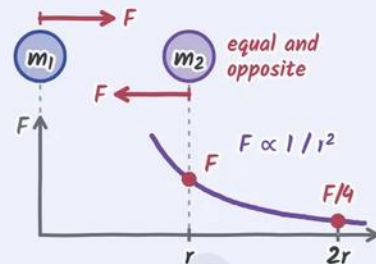
$$F = \frac{Gm_1m_2}{r^2}$$

universal gravitational constant

$$G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$$

always attractive, along the line joining the masses

$$F \propto \frac{1}{r^2}$$



equal and opposite pulls along the line of centres; twice as far, a quarter of the pull

every particle pulls every other, never a push; equal and opposite pulls (third law); r centre to centre; G the same everywhere