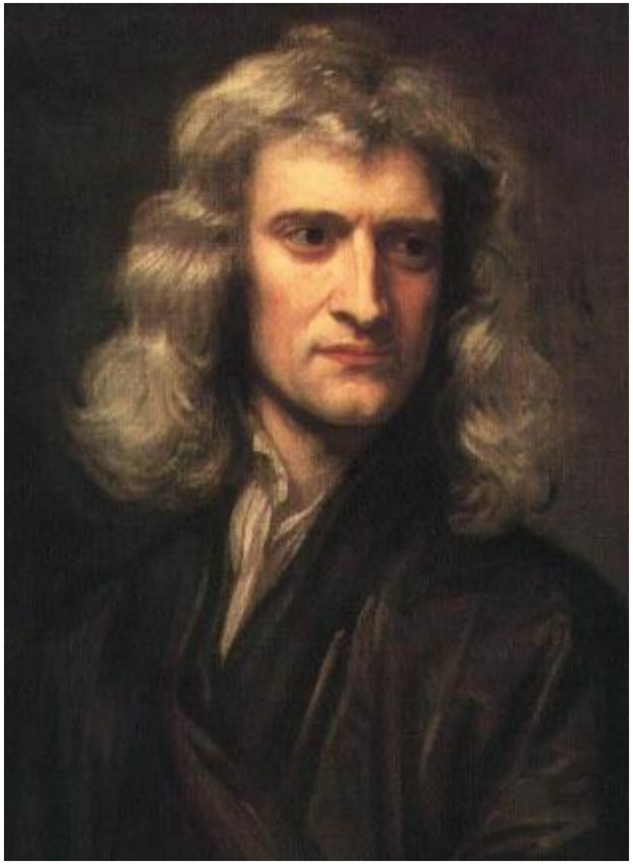
Cosmological Models

I. Planetary Motion
II. Aristotle and Ptolemy
III. Copernicus
IV. Galileo
V. Kepler's Laws
VI. Newton's Laws
VII. Einstein

	The student will be able to:	HW:
1	Describe and illustrate the apparent motion of each of the eight planets as seen from Earth bringing special attention to the similarities and differences. ✓	1 – 5
2	Define, illustrate, and apply the following concepts: direct or prograde motion, retrograde motion, conjunction, opposition, and elongation. ✓	
3	Explain and illustrate aspects of ancient geocentric models of the universe including the concepts of deferents, epicycles, and the works of Ptolemy. ✓	6 – 8
4	Explain and illustrate the heliocentric model of the universe proposed by Copernicus including its seven main points and its own inconsistencies. ✓	9 – 11
5	Explain and illustrate how Galileo was able to provide evidence for the validity of the heliocentric model. ✓	12
6	Desribe Tycho Brahe's contribution to the formation of Kepler's Laws. ✓	13 – 14
7	Define and apply the characteristics of ellipses: focus, semi-major axis, semi-minor axis, and eccentricity. ✓	15 – 16
8	Define, illustrate, and apply the concepts of aphelion and perihelion. ✓	
9	Explain, illustrate, and apply Kepler's three laws of planetary motion and properties of ellipses to solve problems involving orbits. ✓	17 – 21
10	Explain, illustrate, and apply methods for determining the absolute and relative scale of the solar system. ✓	22 – 25
11	Explain, illustrate, and apply Newton's Laws of Motion and Universal Gravitation.	26 – 29
12	Compare and contrast Newton's Laws with Kepler's Laws.	30 – 32



Newton
1643 – 1727 AD

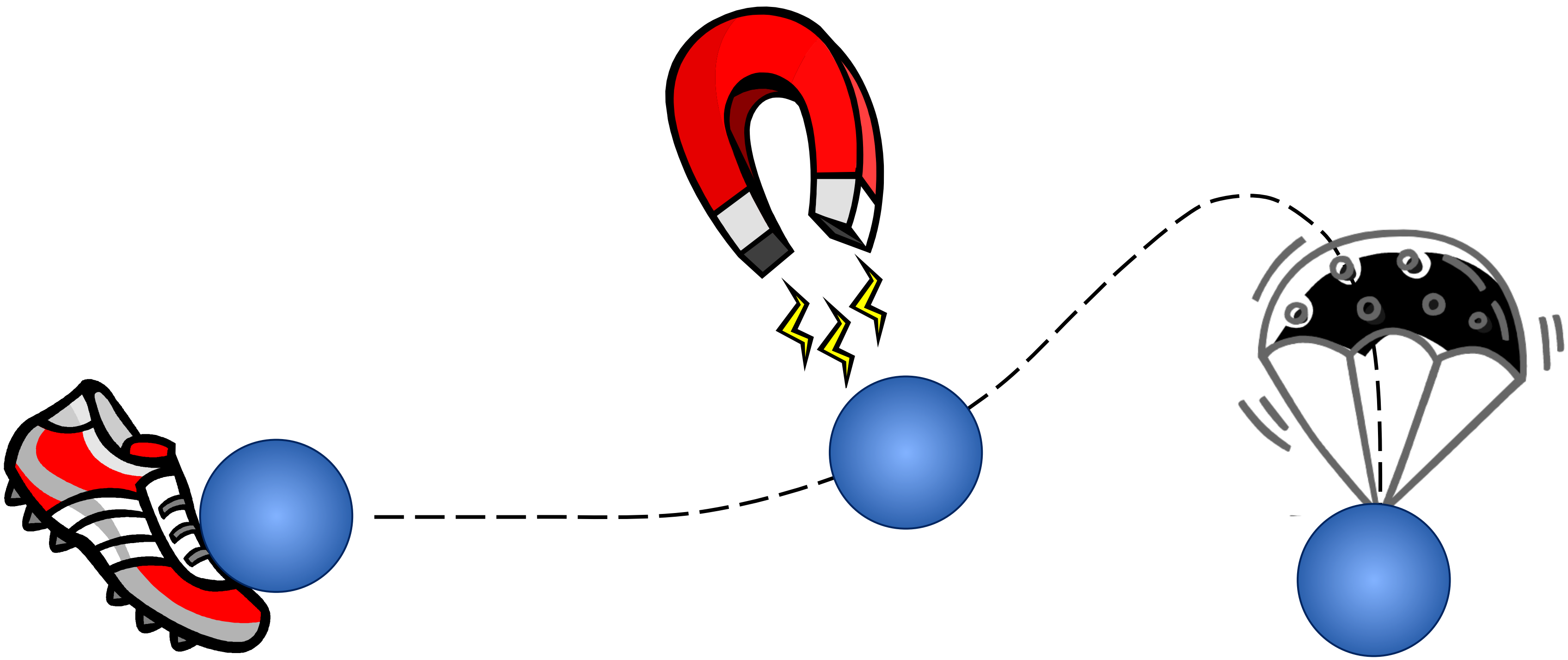
Isaac Newton was an English scientist and mathematician that developed an understanding of motion that is the basis for physics.

In 1687 he published 3 Laws of Motion and the Law of Universal Gravitation. These laws allow us to analyze and understand the motion of the planets (and anything else that moves)!

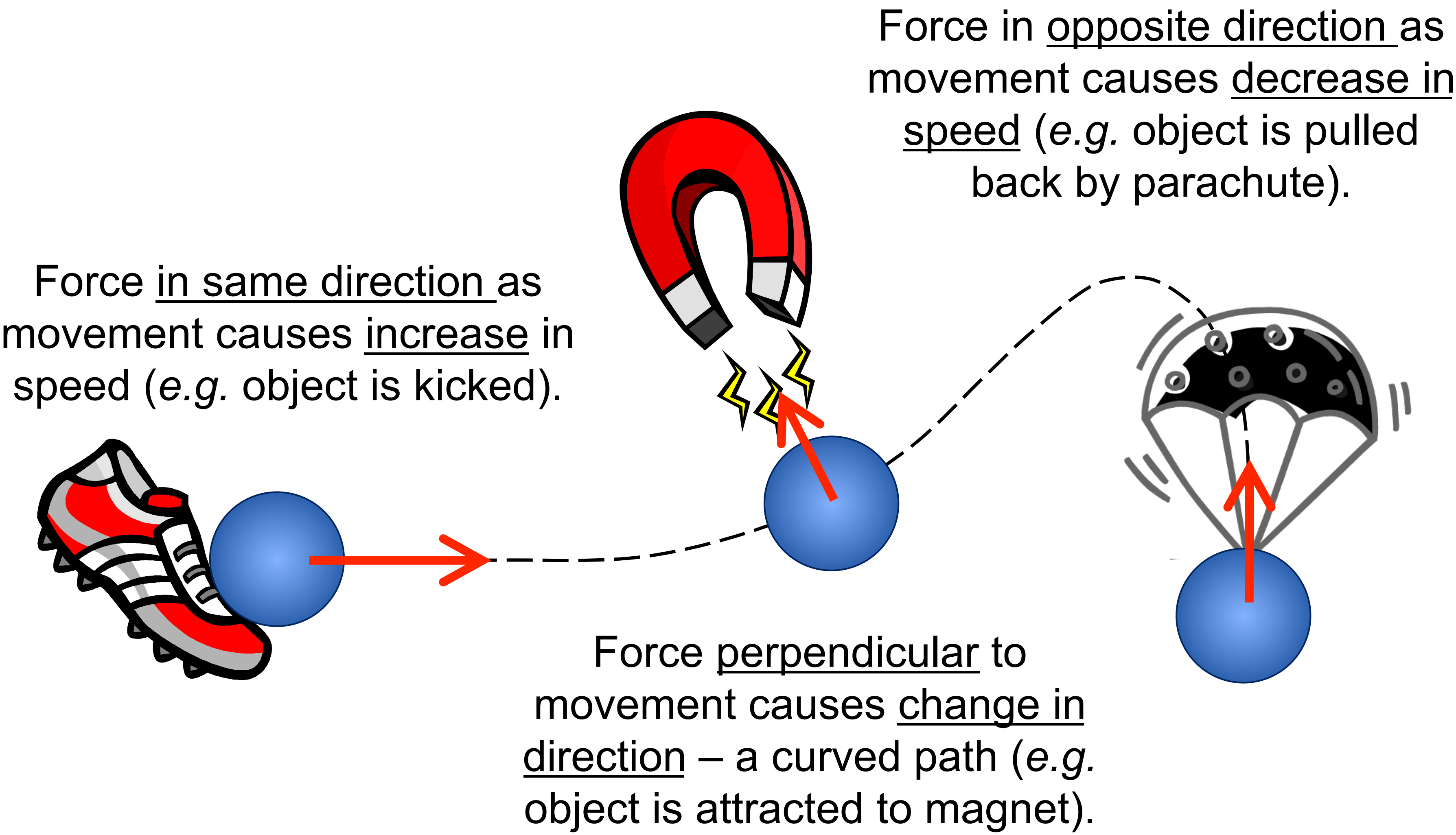
Newton's 3 Laws of Motion

1. In the absence of force, an object will either remain at rest or remain in motion with constant speed and direction. *i.e.* Objects have *inertia* – the tendency to maintain a state of motion.
2. The acceleration of an object is proportional to force upon it and inversely proportional to its mass. ($F = ma$) Note: acceleration is the rate at which velocity changes.
3. Forces occur in equal and opposite pairs. For every force "action" there is an equal and opposite force "reaction".

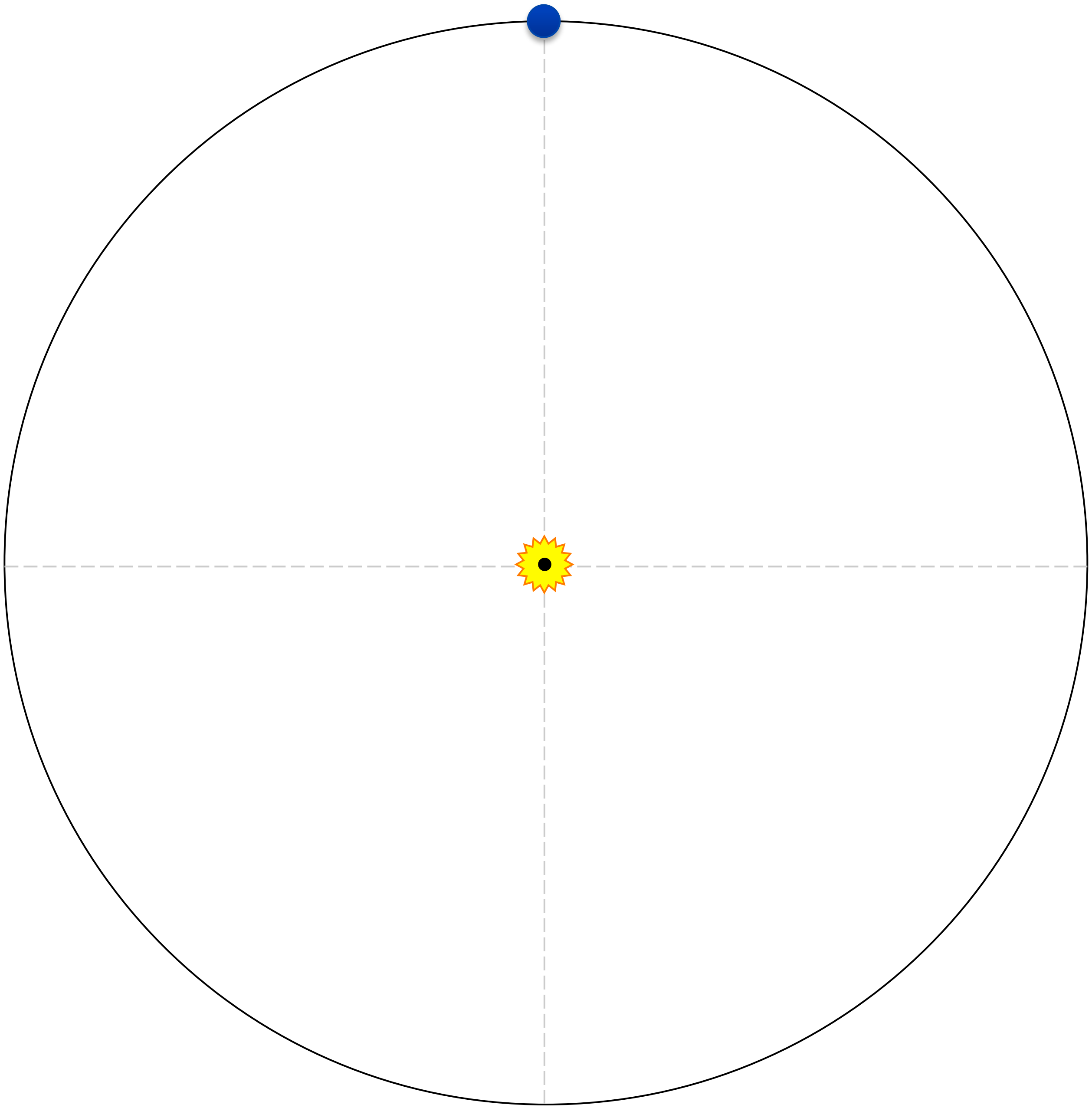
What can a force do to an object?



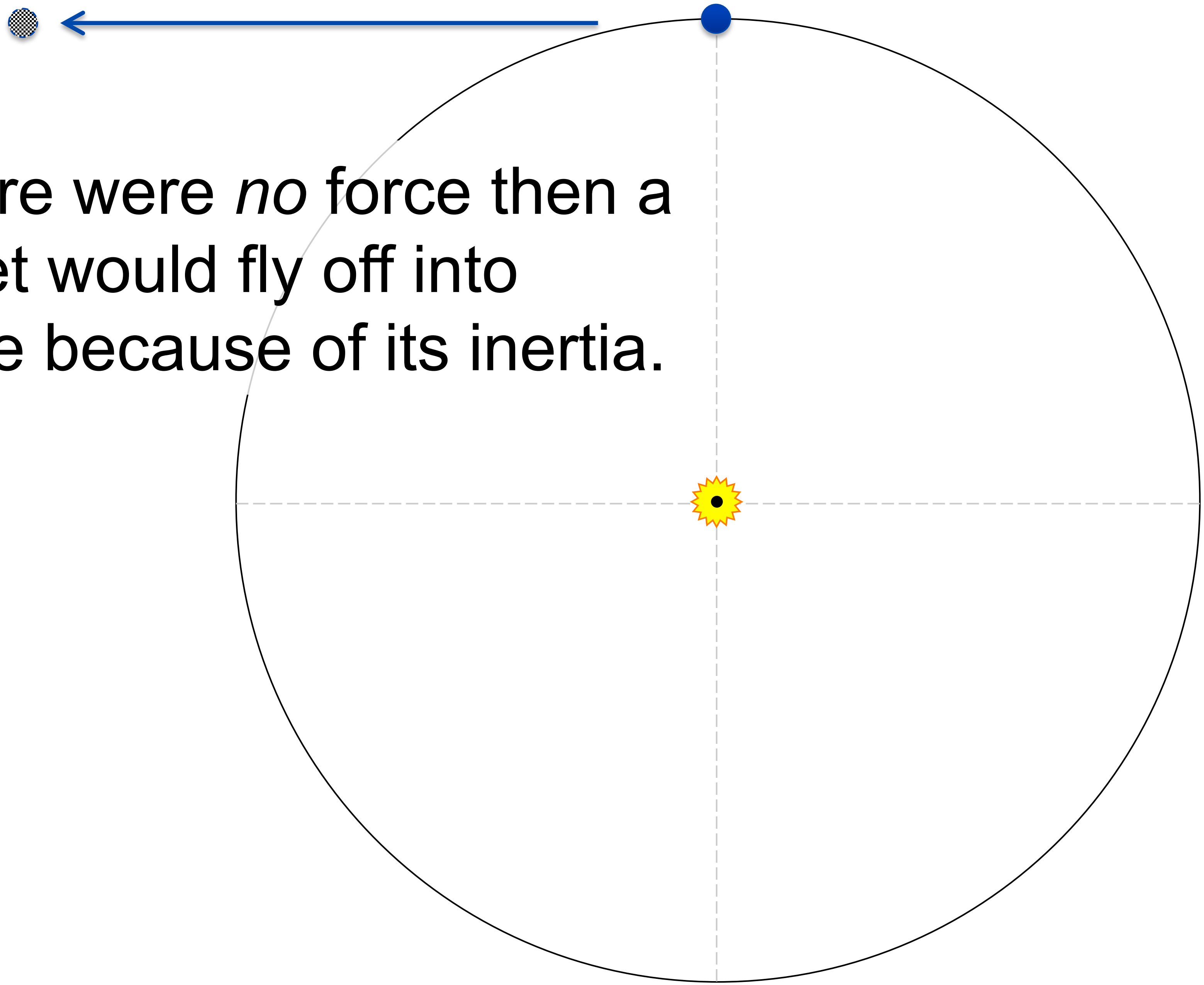
What can a force do to an object?
(red arrows represent forces)

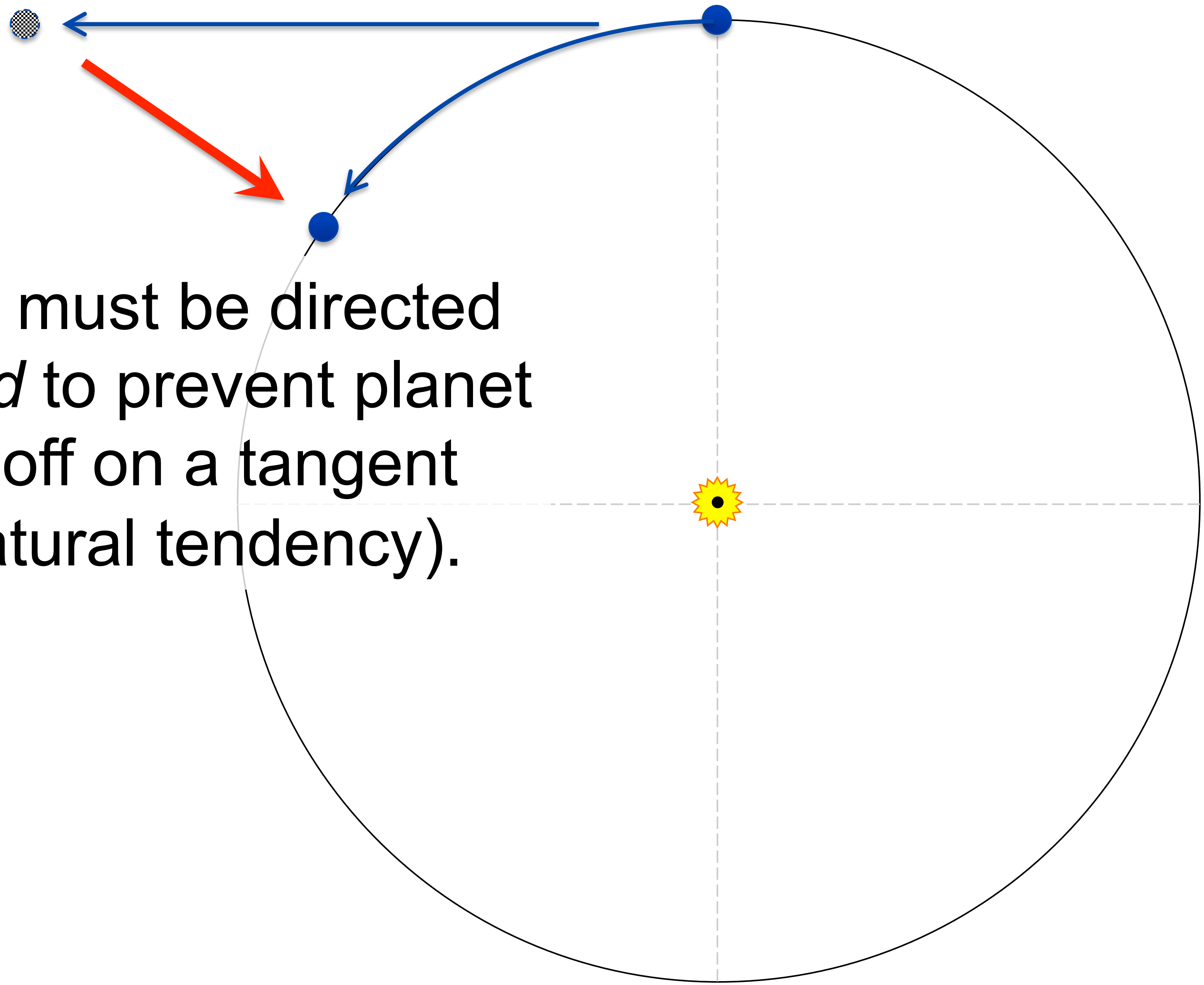


What type of force causes an orbit?

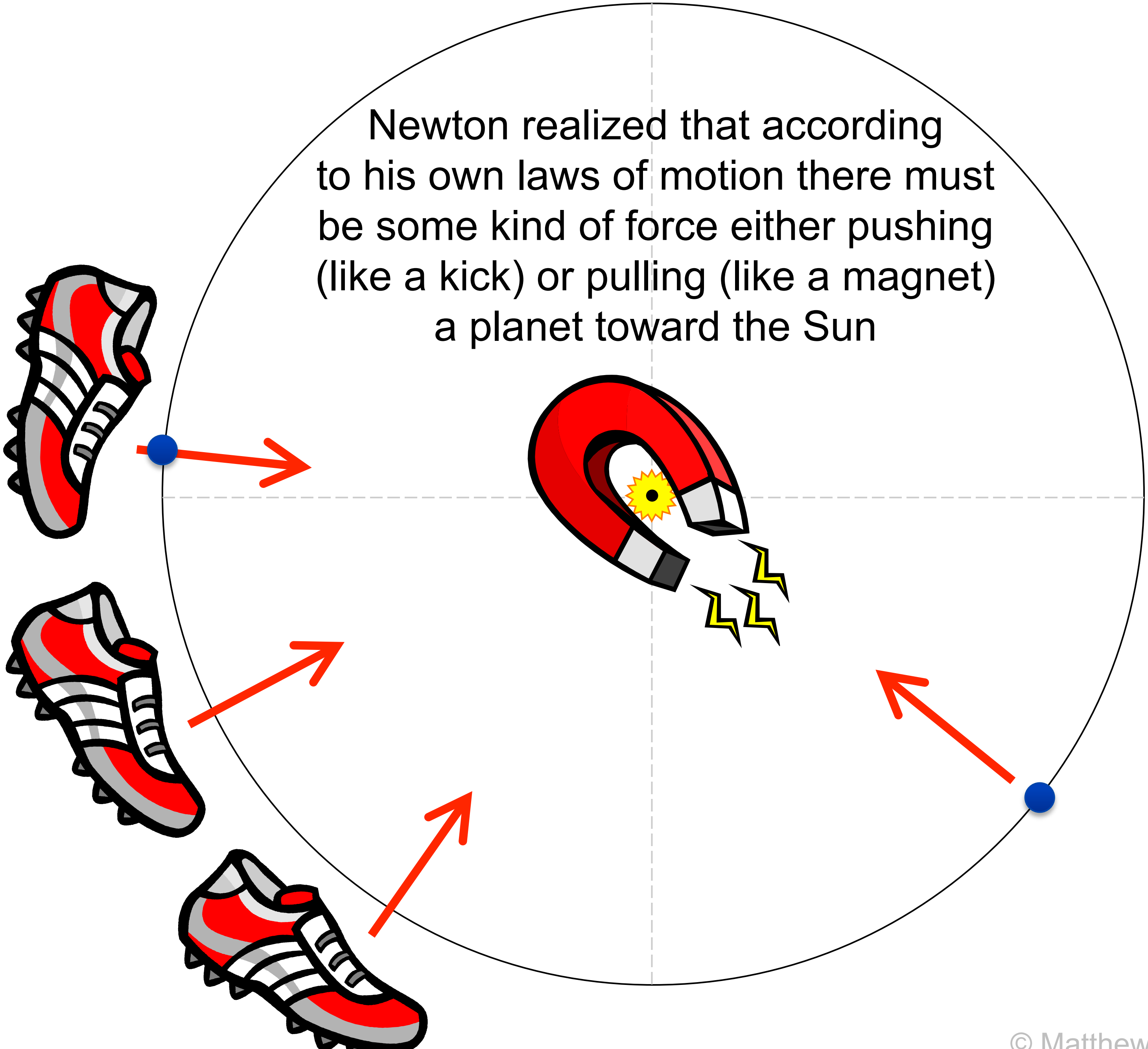


If there were *no* force then a planet would fly off into space because of its inertia.





Force must be directed *inward* to prevent planet flying off on a tangent (its natural tendency).


Newton realized that according
to his own laws of motion there must
be some kind of force either pushing
(like a kick) or pulling (like a magnet)
a planet toward the Sun

Newton's Law of Universal Gravitation

Of course it isn't kicking or magnets that keep planets in orbit – Newton realized that gravity must affect all objects (not just Earth). From this he concluded that every object in the universe attracts every other object in the universe.

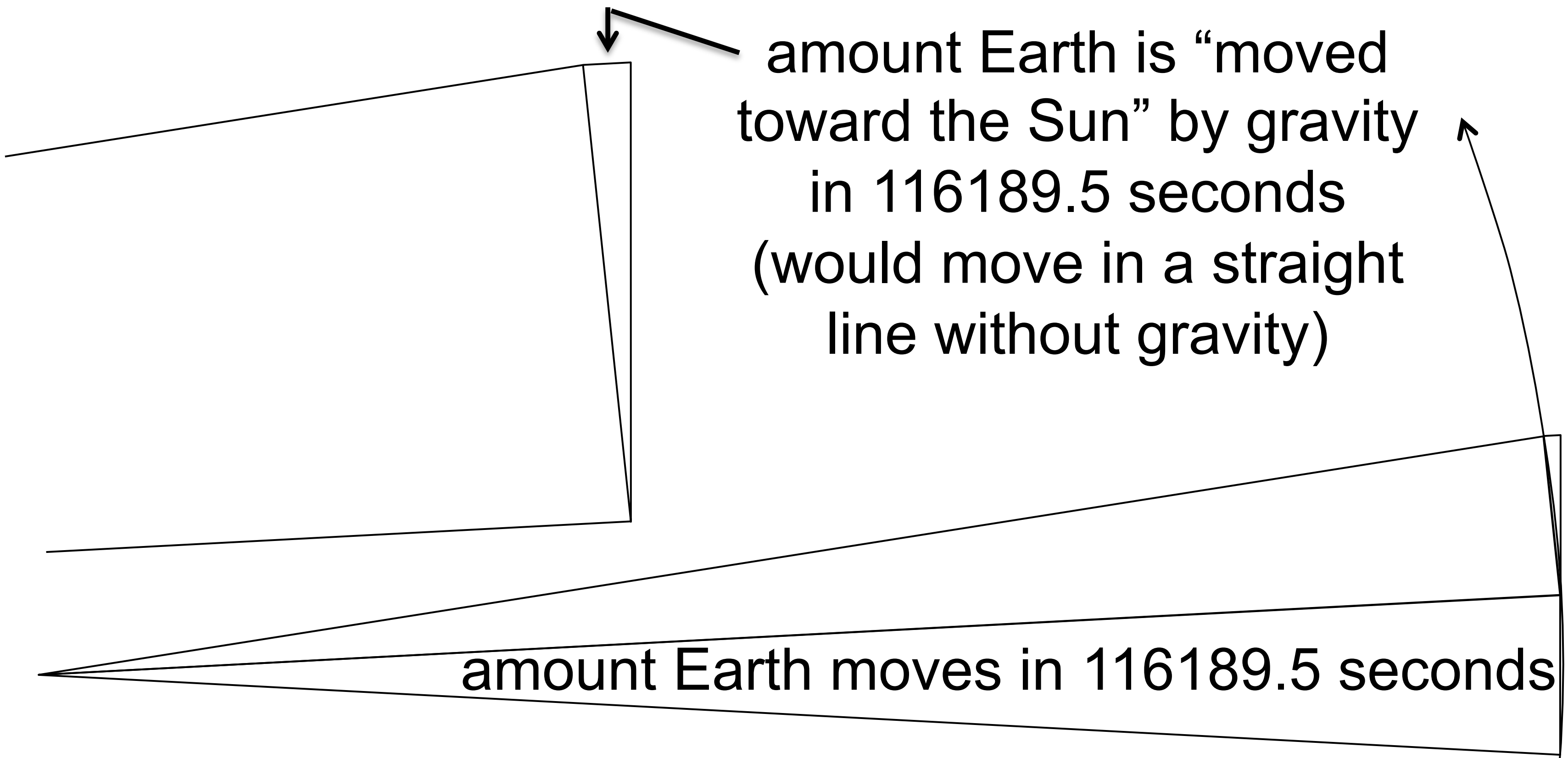
Furthermore, Newton analyzed the motion described by Kepler's laws and determine the mathematical relation that the amount of attractive gravitational force is proportional to the mass of each object and inversely proportional to the square of the distance between the two objects.

Newton's Achievement

- Newton's Laws give us a means to understand *why* the planets move as they do.
- Newton was able to *derive* Kepler's Laws from his own Laws of Motion and Gravitation.
- How do Newton's Laws relate to Kepler's Laws? Be specific!

1. What keeps a planet orbiting the Sun?
2. Why doesn't a planet get pulled into the Sun?
3. Mars moves at a slower speed in its orbit than Earth does. What would happen if Mars moved as fast as Earth? How does this relate to Kepler's 3^{rd} Law?

Understanding Inverse Square Law of Gravity

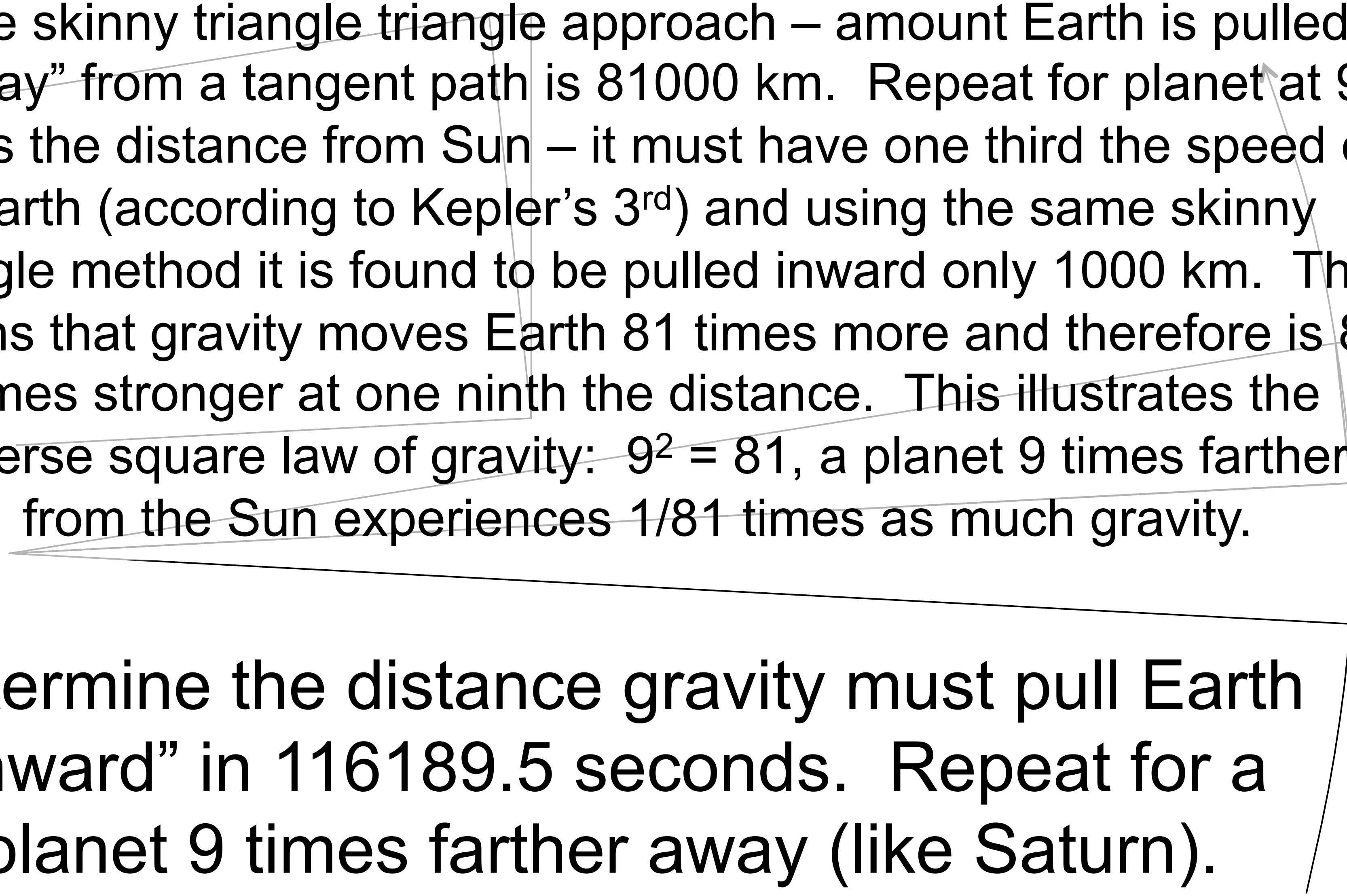


Determine the distance gravity must pull Earth “inward” in 116189.5 seconds. Repeat for a planet 9 times farther away (like Saturn).

Earth: r = 150 million km, v = 30 km/s

Understanding Inverse Square Law of Gravity

Use skinny triangle triangle approach – amount Earth is pulled "away" from a tangent path is 81000 km. Repeat for planet at 9 times the distance from Sun – it must have one third the speed of Earth (according to Kepler's 3rd) and using the same skinny triangle method it is found to be pulled inward only 1000 km. This means that gravity moves Earth 81 times more and therefore is 81 times stronger at one ninth the distance. This illustrates the inverse square law of gravity: $9^2 = 81$, a planet 9 times farther from the Sun experiences 1/81 times as much gravity.



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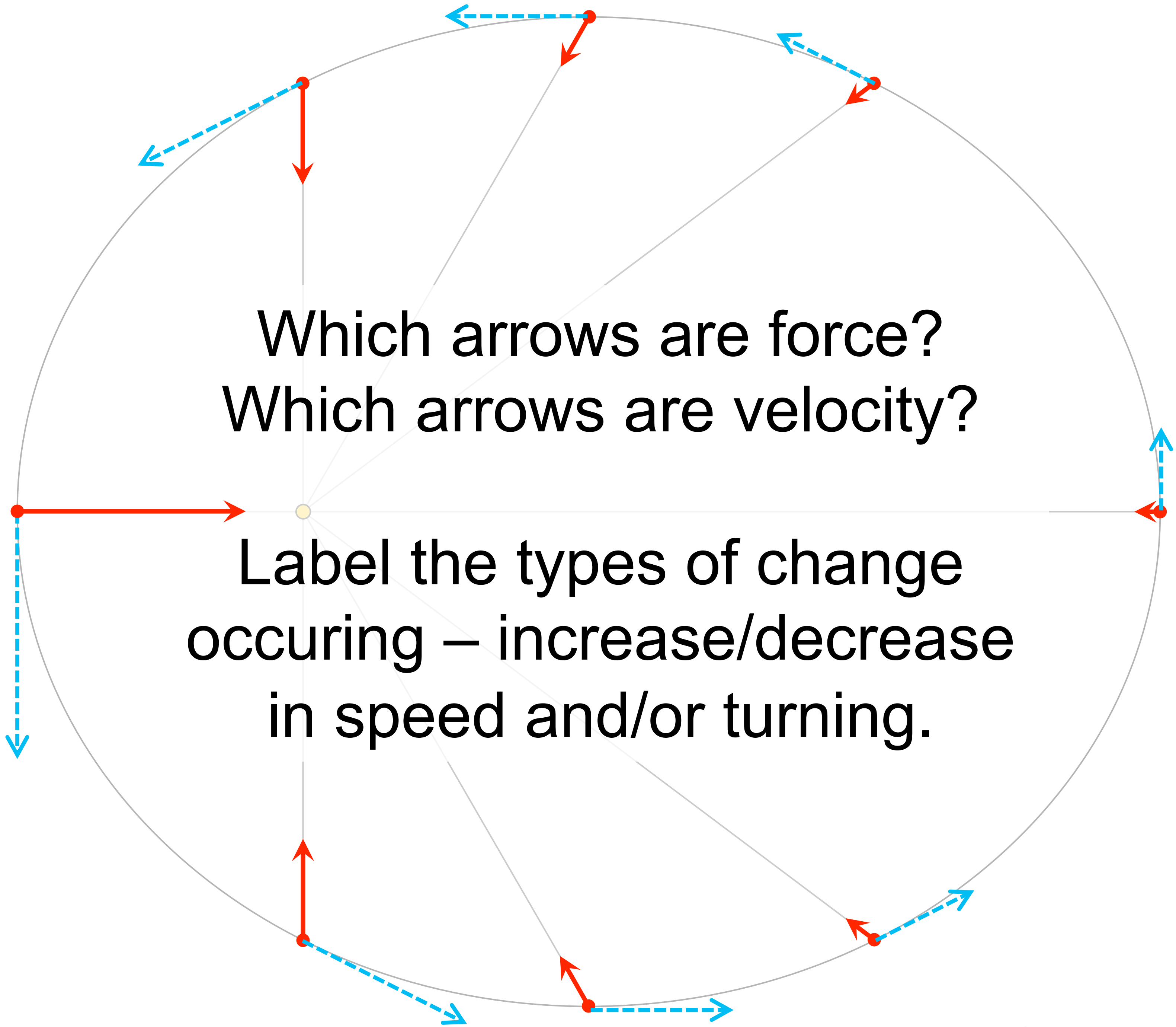
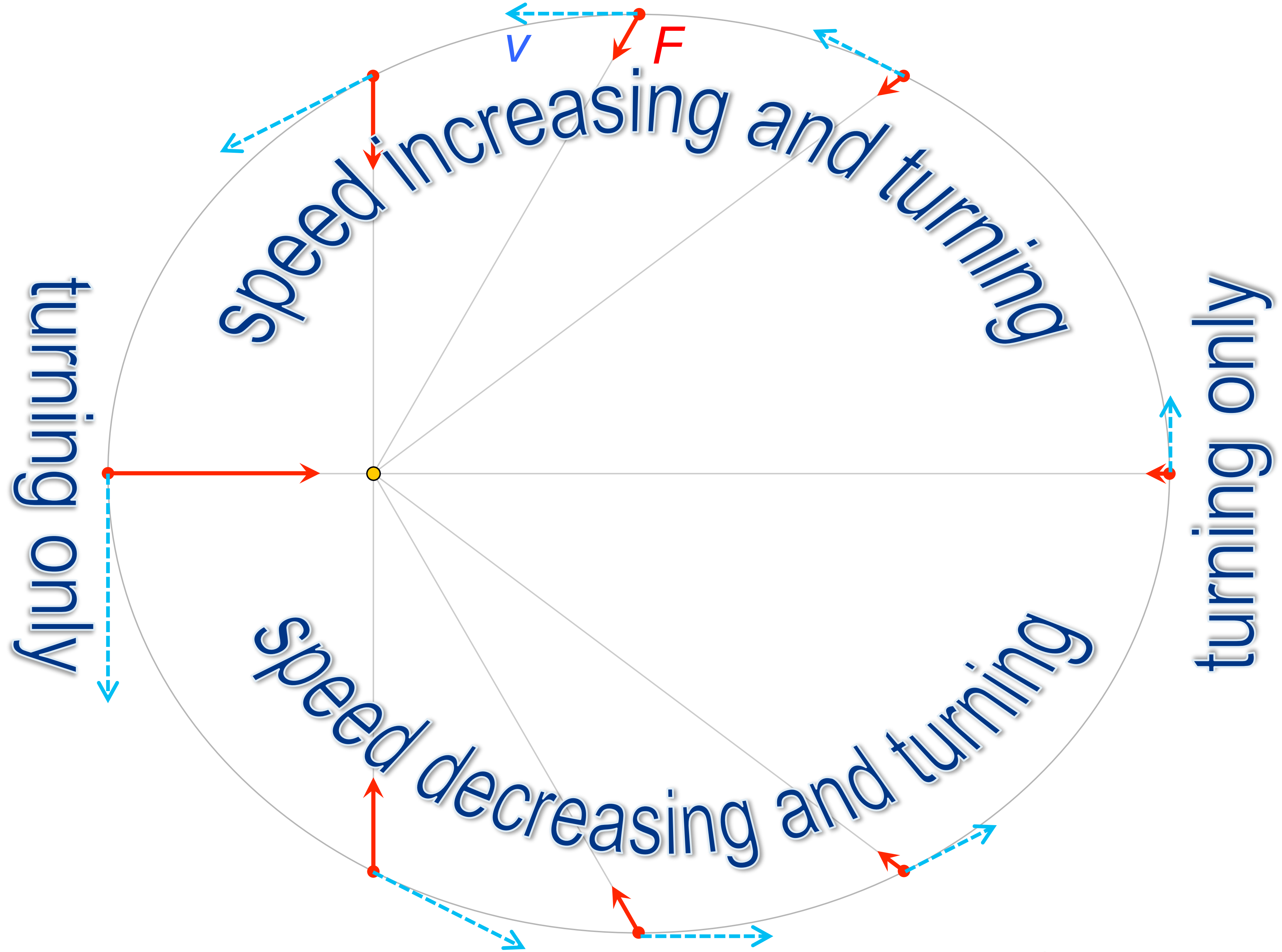
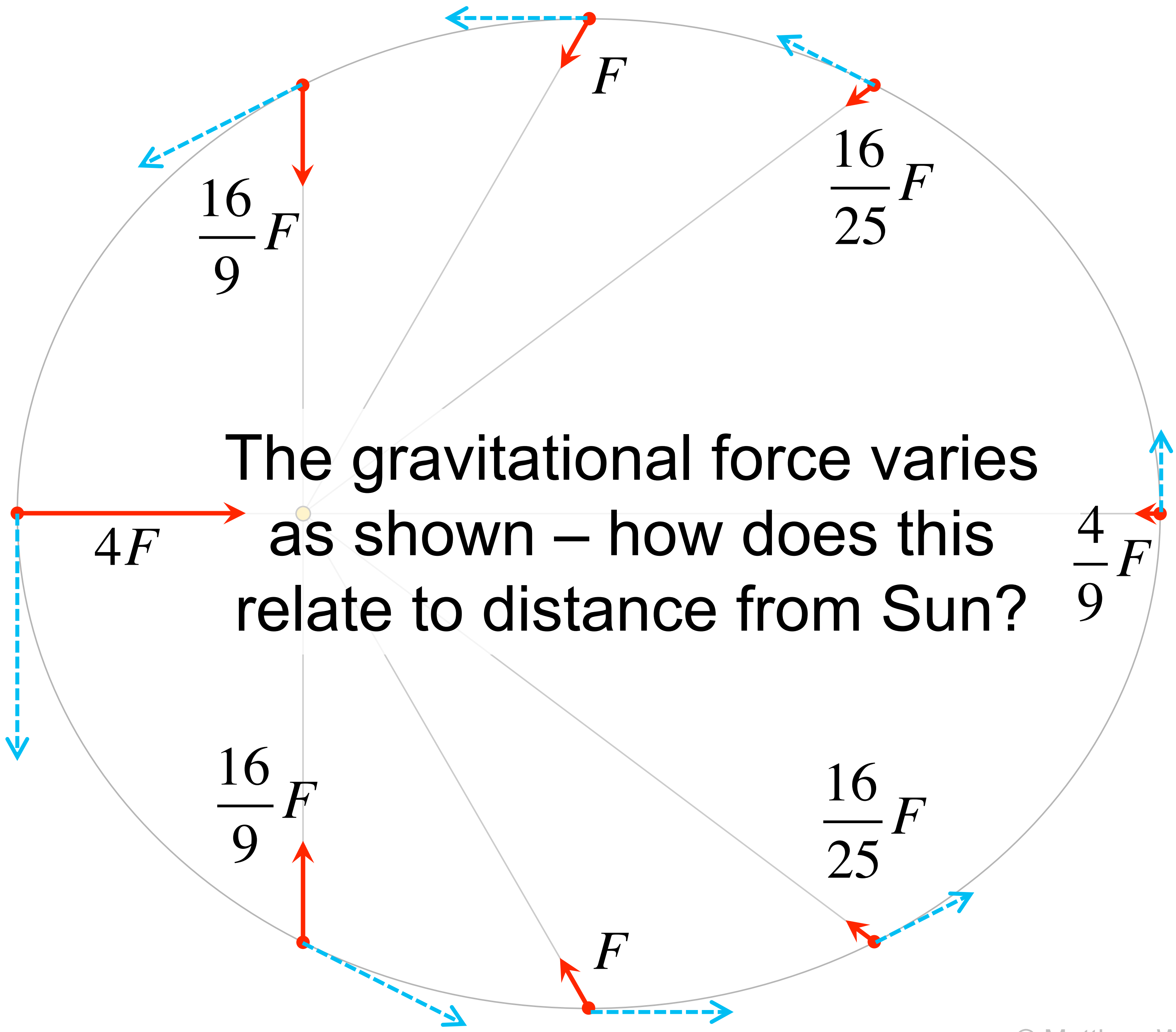
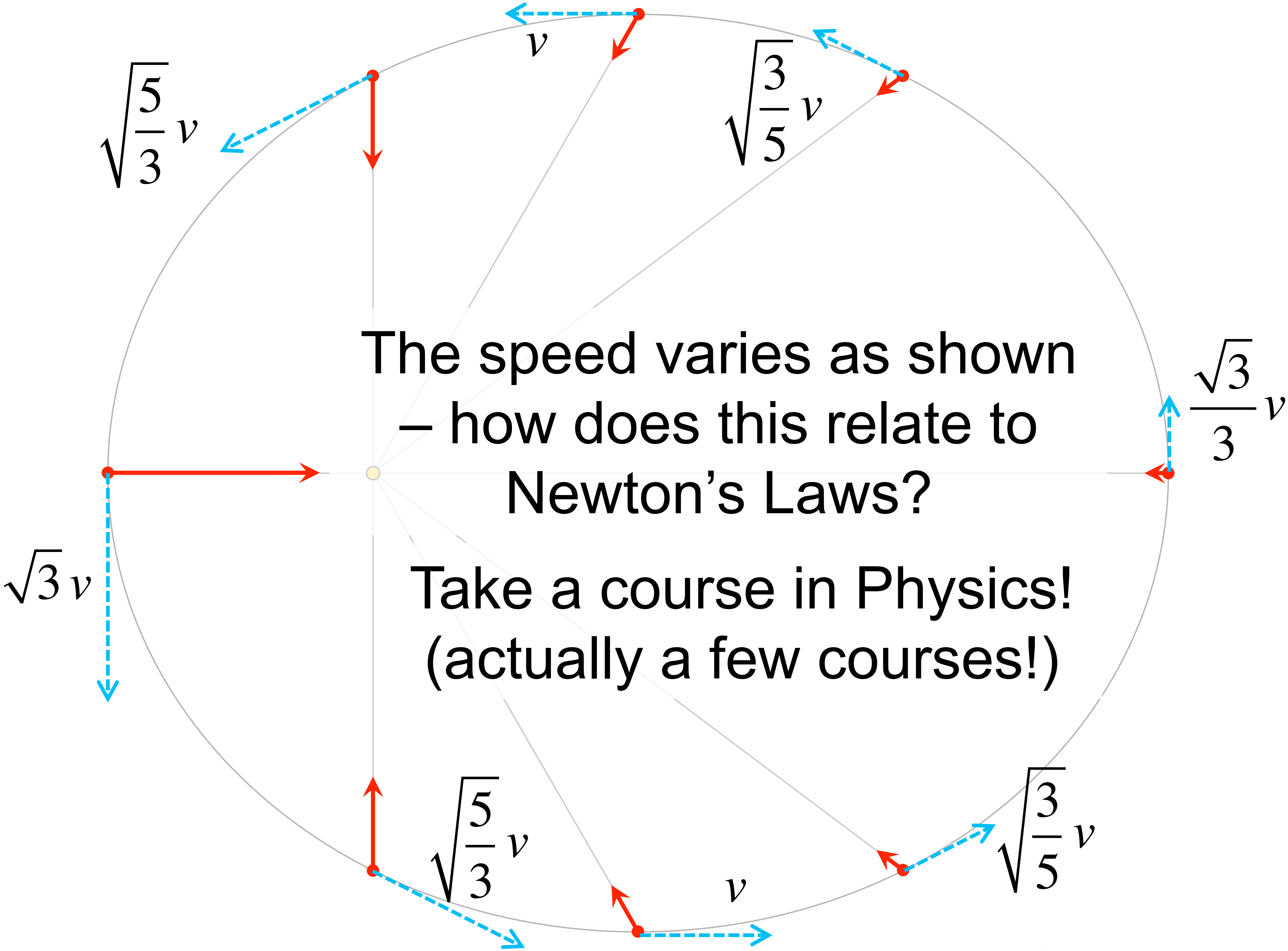

Which arrows are force?
Which arrows are velocity?
Label the types of change
occuring – increase/decrease
in speed and/or turning.


V
F
speed increasing and turning
turning only
turning only
speed decreasing and turning

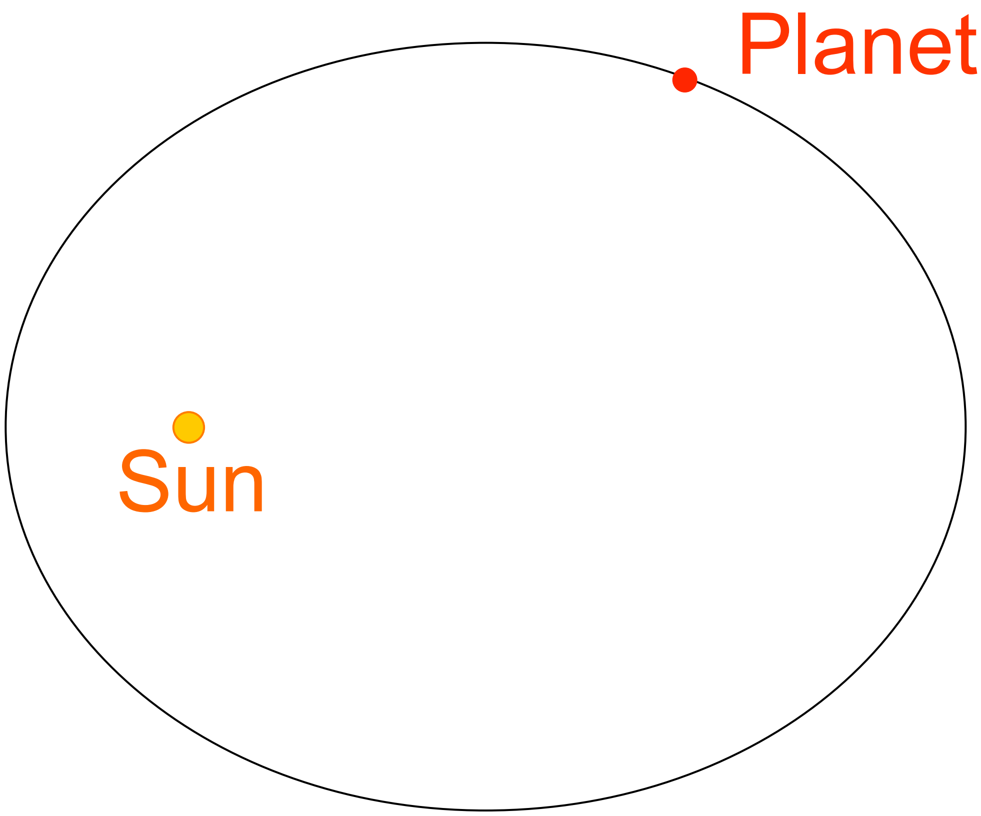

The gravitational force varies
as shown – how does this
relate to distance from Sun?
F
$\frac{16}{25}F$
$\frac{16}{9}F$
$4F$
$\frac{4}{9}F$
$\frac{16}{9}F$
F
$\frac{16}{25}F$



The speed varies as shown – how does this relate to Newton's Laws?
Take a course in Physics! (actually a few courses!)
v
$\sqrt{\frac{5}{3}}\,v$
$\sqrt{\frac{3}{5}}\,v$
$\frac{\sqrt{3}}{3}\,v$
$\sqrt{3}\,v$
$\sqrt{\frac{5}{3}}\,v$
v
$\sqrt{\frac{3}{5}}\,v$

Newton's Modifications to Kepler's 1st Law

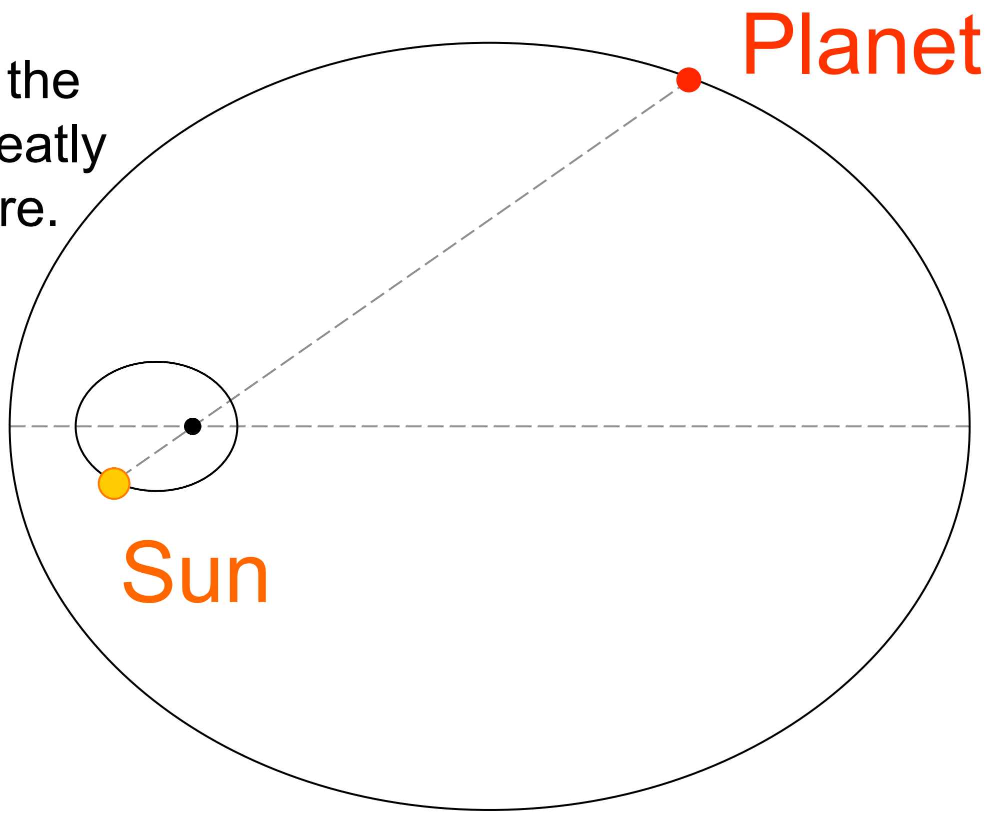
The Sun cannot simply be at rest at one focus as Kepler stated. Instead…



Newton's Modifications to Kepler's 1st Law

The Sun and planet *each* move in ellipses around a common focus.

Note: the size of the Sun's ellipse is greatly exaggerated here.



The two ellipses have major axes that lie on the same line. The Sun and planet move in synchronization – always directly opposite one another on either side of the one focus that the two ellipses share.

Newton's Modifications to Kepler's 3rd Law

p^2 is proportional to a^3/M_{total}

In Newton's version, the total mass of the Sun and planet has an effect on the period of each.

Because the mass of any one planet is much less than that of the Sun, the total mass is nearly the same as the mass of the Sun itself.

Newton's Modifications to Kepler's 3rd Law

p^2 is proportional to a^3/M_{total}

This is a minor discrepancy when applied to the solar system! This is why Kepler's 3rd Law in most cases can be used without worrying about the masses involved. It only amounts to a difference of at most 2 days when analyzing the solar system (in the case of Jupiter).