

Lecture Outlines

Chapter 2

Astronomy Today

8th Edition

Chaisson/McMillan

Astronomy Today^{8e}

CHAISSON McMILLAN

Chapter 2

The Copernican Revolution



Units of Chapter 2

2.1 Ancient Astronomy

2.2 The Geocentric Universe

2.3 The Heliocentric Model of the Solar System

Discovery 2-1 The Foundations of the Copernican Revolution

2.4 The Birth of Modern Astronomy

Units of Chapter 2, continued

2.5 The Laws of Planetary Motion

More Precisely 2-1 Some Properties of Planetary Orbits

2.6 The Dimensions of the Solar System

2.7 Newton's Laws

2.8 Newtonian Mechanics

More Precisely 2-2 Weighing the Sun

2.1 Ancient Astronomy

- Ancient civilizations observed the skies
- Many built structures to mark astronomical events

**Summer solstice
sunrise at
Stonehenge:**



2.1 Ancient Astronomy

Spokes of the Big Horn Medicine Wheel are aligned with the rising and setting of the Sun and other stars



(a)

2.1 Ancient Astronomy

This temple at Caracol, in Mexico, has many windows that are aligned with astronomical events



(b)

2.2 The Geocentric Universe

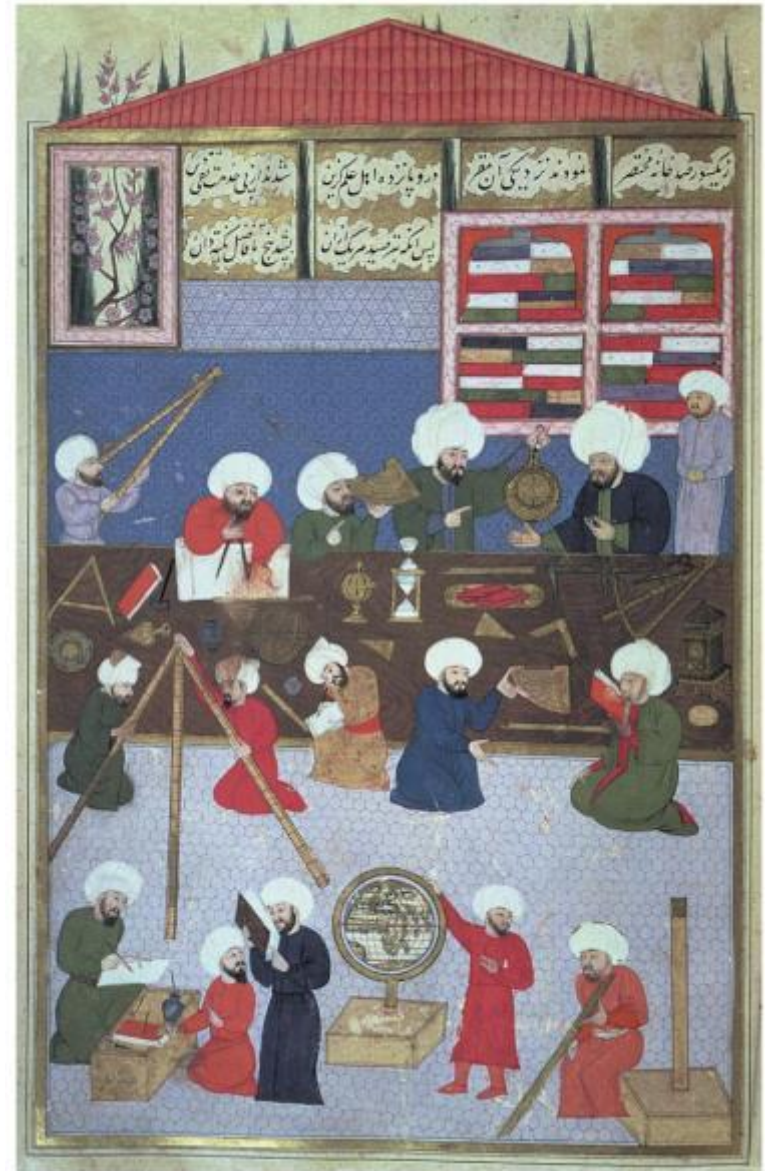
Ancient astronomers
observed:

Sun

Moon

Stars

**Five planets: Mercury,
Venus, Mars, Jupiter,
Saturn**



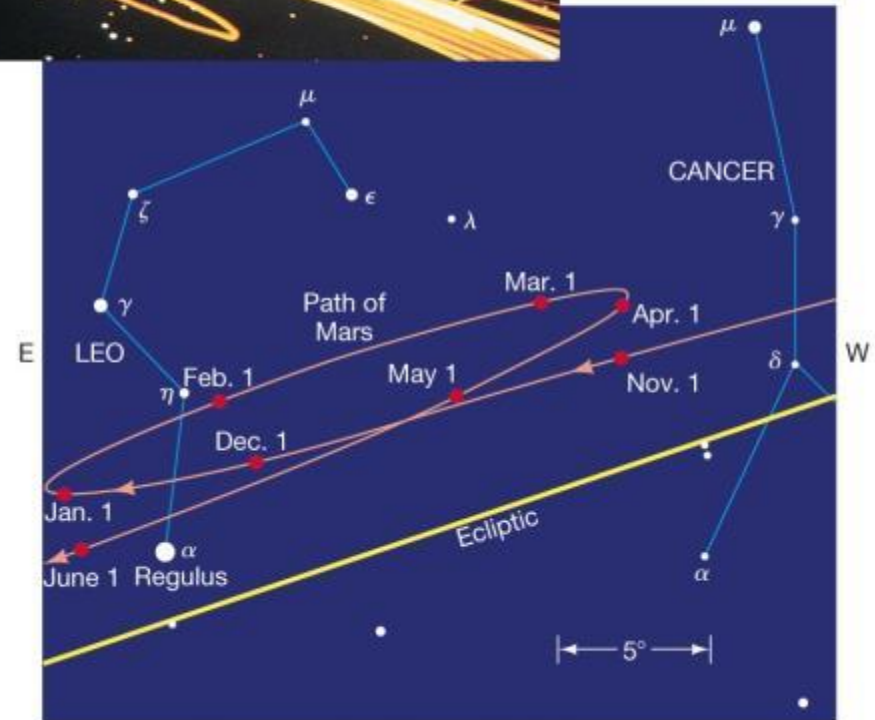
2.2 The Geocentric Universe

Sun, Moon, and stars all have simple movements in the sky

Planets:

- Move with respect to fixed stars
- Change in brightness
- Change speed
- Undergo retrograde motion

Motions of the planets relative to the stars produce continuous streaks on a planetarium "sky."



Observed planet motions can be complicated because each planet travels with a different speed around the Sun.

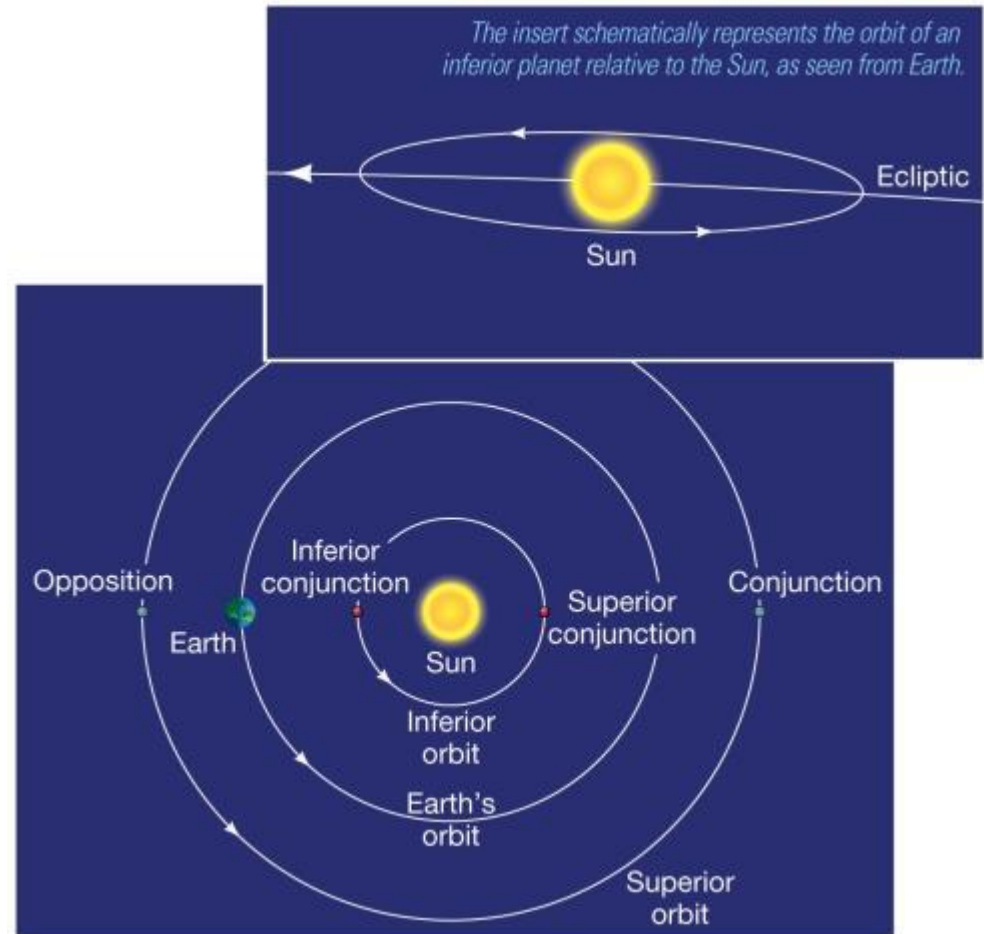
2.2 The Geocentric Universe

- Inferior planets: Mercury, Venus
- Superior planets: Mars, Jupiter, Saturn

Now know:

Inferior planets have orbits closer to Sun than Earth's

Superior planets' orbits are farther away



2.2 The Geocentric Universe

Early observations:

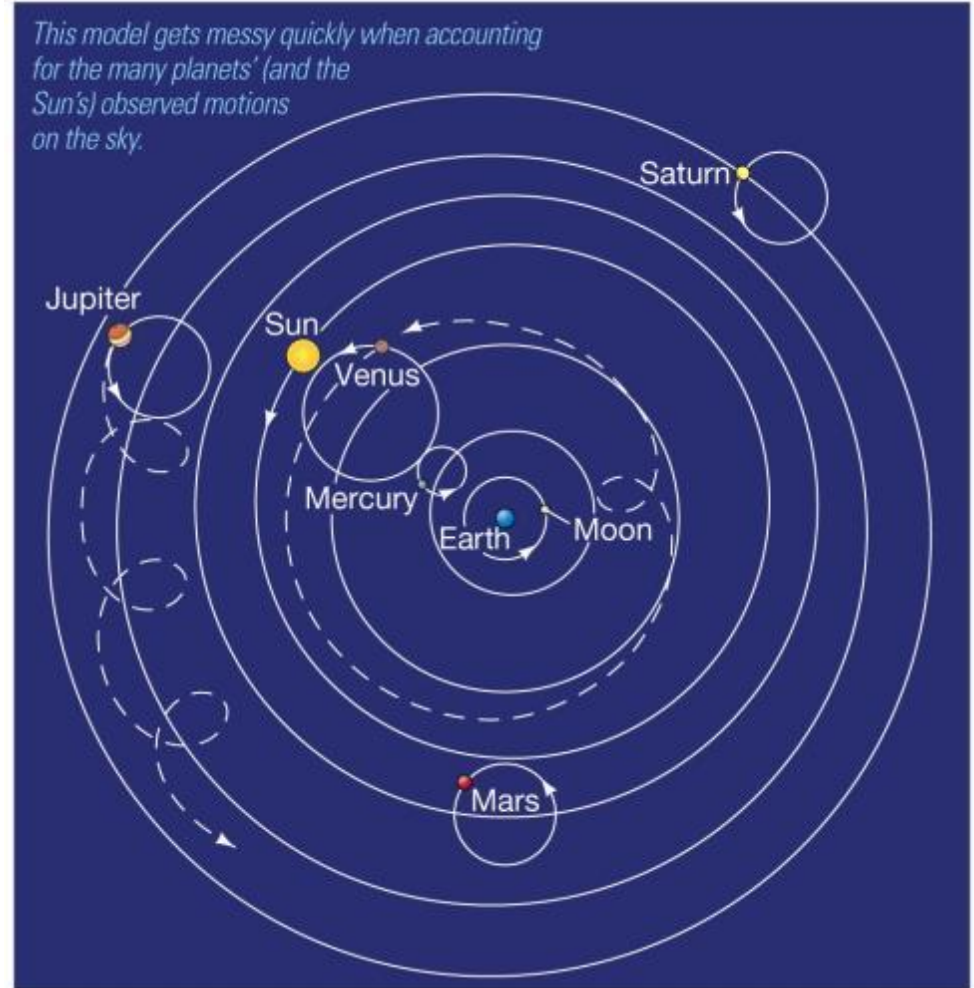
- **Inferior planets never too far from Sun**
- **Superior planets not tied to Sun; exhibit retrograde motion**
- **Superior planets brightest at opposition**
- **Inferior planets brightest near inferior conjunction**

2.2 The Geocentric Universe

Earliest models had **Earth** at center of solar system

Needed lots of complications to accurately track planetary motions

epicycle (used to explain planetary motions) = Ptolemy's theory



ASTRONOMY



ASTRONOMY

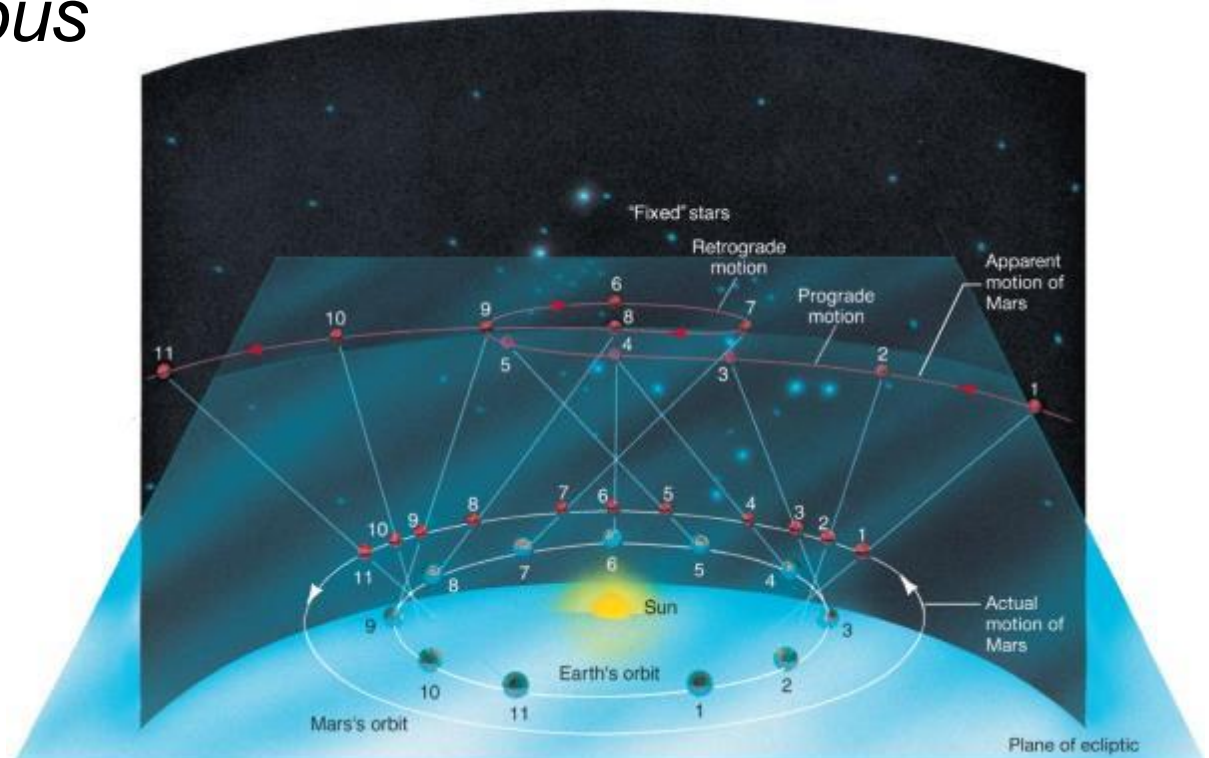
2.3 The Heliocentric Model of the Solar System

Sun is at center of solar system. Only Moon orbits around Earth; planets orbit around Sun.

*Nicholas Copernicus revived this theory;

De revolutionibus

This figure shows retrograde motion of Mars.



Discovery 2-1: The Foundations of the Copernican Revolution

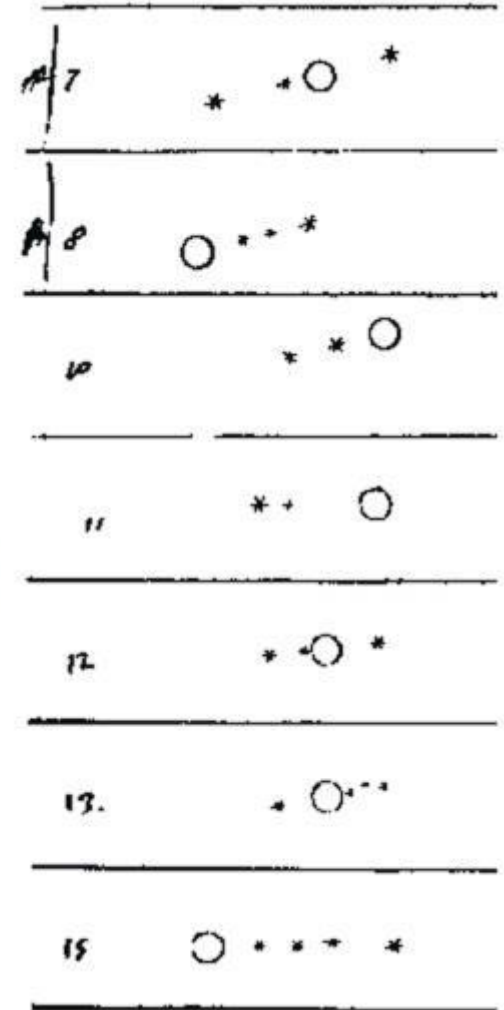
- 1. Earth is not at the center of everything.**
- 2. Center of Earth is the center of Moon's orbit.**
- 3. All planets revolve around the Sun.**
- 4. The stars are very much farther away than the Sun.**
- 5. The apparent movement of the stars around the Earth is due to the Earth's rotation.**
- 6. The apparent movement of the Sun around the Earth is due to the Earth's rotation.**
- 7. Retrograde motion of planets is due to Earth's motion around the Sun.**

2.4 The Birth of Modern Astronomy

Telescope invented around 1600

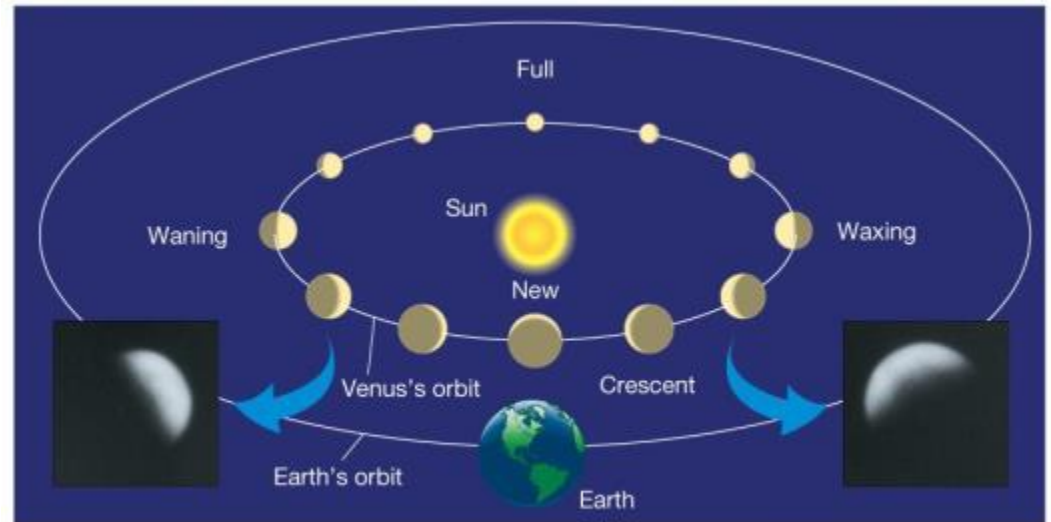
Galileo built his own, made observations:

- **Moon has mountains and valleys**
- **Sun has sunspots, and rotates**
- **Jupiter has moons (shown)**
 - **Io, Ganymede, Callisto, Europa**
- **Venus has phases**

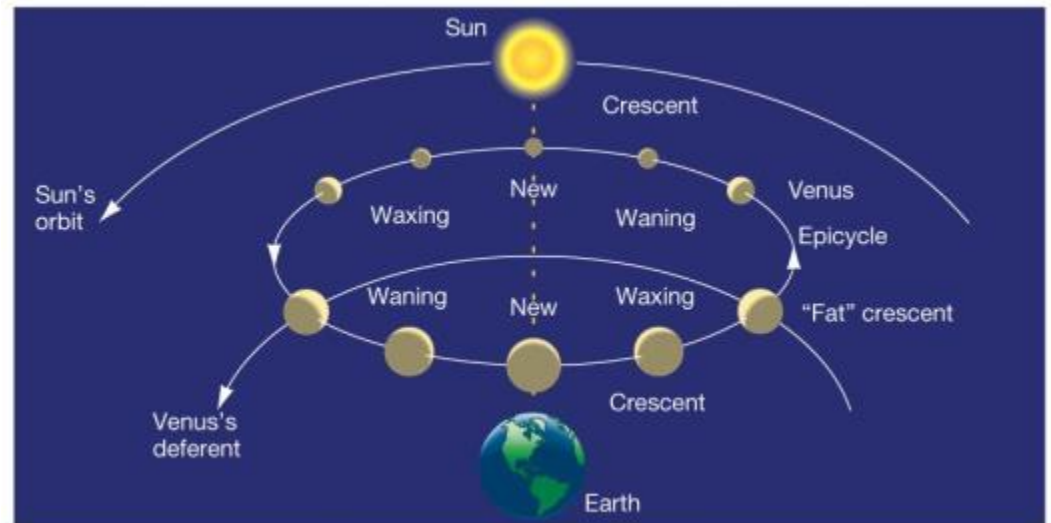


2.4 The Birth of Modern Astronomy

Phases of Venus cannot be explained by geocentric model



(a) Sun-centered model



(b) Ptolemy's model

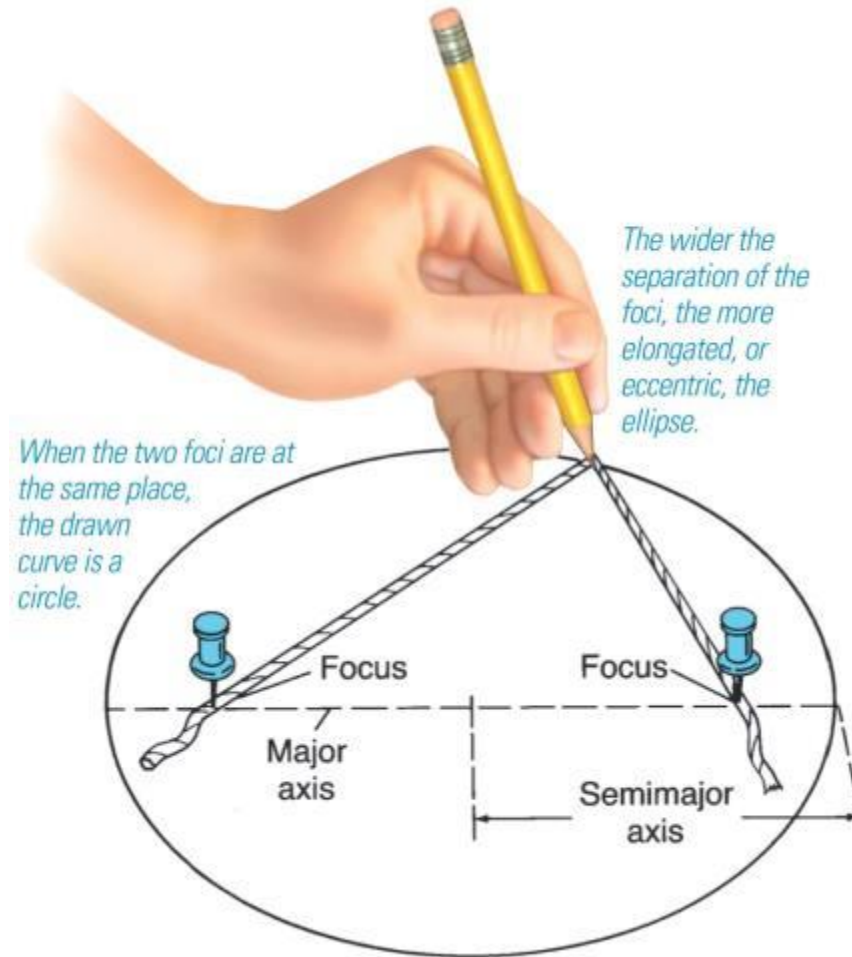
2.5 The Laws of Planetary Motion

Kepler's laws were derived using observations made by Tycho Brahe



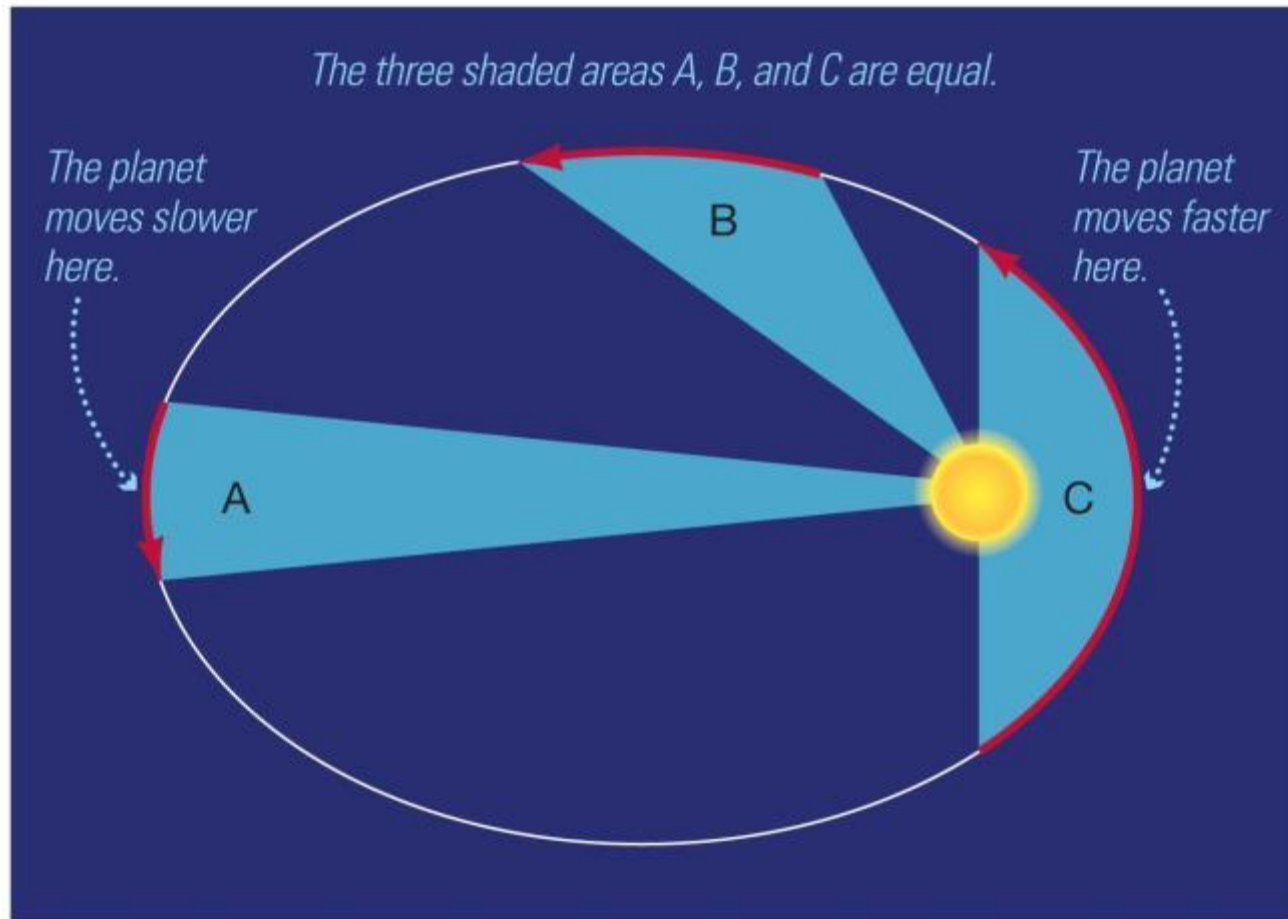
2.5 The Laws of Planetary Motion

1. Planetary orbits are ellipses, Sun at one focus



2.5 The Laws of Planetary Motion

2. Imaginary line connecting Sun and planet sweeps out equal areas in equal times



2.5 The Laws of Planetary Motion

3. Square of **period** of planet's orbital motion is proportional to cube of **semimajor axis**

TABLE 2.1 Some Solar System Dimensions

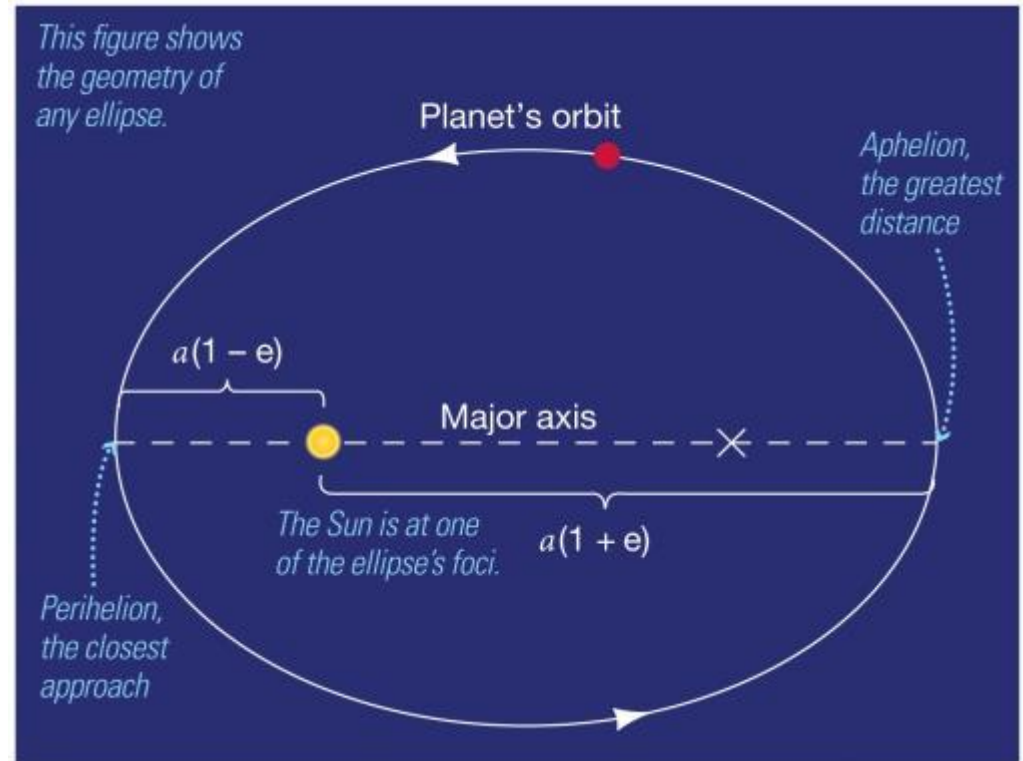
Planet	Orbital Semimajor Axis, a (AU)	Orbital Period, P (years)	Orbital Eccentricity, e	P^2/a^3
Mercury	0.387	0.241	0.206	1.002
Venus	0.723	0.615	0.007	1.001
Earth	1.000	1.000	0.017	1.000
Mars	1.524	1.881	0.093	1.000
Jupiter	5.203	11.86	0.048	0.999
Saturn	9.537	29.42	0.054	0.998
Uranus	19.19	83.75	0.047	0.993
Neptune	30.07	163.7	0.009	0.986

More Precisely 2-1: Some Properties of Planetary Orbits

Semimajor axis and eccentricity of orbit completely describe it

Perihelion: closest approach to Sun

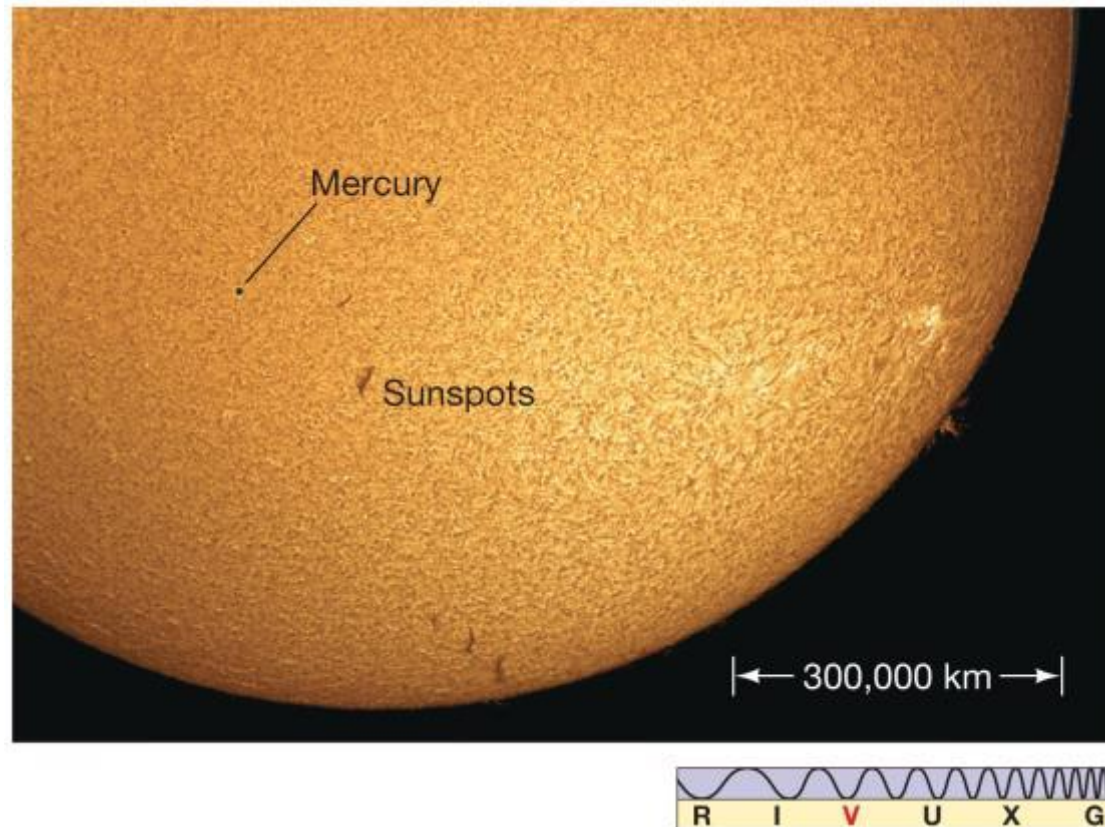
Aphelion: farthest distance from Sun



2.6 The Dimensions of the Solar System

Astronomical unit: mean distance from Earth to Sun (~ 150,000,000 km)

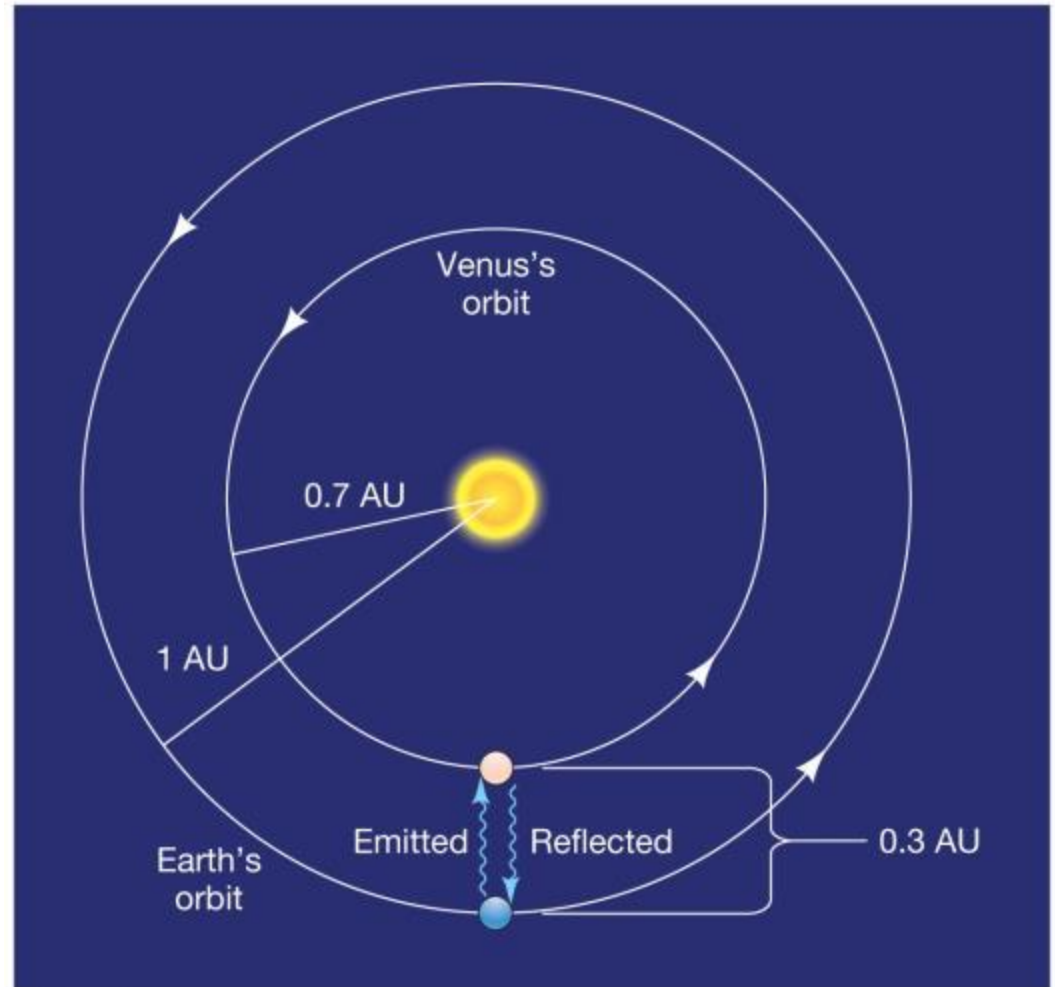
First measured during transits of Mercury and Venus, using triangulation



2.6 The Dimensions of the Solar System

Now measured using **radar**:

Ratio of mean radius of Venus's orbit to that of Earth is very well known



Newton's Laws

Mass- total amount of matter: doesn't ever change

Weight- gravitational force by Earth (or other planetary body may be standing on); changes depending on where you are

2.7 Newton's Laws

Newton's laws of motion explain how objects interact with the world and with each other.

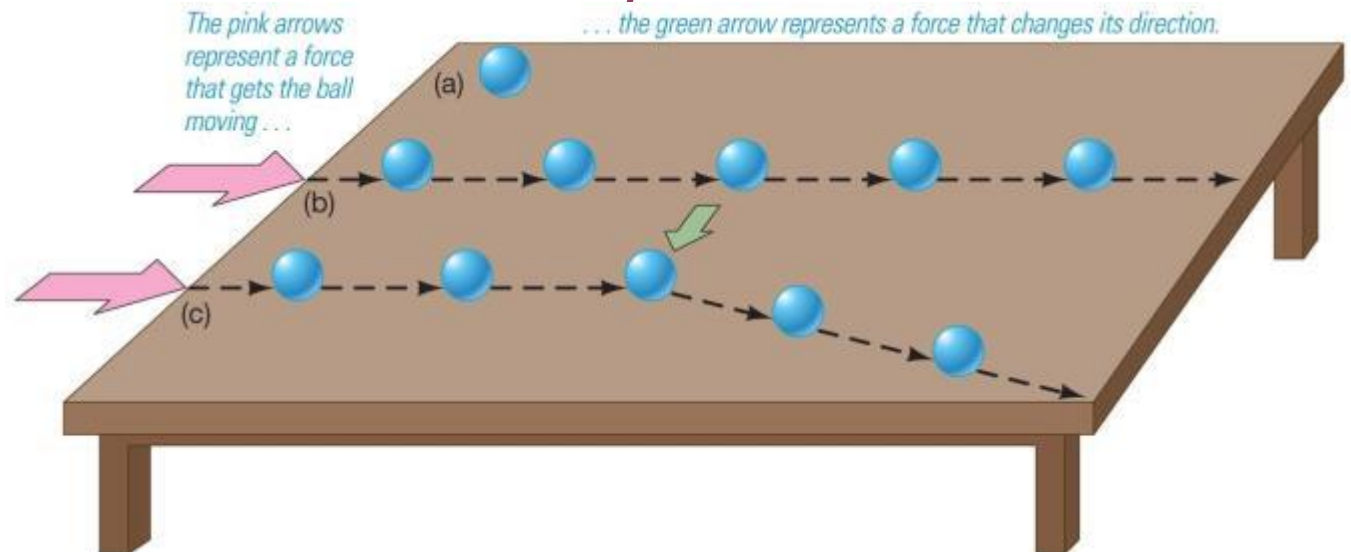


2.7 Newton's Laws

Newton's first law:

An object at rest will remain at rest, and an object moving in a straight line at constant speed will not change its motion, unless an **external force** acts on it.

“An object in motion stays in motion, an object at rest stays at rest, unless acted on by external force”



2.7 Newton's Laws

Newton's second law:

When a force is exerted on an object, its acceleration is inversely proportional to its mass:

$$a = F/m \text{ or } F=ma$$

Newton's third law:

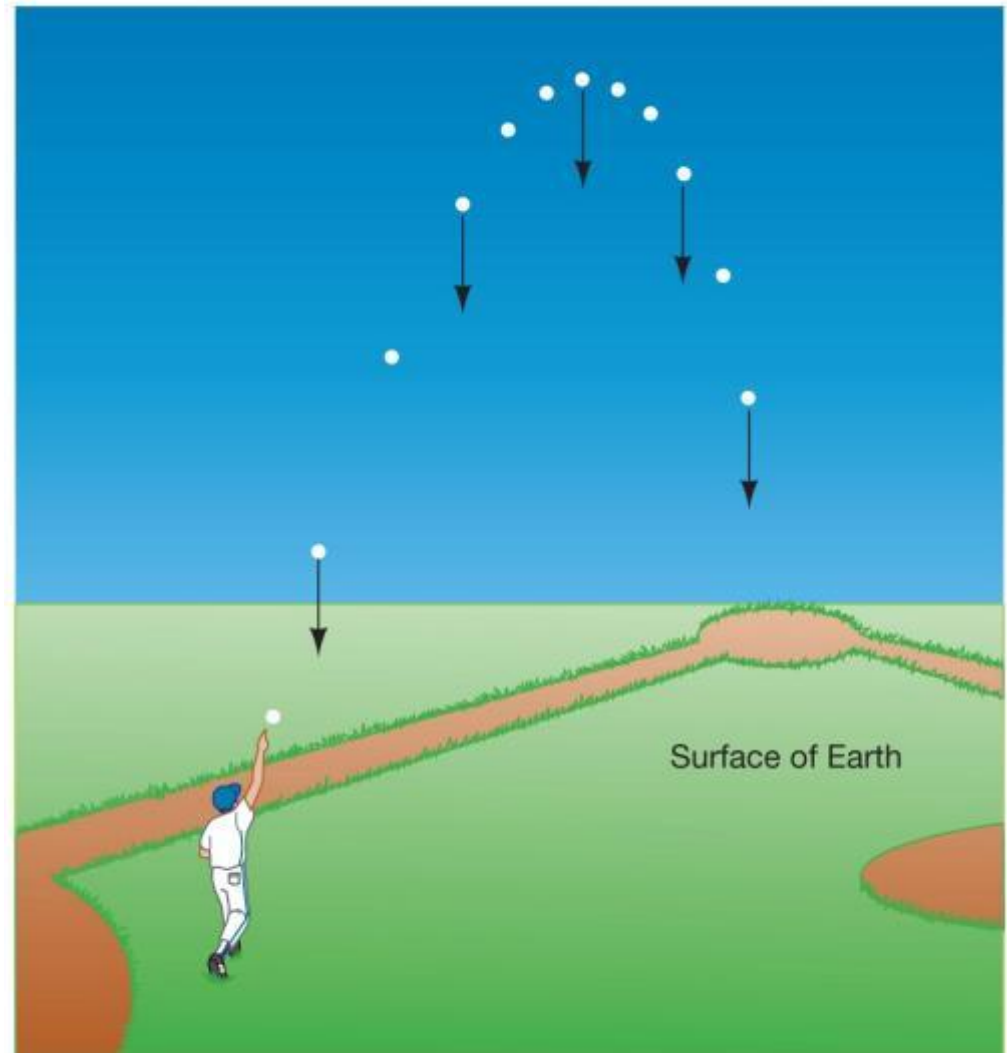
When object A exerts a force on object B, object B exerts an equal and opposite force on object A.

“Every action has an equal and opposite reaction”

2.7 Newton's Laws

Gravity

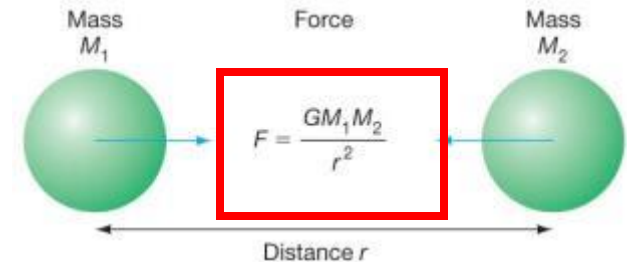
On the Earth's surface, acceleration of gravity is approximately constant, and directed toward the center of Earth



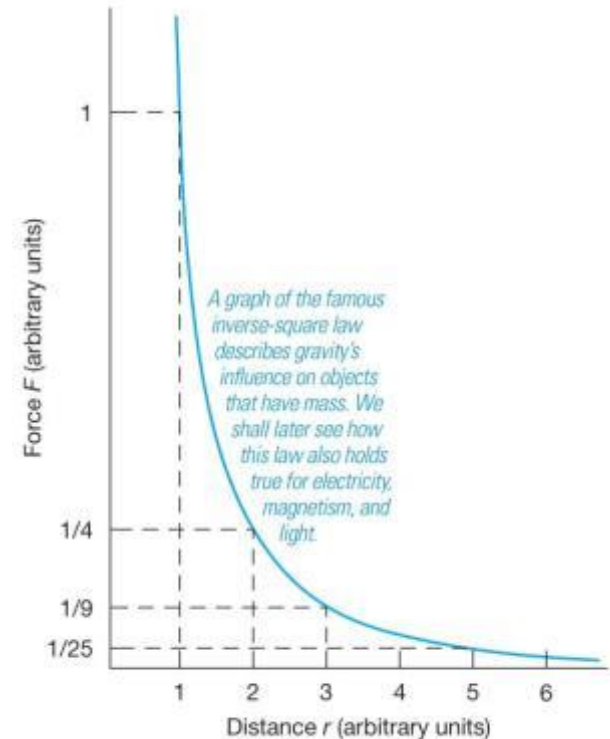
2.7 Newton's Laws

Gravity

For two massive objects, gravitational force is proportional to the product of their masses divided by the square of the distance between them



(a)



(b)

2.7 Newton's Laws

Gravity

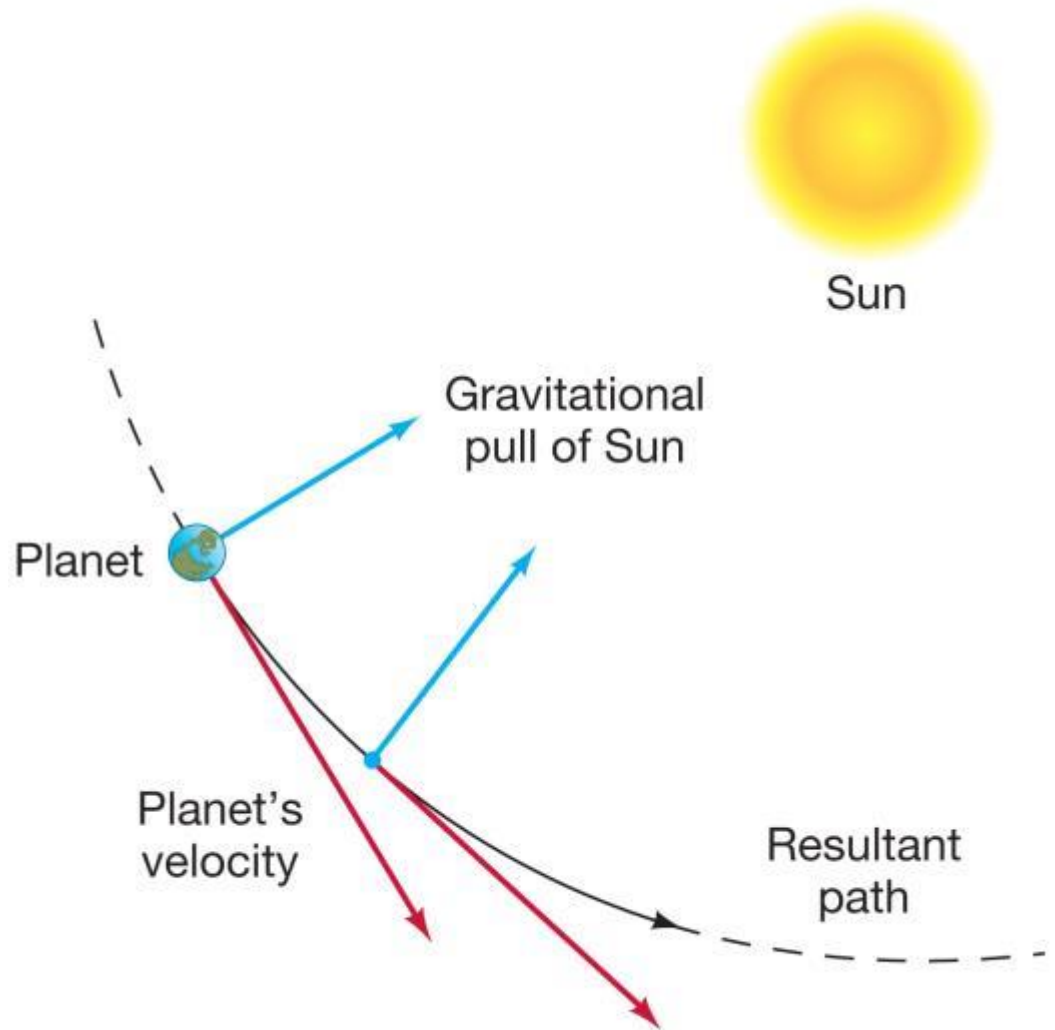
$$F = \frac{Gm_1m_2}{r^2}$$

The constant G is called the gravitational constant; it is measured experimentally and found to be

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

Newton's Laws

The gravitational pull of the Sun keeps the planets moving in their orbits.



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Newton's Laws

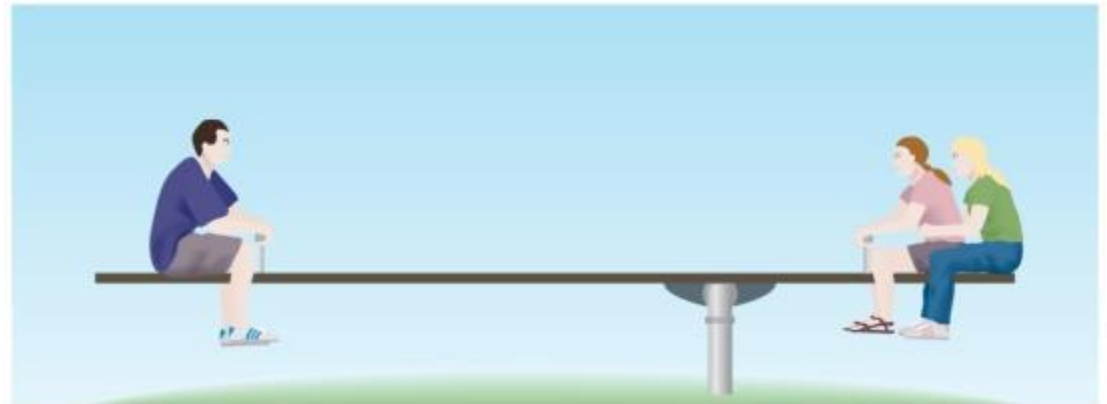
Massive objects actually orbit around their common center of mass

Equal masses-closer to center



(a) Equal masses Center of mass

Unequal masses-closer to more massive object

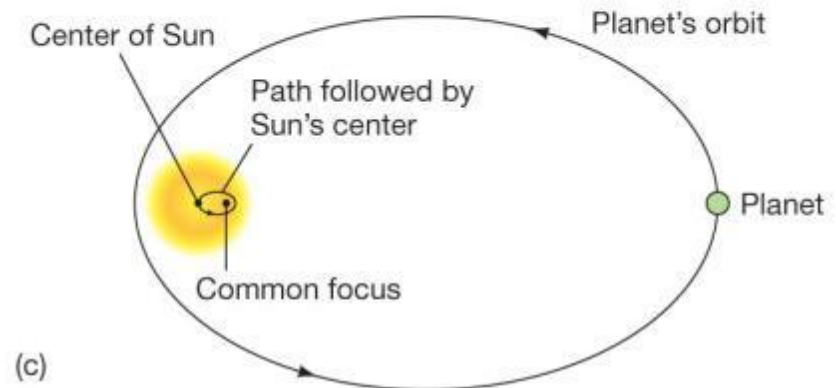
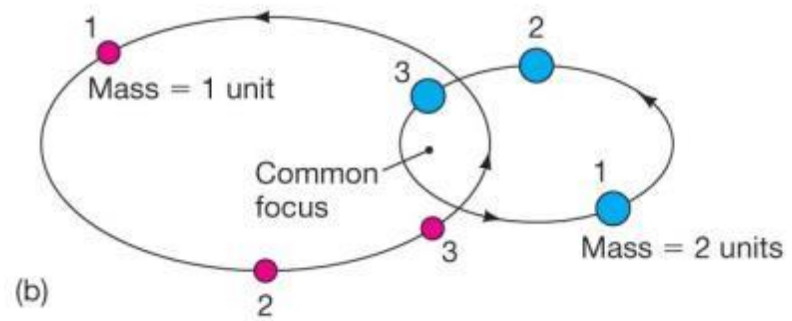
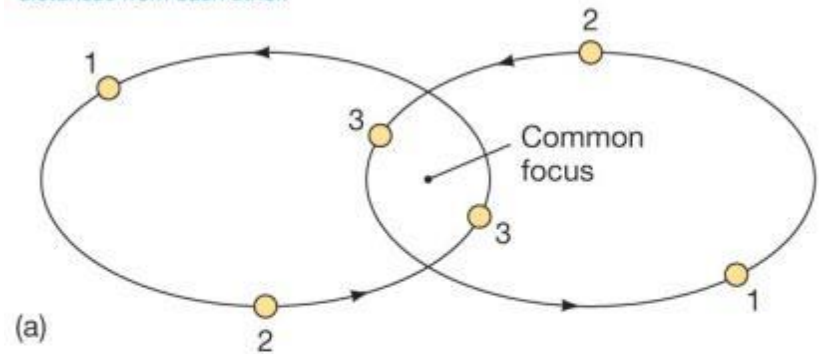


(b) Unequal masses Center of mass

2.8 Newtonian Mechanics

Kepler's laws are a consequence of Newton's laws; first law needs to be modified: The orbit of a planet around the Sun is an ellipse, with the center of mass of the planet–Sun system at one focus.

The resulting orbits for mutually gravitating bodies depend on their masses and distances from each other.



More Precisely 2-3: Weighing the Sun

Newtonian mechanics tells us that the force keeping the planets in orbit around the Sun is the gravitational force due to the masses of the planet and Sun.

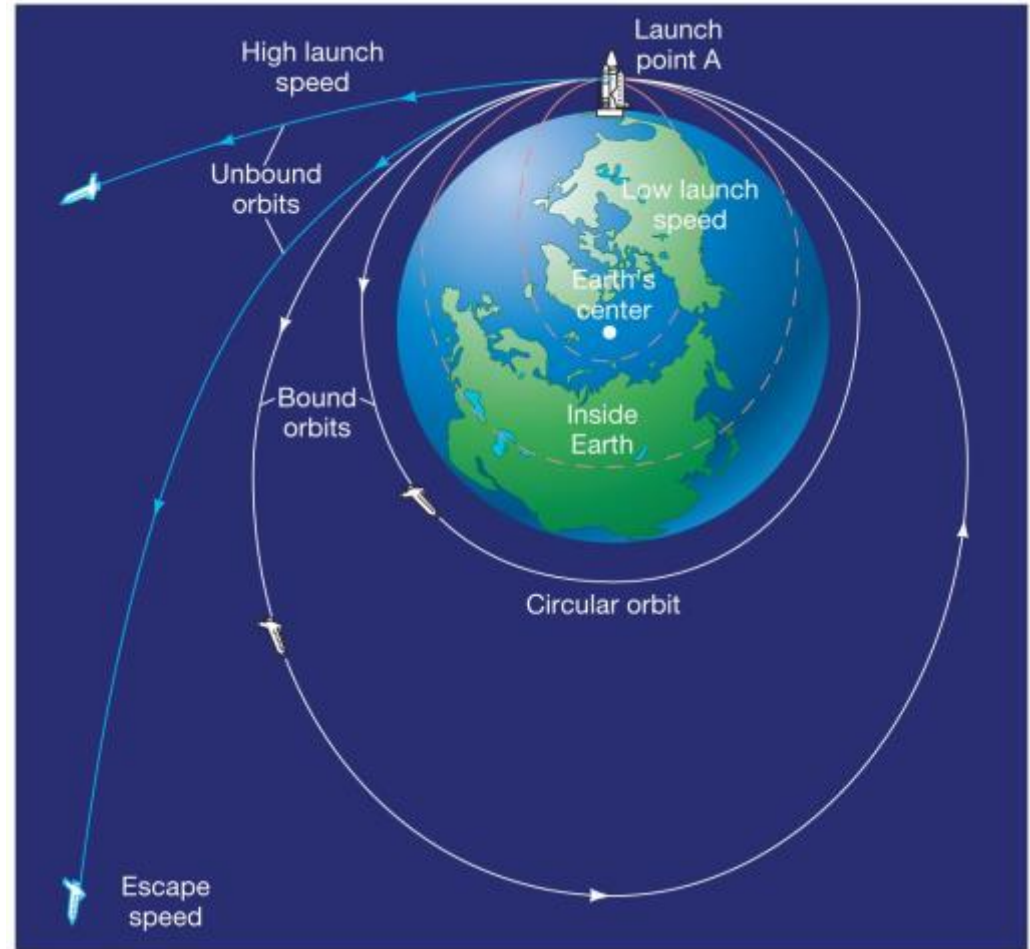
This allows us to calculate the mass of the Sun, knowing the orbit of the Earth:

$$M = rv^2/G$$

The result is $M = 2.0 \times 10^{30}$ kg (!)

2.8 Newtonian Mechanics

Escape speed: the speed necessary for a projectile to completely escape a planet's gravitational field. With a lesser speed, the projectile either returns to the planet or stays in orbit.



Summary of Chapter 2

- **First models of solar system were geocentric but couldn't easily explain retrograde motion**
- **Heliocentric model does; also explains brightness variations**
- **Galileo's observations supported heliocentric model**
- **Kepler found three empirical laws of planetary motion from observations**

Summary of Chapter 2 (cont.)

- **Laws of Newtonian mechanics explained Kepler's observations**
- **Gravitational force between two masses is proportional to the product of the masses, divided by the square of the distance between them**