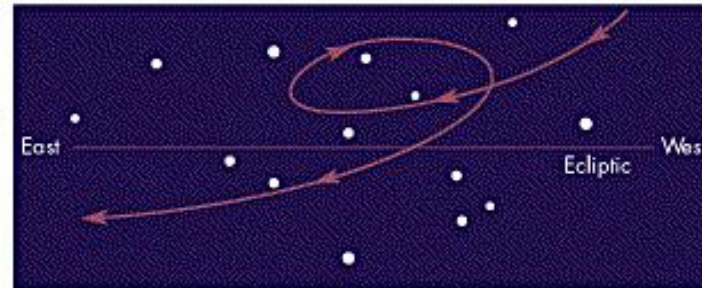
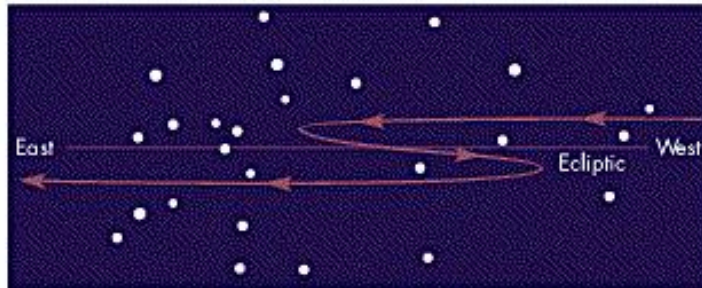
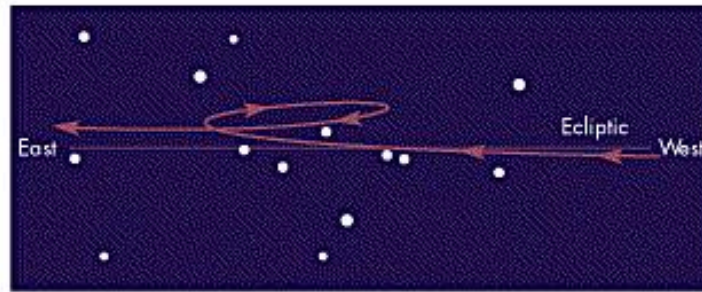


Retrograde Loops of Mars



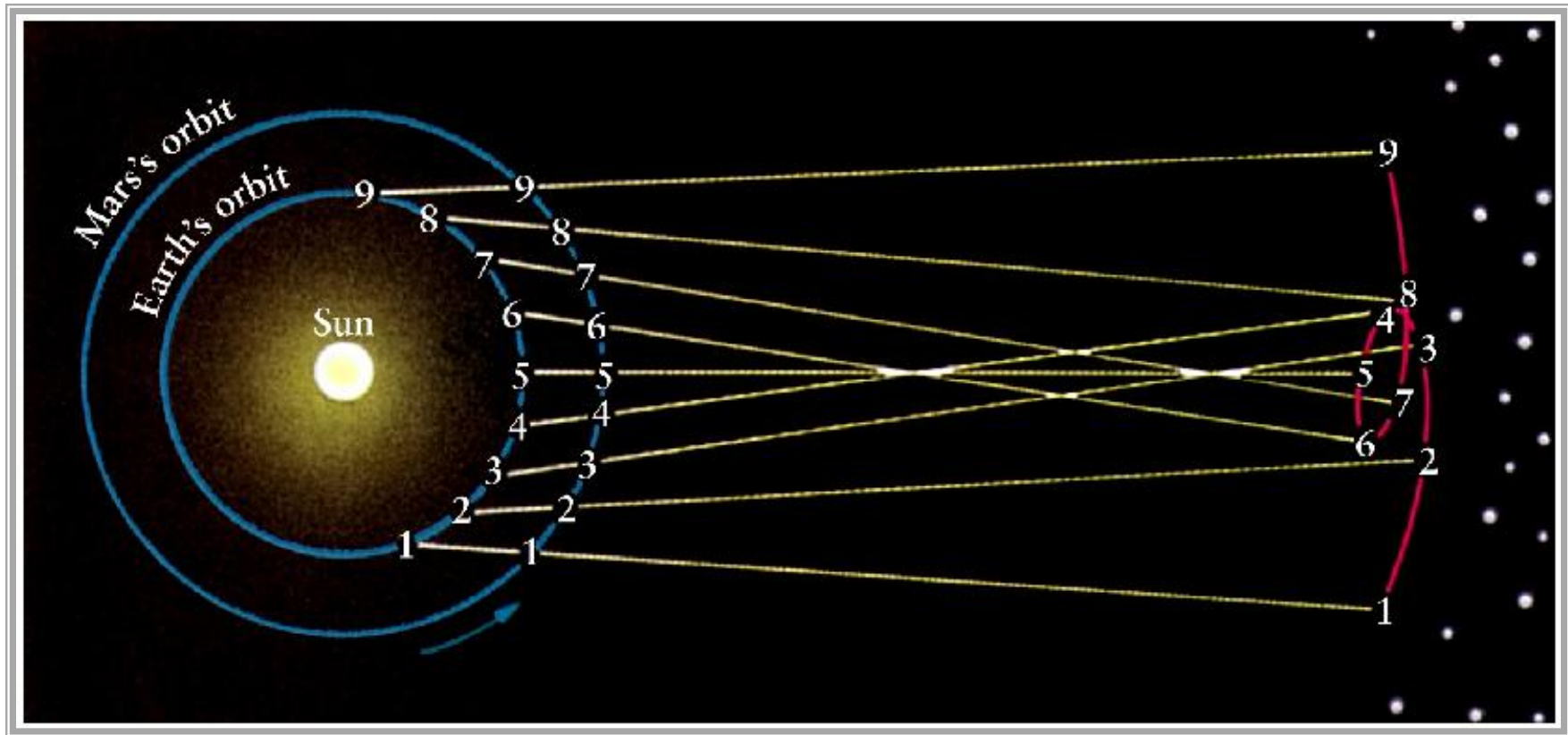
The geocentric model offers no easy way of creating retrogradeloops from an Earth-based perspective.

Copernicus (1543)



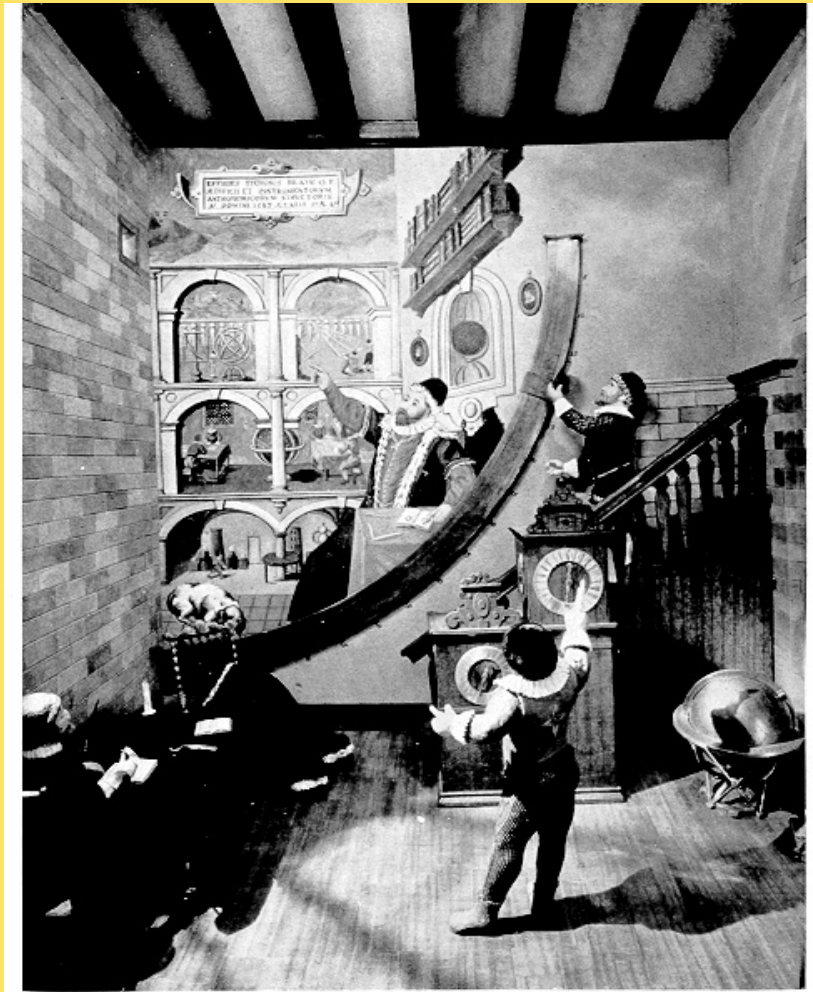
- ❖ Ptolemaic model failed to reproduce the observations
- ❖ Also, the model is not really based on uniform circular motion
- So Copernicus favors the heliocentric (Sun-centered) model
- ❖ Has a natural explanation for apparent retrograde motion of planets
- ❖ However, Copernicus' conception of the model actually did no better in reproducing the observations than did the geocentric model

Heliocentric vs Geocentric



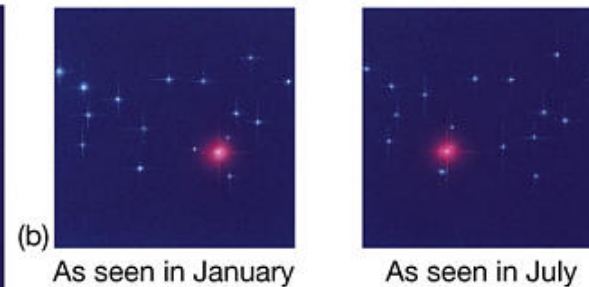
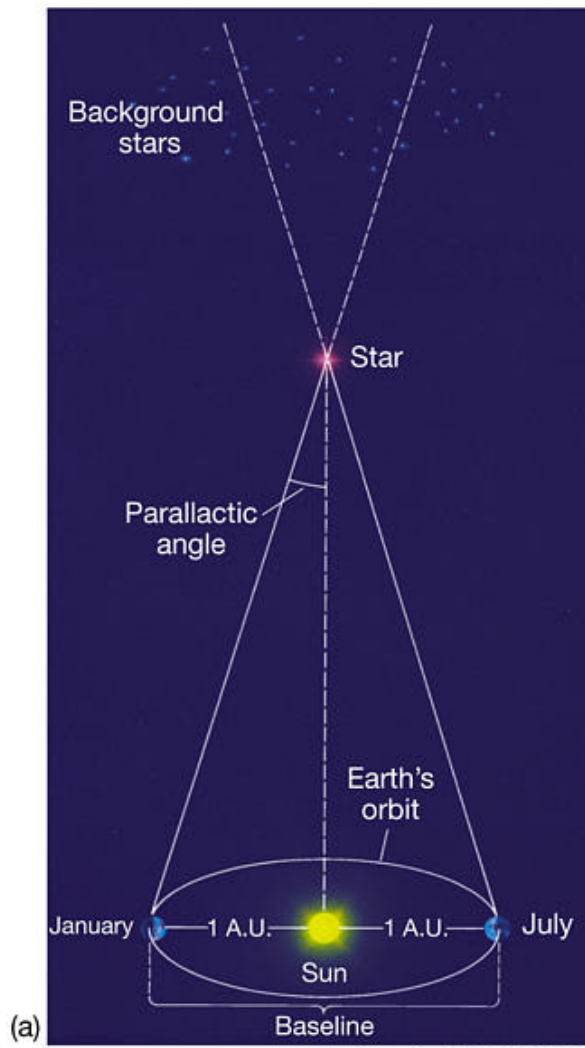
Copernican model better in terms of Occam's Razor

Tycho Brahe



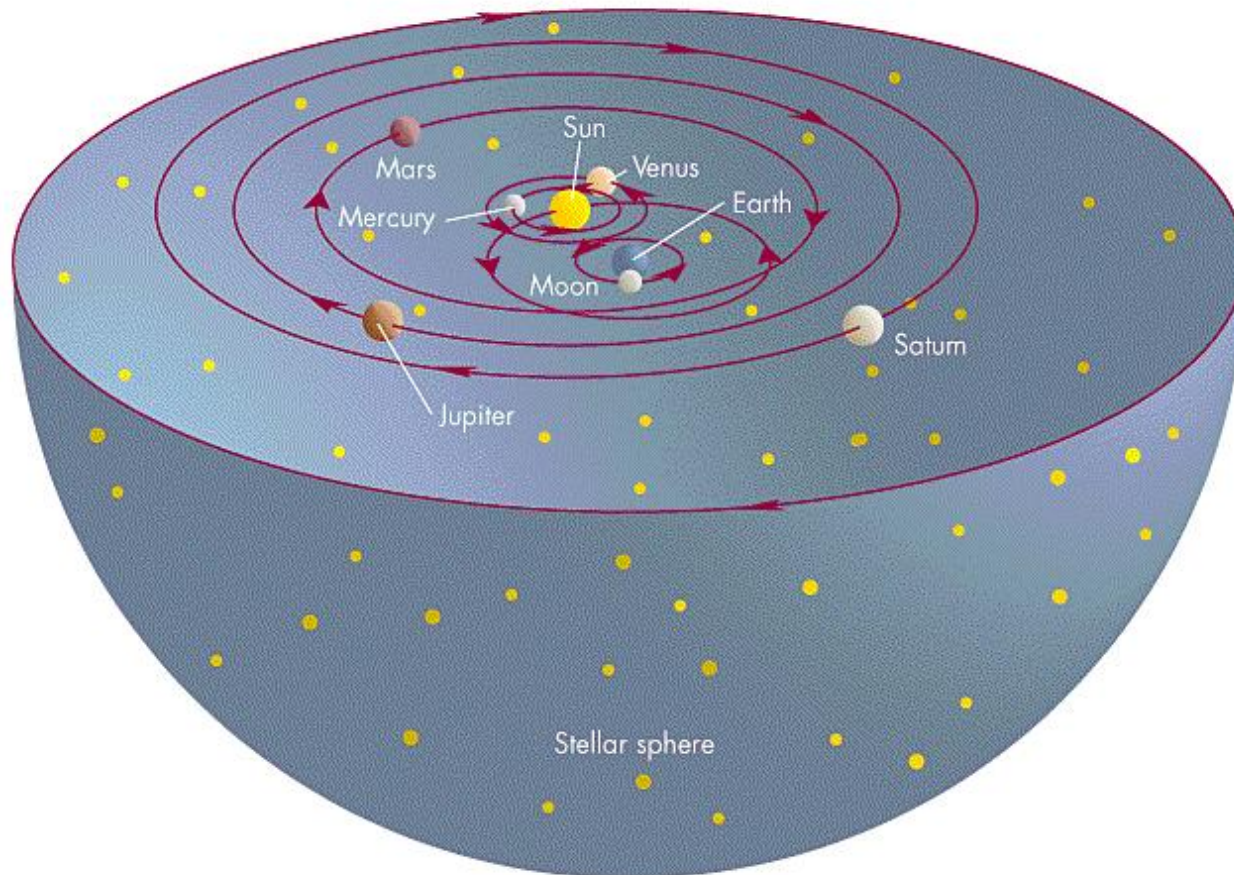
- (1546-1601) Made regular and careful (i.e., accurate) measurements of planet and star positions, especially of Mars
- He rejected the heliocentric model because he was unable to observe stellar parallax (but actually, stars are just far away)

Stellar Parallax



Stellar parallax refers to how stars in the sky appear to “bob” back and forth over the course of a year due to the Earth’s motion around the Sun.

Tycho's Hybrid Model



Johannes Kepler

- (1571–1630) Worked for Brahe and “inherited” Brahe’s data after his death
- Used the Copernican model but could not match observations for Mars
- Kepler abandoned circles (!) and adopted the oval shaped ellipses



Kepler's Laws

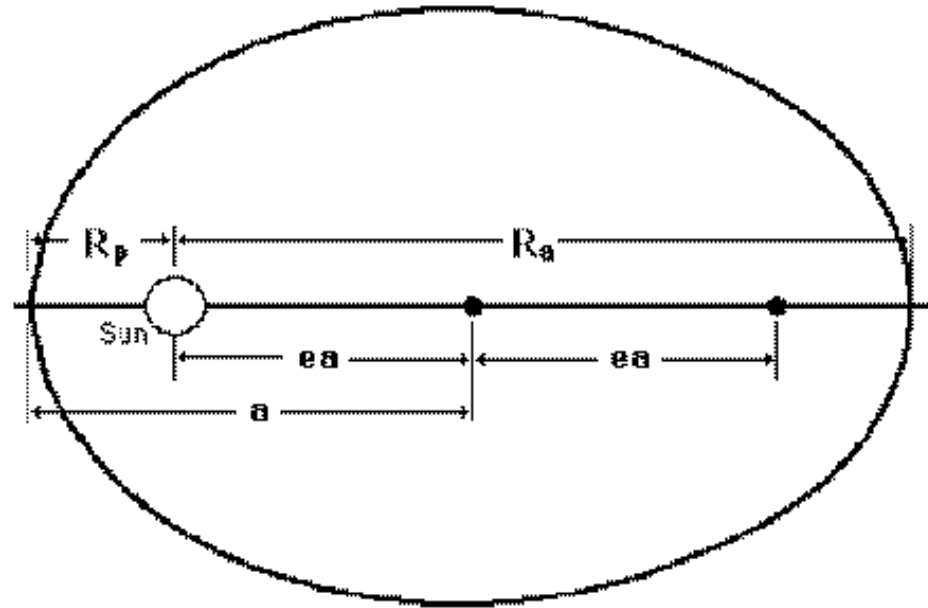
3 laws of planetary motion:

- I. Planets move on elliptical orbits with the Sun at one focus
- II. A planet “sweeps out” equal areas in equal times as it moves around the Sun
- III. The square of the sidereal period is proportional to the cube of the orbital semi-major axis:

$$P^2 = a^3$$

Ellipses

Oval shaped contours



a = semi-major axis

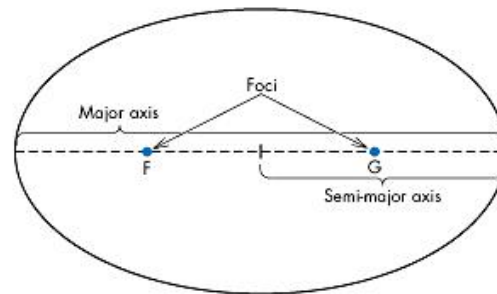
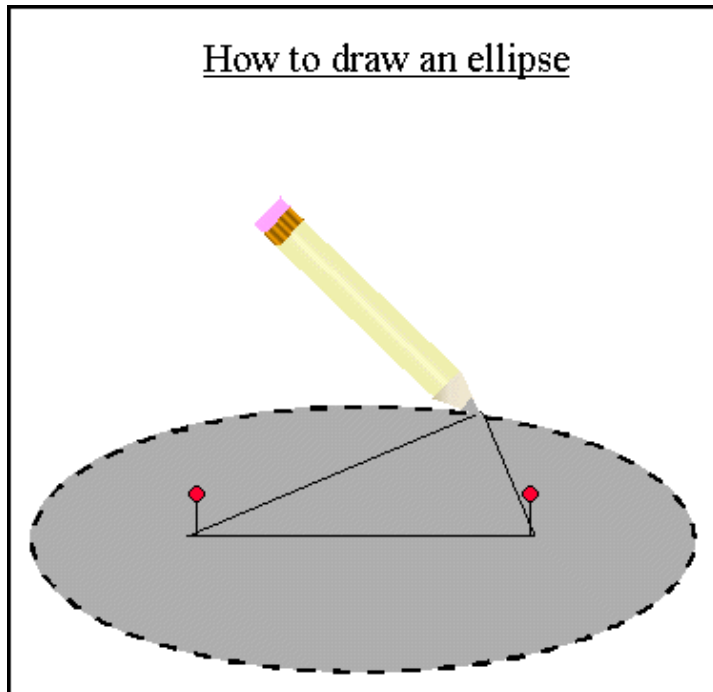
b = semi-minor axis

e = eccentricity ($e=0$ is a circle; $e=1$ is a line)

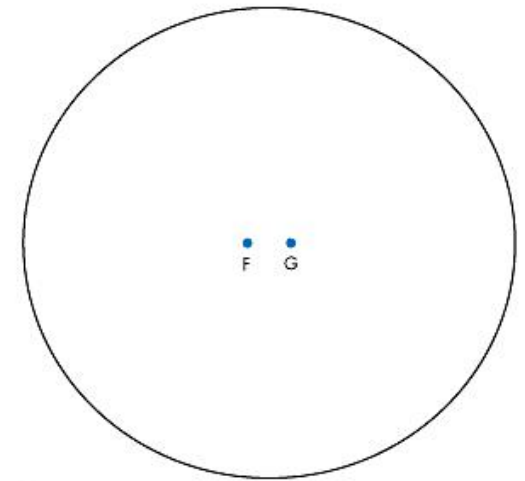
two foci in an ellipse, instead one center for a circle

Solar System: perihelion=closest approach to Sun;
aphelion=furthest distance from Sun

Making Ellipses



A



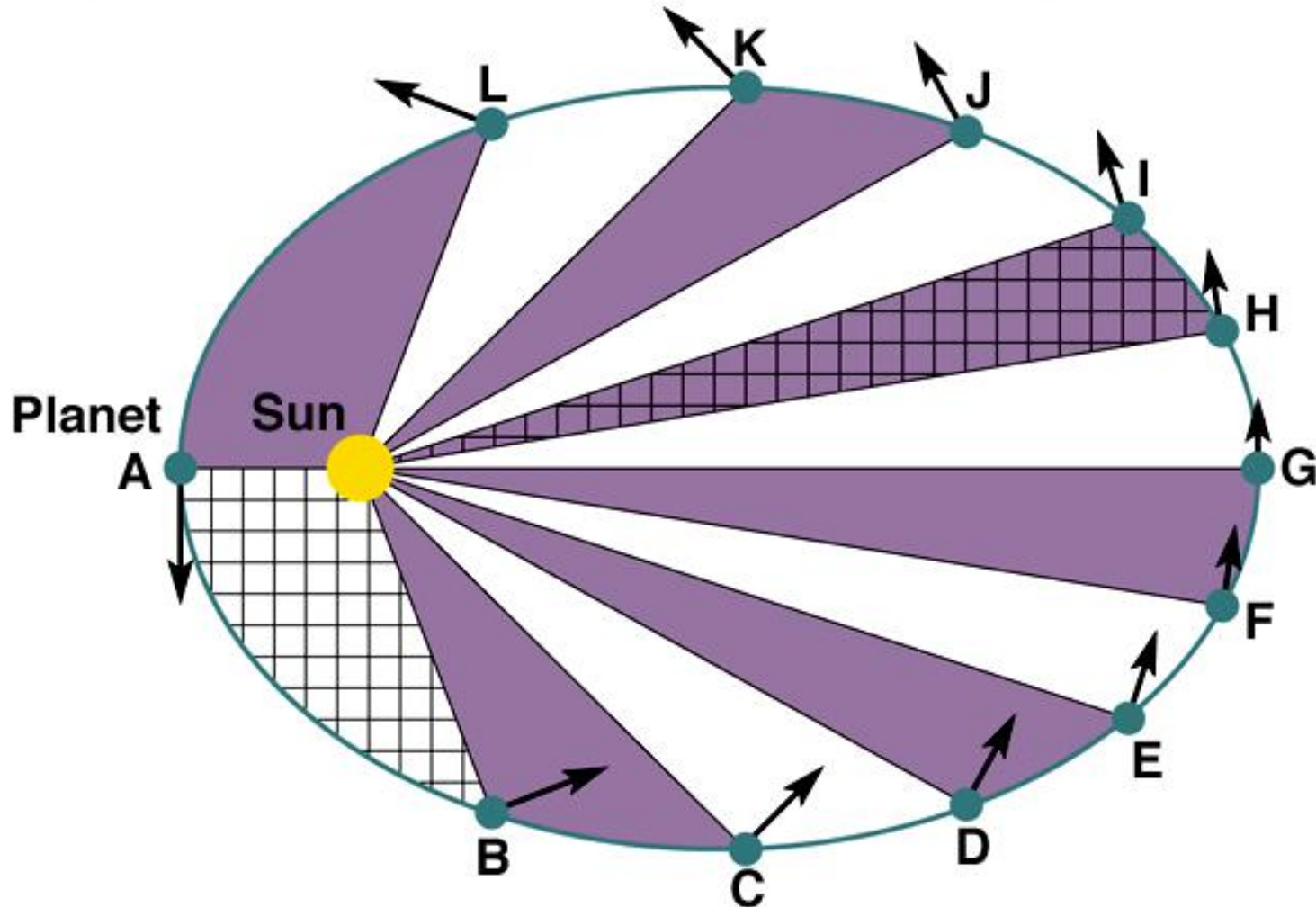
B



C

Illustration of how to make ellipses. The degree of “squashedness” (called eccentricity) is related to how far apart the foci are from one another.

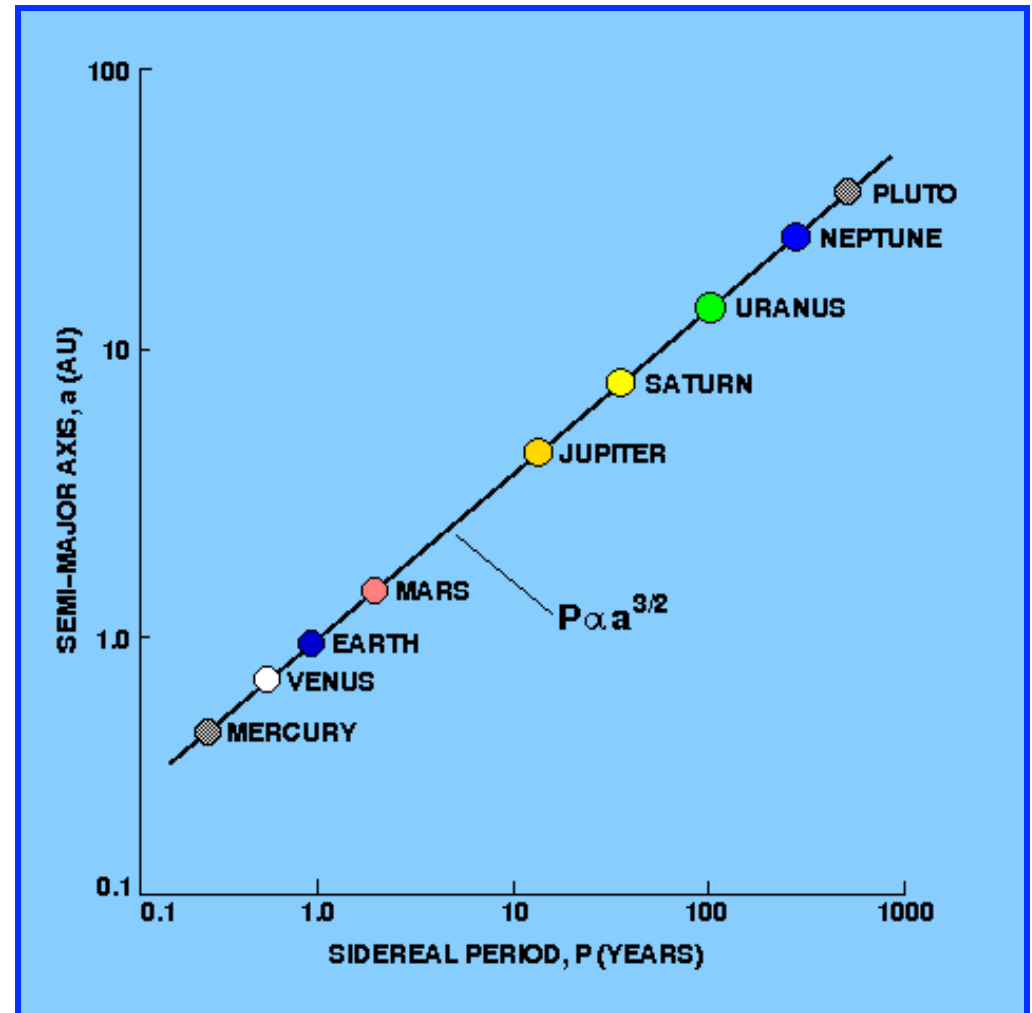
Kepler's second law—the law of equal areas.



Each wedge has the same area. The amount of time in moving from 1 letter to the next is the same for every interval.

Kepler's 3rd Law

The line shows Kepler's 3rd law in a "log-log" plot. The points are actual values for worlds in our solar system.



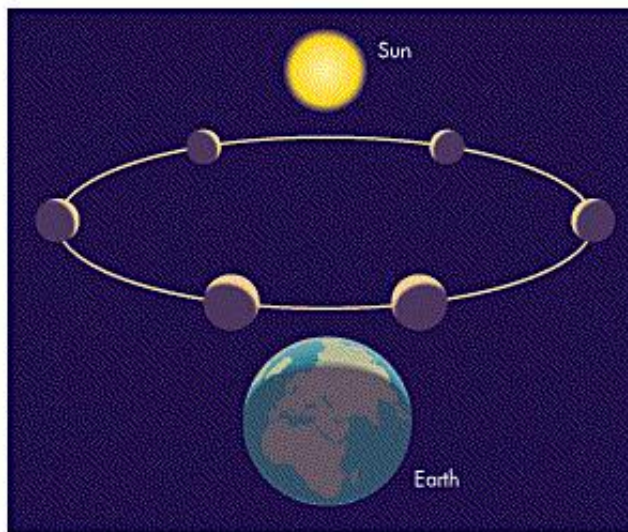
Galileo Galilei



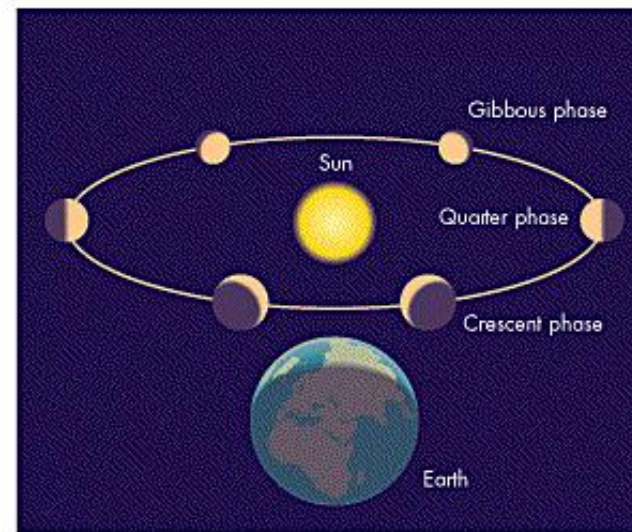
(1564–1642) First to use a telescope to study the heavens. His observations confirmed the heliocentric model, both conceptually and definitively:

- ❖ Terrain on the Moon
- ❖ Discovered satellites of Jupiter – a mini-solar system
- ❖ Observed motion of sunspots implying rotation of the Sun
- ❖ Observed phases of Venus that confirmed a prediction of the heliocentric model

Galileo and Phases of Venus



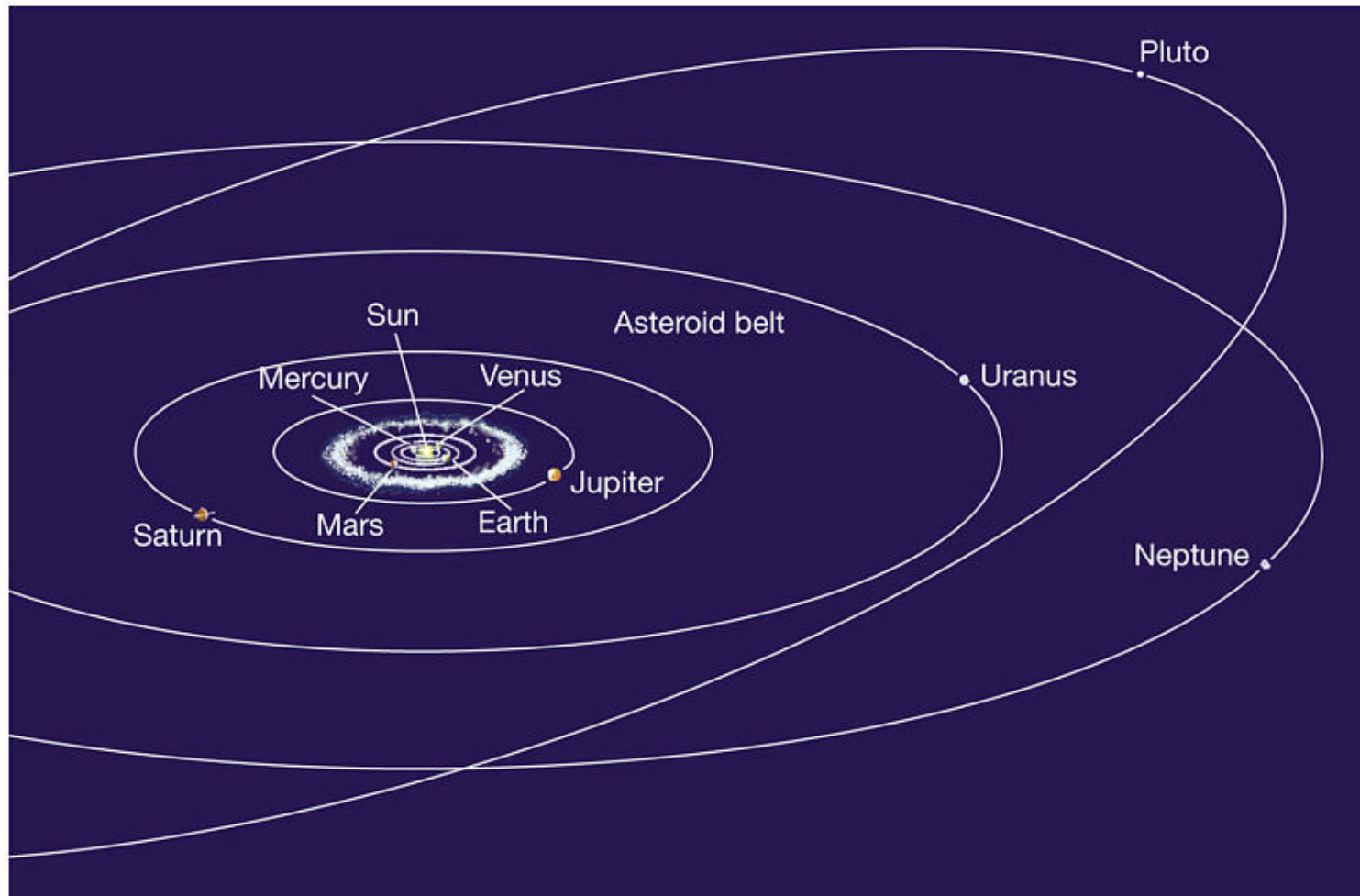
A The Ptolemaic system



B The Copernican system

Illustration of how the two main views (geocentric vs heliocentric) lead to different predictions for the range of phases of Venus seen from Earth.

The Modern Solar System



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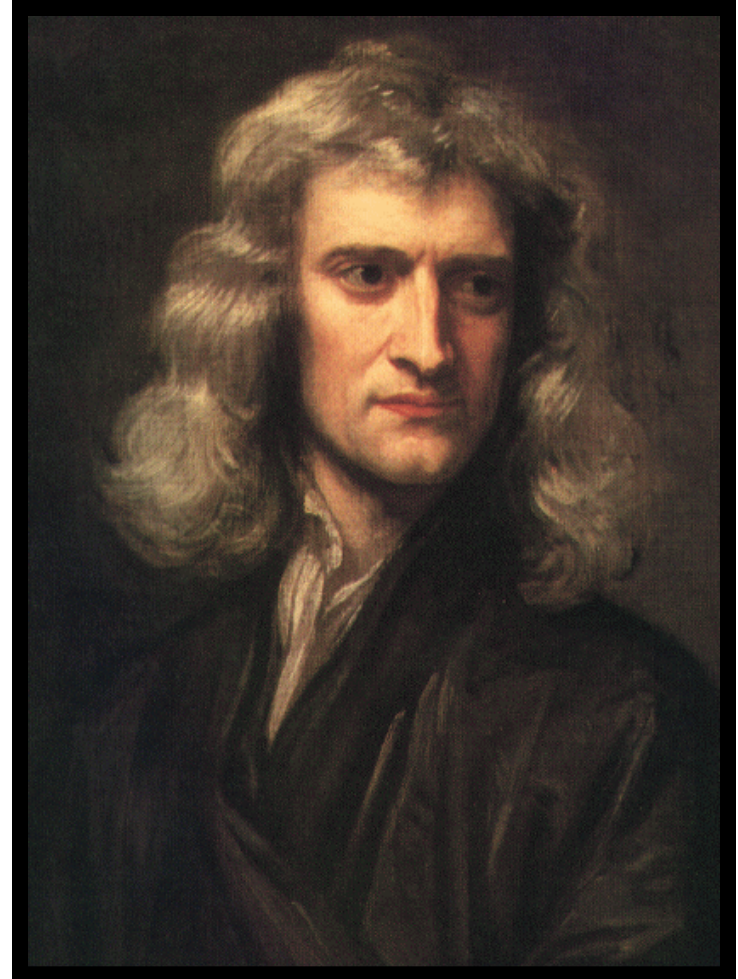
The solar system as we are familiar with it today. Nowadays Pluto is classified as a “dwarf planet”.

Review of Motion Terms

- FORCE – push or pull
- SPEED – rate change in distance with time (i.e., distance over time)
- VECTOR – signifies direction and value
- VELOCITY – a vector consisting of the speed and direction
- ACCELERATION – rate change of velocity with time (so also a vector)
- MASS – measure of the quantity of matter

Nature of Motion

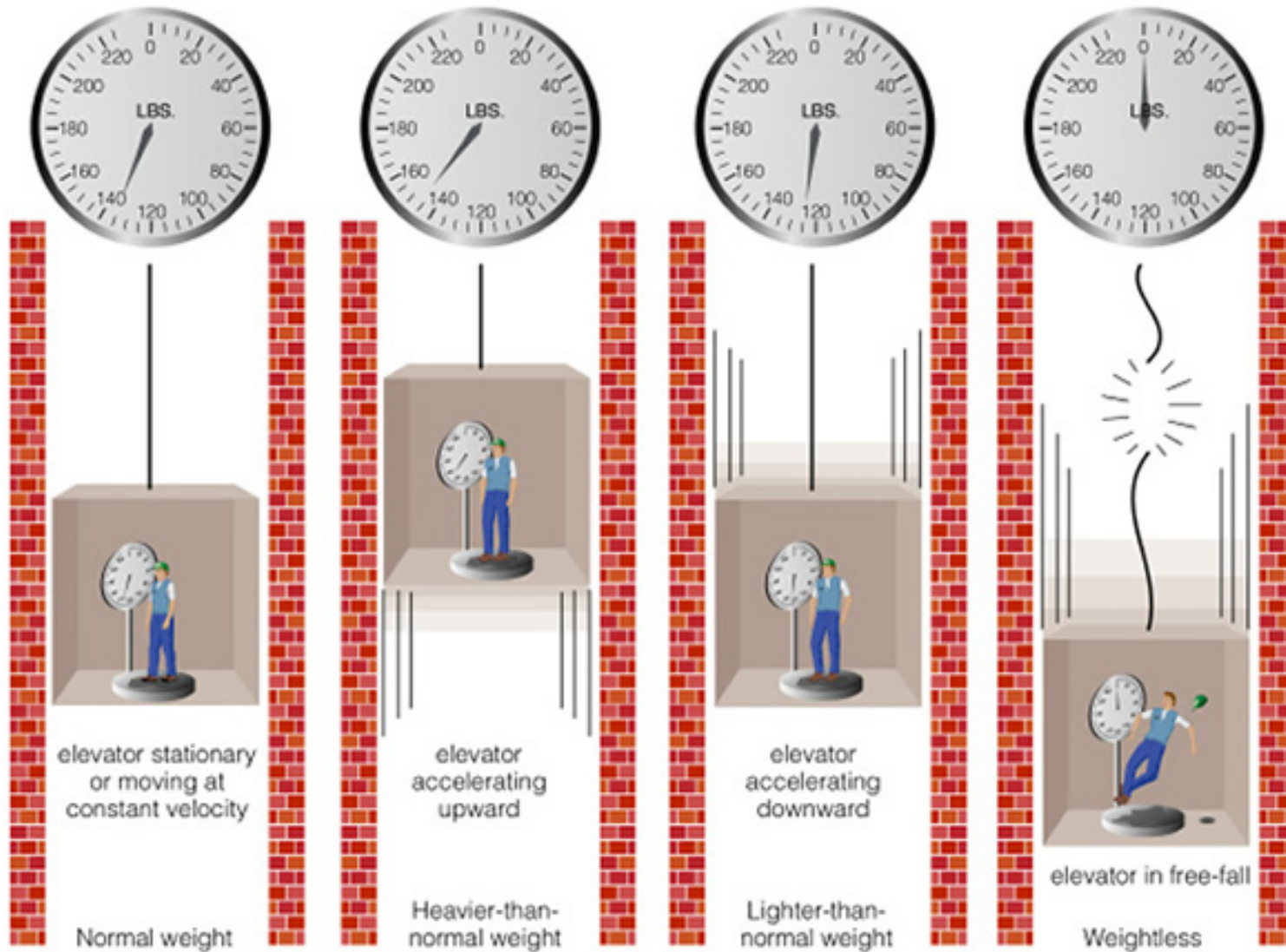
- Galileo - (1600) objects of differing weights when dropped from the same height hit the ground at the same time (in idealized conditions - no air resistance); conducts a range of experiments in a rather modern scientific fashion
- Isaac Newton - (1642-1727) a way-clever guy; did fundamental work on optics, gravity, motion and even invented calculus, all in a 2 year period after receiving his B.A. collected works published in the *Principia* (1687); establishes laws of motion



Newton's Laws of Motion

- *Law of Inertia:* An object remains at rest or continues in motion at constant velocity unless it is acted on by an unbalanced external force.
- *Law of Force:* when an unbalanced force acts on an object, it produces a change in momentum of an object in the direction in which the force acts. ($F=ma$)
- *Law of Action-Reaction:* When one body exerts a force on a second body, the second also exerts a force on the first. These forces are equal in strength but opposite in direction.

Forces and Weight

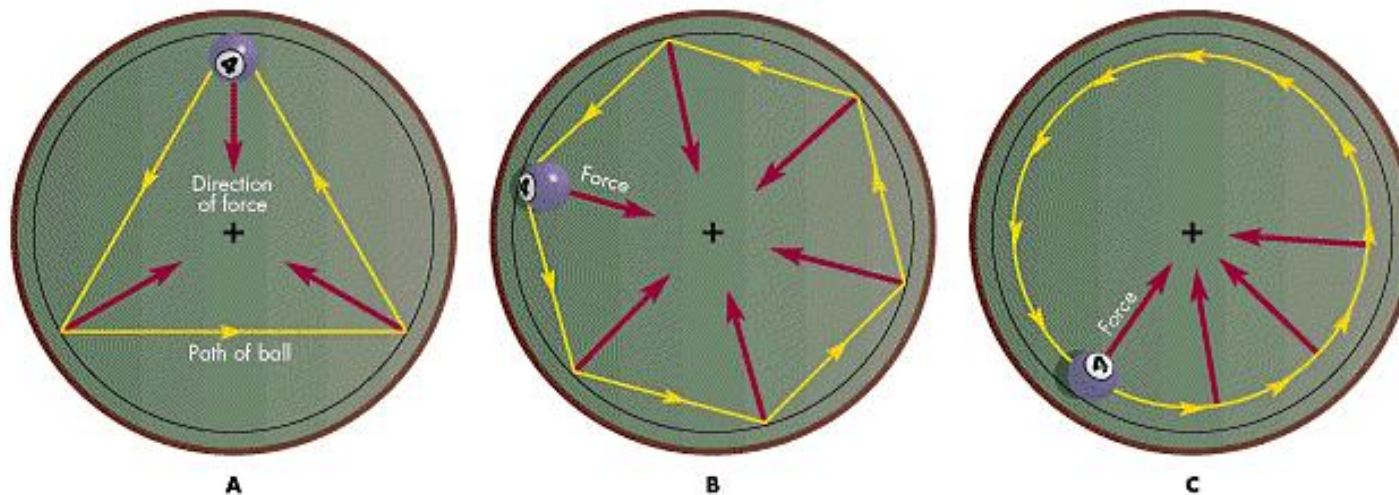


Nature of Circular Motion

- Hooke - (1635-1703)
 - Suggested an attractive central force between Sun and planets is needed to maintain orbits.
 - 1666: Pendulum demonstration of central force.
 - Suggested that the force was gravity (same as on Earth), and that gravity should grow weaker with increasing distance of separation.
 - The force needed to keep a body in circular motion is

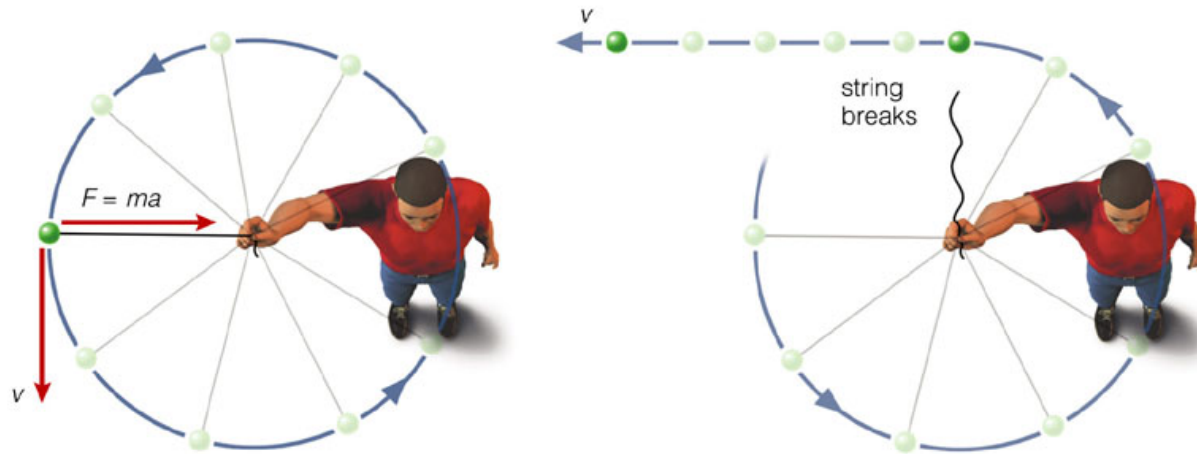
$$F_c = m \frac{v_c^2}{r}$$

Centripetal Force

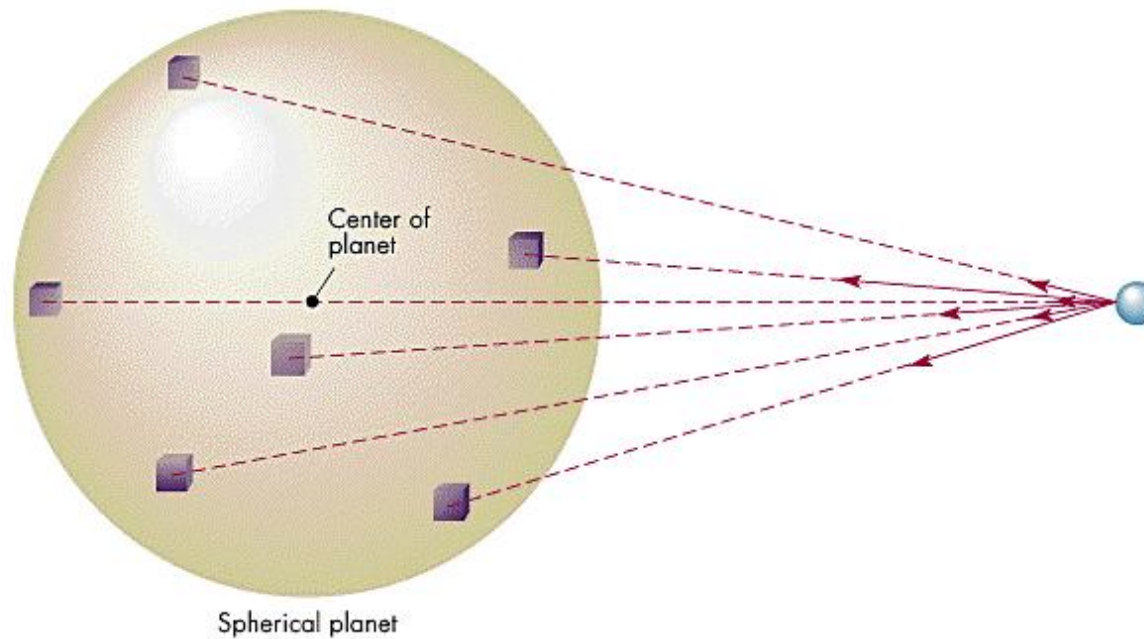


For circular motion, the force needed is seen to be “center-seeking”.

Example of Circular Motion



Newton's Gravity



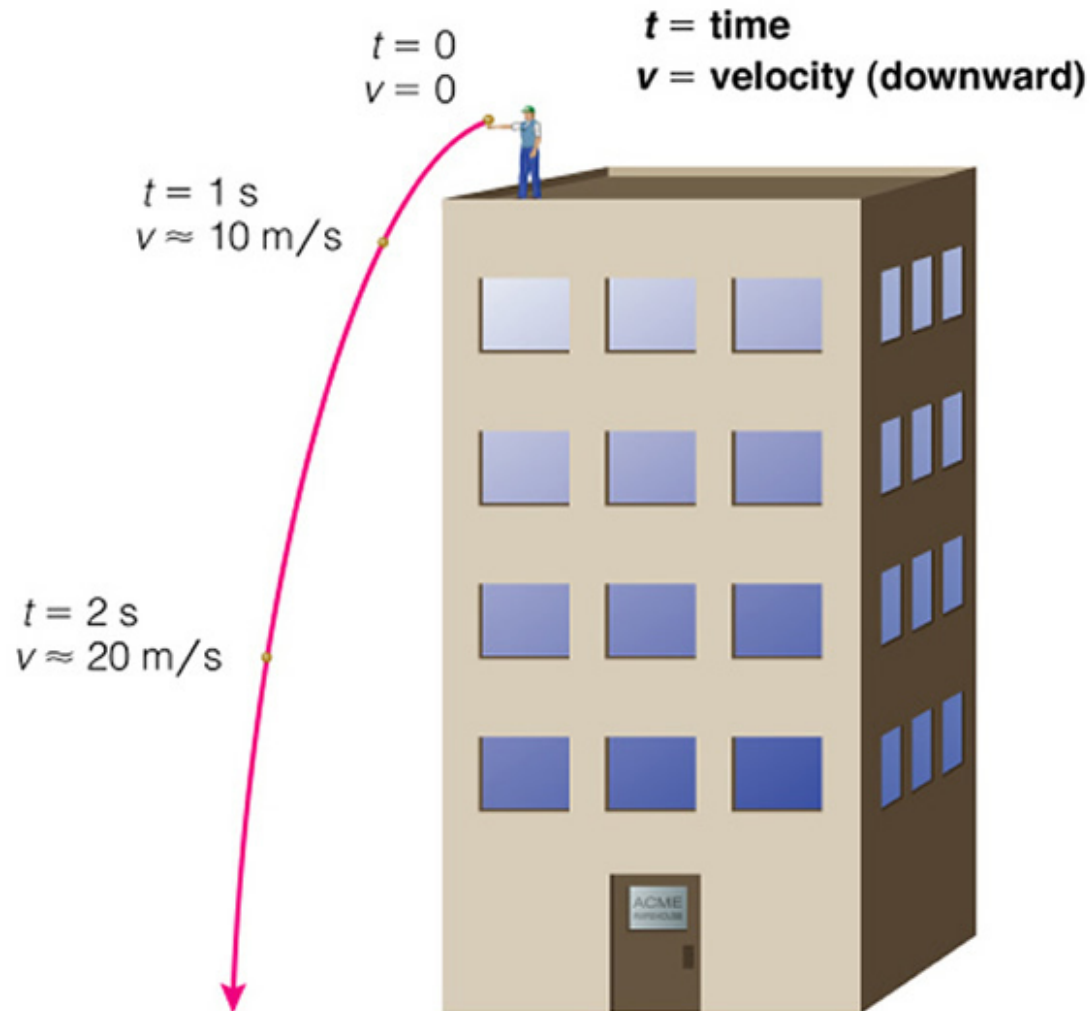
■ = Particle of matter in planet; mass = M

● = Particle of matter outside planet; mass = m

→ = Gravitational force between ■ and ● = $F_G = \frac{GMm}{d^2}$

d = Distance between ■ and ●

Falling Under Gravity



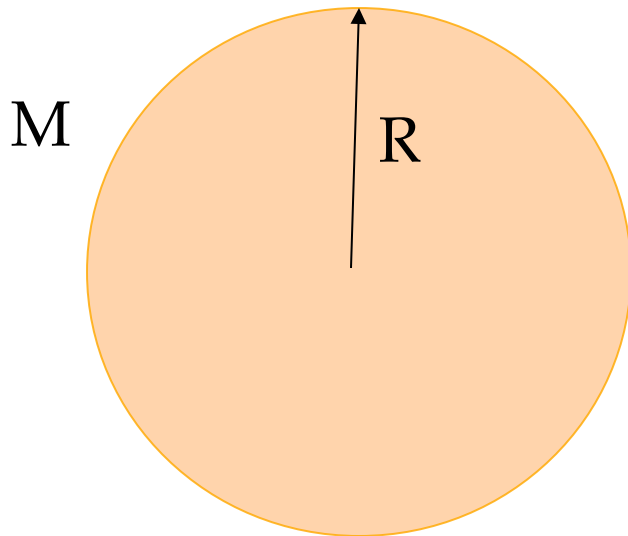
The familiar action of falling can be described by Newton's gravity acting between the object (say, a ball) and the center of the Earth as if all the Earth's mass were located at that point.

Free Fall?

(What is weightlessness?)



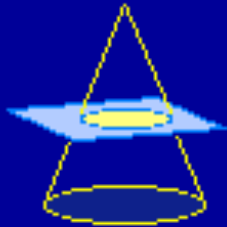
Gravity on Other Bodies



$$g = \frac{GM}{R^2}$$

<i>Planet</i>	<i>g (m/s²)</i>	<i>g/g_E</i>
Earth	9.8	1
Sun	274	28
Moon	1.6	0.16
Venus	8.9	0.90
Mars	3.7	0.38

Conic Sections



Circle



Ellipse



Parabola

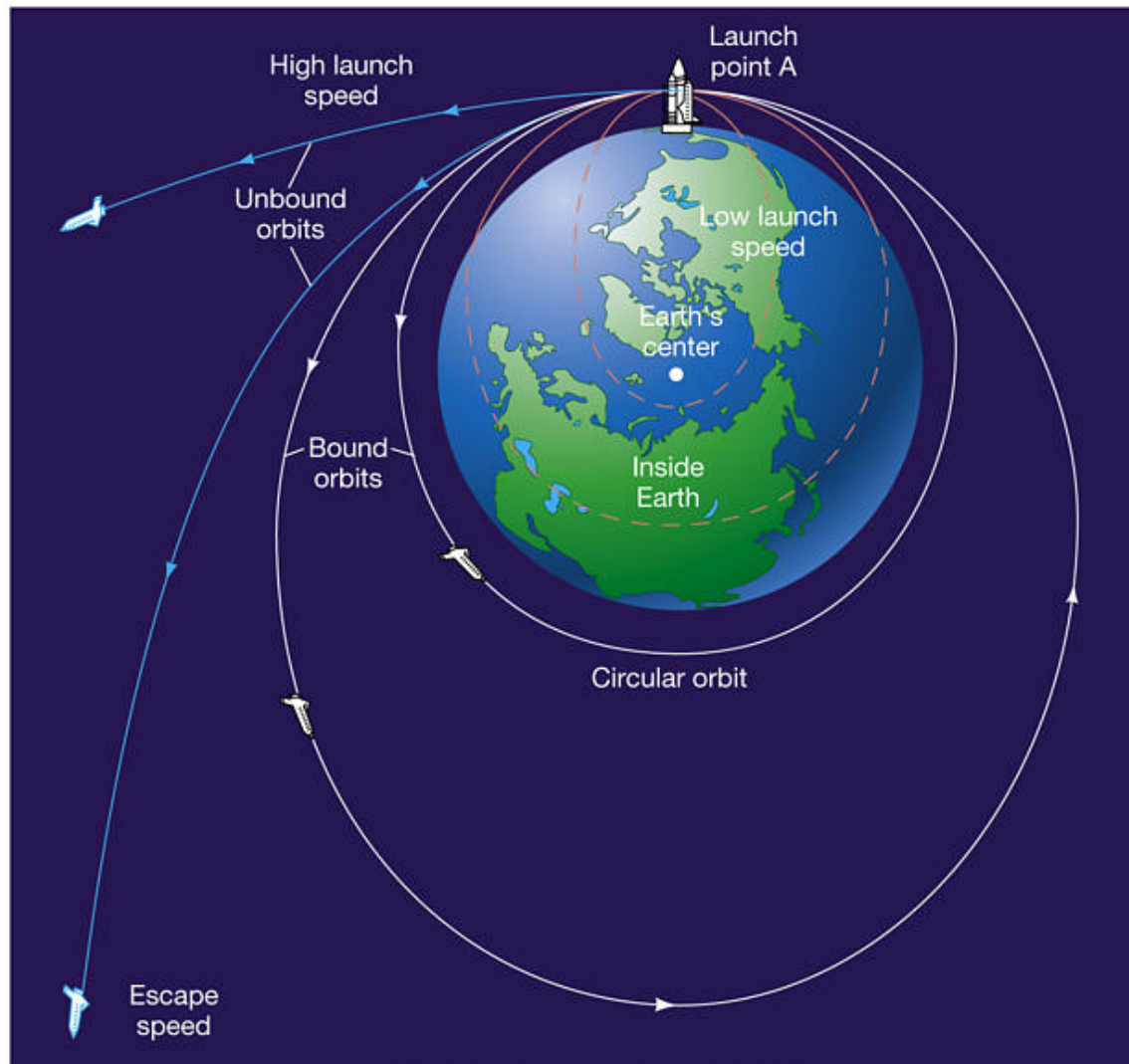


Hyperbola



Conic sections are a family of 4 shapes that result from the intersection of a cone with a plane. These shapes are the allowed orbits from an inverse square law force, like Newtonian gravity. Some shapes are closed curves, others are not.

Escape Velocity



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Several different orbits for several different launch speeds. (Note: objects that fall to Earth are actually on orbits, but the ground gets in the way.)

Escape velocity refers to the minimum speed of launch so that an object does not come back around.

Orbital Details

