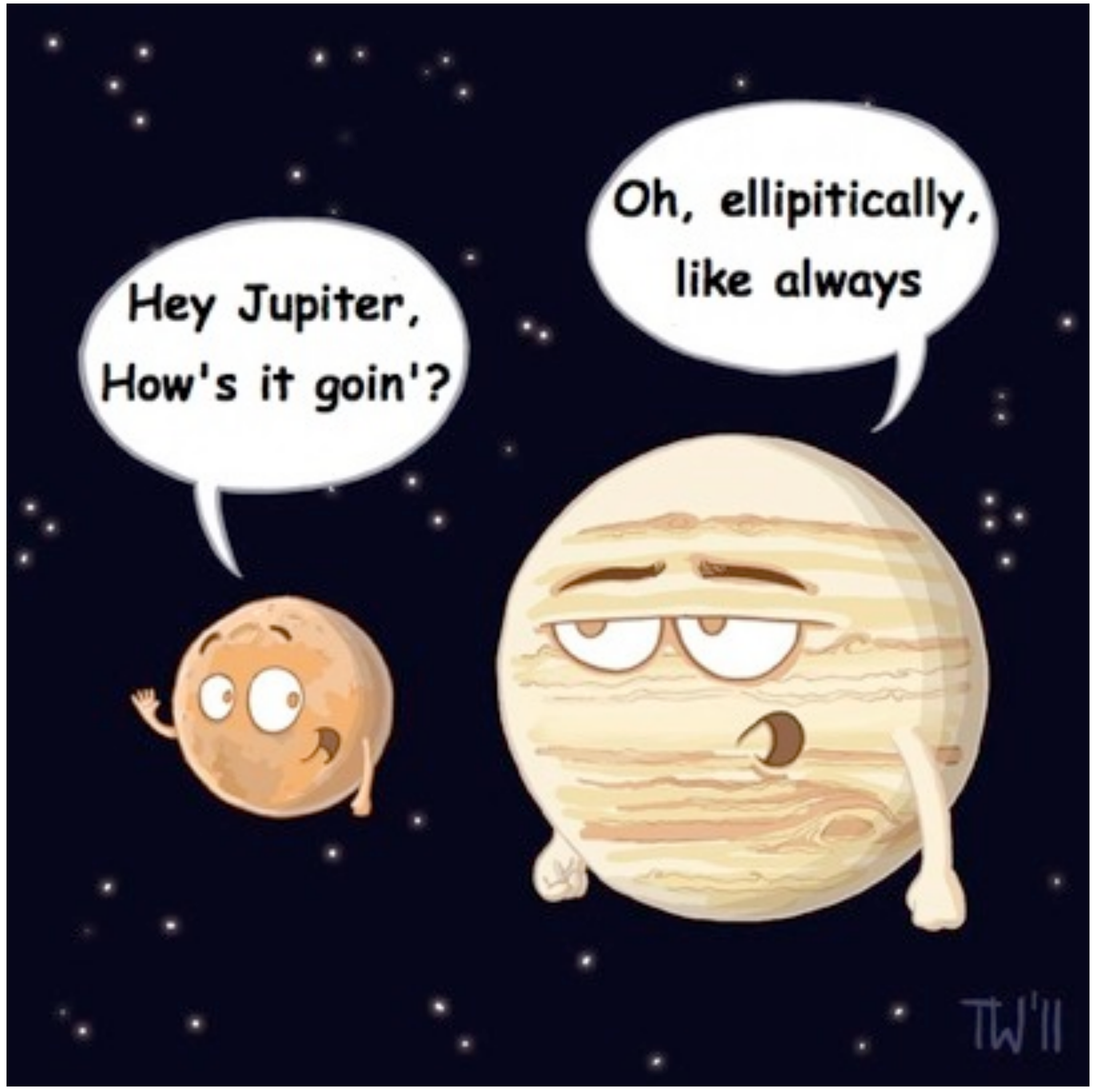
ASTR 150
Jan 23, 2012

- Homework 1 due next Monday (normally would be due this Friday)
- Planetarium Shows begin next week
  - report forms on course website
- Register your iClicker!
- Last time: the Night Sky
- Today: Motion and Gravity
  - hang on tight! most math all semester, get it over with right away



Gravity:
A Force for Death and Life in the Cosmos

The Universe is the way it is
largely because gravity is
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Death by gravity! Crushed star explodes!

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- ... but also for the creation of new stars, galaxies, planets, and life

Birth by gravity! Gas clouds collapse to stars!

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Obi-Wan speaks wisely: “it surrounds us and penetrates us; it binds the Galaxy together”

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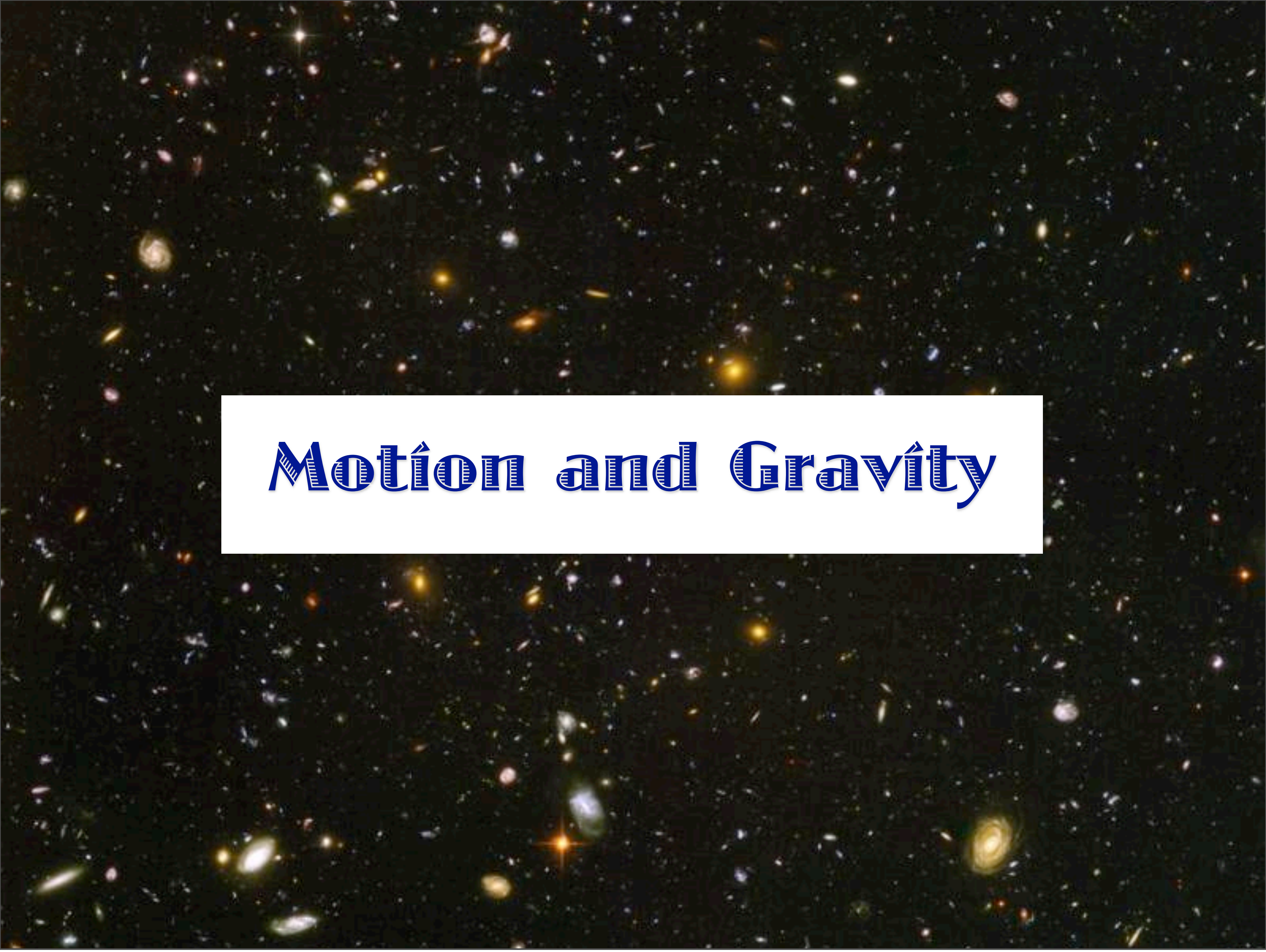
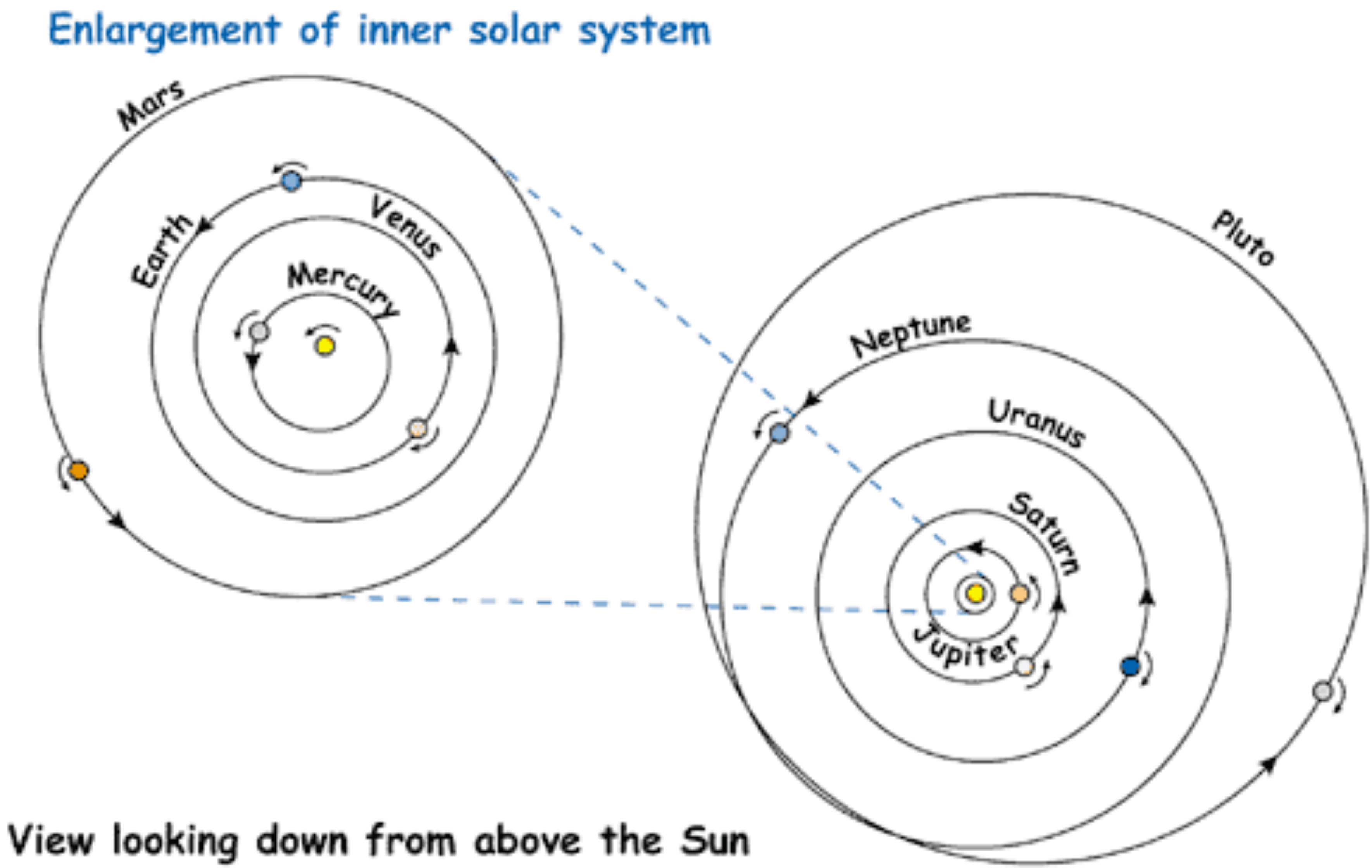

Motion and Gravity



The planets orbit the Sun on nearly-circular orbits animation: http://janus.astro.umd.edu/javadir/orbits/ssv.html

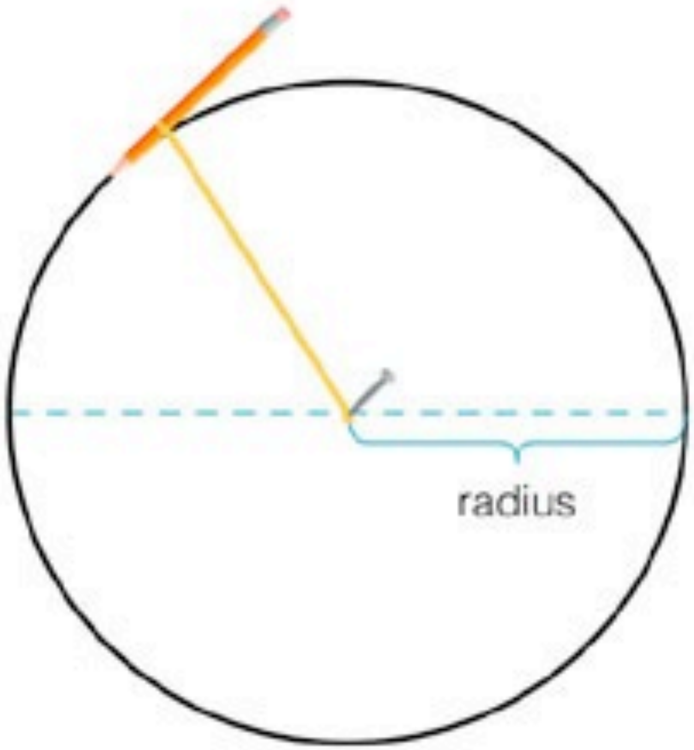
Kepler's Laws of Planetary Motion

- 17th century astronomer
- Developed a mathematical model of orbital motions based on the ellipse
- Summarized his findings in the form of three laws of planetary motion
- apply not only to planets but to anything orbiting Sun

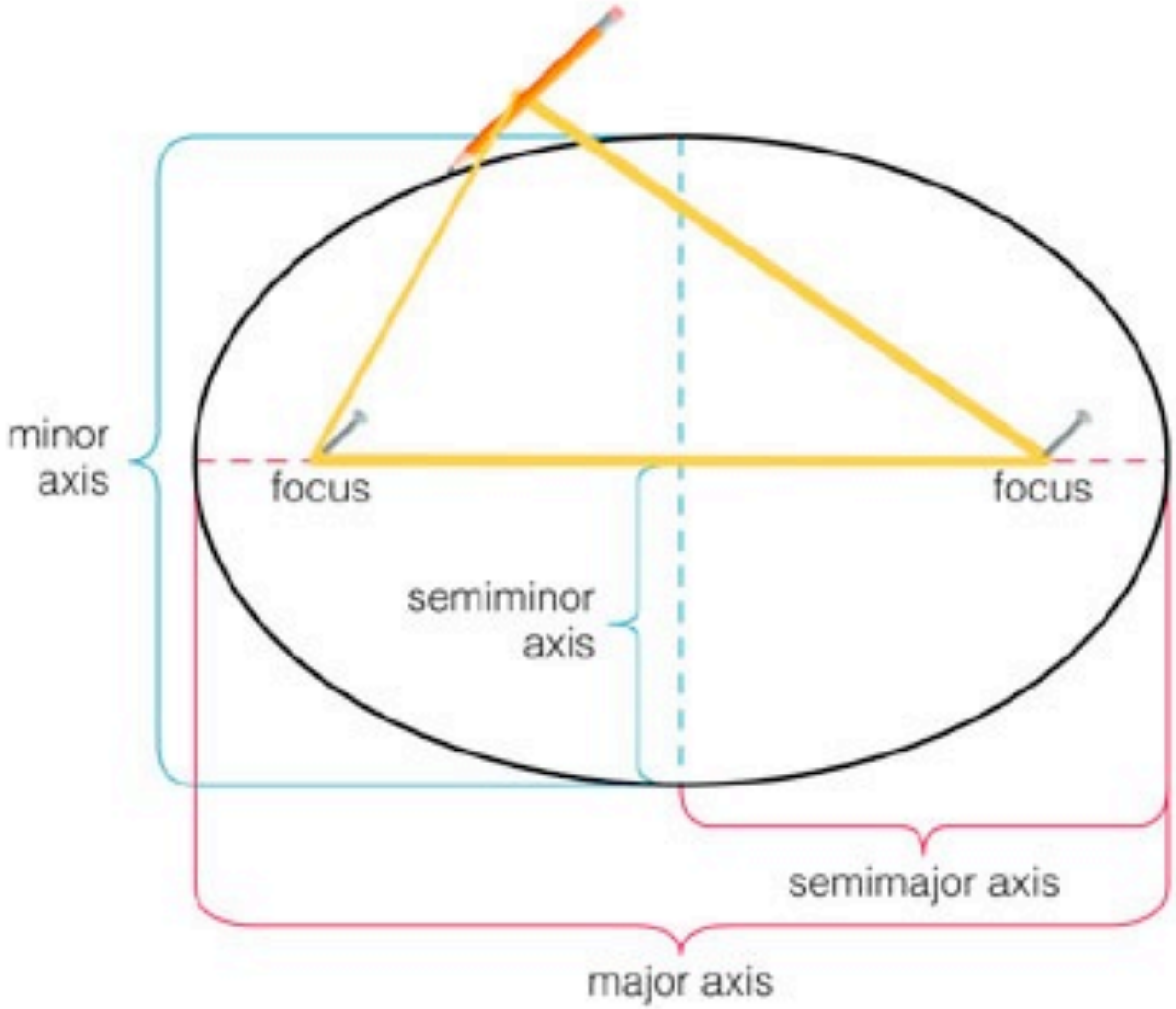
Johannes Kepler (1571-1630)

What is an ellipse?

Circle



Ellipse



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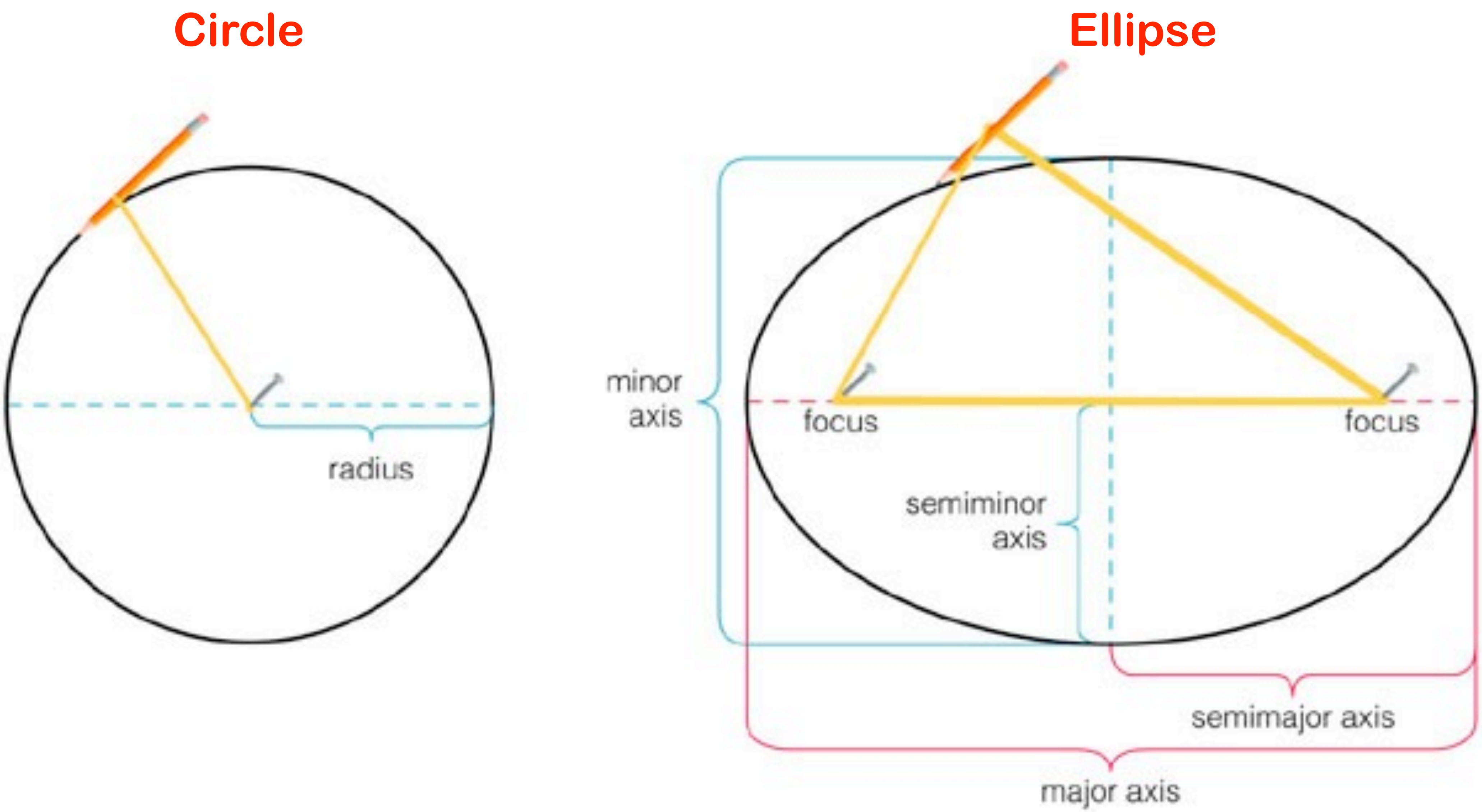
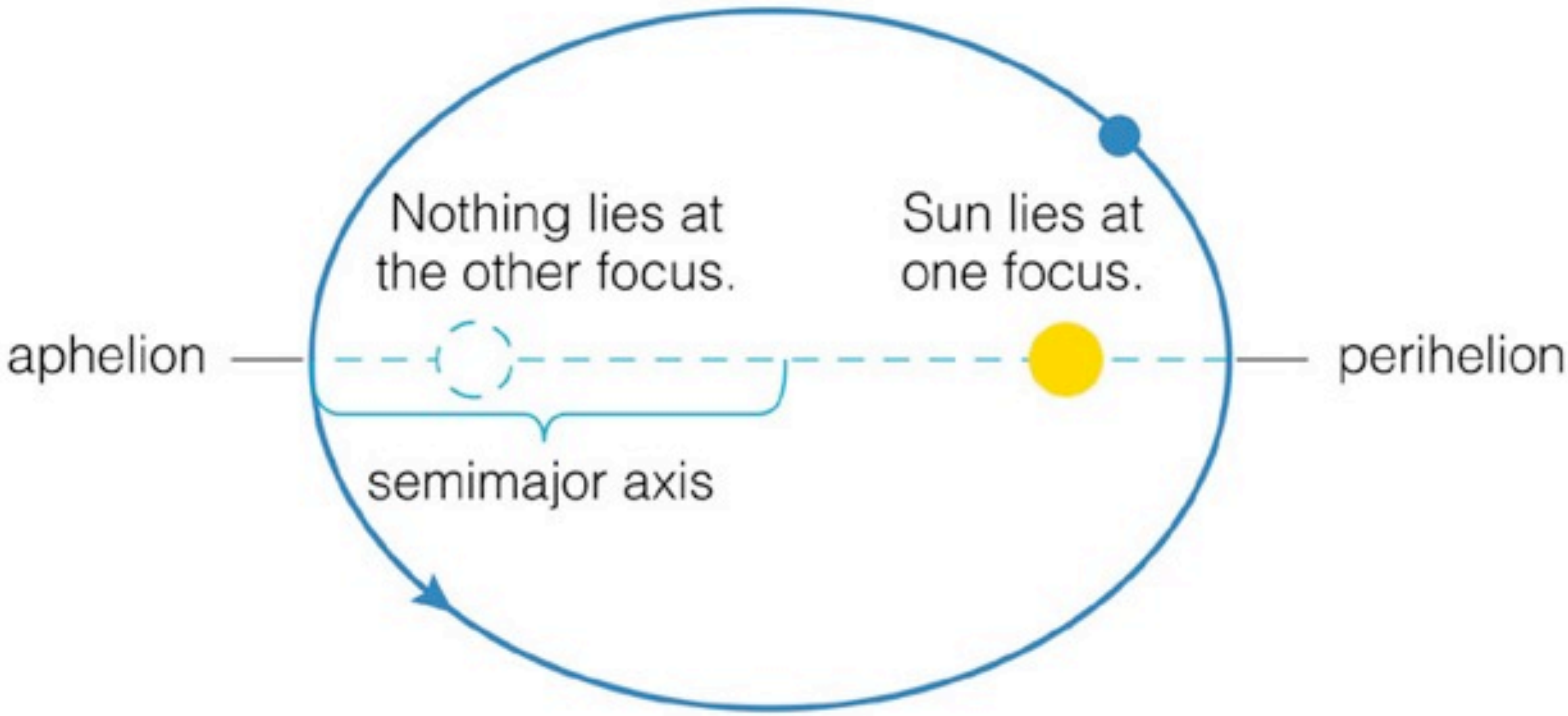


An ellipse looks like a flattened circle

Kepler's Laws of Planetary Motion

Law #1: The orbits of the planets are ellipses with the Sun at one focus



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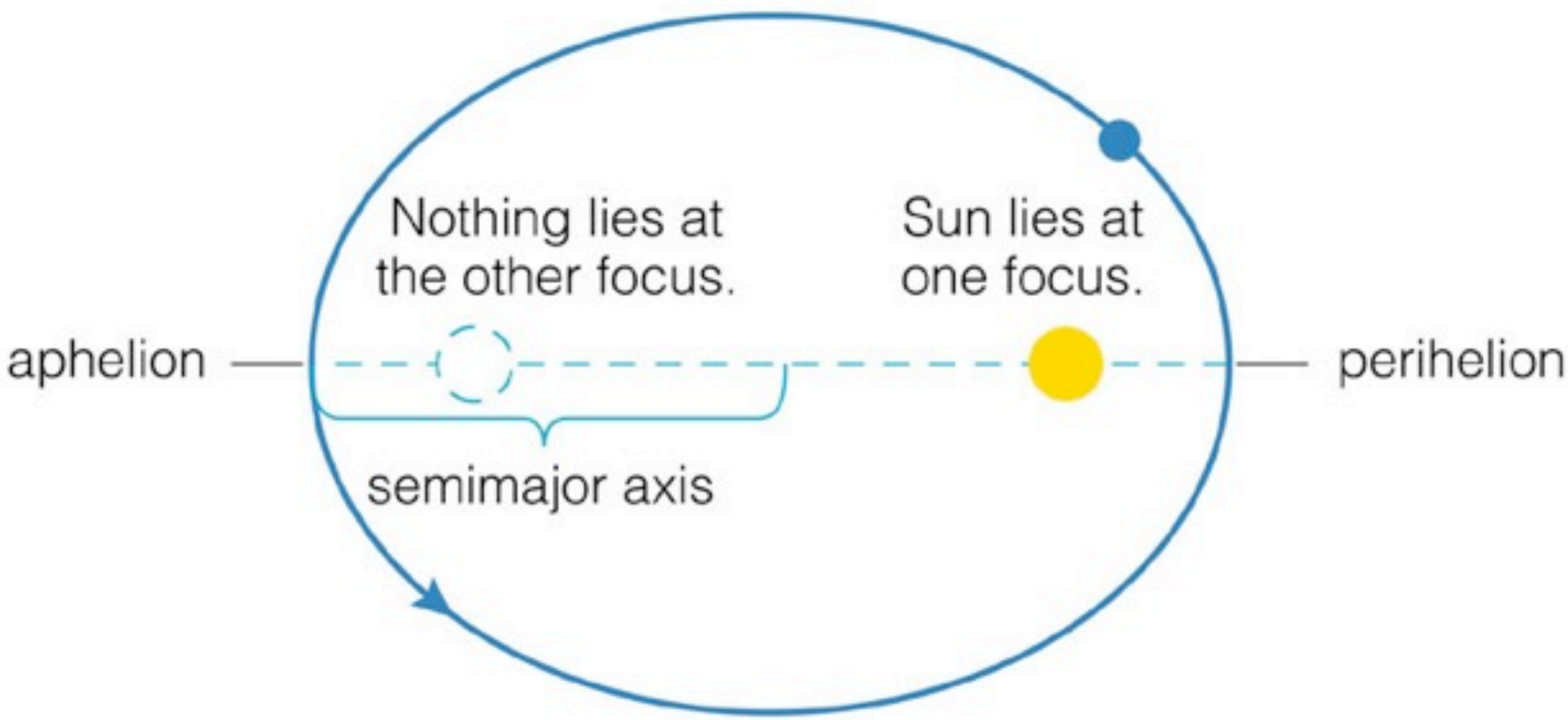
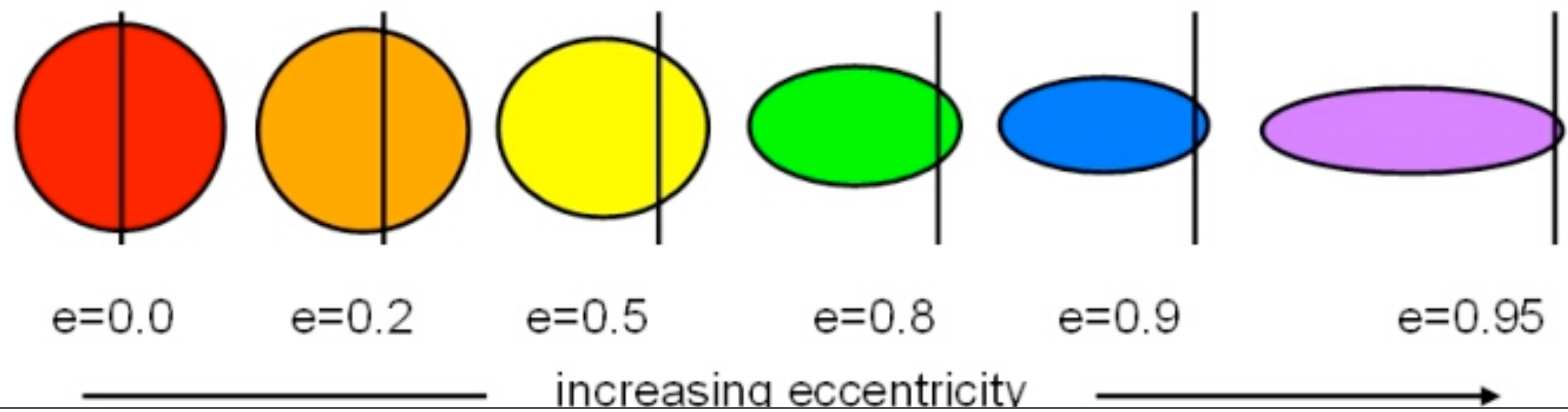


The Sun is not at the center of the ellipse!

Eccentricity of an Ellipse

- Eccentricity, e, is half the distance between the foci divided by the semi-major axis
- allowed values: e is between 0 and 1
- An e = 0 is a perfect circle while a long, thin ellipse has an e close to 1
- Most of the planets' orbits have low eccentricity - i.e. "nearly circular"

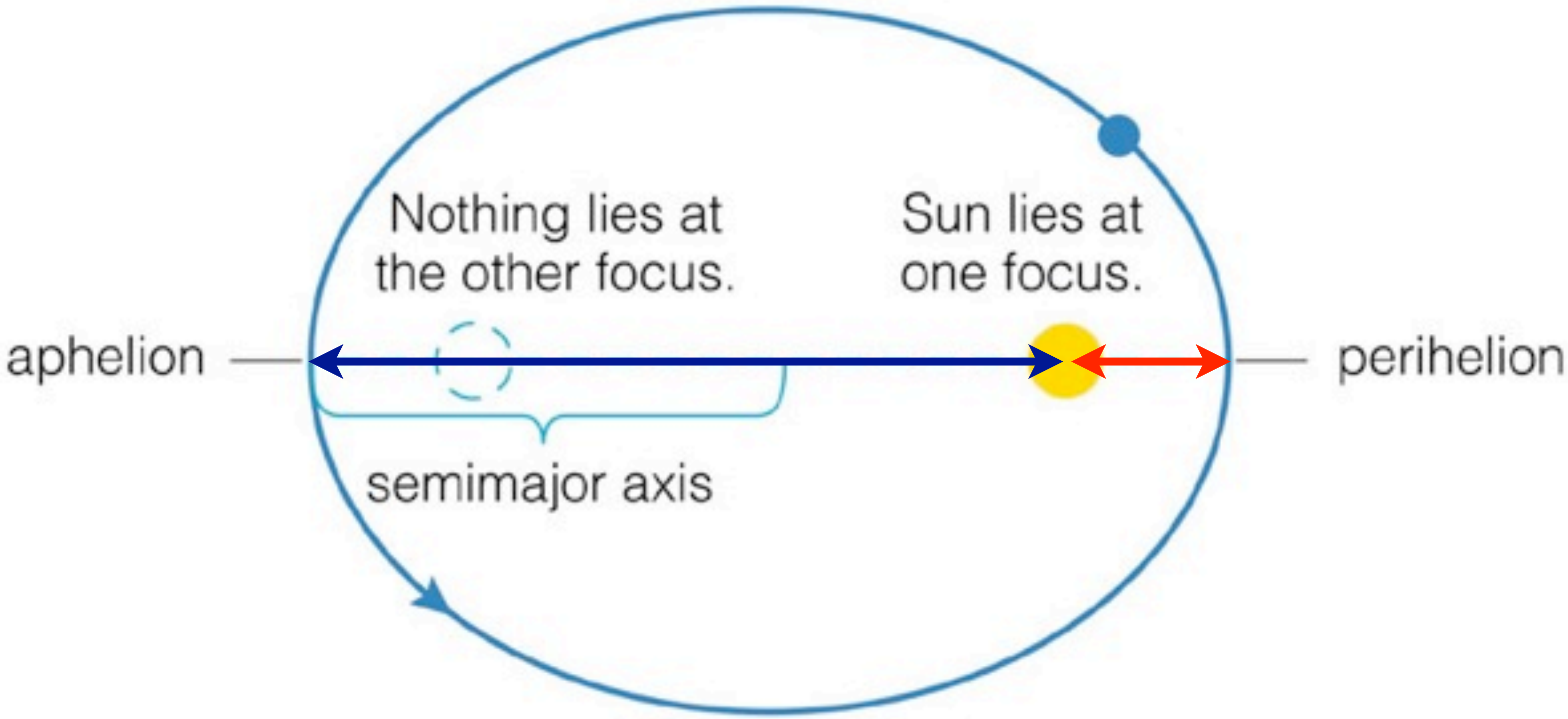


Motion Around Sun: Extremes

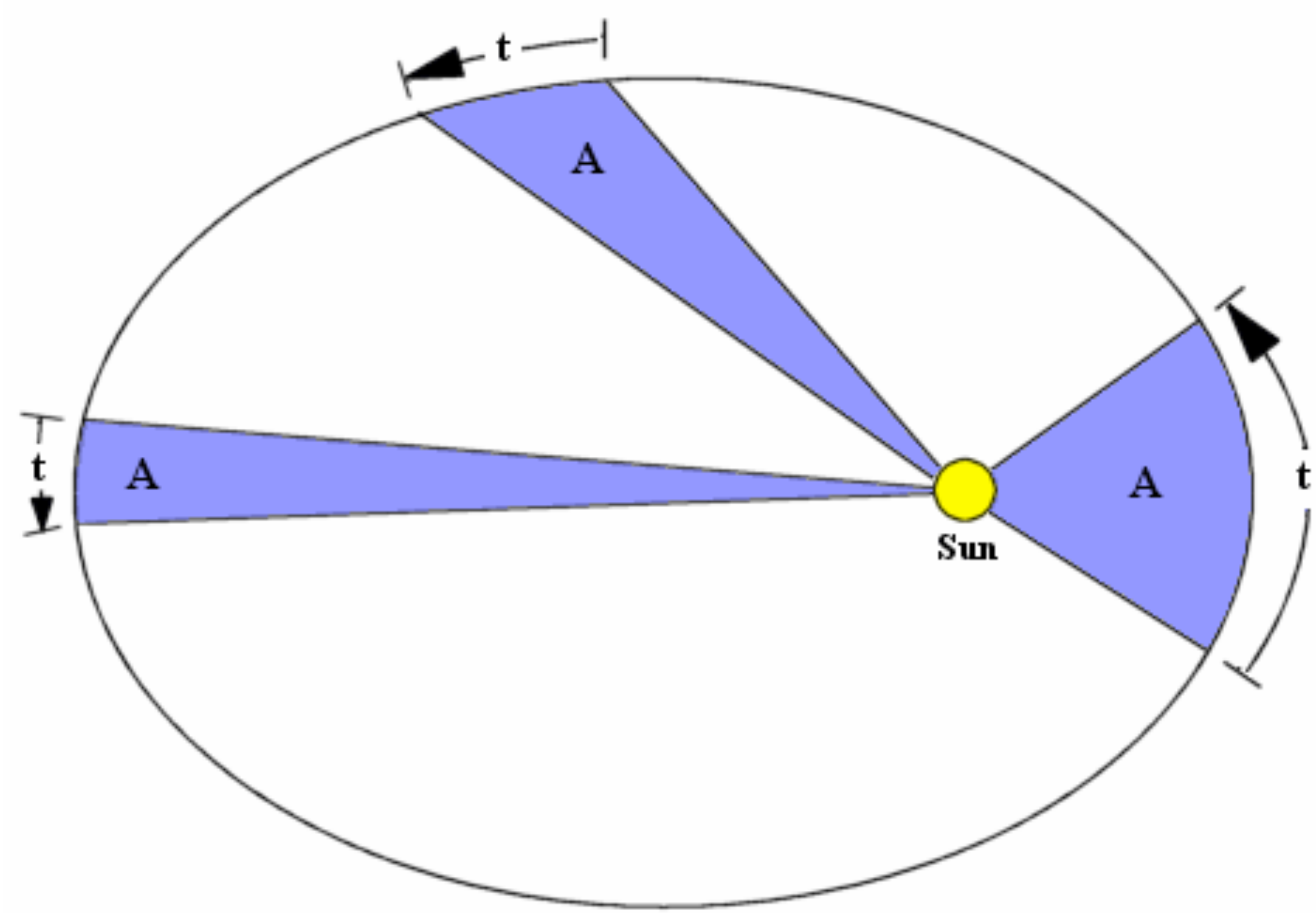
Ellipse orbit: changing distance from Sun

A. Point closest to Sun: "perihelion"
   - distance $d_{\text{closest}} = (1 - e)a$

B. Point farthest from Sun: "aphelion"
   - distance $d_{\text{farthest}} = (1 + e)a$

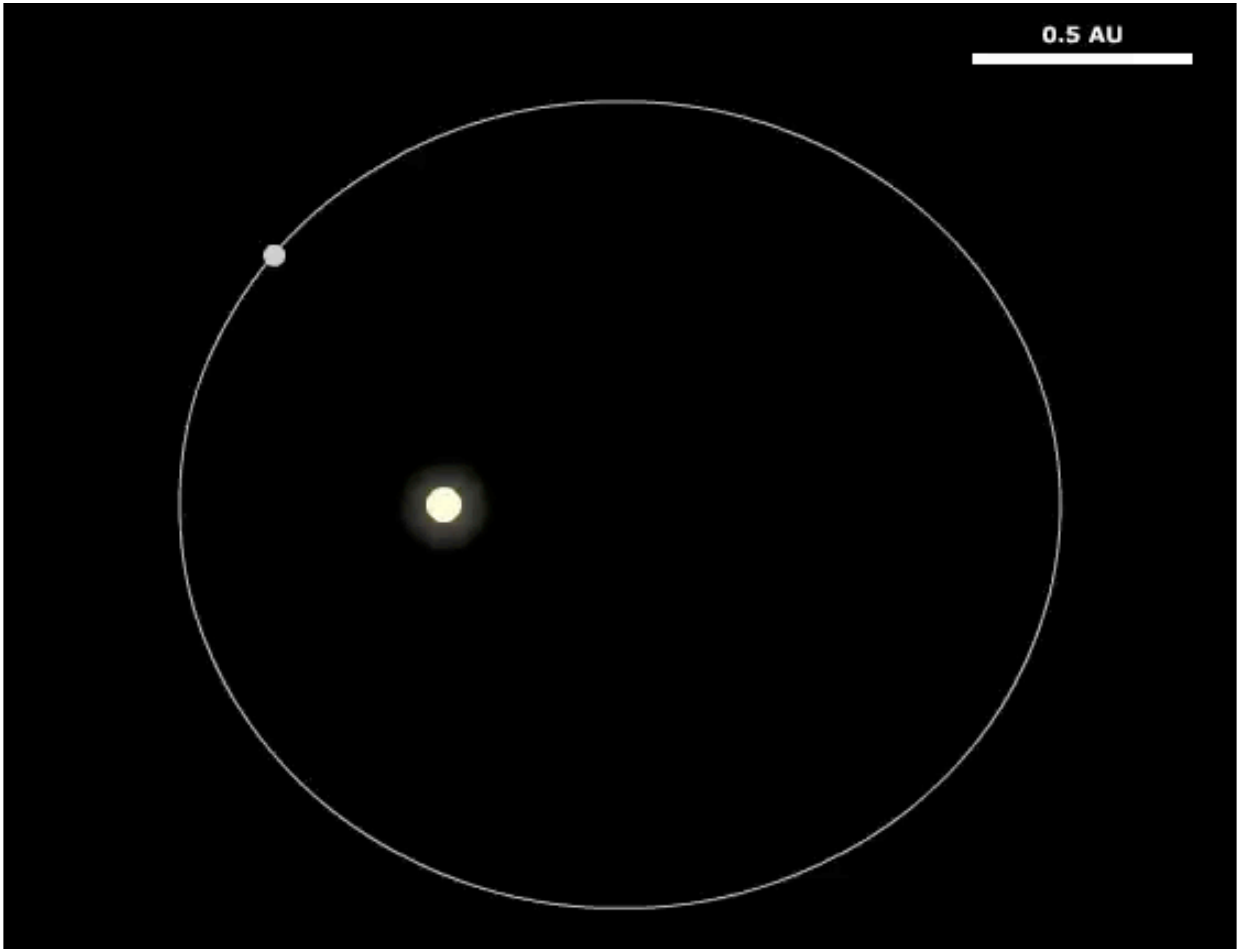


- **Law #2:** An line joining the Sun and planet sweeps out *equal areas in equal times*



A planet in orbit about the Sun sweeps out equal areas **A** in the same time interval **t**

- **Law #2:** An line joining the Sun and planet sweeps out *equal areas in equal times*



Kepler's Laws of Planetary Motion

Law #3: The square of a planet's orbital period around the Sun is directly proportional to the cube of the semi-major axis of its orbit

$$P^2 = a^3$$

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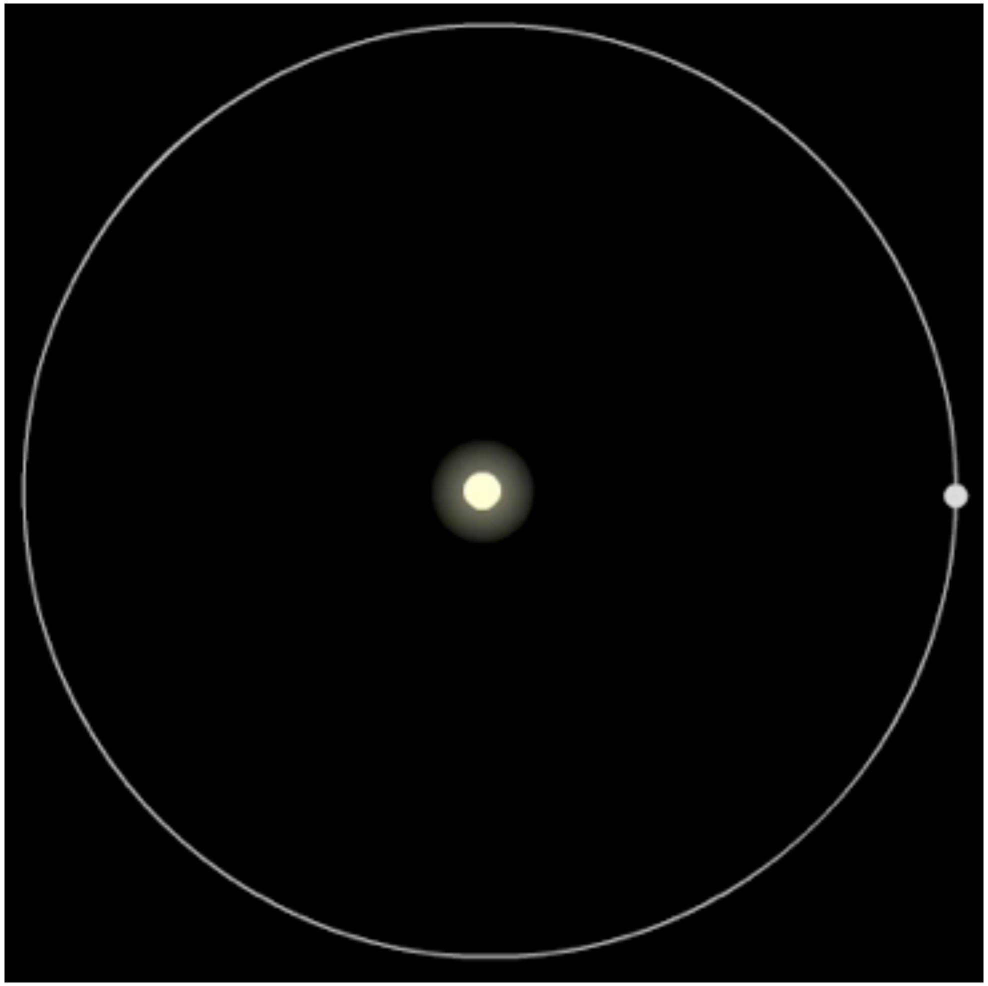
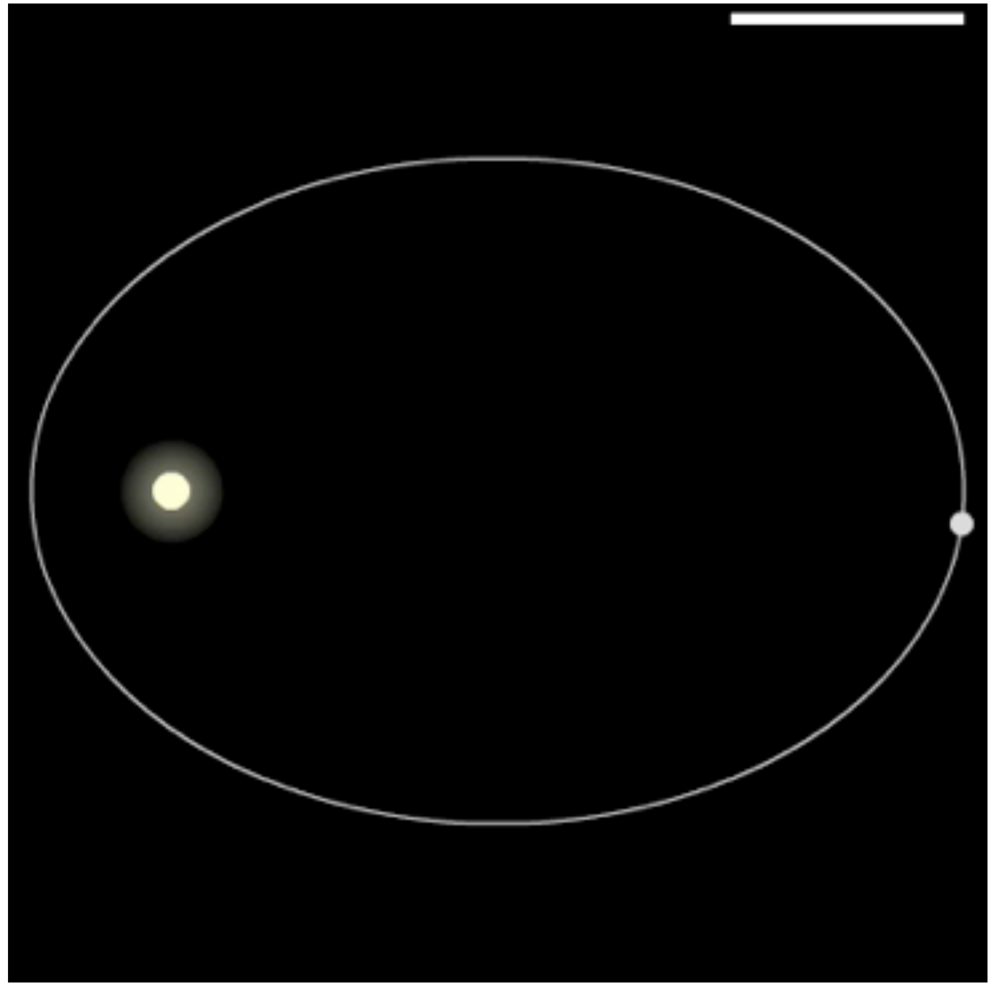
Orbital period (in years)

Orbit semi-major axis (in Astronomical Units)

Average distance from Earth to the Sun = 1 Astronomical Unit (AU)

Kepler's 3rd Law works for orbits of any eccentricity!

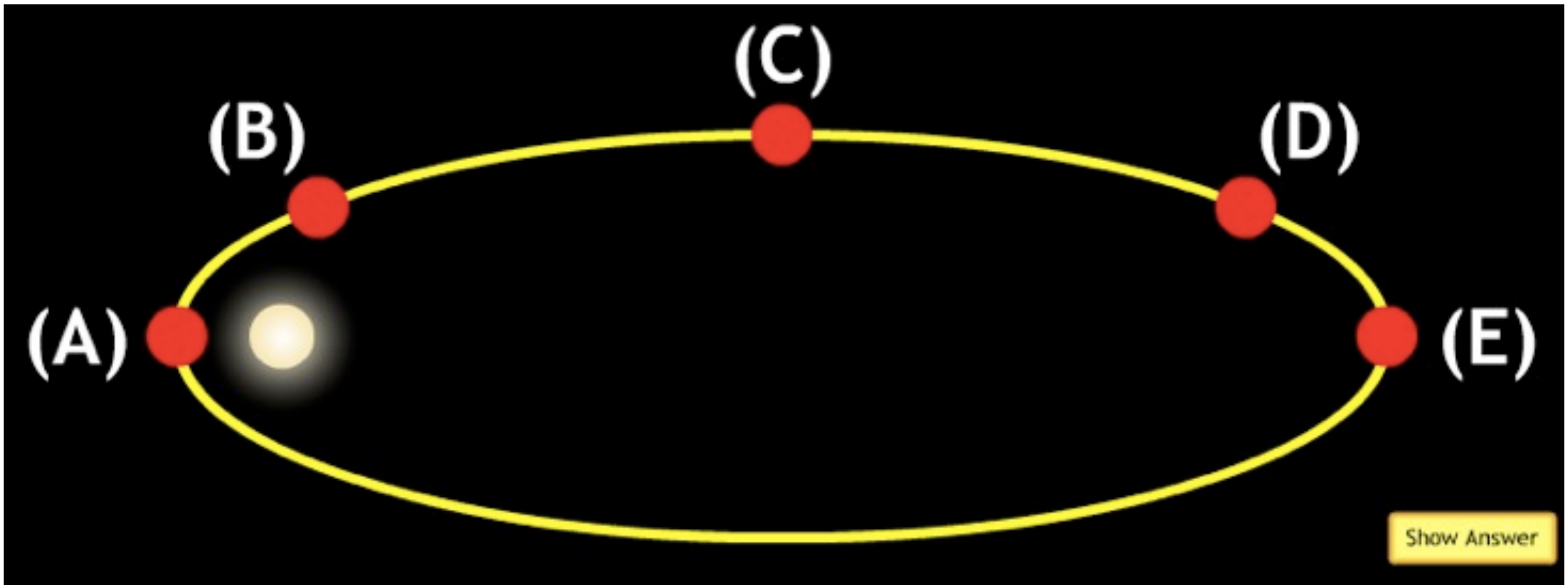




Both objects have orbits with a semi-major axis (a) of 1 AU, so both have a period (P) of 1 year

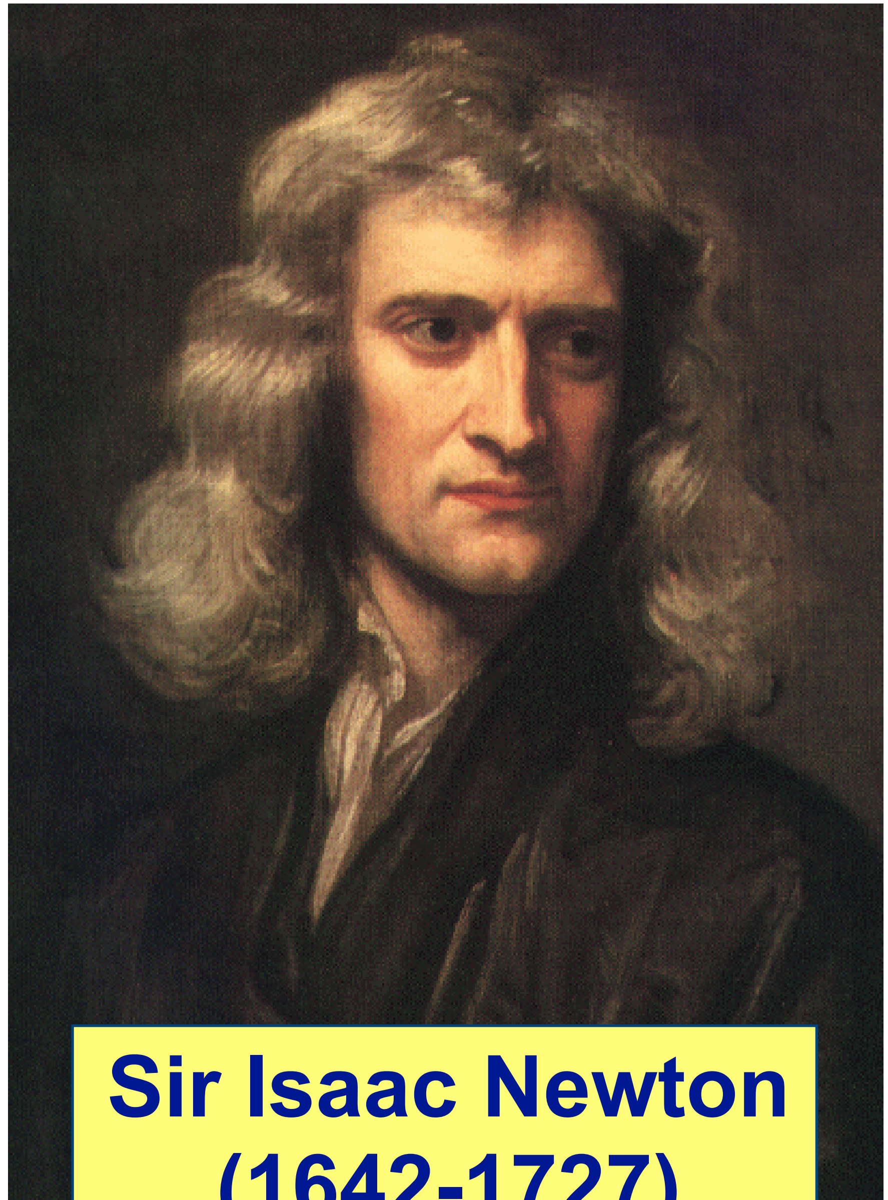
i>Clicker Question

The orbit of a comet is shown below. At which point in the orbit would the comet's speed be smallest?



<u>Why</u> do the planets move they way they do?

- Newton's answer: GRAVITY
- He developed some basic rules governing the motion of all objects
- Used these laws and Kepler's Laws to derive his unifying Law of Gravity



Sir Isaac Newton (1642-1727)

Describing Movement

need precise language not just for planets but for all moving objects

Speed: rate of motion

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

mathematically: $v = d/t$

so: $d = vt$ distance travelled = speed x travel time

Fine print: valid when speed constant = not changing

Velocity: speed and direction of travel

example:

- **if 10 mi East in 1/2 hr, then velocity = 10/(0.5) = 20 mph East**

Q: can two objects have same speed, different velocity?

Q: does a car's "speedometer" really measure speed or velocity?

Acceleration

Acceleration:

change in speed or direction of motion

but velocity is speed and direction, so acceleration is change in velocity

intuitively: acceleration is rate of speeding up or slowing down

sometimes useful to distinguish

- acceleration=speed up
- deceleration=slow down

Motion: Special Cases

Galileo Galile

Special Motion I: "Free Body"

moving with no external influences

(including friction, gravity)

free body moves in

- straight line,
- with constant speed
- = constant velocity

Galileo: this is "natural motion" of objects

keep speed and direction unless something happens to change this

Motion: Special Cases

Special Motion II: "Free Fall"

motion due to gravity only

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Demo: Tower of Pisa Experiment

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even if fall in straight line, speed changes

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- same acceleration for all objects
  independent of size, mass
- Einstein called this independence the "equivalence principle", crucial for his General theory of Relativity

Explaining Motion: Isaac Newton

Newton:

- why Kepler's laws for planets?
  - Are planets special?

Can we understand general rules for motion?

New concepts

- mass = "amount of stuff"
  - measure in kilograms (kg): 1kg of anything has same mass
- force = push or pull on an object
  - can have more than one force acting, in different directions
- net force = total of all forces acting
  - if forces unbalanced, net force is present

Explaining Motion: Newton's Laws

forces & motion linked

Newton I. "Inertia"

What if no forces act?

- an object at rest stays at rest if no forces act on it
- a moving object goes in straight line with constant speed if no forces act on it
  - that is, constant velocity

Newton I describes free bodies

Explaining Motion: Newton's Laws

Newton II. "F=ma"

What if a force does act?

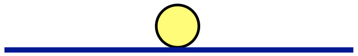
- a net force on an object causes it to accelerate
- $a \propto F$: more force, more acceleration

  $\propto$ = "is proportional to"
- $a \propto \frac{1}{m}$: more massive objects harder to accelerate
- so $a = F/m$ or

  $$F = ma \qquad \text{Force} = \text{mass} \times \text{acceleration}$$

Newton II: F=ma

Example: ball on table, at rest



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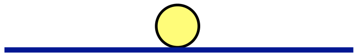

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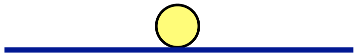

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  - (test: yank table away, ball falls)

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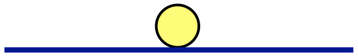

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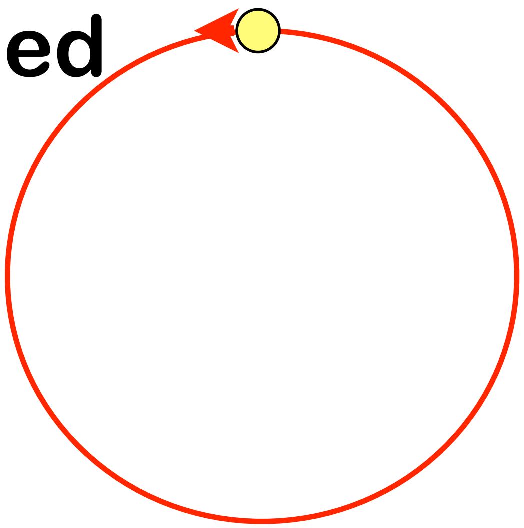

- changing direction: changing velocity

Newton II: F=ma

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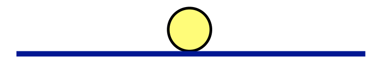

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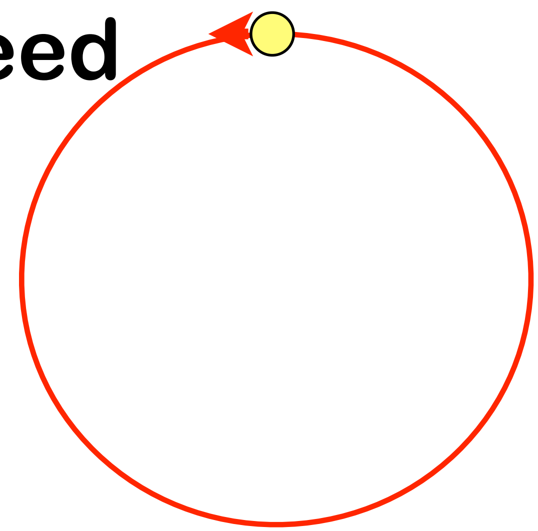
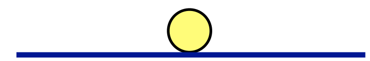


- changing direction: changing velocity
- must be acceleration

Newton II: F=ma



Example: **ball on table, at rest**

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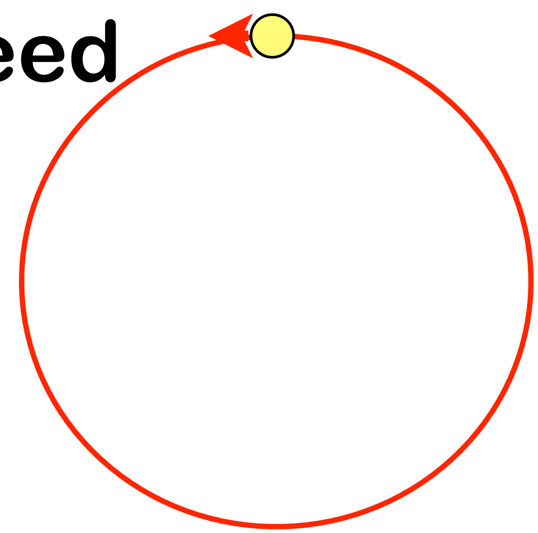

Example: **move in circle, constant speed**

- **changing direction: changing velocity**
- **must be acceleration**
- **must be force**

Explaining Motion: Newton's Laws

Newton III. "Action/Reaction"

a rule for how forces behave between objects

if 2 bodies interact

- the force exerted by object 2 on object 1 is equal to but opposite in direction to
- the force exerted by object 1 on object 2

Example: you standing still

- your force on floor (weight) downward is
- same as floor push upwards on you

Example: Jump shot

i>Clicker Question

A boy is spinning a rock tied to a rope horizontally above his head. In which direction will the rock go if the string breaks?

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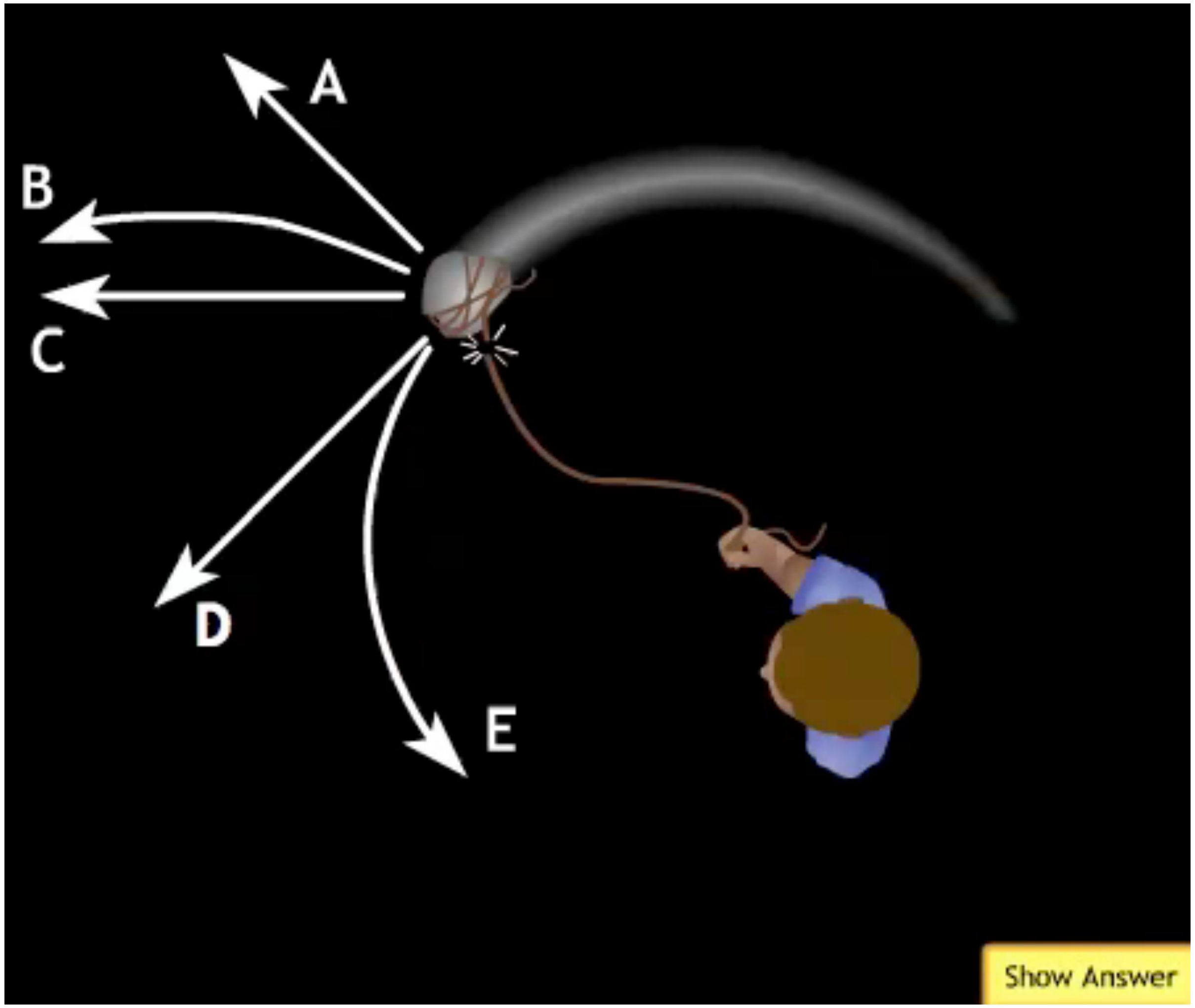
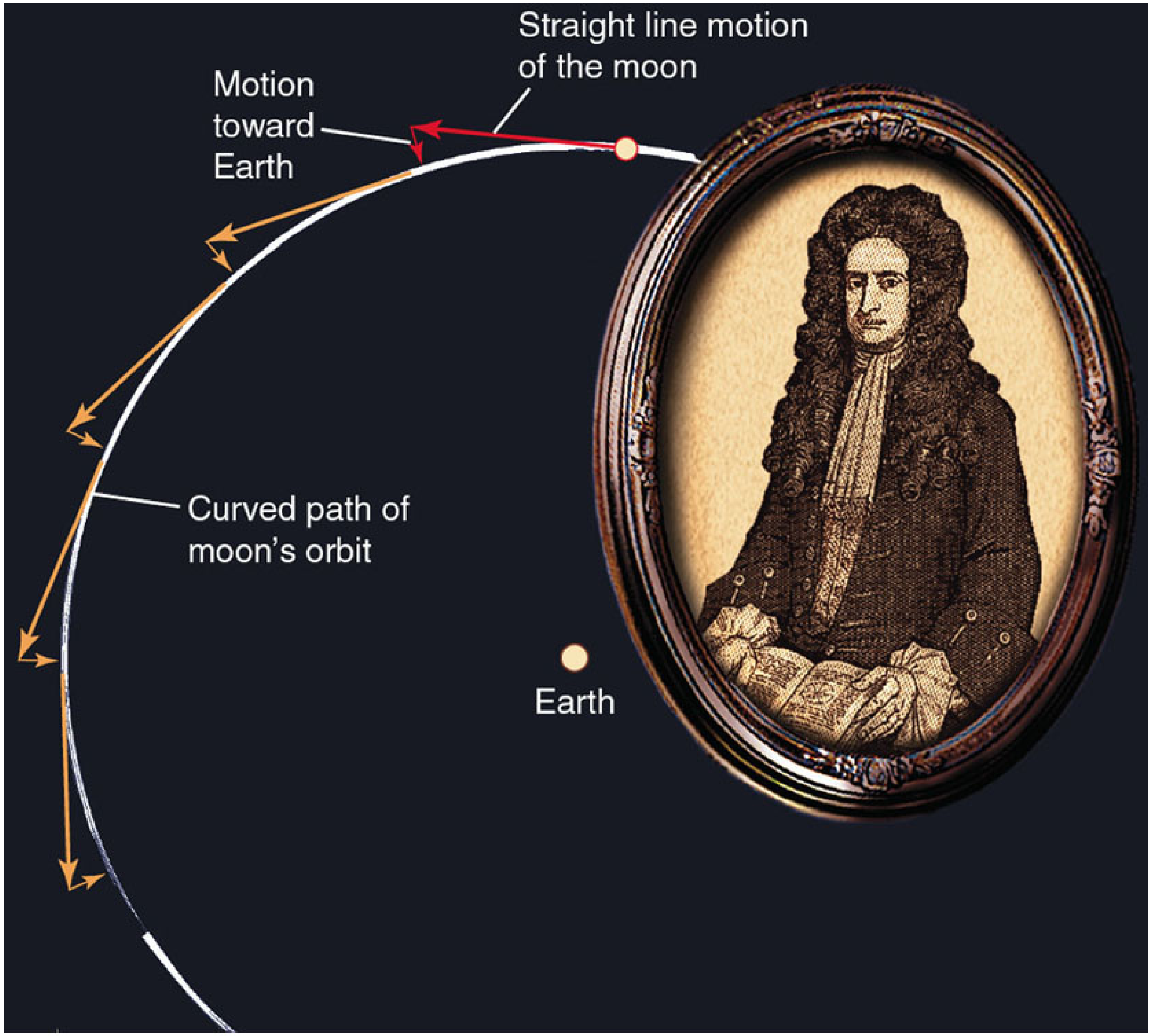


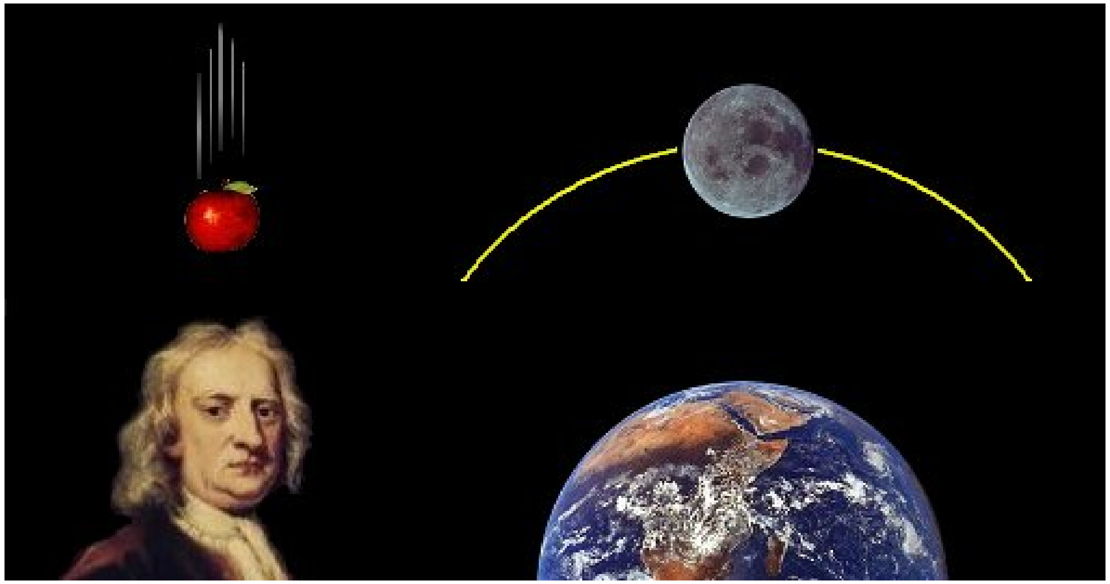
A force must pull the Moon toward Earth's center

If there were no force acting on the Moon, it should follow a straight line and leave Earth



Newton's Great Insight

- The same force makes things fall down on Earth and keeps the planets in their orbits
- GRAVITY
- Newtonian gravitation is sometimes called universal mutual gravitation



Gravity makes apples fall from trees and keeps the Moon orbiting the Earth

Universal Gravitataion

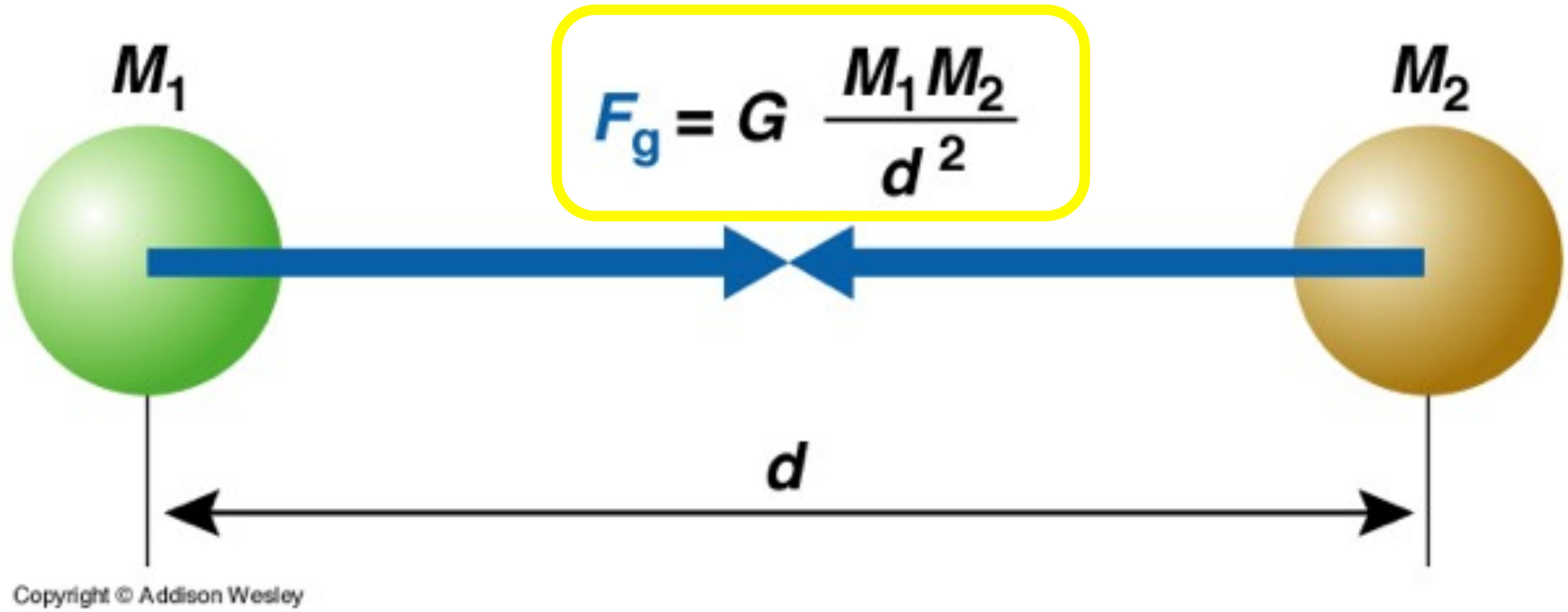
Newton's law of gravity combines these ideas

- gravity acts beyond the Earth
  "reaches out" into space
- gravity directed on line connecting centers of bodies
- gravity strength decreases with distance
- all objects with mass are sources of gravity
  everything attracts everything else in the universe!

Universal Gravitation Law

Summarize gravity properties in compact way

- for two masses separated by distance d
- gravity force proportional to the product of their masses
- gravity force inversely proportional to the square of the distance between their centers
  - “inverse square law”
  - in equation, G is just a fixed number (grav. constant)



iClicker Poll: Inverse Square Law

The force of gravity on you is your weight.

If you go into space and double your distance from the center of the earth, your weight will be

A. 2 times stronger
B. 4 times stronger
C. 2 times weaker
D. 4 times weaker
E. your weight cannot change just by relocating

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Guaranteed weight loss: go to space!

Gravity and Planet Motion

Newton II: for planets, force is gravity only: free fall

So: find acceleration when

$$F = F_{\rm grav} = G\frac{m_{\rm planet} m_{\rm sun}}{d^2}$$

acceleration gives change in velocity

- ...which tells where move to next
- ...where there is a new acceleration
- and so forth: Newton II + gravity force predicts orbit

What is prediction?

- orbits are ellipses, with Sun at one focus
- equal areas in equal times

$$P^2_{\rm in\,years} = a^3_{\rm inAU}$$

So: Newton's laws + gravity gives Kepler's laws

theory agrees with observation! Woo hoo!

Testing Newton's Gravity

Moons of Jupiter: orbits obey Kepler's laws

- Jupiter gravity works like Sun's, Earth's

1830's: Uranus observed orbit did not follow predictions of Newtonian solar system model

- the death of Newton's gravity?

First rule of Science: theory must agree with all data, not just some

- even one clear failure enough to kill theory

maybe...but also: maybe have not included all soruces of gravity

- maybe unknown objects causes Uranus devitaions
- a new planet?

iClicker Poll: Uranus Discrepancy

1830's problem: measured Uranus orbit doesn't match predictions of Newtonian Gravity theory

Vote your conscience!

Which seems more likely to you?

A. Newton's gravity theory correct, but not all gravity sources included
B. Newton's gravity theory incorrect (or at least incomplete)

iClicker Poll:
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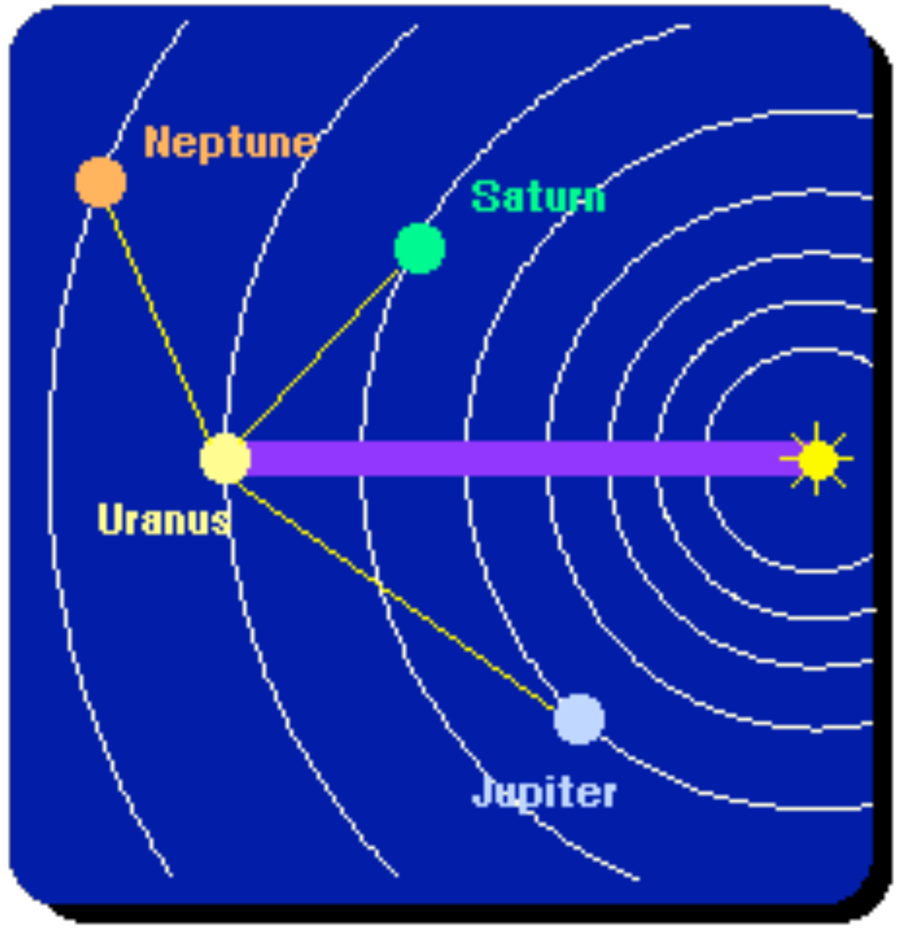
Q: What experiment/observation would tell which is right?

Neptune was discovered due to its perturbations on

- Astronomers noted discrepancies between Uranus' orbit and calculations
- Predicted the position of an unknown planet based on its gravity perturbations
- Neptune was found at almost exactly the predicted location!
- Existence of Neptune predicted by Newton's laws!



Uranus' orbit is *perturbed* by the other planets