AST 2002
Introduction to Astronomy
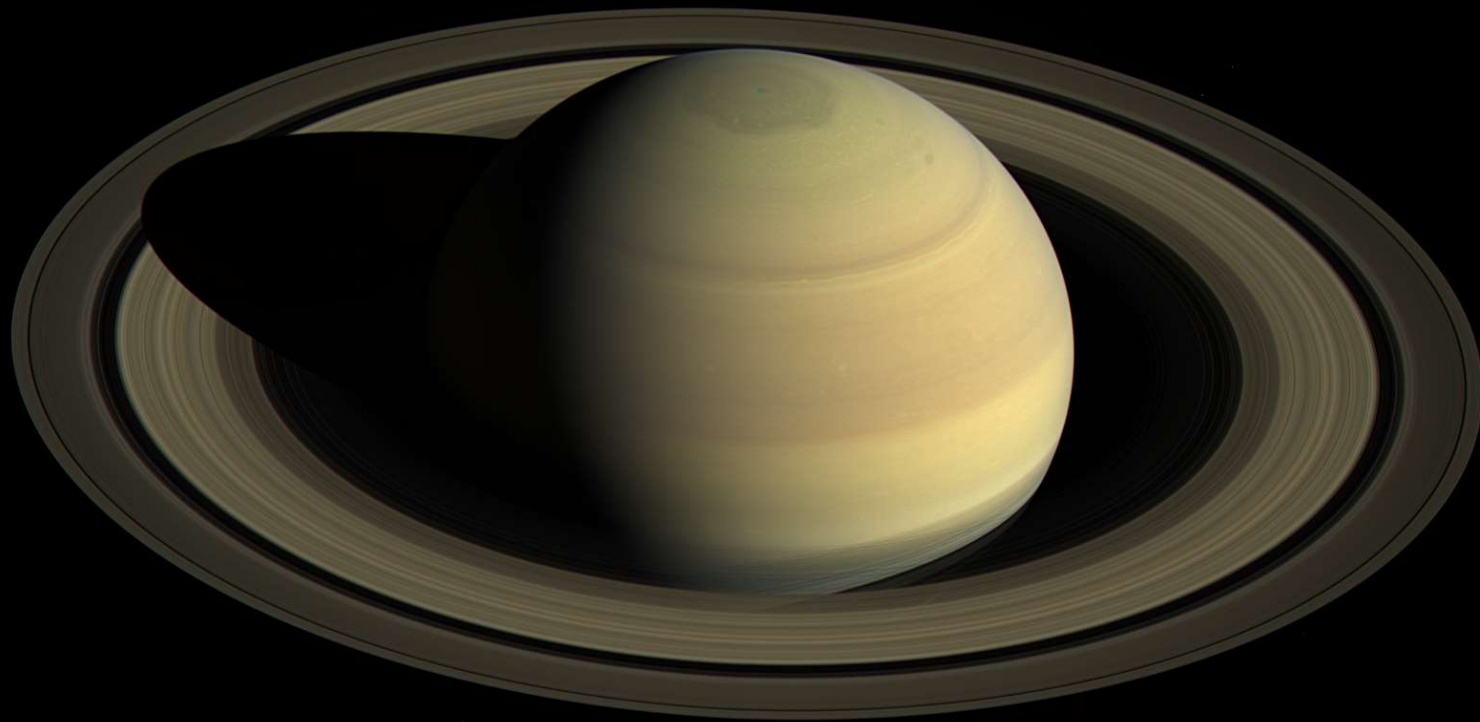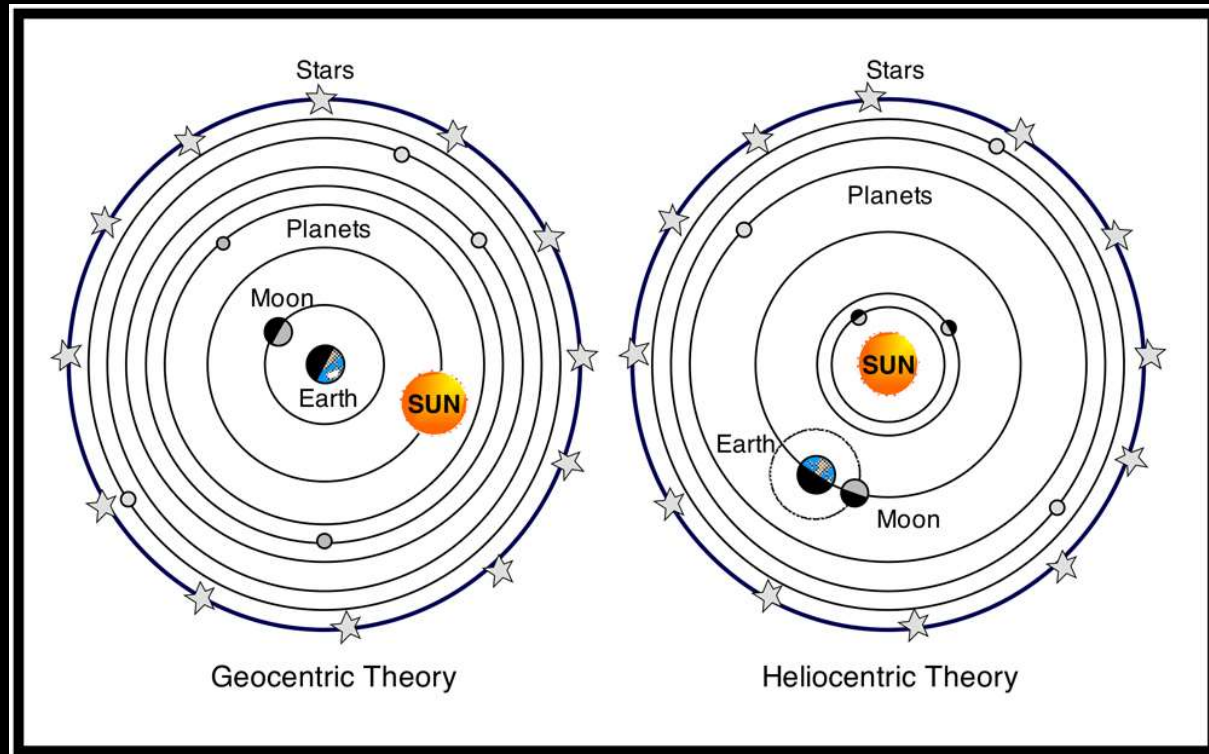
Geocentric Theory

Heliocentric Theory

In the Greek Geocentric model, the retrograde motion of a planet occurs when:

A: Earth is about to pass the planet in its orbit around the Sun.
B: The planet actually goes backwards in its orbit around the Earth.
C: The planet is aligned with the Moon in our sky.

Epicenters

Heliocentric Theory

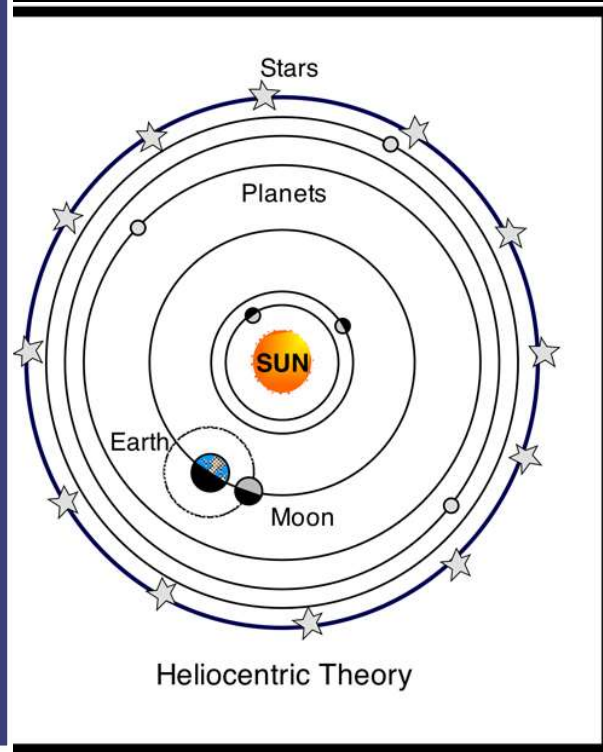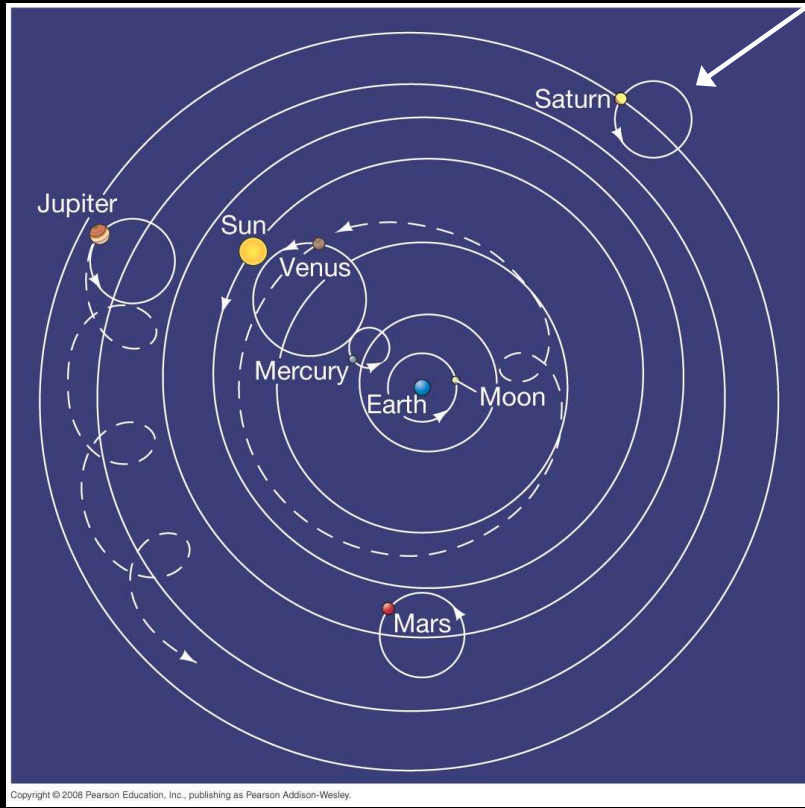Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

In the Greek Geocentric model, the retrograde motion of a planet occurs when:

A: Earth is about to pass the planet in its orbit around the Sun.
B: The planet actually goes backwards in its orbit around the Earth.
C: The planet is aligned with the Moon in our sky.

Claudius Ptolemy (AD 100-170): The Ptolemaic geocentric version of the solar system had been accepted for over 1500 years, with a system based on circles moving within circles (epicenters) to explain retrograde motion…

The Beginning of the Scientific Revolution:

Nicolaus Copernicus (1473-1543): Published new heliocentric model of the solar system which explained retrograde motion, but ultimately still required epicenters… *not yet very useful.*
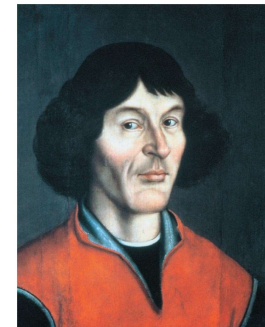
Tycho Brahe (1546 – 1601): Made extremely accurate and comprehensive astronomical observations of the positions of stars and planets, typically >5 times as accurate as other available observations of the time.

Johannes Kepler (1571 – 1630): Initially an assistant to Tycho Brahe, he was an avid astrologer and astronomer (there was little distinction at the time). Developed new model and 3 laws for planetary motion based on Ellipses rather than circles.

Kepler's 1st Law:
Bodies in orbit follow Elliptical paths

The orbit of each planet around the Sun is an ***ellipse*** with the Sun at one focus. An ellipse looks like an elongated circle...

Sun lies at one focus.

Nothing lies at this focus.

perihelion
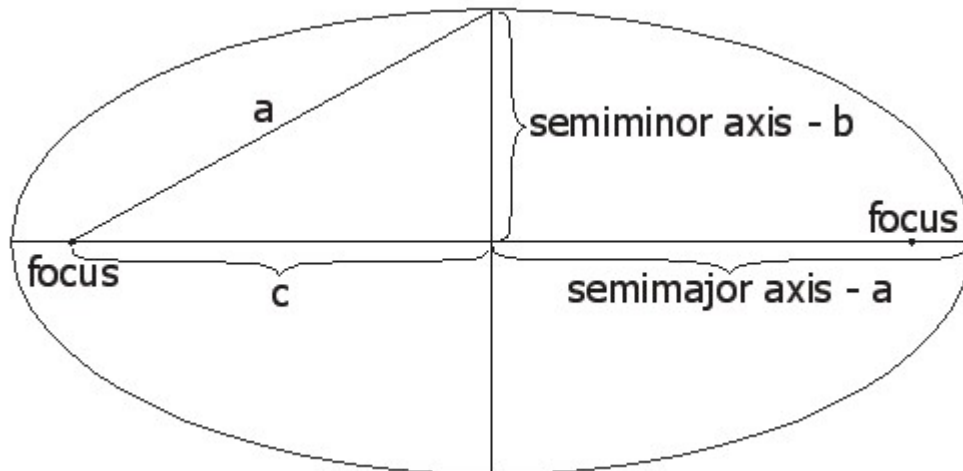
aphelion
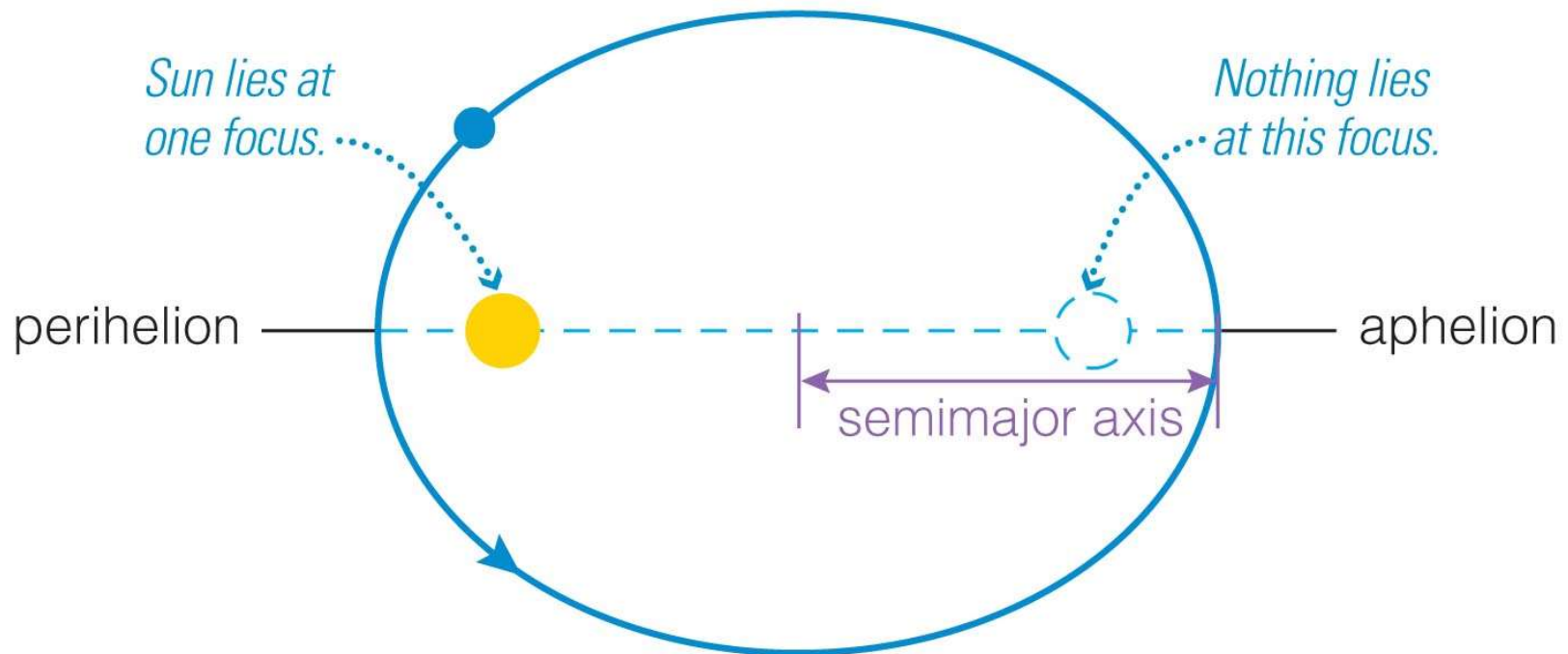
semimajor axis

What is an ellipse?

The size of the ellipse is defined by the Semi-major axis, a.

The distance to the focus points is given as c (always a proportion of a)

The *eccentricity*, e, is defined as $e = \frac{c}{a}$ (or, equivalently, $c = a \times e$)
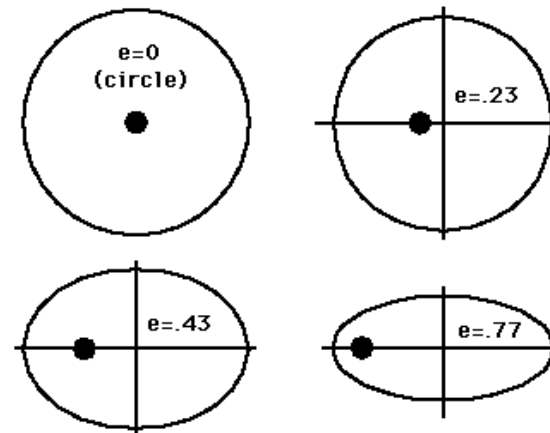
- *Eccentricity values must lie between 0 (perfect circle) and 1.*

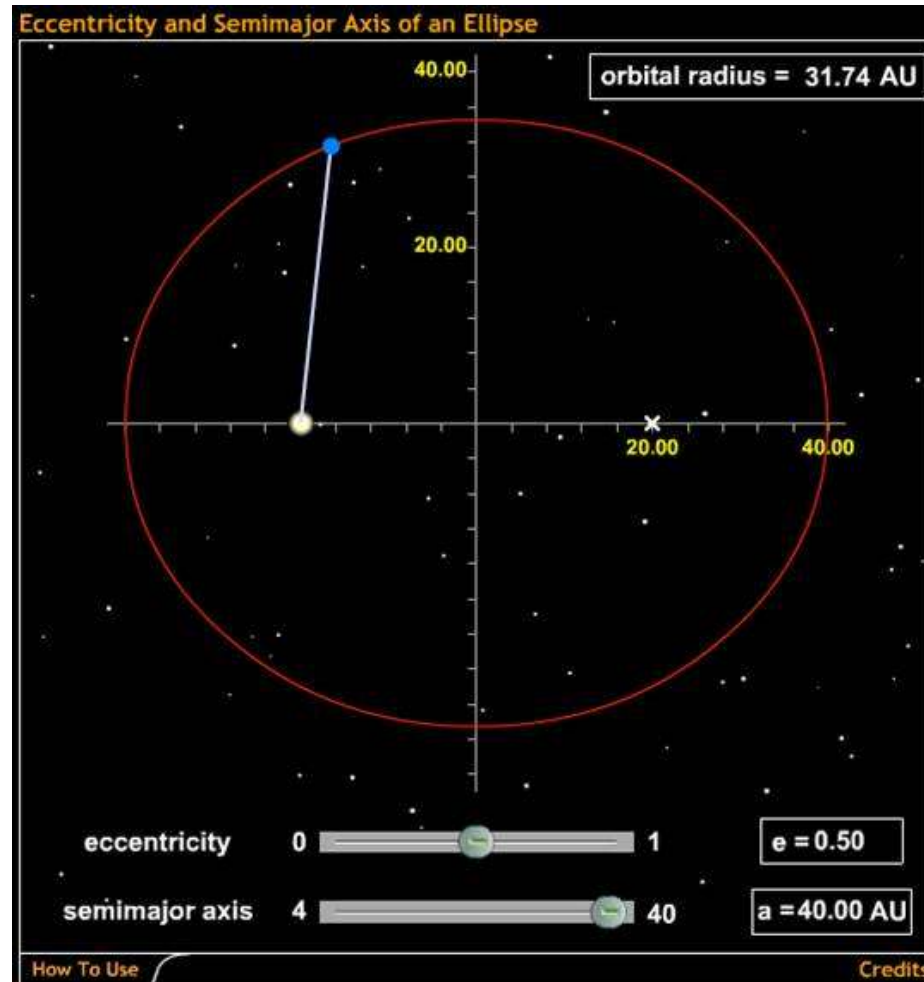There is also a *semi-minor axis*, b. They can be related by: $b^2 = a^2(1 - e^2)$

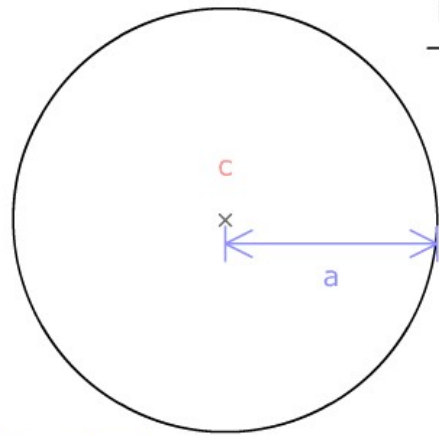In the case of a circle, the two foci lie on top of each other. $c = 0$, therefore $e = 0$
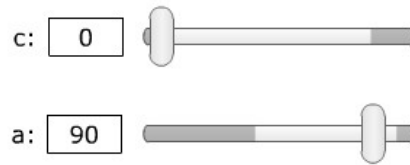
Eccentricity of an Ellipse - Demo

PLAY   Eccentricity and Semimajor Axis of an Ellipse

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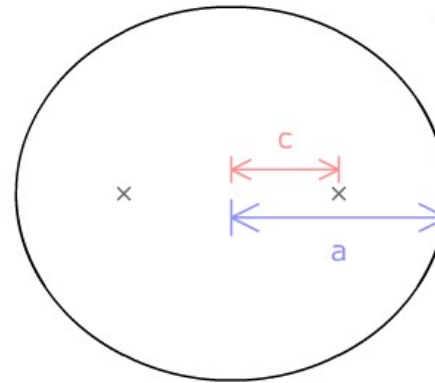
Examples of Ellipses

Eccentricity Demonstrator

$$e = \frac{c}{a} = \frac{0}{90} = 0.000$$

c: 0

a: 90

astro.unl.edu

Eccentricity Demonstrator
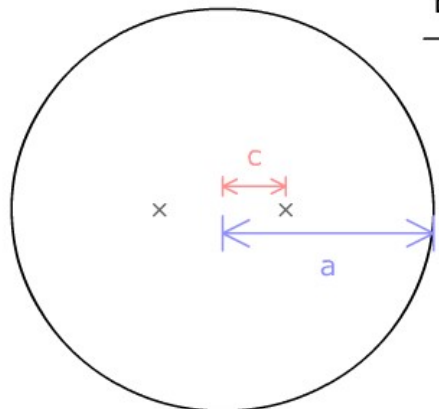
$$e = \frac{c}{a} = \frac{45}{90} = 0.500$$

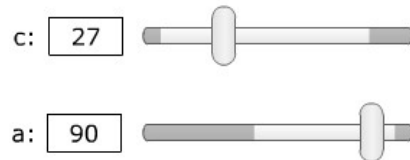c: 45

a: 90
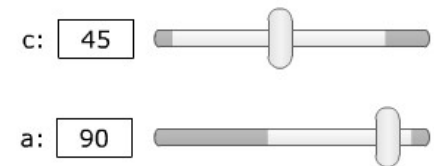
astro.unl.edu

Eccentricity Demonstrator

$$e = \frac{c}{a} = \frac{27}{90} = 0.300$$

c: 27

a: 90

astro.unl.edu

Eccentricity Demonstrator

$$e = \frac{c}{a} = \frac{80}{90} = 0.889$$

c: 80

a: 90
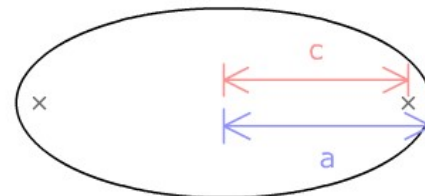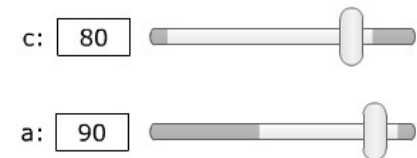
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Perihelion: The closet an object will come to the Sun
$$R_p = a(1 - e)$$
Aphelion: The furthest an object will be from the Sun
$$R_a = a(1 + e)$$
The longest length is *twice* the semi-major axis, $2a$

Important:
The *Semi-major axis* is also equal to the average distance from a focus to points on the ellipse.

Could just assume an average: $a = \dfrac{R_p + R_a}{2}$

Kepler's 2nd Law:
As a planet moves around its orbit, it sweeps out equal areas in equal times

Near perihelion, in any particular amount of time (such as 30 days) a planet sweeps out an area that is short but wide.
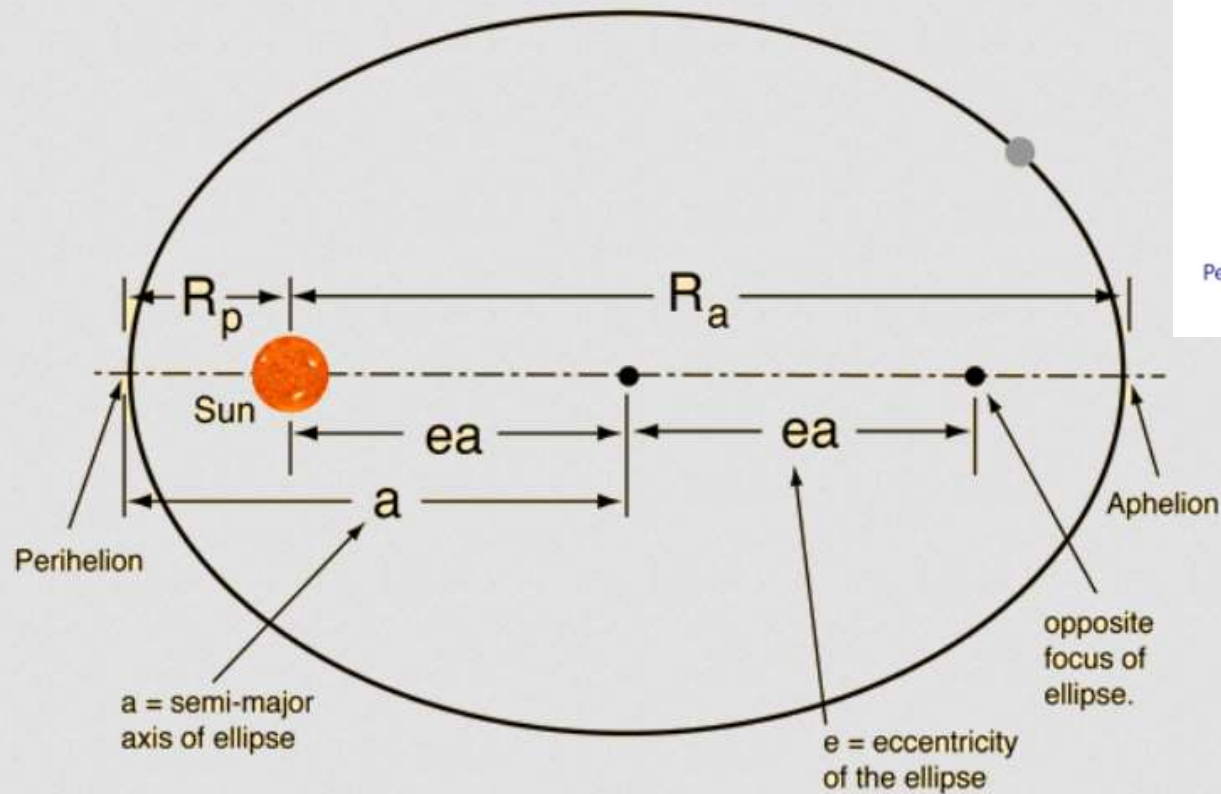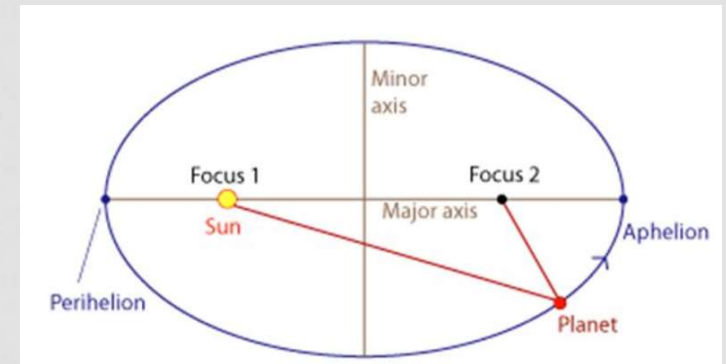
Near aphelion, in the same amount of time a planet sweeps out an area that is long but narrow.

perihelion

aphelion
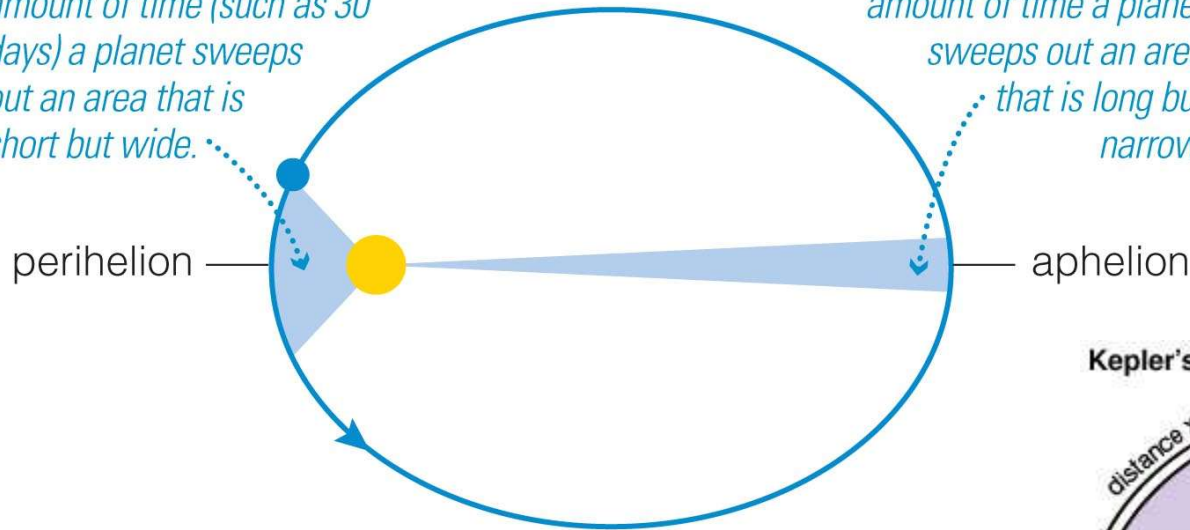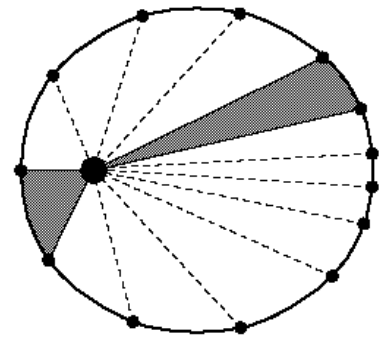
The areas swept out in 30-day periods are all equal.

Kepler's Second Law

distance x

area x

planet's orbit around sun

Planet moves distance x and distance y in same amount of time. Area x equals area y. Planet moves fastest when nearest the sun.

aphelion

sun

perihelion

area y

distance y

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Time to travel distance x = time to travel distance y
Area x = Area y
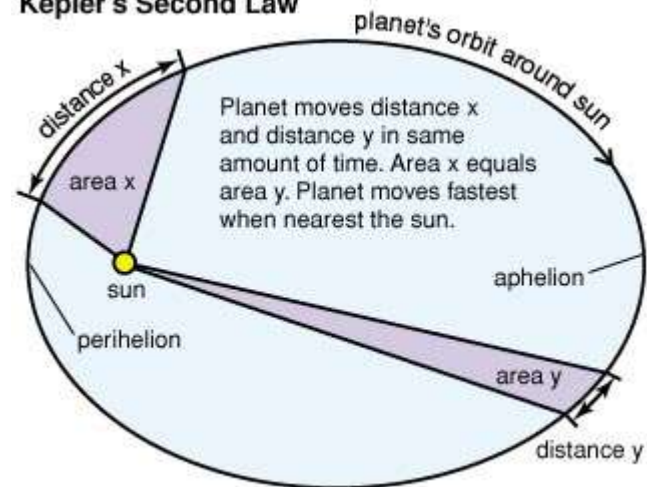
Consequences of Kepler's 2nd law:
Orbital Speed Varies
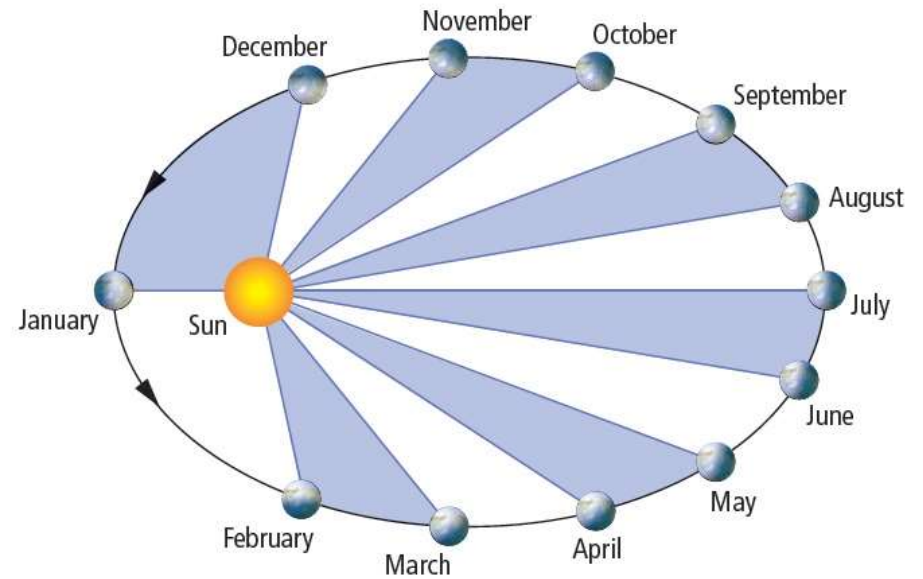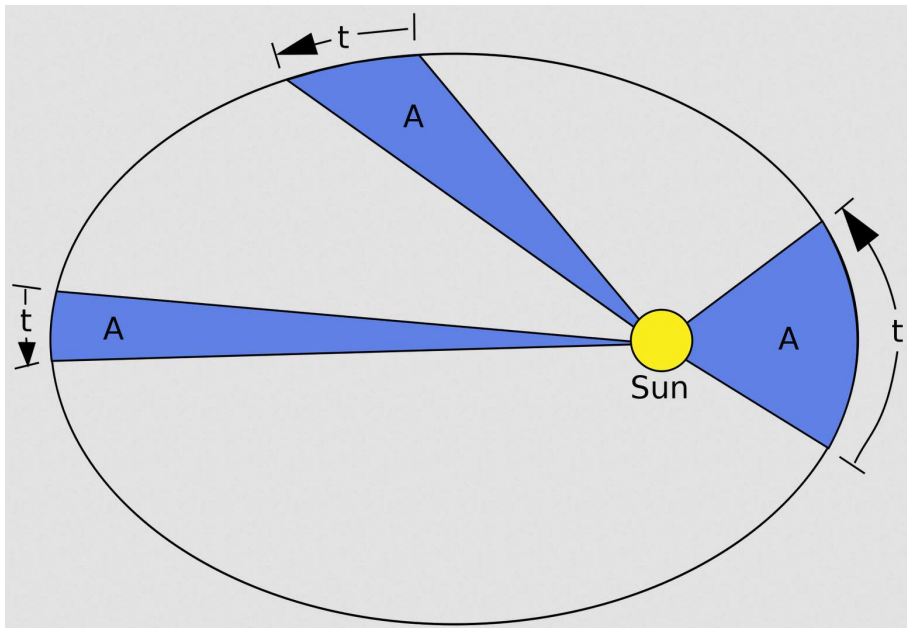
This means that a planet travels:
- faster when it is nearer to the Sun (at perihelion)
- slower when it is farther from the Sun (at aphelion)
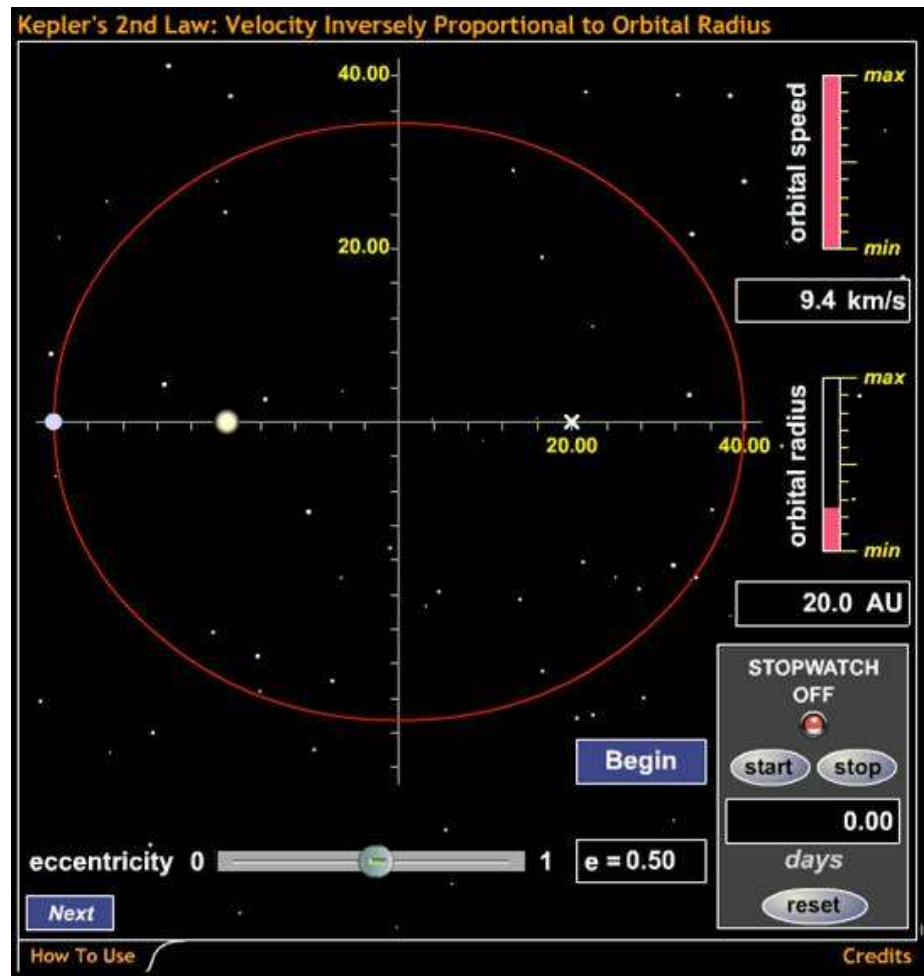
PLAY Kepler's 2nd Law

iClicker Question

At what time of the year is Earth moving fastest in its orbit?

A. January

B. March

C. July

D. November

iClicker Question

At what time of the year is Earth moving fastest in its orbit?

A. **January**

B. March

C. July

D. November

Remember: The Earth is actually closer to the Sun in January rather than July, our seasons are caused by the Earth's tilt.

Kepler's 3rd Law:

More distant planets orbit the Sun at slower average speeds, according to $p^2 = a^3$

Where p = orbital period, in years, a = the average distance from the Sun, in AU

In words: *"The square of the orbital period of a planet (in years) is directly proportional to the cube of the semi-major axis of its orbit (in AU)."*

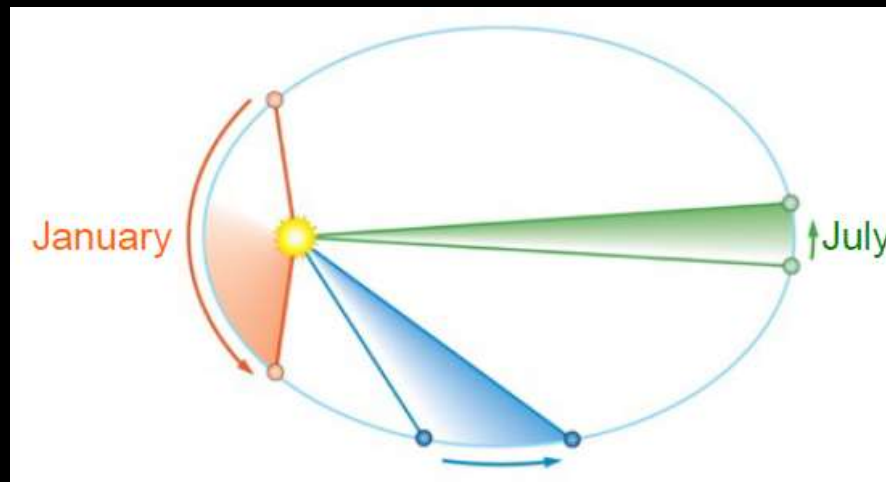When it comes to the Earth, the ratio between its fastest speed and slowest speed reduces to 16/15, which is the same ratio between the notes *fa* and *mi*. Needless to say, Kepler thought this was fantastically important:

*"The Earth sings Mi, Fa, Mi: you may infer even from the syllables that in this our home **mi**sery and **fa**mine hold sway."*

Kepler's argument was religious. He said that since the *son* of God was at the center of the Christian faith, the *sun* ought to be at the center of the universe. Ergo, heliocentrism.

To read more about Kepler's own eccentricities see:
https://www.space.com/35772-copernicus-vs-catholic-church-real-story.html

Kepler's Third Law

Kepler's 3rd Law: Orbital Period vs. Orbital Radius

orbital velocity

max

min

26.65 km/s

orbital radius

max

min

2.50 AU

STOPWATCH
OFF
start   stop

Begin

0.00

days

0.000

years

reset

eccentricity 0   1   e = 0.50

semimajor 0.5   5   a = 5.00 AU
axis

How To Use   Credits
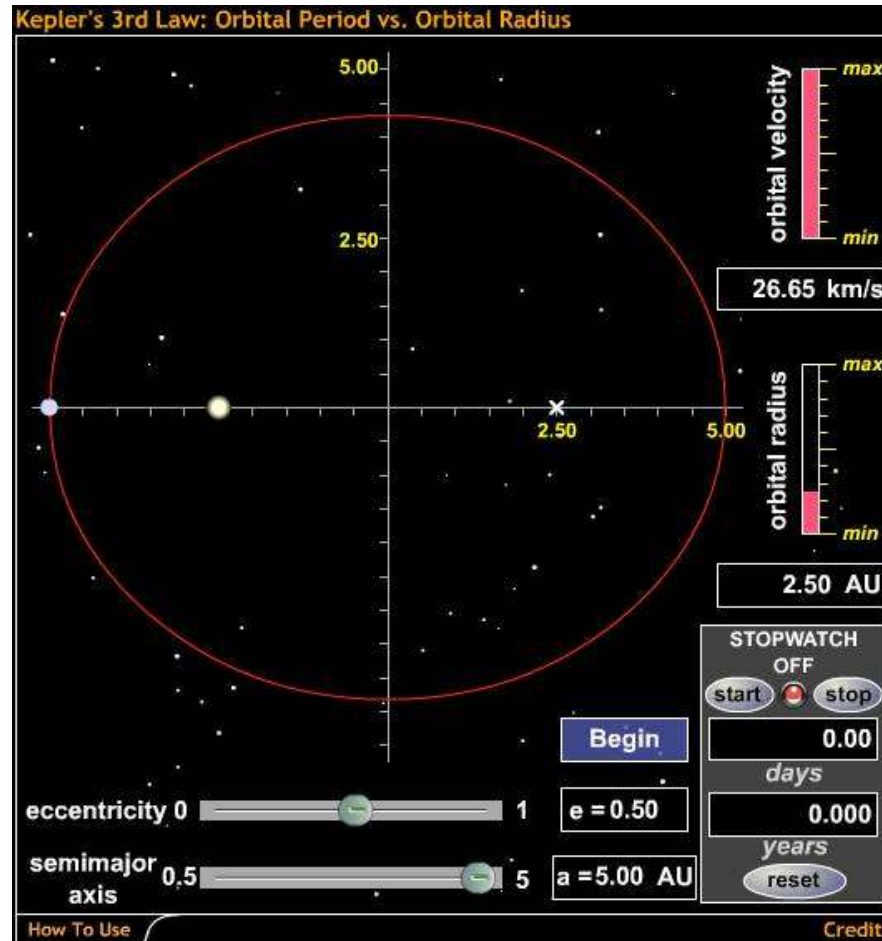
PLAY   Kepler's Third Law

Kepler's 3rd Law: Graphical version

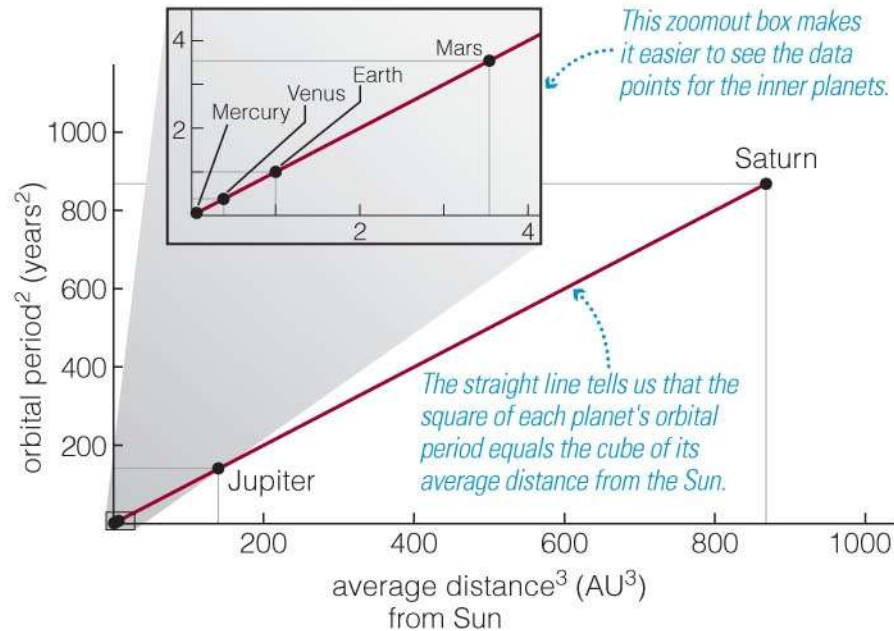**a** This graph shows that Kepler's third law ($p^2 = a^3$) holds true; the graph shows only the planets known in Kepler's time.
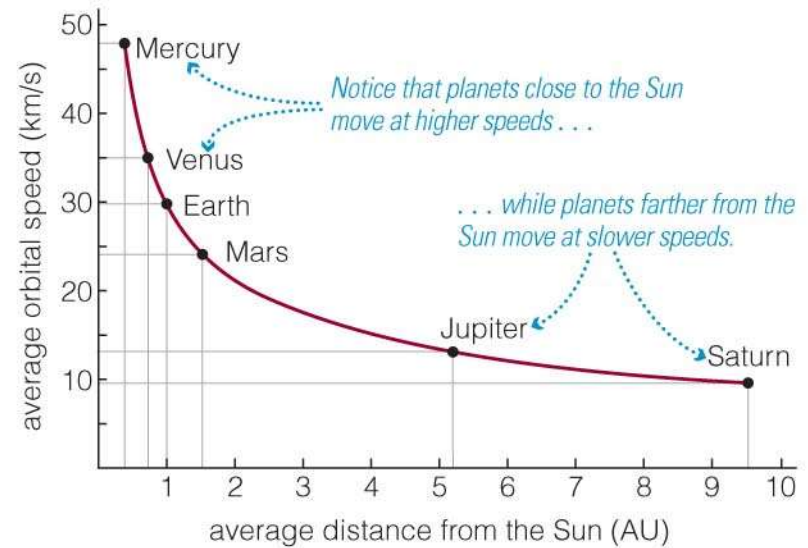
b This graph, based on Kepler's third law and modern values of planetary distances, shows that more distant planets orbit the Sun more slowly.

a planet's average speed, *v*, is 2π*a*/*p* (circumference of orbit divided by orbital period)

If $p^2 = a^3$ then $p = \sqrt{a^3} = a^{1.5}$

if we substitute this in for p, we get $v = \dfrac{2\pi}{a^{1.5}}$ therefore $v \propto a^{0.5}$ or $v \propto \dfrac{1}{\sqrt{a}}$

Thought Question (iClickers ready)

An asteroid orbits the Sun at an average distance a = 4 AU. How long does it take to orbit the Sun?

A. 4 years

B. 8 years

C. 16 years

D. 64 years

(Hint: Remember that $p^2 = a^3$.)

(*Even bigger hint: work out a^3 first*).

Thought Question (iClickers ready)

An asteroid orbits the Sun at an average distance a = 4 AU. How long does it take to orbit the Sun?

A. 4 years

B. 8 years

C. 16 years

D. 64 years

The beauty of Kepler's 3rd Law is that is allows a method for:
- **Determination of orbital period (in years) given average orbital distance, in AU**
- **Determination of orbital distance in AU, given orbital period (in years)**

(Hint: Remember that $p^2 = a^3$.)

(*Even bigger hint: work out a³ first*).

We need to find p so that $p^2 = a^3$.
Because $a = 4$, $a^3 = 4^3 = 64$.
Therefore, $p = 8$, $p^2 = 8^2 = 64$.

Galileo

- **Kepler nailed the mathematical description of planetary motion.**
- **But, his books were not very…. accessible**
  - **The combination of writing in Latin and using lots of math is not the way to get a best-seller.**
  - **However, if the Bishops can't understand it, they are unlikely to burn you….**
- **It was left to Galileo (1564-1642) to popularize the Copernican model and Kepler's laws.**
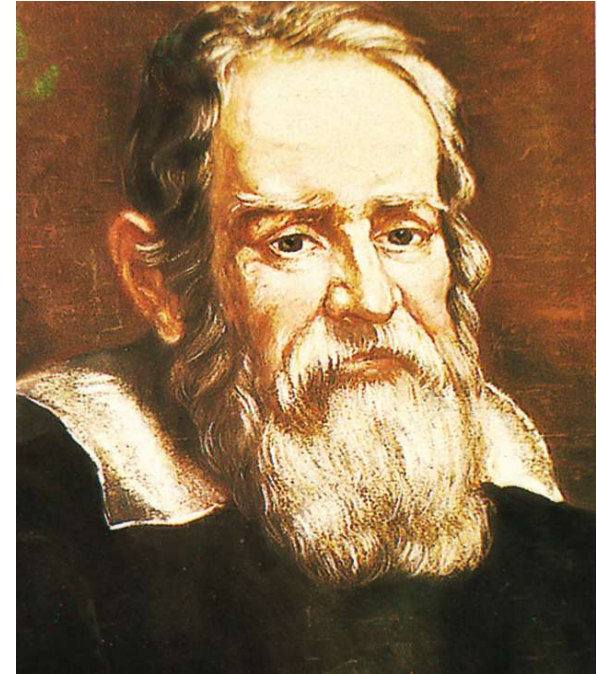
Galileo (cont.)

- **In addition to his observations Galileo wrote a book in Italian called "*Dialogue of the Two Chief World Systems*"**

  - **It featured a fictionalized debate between Copernican and Ptolemaic advocates**

  - **Released in 1632 in Italian so accessible to the general public and to the Church…**

- **In 1633, Galileo was found to be "vehemently suspect of heresy" based on the book, which was then placed on the Index of Forbidden Books, from which it was not removed until 1835**

- **Copernicus' book was also banned at the same time**
- **Galileo was formally vindicated by the Church in 1992.**
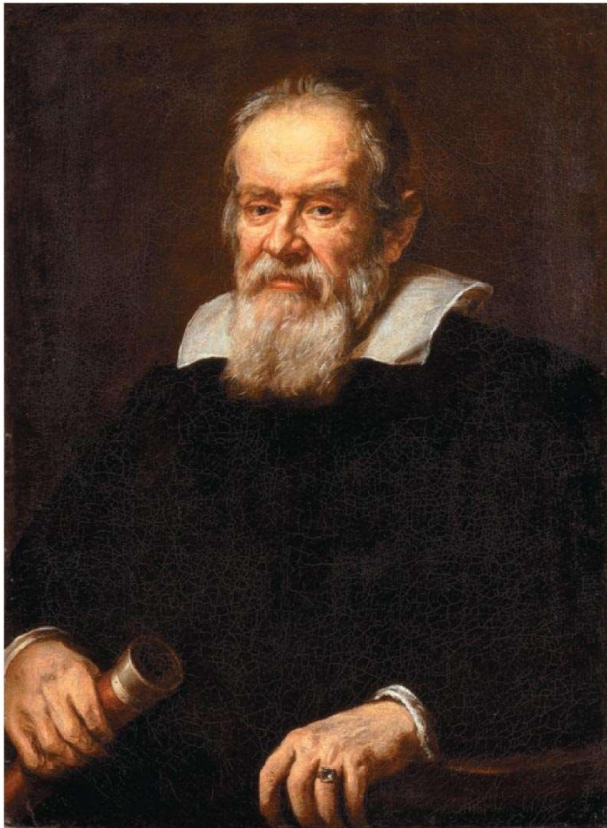- **http://www.inquiriesjournal.com/articles/1675/copernicus-galileo-and-the-church-science-in-a-religious-world**

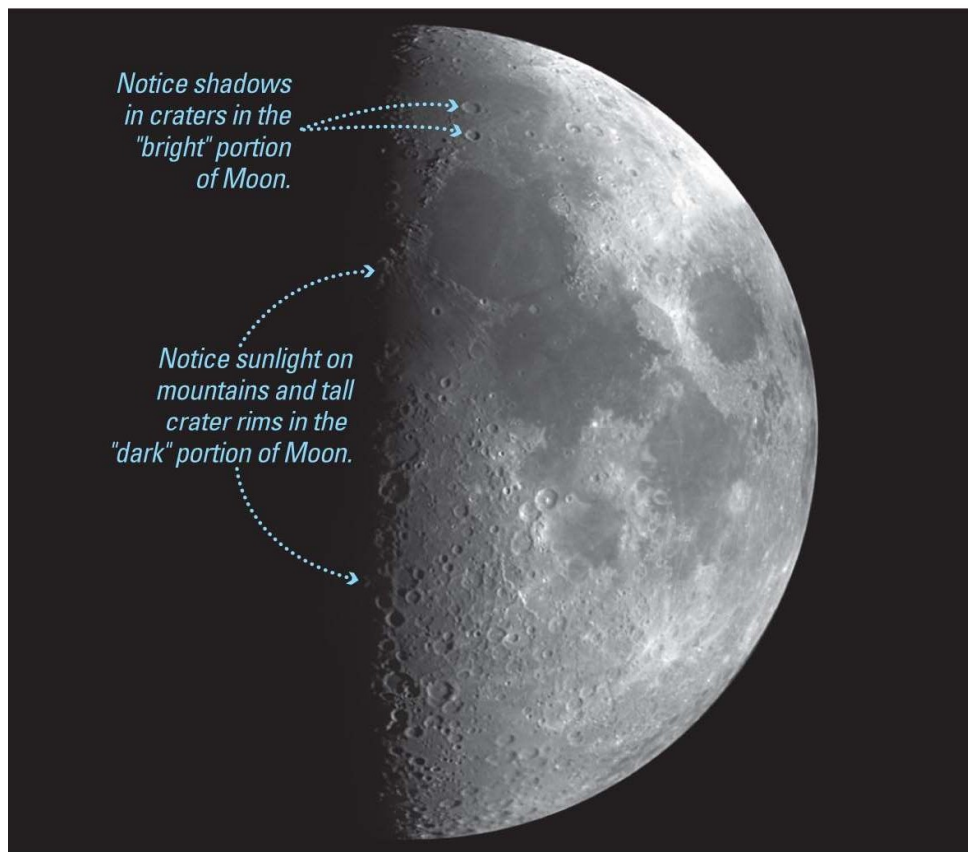# How did Galileo solidify the Copernican revolution?

- **Galileo (1564–1642) overcame major objections to the Copernican view. Three key objections rooted in the Aristotelian view were the following:**

  1. **Earth could not be moving because objects in air would be left behind.**

  2. **Noncircular orbits are not "perfect" as heavens should be.**

  3. **If Earth were really orbiting Sun, we'd detect stellar parallax.**

- **Galileo did not invent the telescope, but he was the first to use it, and modify it for use in astronomy.**

Overcoming the first objection (nature of motion):

Galileo's experiments showed that objects in air would stay with a moving Earth.

- Aristotle thought that all objects naturally come to rest.

- Galileo showed that objects will stay in motion unless a force acts to slow them down (Newton's first law of motion).

Overcoming the second objection (heavenly perfection):

Notice shadows in craters in the "bright" portion of Moon.

Notice sunlight on mountains and tall crater rims in the "dark" portion of Moon.

- Tycho's observations of comet and supernova already challenged this idea.

- Using his telescope, Galileo saw:
  - Sunspots on the Sun ("imperfections")
  - Mountains and valleys on the Moon (proving it is not a perfect sphere)

Overcoming the third objection (parallax):

- Tycho *thought* he had measured stellar distances, so lack of parallax seemed to rule out an orbiting Earth.

- Galileo showed stars must be much farther than Tycho thought—in part by using his telescope to see that the Milky Way is countless individual stars.

- If stars were much farther away, then lack of detectable parallax was no longer so troubling.

• Galileo also saw four moons orbiting Jupiter, proving that not all objects orbit Earth.

It was Galileo's observation of the phases of Venus that buried the geocentric model.

GEOCENTRIC

Ptolemaic View of Venus

Sun

Sun's orbit of Earth

crescent new crescent

new Venus's orbit of Earth
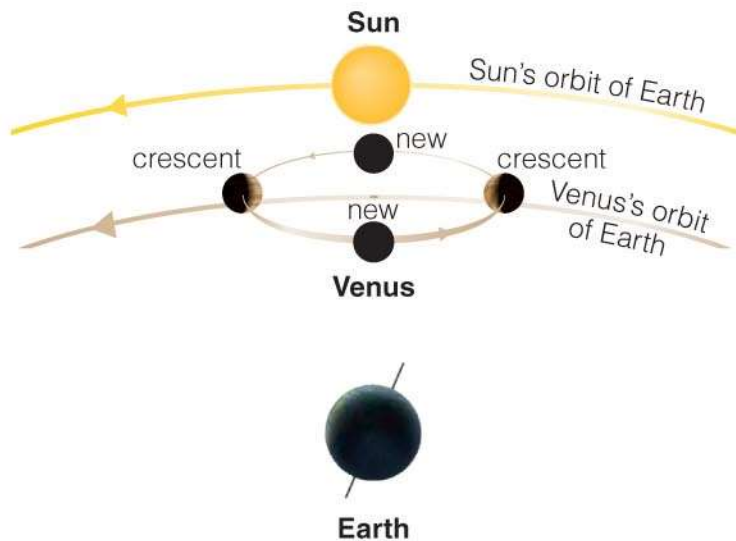
Venus

Earth

a In the Ptolemaic model, Venus orbits Earth, moving around a smaller circle on its larger orbital circle; the center of the smaller circle lies on the Earth–Sun line. If this view were correct, Venus's phases would range only from new to crescent.

**No gibbous or full phases
As will never be further than the Sun**

HELIOCENTRIC

Copernican View of Venus

full

gibbous   gibbous

quarter   quarter

Sun

crescent   crescent

new
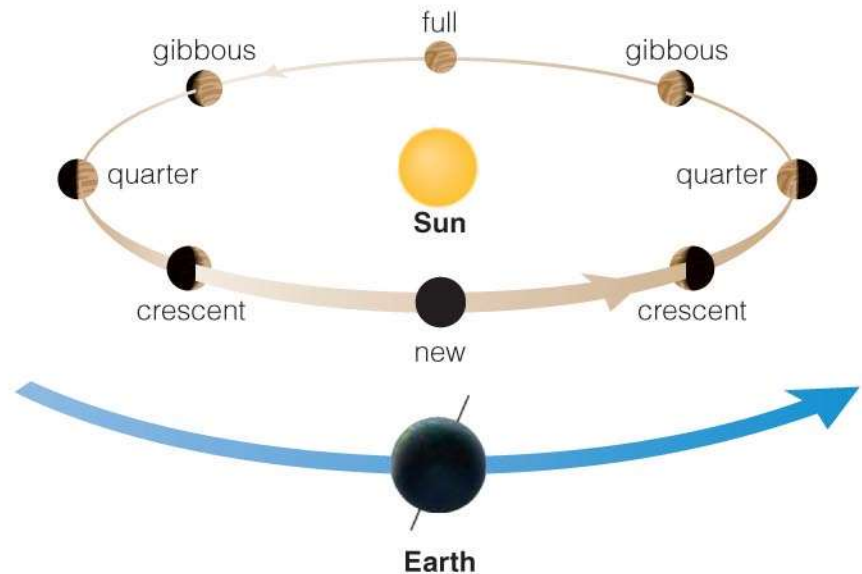
Earth

b In reality, Venus orbits the Sun, so from Earth we can see it in many different phases. This is just what Galileo observed, allowing him to prove that Venus orbits the Sun.

All phases are seen!

Galileo's observations of phases of Venus *proved* that it orbits the Sun and not Earth.

A little bit about your Instructor, Dr. Chris Bennett

- Assistant Professor in the Department of Physics, as of Aug 2016

- Ph.D. in Astrochemistry (Physical Chemistry) from the University of Hawai'i at Mānoa in 2009

- Build Laboratory Equipment to Simulate Interaction of Radiation (e.g., from the Sun, or magnetospheres) with Surfaces

  - Interstellar Dust, Comets, Planetary Rings, Icy dwarf planets (e.g., Pluto), Icy Satellites (e.g., Jupiter's moon Europa), Mercury, the Moon

  - Monitor how changes spectroscopically, or what is sputtered from the surface… both can be compared to spacecraft observations…

- Have worked with Apollo Lunar Samples and Meteorites

- Currently working with the Center for Lunar and Asteroid Surface Science (CLASS) here at UCF

- Was part of a <$1B Uranus Mission Concept Study (CAELUS) with JPL

- Interested in developing new instrument techniques for planetary space missions (e.g., 3D-IR Raman, nanoIR, MS/MS techniques)

iClicker Question (not graded)

Question: Am I an idiot for purchasing this product thinking it will help my cold?

A. Yes
B. No

iClicker Question (not graded)

Question: Am I an idiot for purchasing this product thinking it will help my cold?

A. Yes

B. No. Although labeled as such, Zicam is not a Homeopathic remedy… Zinc (not Vitamin C) actually helps reduce the severity of colds…

Dilution Factors used in Homoeopathy

- 1X means it has been diluted by a factor of 100
- 1C means it has been diluted by a factor of 100

X Scale (or D Scale)	C scale	Dilution Ratio	Notes
1X	-	1:10	Often described as 'low potency'
2X	1C	1:100	Called higher potency than 1X by homeopaths
6X	3C	10^{-6}	
10X	5C	10^{-10}	
26X	13C	10^{-26}	If pure was used as the diluent, statistically not a single molecule would be present in ~100 doses
60X	30C	10^{-60}	Typically advocated for homeopathic remedies.
400X	200C	10^{-400}	Dilution of popular homeopathic flu preparation *Oscillococcium*

However, the 'Placebo effect' IS REAL!

Hallmarks of Science:

OCCAM'S RAZOR
Now with only one blade

#1: Modern science seeks explanations for observed phenomena that rely solely on natural causes.

(A scientific model cannot include divine intervention.)

#2: Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.

("Occam's razor" - 'the simplest answer is most often correct')

#3: A scientific model must make ***testable predictions*** about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations.

The Scientific Method

OBSERVATION → QUESTION → HYPOTHESIS → PREDICTION → EXPERIMENT → RESULTS → REJECT HYPOTHESIS / THEORY

Fb/A Science Enthusiast
AScienceEnthusiast.com
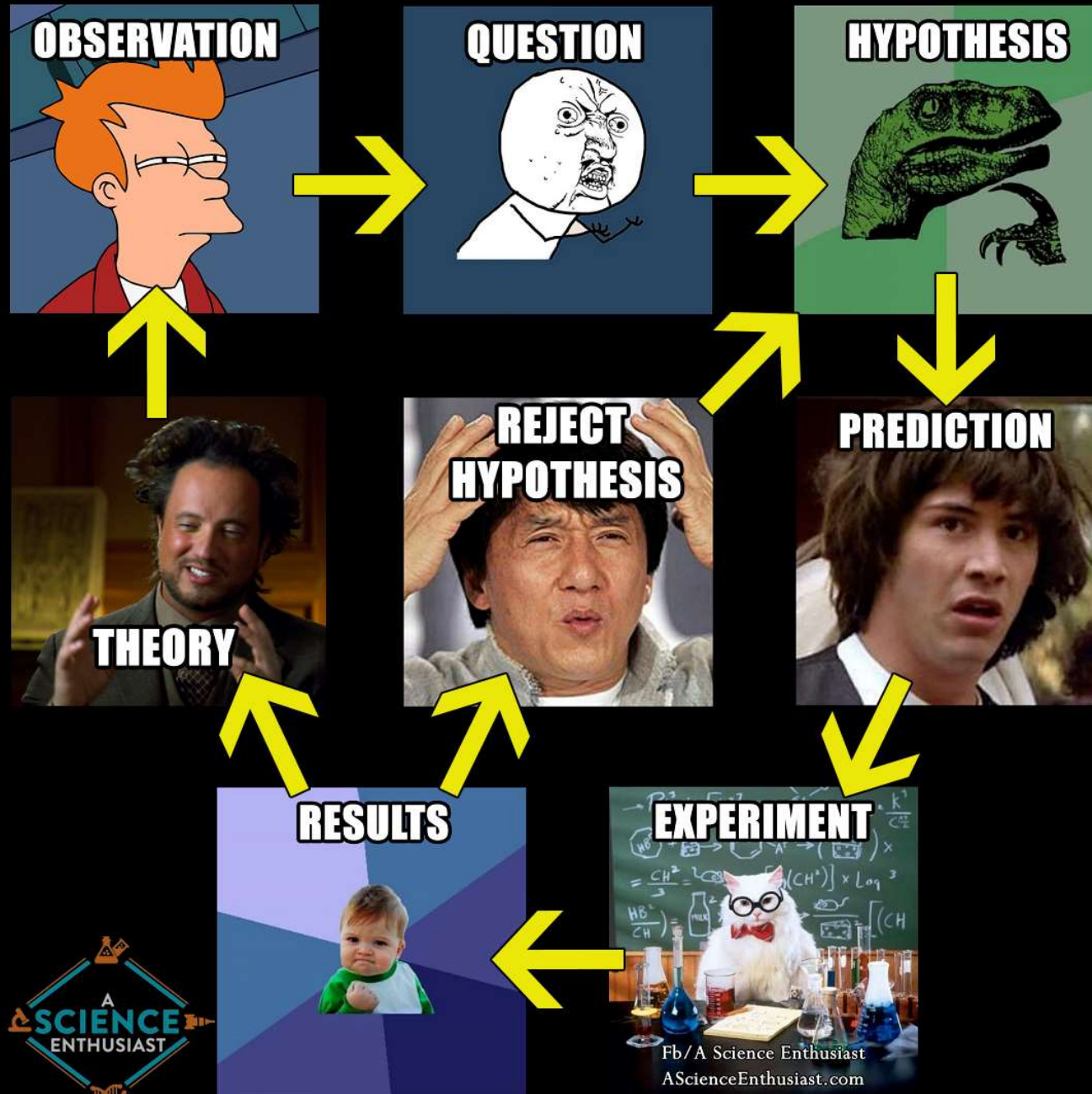
The Scientific Method
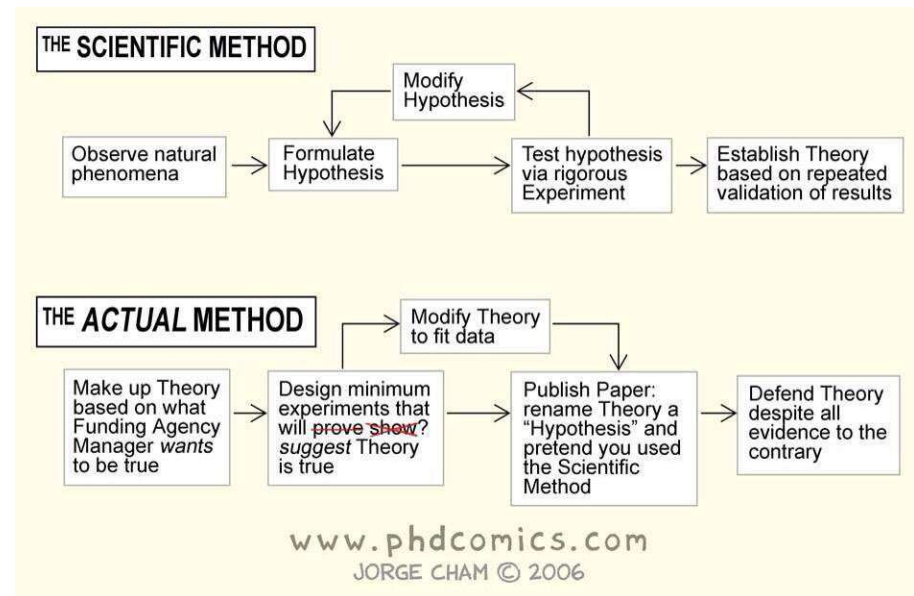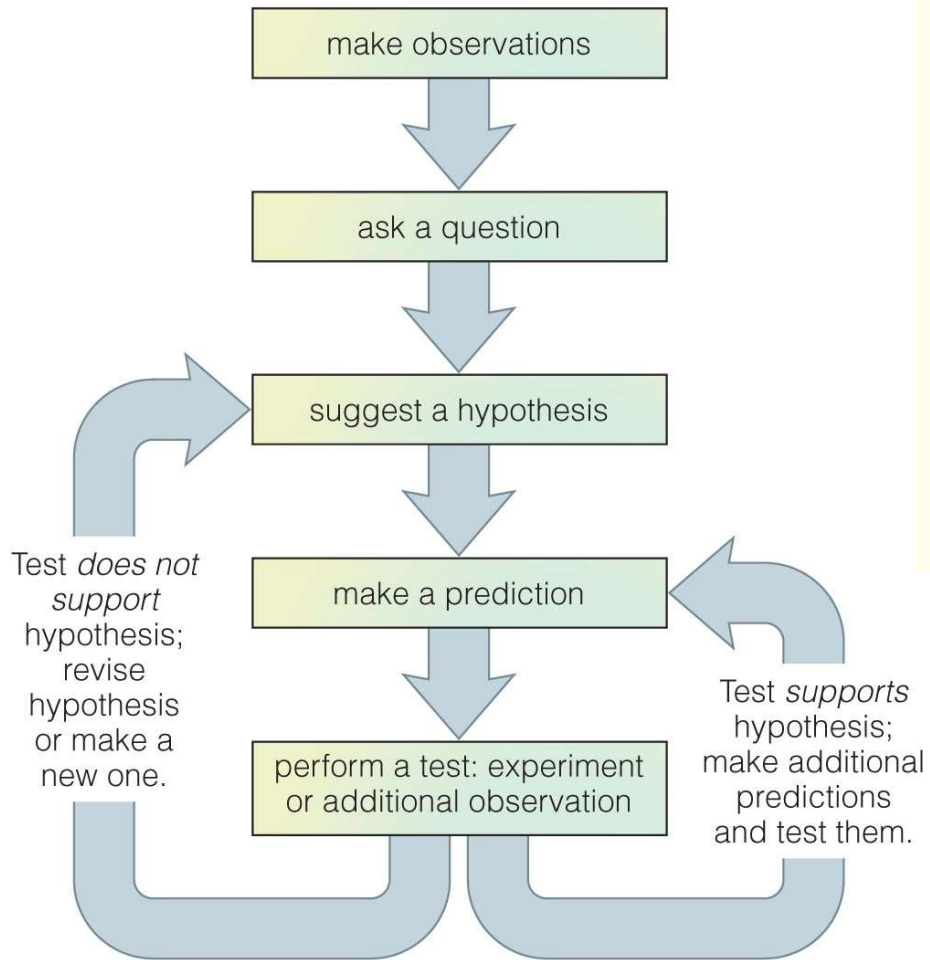
- **It doesn't always work as intended**
- **Some of the best discoveries were unintentional**

Important: Scientific Terminology

Hypothesis: an idea that can explain a phenomenon

Theory: a hypothesis which tests have failed to disprove

Physical law: theories that have become very well tested and are of fundamental importance

Except from Wikipedia:

Both scientific laws and scientific theories are produced from the scientific method through the formation and testing of hypotheses, and can predict the behavior of the natural world. Both are typically well-supported by observations and/or experimental evidence.[30] However, scientific laws are descriptive accounts of how nature will behave under certain conditions.[31] *Scientific theories are broader in scope, and give overarching explanations of how nature works and why it exhibits certain characteristics. Theories are supported by evidence from many different sources, and may contain one or several laws*.[32]

Important: Scientific Terminology

Hypothesis: an idea that can explain a phenomenon

Theory: a hypothesis which tests have failed to disprove

Physical law: theories that have become very well tested and are of fundamental importance

More excepts from Wikipedia:

A common misconception is that scientific theories are rudimentary ideas that will eventually graduate into scientific laws when enough data and evidence have been accumulated. A theory does not change into a scientific law with the accumulation of new or better evidence. A theory will always remain a theory; a law will always remain a law.[30][33][34] Both theories and laws could potentially be falsified by countervailing evidence.[35]

Theories and laws are also distinct from hypotheses. Unlike hypotheses, theories and laws may be simply referred to as scientific fact.[36][37] However, in science, theories are different from facts even when they are well supported.[38] For example, evolution is both a theory and a fact.[4]

Theories are kind of a big deal in Science

What is a Theory:

The word theory has a different meaning in science than in everyday life.

In science, a theory is NOT the same as a hypothesis.

A scientific theory must:

- Explain a wide variety of observations with a few simple principles
- Be supported by a large, compelling body of evidence
- NOT have failed any crucial test of its validity

However,

- **Scientists <u>do not</u> BELIEVE in theories…..**
- **Scientific theories are always tentative and subject to corrections or inclusion in a yet wider theory**

A few Examples of Scientific Theories:

- Germ Theory
- Theory of Evolution
- Gravitational Theory (actually several different versions)

The Theory of Evolution & Natural Selection
Charles Darwin – The origin of Species.

- Every species is fertile enough that if all offspring survived to reproduce, the population would grow (fact).
- Despite periodic fluctuations, populations remain roughly the same size (fact).
- Resources such as food are limited and are relatively stable over time (fact).
- A struggle for survival ensues (inference).
- Individuals in a population vary significantly from one another (fact).
- Much of this variation is heritable (fact).
- Individuals less suited to the environment are less likely to survive and less likely to reproduce; individuals more suited to the environment are more likely to survive and more likely to reproduce and leave their heritable traits to future generations, which produces the process of natural selection (fact).
- This slowly effected process results in populations changing to adapt to their environments, and ultimately, these variations accumulate over time to form new species (inference).

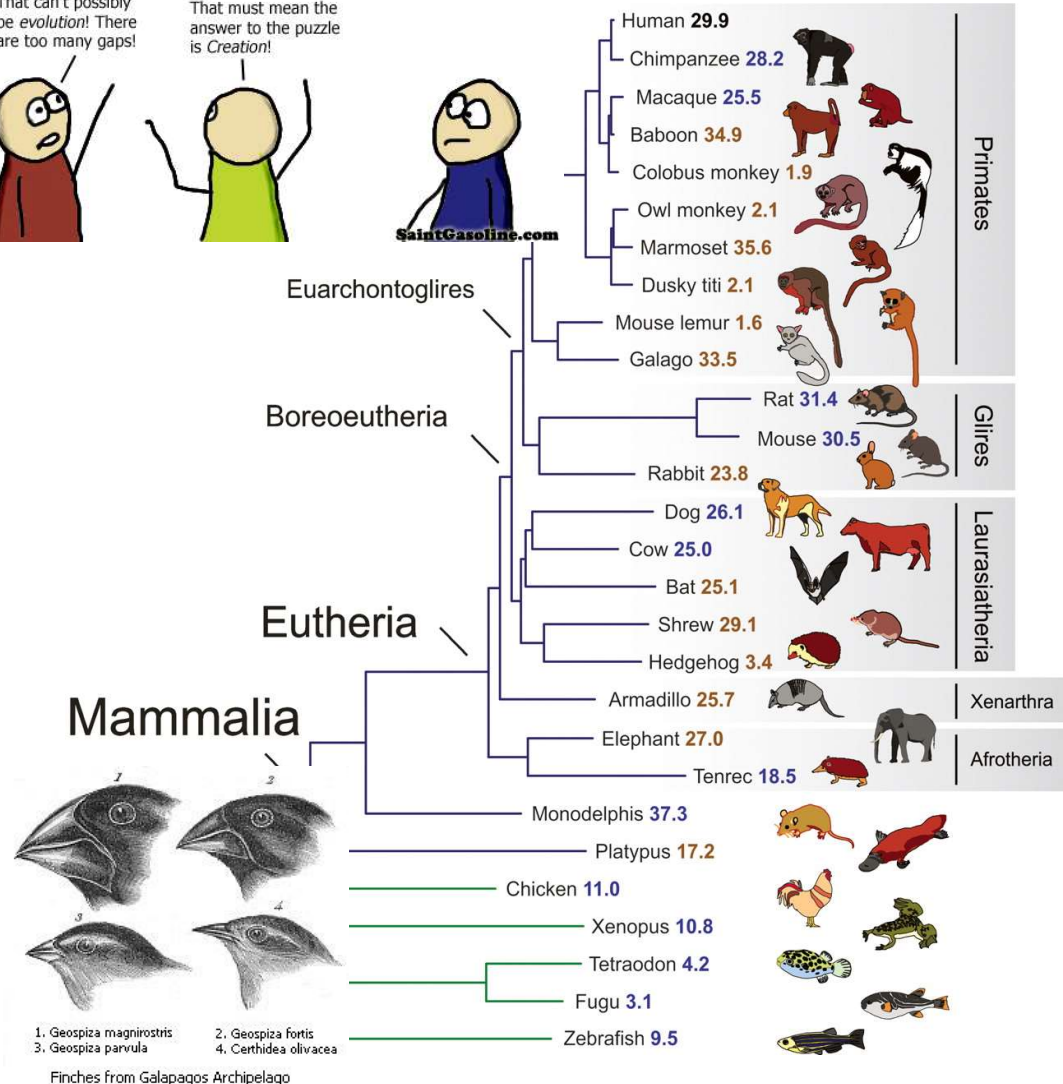**Creationist Wheel of Fortune:** Where *every* spin lands on *Bankrupt!*

EVOL T ON

That can't possibly be *evolution!* There are too many gaps!

That must mean the answer to the puzzle is *Creation!*

SaintGasoline.com

Apes and Humans have a common ancestor

Human **29.9**
Chimpanzee **28.2**
Macaque **25.5**
Baboon **34.9**
Colobus monkey **1.9**
Owl monkey **2.1**
Marmoset **35.6**
Dusky titi **2.1**
Mouse lemur **1.6**
Galago **33.5**
Primates

Euarchontoglires

Rat **31.4**
Mouse **30.5**
Rabbit **23.8**
Glires

Boreoeutheria

Dog **26.1**
Cow **25.0**
Bat **25.1**
Shrew **29.1**
Hedgehog **3.4**
Laurasiatheria

Eutheria

Armadillo **25.7**
Xenarthra

Elephant **27.0**
Tenrec **18.5**
Afrotheria

Mammalia

Monodelphis **37.3**
Platypus **17.2**
Chicken **11.0**
Xenopus **10.8**
Tetraodon **4.2**
Fugu **3.1**
Zebrafish **9.5**

1. Geospiza magnirostris   2. Geospiza fortis
3. Geospiza parvula   4. Certhidea olivacea

Finches from Galapagos Archipelago

End of Todays Lecture