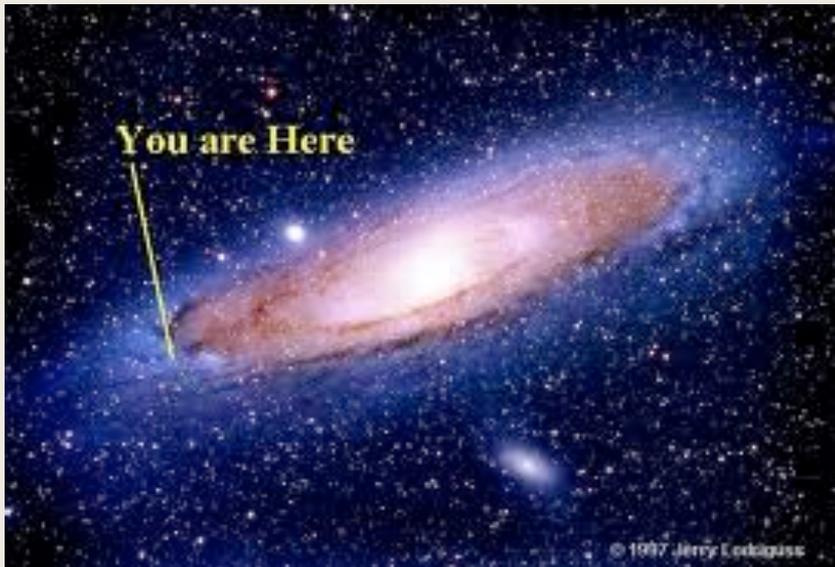


ASTRONOMY

& the Advent
of the
Scientific
Method

SCIENCE STARTED WITH THE STUDY OF OUR PLACE IN THE UNIVERSE...

ASTRONOMY-the study of all celestial objects and space itself (black holes, planets, stars, meteors..) their formation, movement, energy...



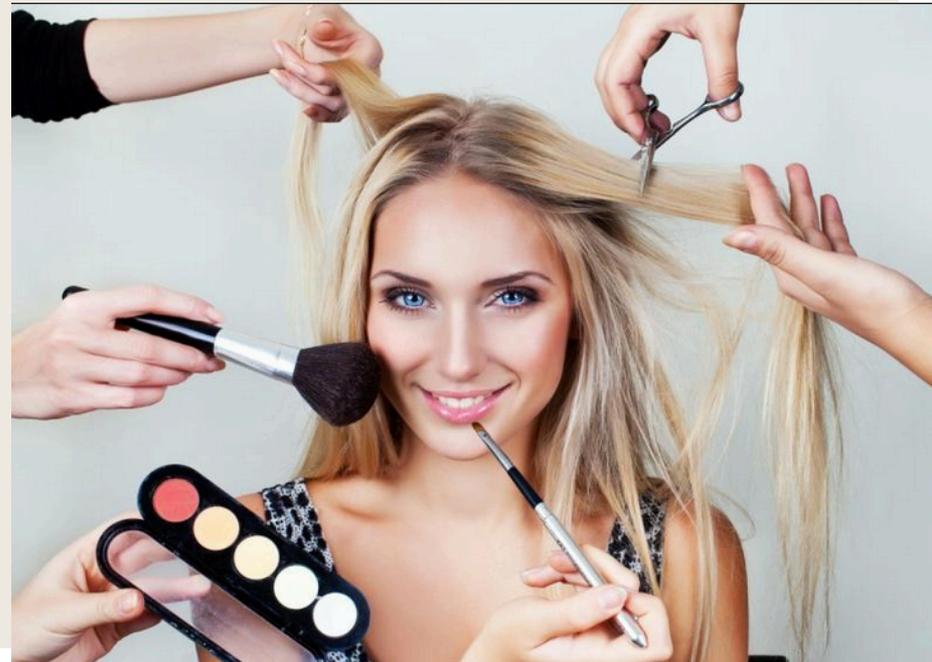
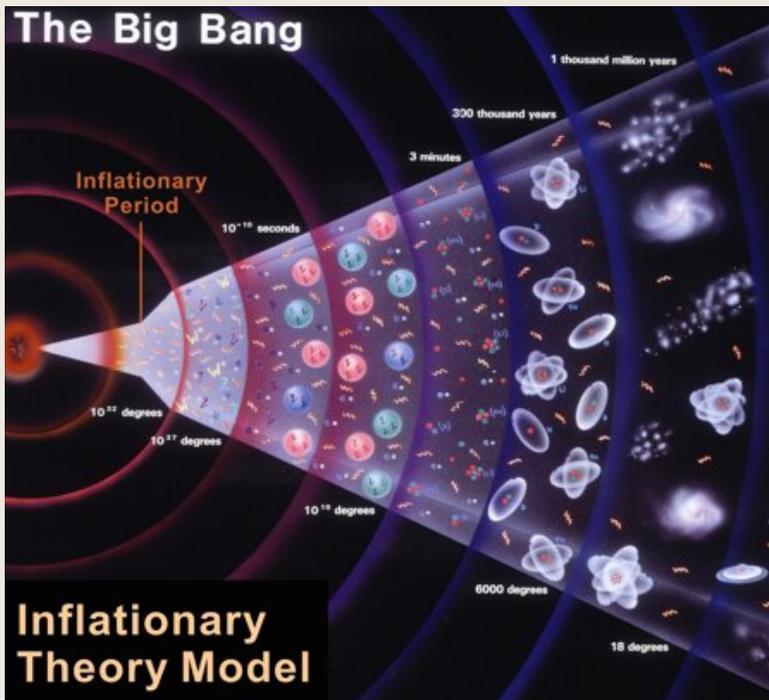
NOT BE CONFUSED WITH...**ASTROLOGY**-the control of planets over human behavior (this is NOT science!)



HOW DID IT ALL BEGIN?

Cosmology- the study of the origin of the universe (Big Bang Theory) is a branch of astronomy.

NOT TO BE CONFUSED WITH **Cosmetology**- the study of hair and make up!



Ancient Peoples Studied the Skies



North America



South America



Europe



Asia



- Every culture made *observatory calendars* to measure the sun's movement across the sky
- Became cultural centers - pagan celebrations of the solstices

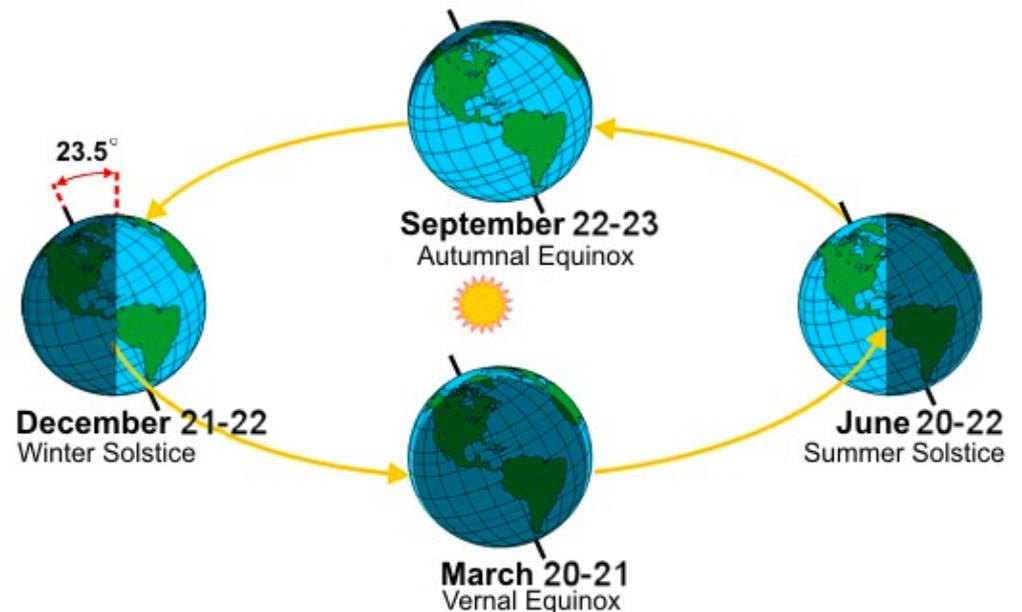
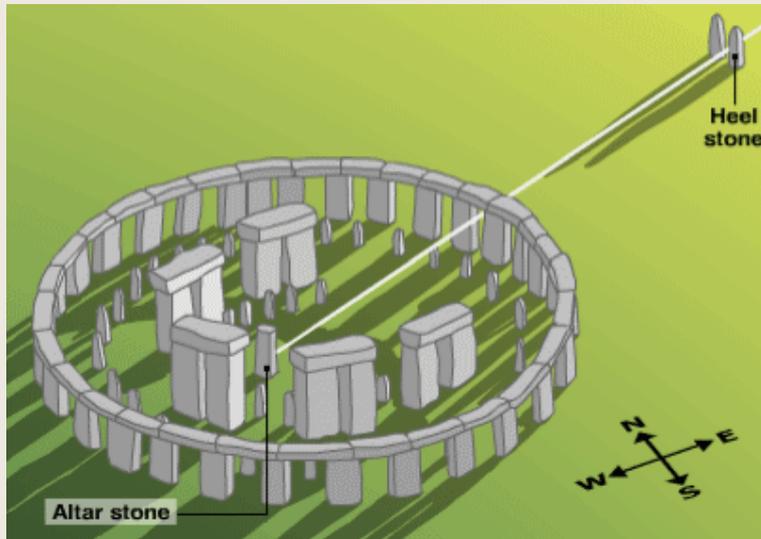
YEARLY CALENDAR MEANT SURVIVAL

Equinox- Equal day/night during 1st day of spring and fall

Summer solstice = longest day

Winter solstice = shortest day

Used to determine planting and harvesting times. Sailors navigated by stars!



What did we observe?

Observations— FACTS;
what you know to be true
based on your senses (see,
hear, taste, touch, smell)

Example Observations

- Stars appear to rotate around the North Star Polaris
- The sun and moon rise in the east and set in the west



[Wheel in the sky video](#)

Observations lead to Inferences

Inference – an explanation,
based on observed information.
What you **THINK** to be true.

Aztec Origin myth-explanation
That the moon contained a rabbit
Hopping across the sky



Incan Observatory
-saw star (and planets) in motion



On Qualitative & Quantitative Observations

Qualitative (Quality)

- Descriptive of quality, characteristics
- Appearance, sounds, tastes, smells, textures
- **Example:** The roasted aroma of the brown coffee was just as rewarding as the smooth taste.



Quantitative (Quantity)

- Numerical values
- Counted or measured
- **Example:** the 35 coffee beans were brewed into 50 ml of coffee



ASTRONOMY & WESTERN THOUGHT

Aristotle 384-322 BC

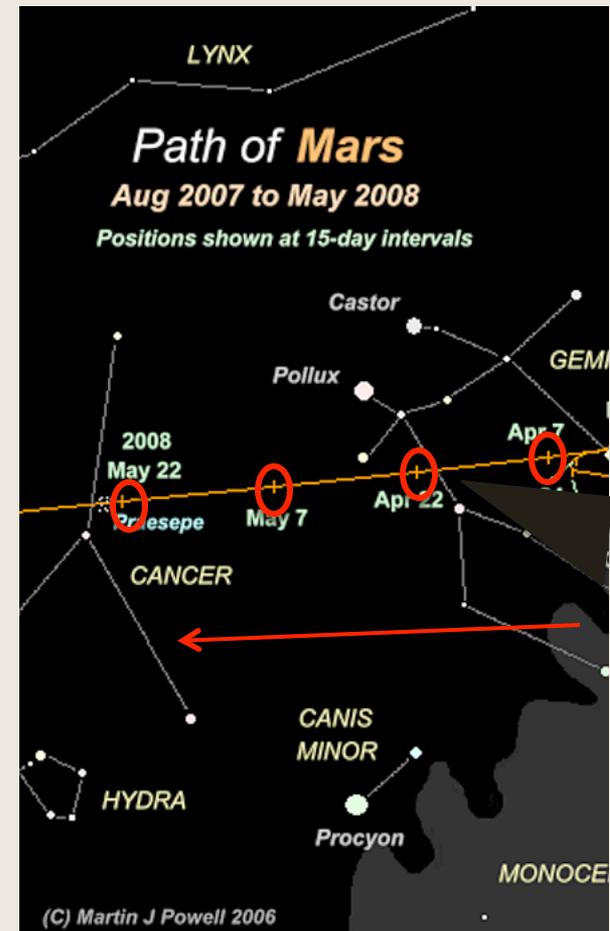


- **Qualitative Observations:**
 - stars, moon etc in spiral motion
 - no evident Earth motion, or 'Great wind'
- From observations, used **inductive reasoning** to create an explanation
- **Inferred:** a perfect static, universe: **geocentric** (earth centered) with planets in perfectly circular orbits
- No experimentation; Aristotle's word was enough –Not a scientist but a philosopher

'Wandering' Stars Pose a Challenge

Planets Move Independent of Constellations

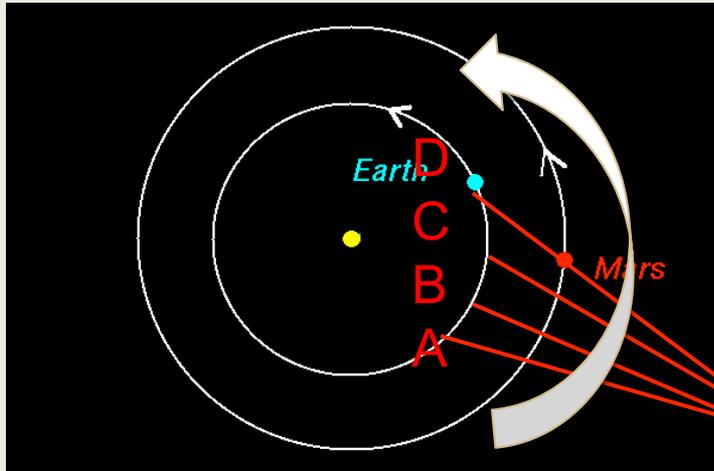
- Inferred: 'wanderers' orbit Earth on perfectly circular paths...
- Term **PLANET** from Greek translation *Planetes* = Wandering Star



Mars Observation, Part B

'Wanderers' Change Course

orbiting CCW



appears to
change
direction,
orbit CW

When the **observed** data
doesn't match your **inferences**...
we ask **questions** and make
predictions (new **hypotheses**)

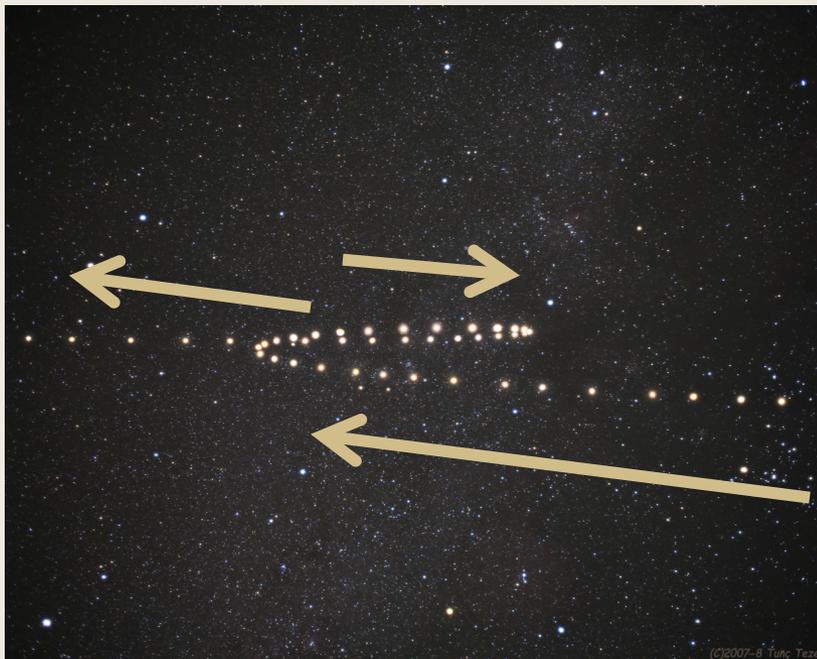
A
B
C
D



RETROGRADE MOTION

(RETRO = BACK)

Retrograde Motion- *apparent* backward planetary motion

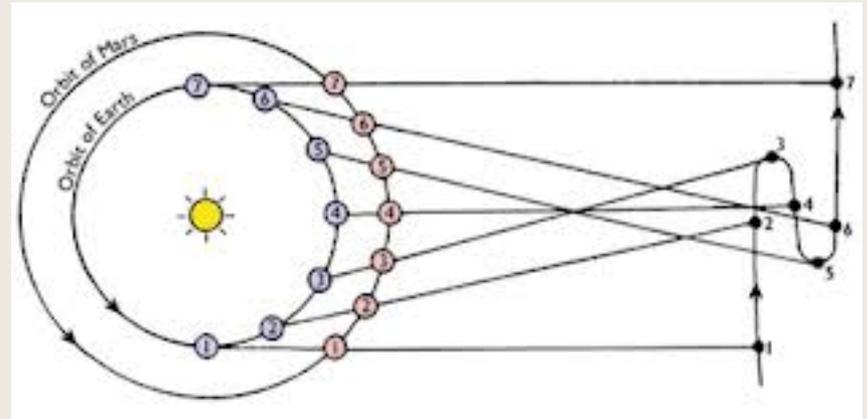


[Retrograde of all planets](#)

[Break down of Mars retrograde](#)

An optical illusion -

- the planets simply move at different velocities
- like passing a slower car on the freeway: it *appears* to go backwards

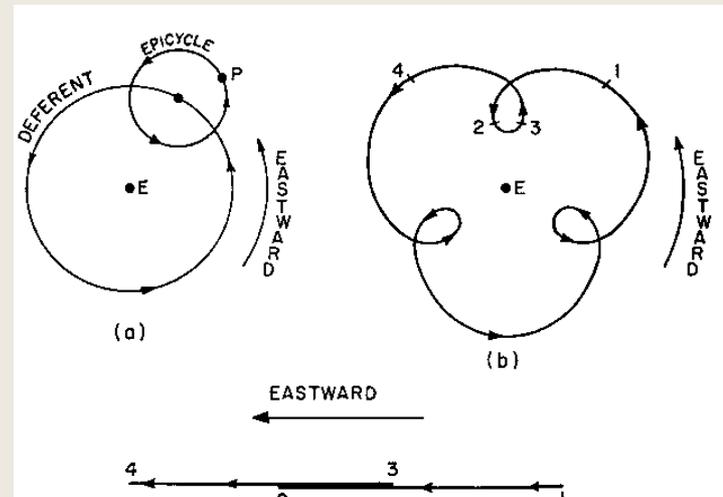


New Observations Dictate a New Hypothesis

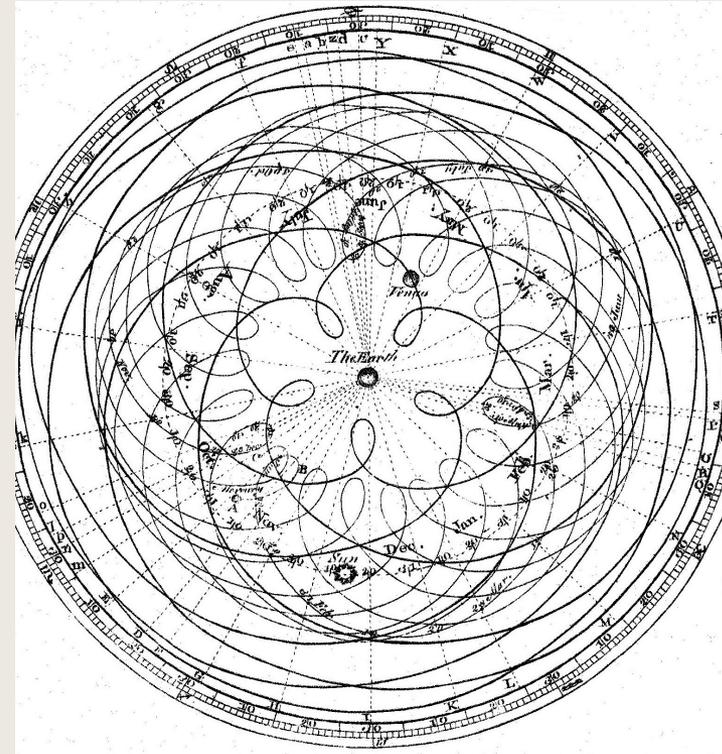
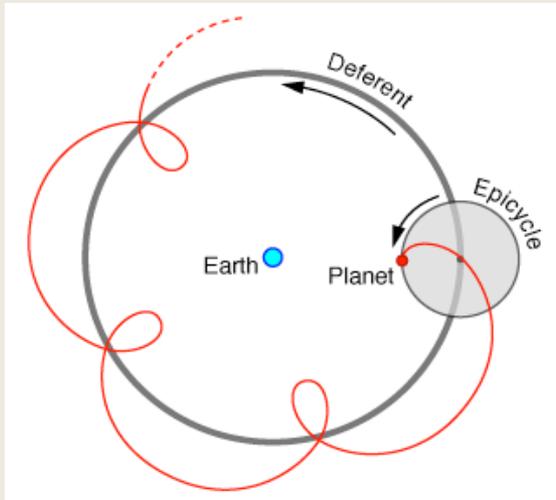
Ptolomy 140 AD



- Ptolomy adds **epicycles** = orbits on orbits – in an attempt to explain retrograde motion and predict it's occurrence
- Predictions don't match model so more epicycles added (80+!) Still, a lasting hypothesis



[Ptolemaic Simulator](#)

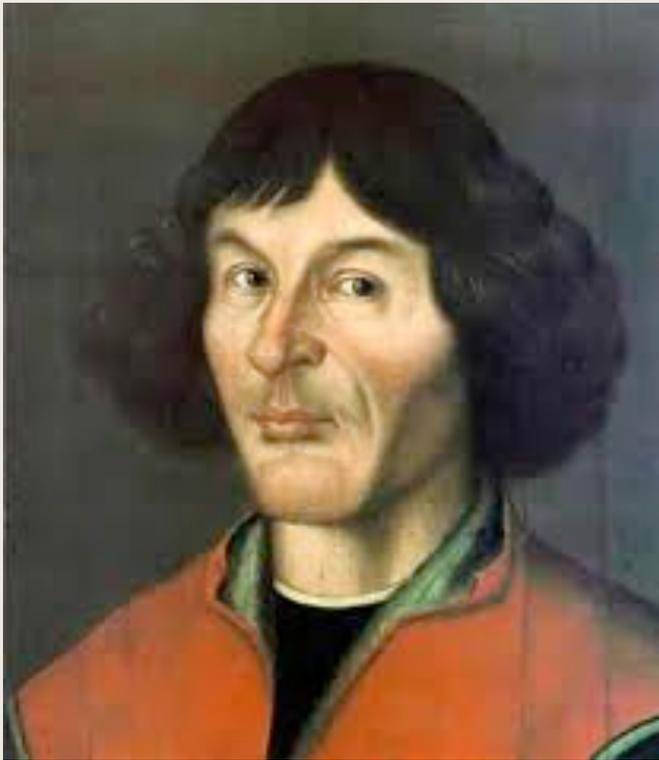


- Too many epicycles, maybe there is an easier answer...?

[Epicycle animation](#)

Need a New Hypothesis

Copernicus 1473-1543 AD

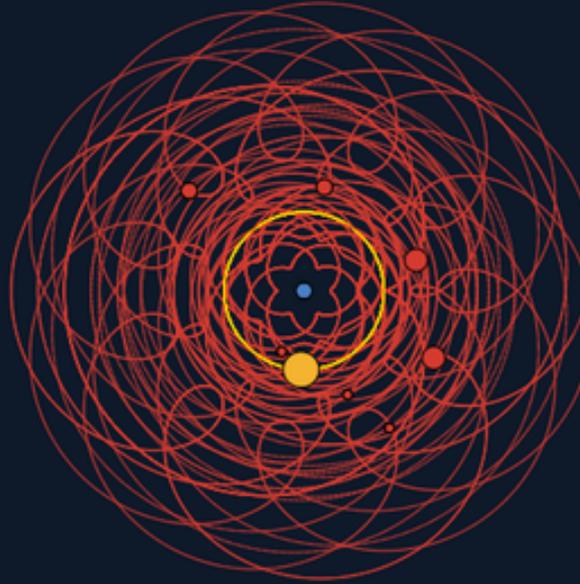


- Unable to make epicycles work also
- Instead: Proposes the universe is **heliocentric** (*sun centered*); orbits are still perfect circles
- Waited until old age to publish, and then in Latin, not Italian *why?*

Heliocentrism



Geocentrism



- **The Law of Parsimony-**
The explanation requiring the fewest assumptions is most likely to be correct.
- **Keep it simple!**

On Hypotheses

- Inferences based on previous knowledge, reason – **inductive reasoning** - from details find explanation
- NOT a wild guess

- To be scientific it must be:
 - **Testable** – can design an experiment or study to test prediction, observe supporting data

 - **Falsifiable** – not only potentially right, but also potentially wrong

Hypothesis are conditional, justified, statements

- **IF** we change this **independent variable (IV)**



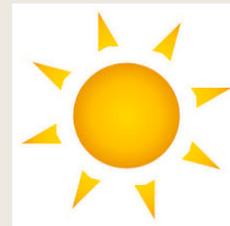
intentionally manipulated

- **THEN** this **dependent variable (DV)** will change

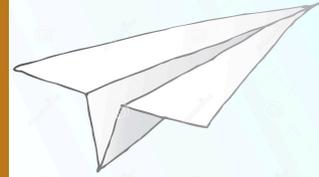


what you think the IV will affect

- **BECAUSE** of this reason, logic, relationship, etc

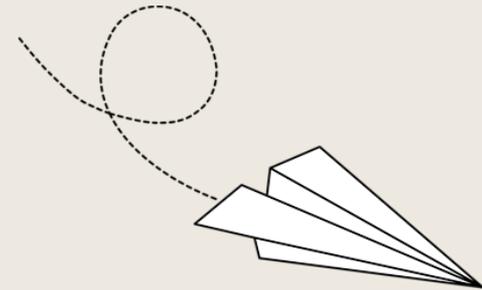


On Experimental Design Elements



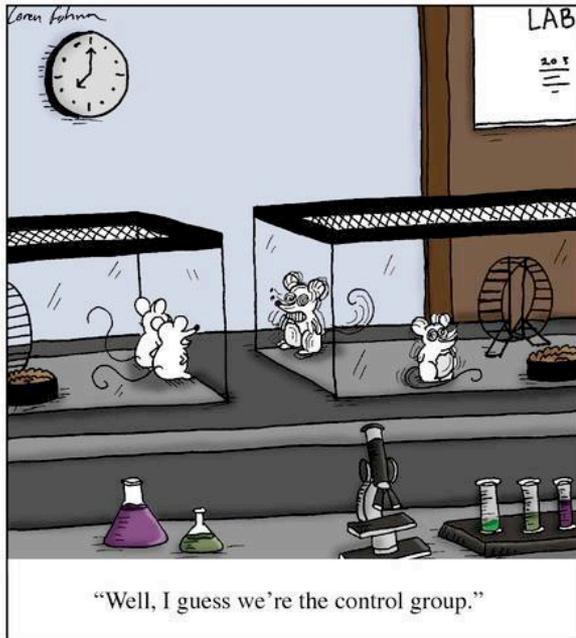
- **Independent Variable-** the manipulated variable to test the question-the size of the paper airplane

- **Dependent Variable-** data or measured result of your test – the distance the airplane flies



- **Constants** – items kept the same to ensure valid results – type of paper, force of throw, wind

Experimental vs Control Groups



Zero drops of fertilizer

● = fertilizer



2 drops of fertilizer



4 drops of fertilizer



6 drops of fertilizer

- **Control Group-**
NO change to IV for comparison

- **Experimental Groups-**
IV changed to test hypothesis

The Advent Of **Empiricism**-all knowledge must be through experience

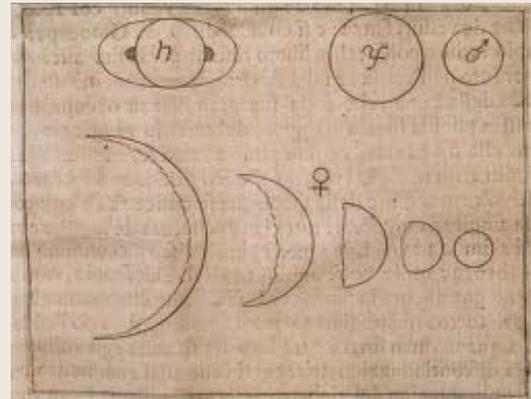
Galileo Galilei 1564-1642



1st true scientist that **tested** and sought out observations to prove conclusions

Used a telescope to generate **evidence** in support of heliocentric model

1. Discovered Jupiter had moons- Earth is not only thing orbited
2. Phases of Venus -makes clear Venus orbits the sun



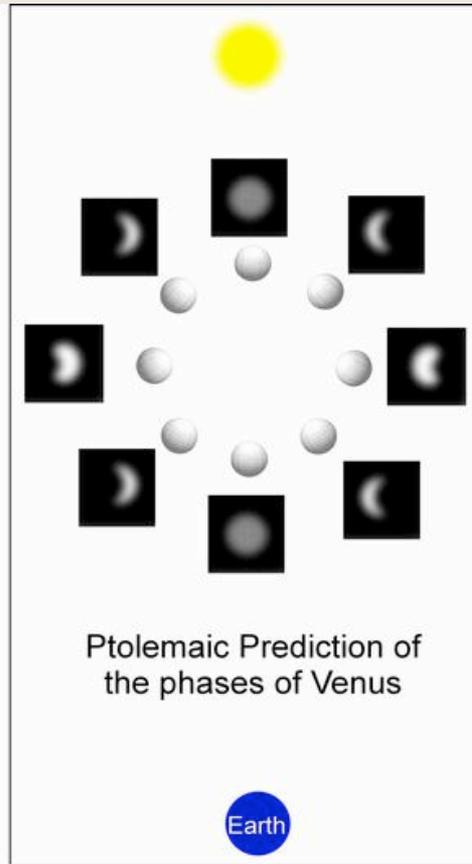
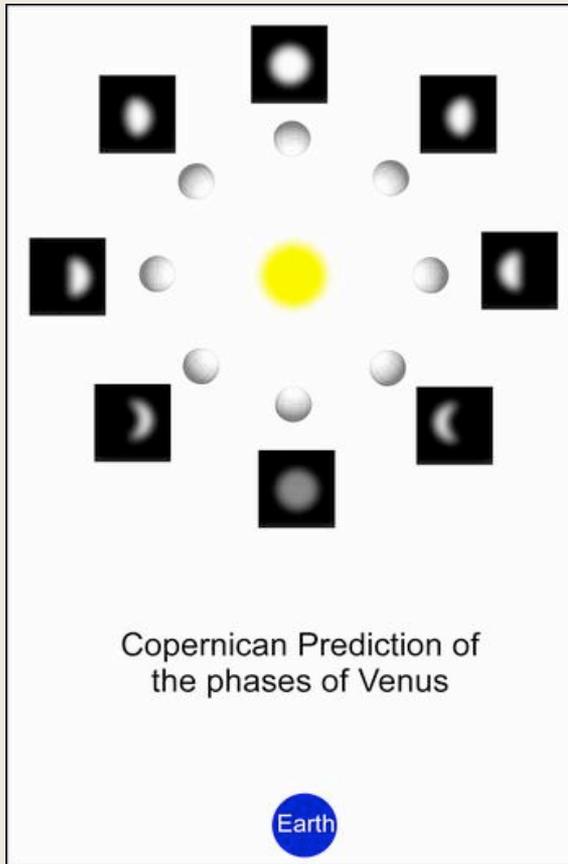
[Venus phases diagram and animation](#)

Galileo: Qualitative Evidence

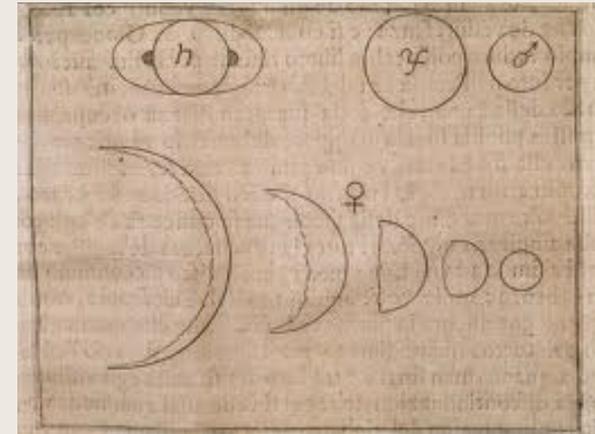
descriptive

heliocentric
model

geocentric
model (*Venus on an epicycle*)



Which model better matches our observations?



Test the Hypothesis? That's Science

- Design the Test:
 - Manipulate the Independent variable
 - Assess impact on dependent variable

In Hypotheses:

IF (independent Variable)
THEN (dependent variable)

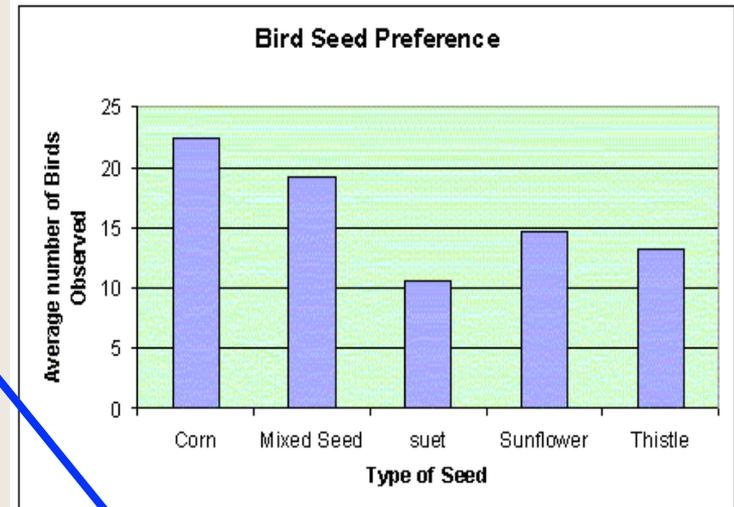
In Tables:

Left-most column of table

pH of Water	Number of Tadpoles
8.0	45
7.5	69
7.0	78
6.5	88
6.0	43
5.5	23

Independent variable

In Graphs:



X-axis of graph

No Cussing!

The following 4-Letter
Words are forbidden here:

Inch Mile

Foot Pint

Yard Acre

Also, no f-bombs: (fahrenheit)

*keep it clean
keep it metric*

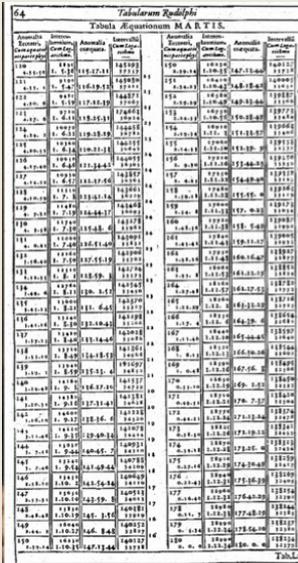
Data Makes The Difference-repeat trials and analysis



nerdtrek.com

Made 35 yrs of detailed planet positions

Tycho Brahe
1546-1601

A page from Tycho Brahe's 'Tabularum Rudolphi' (Table of Rudolph II), showing astronomical data for Mars. The table has multiple columns with numerical values and some text. The title at the top is 'Tabularum Rudolphi Tabula Aequinoctium M. A. R. T. I. S.'.

Johannes Kepler
1571-1630



Inherited and analyzed Brahe's data

Couldn't make sense of it

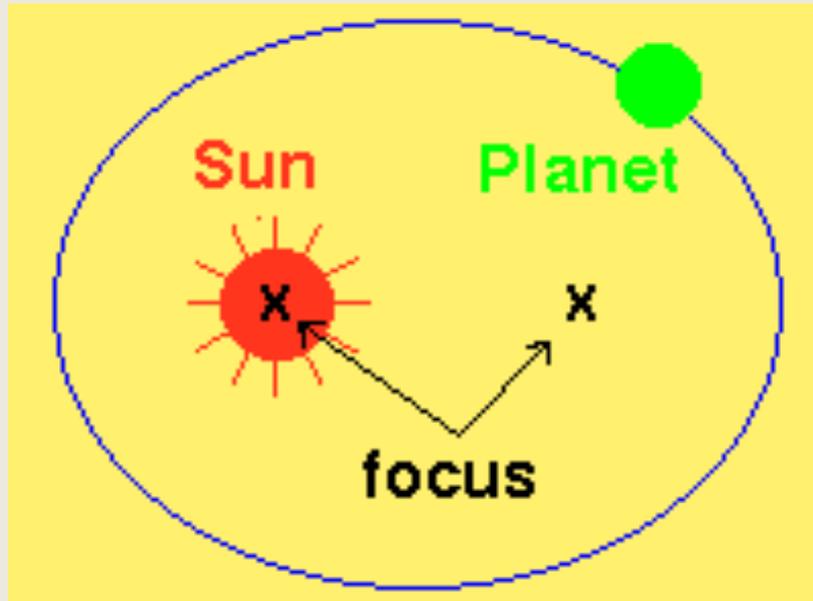
Inferred movement of planetary orbits & made 3 laws
LAWS-Mathematical relationship that explains how phenomena work but not why.

[Video summary](#)

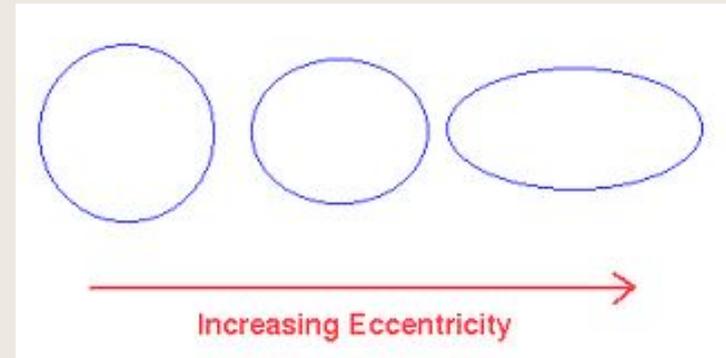


Kepler's Analysis: First Law

Planet orbits are ellipses with the sun at one of two foci points



More oval = More eccentric

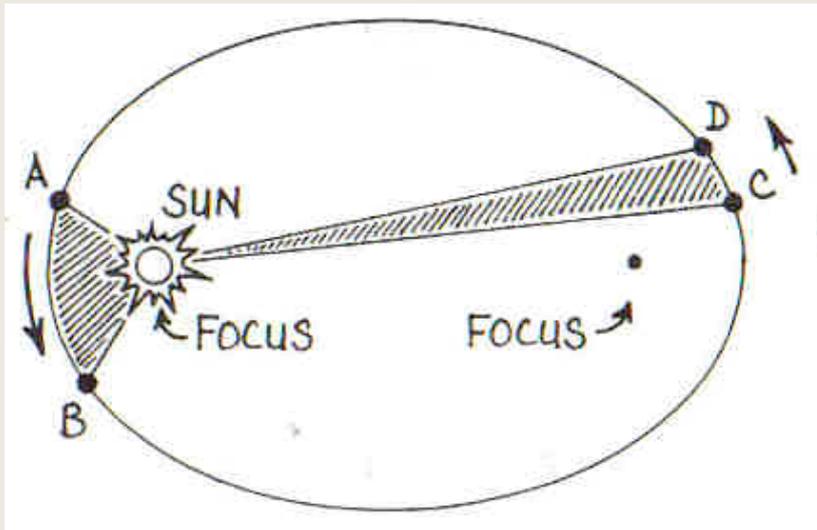


<http://astro.unl.edu/naap/pos/animations/kepler.swf>

Play with animation to see what features affect eccentricity

Kepler's Analysis: 2nd Law

The planets sweep out equal areas in equal time



Observed: larger arc when closer (perihelion) and smaller arc when farther (aphelion)

Infer: Planet must go faster when closer to sun and slower when farther from sun

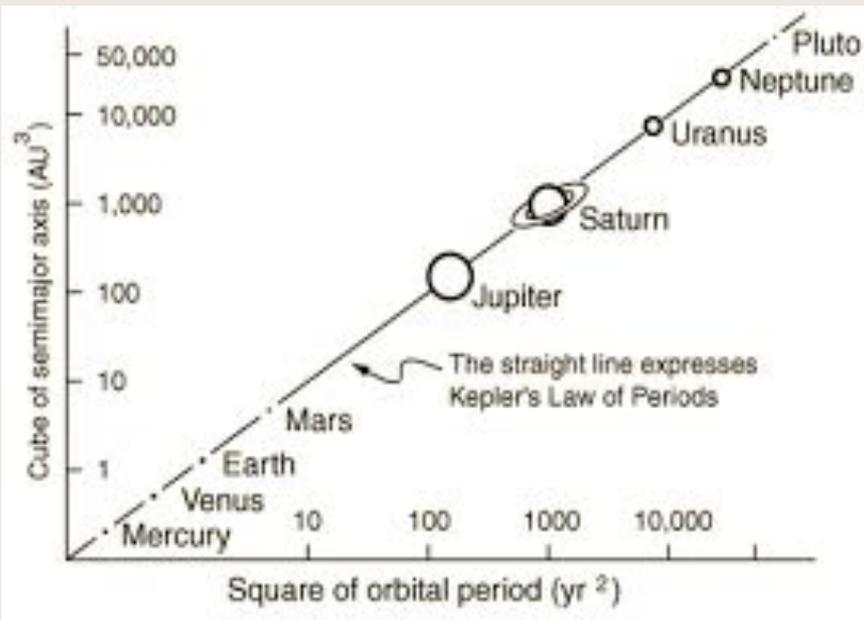
Almost worked out gravity!

http://highered.mcgraw-hill.com/sites/0072482621/student_view0/interactives.html#

<http://www.physics.sjsu.edu/tomley/Kepler12.html>

Kepler's 3rd Law of Planetary Motion

The time it takes to complete a revolution (orbital period) is directly proportional to the distance to the sun.



$$\text{Period}^2 = \text{Distance}^3$$

Time (years) Distance (AU)

Astronomical unit (AU): = average distance from Earth to the sun (1AU = 150,000,000km)

For Earth...

$$p=1\text{yr} \quad d=1\text{AU}$$

Check...does $p^2=d^3$?

The farther the planet the longer it takes to complete a revolution

From Conclusion to Theory

- **1610 Galileo**
 - Views the phases of Venus
 - Jupiter has 4 major moons orbiting it
 - Earth's moon is cratered, therefore not a perfect body
- **1609 Kepler's Laws of planetary motion**
- **1687 Newton explains Kepler**
 - universal gravitation
 - laws of motion

From Conclusion to Theory

- **1727** Bradley discovers stellar aberration – apparent change in starlight angle due to Earth's velocity change
- **1742** Catholic fathers leSeur & Jacquier defend Newton, heliocentrism mathematically
- **1838** Bessel measures parallax, finds stars are distant, not in Earth's epicycle
- **Late 20th century** over 300 exoplanets identified (orbiting other stars)

No such thing as 'just a theory'

- Many studies in different subjects
 - Varied types of tests/evidence
- Challenged by peers/confirmed by peers
 - Predicts new evidence

Wide variety of different investigations yield different conclusions yet all point to same unifying **EXPLANATION** of a natural event=>**SCIENTIFIC THEORY**

all life is composed of cells; all matter is composed of atoms; the plates of the earths surface are in motion; life on earth has changed over time; gravity exists between all bodies of matter

SCIENTIFIC LAW

- Mathematical relationship that explains how phenomena work but not why.
- Predicts results

- Ex. Newton's Laws of Motion
- Kepler's Laws of Planetary Motion

Early astronomy video review:

Great Moments in Science and Technology:

<http://www.youtube.com/watch?v=IBvMhpx8Q0Q>

<http://www.youtube.com/watch?v=ShQXRBDDBfaA>

OR:

Past is Present

<http://www.youtube.com/watch?v=zHUWP9zu4W8>

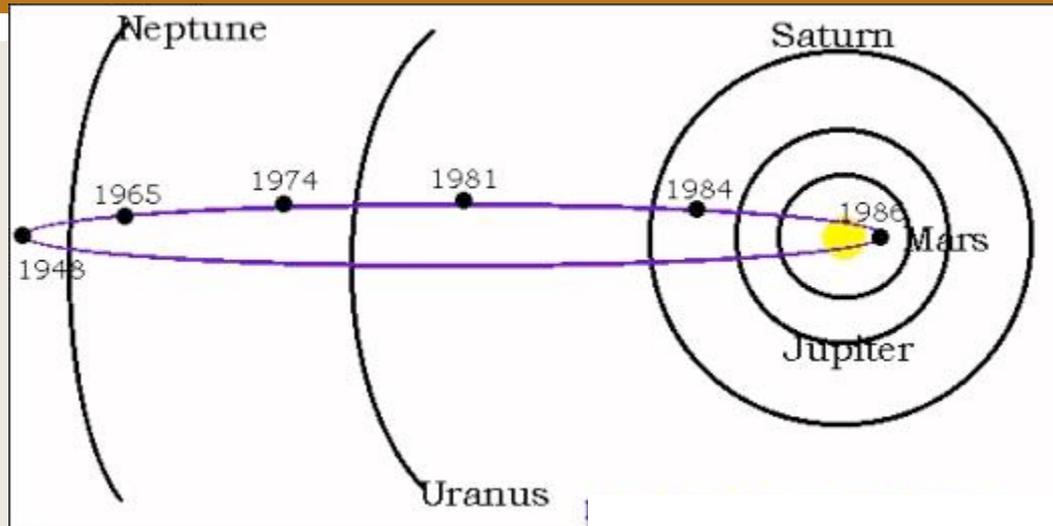
Was Copernicus' idea a new idea?

<http://www.youtube.com/watch?v=RMUc3fnL4zQ>

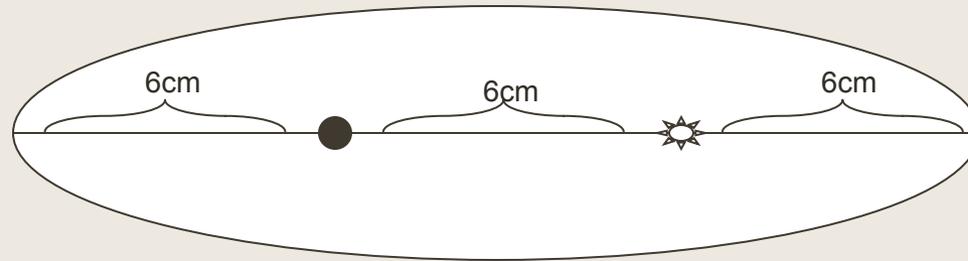
Where is the center of the universe, after all?

<http://www.astronomycast.com/2008/02/ep-77-where-is-the-centre-of-the-universe/>

WARM UP!



1. What are the foci for the ellipse?
 2. Someone measure the major axis for us...come up!
Using $1.65\text{cm} = 1 \text{ AU}$ determine d in AU
 3. Determine period in years using Kepler's 3rd law
- Bonus: How old will you be when it comes around the sun again when the last time was in 1986?



What is the major axis of the orbit (in cm)?

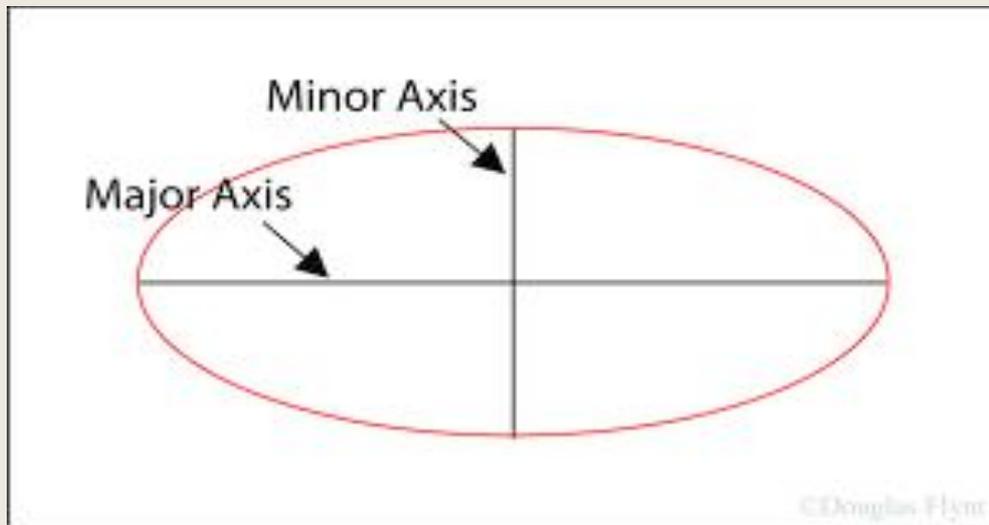
What is the semi-major axis (in cm)?

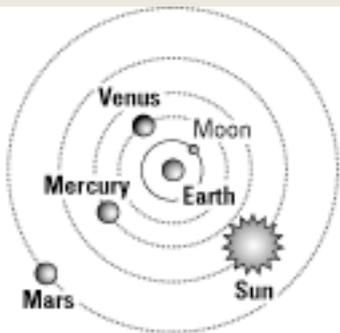
What is the average distance from sun to planet (in AU)?

[Use a scale of 15cm=1AU]

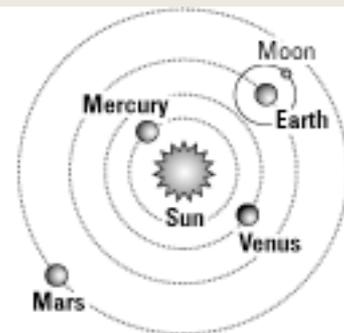
What is the orbital period for this planet? $p^2=d^3$

OTHER STUFF....

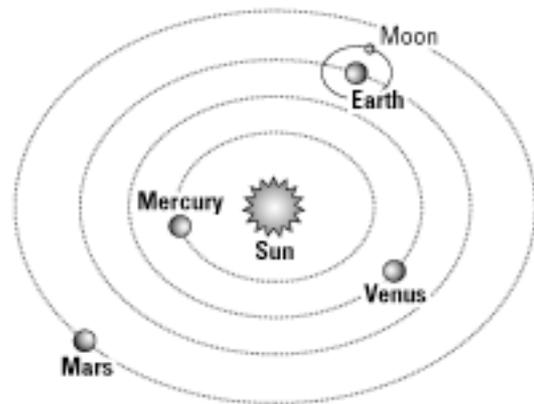




A

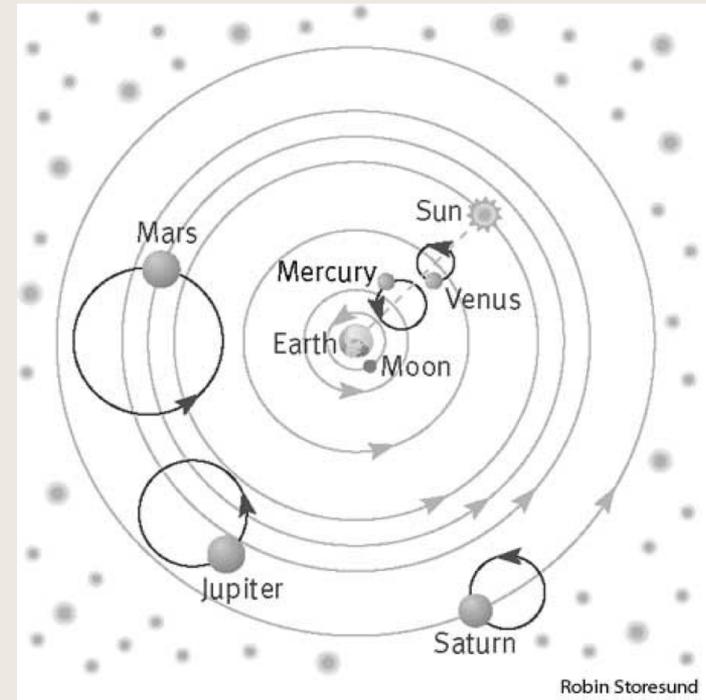
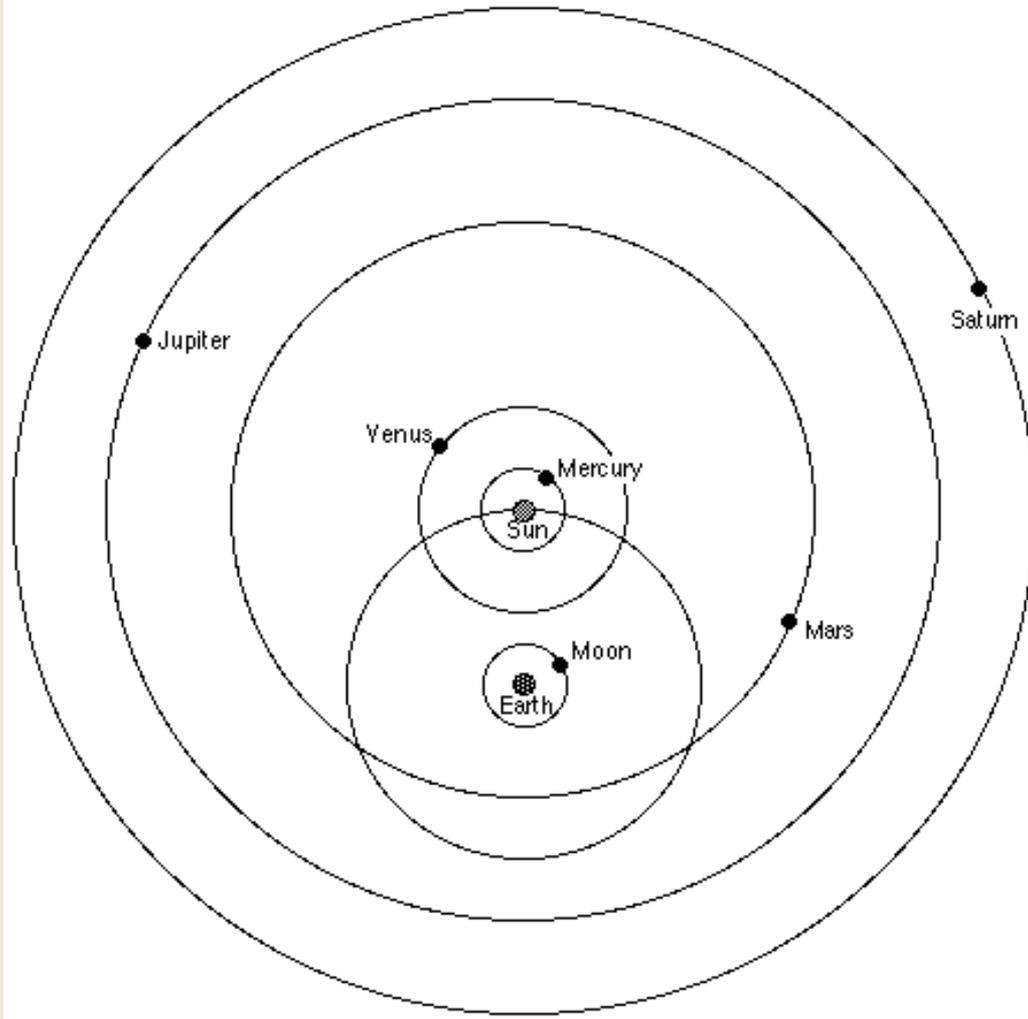


B

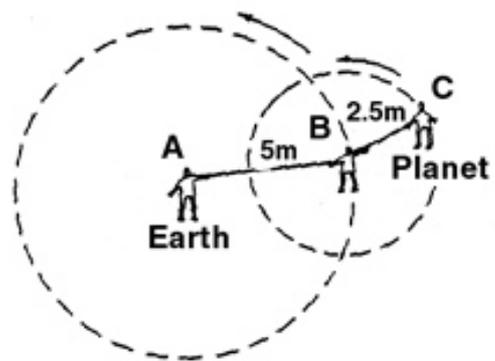


C

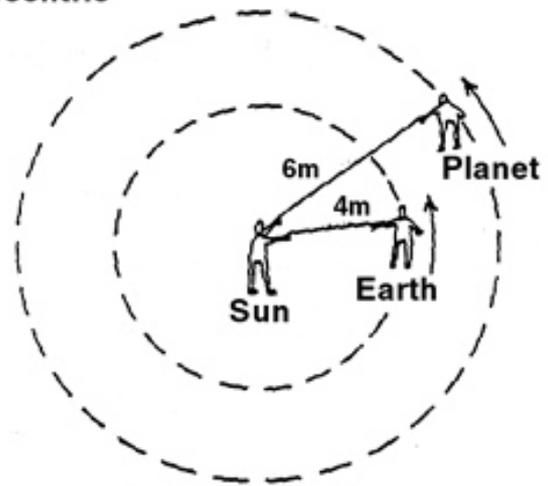
Brahe's Model of the Solar System



geocentric

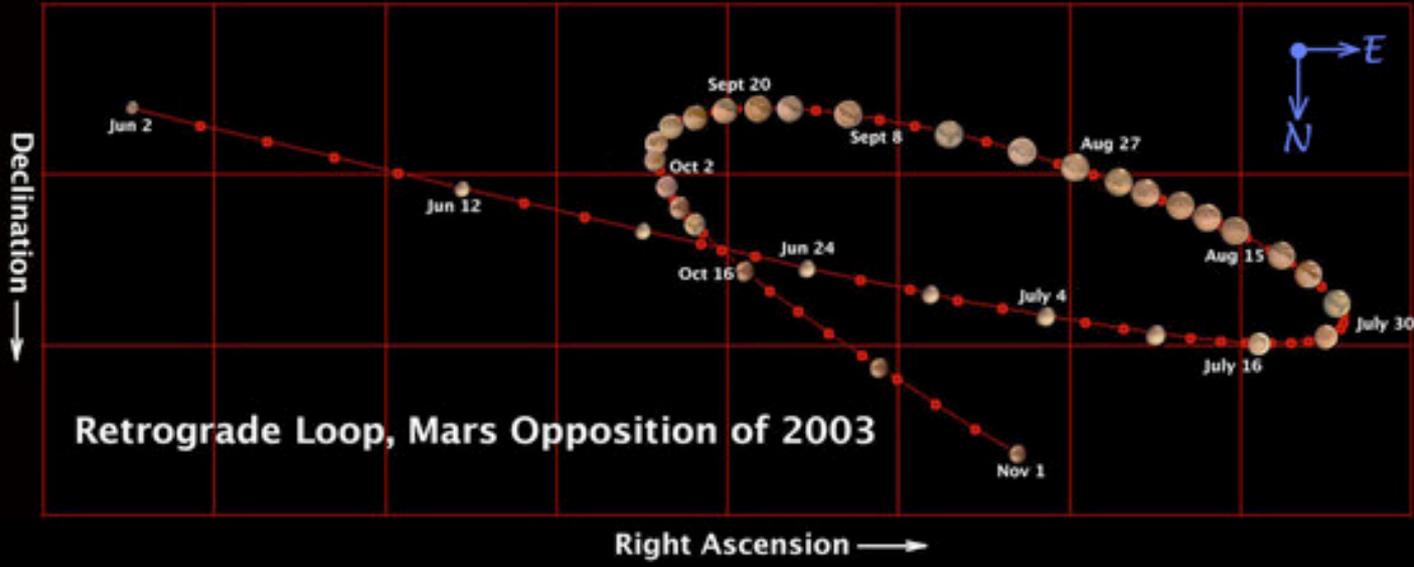


heliocentric





Aug 6 Aug 20 Aug 28 Aug 31 Sept 5 Sept 16 Sept 26 Oct 7



Bonus Material...

Sun's path through the year