

# **The Copernican Revolution**

The Beginning of Modern  
Astronomy

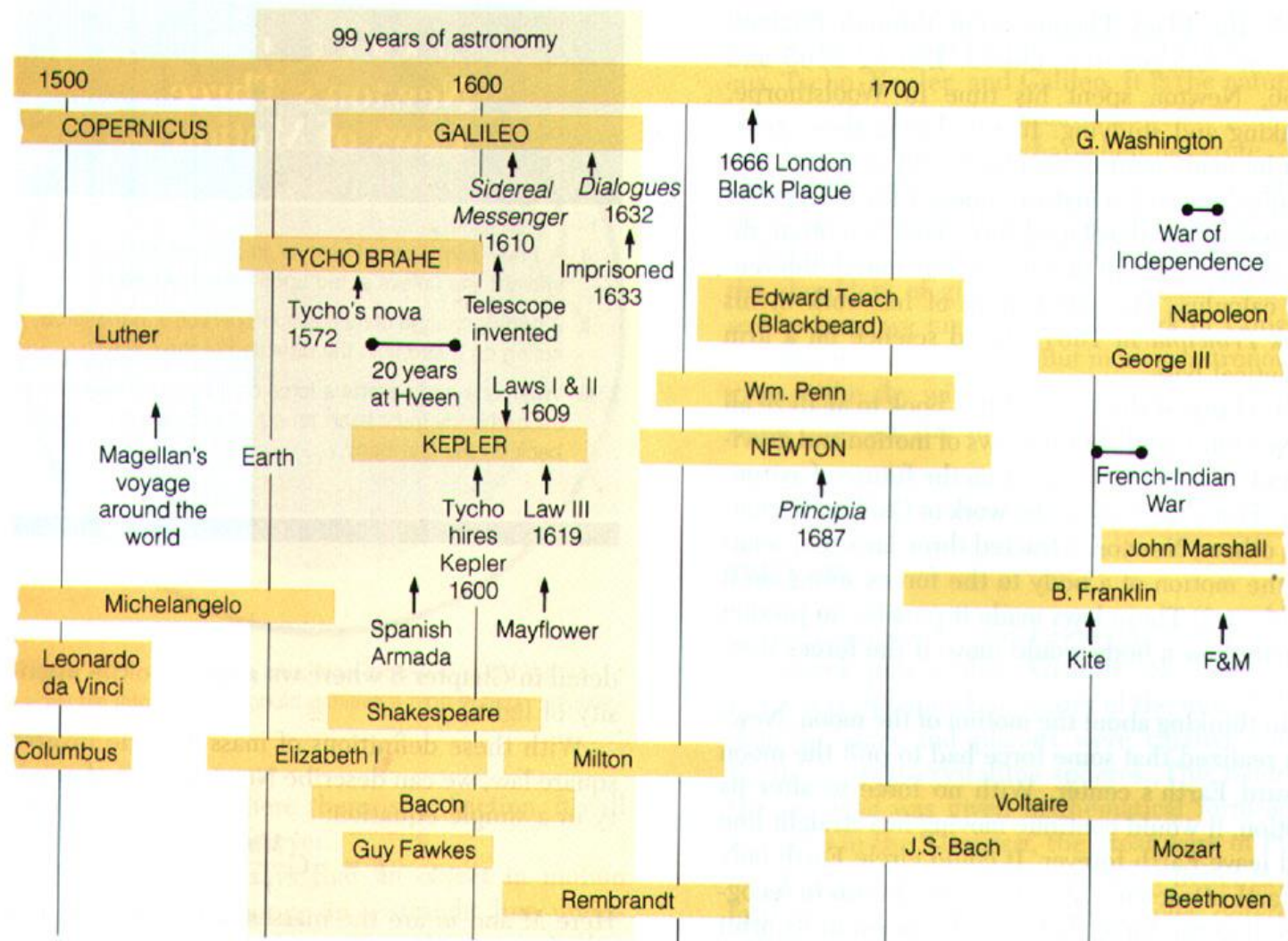
# The 15th Century

- In 1453 Ottoman Turks overrun Constantinople.
- Romans flee west into Europe and take books with them.
- This ends the Middle Ages.
- Most people cannot read or write and generally believe that:

# The 15th Century Astronomy

- Earth is stationary sphere at the center of heaven. It's habitable surface is a flat circle with Jerusalem at it's center.
- Stars and planets made of a perfect substance called aether a 5<sup>th</sup> heavenly element.
- Moon, sun and stars held in place by invisible crystalline spheres.
- Heaven is its own sphere above the stars.
- Hell is where Satan lives and is below the habitable surface of earth.

# 99 Years That Shook Astronomy



**Figure 4-22** The 99 years between the death of Copernicus in 1543 and the birth of Newton in 1642 marked the transition from the ancient astronomy of Ptolemy and Aristotle to the revolutionary theory of Copernicus. This period saw the birth of modern scientific astronomy.

Recall that astronomical models need to explain the following observations of the sky:

1. Why does the celestial sphere appear to move east to west each day (diurnal motion)?
2. Why do the Sun and planets appear to move eastward along the Zodiac?
3. How can planetary alignments such as oppositions and conjunctions be explained?
4. Why are Mercury and Venus never seen opposite of the Sun in the sky?
5. Why do planets have retrograde motion that causes them to appear to go backwards?

# Claudius Ptolemy(90AD -168AD )

Roman Citizen who studied Math,  
Astronomy, Geography, and Astrology.

Suggested an Earth centered Universe in a  
book titled *Almagest*.

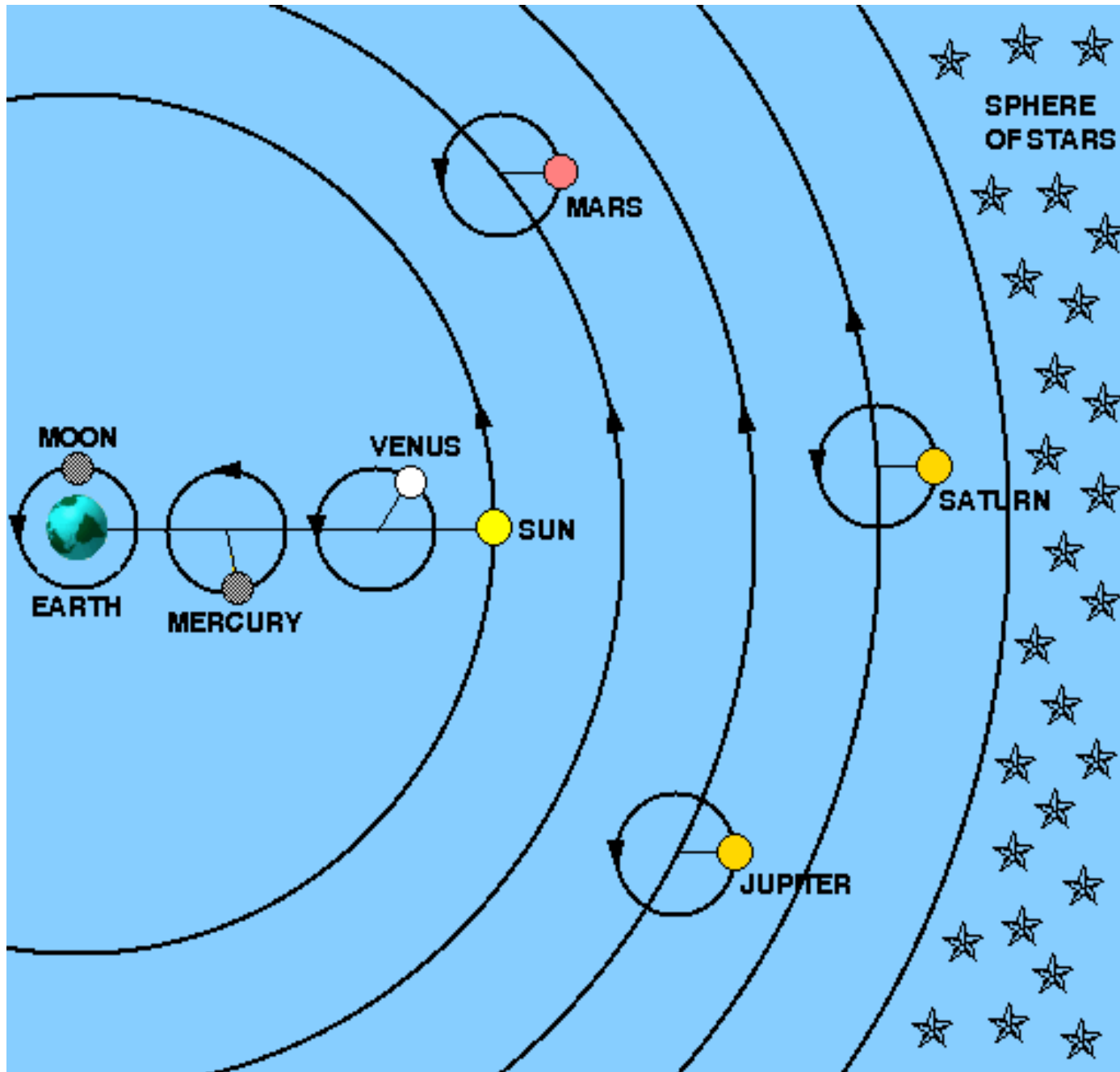
Developed geometric models that he used  
to compute the past and future position of  
the planets.

Created a star catalogue containing 48  
constellations.

Thought to be the FINAL word on  
Astronomical matters through to the end  
of the middle ages.



# Ptolemy's Model





# Nicholas Copernicus (1473-1543)

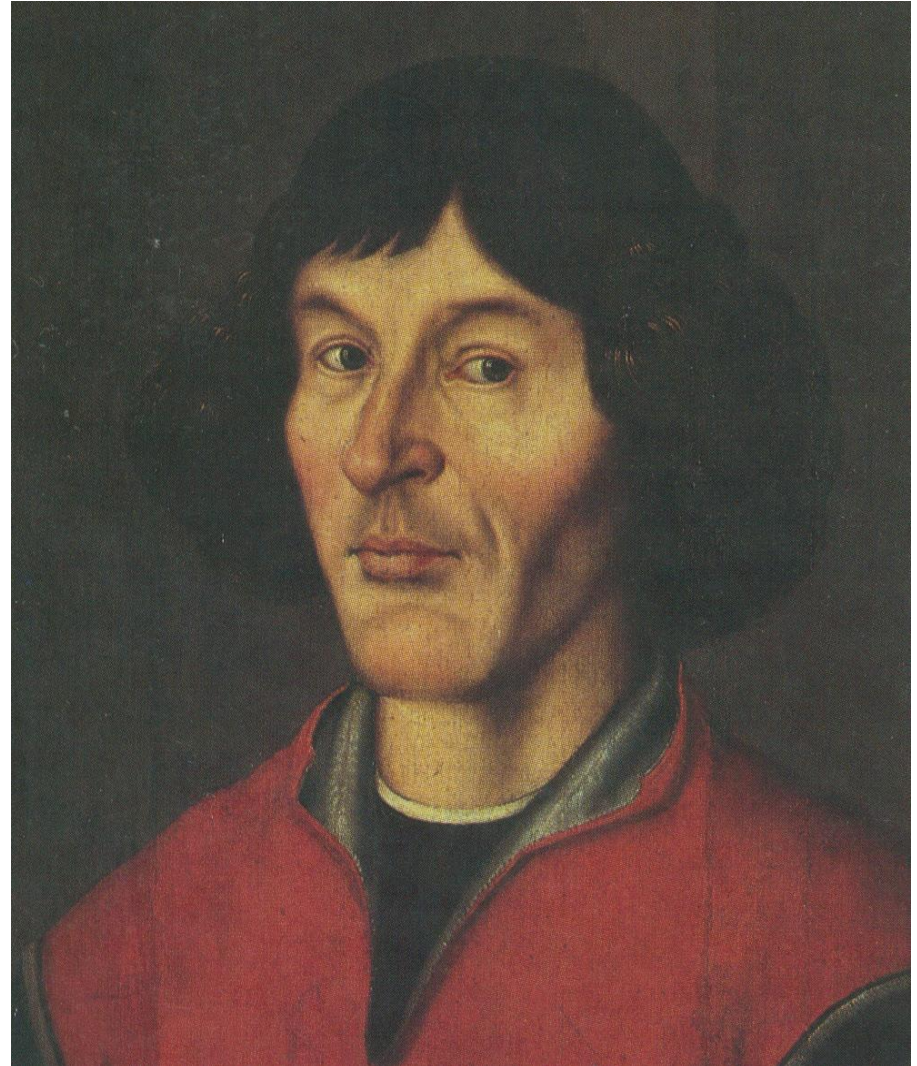
Polish Catholic Cleric

Observed night sky from  
an observation tower.

Trying to solve the calendar  
problem.

Suggested a Sun centered  
Universe in a book titled *De  
Revolutionibus*, which was not  
published until  
the year he died.

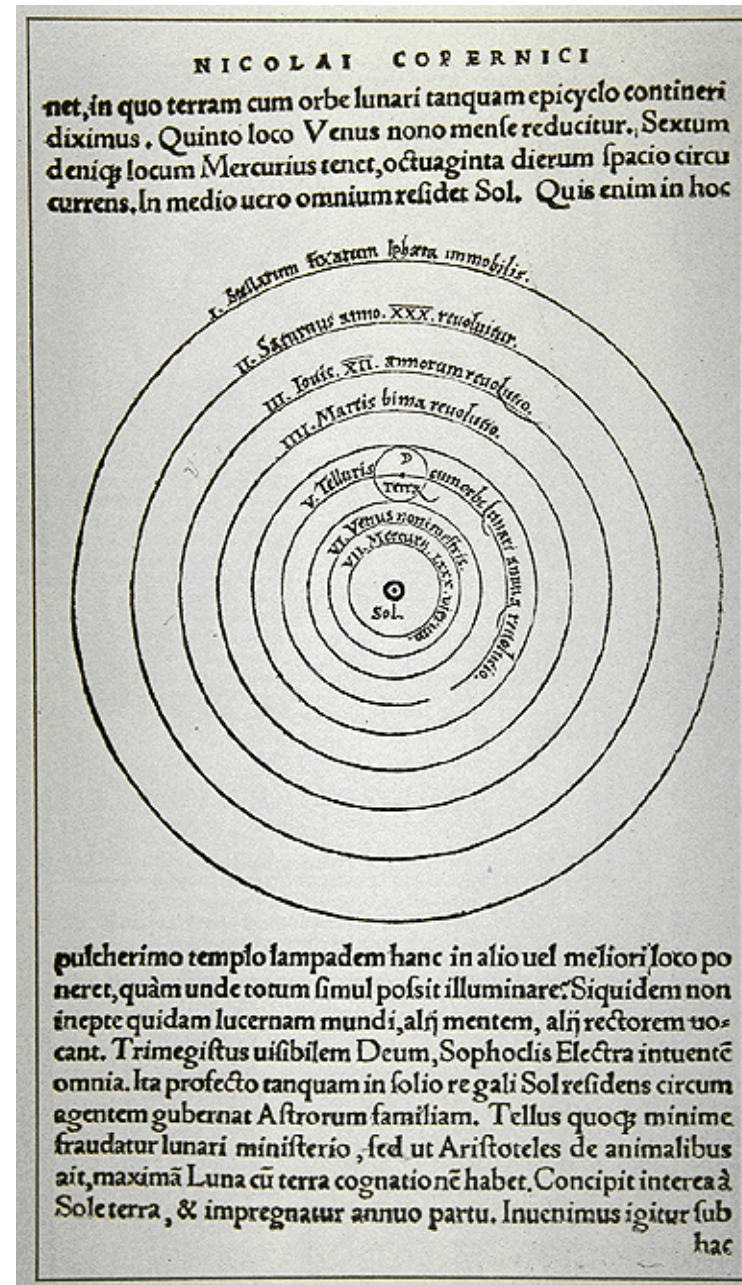
NOTE: He was well educated  
and had read Greek astronomy.



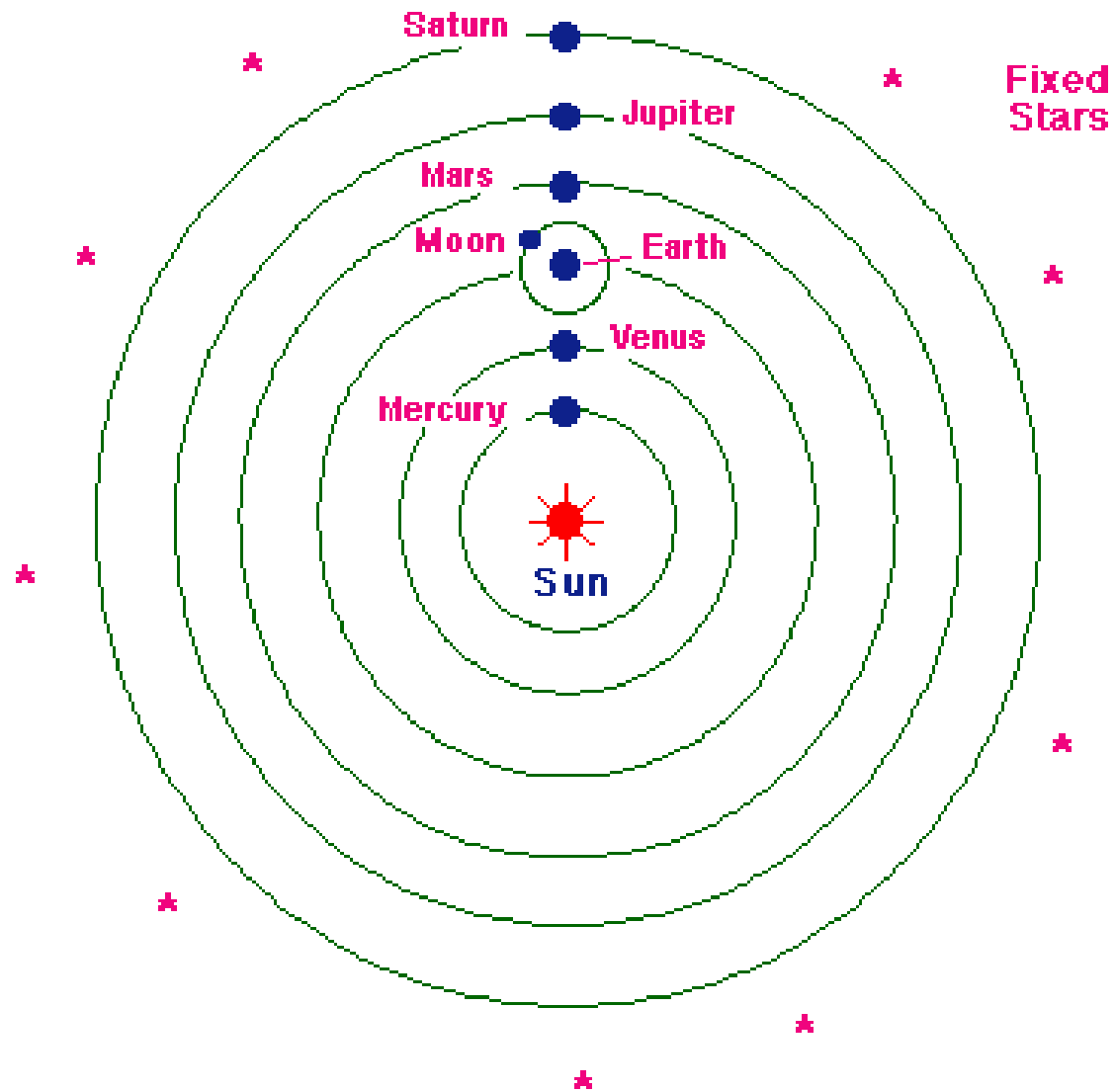


# Copernican Model

- Heliocentric Universe
- *De Revolutionibus Orbium Celestium* (On the Revolutions of the Heavenly Spheres)
- Idea was opposed by the Catholic Church (recall Cosmas flat earth and pagans round earth.)



# Copernican Model

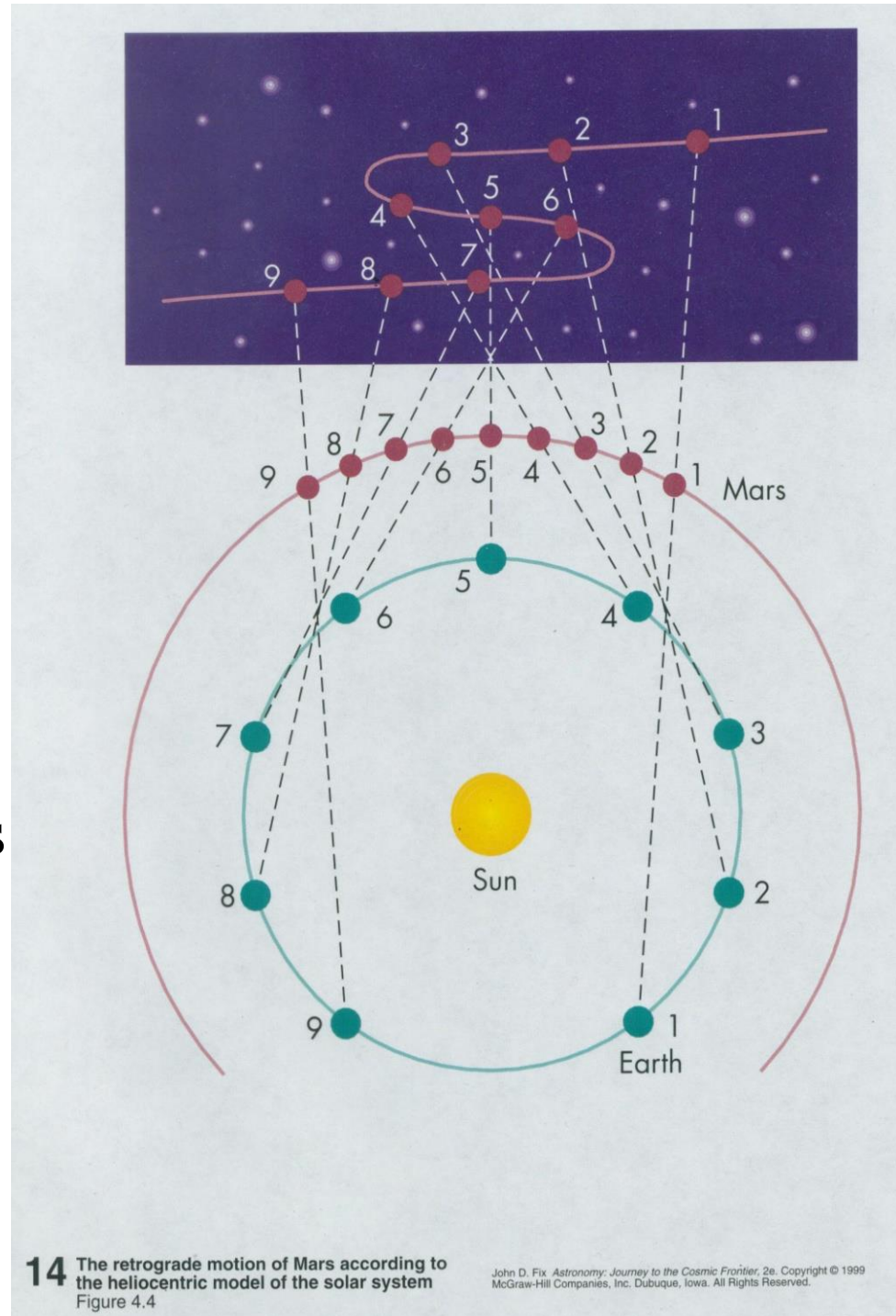


# Copernican Model Explained

- Earth's rotation caused daily motion from east to west.
- Mercury and Venus were inferior planets, which explained why they are always seen near the Sun.
- Sun's annual motion along the ecliptic (Zodiac) was caused by Earth's orbital motion (this one was difficult to accept.)
- Retrograde motion was a natural phenomenon of one planet passing another planet as they orbited the Sun.

# Retrograde Motion

As a faster moving planet overtakes and passes a slower moving superior planet the superior planet **appears** to move backwards as you pass by it.



# Copernican Model

## Why believe Copernican model?

- Ptolemy's model had worked for 1500 years.
- Ptolemy's model provided a metaphor of the earth and humans living at the center of God's creation.
- Copernicus did not prove that the Earth orbited the Sun.
- Copernican model did not predict the positions of planets any better than Ptolemy's model.



# Occam's Razor



- William of Occam England, 14<sup>th</sup> Century
- "If you have two theories which both explain the observed facts then you should use the simplest until more evidence comes along"
- "The simplest explanation for some phenomenon is more likely to be accurate than more complicated explanations."
- KISS

# Copernican Model

## Why believe Copernican model?

- It was aesthetically more pleasing.
- It was more simple.
- It explained complex motions as naturally occurring.

# SN 1572, Tycho's Supernova

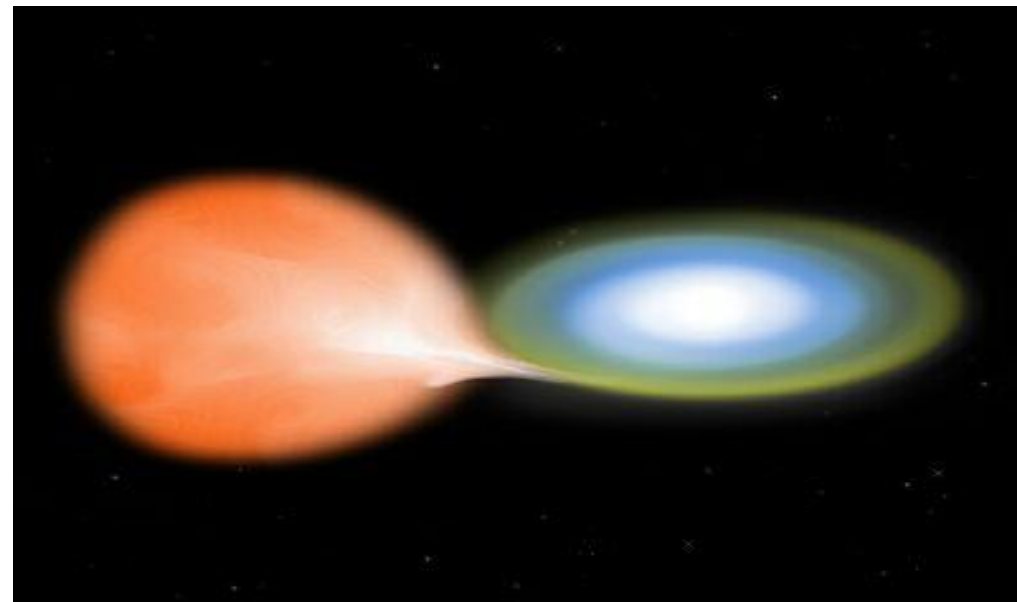
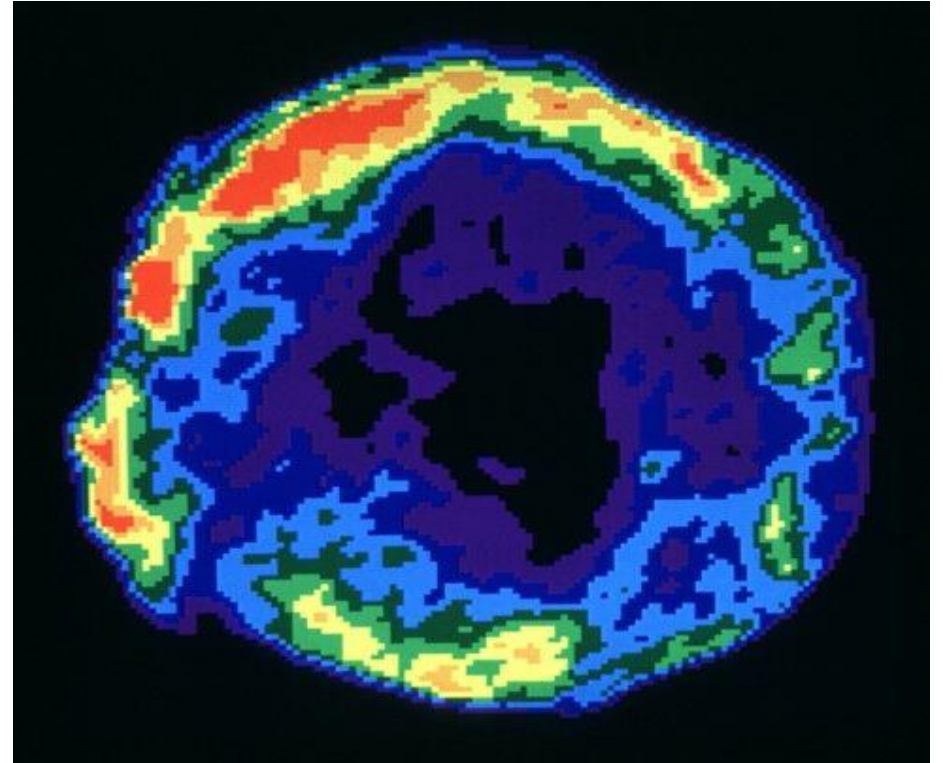
"On the 11th day of November in the evening after sunset, I was contemplating the stars in a clear sky. I noticed that a new and unusual star, surpassing the other stars in brilliancy, was shining almost directly above my head; and since I had, from boyhood, known all the stars of the heavens perfectly, it was quite evident to me that there had never been any star in that place of the sky, even the smallest, to say nothing of a star so conspicuous and bright as this. I was so astonished of this sight that I was not ashamed to doubt the trustworthiness of my own eyes. But when I observed that others, on having the place pointed out to them, could see that there was really a star there, I had no further doubts. A miracle indeed, one that has never been previously seen before our time, in any age since the beginning of the world."

# SN 1572, Tycho's Supernova



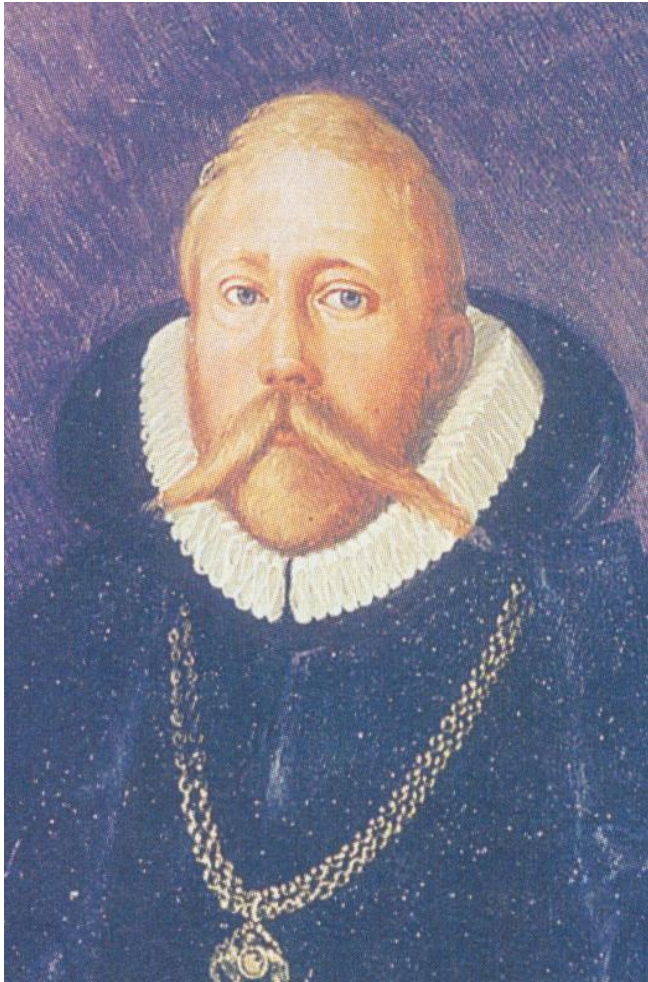
<http://www.seds.org/~spider/spider/Vars/sn1572.html>

This showed him the universe was not changeless and it shook his very core beliefs.



<http://www.solstation.com/x-objects/tycho-s.htm>

# Tycho Brahe (1546-1607)

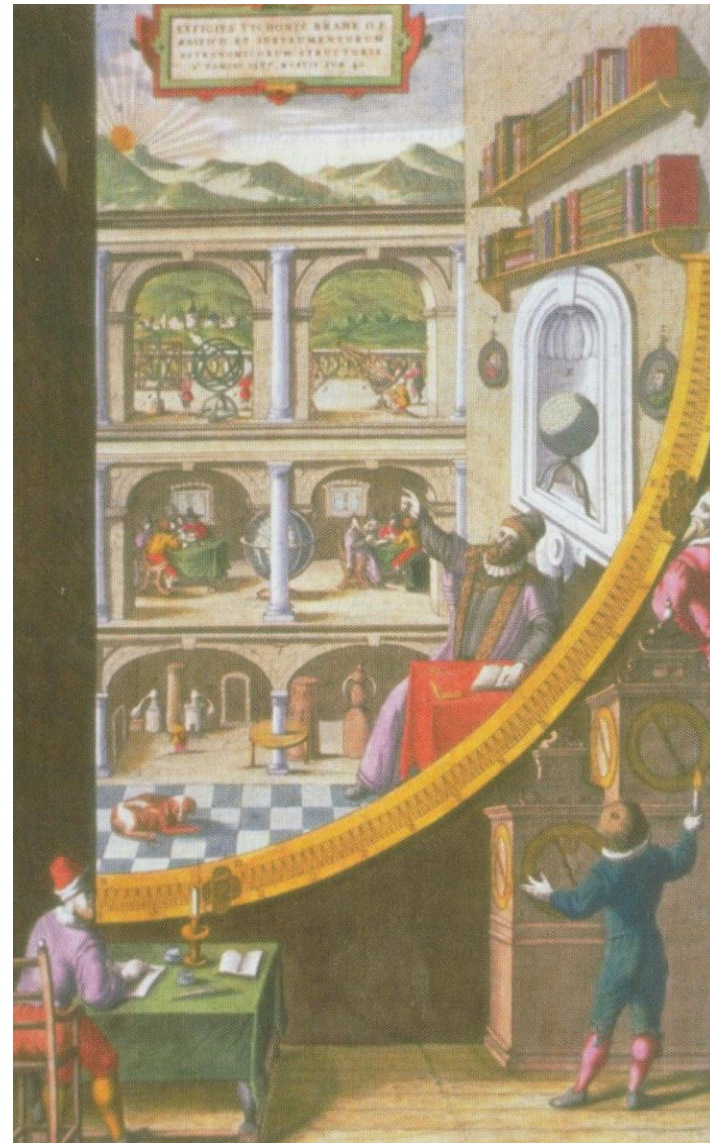


- Supernova caused him to do research astronomy
- Danish nobleman
- Keen eyed observer
- Had a gold nose.
- Built an observatory named Uraniborg on the Danish island of Hveen.



# Tycho's Observatory

- Used for 20 years.
- Largest quadrants in the world.
- Made the most accurate observations of planetary and star positions ( $\pm 1$  arcminute.)
- 1 arcminute is  $1/60$  of a degree.



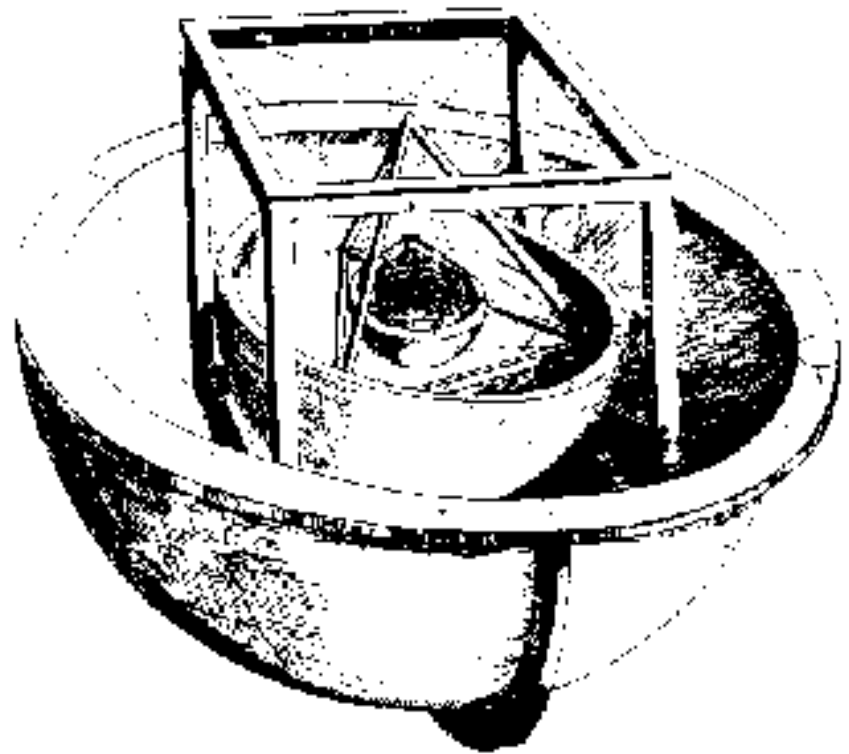
# Johannes Kepler (1571-1630)



- German Lutheran theologian & mathematician.
- Sought to prove Copernican model correct.
- He saw Copernican model as representing God in the center of the universe with his creation surrounding him.

# Kepler's Model

- He believed that God created the universe using the language of geometry.
- Used the 5 regular solids with equal sized faces to hold up the celestial spheres.
- That explained why there were only 6 planets.
- **TOTALLY WRONG**, but he believed in it until he died.



# Kepler & Tycho

- Kepler was exiled from Graz for being Lutheran.
- Tycho had left Uraniborg for Prague.
- Tycho invited Kepler to join him Prague.
- A strained relationship and collaboration developed. (They did not like each other!)

# Kepler & Tycho

- Kepler needed Tycho's precise observations to prove his model of nested spheres.
- Tycho needed Kepler's theoretical and mathematical mind to prove Tycho's model to be correct (a strange combination of an Earth centered and Copernican model that never gained favor.)

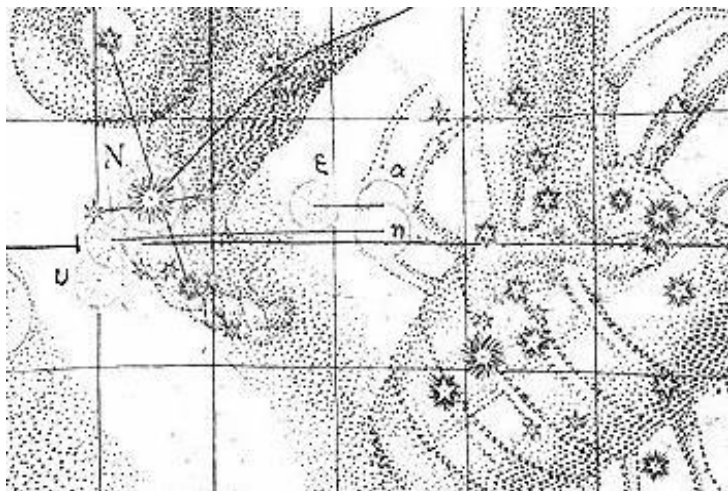


# SN 1604, Kepler's Supernova

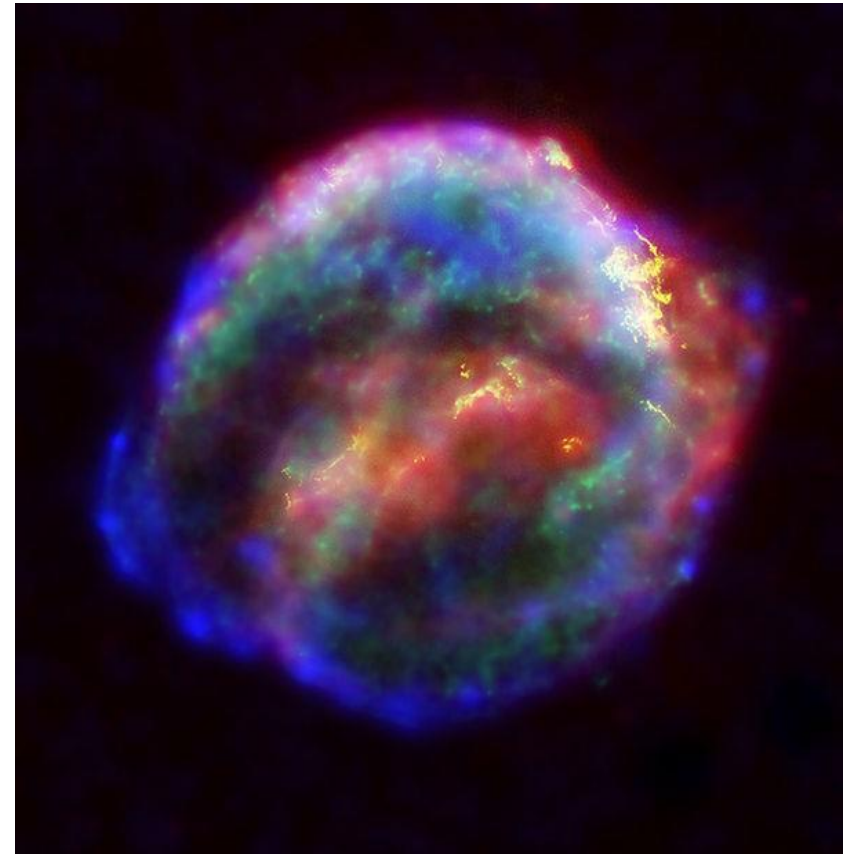
A few years before Tycho died another supernova was observed by Kepler in constellation of Ophiuchus on October 17<sup>th</sup> 1604.

It had been observed by others as early as Oct. 4<sup>th</sup>.

(Last known supernova in Milky Way.)



<http://www.seds.org/~spider/spider/Vars/sn1604.html>



[http://en.wikipedia.org/wiki/Johannes\\_Kepler](http://en.wikipedia.org/wiki/Johannes_Kepler)

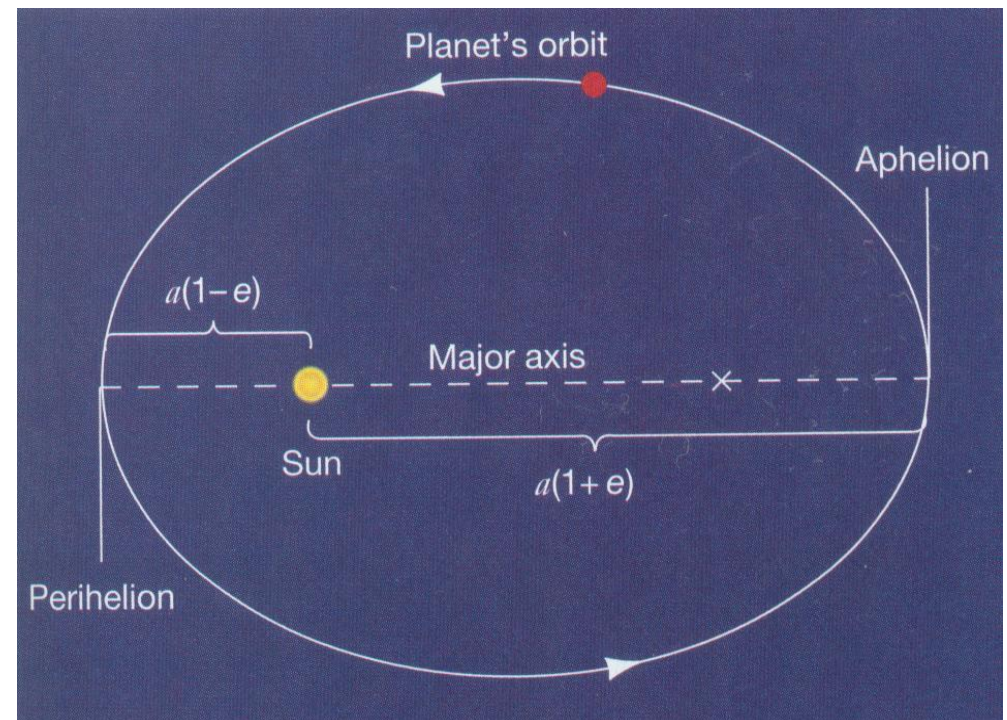
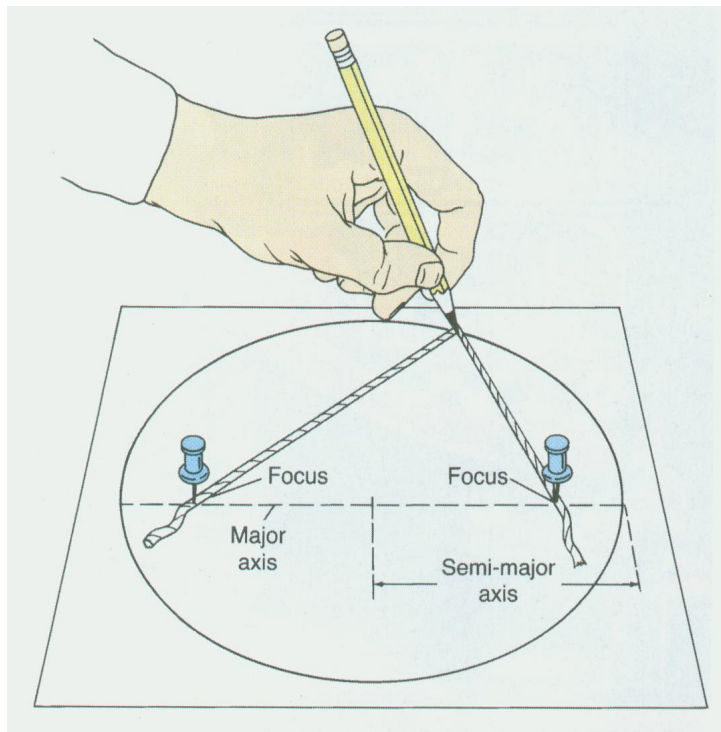
# Kepler & Tycho

- After Tycho's death, and many court battles with his relatives, Kepler gained access to Tycho's data.
- Tycho had always claimed that the data for Mars was the most difficult to reconcile with any theory.
- Working on Mars caused Kepler to abandon perfect circular orbits and replace them with elliptical orbits.

# Kepler's Laws

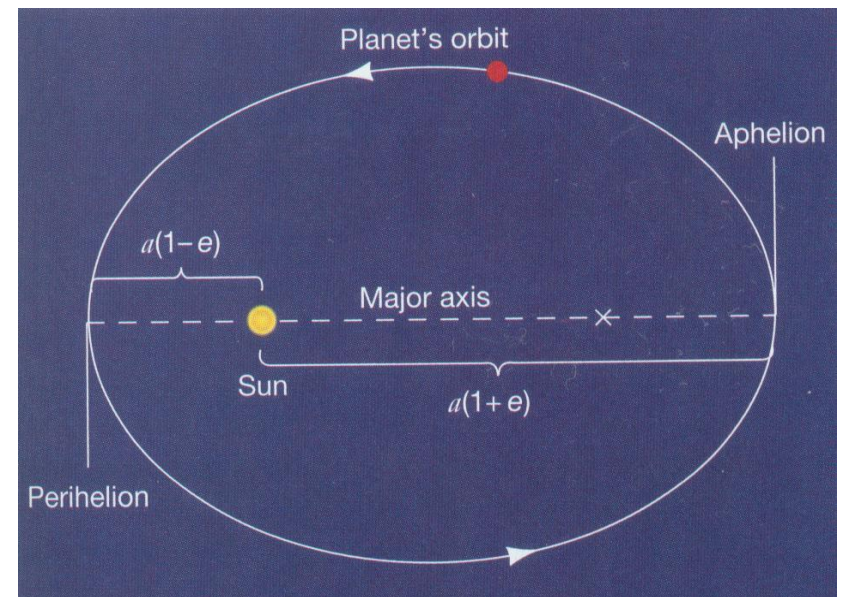
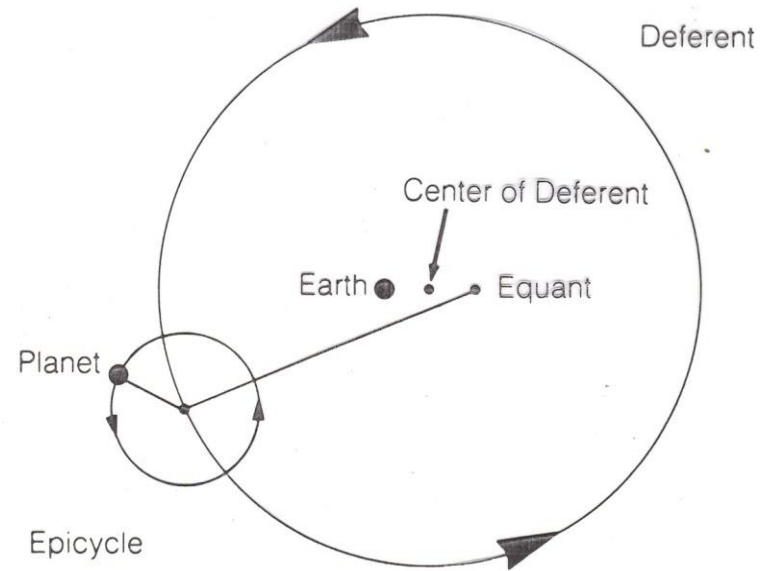
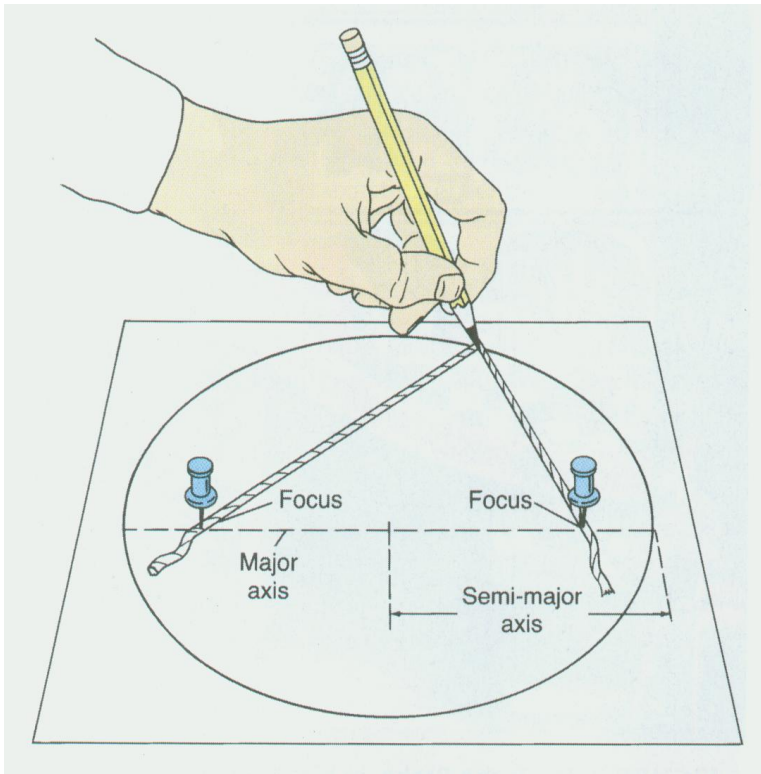
## 1<sup>st</sup> Law

- Planets orbit the Sun in elliptical paths with the Sun at one focus.





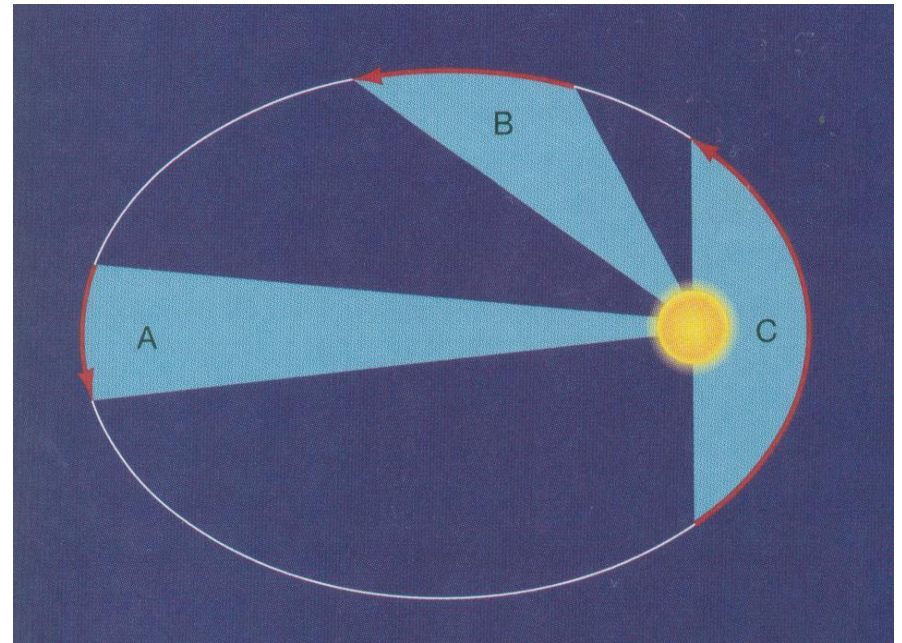
# Kepler & Ptolemy



# Kepler's Laws

## 2<sup>nd</sup> Law

- Law of Areas
- A line connecting the Sun and a planet sweeps out equal areas in equal times.
- This means that a planet moves fastest when it is closest to the Sun.





# Kepler's Laws

## 3rd Law

- The Harmonic Law
- $P^2 = a^3$  where
  - $P$  = orbital period in years
  - $a$  = semi-major axis in Astronomical Units (au).

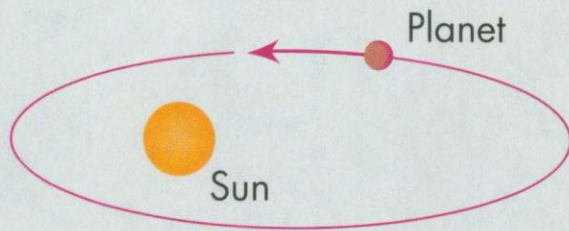
An au = average distance between Earth and Sun  
~ 93,000,000 miles or 150,000,000 Km.

# Kepler's Laws

## 3rd Law

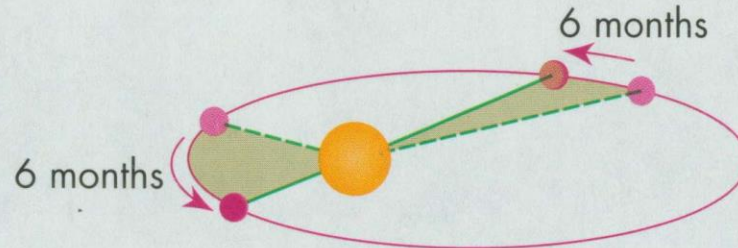
- Example Calculation for Jupiter
- $a = 5.2 \text{ au's}$
- $P^2 = a^3$  substituting for a
- $P^2 = (5.2)^3 = 5.2 \times 5.2 \times 5.2 = 140.6$
- Take square root of 140.6
- $P = 11.86 \text{ years}$

# Review of Kepler's Laws



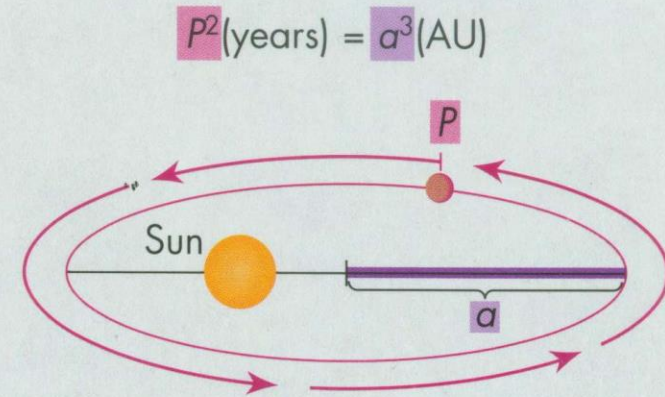
**A**

1<sup>st</sup> Law



**B**

2<sup>nd</sup> Law

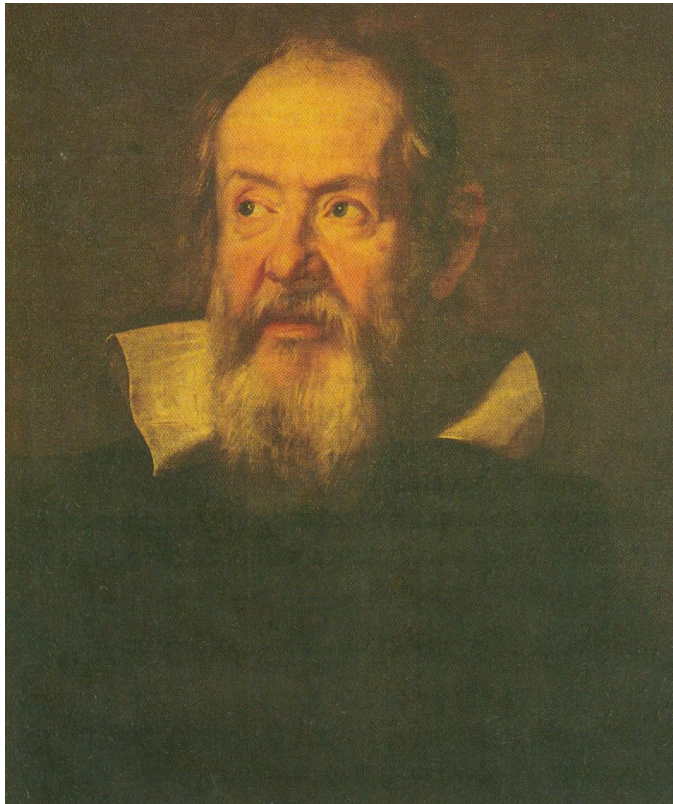


$P^2(\text{years}) = a^3(\text{AU})$   
 $P$  = time to complete orbit  
 $a$  = semi-major axis

**C**

3<sup>rd</sup> Law

# Galileo Galilei (1564-1642)



- The father of Physics
- First person to point a telescope at the night sky.
- In 1610 he wrote *The Starry Messenger* in which he published his observations.

# Galileo's Telescopic Discoveries



- Craters on Moon
- Sunspots
- Moon's of Jupiter
- Phases of Venus

**All of these data were used as evidence for the Copernican Model.**

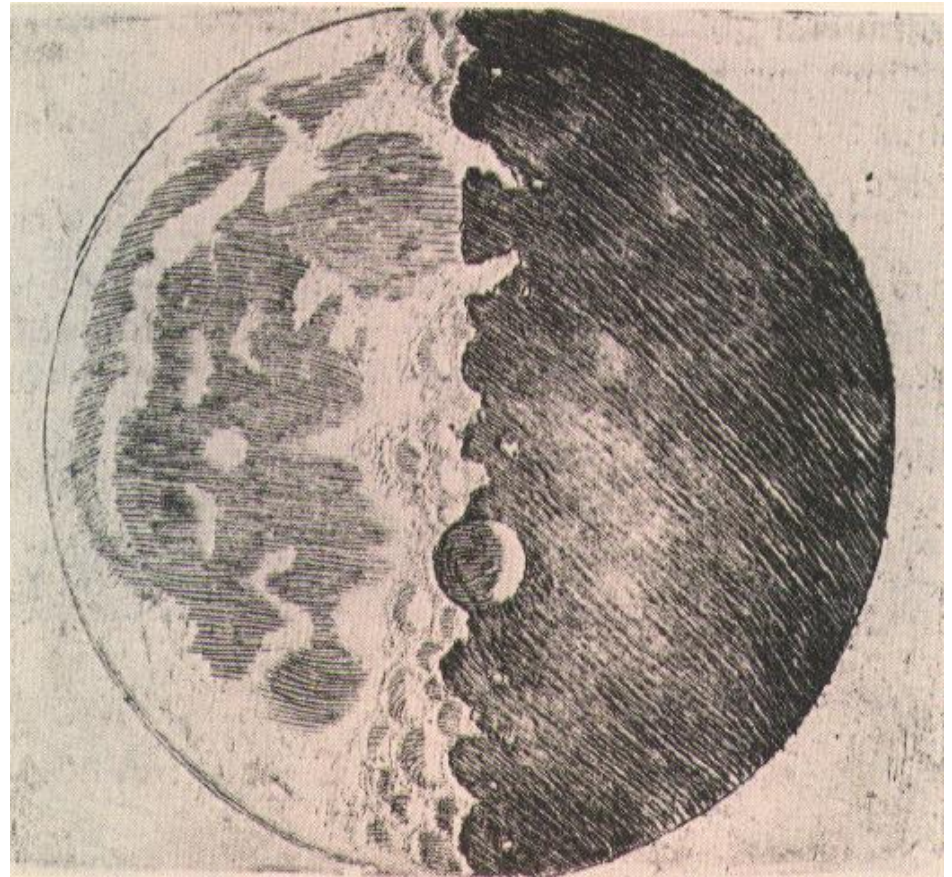
Replica of Galileo's telescope from

<http://www.museum.vic.gov.au/scidiscovery/scientists/galileo.asp>



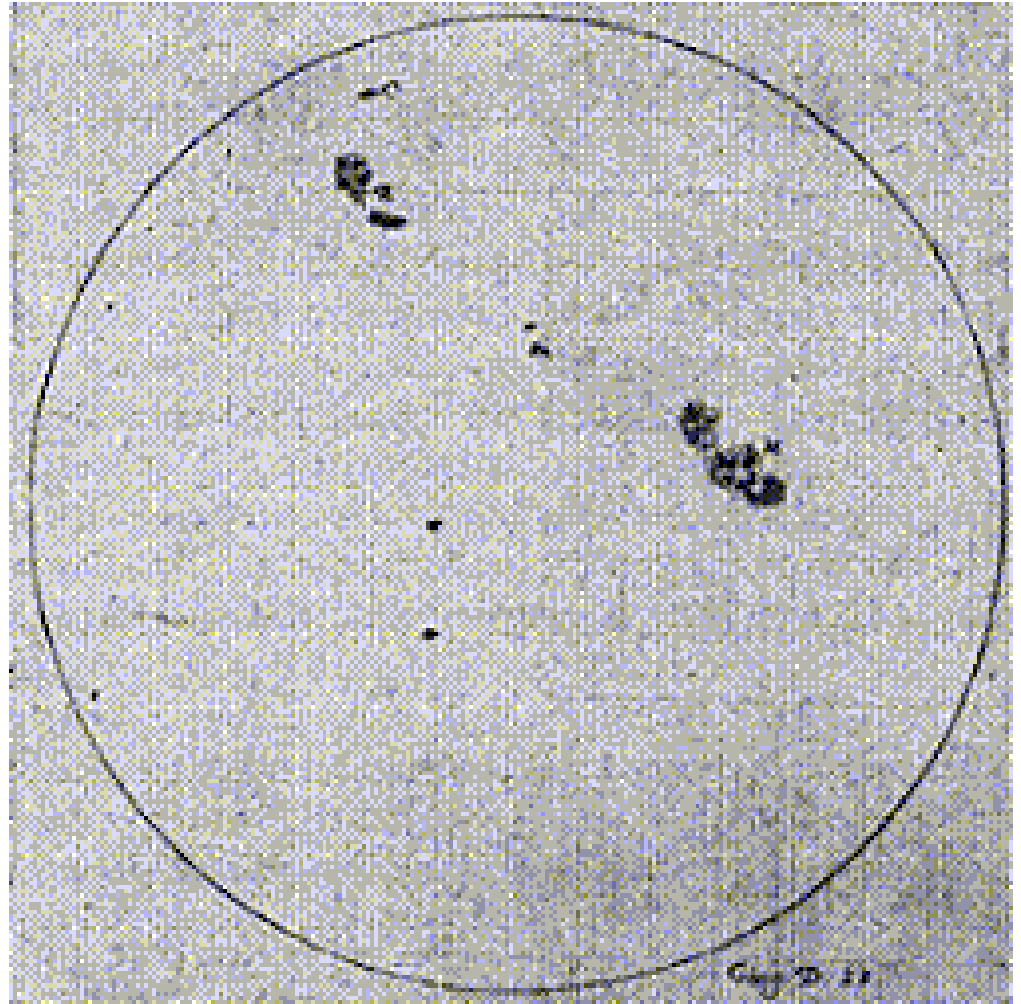
# Craters on the Moon

- Moon is NOT perfect
- It has craters
- It has mountains



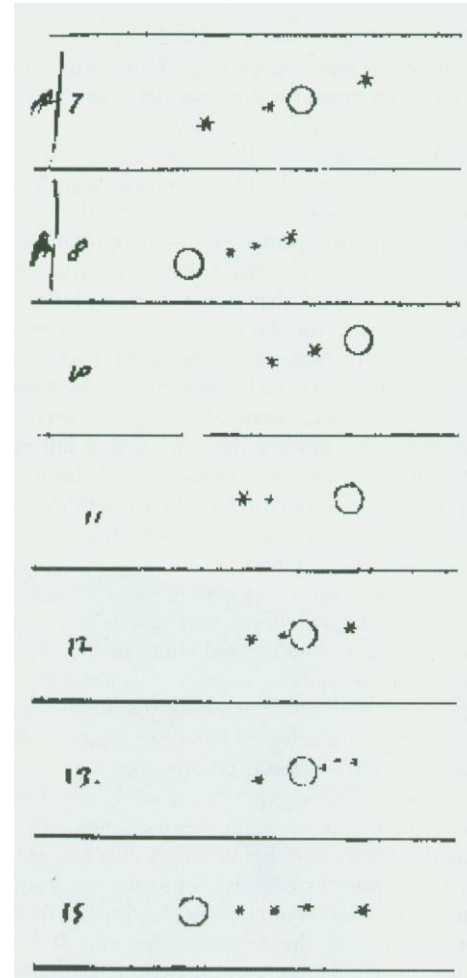
# Sunspots

- Sun is NOT perfect.
- It has dark spots.
- What are sunspots?
- The Sun may rotate, which implies the Earth may rotate.



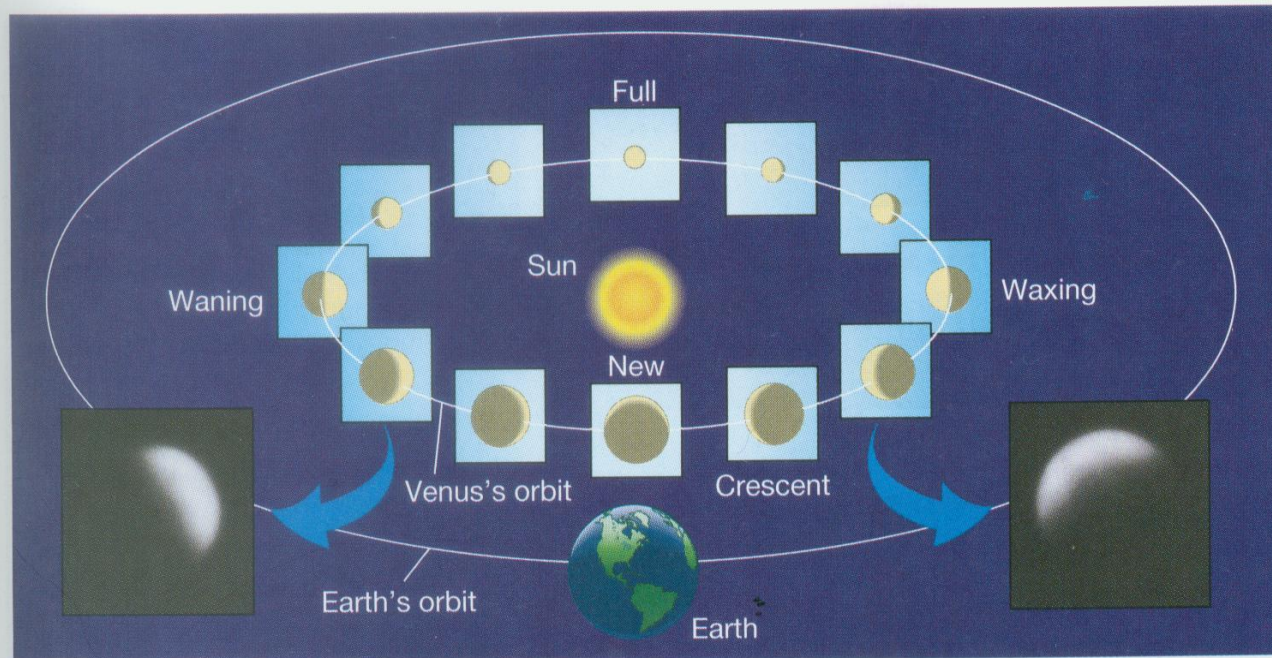
# Moons of Jupiter

- January 7-15, 1610
- These moon's do not revolve around the Earth or the Sun!
- They form a miniature solar system of their own.

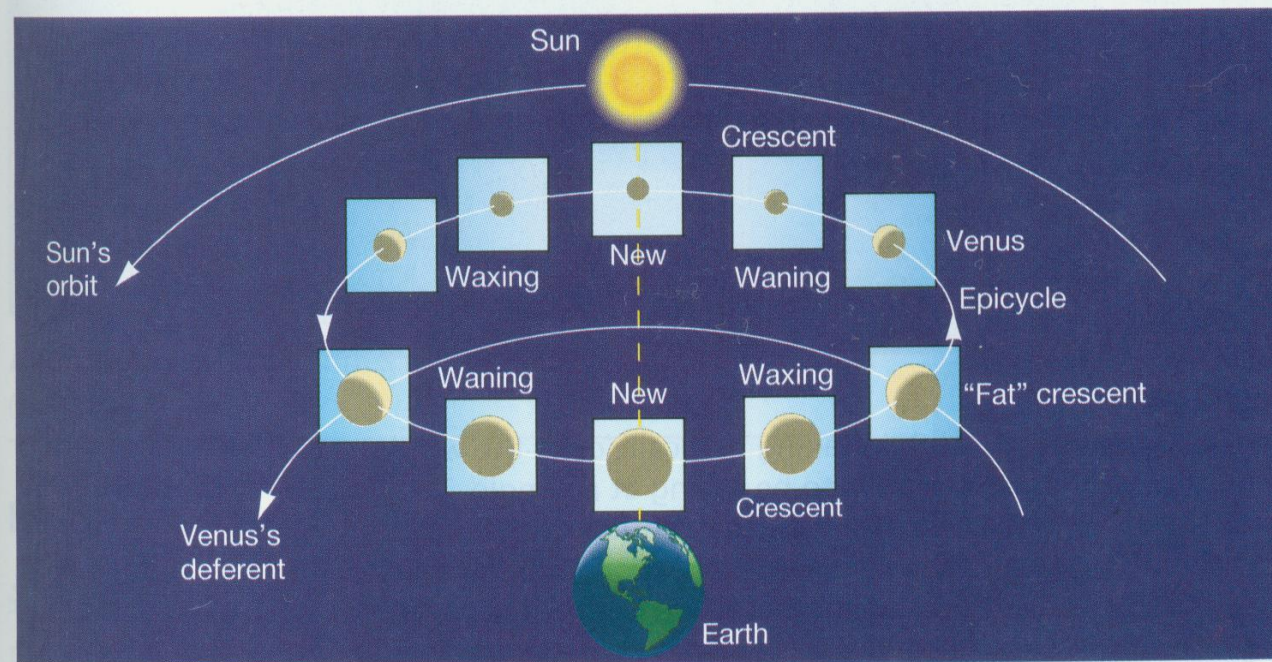
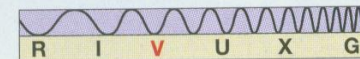




# Phases of Venus



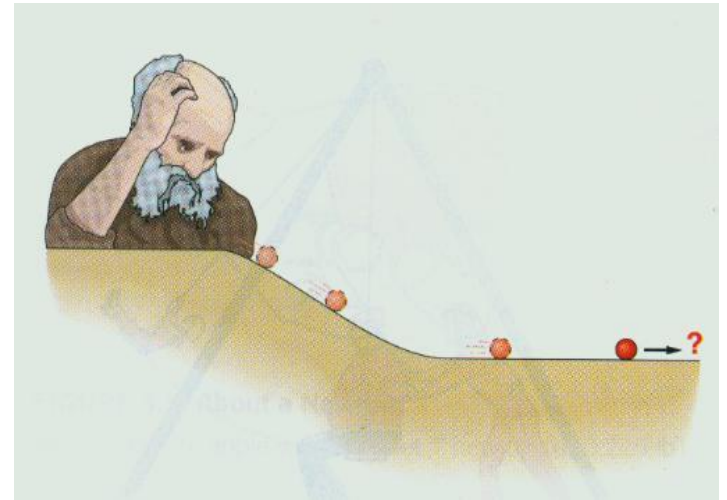
(a) Sun-centered model



(b) Ptolemy's model

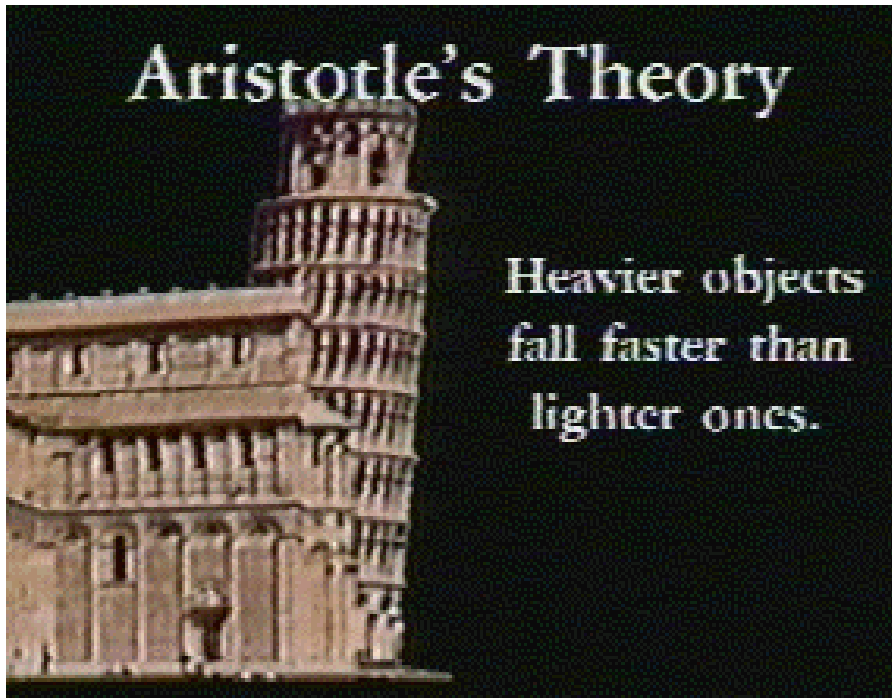
# Galileo Galilei's Observations

- Studied balls rolling down inclined planes.
- The smoother and more polished the surface the farther the ball rolled.
- Therefore, balls rolling down infinitely smooth surfaces roll infinitely far.
- Counter to Aristotle!

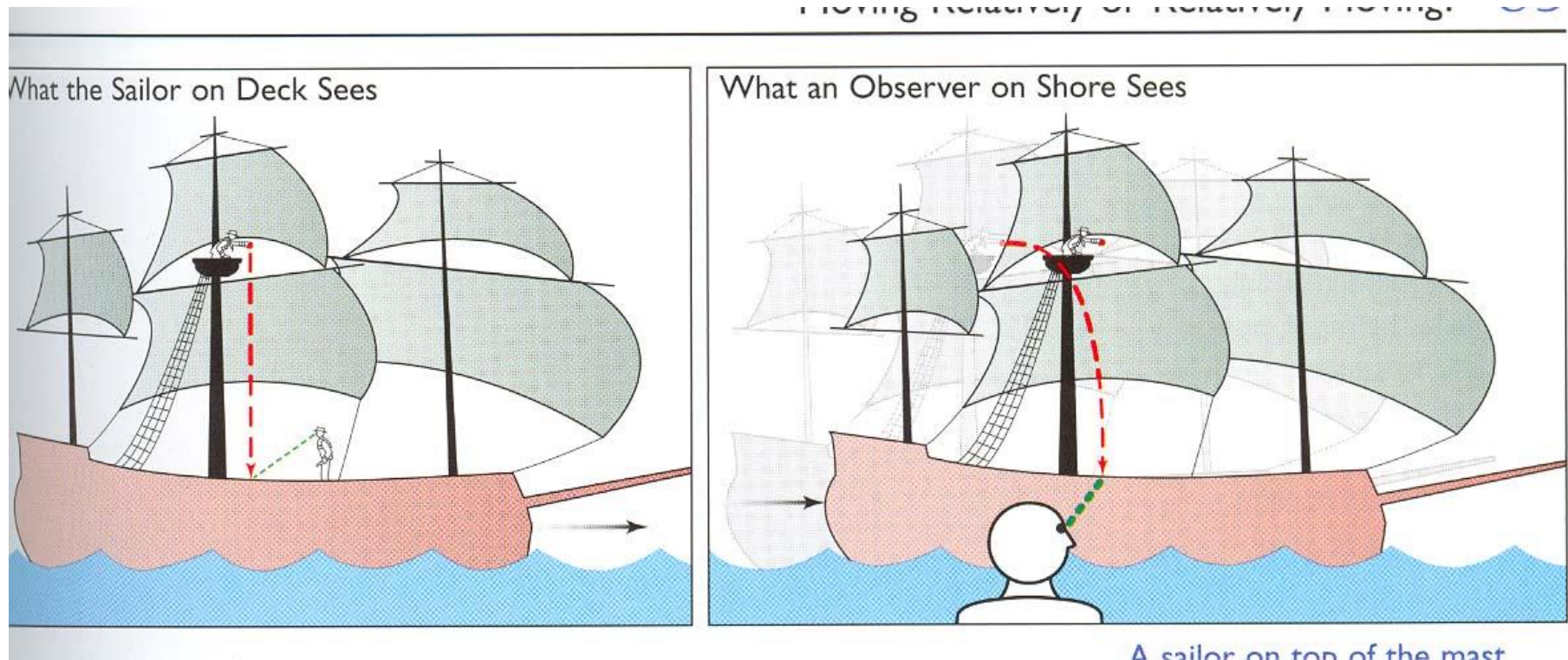




# Galileo Galilei's Observations



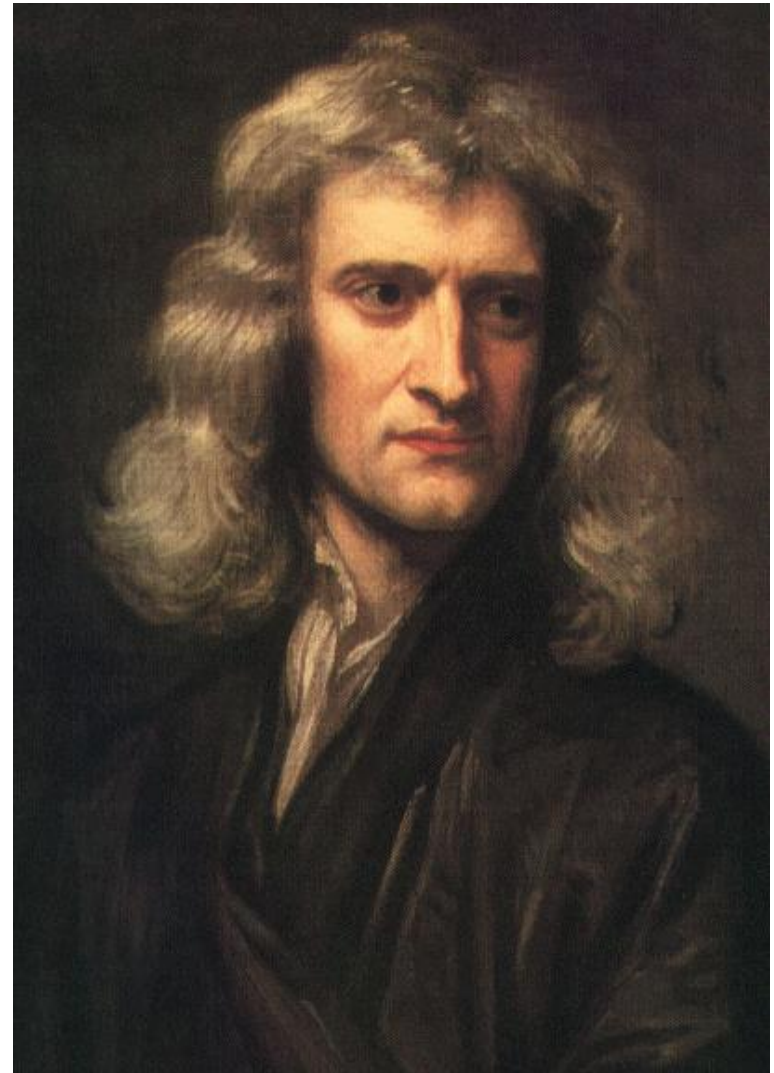
# Galileo Galilei's Observations



Object dropped from a moving object continues to move in direction of the moving object.

# Isaac Newton (1642-1727)

- Develops Laws of Motion
- Develops idea of gravity to get Edmund Halley off his back.
- Halley paid to publish *Mathematical Principles of Natural Philosophy*.
- Derived Kepler's three laws of planetary motion using laws of motion and gravity.



# Newton's Laws

## 1<sup>st</sup> Law

- Law of Inertia
- A body at rest will remain at rest, and a body in motion will remain in motion, unless acted upon by an unbalanced force.



# Newton's Laws

## 2nd Law

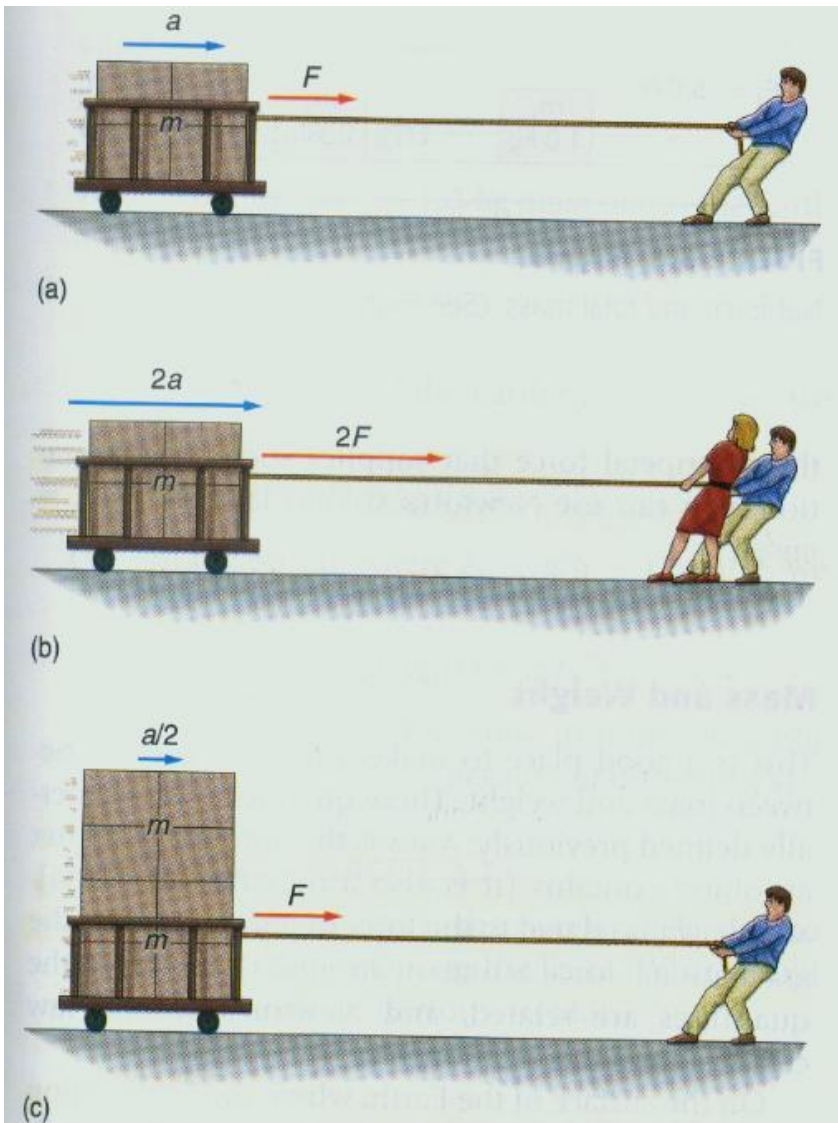
- An acceleration is caused by an unbalanced force acting on an object and is directly proportional to the magnitude (strength) of the force applied in the direction of the force.
- The acceleration of an object being acted upon by an unbalanced force is inversely proportional to the object's mass,  $m$ .



# Newton's Laws

## 2nd Law

- Force Law
- $F = ma$
- Force units are,  
 $F = (\text{kg})(\text{m}/\text{s}^2) = \text{N}$  ( 1 Newton).
- 1N ~ the weight of an apple.



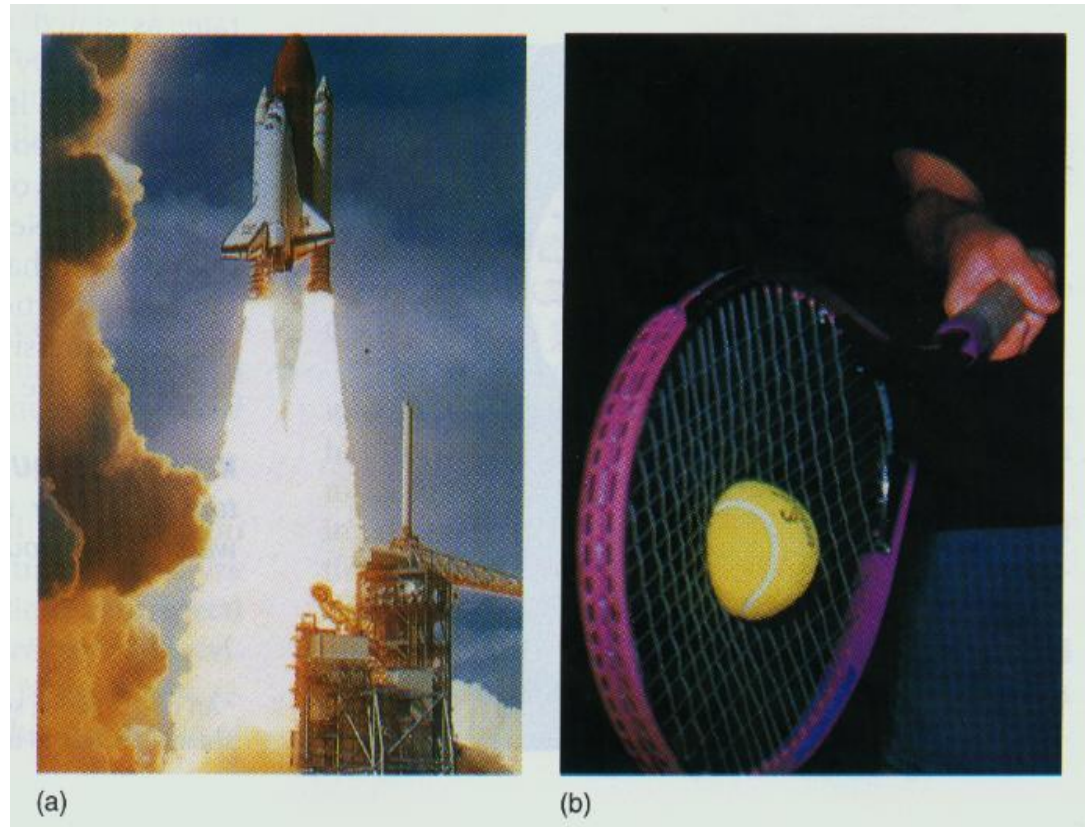
**FIGURE 3.4 Force, Mass, and Acceleration**

(a) An unbalanced force  $F$  acting on a mass  $m$  produces an acceleration  $a$ . (b) If the mass remains the same and the force is doubled, the acceleration is doubled. (c) If the mass is doubled and the force remains the same, the acceleration is reduced by one-half.

# Newton's Laws

## 3rd Law

- Action and Reaction
- For every action there is an equal and opposite reaction.
- $F_1 = -F_2$
- $m_1 a_1 = -m_2 a_2$
- Forces act in opposite directions on different objects.

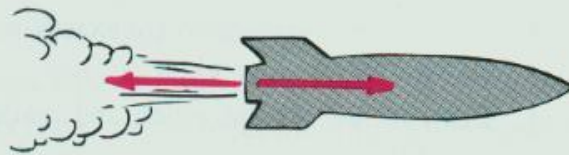


# Newton's Laws

## Examples of 3rd Law



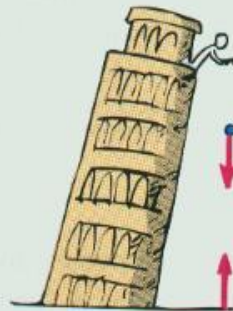
Action: tire pushes on road    Reaction: road pushes on tire



Action: rocket pushes on gas    Reaction: gas pushes on rocket



Action: man pulls on spring    Reaction: spring pulls on man



Action: earth pulls on ball

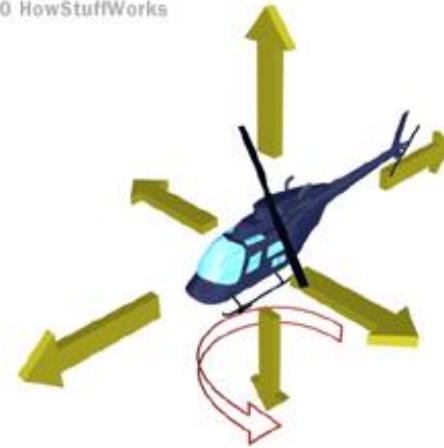
Reaction: ball pulls on earth

# Newton's Laws

## Examples of 3rd Law



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<http://travel.howstuffworks.com/helicopter.htm>

- The rotating blade supports weight of helicopter.
- Rotating blade applies a torque to the helicopter.
- Small tail rotor counteracts torque of



# Newton's Laws

## Examples of 3rd Law

Use 3<sup>rd</sup> law to explain how this helicopter flies.

<http://www.helis.com/introduction/>



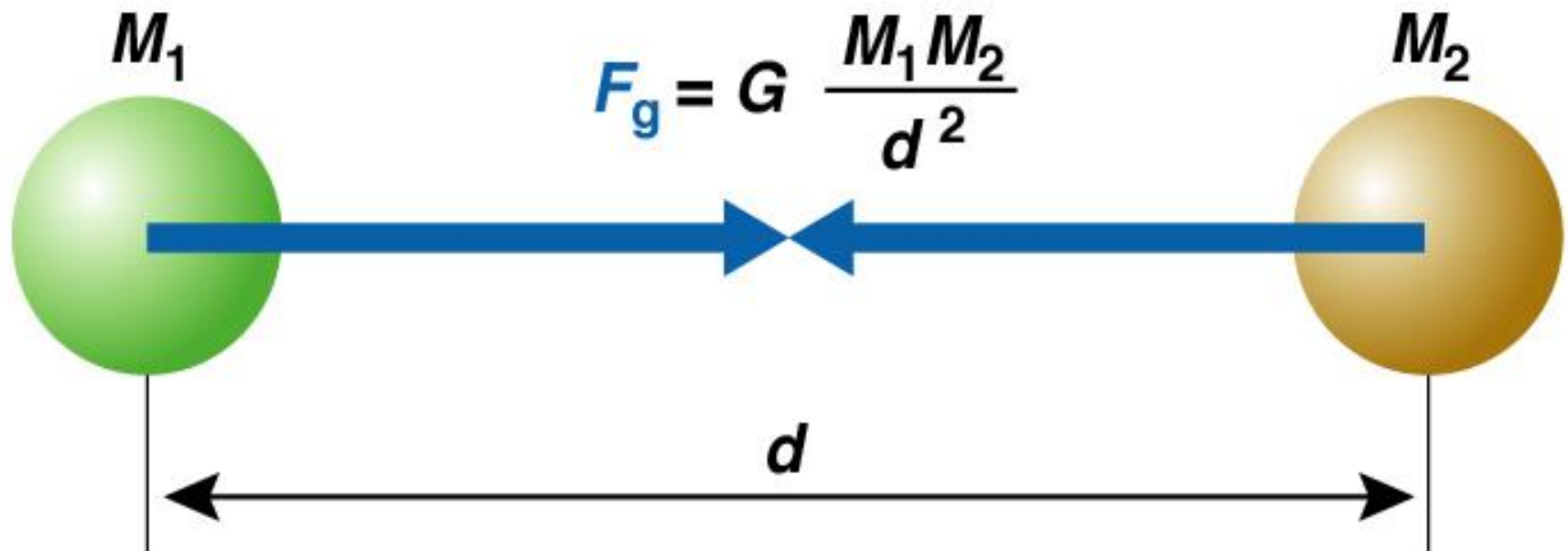
Helicopter History Site - Thanks Boeing



# Newton's Gravity

## The Universal Law of Gravitation:

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the *square* of the distance between their centers.



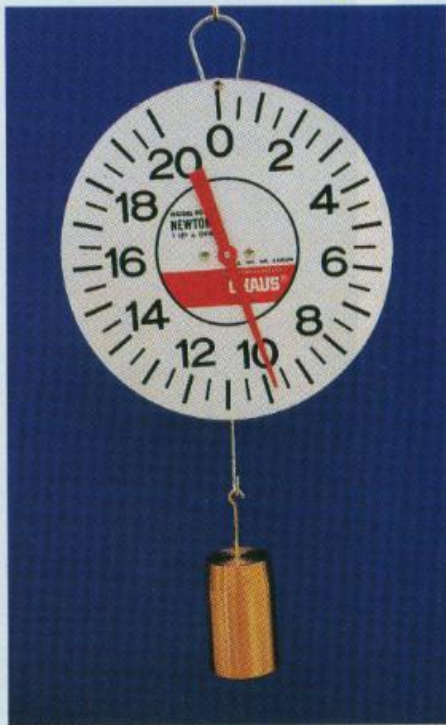
# Newton's Laws

## 2<sup>nd</sup> Law

### Mass & Weight

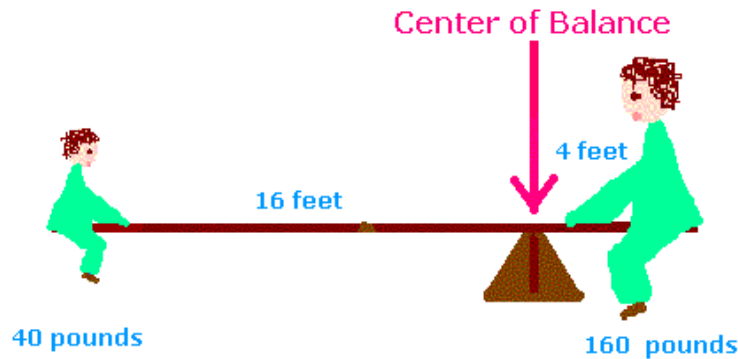
**FIGURE 3.7 Mass and Weight**

A mass of 1.0 kg is suspended on a scale calibrated in newtons, which shows the weight to be 9.8 N. This is equivalent to a weight of 2.2 lb.



- Mass is not equal to weight.
- Weight is force of gravity acting on a mass.
- $F = ma = mg$ .
- $W = mg$ .
- $W = (1.0\text{kg})(9.8\text{m/s}^2)$   
 $= 9.8\text{N}$ .

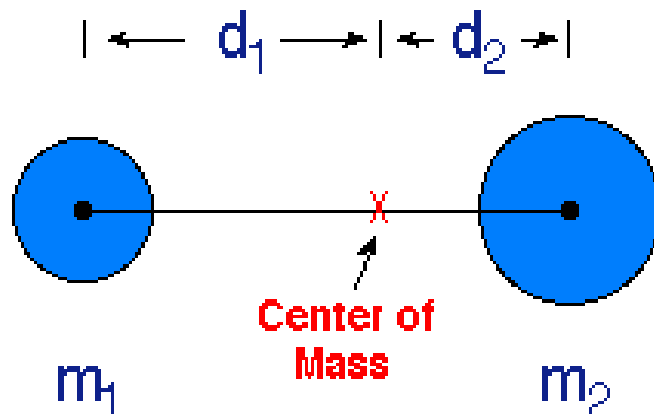
# Center of Mass



When the weights are different, adjust the distances.

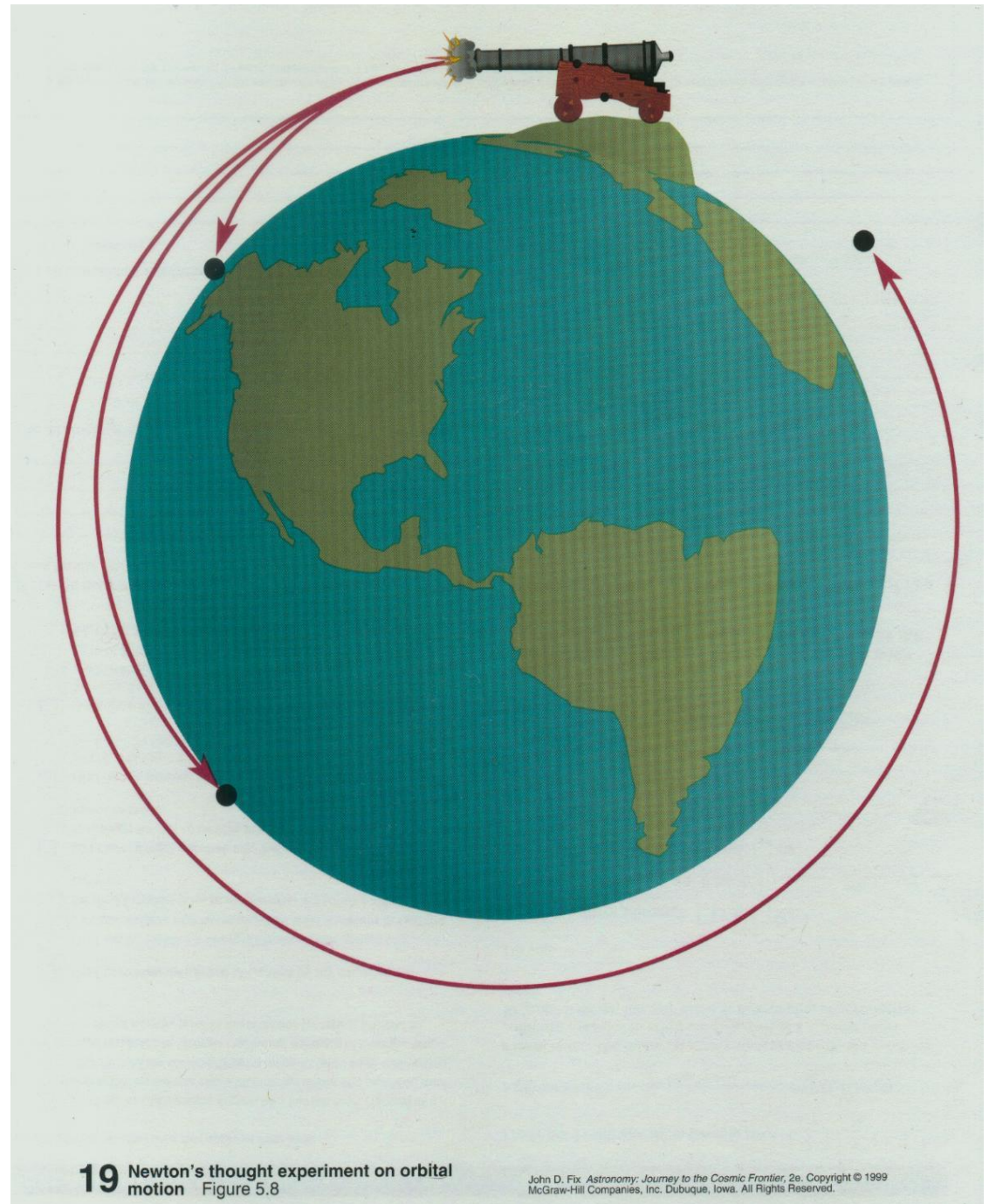
$$\text{weight} * \text{distance} = \text{weight} * \text{distance}$$

$$40 \text{ pounds} * 16 \text{ feet} = 160 \text{ pounds} * 4 \text{ feet}$$



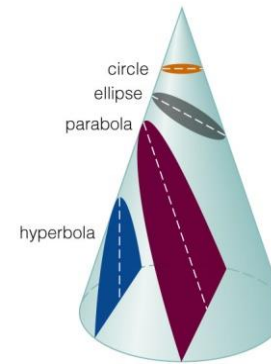
- The only way to determine the mass of a planet is to observe a moon orbiting it.
- The only way to determine the mass of the stars is to observe double stars orbiting each other.

# Orbital Motion and Freefall

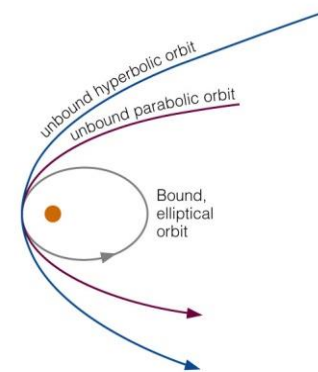


# Newton's' Revision of Kepler's 1<sup>st</sup> Law

- All orbits are conic sections.
- These include circles, ellipses, parabolas, and hyperbolas.



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# Newton's Revision of Kepler's 3<sup>rd</sup> Law

- $P^2(M_1+M_2)=a^3$

solving for mass

- $M_1+M_2=a^3/P^2$

This is the ONLY way to determine masses of astronomical objects.

# Resources

Chaisson and McMillian, (2002). *Astronomy Today* (4<sup>th</sup> Ed.)

Hewitt, (1998). *Conceptual Physics* (8<sup>th</sup> Ed.)

<http://www.usoe.k12.ut.us/curr/science/sciber00/8th/forces/sciber/newtons.htm>

Shipman, Wilson, and Todd, (2003). *An Introduction to Physical Science* (10<sup>th</sup> Edition).