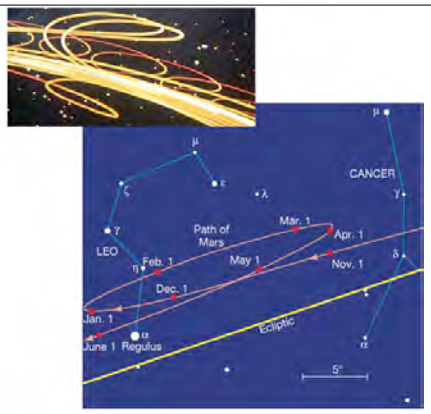
The Copernican Revolution

The Beginning of Modern Astronomy

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 5th heavenly element.
- Moon, sun and stars held in place by invisible crystalline spheres.
- The heavens are perfect and unchanging
- Heaven is its own sphere above the stars.
- Hell is where Satan lives and is below the habitable surface of earth.



Motion of the Planets

- Move generally east to west on ecliptic
- Closer planets appear brighter
- Move a differing speeds
- East to west movement - prograde
- Sometimes moves backwards - retrograde

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)?

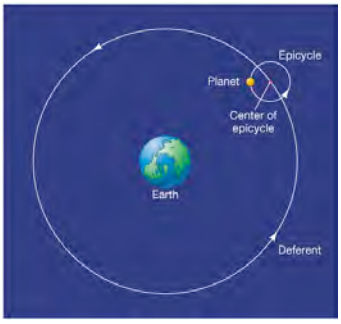
2. Why do the Sun and planets appear to move eastward along the Zodiac?

3. How can planetary alignments such as oppositions and conjunctions be explained?

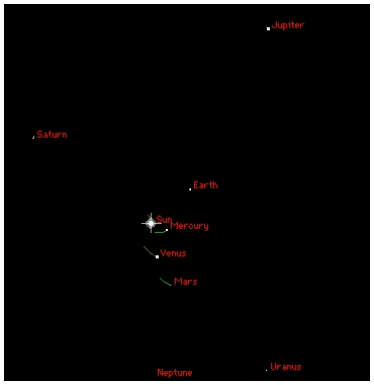
4. Why are Mercury and Venus never seen opposite of the Sun in the sky?

5. Why do planets have retrograde motion that causes them to appear to go backwards?

Geocentric Model



- Animation



Recall Ptolemy's Model

Explained retrograde motion

But required very complex modeling to explain full cycles of motion

Idea accepted in its time

Nicholas Copernicus (1473-1543)

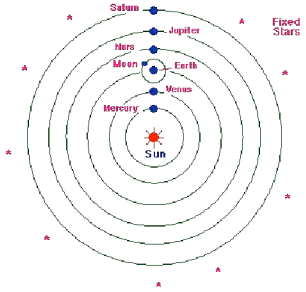
Suggested a Sun centered Universe in a book titled De Revolutionibus, which was not published until the year he died.

Copernican Model

- Heliocentric Universe
- *De Revolutionibus Orbiun Celestium* (On the Revolutions of the Heavenly Spheres)
- Idea was opposed by the Catholic Church

http://es.rice.edu/ES/humsoc/Galileo/Images/Astro/Conceptions/copernican_universe.gif

Copernican Model



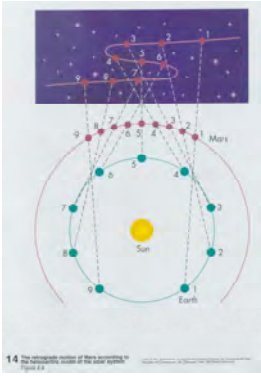
Animation

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.
animation



Copernican Model
Why believe Copernican model?
(with sarcasm)

- 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.
- Scientific Method works for both but only one is WRONG!

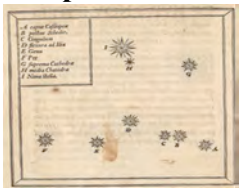
Occam's Razor

- William of Occam England, 14th 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 (instructor's editorial comment)

Copernican Model
Why believe Copernican model?

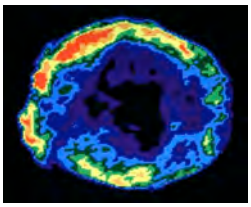
- It was aesthetically more pleasing.
- It was more simple.
- It explained complex motions as naturally occurring.
- Ideas were not accepted
- Went against the dogma of the day

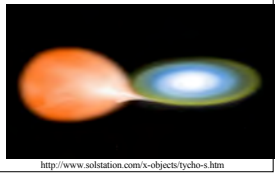
SN 1572, Tycho's Supernova



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

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





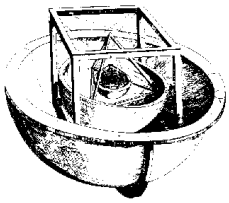
http://www.solstation.com/x-objects/tycho-s.htm

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.

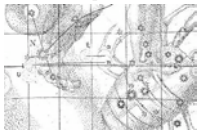
Kepler's Model

- 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.

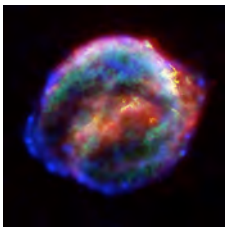


SN 1604, Kepler's Supernova

A few years before Tycho died another supernova was observed by Kepler in constellation of Ophiuchus on October 17th 1604. It had been observed by others as early as Oct. 4th.
(Last known supernova in Milky Way.)



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

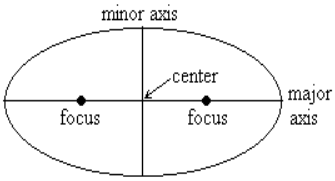


http://en.wikipedia.org/wiki/Johannes_Kepler

Kepler & Tycho

- Both Worked together for many years
- Tycho gained a lifetime of data, Kepler wanted to review it
- 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.

Parts of an ellipse

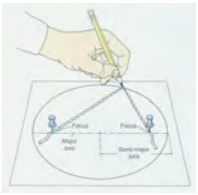


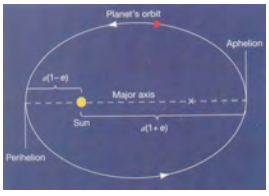
FYI - Semi Major Axis is from center to orbit along major axis

Kepler's Laws
1st Law

Deals with Shapes of orbits

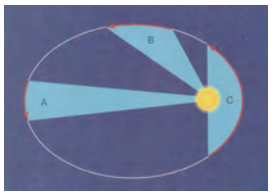
- Planets orbit the Sun in elliptical paths with the Sun at one focus.





Kepler's Laws
2nd Law

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



Kepler's Laws
3rd Law

- Deals with size of orbit w/r/t orbital period
- 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 Earth
- a = 1 au's
- $P^2 = a^3$ substituting for a
- $P^2 = (1)^3 = 1x1x1 = 1$
- Take square root of 1
- P = 1

Kepler's Laws
3rd Law

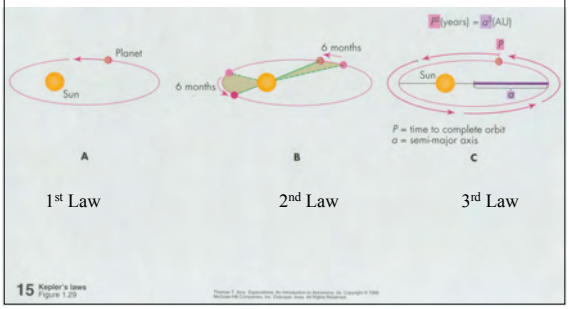
- Example Calculation for Jupiter
- a = 5.2 au's
- $P^2 = a^3$ substituting for a
- $P^2 = (5.2)^3 = 5.2 \times 5.2 \times 5.2 = 140.6$
- Take square root of 140.6
- P = 11.86 years

- What is the orbital period for a planet that has has a semi major axis of 9.537 au?
- a = 9.537 au's
- $P^2 = a^3$ substituting for a
- $P^2 = (5.537)^3 = 5.537 \times 5.537 \times 5.537 = 867.432$
- Take square root of 867.432
- P = 29.45 years
- What planet?

TABLE 1.1 Some Planetary Properties

PLANET	ORBITAL SEMI-MAJOR AXIS, *a* (astronomical units)	ORBITAL PERIOD, *P* (Earth years)	ORBITAL ECCENTRICITY, *e*	P^2/a^3
Mercury	0.387	0.241	0.206	1.002
Venus	0.723	0.615	0.007	1.001
Earth	1.000	1.000	0.017	1.000
Mars	1.524	1.881	0.093	1.000
Jupiter	5.203	11.86	0.048	0.999
Saturn	9.537	29.42	0.054	0.998
Uranus	19.19	83.75	0.047	0.993
Neptune	30.07	163.7	0.009	0.986
Pluto	39.48	248.0	0.249	0.999

Review of Kepler's Laws



1st Law 2nd Law 3rd Law

Meanwhile….Galileo Galilei (1564-1642) lived about the same time

- The father of Physics
- First person to point a telescope at the night sky.
- Proved Aristotle Wrong

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

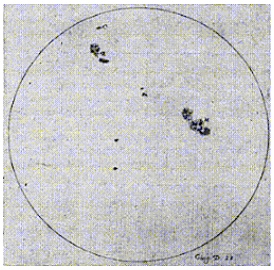
Craters on the Moon

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

http://www.hao.ucar.edu/public/education/sp/images/galileo.html

Sunspots

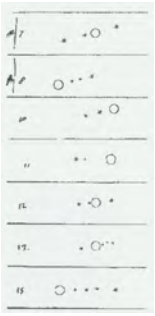
- Sun is NOT perfect.
- It has dark spots.
- What are sunspots?
- The Sun may rotate, which implies the Earth may rotate.



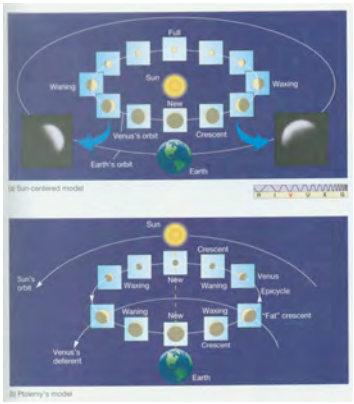
http://www.sunblock99.org.uk/sb99/people/KMacpher/first_obs.html

Moons of Jupiter

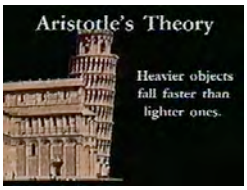
- January 7-15, 1610
- These moon's do not revolve around the Earth or the Sun!
- They form a miniature solar system of their own.



Phases of Venus

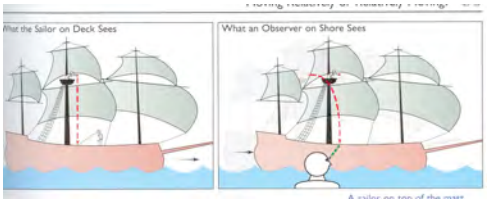


Galileo Galilei's Observations



http://www.endex.com/gf/buildings/ltpisa/ltpnews/physnews1.htm

Galileo Galilei's Observations



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

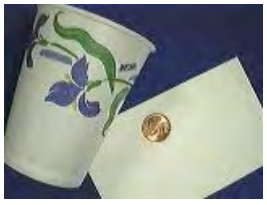
Isaac Newton (1642-1727)

- Develops Laws of Motion
- Develops idea of gravity
- Derived Kepler's three laws of planetary motion using laws of motion and gravity.

http://www.hao.ucar.edu/public/education/sp/images/newton.html

Newton's Laws
1st Law

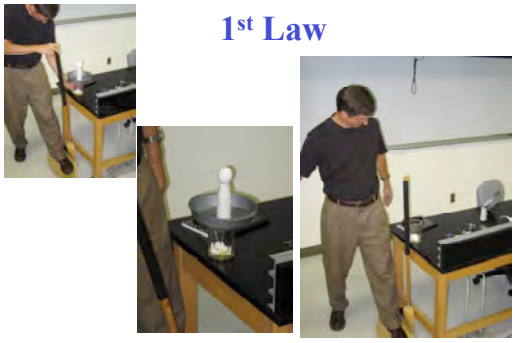
- Law of Inertia
- A body at rest will remain at rest, and a body in motion will remain in motion, unless acted upon by an unbalanced force.



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.
- $a \alpha F$

Newton's Laws
1st Law



Newton's Laws
2nd Law

- The acceleration of an object being acted upon by an unbalanced force is inversely proportional to the object's mass, m.
- $a \alpha 1/m$

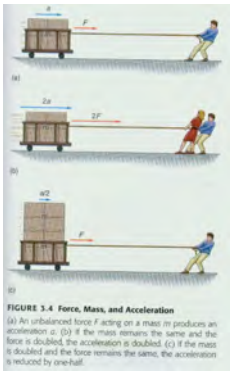


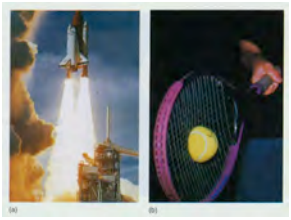
FIGURE 3.4 Force, Mass, and Acceleration
(a) An unbalanced force F acting on a mass m produces an acceleration a. (b) If the mass remains the same and the force is doubled, the acceleration is doubled. (c) If the mass is doubled and the force remains the same, the acceleration is reduced by one-half.

Newton's Laws
2nd Law

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

Newton's Laws
3rd Law

- Action and Reaction
- For every action there is an equal and opposite reaction.
- $F_1 = -F_2$
- $m_1a_1 = -m_2a_2$
- Forces act in opposite directions on different objects.



Newton's Laws
Examples of 3rd Law

Newton's Laws
Examples of 3rd Law

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

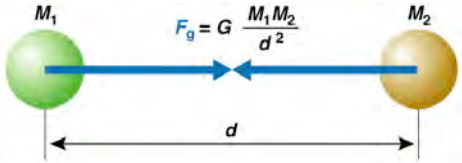
Use 3rd law to explain how this helicopter flies.

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

Newton's Gravity

The **Universal Law of Gravitation:**

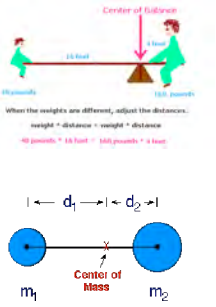
1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the *square* of the distance between their centers.



Newton's Laws
2nd Law
Mass & Weight

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

Center of Mass



- The only way to determine the mass of a planets 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 1st Law

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

Newton's Revision of Kepler's 3rd 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* (4th Ed.)

Hewitt, (1998). *Conceptual Physics* (8th 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* (10th Edition).