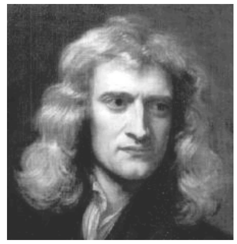
Birth of Science

- Tycho Brahe observes motion of planets
- Kepler discovers 3 laws of motion for planets
- Newton discovers laws of motion for all objects

- Homework 2 is ready
  - Due at 6:00am on Tues, 23rd Jan.
  - On angel.msu.edu, go to Lessons>Homework>Homework2.

Brahe (1546-1601)

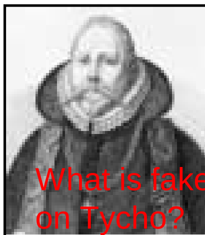
Kepler (1571-1630)



Newton (1643-1727)

Questions on reading

1. When Kepler was a college student, the most accurate description of the motion of planets uses the terms
   a. Velocity, position, & acceleration
   b. Circular orbits
   c. Elliptical orbits

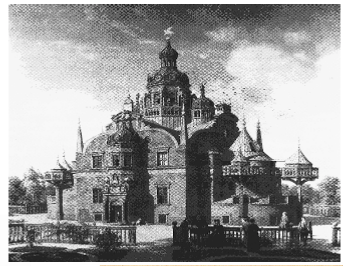


What is fake on Tycho?

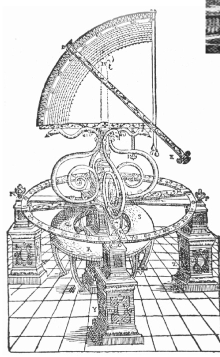
Tycho Brahe's Observations

- On Uraniborg, Tycho measured positions of the planets for 20 years
- Highly accurate & reliable
  - Accuracy limited by human eye, not by instruments. Superseded only with telescopes.
  - Tyco measured & compensated for instrument flexure, the biggest error.

Uraniborg



Brass azimuthal quadrant, 65 cm radius (ca 1576)



Great quadrant (1582)

Kepler analyzes Tycho's data

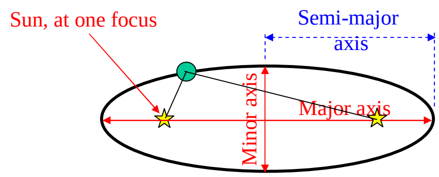
- Kepler was Tycho's assistant
  - 20 yrs' data on planetary motions.
  - Tycho tried to fit data with Ptolemy-like model.
- Kepler analyzed the data
  - Found 3-d orbits from 2-d positions in the sky
  - Concentrated on orbit of Mars.
  - Had to subtract off Earth's (imperfectly known) orbit.
- Discovered 3 "laws," which describe the motions of the planets.

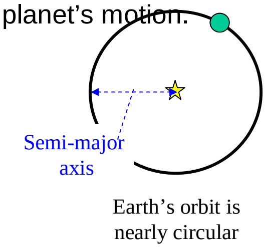
Brahe (1546-1601) Kepler (1571-1630)

- Their meeting at Benatek (in Czechoslovakia)
  - …on 4 February 1600, Tycho de Brahe and Johannes Keplerus, co-founders of a new universe, met face to face, silver nose to scabby cheek. Tycho was fifty-three, Kepler, twenty-nine. Tycho was an aristocrat, Kepler a plebian. — Koestler, *The Sleepwalkers*, p302

Kepler's First Law

- Orbit of a planet is an ellipse, with the sun at one focus.
- Definition of an ellipse
  - (Distance between planet & focus #1) + (distance between planet & focus #2) is the same for the entire orbit.
- This was an unexpected result in Kepler's time.
  - Ellipse is a simply defined shape, not any shape. The motion of the planets must have a deeper cause.
  - If the sun is at a focus, it must affect the planet's motion.





Kepler1 simulation

Kepler's Second Law

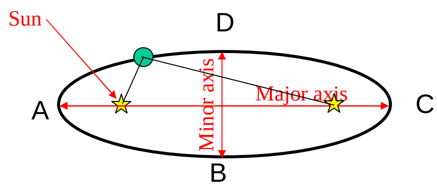
- The line joining the planet and the sun sweeps out equal areas of space in equal amounts of time.
- Planet moves
  - more slowly when it is far from sun
  - more rapidly when close to sun

Kepler2 simulation

Kepler's Laws

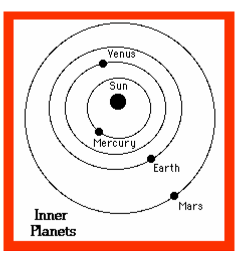
- Law 1: Orbit of a planet is an ellipse, with the sun at one focus.
- Law 2: The line joining the planet and the sun sweeps out equal areas of space in equal amounts of time.

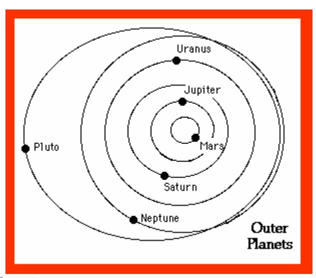
2. Winter is a few days shorter than summer for us in the northern hemisphere. Therefore Earth is at A, B, C, or D in January?



Kepler's Third Law

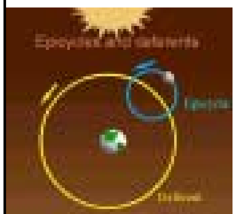
- $P^2 = a^3$
  - P = period of orbit, in years
  - a = semi-major axis of orbit, in AU. (Average Earth-sun distance is 1 AU.)



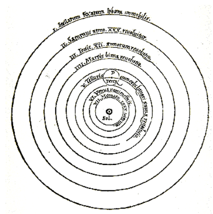


Fast solar simulation
http://web.cuug.ab.ca/~kmcclary/fastsolar.html

The Motions of the Planets

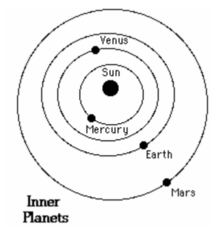


Ptolemy
140 AD



Copernicus
1543

Simpler model



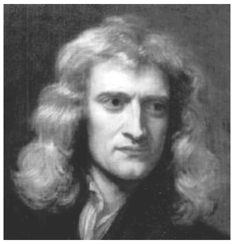
Kepler
1609

More accurate description of data

Kepler's 3 Laws

- Orbit of a planet is an ellipse, with the sun at one focus.
- The straight line joining the planet and the sun sweeps out equal areas of space in equal amounts of time.
- $P^2 = a^3$
- But why??
  - These are descriptive laws, but there must be deeper reasons for the planets to do this.

Isaac Newton



1643-1727

- One of the great geniuses of the millennium.
  - Invented *calculus* (mathematics of change)
  - Invented *mechanics* (the description of how things move). *Principia*, 1687.
  - Discovered *Law of Gravity*
- Kepler's laws can be derived from Newton's laws
- But Newton's laws are a general descriptions of a far wider range of phenomena
  - universally valid
    - except on the smallest or largest scales, or in extreme situations (strong gravity, high velocities).

"Natural" motion for Newton & Aristotle

- Natural motion is motion that needs no explanation: the object naturally moves that way.
- Aristotle: For heavenly objects, natural motion is motion in a circle with the same speed. For base objects, natural motion is rest.
  - A book falls off the table and comes to rest on the floor. This needs no explanation because rest is the natural state.
- Newton: Natural motion is moving at the same speed in the same direction.
  - Newton's <u>First Law</u>: In the absence of a force, an object moves at the same speed in the same direction.
- Q3: A book falls off the table and lands on the floor. For Newton, what is natural?
  a. The book is on the floor.
  b. The book is halfway to the floor.
  c. The book is just starting to fall.
  d. I push the book off the table.

- Q4: Venus moves around the sun in a circle at the same speed. Does Newton consider this motion natural?
  a. Yes, Venus is a heavenly object.
  b. Yes, the speed is the same.
  c. No, the direction is not always the same.
  d. No, Venus is not at rest.

Newton's Second Law

- Newton's First Law: In the absence of a force, an object moves at the same speed in the same direction.
- Newton's Second Law tells how to find the motion if there is a force.
  - *Force* **=** *mass x acceleration*
    F **=** *m x a*
  - Acceleration is change in velocity divided by amount of time
- Q5 The velocity changed in
  a. Case A only
  b. Case B only
  c. Neither cases A nor B
  d. Both cases A and B
- Q6 The acceleration is greatest for which case? A, B, C, or D

- Case A
  - Velocity at start
  - Velocity after 1 s
- Case B
  - Velocity at start
  - Velocity after 1 s
- Case C
  - Velocity at start
  - Velocity after 1 s
- Case D
  - Velocity at start
  - Velocity after 2 s