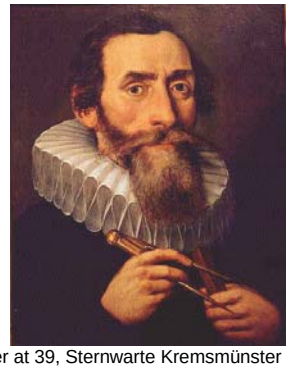
Kepler's Laws—20 Jan

- Homework 1
  - Due at 6:00am on Thurs, 22nd Jan.
  - On angel.msu.edu, go to Lessons>Homework>Homework1.
  - The lower grade does not count.
- Clicker
  - Register at iClicker.com
  - Use your email address
  - You may use paper answers 2 times.
- The discovery of the laws of motion, the first science.
  - *De Revolutionibus Orbium Coelestium*, Copernicus, 1543
  - *Astronomia Nova*, Kepler, 1609
  - *Philosophiae Naturalis Principia Mathematica*, Newton, 1687
- How Kepler figured out the path of Mars from Tyco's observations. Discovery of his three laws.

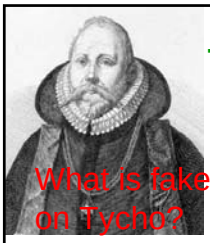


Kepler at 39, Sternwarte Kremsmünster
http://members.nextra.at/stewar/

Copernicus	1473–1543
Columbus sails	1492
Tycho Brahe	1546–1601
Shakespeare	1564–1616
Johannes Kepler	1571–1630
Jamestown	1607
King James Bible	1611
Harvard College	1636
Isaac Newton	1642–1727

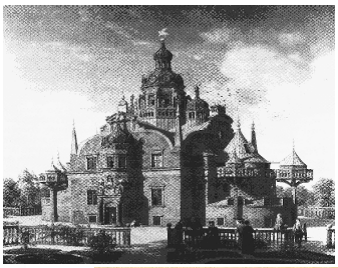
Questions on reading

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
2. Same question for Newton
3. Today the most accurate description of the motion of planets uses the terms
   a. Velocity, position, & acceleration
   b. Circular orbits
   c. Elliptical orbits

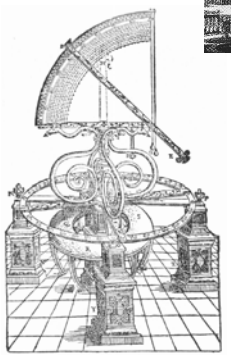


Tycho Brahe's Observations

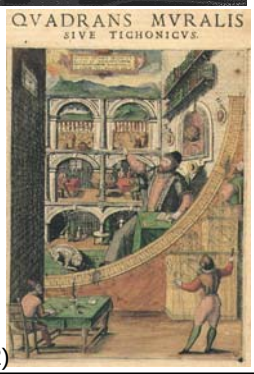
Uraniborg



Brass azimuthal quadrant, 65 cm radius (ca 1576)



- 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.



Great quadrant (1582)

Kepler analyzes Tycho's data

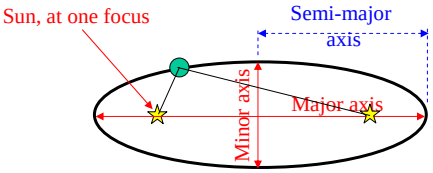
- Kepler was Tycho's assistant
  - 20 yrs' data on planetary motions.
  - Tycho tried to fit data with Ptolemy-like model.
- Kepler analyzed the data
  - Found 3-d orbits from 2-d positions in the sky
  - Concentrated on orbit of Mars.
  - Had to subtract off Earth's (imperfectly known) orbit.
- Discovered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

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

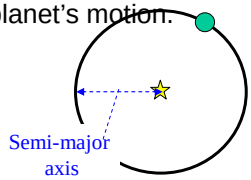
- Their meeting at Benatek (in Czechoslovakia)
  - …on 4 February 1600, Tycho de Brahe and Johannes Keplerus, co-founders of a new universe, met face to face, silver nose to scabby cheek. Tycho was fifty-three, Kepler, twenty-nine. Tycho was an aristocrat, Kepler a plebian. — Koestler, *The Sleepwalkers*,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

Kepler's First Law 1605

- 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



Earth's orbit is nearly circular

Kepler's Second Law 1602

- 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

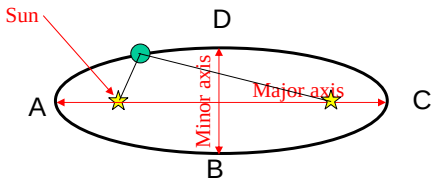
Kepler2 simulation

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.

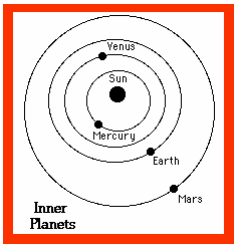
2. Winter is a few days shorter than summer for us in the northern hemisphere. Therefore Earth is at A, B, C, or D in January?

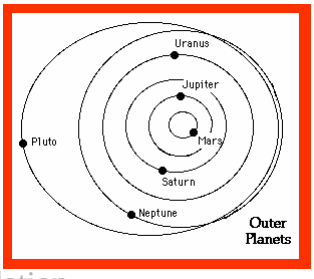
- What do I need to find out before I can answer the question?



Kepler's Third Law 1618

- $P^2 = a^3$
  - 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

Kepler's Third Law 1618

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

1. A 10th object (planet?) was found beyond the orbit of Pluto. ___ has the shorter period.
   A. Pluto
   B. 10th object
   C. Not enough information to answer.

- What do I need to find out before I can answer the question?

Questions concerning Kepler's Laws

- A planet's path is an ellipse with the sun at one focus.
- A planet "sweeps" out the same area in an equal amount of time.
- The planets' periods P and semi-major axes a are related by
  $P^2=a^3$
- A planet, which has an almost circular orbit, and a comet, which has a highly elliptical orbit, have the same periods. Draw their orbits on a single picture.

1. Grading: sun's position
2. Grading: lengths of major axes.

- What do I need to find out?

Questions concerning Kepler's Laws

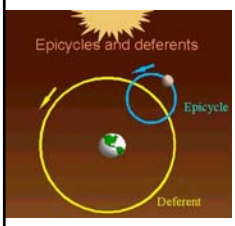
- A planet's path is an ellipse with the sun at one focus.
- A planet "sweeps" out the same area in an equal amount of time.
- The planets' periods P and semi-major axes a are related by

  $P^2=a^3$

- A planet, which has an almost circular orbit, and a comet, which has a highly elliptical orbit, have the same periods. Draw their orbits on a single picture.

1. Grading: sun's position
   A. Centered for comet
   B. Offset for comet
2. Grading: lengths of major axes.
   A. Same for both
   B. Different

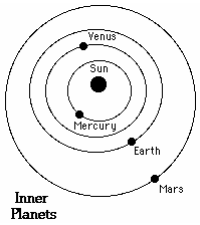
The Motions of the Planets



Ptolemy
140 AD

Copernicus
1543

Simpler model



Kepler
1609

More accurate description of data

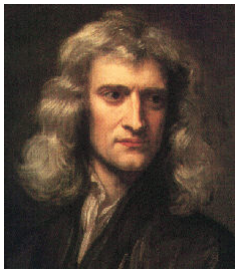
Kepler's 3 Laws

- 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.

Newton's Laws of Motion & Gravity

- *De Revolutionibus Orbium Coelestium*, Copernicus, 1543
- *Astronomia Nova*, Kepler, 1609
- *Philosophiae Naturalis Principia Mathematica*, Newton, 1687

- Newton invented calculus (MTH 132) & mechanics (PHY 183)
- Nature and Nature's laws lay hid in night:/ God said, Let Newton be! and all was light. —Newton's epitaph by Alexander Pope
- Newton: Same laws apply to a falling apple & moving planet.
- Description of motion
- Gravity $\propto 1/R^2$ implies K's 3rd Law



Isaac Newton (at 47) by Godfrey Kneller
Trustees of the Portsmouth Estate
www.huntington.org/LibraryDiv/Newton/Newtonexhibit.htm

Copernicus	1473–1543
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George Washington	1732-1799