Reading: Bennett, Chapter 3, Sections 3.4-3.5
Chapter 5, through Section 5.3
Web-based article on orbits
Homework 3: Due in recitation Friday / Monday
Homework 4: Available now: due on September 26/29
Exam 1: Thursday, October 2 - room(s) to be posted on website

Brief review of last time: **Og through Tycho Brahe**

- Early Science
  - prehistoric discoveries: visual observations - motivations
  - Greek Astronomy
    - perfect, immutable heavens, with Earth at the center
    - uniform circular motions - epicycles
    - computational scheme consistent with observations
- The Renaissance
  - Copernicus - Sun to the center
  - Tycho Brahe - detailed observations to test Copernican model

a famous experiment

1612 (?)

1971

1610 - Johannes Kepler

mathematician and klutz

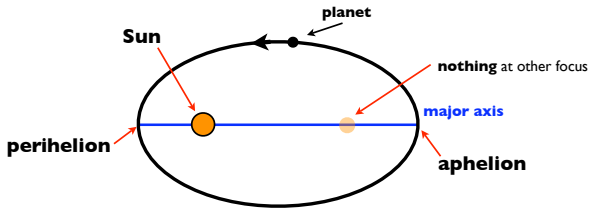
used Tycho's data on the motion of Mars:
with no circular motion bias
to discover

Kepler's Laws of Planetary Motion

These are simple empirical laws explaining planetary motion, derived from data only, with no preconceptions.

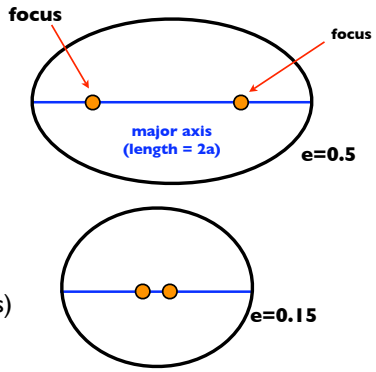
Kepler's Law #1

- Planets orbit the Sun in ELLIPTICAL orbits around, with the Sun at one 'focus' of the ellipse.
- abandonment of "perfect circular motion"



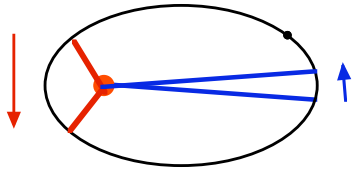
Anatomy of an ellipse

- **DEFINITION**
  where your distance from two fixed points adds up to a constant
- **FOCI** - the two reference points
- **MAJOR AXIS**
  - longest dimension of ellipse
  - contains foci
  - usually refer to "semimajor axis" **a**
- **ECCENTRICITY**
  - measure of the flatness of the ellipse
  - e= (distance between foci) / 2a
  - e = 0 for a circle (semimajor axis = radius)
  - $0 \leq e \leq 1$ for an ellipse
  - e = 1 for a parabola



Kepler's Law #2

- A line joining the planet to the Sun sweeps out equal areas in equal times.
- abandon concept of constant speed



planet moves faster when closer to the Sun

Kepler's Law #3

- The Law of Periods:

$$\text{Period}^2 = (\text{semimajor axis})^3$$

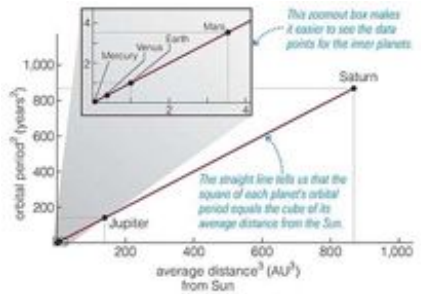
$$P^2 = a^3$$

(P in years, a in A.U.)

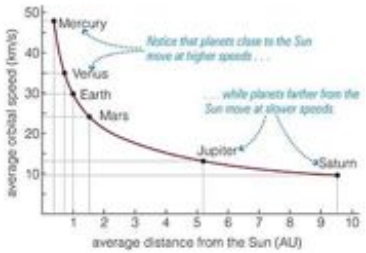
Bigger orbit (larger a) —> longer Period

Kepler's 3rd Law

Planet	P[y]	a[a.u.]	P^2	a^3	P^2/a^3
Mercury	0.241	0.387	0.0581	0.058	1.00208
Venus	0.615	0.723	0.3782	0.3779	1.00077
Earth	1.000	1.000	1	1	1
Mars	1.881	1.524	3.5382	3.5396	0.99959
Jupiter	11.86	5.203	140.66	140.85	0.99864
Saturn	29.42	9.539	865.54	867.98	0.99719
Uranus	84.01	19.19	7057.7	7066.8	0.9987
Neptune	164.8	30.06	27159	27162	0.99988



a This graph shows that Kepler's third law ($p^2 = a^3$) does indeed hold true; for simplicity, the graph shows only the planets known in Kepler's time.



b This graph shows how the orbital speeds of the planets depend on their distances from the Sun: More distant planets orbit the Sun more slowly. (Kepler knew the form of the relationship but could not determine speeds in km/s because the numerical value of the astronomical unit was not yet known.)

1666: Isaac Newton

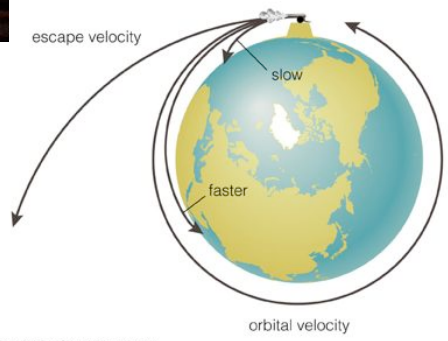
mathematician: Invented calculus as a youth . . .

SYNTHESIZED:

Galileo's Experiments
+
Kepler's Laws
+
Calculus
into Physical Laws;
the basis of Modern Science

Apple falls -> Earth and apple attract each other
Moon and Earth attract each other, too

If moon moves sideways as it falls, it could forever circle the Earth...



Newton's Legacy

- **Force of Gravity pulls planets towards Sun**
  - without gravity, planets would fly away in straight lines
- Newton's theory of gravity explains -simply- the orbits of the planets

> Understanding motions of the planets was the principal discovery of astronomy from prehistory through 1700.

- Improved observations ("technology") demanded more precise models of the Solar System
- This precision was
  - approached by complex models (epicycles, etc.) but
  - achieved by discovery of the underlying simplicity: **Gravity**