Reading: Ch. 3, Sect. 3.2 - 3.3
Homework 3: Due Tomorrow and Mon.
Homework 4: Now available, due next recitation cycle, or next Tuesday for fast grading.
Exam 1: Tuesday, Oct. 1; review materials posted

Last time: the Greeks to Copernicus, Tycho, and Galileo

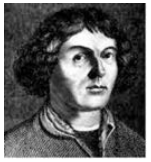
- Greek Astronomy: perfect, immutable sky with Earth at the center
  - uniform circular motions - epicycles
- The Renaissance
  - Copernicus - Sun to the center
  - Tycho Brahe - detailed observations
  - Galileo - telescope views of planets + physics experiments

Today: **Kepler to Newton**

- Kepler's Laws
  - simple, empirical description of planetary motion
  - abandoned all previous assumptions: not even circles!
- **Newton!**
  - gravity as the physical law - orbits are continual falls
  - physical laws - simplicity restored to celestial mechanics

towards the modern view

- 1200s: Ptolemy's method off by several *degrees*
  - response: add more epicycles . . .



- 1543: Copernicus (1473-1543)
  - moved sun to center -----> Revolutionary!

- 1580: Tycho Brahe (1546-1601)
  - precise positions of planets
  - stars are fixed, therefore very distant
  - sky is not immutable

- 1609: Galileo (1564–1642)
  - astronomer: telescope studies show Copernicus right
  - physicist: experiments with Gravity

1610 - Johannes Kepler

mathematician and klutz

(1571-1630)

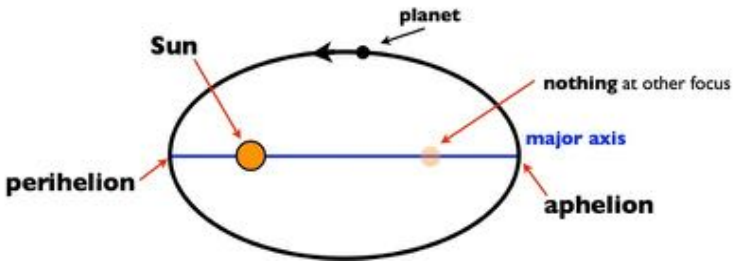
used Tycho's data on the motion of Mars:
with no circular motion bias
to discover

Kepler's Laws of Planetary Motion

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

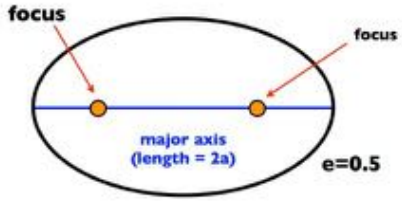
Kepler's Law #1

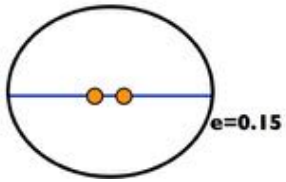
- Planets orbit the sun in ELLIPTICAL orbits around the sun, with the sun at one 'focus' of the ellipse.
- abandonment of "perfect circular motion"



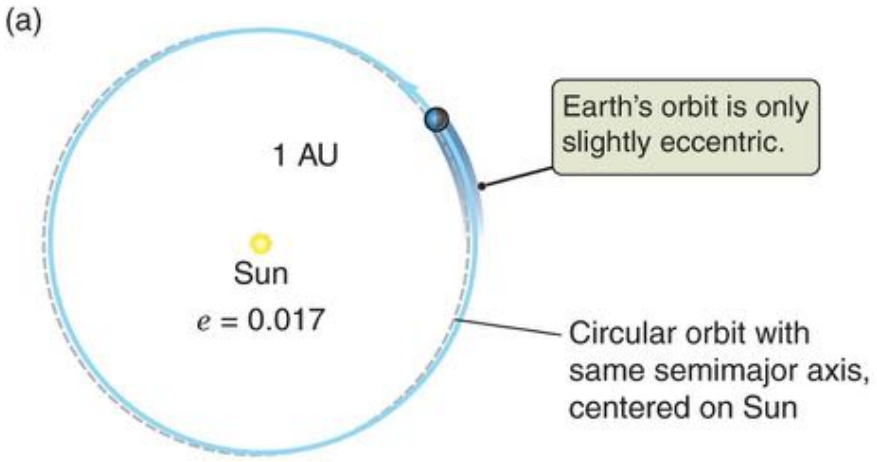
Anatomy of an ellipse

- **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)
  - $0 \le e \le 1$ for an ellipse
  - e = 1 for a parabola



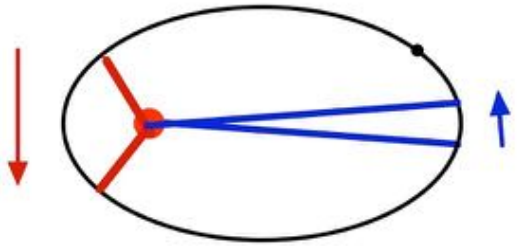


The Earth's orbit is an ellipse



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	0.0580	1.0021
Venus	0.615	0.723	0.3782	0.3779	1.0008
Earth	1	1	1	1	1
Mars	1.881	1.524	3.5382	3.5396	0.9996
Jupiter	11.86	5.203	140.66	140.85	0.9986
Saturn	29.42	9.539	865.54	867.98	0.9972
Uranus	84.01	19.19	7057.7	7066.8	0.9987
Neptune	164.8	30.06	27159	27162	0.9999

1627: Kepler's Rudolphine Tables

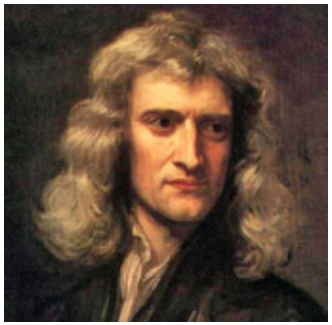
- Final publication of Tycho's star catalog
- Planetary position tables computed with Kepler's laws
- Recipes to allow users to calculate positions on their own

DIALOGO
DI
GALILEO GALILEI LINCEO
MATEMATICO SOPRAORDINARIO
DELLO STVDIO DI PISA.
E Filosofo, e Matematico primario del
SERENISSIMO
GR. DVCA DI TOSCANA.
Doue ne i congressi di quattro giornate si discorre sopra i due
MASSIMI SISTEMI DEL MONDO
TOLEMAICO, E COPERNICANO;
Proponendo indeterminatamente le ragioni Filosofiche, e Naturali tanto per l'vna, quanto per l'altra parte.
CON PRI VILEGI.
IN FIORENZA, Per Gio: Batista Landini MDCXXXII.
CON LICENZA DE' SVPERIORI.

(1632)

1666: Isaac Newton (1643-1727)

mathematician: Invented calculus as a youth . . .

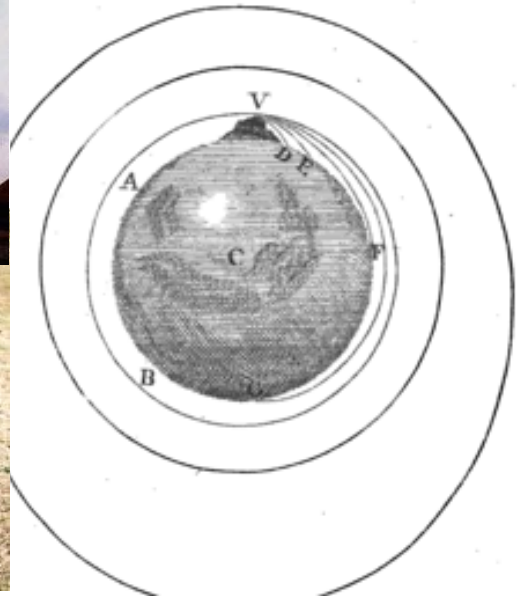


SYNTHESIZED:

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...



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

Newton's Synthesis

- **Mathematics** - Calculus
  - How to define/formulate/calculate motion *&* acceleration
- **Physics** - definitions / laws
  - energy of interaction between masses
  - momentum - resistance to change in motion
  - *correspondence with mathematical definitions*
- **Universal Gravitation**
  - dependence of gravitational force on mass & distance
  - connecting Galileo's experiments & Kepler's Laws
  - successful synthesis of earthly & cosmic behavior
  - blueprint for modern physics

Newton's Synthesis

- **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**