Reading: today: web-based reading on satellite orbits; Chap. 3 Sec. 5
Chap. 7, Sect. 1, 2 (for next week)
Exam 1: Tuesday, October 1, 6:45-8:00. **Room 5 Physics (next door)**
ESSAY QUESTION

Last time: more **Newton**

- Physical Laws and definitions of force, velocity, acceleration
- #1: Inertia; #2: Forces (F=ma); #3: Action/Reaction
- Newton's Law of Universal Gravitation
  - gravity as a central, universal, cosmic force

Today: Rocket Science

- orbits - circular velocity and escape velocity
- Holman Transfer orbit - adjust size and eccentricity to take a trip from one planet to the next
- flyby, orbit, and landing
- Gravitational assist

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**

Rocket Science:

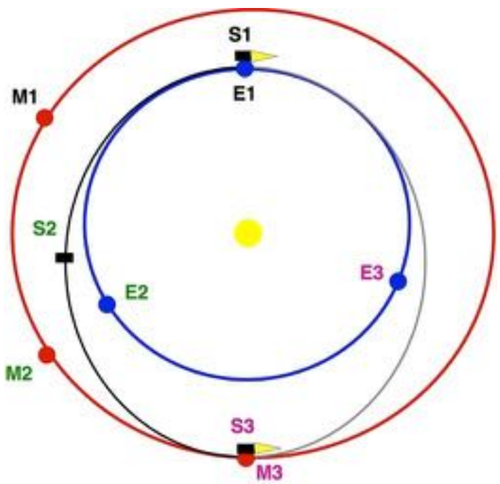
How to send a spacecraft to Mars

0- Don't shoot AT it - it is a MOVING target !!!

1. accelerate to break free from Earth's gravity

2. coast in "transfer orbit" to reach Mars' orbit

3. get captured by the gravity of Mars



1- accelerate to break free of Earth

- Circular velocity
  = speed needed to maintain a circular orbit

$$v_c^2 \approx \frac{\textbf{Mass of main body}}{\textbf{size of orbit}}$$

  - **for near-Earth orbit**, v_c= 7.7 km/s (=17,000 mph)
  - **for Earth around Sun**, v_c= 30 km/s (= 67,000 mph)
  - **for near-Mars orbit**, v_c= 3.4 km/s (= 7,600 mph)
  - **for Mars around Sun**, v_c= 24 km/s (= 54,000 mph)
- Escape Velocity
  = speed needed to escape (forever) grav. pull

$v_{esc}= v_c \times \sqrt{2}$

from near–Earth orbit,
v_{esc}= 11 km/s (= 24,000 mph) away from Earth

Exceed escape velocity – into a Sun-centered orbit!

2- coast in "transfer orbit" to Mars

- Transfer Orbit: an ellipse with:
  - perihelion at Earth distance (1 a.u.)
  - aphelion at Mars min. distance (1.38 a.u.)

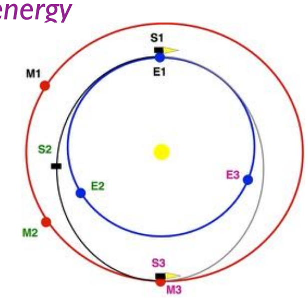
    e=0.160; a=1.19a.u.; P = 15.6 months
  - this gets probe to Mars with *minimum energy*

Kepler 1:
perihelion distance = **a** x **(1-e)**
aphelion distance = **a** x **(1+e)**

How fast do you need to go to achieve the transfer orbit to Mars?

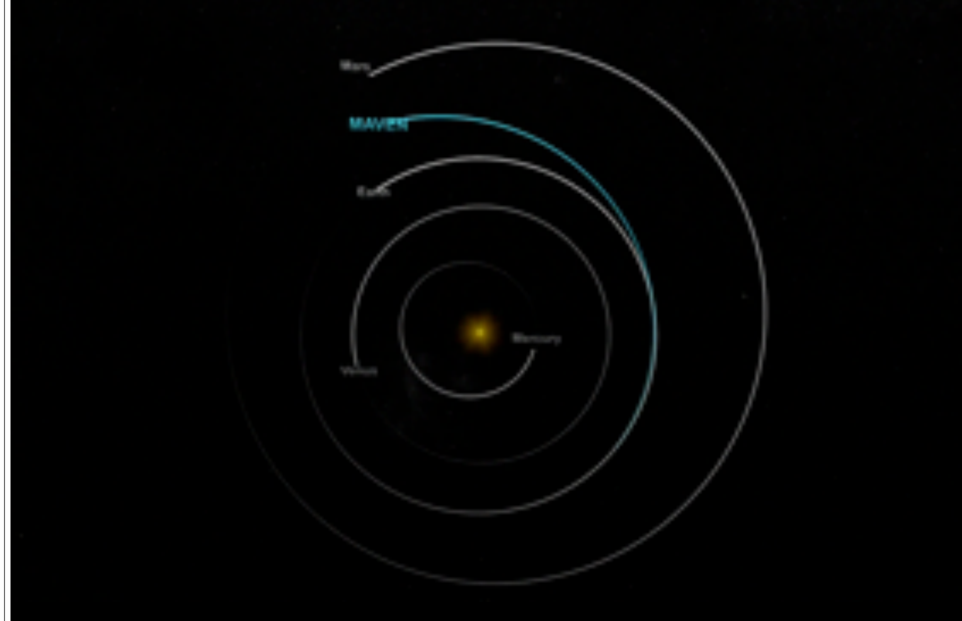
Kepler's Second Law tells us!

32.3 km/s w.r.t. the Sun



- Coast for P/2 (about 7+ months):
  - If you left at the right time, reach Mars near aphelion
  - "Launch Window" open every 25 months (or so)

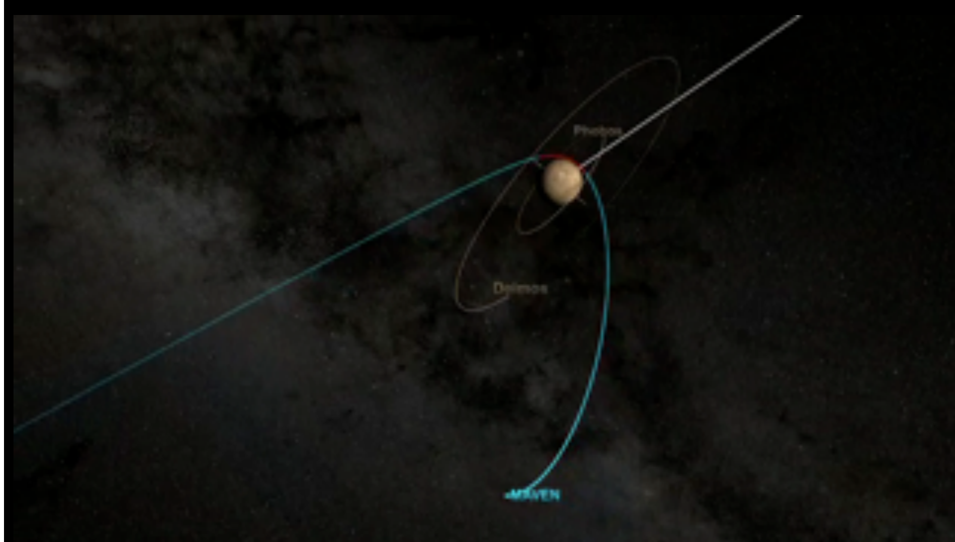
MAVEN Cruise trajectory



3- get captured by Mars

- Rendezvous with Mars:
  - spacecraft speed = 23.4 km/s (via Kepler 2)
  - Mars speed = 26.7 km/s
  - relative velocity = 3.3 km/s
- circular velocity for Mars orbit is 3.4 km/s
  - an orbital maneuver (burn) is needed to reach Mars orbit
  - timing is critical here!

MAVEN arrival



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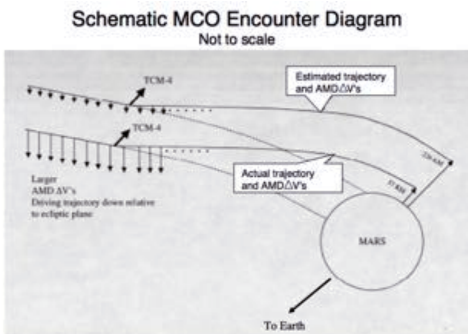
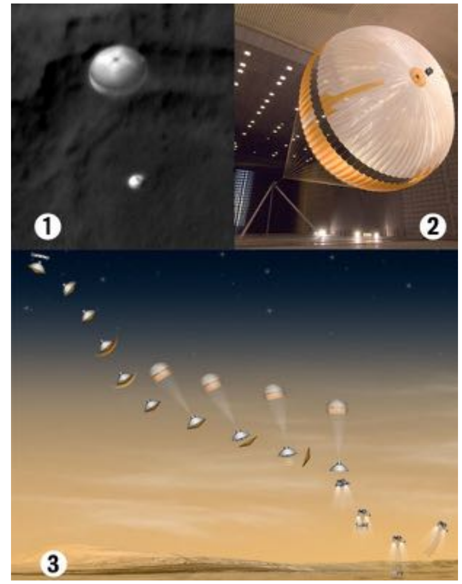
Mars Climate Observer (1999) got it wrong...

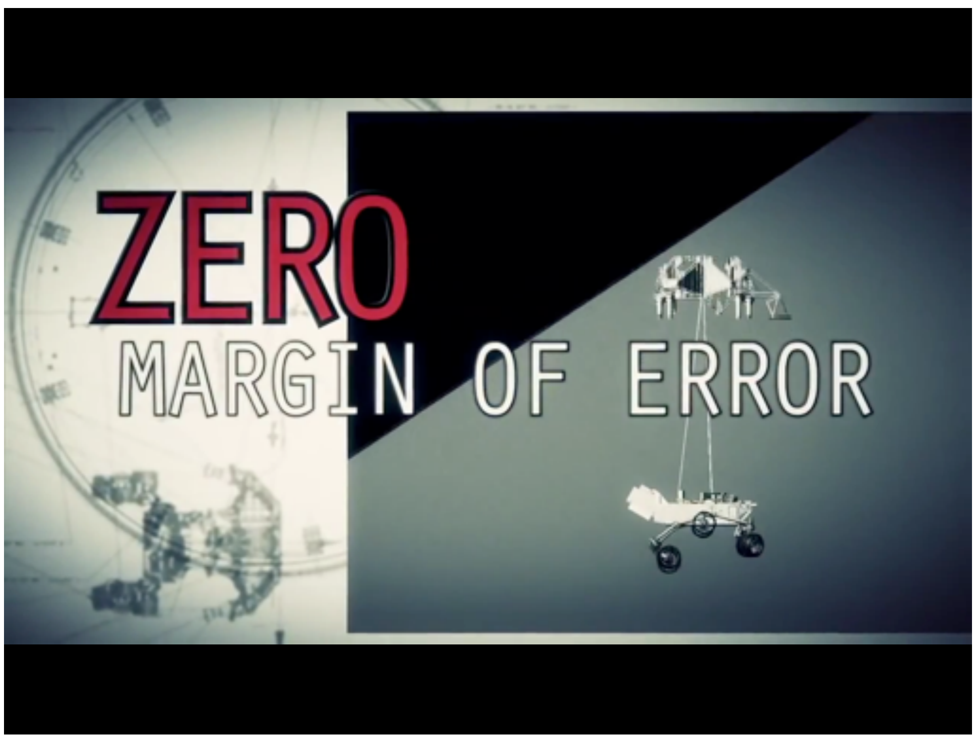
unit confusion (English vs. Metric)

came too close - burned up in atmosphere



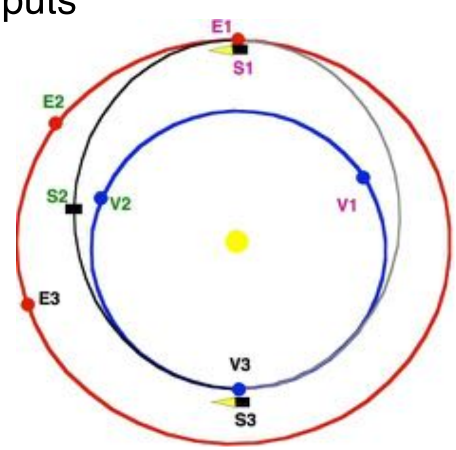
Curiosity Rover - landing

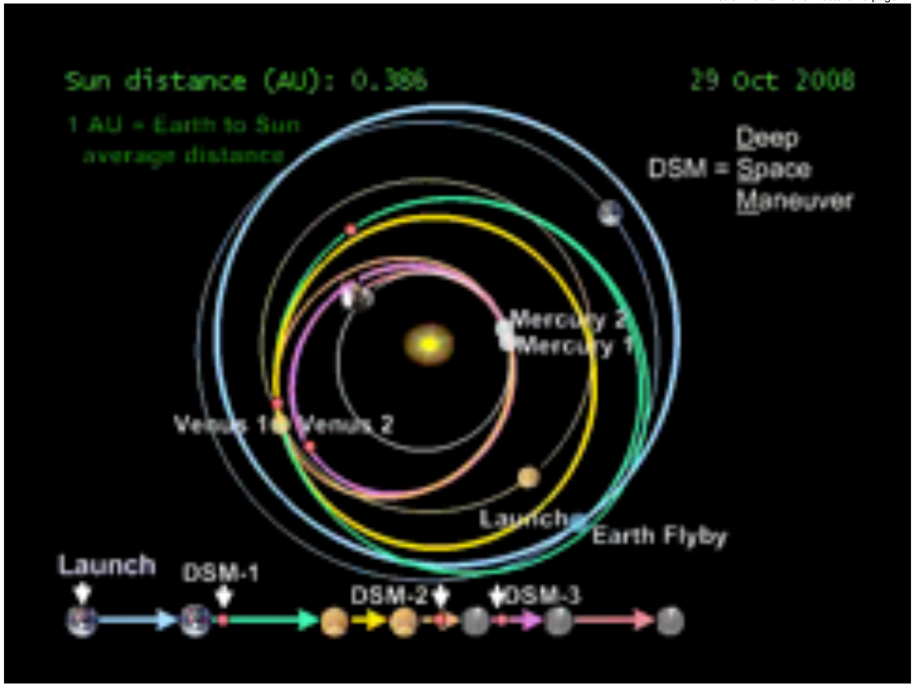




Similar scheme to reach Venus orbit

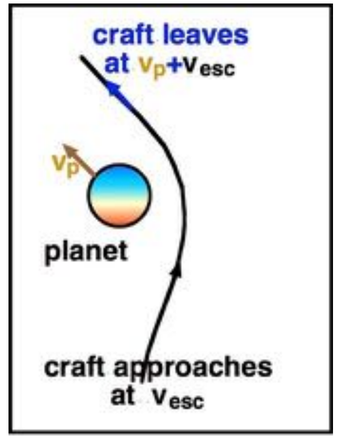
- BUT: Decelerate from Earth
- Venus transfer orbit puts
  - Earth at Aphelion
  - Venus at Perihelion
- MERCURY:
  much tougher

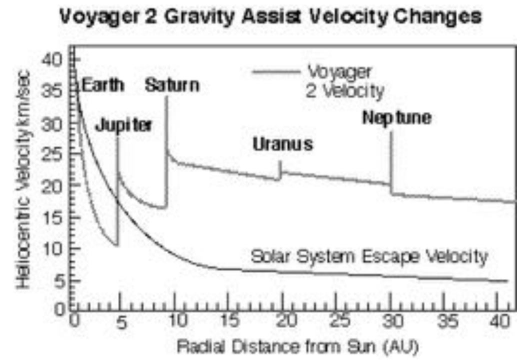




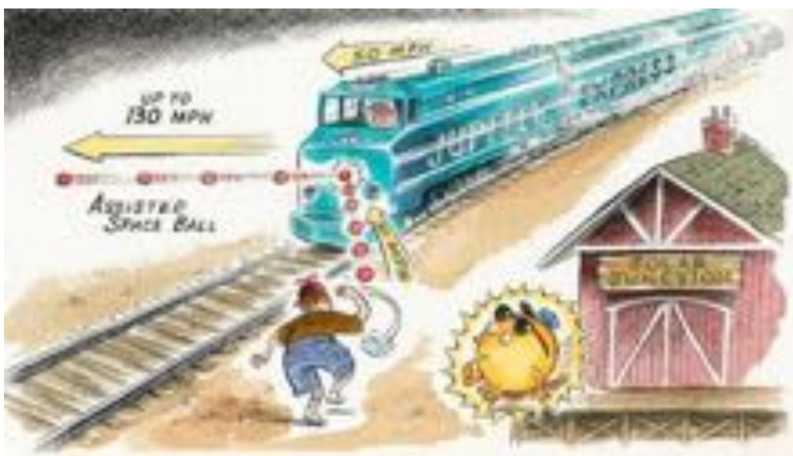
Getting to the Outer Planets

- requires a lot of energy (fuel) and time
- special trick: **gravity assist**
  - slingshot effect of planet's gravity on the spacecraft



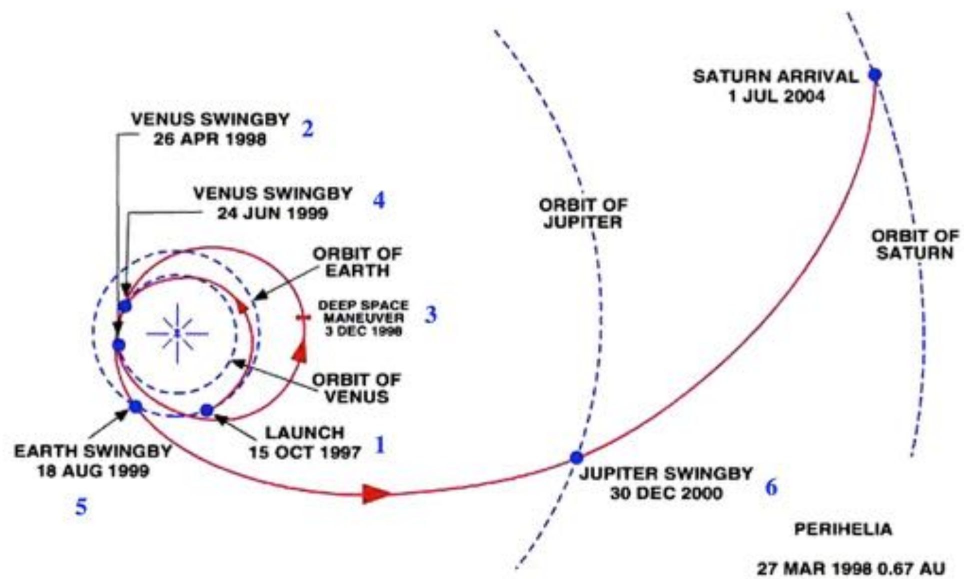


craft steals angular momentum (orbital energy) from planet



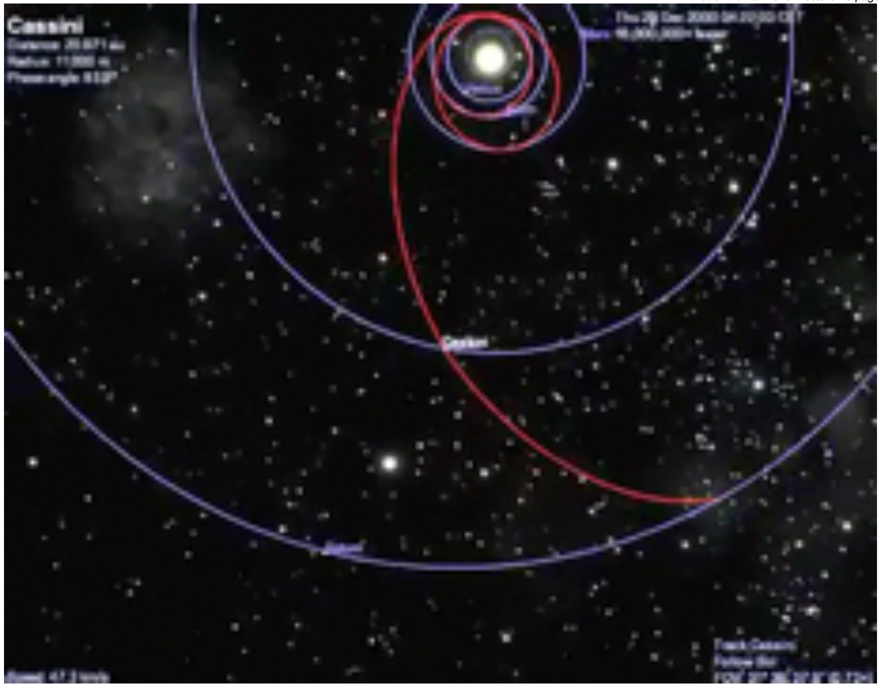
http://www2.jpl.nasa.gov/basics/grav/primer.php

CASSINI INTERPLANETARY TRAJECTORY

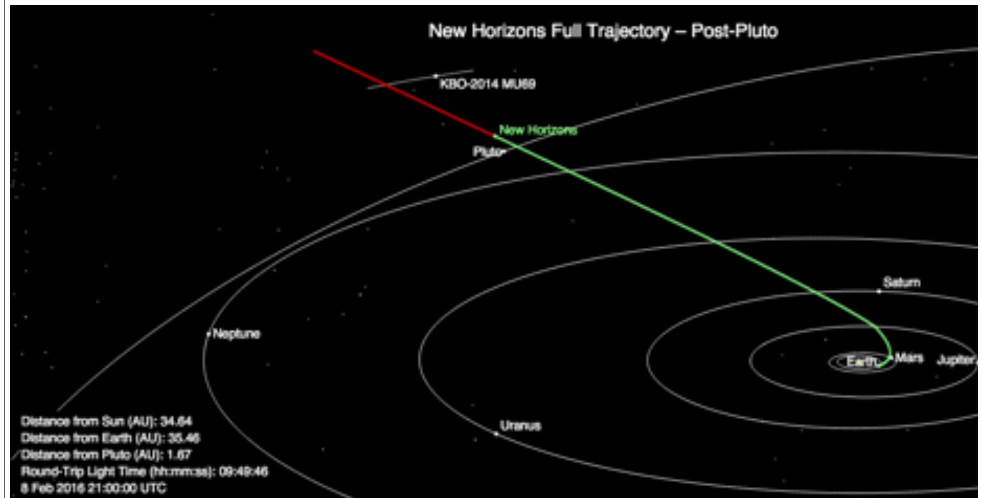


PERIHELIA

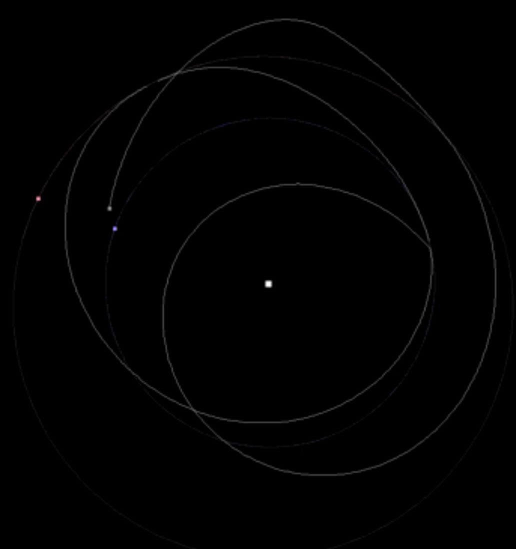
27 MAR 1998 0.67 AU
29 JUN 1999 0.72 AU



New Horizons to Pluto and beyond



Trajectories in “The Martian”



Trajectories in “The Martian”