

Reading: WWW-based reading on satellite orbits
 Bennett, Chapter 7, Sect. 7.1-7.2, Chapter 9, Sect. 9.1 (for Tuesday)
 Exam 1: Thursday, October 2 - rooms to be posted on website, review aids posted also

Brief review of last time: Newton's Laws

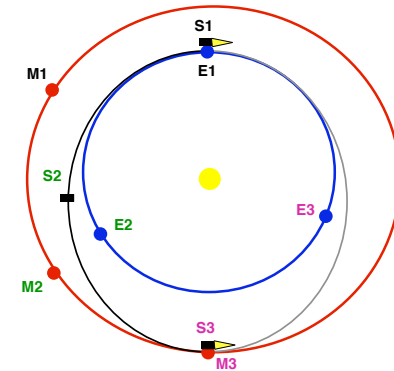
- **Newton's Laws**
 - physical laws describing motion of objects
 - definitions of Force, Velocity Acceleration, Inertia...
- **Newton #1: Law of Inertia**
 - objects move at constant velocity unless a force acts
- **Newton #2: Law of Force**
 - Force = mass x acceleration; $a=F/m$
- **Newton #3: Law of Action and Reaction**
 - force exerted by one object is equal and opposite to force exerted by the other
- **Newton's Law of Universal Gravitation**
 - gravity as a central, universal, cosmic force

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

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

- 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

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

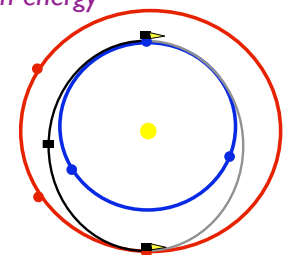
from near-Earth orbit,
 $v_{esc} = 11$ km/s (= 24,000 mph) away from Earth

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

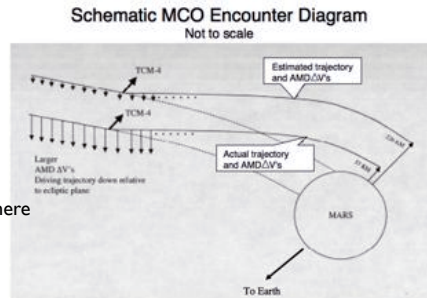
How Fast do you need to go to go achieve the transfer orbit to Mars?
 Kepler's Second Law tells us!
32.3 km/s w.r.t. the Sun



- **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)

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 get into Mars orbit
 - timing is critical here!

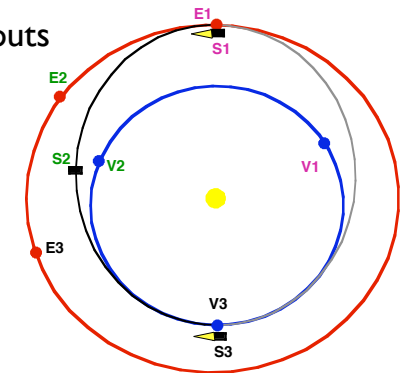


Mars Climate Observer (1999) got it wrong...

unit confusion (English vs. Metric)
approach too close - burned up in atmosphere

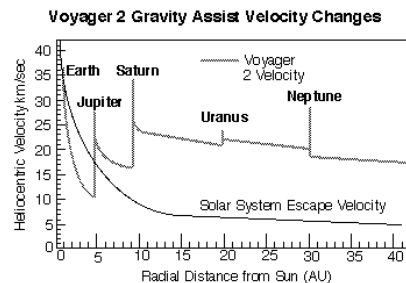
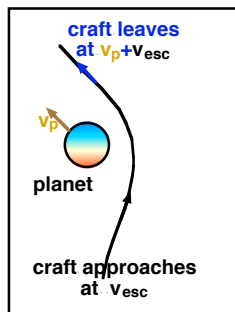
Similar scheme to reach Venus

- BUT: **Decelerate** from Earth
- Venus transfer orbit puts
 - Earth at **Aphelion**
 - Venus at **Perihelion**



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

CASSINI INTERPLANETARY TRAJECTORY

