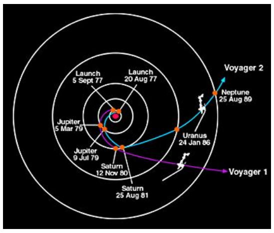
Today's Class: Gravity & Spacecraft Trajectories

- Read about *Explorer 1* at http://en.wikipedia.org/wiki/Explorer_1
- Read about Van Allen Radiation Belts at http://en.wikipedia.org/wiki/Van_Allen_radiation_belt
- Complete Daily Health Form



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CU Astronomy Club

- Need some Space?
- Escape the light pollution, join us on our Dark Sky Trips
  - Stargazing, astrophotography, and just hanging out
  - First trip: September 11
- Open to all majors!
- The stars respect social distancing and so do we
- Head to our website to join our email list: https://www.colorado.edu/aps/our-department/outreach/cu-astronomy-club
- Email Address: astronomyclub@colorado.edu

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Commercial Crews and Private Astronauts will boost International Space Station's Science

Article by Elizabeth Howell
Presentation by Henry Larson

- SpaceX's **Demo 2 flight** showed what human spaceflight can look like under **private enterprise**
- NASA relied on **Russia's Soyuz spacecraft** to send astronauts to the ISS in the past
- "We're going to have **more people** on the International Space Station than we've had in a long time," NASA Administrator Jim Bridenstine
- NASA is primarily using **SpaceX and Boeing** for their **"commercial crew"** program

Question: Will having private companies working so closely with nationa space programs pose a problem for the regulation of spaceflight in the future? Why?

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Last Class

- **Where do objects get their energy?**
  - Conservation of energy: energy cannot be created or destroyed but only transformed from one type to another.
  - Energy comes in three basic types: kinetic, potential, radiative.

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Today's Learning Goals

- What are range of common Earth orbits?
- How do spacecraft travel from one orbit to another?
- How can we use the gravitational energy of planets to assist in exploring the solar system?

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Class Exercise: Which of the following processes violates a conservation law?

a) Mass is converted directly into energy.
b) An object orbiting the Sun and affected only by the Sun's gravity spirals into the Sun.
c) One ball hits a second ball and stops moving while the second ball starts moving in the same direction.
d) An object speeds up as it approaches the Sun and turns around it, and then slows down as it moves further away, never to return.
e) An object orbits Earth on a perfectly circular orbit with no rockets firing.

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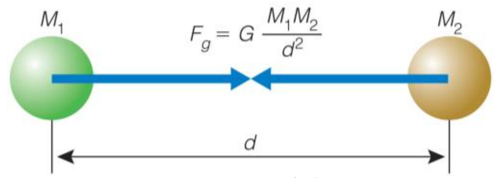
What determines the strength of gravity?

The **universal law of gravitation:**

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the *square* of the distance between their centers.



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Why do all objects fall at the same rate?

Combine Newton's 2nd Law (F=ma) with Law of Gravity:

$$a_{rock} = \frac{F_g}{M_{rock}} \qquad F_g = G\frac{M_{Earth} M_{rock}}{R_{Earth}^2}$$

$$a_{rock} = G\frac{M_{Earth} M_{rock}}{R_{Earth}^2 M_{rock}} = G\frac{M_{Earth}}{R_{Earth}^2}$$

- The gravitational acceleration of an object like a rock does not depend on its mass because M_{rock} in the equation for acceleration cancels M_{rock} in the equation for gravitational force.
- This "coincidence" was not understood until Einstein's general theory of relativity.

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Spacecraft in Circular Orbit

- To stay in a circular orbit requires a constant centripetal acceleration $a = \frac{v^2}{R}$, where R = orbit radius, v = orbital velocity.
- Combine Newton's Second Law (F=ma) with centripetal acceleration & Law of Gravity: $\frac{GmM_E}{R^2} = \frac{mv^2}{R}$ ⇨ $v = \sqrt{GM_E/R}$, M_E= Earth mass, m = spacecraft mass.

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Orbiting the Earth: some numbers

v = orbital velocity= $\sqrt{GM_E/R}$

- G = 6.67 x 10^{-11}
- M_E = 6 x 10^{24} kg → GM_E = 40 x 10^{13}
- Want an orbit with an altitude of 200 km:
  - R = Earth radius + altitude = 6600 km = 6.6 x 10^6 m
- v ≅ 7785 meters/s ≅ 28,000 km/hr ≅17,500 miles/hr
- And it takes about 1.5 hours (90 minutes) to complete an orbit (P = 2πR/v).

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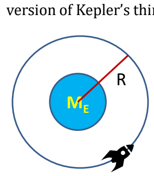
Class Exercise

- Derive an expression for the orbital period (P) of a spacecraft in a circular orbit around the Earth in terms of Earth's mass (M_E) & and orbital radius (R). This was originally derived by Newton as his version of Kepler's third law.



$P = \frac{2\pi R}{v}$ or $P^2 = \frac{4\pi^2 R^2}{v^2}$

Now, plug in v from previous page so (after a little algebra):

$P^2 = \frac{4\pi^2}{GM_E} R^3$

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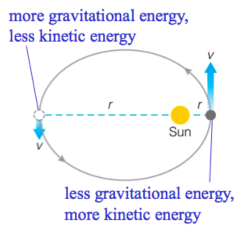
How do gravity and energy together allow us to understand orbits?



- Total orbital energy (TE) (gravitational + kinetic) stays constant if there is no external force.
- Orbits cannot change spontaneously.

Total orbital energy stays constant.

TE = KE + PE = $\frac{1}{2}mv^2 + \left(\frac{-GMm}{r}\right)$

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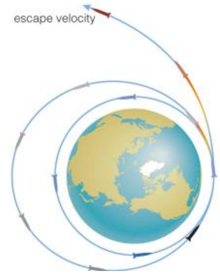
Escape Velocity



- If an object gains enough orbital energy, it may escape (change from a bound to unbound orbit).
- **Escape velocity** from Earth ≈ 11 km/s from sea level (about 40,000 km/hr)

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Common Earth Orbits

- Low Earth Orbit (LEO) [Hubble Space Telescope, HST]
- Geostationary Orbit (GEO) [Communications satellites]
- High Earth Orbit (HEO) [Chandra X-ray Observatory]
- Sun Synchronous Orbits [Remote sensing satellites, COBE]

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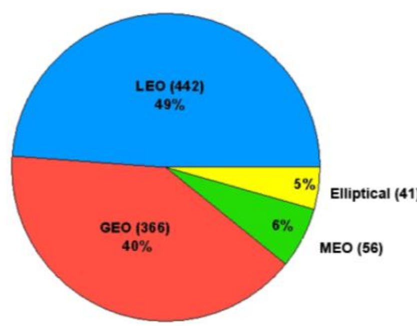
Distribution of Satellites in Orbits



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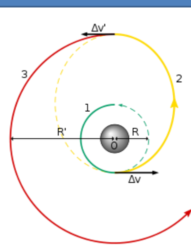
Hohmann transfer orbit

- The **Hohmann transfer orbit** is an elliptical orbit used to transfer between two circular orbits of different radii in the same plane. The orbital maneuver to perform the Hohmann transfer uses two engine impulses, one to move a spacecraft onto the transfer orbit and a second to move off it.
- Use conservation of energy to calculate total required Δv.



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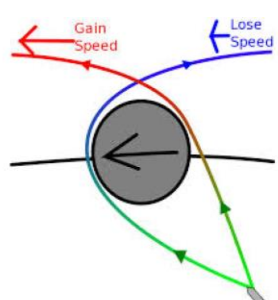
Gravitational Slingshot



Gravity Assists –

Think about the angular momentum!

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What have we learned?

- **What are range of common Earth orbits?**
  - LEO, GEO, HEO
- **How do spacecraft travel from one orbit to another?**
  - Hohmann transfer: use elliptical orbit to transfer between 2 circular orbits
- **How can we use the gravitational energy of planets to assist in exploring the solar system?**
  - Gravitational assist (slingshot): tap gravity well and motion of planets around the Sun.