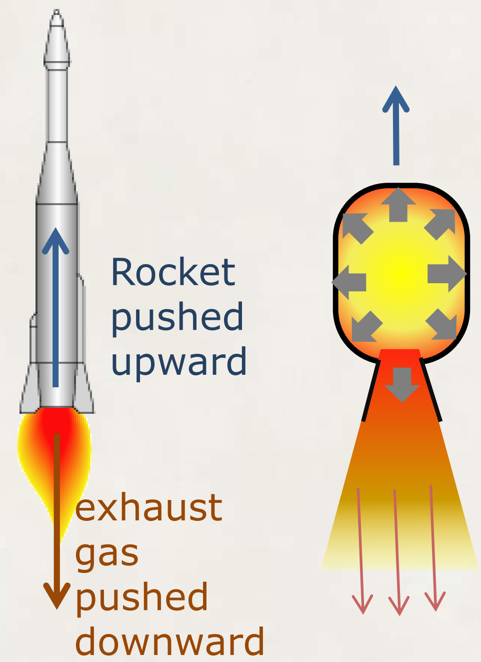
Rockets and Space Travel

ASTR 101

10/15/2018

Rockets and Space travel

- Airplane:
  - glides in air, burns fuels in air.
- Rocket:
  - travels in empty space,
  - has to carry both fuel and the oxidizer
    (for example liquid oxygen and hydrogen).



- The chemical reaction (burning) between the fuel and the oxidizer generates a large volume of hot gases which is expelled through a nozzle at a high velocity.

- What moves a rocket forward is the thrust exerted on the rocket by escaping hot gas.

according to the Newton's third law:

"for every action there is an equal and opposite reaction"

  - Rocket pushes exhaust gases out
  - Exhaust gas pushes the rocket in the opposite direction.

Like air rushing from a balloon pushes the balloon forward

There are several types of rocket engines:

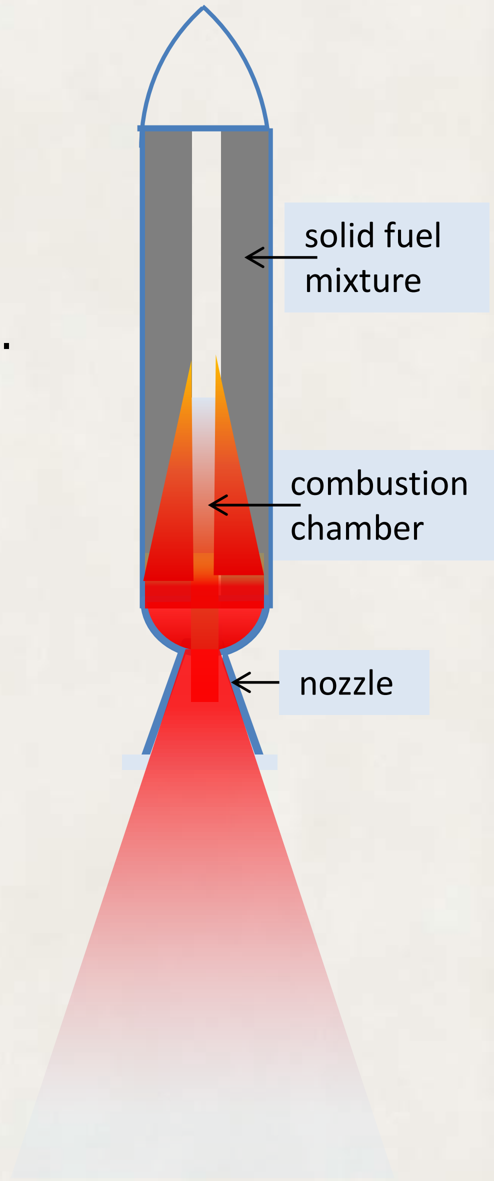
Solid fuel rocket engines:

- The fuel and the oxidizer in solid form are premixed and stored in the combustion chamber.
  - for example: gunpowder (charcoal and potassium nitrate earliest type), or aluminum power and ammonium perchlorate(type of a modern rocket fuel).

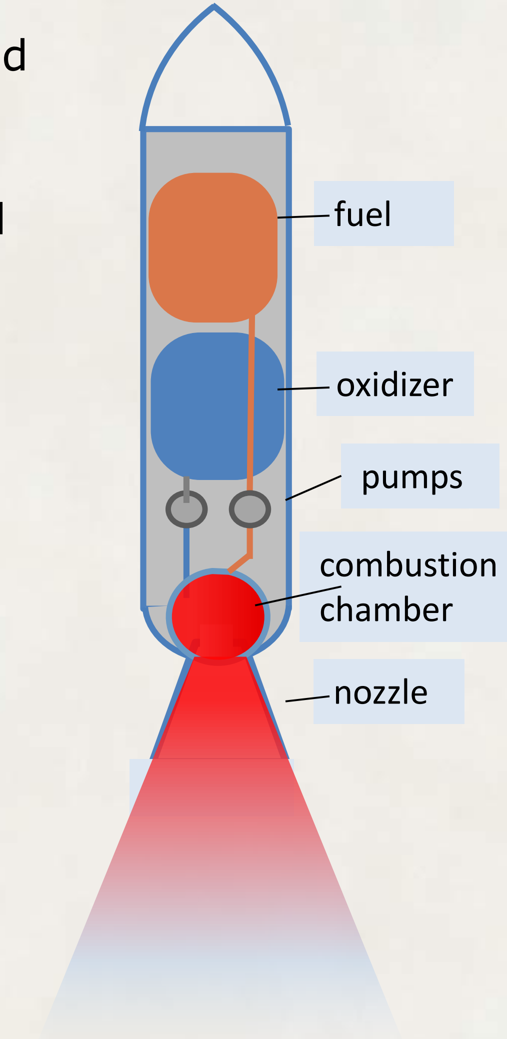
- Once ignited mixture burns and produce hot gases, which escape though a nozzle at the end of the chamber producing the thrust.

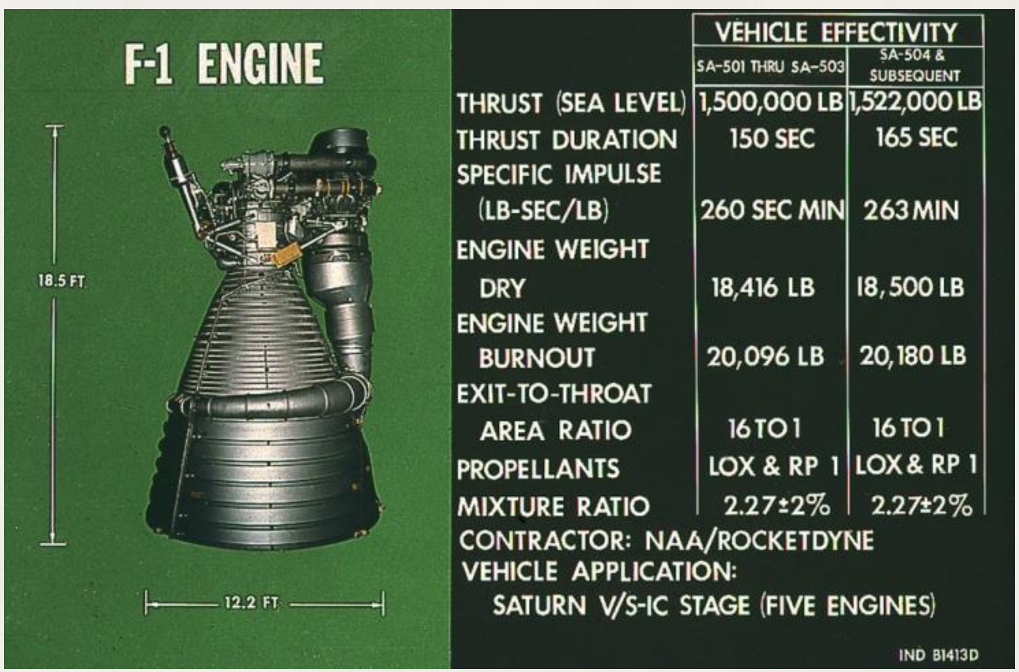
They are:

- simple,
- relatively inexpensive
- produce a larger thrust
- but lacks controllability
  - can't be turned off once the burn starts, it goes until all of fuel is used up.



- Liquid fuel rocket :
  - The Fuel and oxidizer (usually liquid Oxygen) are in liquid form, stored in separate tanks.
  - Fuel and the oxidizer are injected into the combustion chamber by mechanical pumps where they are combined and burned.
  - Hot combustion gases are ejected through a nozzle at a high velocity producing the thrust.
  - flow of the liquid fuel and oxidizer into the combustion chamber can be easily controlled.
    - can be turned on and off, or the thrust can be adjusted as needed.





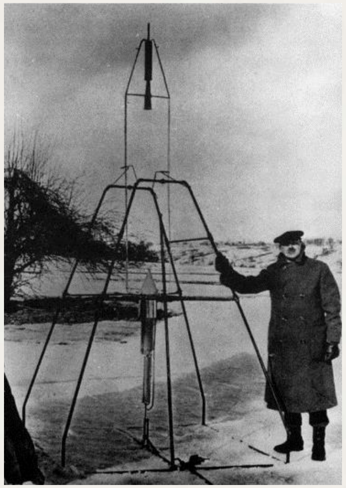
F1 engine of the Saturn rockets used in the Apollo missions . Each second it burned 670 gallons of liquid oxygen and 260 gallons of fuel to produce 6,700,000 N of thrust.

History of Rockets

- First recorded use of rockets was by Chinese. By13th century they had used rockets as missiles in warfare.
- Late 19th century Russian inventor Konstantin Tsiolkovsky first proposed the idea of space exploration by rockets.
- Early in the 20th century in the US, Robert H. Goddard first developed liquid fuel rockets.
- Major developments of liquid fuel rockets were done by Germans during the world war II, which later paved the way to space age.
  - The V-2 rocket (a ballistic missile) developed by Germans had the capability of delivering a 800 kg warhead to a distance of 320 km (200 miles). It used liquid oxygen and alcohol as fuel.

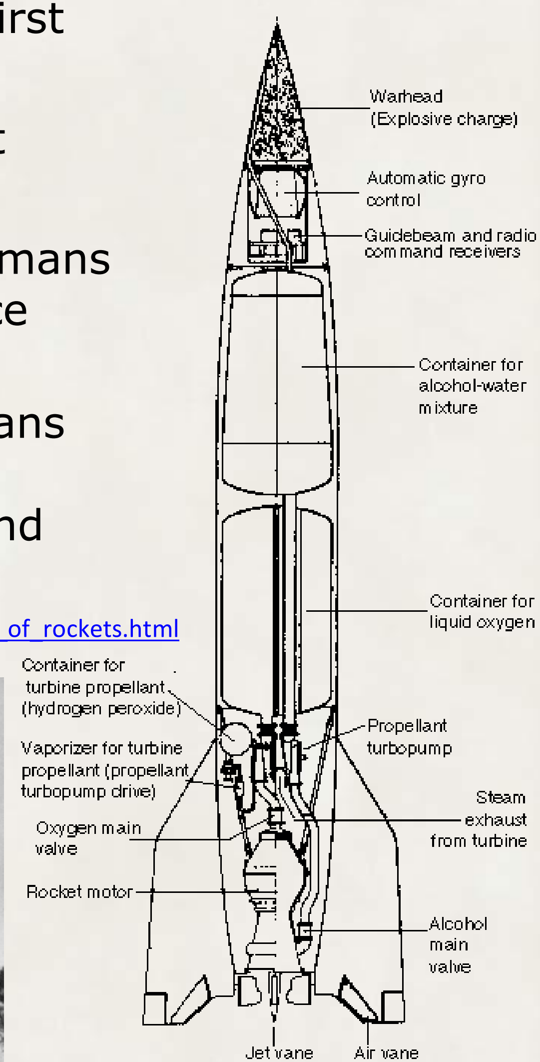
A good overview of the history of rockets: www.grc.nasa.gov/WWW/k-12/TRC/Rockets/history_of_rockets.html

A 13th century Chinese rocket weapon

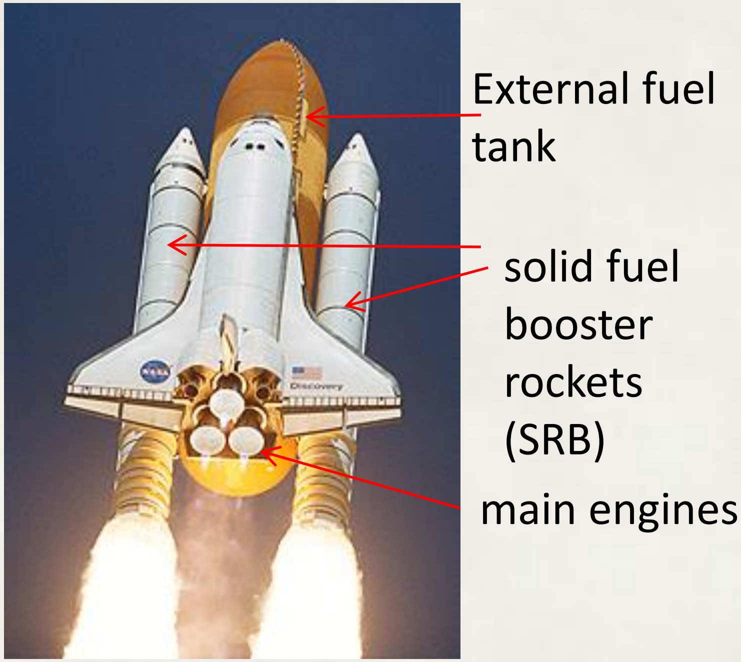


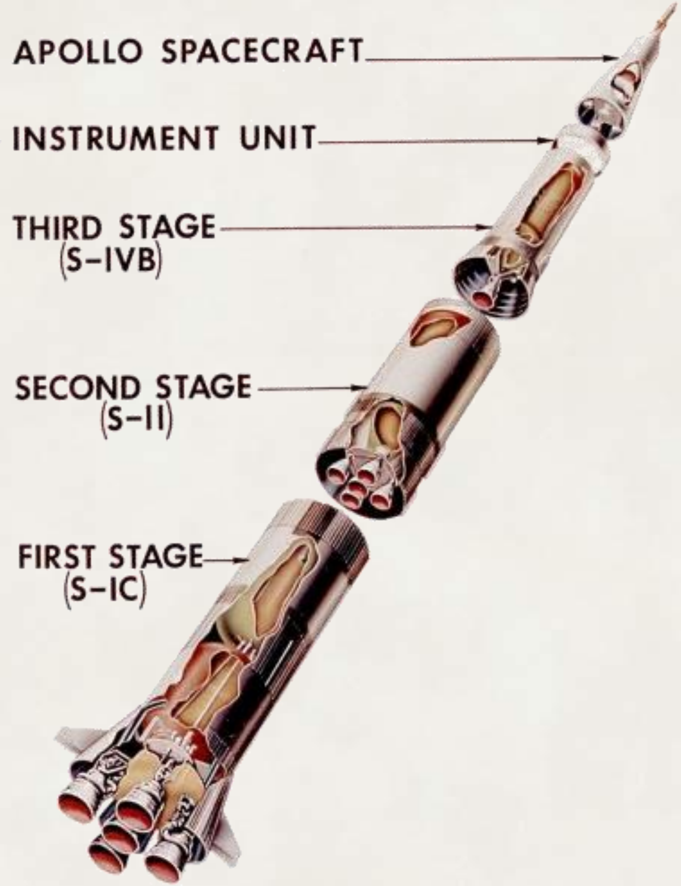
An early Goddard's rocket

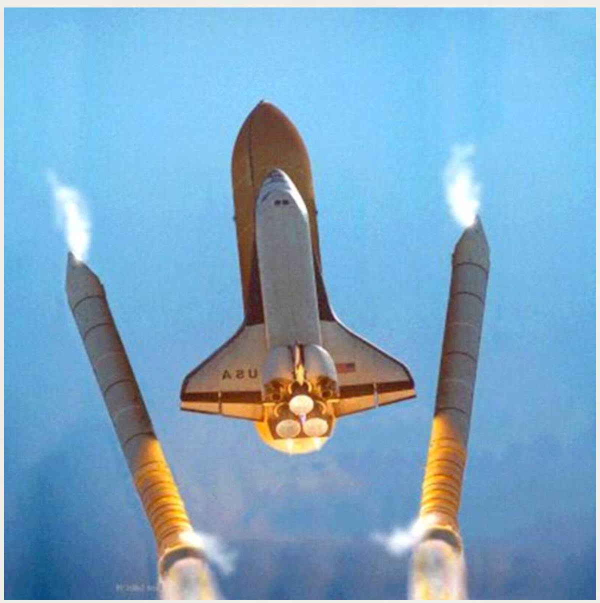
A V-2 rocket launch



V-2 main components

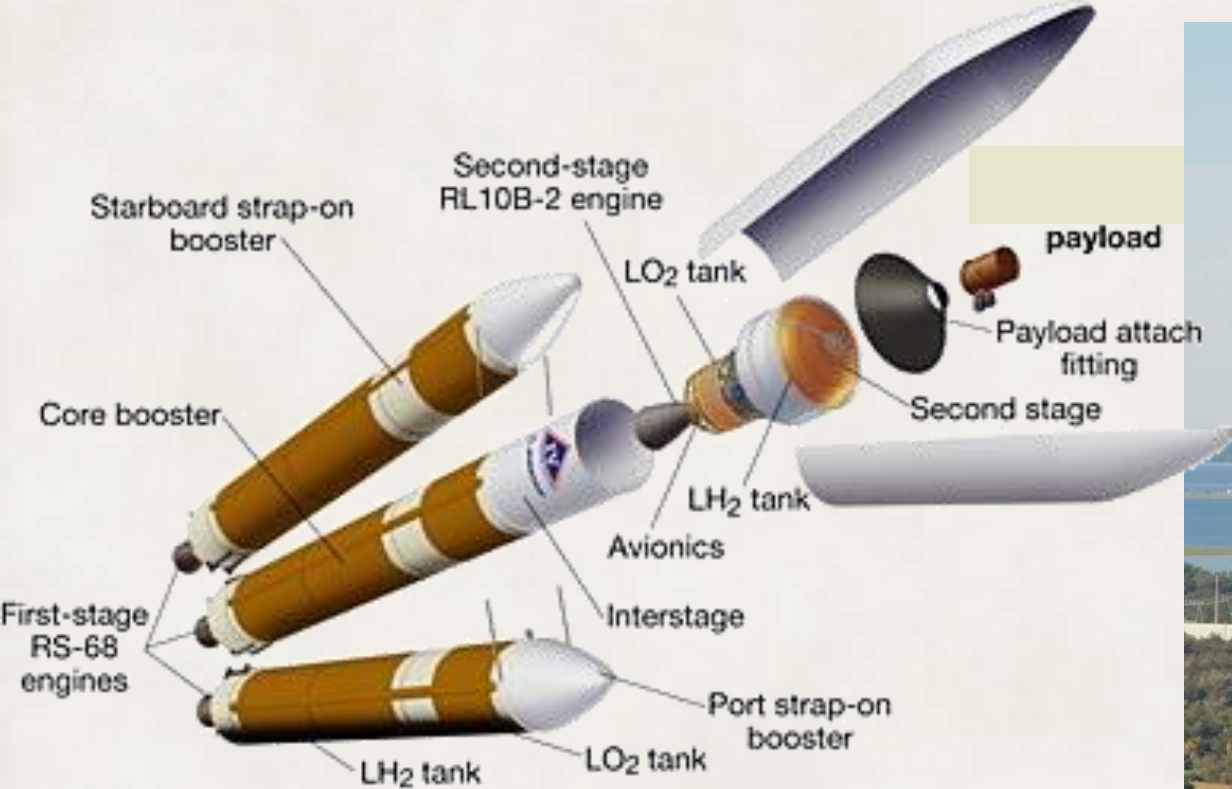






SRBs lasts for two minutes then separates

- To carry larger payloads it is common to stack several rockets to form a multi stage rocket.
- Each stage is successively jettisoned as they run out of the propellant.
  - Thus reducing the mass and allowing the thrust of the remaining stages to be used more effectively to accelerate the rocket to its final speed and height.

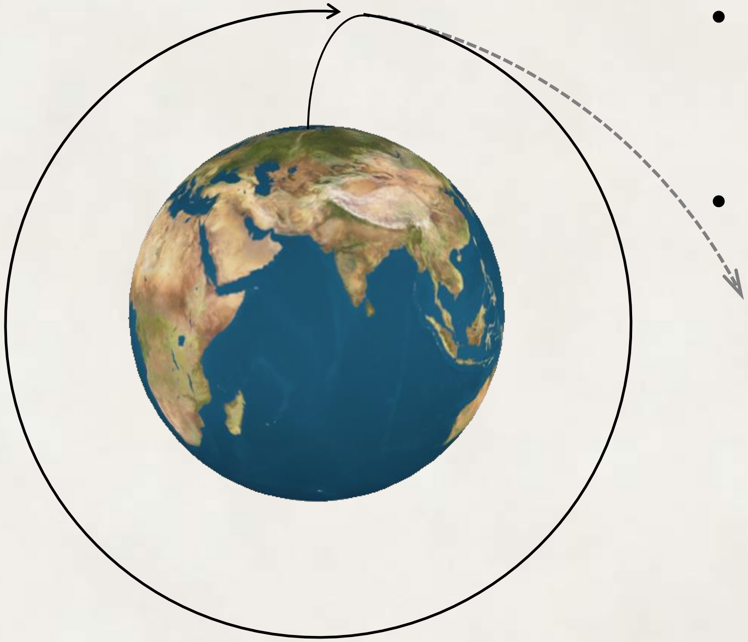


Delta 4 Heavy rocket

- Height: 72m, diameter 5m
- Mass: 700,000 kg
- Fuel: liquid hydrogen and oxygen
- Payload: 14000-26000kg

A Delta 4 launch

Launching satellites and space probes

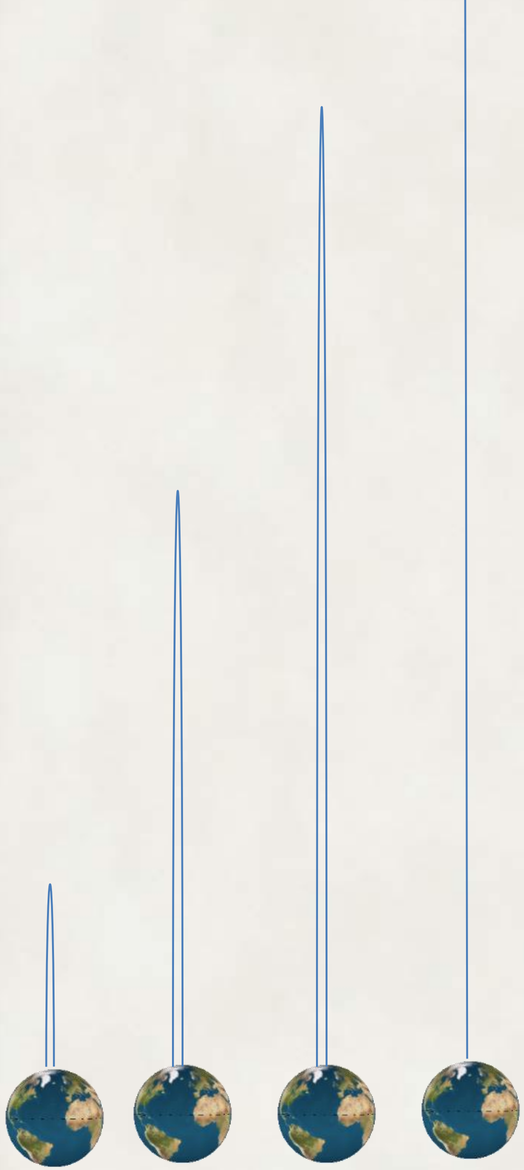


- Launching a spacecraft into an orbit circling the Earth or to outer space is similar to Newton's cannon experiment.
- If an object launched with sufficient speed it will orbit the Earth.
  - First use a rocket to take the satellite to the desired height above the Earth
  - Then use the rocket to propel the satellite at correct speed and direction so that it will be in the desired orbit.
  - for a low Earth orbit it is about 7 km/s.

- If the spacecraft is launched at a higher speed, it will follow a parabolic or hyperbolic path and won’t rerun to the Earth. It escapes the Earth’s gravitational field.

Escape Velocity

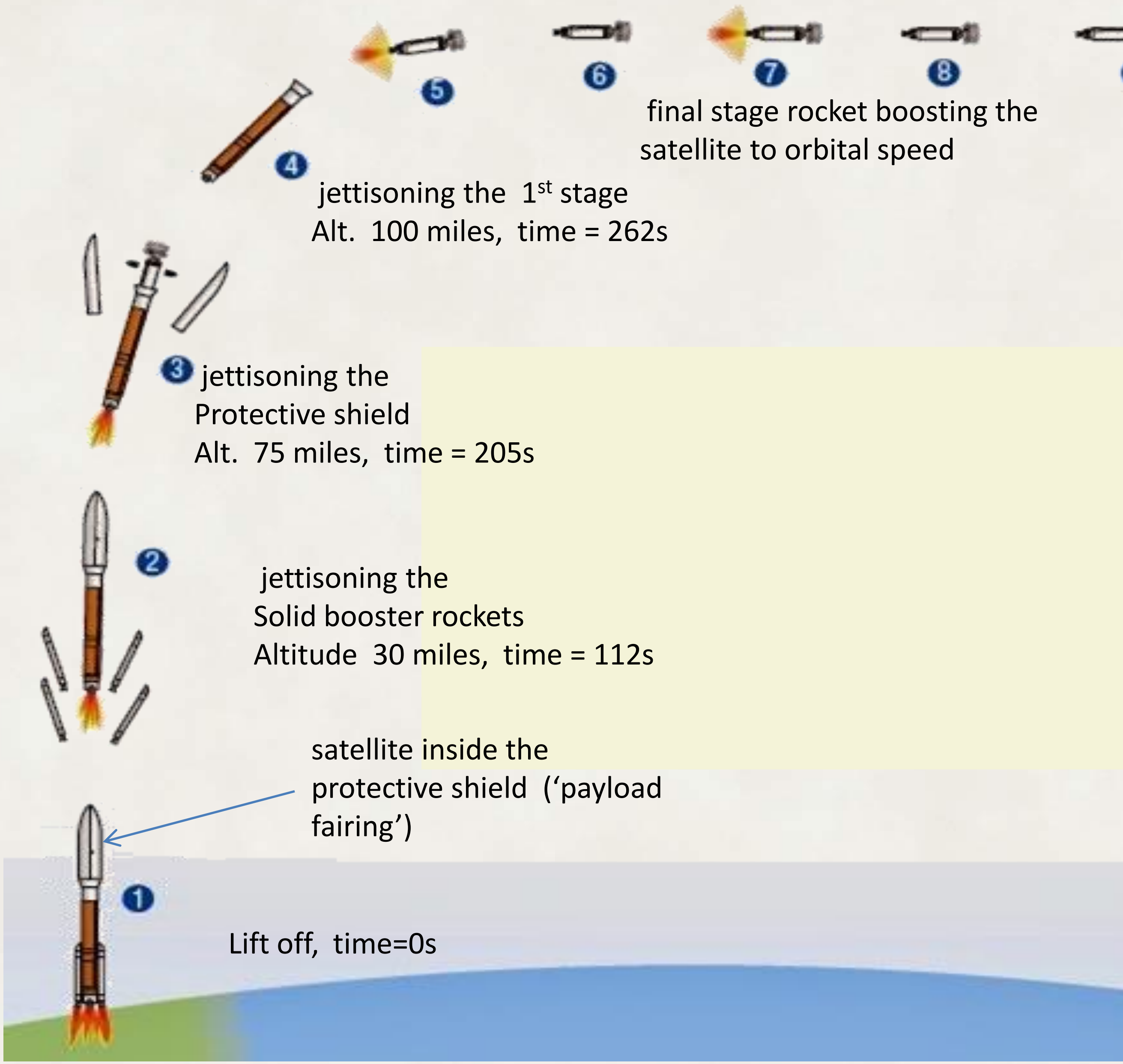
- **Escape velocity** (from Earth): The minimum speed at which an object has to be ejected so that it will escape from Earth.



- When an object (like a cannonball) is ejected vertically it will rise until the Earths gravity slows it down and stops. Then it will fall back to Earth.
- Gravitational pull towards the Earth diminishes as distance from the Earth increases.
- As the ejection speed is increased, there will be a speed at which the Earth's decreasing gravitational pull can never quite slow it to a complete stop.
  - Object continue moving away from Earth and won't return.
  - It has escaped the Earth's gravity.
- Escape velocity from the surface of the Earth:
  - about 11 km/s (40300 km/h or 25000 miles/hour)

- Similarly it is possible to define escape velocities for the Sun (or solar system) Moon and other planets.

  few Escape velocities:
  - from the Moon 2.4 km/s,
  - from Mars 5 km/s,
  - escape velocity from the solar system (at Earth location) 42 km/s



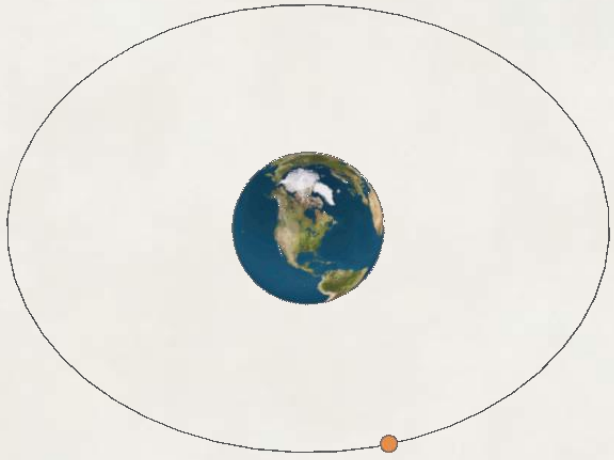
Basic steps of deploying a satellite/spacecraft.

An Atlas V rocket launch

Watch the video “How to Get to Mars” : www.youtube.com/watch?v=XRCIzZHpFtY

Geo-stationary orbits

altitude	speed	period
200 km	7.8 km/s	88 m
1000km	7.4 km/s	105m
10000 km	4.9 km/s	347m
20000 km	3.9 km/s	12 h
35800 km	3.1 km/s	23h 56m



- Once placed in the orbit a satellite circles the Earth with a period depends on the size (distance from earth) of its orbit.
  - In a larger orbit a satellite moves slower. (similar to planets in the solar system following Kepler's laws)
  - and has to travel a larger distance to complete the orbit.
  - So the orbital period gets longer.
- When a satellite is orbiting 35800 km above the Earth in a circular orbit, its period is 23hours 56minutes, equal to the rotation time of the Earth.
  - Such satellite orbiting above the equator in the same direction as the Earth's rotation, it will always stay at the same location above the earth.
  - Such orbits are called **Geostationary (or Geosynchronous)** orbits. Communication satellites are placed in such orbits so that it will cover the same area all the time.

Types of satellite orbits

- **Low-Earth orbits (LEO)** — Moving 180-2000km above the Earth. Used for satellites making observations, for military, weather or other purposes (also space station, Hubble space telescope, space shuttle).

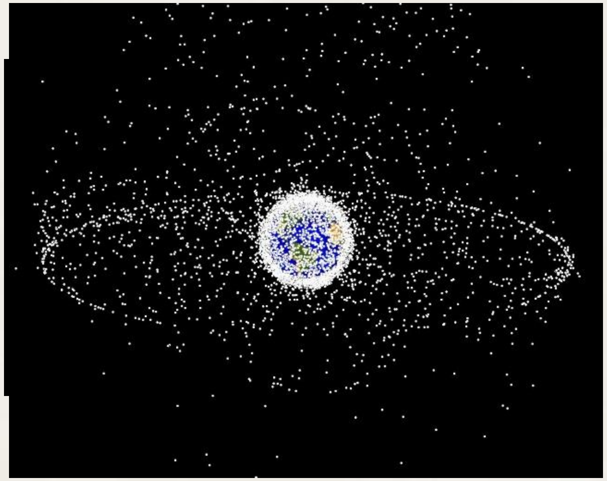
    - Sometimes such satellites are placed in **polar orbits**, with orbit in north-south direction.
    - So the Earth rotates underneath as it goes around the Earth, allowing the satellite to see every part on Earth in successive passes.

- **Medium-Earth orbits (MEO)** 2,000 - 36,000 km above the Earth. Navigation satellites GPS are placed in this region.

- **Geostationary orbits (GEO)** —35800 km above earth, communication satellites.

- The first successful satellite 'Sputnik' was launched on October 4, 1957 by the former USSR.

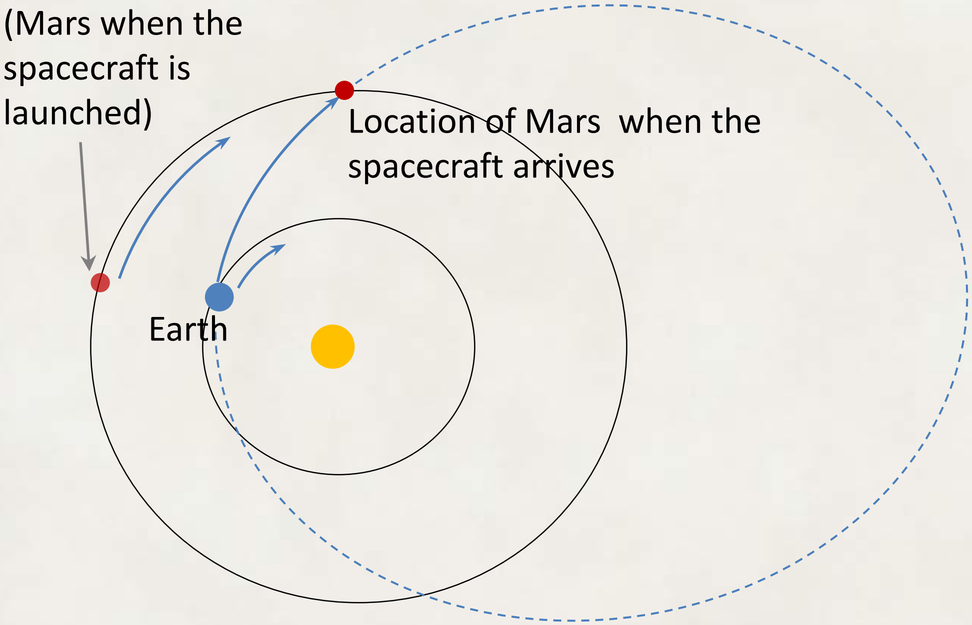
- Over 19,000 man made objects including functional satellites and debris orbit the Earth now

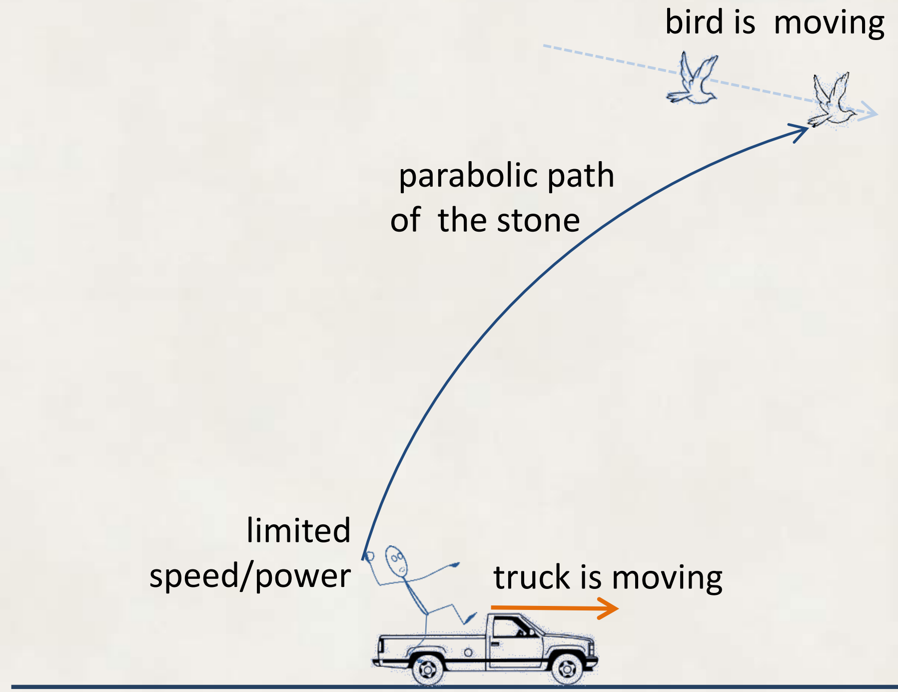


Man made Earth orbiting objects that are currently being tracked. Approximately 95% of the objects are orbital debris.

http://orbitaldebris.jsc.nasa.gov/

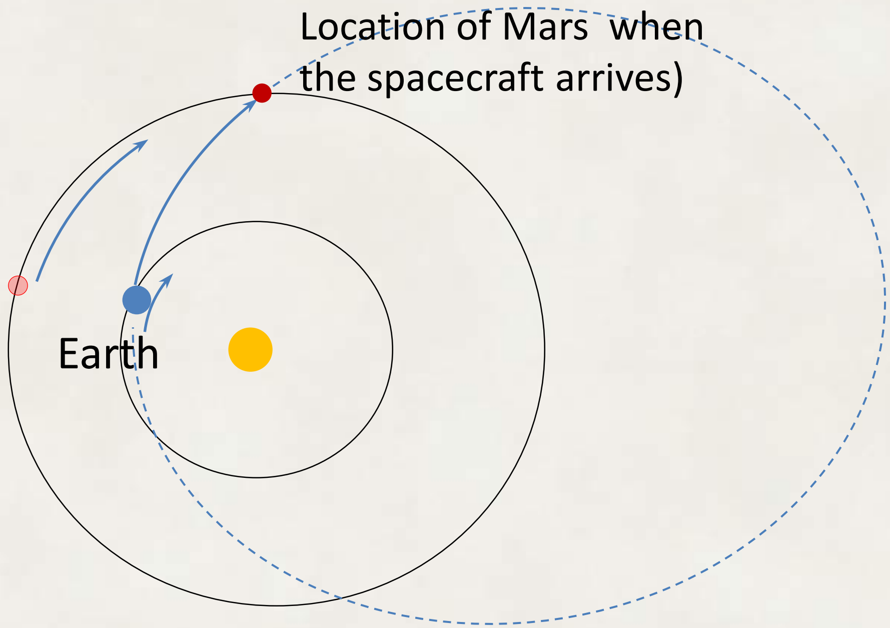
Navigating in the Solar System



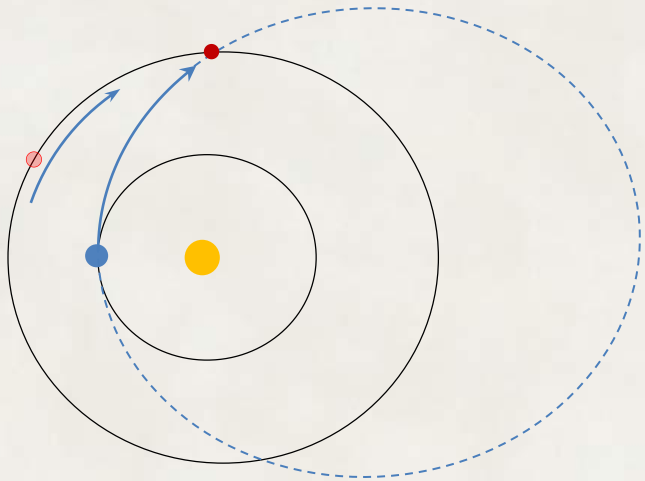


like hitting a flying bird with a stone, from a moving vehicle

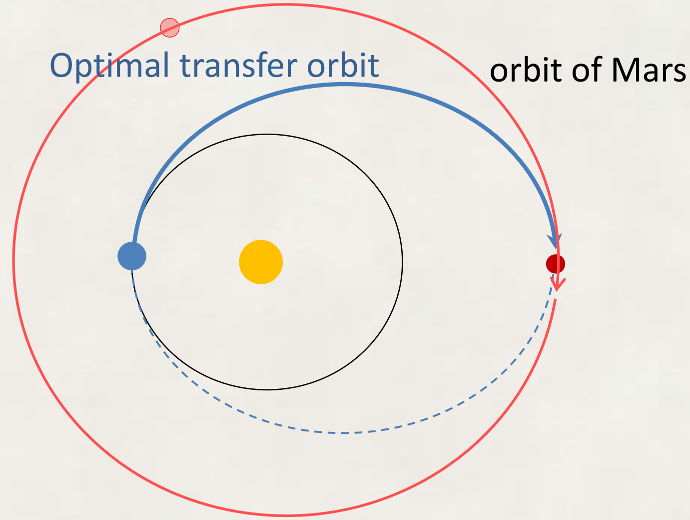
- Suppose we want to send a spacecraft from Earth to Mars.
- Both Earth and Mars are moving, they move in their orbits around the Sun.
- A rocket combustion lasts only a few minutes, after that spacecraft is moving freely without any propulsion power.
- Future location of the planet has to be judged and launched in the correct path to meet it.



- After the launch, spacecraft moves freely under the influence of gravity:
  - first under the gravity of the Earth and then of the Sun
  - It is moving in an orbit around the Sun, according to Newton's laws.
  - Therefore to send a spacecraft to Mars:
    - it should be placed in an orbit which intersects the orbit of Mars
    - when the spacecraft intersect the Mars orbit, Mars has to be there.
  - Such an orbit is called a **transfer orbit**.



Larger initial speed, gets there in a shorter time. But requires powerful rockets to launch and stop. Expensive!



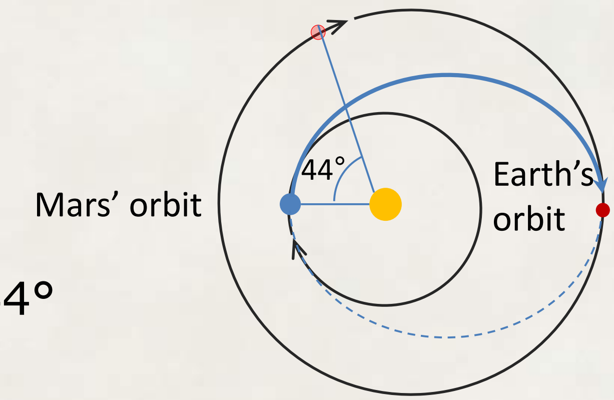
Optimal transfer orbit, takes a longer time, but launched at a lower speed and arrives at a lower speed. Economical!

- A faster speed gets there in a shorter time, but needs a larger rocket. Expensive!
  - Not only it has to be launched, when it arrives at the destination, has to be slowed down.

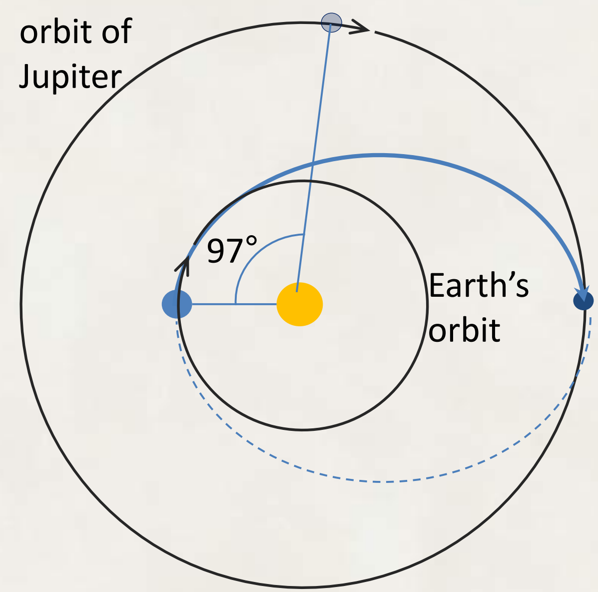
    That needs firing another rocket in opposite direction.
    (No breaks in the empty space!)
- So the optimal transfer orbit is the one just reaches Mars.
- This happens when the transfer orbit just touches the Earth and the Mars orbits along its major axis
- Again, the launch has to be correctly timed so that Mars and Earth are in the correct configuration for space craft to meet Mars when it reaches the Mars' orbit.

- Suitable positioning of planets for an optimal transfer orbit is a **launch opportunity**.

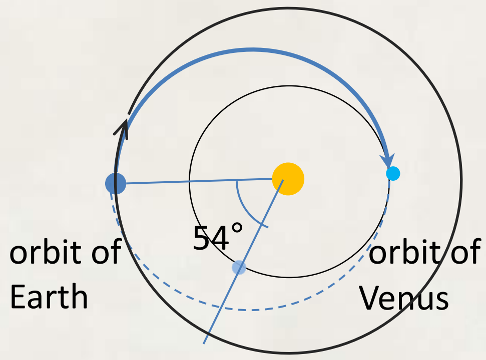
- For Mars a launch opportunity is when Mars is 44° ahead of Earth:
  - Such alignment happens once every two years.
  - would take about 8.5 months to get to Mars in such orbit.

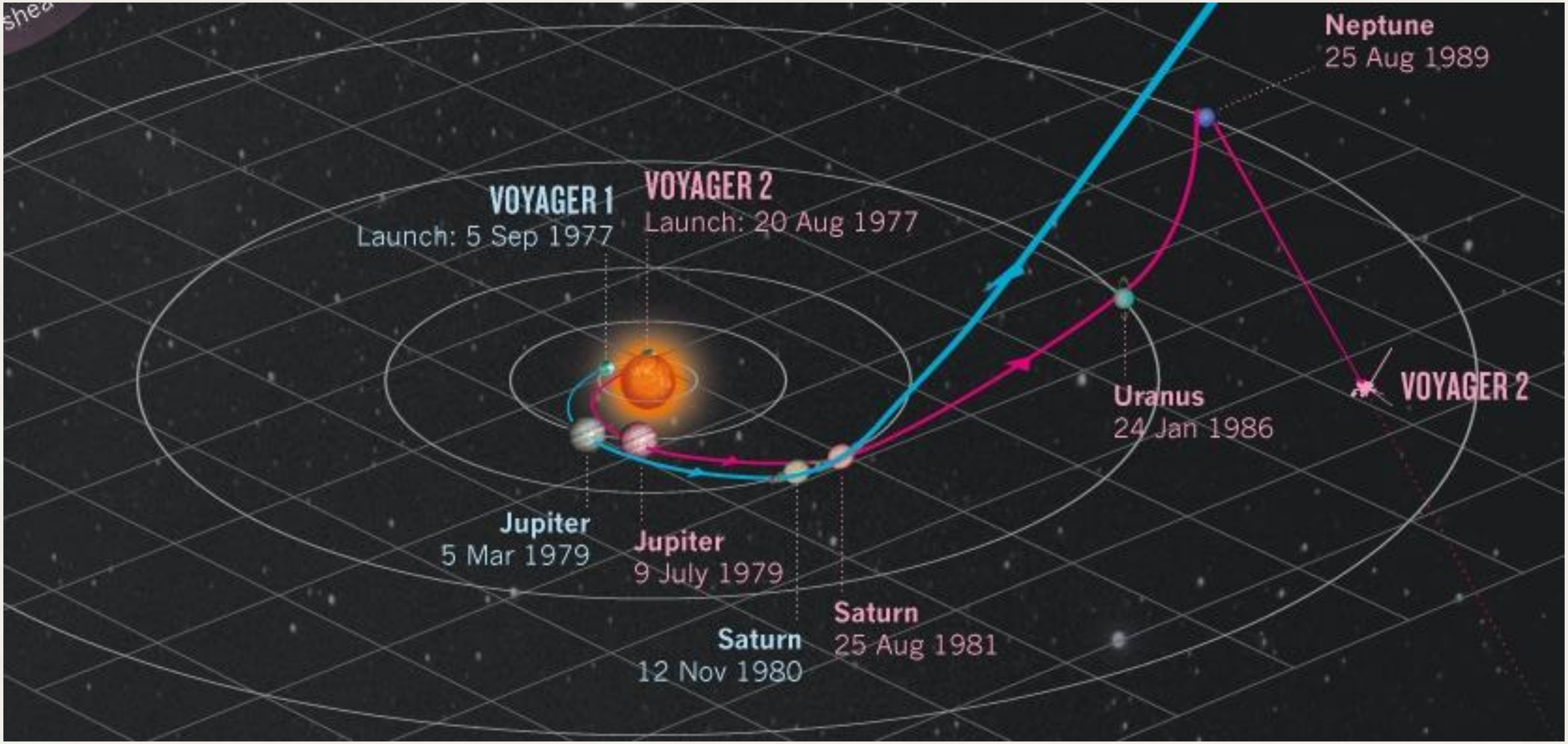


- Similarly to get to Jupiter lunching opportunity is when Jupiter is 97° ahead of Earth.
  - occurs once every 13 months.
  - takes about 33 months to reach Jupiter.



- To go to an inferior planet like Venus, spacecraft has to navigate inward, launch opportunity to Venus occurs when Venus is 54° behind the Earth.
  - takes about 5 months to arrive at Venus.





- By proper timing a spacecraft could be made to fly by several planets in a single mission.
- Voyager missions launched in 1977 was able to fly by all outer planets, Jupiter, Saturn, Uranus and Neptune and now have moved away from the solar system to the interstellar space.
  - Such opportunities are rare, happens once every 175 years.
  - Watch the Video on Voyager: www.youtube.com/watch?v=seXbrauRTY4
  - More information at: voyager.jpl.nasa.gov/where, www.nature.com/news/voyager-outward-bound-1.13040

Review Questions

- What are the advantages of liquid fuel rockets over sold fuel rockets?
- What is the advantage of using a multistage rocket?
- Why do solid fuel rockets are used mainly in the initial (booster) stage of a launch?
- What were the shortcoming of the space shuttle that finally lead to abandoning the shuttle program?
- What are geosynchronous orbits? What are they useful for?
- What is the advantage of putting a satellite in a polar orbit? What are they useful for?
- Why do astronauts feel weightless in an orbiting satellite?
- What is the shape of the path of a spacecraft going to Mars or other planet from Earth?
- What is the "escape velocity"? What happens if something moves faster than the escape velocity?
- What is the escape velocity from the Earth's surface? What is the escape velocity from the Moon?
- Way is it desirable to launch a spacecraft from a location near the equator than from a location in the Arctic circle?