# SATELLITES

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The object we frequently hear when it comes to space missions is a satellite. In this module, we will understand, what satellites are, what keeps them in their orbits and why we inject satellites into a particular orbit for a specific purpose? Parts of satellites and how are satellites used in our day-to-day activities.

## What is a Satellite?

*Fig. 1: Satellite*

A Satellite is a body that orbits around a planet or any celestial body in space. Generally, we categorise satellites based on their formation as natural and artificial.

**Natural Satellites:**

As the name suggests, they are natural objects that revolve around a planet or a star. Natural satellites of a star are called 'planets', and the planet's natural satellites are called 'moon'. For example, the Earth is a planet in the Solar System as it revolves around the Sun (and so are the other seven planets). The Moon is Earth's natural satellite, and moons of other planets have unique names. For example, Mars has two moons, named Phobos and Deimos.

**Artificial Satellites:**

Artificial satellites are designed and manufactured by people and put into orbit to revolve around planets and other bodies using rockets. While artificial satellite orbit, it does a specific task and send the response to ground station on Earth. They serve various purposes such as communication, remote sensing, navigation and scientific exploration. The term spacecraft is more general which includes satellites, interplanetary and lunar crafts, human space modules, space stations, etc.

## How did the concept of Satellite evolve?

The idea of using satellites for worldwide radio coverage and facilitating long-range communications was proposed by Arthur C. Clarke in 1945 in his essay titled 'Extra-Terrestrial Relays'. Later in the year in 1957, on account of the International Geophysical year, USSR launched the world's first artificial satellite, Sputnik - 1, on 4th October 1957 from Russia and later, America launched its first satellite, Explorer -1, on 1st February 1958. Launch of these two satellites encountered Space Race between Russia and America which brought in many technologies and applications of space technology serving common people's life. It is fascinating to learn that the satellites were envisioned to serve global communication long before the first satellite was launched!

Today approximately there are more than 6000 satellites in space operating and many whose lifetime is over and are lying as debris.

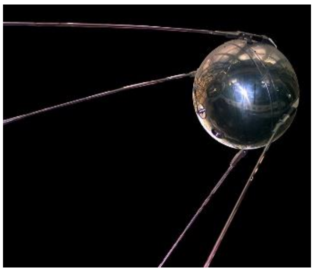


*Fig. 2: Sputnik - 1*

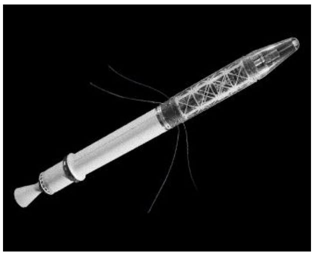


*Fig. 3: Explorer - 1*

## How do we launch a satellite into Space?

Satellites are fixed on the uppermost side of Rocket called - Nose Cone. Rockets are Launched when the propulsion system generates a massive thrust. Once the Rocket generates more thrust than its weight, it lifts into the air to begin its Powered Ascent.

*Fig. 4: PSLV Rocket*

In any Rocket, the weight of the payload system or a satellite is only a tiny portion of the gross lift-off weight of the Rocket. Most of the weight is contributed by the propellants that produce the required thrust. As discussed earlier, the propellant gradually burns off as the Rocket flies upwards, leading to emptied propellant tanks.

The empty propellant tanks and the structure enclosing them contribute to the dead weight of the Rocket, which must be ejected for the Rocket to attain orbital velocity and put the payload in the Orbit. This process is known as Staging. The method involves breaking up a giant Rocket into two or three smaller parts that fall away at different launch stages. The upper stage engine Cuts off at the correct altitude and speed, completing the Rocket's journey from Earth's surface into Orbit. Ultimately, only the payload bay goes upwards into an orbit and achieves the mission goals by beginning its journey.

## What is a Satellite made up of ?

A typical satellite will consist of the following subsystems

1. Payload Subsystem
2. Propulsion Subsystem
3. Structural and Mechanical Subsystem
4. Thermal Subsystem
5. Attitude and Orbit Control Subsystem
6. Electrical Power Subsystem
7. Telemetry, Tracking and Command Subsystem
8. Application payloads

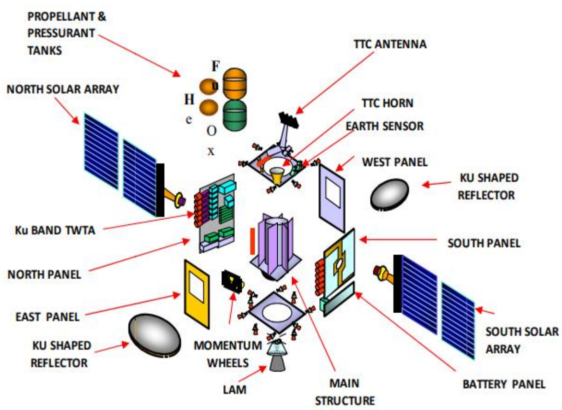



*Fig. 5: Subsystems of a Satellite*

Let us know more about all the subsystems:

1. **Payload Subsystem:**
   The payload of a satellite is tailored based on the mission objective that a satellite is required to carry out. Based on the mission objective, a satellite payload can be broadly classified into three categories, namely
   a) space science mission payloads,
   b) earth observation payloads, and
   c) communication and navigation payloads.

2. **Propulsion Subsystem:**
   Few of the missions may have to change the satellite's velocity in order to move to another orbit, and it is done through the propulsion system present on spacecraft. The propulsion system consists of a propellant, propellant tank, combustion chamber and nozzle; just like in Rockets, here the spacecraft has the smaller versions of the same. It provides the thrust to execute manoeuvring, such as transporting the satellite from its transfer orbit to final orbit, station keeping operations, and decommissioning. There are solid fuel, liquid fuel, and electric and ion propulsion systems.

3. **Structural and Mechanical Subsystem:**
   All the instruments and equipment have to be safely maintained and assembled. When a satellite is launched, and on the way to its intended orbit, it experiences heavy g-forces and vibrations, hence a strong supporting mechanical structure is required. It gives a shape to the satellite and provides space to many other satellite subsystems.

4. **Thermal Subsystem:**
   As satellites consist of various electronic equipment and space has harsh and extreme temperature conditions, it is essential to maintain the equipment in the operating stage. Thermal blankets and heat shields are used to insulate a few electronic devices. Hence, the Thermal subsystem of a satellite helps maintain the required temperature conditions for respective instruments.

5. **Attitude and Orbit Control Subsystem (AOCS):**
   A satellite needs to be placed in a required orientation (specific orbit at a certain angle) and to determine the satellite position; we use ACOS. It consists of actuators and small engines that can place the satellite into its right orbit or whenever the orbital flight path has to be changed when a satellite is likely to collide with another satellite or shift to another orbit.

6. **Electrical Power Subsystem:**
   Satellites in orbit are always conducting a task assigned during their life period. Various electronic equipment and systems in the satellites regularly consume power to do the task and transmit the data back to the ground station. A satellite in space cannot use the AC/DC power like how we use it here on earth. Hence an internal power system is required.

   The electrical subsystem ensures the required power supply to the sensors and actuators present in the satellite and is distributed in the required amount. This subsystem handles the generation, adjustment, and storage of energy needed by the payload and other subsystems. The power required by satellites is generated through Solar panel which uses solar energy and converts solar energy into electrical energy. The electrical energy is stored in the rechargeable batteries, which can be used when the sunlight is absent.

7. **Telemetry, Tracking and Command (TTC) Subsystem:**
   The satellite operates in space, such that it receives the radio signals transmitted from the antennas situated on the earth's surface and retransmits them using a transponder. The TT&C subsystem of the spacecraft is responsible for collecting the data of vital parameters from all other subsystems on the spacecraft through multiple sensors and relaying them back to the ground station. Hence, TT&C can be called the brain of the spacecraft.

8. **Application Payloads:**
A satellite is launched into space on a mission to conduct a specific task. The task could be to capture the images of the Earth, measure the temperature of the atmosphere, send information from one place to another, etc.; these tasks are performed using specific equipment called Payloads. For example, Cameras, Radiometers, Radar, Transponder, etc.

## Types of Satellites:

Satellites are classified as various types based on the following criteria.

**A) Based on mass of the satellite:**

| Type of satellite | Mass |
|---|---|
| Large Satellite | >1000 Kg |
| Medium sized Satellite | 500 – 1000 Kg |
| Mini Satellite | 100 – 500 Kg |
| Micro Satellite | 10 – 100 Kg |
| Nano Satellite | 1 – 10 Kg |
| Pico Satellite | < 1 Kg |

**B) Based on the altitude of the Orbit:**

| Type of Satellite | Altitude |
|---|---|
| Low Earth Orbit Satellite | 200-2000 km |
| Medium Earth Orbit Satellite | 2000 – 35786 km |
| Geostationary Orbit Satellite | 35786 km |

**C) Based on applications:**

- Communication Satellite
- Navigation Satellite
- Remote Sensing or Earth Observation Satellite
- Outer Space Exploration or Space Observatory

## Why do we need Satellites? How is it helping life on Earth?

Sputnik the first artificial satellite was an experimental satellite. It opened up the possibilities of using satellites and space technology for research and applications in various areas. It can be noted that significant contributions have been made to the world's social and economic development in the domains like Land Transportation, Aviation and Maritime, Surveying and Mapping, Urbanization, Environmental Monitoring, Disaster Management, Sustainable Agriculture, Food Security, Human Health, and Natural Resource Management.

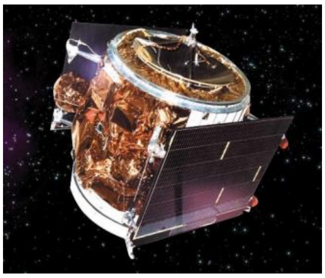


*Fig. 6: APPLE*
*ISRO's first communication satellite*

Satellites help communicate with people across the globe, find the route to a particular destination, predict the weather, guide farmers, and have enabled 5G Technology, e-banking, Tele-medication, Robotics, Artificial Intelligence, and much more.

We observed stars in the sky for navigation in the olden days. Today, we use satellites for the same. By this, we can understand how technology has evolved.

Besides Earth observations, satellites are also used to explore outer space. Many spacecraft were sent to the Moon and neighbouring planets such as Mars, Venus, Jupiter and its moons which led to discoveries that made headlines like the discovery of water on the Moon. Humanity also went on to land spacecraft on asteroids and comets. While some spacecraft were sent close to the Sun, others have crossed our solar system!

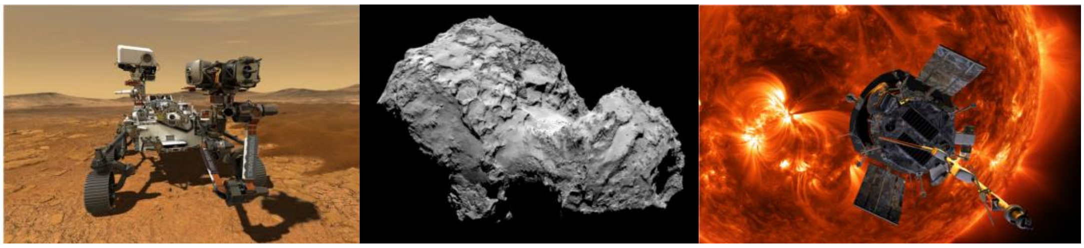


*Fig. 7: From left to right, Perseverance Rover, Rosetta, Parker Solar Probe. (Credits: NASA/ESA)*

From using telescopes to observe space, we now place telescopes in space to peer deeper into the cosmos. Hubble Space Telescope is a famous space telescope gathering information about our universe from Earth's orbit. Today, we understand that Earth is not the only planet in the universe; we have many Earth-like planets in other systems called Exoplanets, some of which can potentially host life. Hundred years ago, the black hole was just an equation, and in 2019, for the first time, an image of the closest supermassive black hole, Sagittarius A* located at the centre of our Milky Way galaxy was captured.


*Fig. 8: From left to right – Hubble Space Telescope (HST), Image captured by HST and Exoplanets.*

## India’s First Satellite:

The Aryabhata spacecraft, named after the famous ancient Indian mathematician and astronomer, was India's first satellite. It was completely designed and fabricated in India and launched by a Soviet Kosmos-3M rocket from Kapustin Yar, Soviet Union, on April 19, 1975. The spacecraft was a 26-sided polygon 1.4 m in diameter. Except for the top and bottom, all other faces of the satellite were covered with solar cells to provide the necessary power. Aryabhata was a scientific satellite and conducted experiments in aeronomy, solar physics and x-ray astronomy. Aryabhata’s success marked a significant milestone in our country's history.

*Fig. 9: Satellite man, UR Rao, sitting beside an Aryabhata model (Credits: The Hindu)*

## Photographing the Earth:

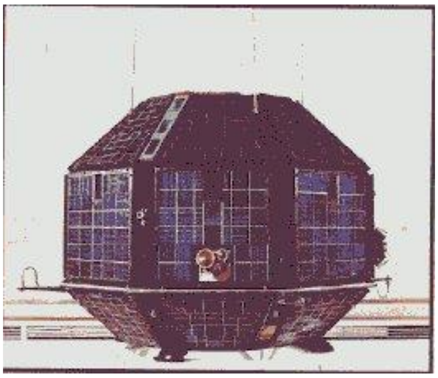


Fig. 10: Bhaskara I

In 1979, a second satellite was sent to orbit called the Bhaskara I, after the 7th century Indian mathematician. It was the first remote sensing satellite by ISRO, with an Earth-observation payload (cameras) and three-band Satellite Microwave Radiometer (SAMIR). It was also used to test the performance of indigenously developed solar cells and heat pipes under prolonged exposure. Subsequently, Bhaskara II was sent in 1981, with the purpose to collect data on hydrology, oceanography, forestry and telemetry.

## Launching satellite from the Indian Soil:

The Rohini series of satellites were India's first attempt to launch a satellite on an indigenously developed rocket. This series consisted of four satellites, each launched by the satellite launch vehicle SLV-3.

The first mission, Rohini Technology Payload (RTP), failed to reach orbit due to the failure of SLV-3. On the second attempt, successfully inserting Rohini Satellite 1 into its intended orbit, India became the 7th country to have the capability to build and launch satellites to space. RS-1 carried a digital sun sensor, a magnetometer, temperature sensors and also relayed the performance of the 4th stage of SLV3. Later, ISRO launched the Rohini series of development satellites, RS-D1 and RS-D2, which carried cameras to experiment with the remote sensing technologies.

Fig. 11: Image of RTP

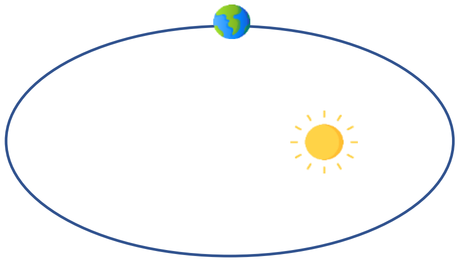
ISRO has made its name worldwide through a few programs like Chandrayaan I and II, Mangalyaan and once held the record of launching maximum (of 104) satellites on a single mission. Currently ISRO is working on Gaganyaan, Chandrayaan-3, NISAR and Aditya L1 missions.

## Kepler's Laws of Planetary Motion:

It was Johannes Kepler, with his observations, who said that the planets do not revolve in a circular orbit around the Sun instead, they orbit in an elliptical orbit. Kepler's Law of planetary motion gives us insights on the elliptical orbit, area covered and time period of an orbit.

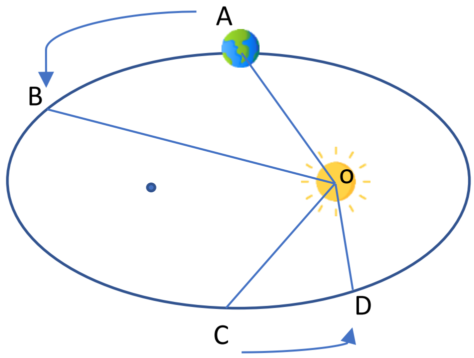
**Law of orbits:**
*"All planets move in elliptical orbits, with the Sun at one focus"*

The photos we see of the Solar system, where the eight planets revolve around the Sun in perfectly circular orbits, are incorrect. Planets usually revolve in elliptical orbits with Sun occupying one focus.



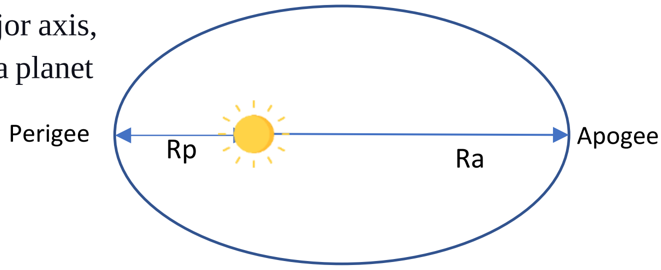
**Law of areas:**
*"A line that connects a planet to the Sun sweeps out equal areas in equal intervals of times"*

Consider a planet moving from point A to B for a certain time period (t), and then moving from point C to D for the same t. By Kepler's second law the areas covered by arcs AoB and CoD are equal. In other words, area velocity is constant for planet motion.




**Law of periods:**
*"The squares of the orbital periods of the planets are directly proportional to the cubes of the semi-major axes of their orbits"*

This law states that the time period, T, and the semi-major axis, a, are related by $T^2 \propto a^3$. We can find the time period of a planet or a satellite if we know the dimensions of the orbit, or we can find the location of a planet or a satellite if we know the time period of that particular orbit.




Semi Major Axis, $a = \frac{Ra+Rp}{2}$

Satellites has various applications due to its placement on various orbit. Orbit is the path followed by the satellite in space. Let us learn different orbit and categories we have.

## Classification of Orbits

**I. Based on shape:**

- **Circular orbit-** A circular orbit is a path on which every point is equally distant from the planet's centre.

- **Elliptical orbit-** An elliptical orbit is a path where the satellite orbits in an elliptical shape around the host planet which would be at one of the two foci of that ellipse.

- **Parabolic orbit-** A parabolic path is a trajectory of an object used for orbital manoeuvring, where an approaching object entering the planet's orbit is low enough to catch it and place it into the planet's orbit, or an object already in orbit can be used to send out of it by increasing its velocity.

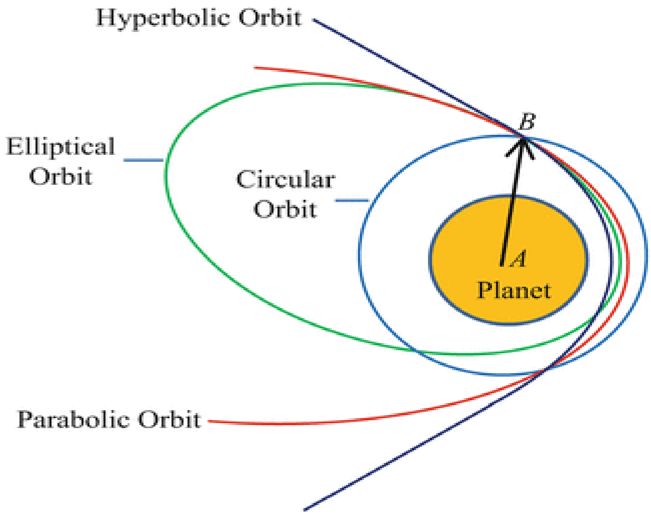



*Fig. 12: Types of Orbits based on shapes*

- **Hyperbolic orbit-** A hyperbolic path is a trajectory of an object used for orbital manoeuvring as well, but this is one where the approaching object already has enough speed to enter the planet's orbit and then escape it with an adjustment to its velocity and direction. This method of manoeuvring is called gravity assist.

**II. Based on inclination:**

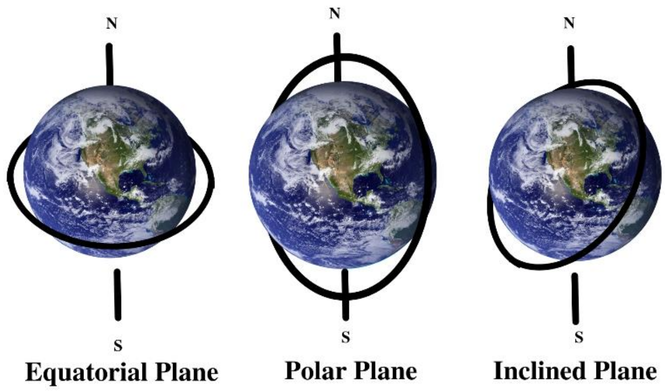



*Fig. 13: Types of Orbits based on inclination*

- **Equatorial orbit-** It is an orbit directly coinciding with the equator such that a satellite in this orbit stays on top of the equator throughout its orbit.
- **Polar orbit-** This orbit is perpendicular to the equator passing over the poles and intersecting twice with the equatorial orbit.
- **Inclined orbit-** As the name suggests, it is inclined at an angle that is not parallel or perpendicular to the equator.

**III. Based on altitude:**

- **Suborbital trajectory -** This path is taken by sounding rockets* and missiles. They are launched to reach the upper atmosphere or outer space but will not have enough speed to escape Earth's gravity or enter an orbit. These short duration trajectories provide an excellent opportunity to conduct scientific experiments at low cost.

- **Low Earth Orbit (LEO) -** The satellite in LEO is at a height of around 180–2,000 km from the Earth's surface. Satellites in this orbit travel at a speed of around 7.8 km per second. At this speed, a satellite takes approximately 90 minutes to circle Earth. The International Space Station (ISS) is also a part of this range, at around 600 km height.

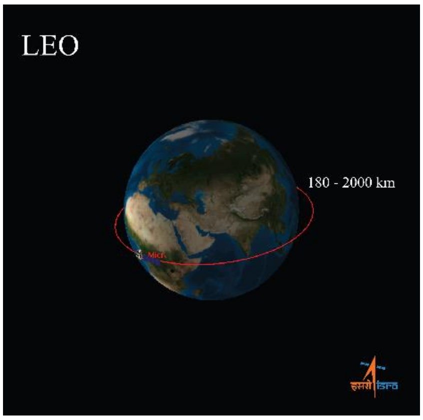



*Fig. 14: LEO*

- **Medium Earth Orbit (MEO) -** As previously mentioned, the satellite in MEO is at a height of around 2,000–35,780 km from the Earth's surface. It can either be a circular or an elliptical orbit.

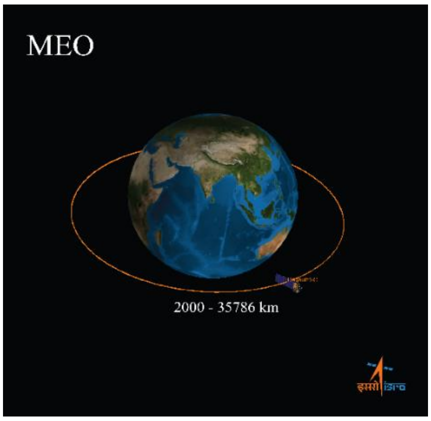



*Fig. 15: MEO*

- **Geostationary Orbit (GEO) -** GEO lie in the equatorial plane and the orbital period of satellites here coincides with the Earth's rotation by taking 23 hours 56 minutes and 4 seconds at the speed corresponding to Earth's spin. Thus, they appear to be *'stationary'* at a position with respect to the rotation of Earth. The height of the geostationary orbit from the Earth's surface is calculated to be 35,786 km in the previous section. GEOs are preferred for communication satellites as they are accessible to a large area on Earth at once as their subtended angular reach extends to 81° on all sides, and as they remain stationary in the sky with respect to the ground stations which will avoid the cost to set up movable antennas to track non-stationary satellites.

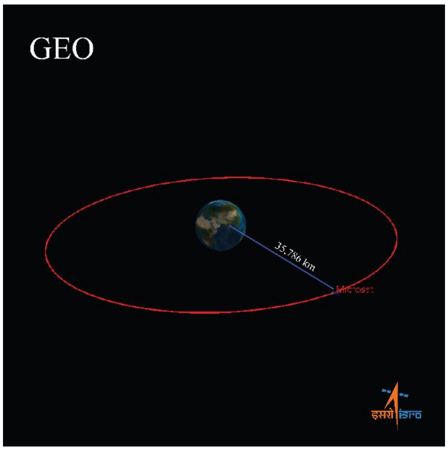



*Fig. 16: GEO*

- **Polar orbit -** Satellites in polar orbits usually travel past Earth from north to south, approximately over Earth's poles. They however do not have to pass accurately over the North and South Pole, even a deviation within 20 to 30 degrees is still classified as a polar orbit. Polar orbits are considered to be a type of LEO, as they are at low altitudes between 200 to 1,000 km.

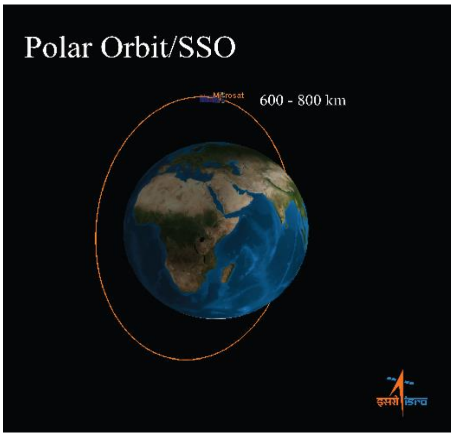



*Fig. 17: Polar Orbit*

- **Sun Synchronous Orbit (SSO) -** is a different and specific type of polar orbit. Satellites orbiting in SSO are synchronous with the Sun, meaning they stay in the same 'fixed' position relative to the Sun. This implies that it always passes over the same spot at a particular local time. for instance, passing the city of New Delhi every day at the same time. SSOs are useful in remote sensing and imaging satellites because this orbit enables the satellite to have similar levels of solar illumination on the Earth's surface every time, they reach a particular point to observe it.

- **Halo orbit -** Consider a system of three objects. Let us take the Sun, Earth and a satellite. There are specific points in the system where the gravitational forces of the two massive bodies are at equilibrium such that a third small body, here a satellite, can safely orbit around the point without drifting into an orbit around the Sun. The points are called Lagrangian points, and the orbit is called a halo orbit. This orbit is preferred for space telescope missions as there will be less noise in space than near Earth. ISRO's upcoming solar mission Aditya L-1 will take such an orbit.

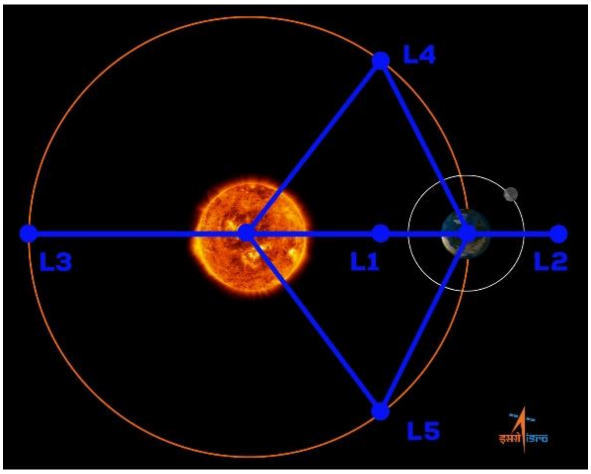



*Fig. 18: Halo Orbit*

## Does satellite need fuel to orbit?

This is one of the most asked questions. The answer is no, the satellite put into orbit does not require fuel while orbiting. The force initially imparted on the satellite when the rocket puts it in the orbit is enough to give the body the kinetic energy to move in a circular orbit without falling back to the ground.

In orbit, though drag is negligible various other perturbances act on the satellite. Although these forces are small in magnitude, after a long time this will change the orbit parameters. For LEO satellites, drag is significant due to the presence of some gases present in low orbits. If not corrected, the height of orbit will slowly decrease and finally, it will re-enter the atmosphere and burn off due to friction. To maintain the intended orbit, small thrusters are used to impart a small amount of energy. The technical term for this process of using thrusters is delta-v or burn. These satellites carry some amount of propellants along with them.

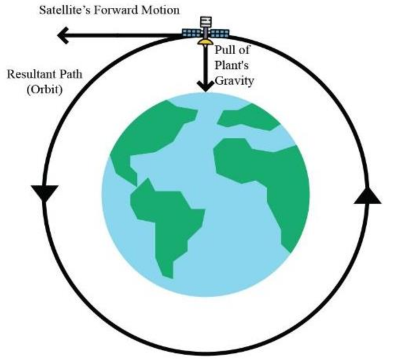



*Fig. 19: Satellite orbiting the Earth*

There are also other risks in orbit like Near Earth Objects (NEO), space debris and solar storms that can change the orbit of the satellite or entirely destroy them. A burn is also used for such emergency rendezvous. But frequent burns will reduce the operational life of the satellite as it will exhaust the fuel and the satellite will start to re-enter Earth's atmosphere. The sustainable solution, in the long run, is to manage human-made issues like space debris.

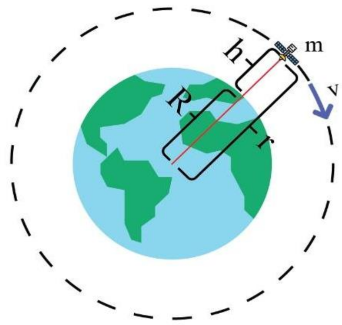



*Fig. 20: Satellite and Earth problem*

## What makes the satellite stay in orbit?

Like Newton's apple, satellites are subjected to gravitation pull, which makes an object fall to the Earth's surface. When a satellite is released by a rocket at the desired height, a tangential force is imparted. This tangential force and the gravitational pull act at a right angle(90º) resulting in a circular motion of the satellite.

## Orbital Velocity:

Consider 'M' to be the mass of the Earth, 'm' to be the mass of the satellite, 'R' to be the radius of the Earth, 'h' to be the height of the satellite from the surface of Earth, '$v_o$' to be the velocity required for a particular orbit for the stability of the satellite, 'g' to be the acceleration due to gravity, and 'G' to be the Newton's Gravitational constant.

When a stone attached to a string and rotated or a satellite orbiting Earth, a revolving object experiences centripetal force pulling it towards the centre. In the case of the stone, it is the string's tension. In case of satellite, it is the virtual string of gravitational force. At the same time, a revolving object also experiences the tangential force that is helping it move circularly. Both the forces must be equal. Mathematically, this can be written as follows;
Gravitational Force = Tangential Force

$$\frac{GMm}{(R+h)^2} = \frac{m{v_o}^2}{(R+h)} \qquad \text{(solve for } v_o\text{)}$$

$$\frac{GM\cancel{m}}{(R+h)^{\cancel{2}}} = \frac{\cancel{m}{v_o}^2}{\cancel{(R+h)}} \qquad \text{(mass of the satellite and (R+h) gets cancelled on both sides)}$$

$$\Rightarrow \; v_o = \sqrt{\frac{GM}{(R+h)}} \quad \text{m/s}$$

# Escape Velocity:

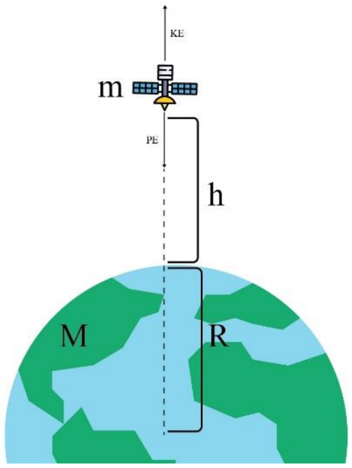


*Fig. 21: Satellite and Earth problem*

If a satellite is launched to space at a certain velocity greater than the orbital velocity, then it escapes from the earth's gravitational force. That velocity is called Escape velocity. Let us derive an equation to find the escape velocity for any celestial body.

Consider 'M' to be the mass of the Earth, 'm' to be the mass of the satellite, 'R' to be the radius of the Earth, 'h' to be the height of the satellite from the surface of Earth, 've' to be the velocity required for a satellite to escape, and 'G' to be the Newton's Gravitational constant.

At a certain point, there is kinetic energy acting on a satellite as well as the gravitational potential energy. According to the law of Conservation of Energy, the total energy of a closed system remains constant. Which means the sum of kinetic energy (KE) and gravitational potential energy (GPE) will be constant at all the points. Let us consider the total energy in two cases, first being the initial at a certain altitude 'h' m and second being at an infinite altitude.

| At height 'h' | At infinite altitude, $h = \infty = \frac{1}{0}$ |
|---|---|
| $KE_i = \frac{mve^2}{2}$ and $GPE_i = -\frac{GMm}{R+h}$ | $KE_\infty = \frac{m(v\infty)^2}{2}$ and $GPE_\infty = -\frac{GMm}{R+\infty} = 0$ |
| Total Energy, $TE_i = KE_i + GPE_i$ | Total Energy, $TE_\infty = KE_\infty + GPE_\infty$ |
| $\Rightarrow TE_i = \frac{mve^2}{2} - \frac{GMm}{R+h}$ | $\Rightarrow TE_\infty = \frac{mv\infty^2}{2}$ |

Applying the law of conservation of energy,

$$TE_i = TE_\infty$$

$$\frac{mve^2}{2} - \frac{GMm}{R+h} = \frac{mv\infty^2}{2}$$ (V $at$ ∞ being a minute value, we neglect the term)

$$\frac{\cancel{m}ve^2}{2} = \frac{GM\cancel{m}}{R+h}$$ (Solving for $v_e$)

$$v_e = \sqrt{\frac{2GM}{R+h}} \text{ m/s}$$

Which is also equal to $\sqrt{2}$ times $v_o$, ( $v_o = \sqrt{\frac{GM}{R+h}}$ )

Let us calculate the orbital velocity and escape velocity of Earth at the surface of the earth.

$G = 6.674 \times 10^{-11}$ Nm$^2$kg$^{-2}$
$M = 5.972 \times 10^{24}$ Kg
$R = 6.37 \times 10^{6}$ m
h = 0 m

$$v_o = \sqrt{\frac{GM}{(R+h)}}$$

Substituting the values mentioned above,

$$v_o = \sqrt{\frac{(6.674\times10^{-11})\times(5.972\times10^{24})}{6.37\times10^{6}}} = \sqrt{\frac{3.985\times10^{14}}{6.37\times10^{6}}} = 7.91\text{x } 10^3 \text{ m/s}$$

$$v_e = \sqrt{\frac{2GM}{R+h}} = \sqrt{2xv_o} = \sqrt{2 \text{ x } 7.91\text{x}10^3} = 11.18\text{x}10^3 \text{ m/s}$$

Hence, by using the above formulae, we can find the orbital velocity and escape velocity for any satellite orbiting any celestial body at any altitude, for example, Mangalayaan Spacecraft is orbiting the Mars, Chandrayaan 2 orbiting Moon and ISS orbiting Earth.

## Difference between orbital velocity and escape velocity:

| **Orbital velocity** | **Escape velocity** |
|---|---|
| It is the velocity at which a satellite orbits a celestial body and is fast enough to counteract the gravitation force of the respective celestial body. | It is the speed at which a satellite needs to be launched in order to break free from the gravitational attraction of the celestial body. |
| $\mathbf{V_o} = \sqrt{(\frac{GM}{R})}$<br>where G = Gravitational Constant,<br>M = Mass of the celestial body and<br>R= Radius of the celestial body | $\mathbf{V_e} = \sqrt{(\frac{2GM}{R})}$<br>where G = Gravitational Constant,<br>M = Mass of the celestial body and<br>R= Radius of the celestial body |
| The orbital velocity is high closer to the celestial body and reduces as we move away from it. | The escape velocity decreases with altitude and it is equal to √2 times the velocity required to remain in orbit at the same altitude. |
| Orbital Velocity of the Earth = 7.9 x $10^3$ m/s | Escape velocity of the Earth = 11.18 x $10^3$ m/s |

## Flight Path of a satellite

An image of the Mission Flight Path will be shown during the satellite launch missions; the flight path of Chandrayaan 1 and 2 are shown below for reference. You can observe many orbits; these orbits are nothing but the path a spacecraft takes to reach the destination. A spacecraft goes from one orbit to another in order to reach the final orbit.

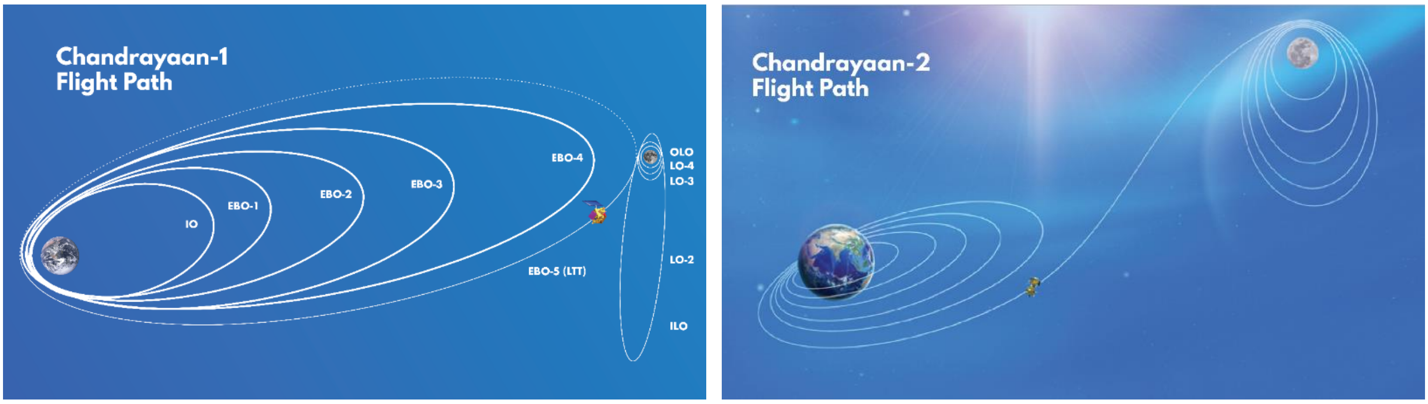



*Fig. 22: Flight Path of Chandrayaan 1 and 2 Missions*

Transfer orbits belong to a unique category of orbits that are used to move the satellite from one orbit to another. When satellites are launched to space with launch vehicles, the satellites are not always injected directly into their final orbit. Instead, they are often placed in a transfer orbit, an orbit where the satellite or spacecraft can be shifted from one orbit to another using comparatively lesser energy from built-in thrusters.

- **Hohmann transfer orbit -** Hohmann Orbit is an elliptical orbit that is used to assist a transfer between two concentric circular orbits. It is one of the most efficient orbit transfers as it uses a relatively small amount of propellant. It uses two impulse boosts, one to shift the satellite from an initial circular orbit to an elliptical Hohmann orbit, and another to shift it from the elliptical Hohmann orbit to the desired final circular orbit. This is most commonly used for interplanetary transfers or transfers between any two celestial bodies and is usually done when the bodies are at their closest points to each other.

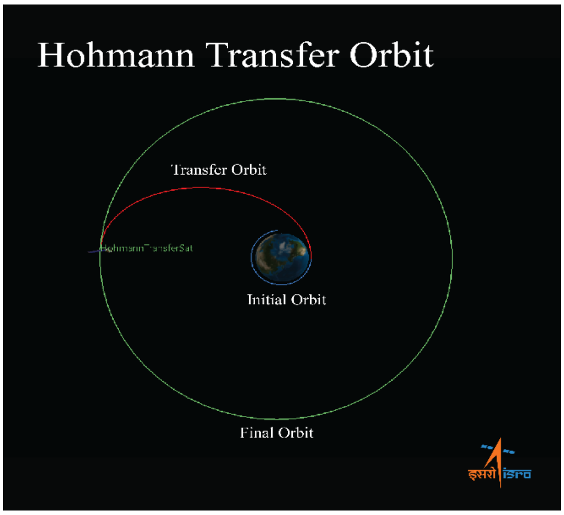



*Fig. 23: Hohmann Transfer Orbit*

Did you Know:

Walter Hohmann, a structural engineer and rocket pioneer from Germany, came through the problem of sending a spacecraft into earth orbit and to other celestial bodies too. He invented an orbital manoeuvre that could take a spacecraft from one orbit to another with the least energy expenditure, called the Hohmann Transfer orbit. Today, these transfer orbits are widely used for manoeuvering spacecrafts.

- **Bi-elliptical transfer -** Bi-elliptical Transfer is another method of transferring a satellite from one orbit to another. This transfer involves a couple of half elliptical manoeuvres. First, the satellite is boosted at the perigee of the initial orbit and takes a half elliptical path. When the satellite reaches the new apogee, a second burn boosts the satellite to follow another half elliptical path reaching the new perigee. A final burn at this point helps the satellite into the desired orbit. Some bi-elliptical transfers can be more fuel-efficient than Hohmann transfer.

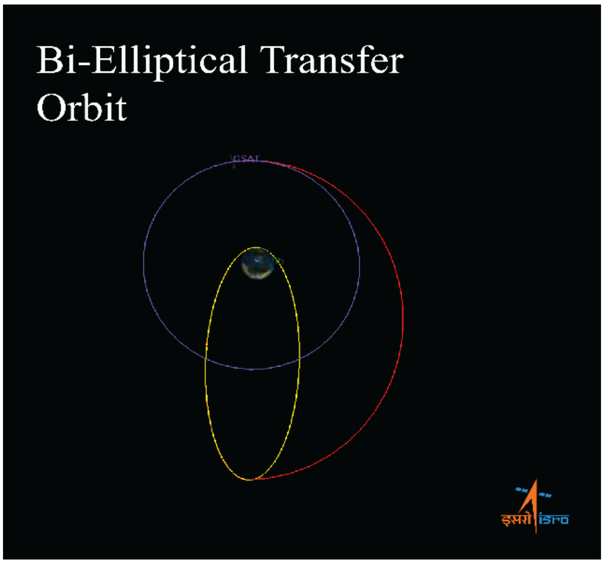



*Fig. 24: Bi-Elliptical Transfer Orbit*

- **Geosynchronous Transfer Orbit (GTO):** This orbit transfers geostationary satellites into geosynchronous orbits. Both geostationary and geosynchronous orbits have a rotation period the same as the rotation period of Earth (23 hours, 56 minutes 4 seconds), but the orbit plane of geosynchronous satellites can be at any inclination with respect to the equatorial plane of Earth. Often Geo Stationary communication satellites have been injected in GTO and manoeuvred to GEO from a mission design optimization point of view.

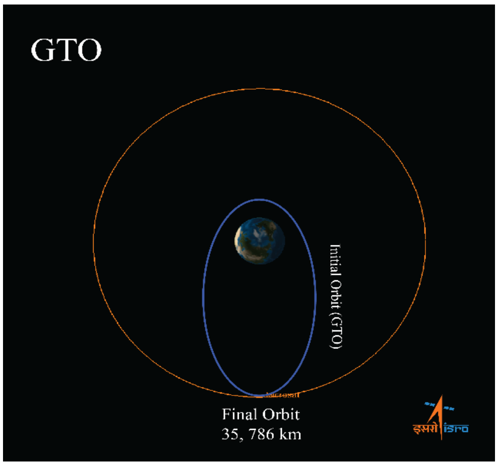



*Fig. 25: GTO*

- **Lunar Transfer Orbit (LTO)** - It is a transfer made from the Earth's orbit to the Moon'. There is a manoeuvre called trans-lunar injection which carries satellites from LEOs to lunar orbits with Hohmann-like transfers.

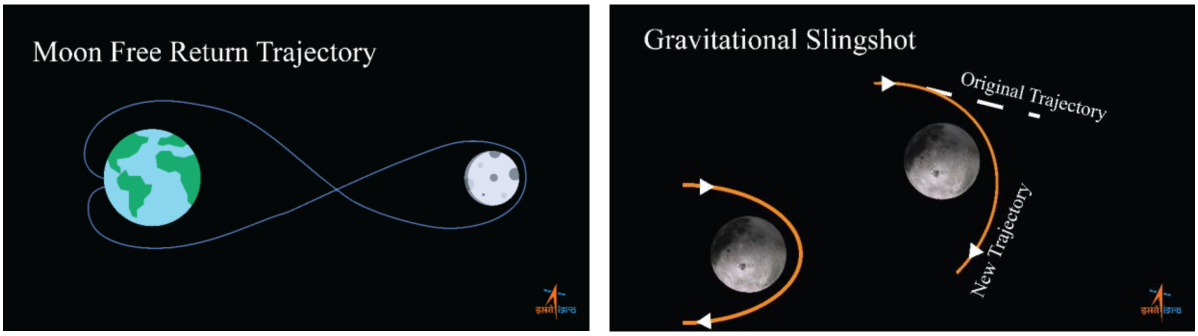



*Fig. 26: LTO - (left) Moon Free Return Trajectory and (right) Gravitational Slingshot*

## How do satellites send us the information from Space to Earth?

Sensors or respective payloads provide data to satellites in general. As a result, the Satellite's telemetry subsystem transmits this information to the ground stations through the Antenna present on the Satellite. Similarly, if any information needs to be sent to a satellite from the Earth, the Ground station antenna sends that information to a satellite's receiving Antenna. The information collected is sent to an onboard computer to perform the task.

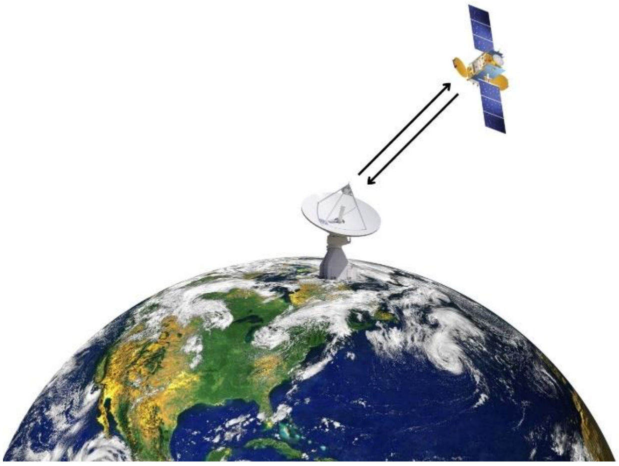


*Fig. 27: Satellite Communication*

## Is ISS a satellite?

The International Space Station (ISS) is the largest artificial object/satellite ever sent to space by human beings. It weighs around 444,615 kg and is around 73 m long and 109 m wide. It has an overall volume of 915.6 $m^3$. The ISS has been orbiting Earth for more than 23 years and has been inhabited by astronauts from various countries for more than 21 years.

ISS is a multi-national orbiting platform in Low Earth Orbit (LEO). It has a modular design, constructed by assembling individual modules in space launched by various space agencies around the world. The major partners in ISS are NASA (USA), ESA (Europe), JAXA (Japan), RosCosmos (Russia), and CSA (Canada). The ISS provides habitable volume for astronauts along with a scientific laboratory in space where astronauts live and carry out various scientific experiments. The scientific experiments being carried out in various disciplines have enormously benefitted the lives of many, back here on earth and have contributed to improving the understanding of various scientific phenomena.

*Fig. 28: International Space Station (ISS). (Credits: NASA)*

## Space Telescope: A tool to observe the planets.

Astronomers for hundreds of years have used telescopes to look into the night sky to uncover the mysteries of the Universe. Space telescopes or Space Observatory are telescopes in outer space to explore celestial bodies. Space telescopes are nothing but a Spacecraft that are more advantageous than ground-based telescopes as they can provide the best data without any hindrance from the particles in the Earth's atmosphere and light pollution.

Space telescopes are very difficult to build, operate, and involve many expenditures. However, space telescopes have made fantastic discoveries in the past few decades and helped us learn more about the unknown Universe, which would not have been possible with ground-based telescopes. The Hubble Space Telescope (HST), Kepler, and James Webb Space Telescope are some well-renowned space telescopes that has helped detect many stars, galaxies, exoplanets, other celestial bodies, in fact find the answers to the birth of the Universe.

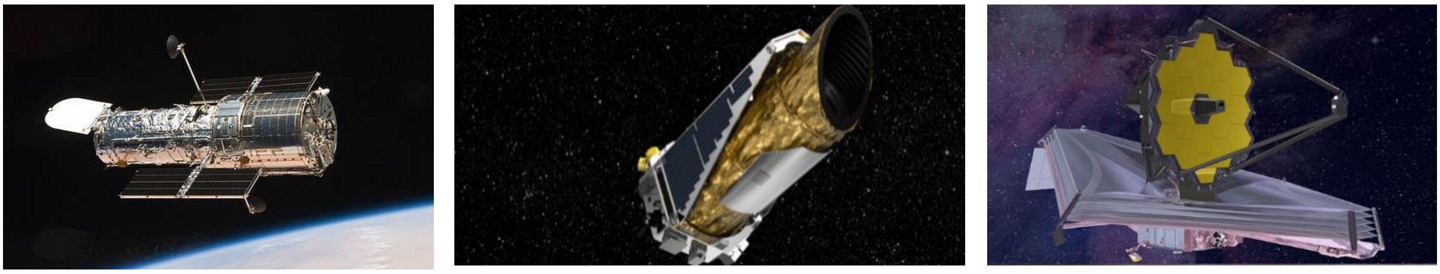


*Fig. 29: Space Telescopes: (left to right) Hubble Space Telescope, Kepler Space Telescope and James Webb Space Telescope.*

## Space Debris:

Once we enter space, it is a minefield of objects waiting to collide. Space debris or space junk are the leftovers of space exploration missions that orbit around the Earth, hence the term orbital debris. Orbital debris includes all the artificial objects that are no longer functional, such as rocket stages, payload fairings, decommissioned satellites, and other spacecraft fragments.

There are around 130 million objects greater than 1 mm to 1 cm and more than 36,000 debris greater than 10 cm. Most of the debris is in Low Earth Orbit (LEO), travelling at speeds up to 7 to 8 km/sec. This speed is sufficient for a relatively small piece of debris to damage a satellite or spacecraft.

In 1996, a French satellite named Cerise was hit by debris from a French rocket that had exploded a decade earlier. Another space debris collision happened on February 10, 2009, when an active communication satellite, Iridium 33 of the US, collided with the defunct Russian military satellite Kosmos 2251. This collision resulted in the creation of another 2,300 pieces of debris. In 2007, China's anti-satellite test, which used a missile to destroy an old weather satellite, added more than 3,500 pieces of large, trackable debris and much smaller debris.

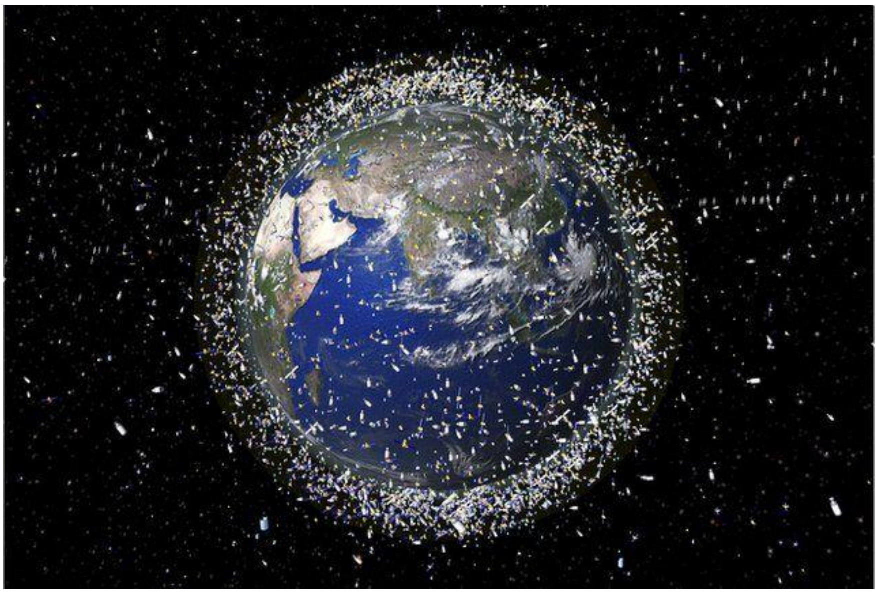


*Fig. 30: Space Debris in the LEO. (Credits: Science photo library)*

Since then, there has been a peak increase in the number of satellites being launched in LEO. That rate has skyrocketed, with more than 1,300 new satellites launched into LEO in 2020 and more than 1,400 satellites launched in 2021. As of March 2022, there are over 8,500 objects in orbit, according to the United Nations' Outer Space Objects Index. Until we take active measures to reduce space junk and track them, we might end up closing our way to outer space.

**-------------------------x---x---x--------------------------**