1. What is Space?

- Space, also known as outer space, is the **area directly outside of Earth's atmosphere.**
- Space is an **almost perfect vacuum, nearly void of matter** and with extremely low pressure.
- In space, sound doesn't carry because there aren't molecules close enough together to transmit sound between them.
- Space technically **begins at the Kármán Line,** which is about **100 km or 62 miles above the Earth.**
- Kármán Line is an **imaginary boundary** at an altitude where there is **no appreciable air to breathe or scatter light.**
    - Passing this altitude, blue starts to give way to black because oxygen molecules are not in enough abundance to make the sky blue.
- In space, long distances are **measured in "light-years,"** representing the distance it takes for light to travel in a year (roughly 5.8 trillion miles (9.3 trillion kilometers)).

2. Orbits and its types

2.1. What is an orbit?

- An orbit is a **regular, repeating path** that an object in space takes around another one **due to gravity.**
- **An object in an orbit is called a satellite.** A satellite can be natural, like the moon, or human made.
- **All orbits are elliptical,** which means they are an ellipse, similar to an oval. For the planets, the orbits are almost circular.
- The orbits of comets have a different shape. They look like a "squashed" circle.

2.2. Types of Orbits

2.2.1. Earth Orbits

- The orbits, which are **assigned to satellites with respect to earth,** are called Earth Orbits. The satellites present in those orbits are called Earth Orbit Satellites.
- Satellites that orbit Earth, including the Moon, do not always stay the same distance from Earth. Sometimes they are closer, and at other times they are farther away.
- The **closest point** a satellite comes to Earth is called its **perigee**. The **farthest point** is the **apogee**.
- According to the height of satellites from the Earth, the orbits can be classified as High Earth orbit, Medium Earth orbit, and Low Earth orbit.

2.2.1.1. Types of Earth Orbits

Low Earth Orbit (LEO)

- A low Earth orbit (LEO) is an orbit that is relatively **close to Earth's surface.**
- It is normally at an altitude of less than 1000 km and could be as low as 160 km above Earth.
- Unlike satellites in GEO that must always orbit along Earth's equator, LEO satellites **do not always have to follow a particular path** around Earth in the same way – their plane can be tilted.

- LEO is the orbit most **commonly used for satellite imaging,** as being near the surface allows it to take images of higher resolution.
- It is also the orbit used for the International Space Station (ISS), as it is easier for astronauts to travel to and from it at a shorter distance.
- Individual LEO satellites are **less useful for tasks such as telecommunication.**
    - They move so fast across the sky and therefore require a lot of effort to track from ground stations.
- Therefore, communications satellites in LEO often work as part of a large combination or constellation of multiple satellites to give constant coverage.

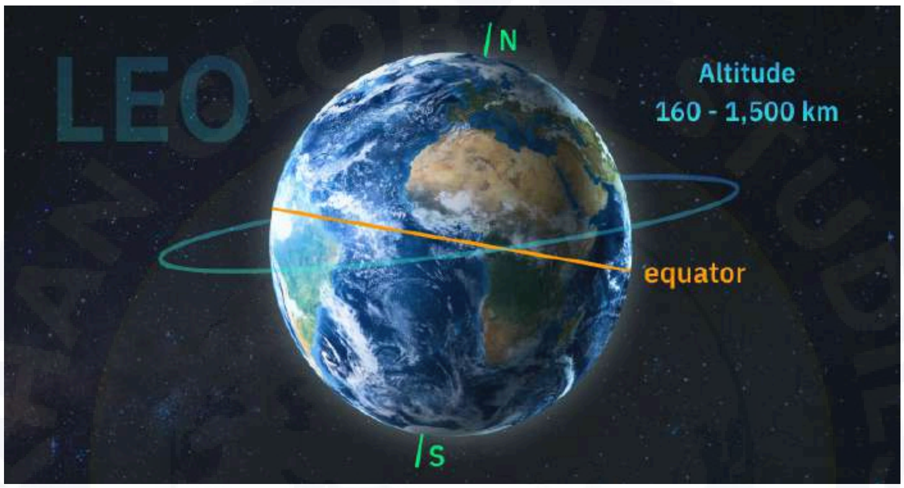


Figure.1. Low Earth Orbit

Medium Earth Orbit (MEO)

- Medium Earth orbit comprises a wide range of orbits anywhere **between low Earth and geostationary orbits.**
- MEO is similar to LEO in that it also does **not need to take specific paths around Earth,** and it is used by a variety of satellites with many different applications.
- Positioning and navigation services, like GPS (Global Positioning System), extensively use MEO type of satellites because MEO satellites are located at a medium altitude, so they have a wider field of view.
- This allows the satellites to pick up a greater number of navigational signals, resulting in a more precise and reliable navigational system.

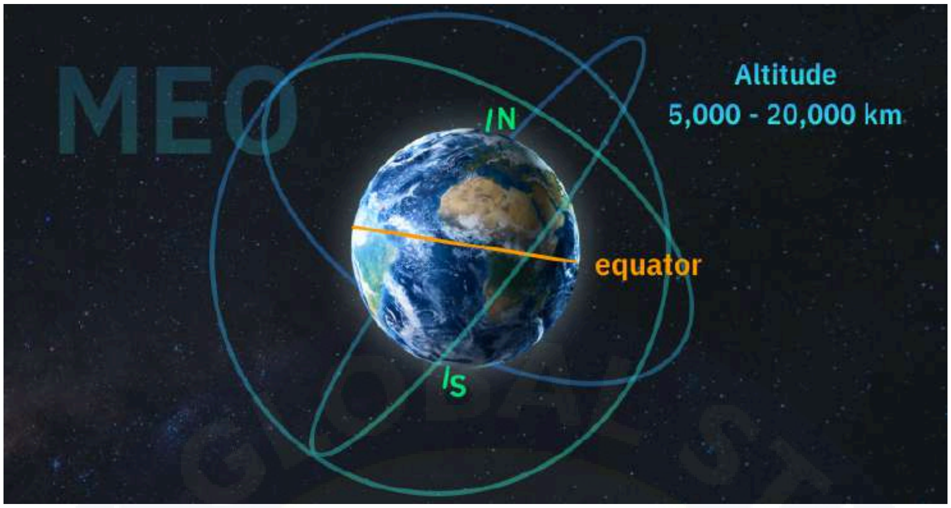


Figure.2. Medium Earth orbit

Geosynchronous Orbit (GSO)

- When a satellite reaches exactly **42,164 kilometres from the centre of the Earth** (about 36,000 kilometres from Earth's surface), it enters a spot in which its orbit matches Earth's rotation. This special, high Earth orbit is called geosynchronous.
- Satellites in GSO **take 24 hours to complete one rotation** around the Earth.
- Most of the communication satellites are placed in the geosynchronous orbit so that they appear stationary at the same point in the sky, making it easier for ground-based satellite antennas to communicate with them.
- A satellite in a circular geosynchronous orbit directly over the equator (eccentricity and inclination at zero) will have a geostationary orbit that does not move at all relative to the ground.

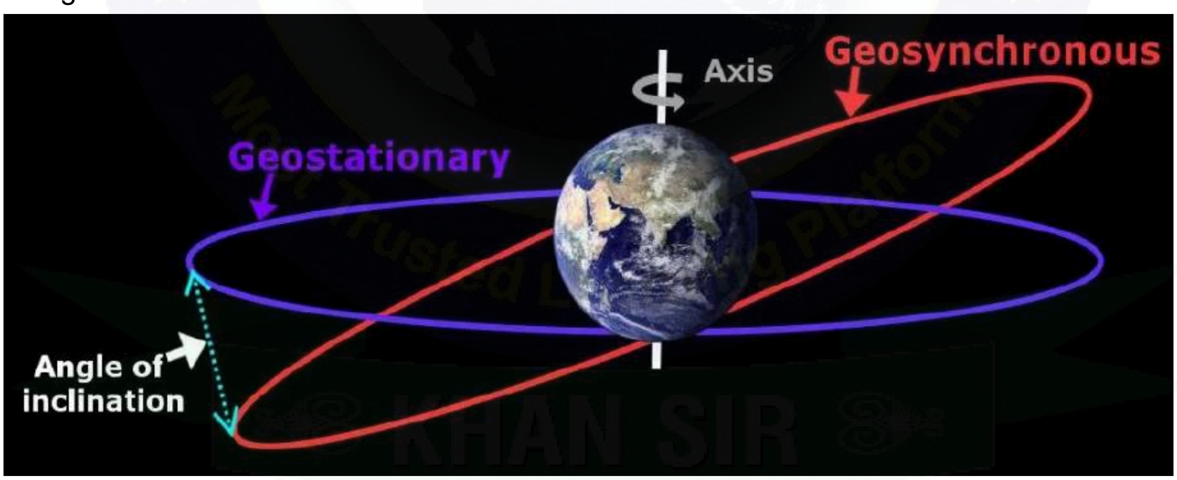


Figure.3. Geosynchronous Orbit

Geostationary Orbit (GEO)

- Satellites in geostationary orbit (GEO) circle Earth above the equator **from west to east following Earth's rotation** and travel at exactly the **same rate as Earth, i.e., 23 hours 56 minutes and 4 seconds.**
    - This makes satellites in GEO appear to be 'stationary' over a fixed position.

- The speed of GEO satellites should be about **3 km per second at an altitude of 35,786 km** to perfectly match the Earth's rotation.
- **Telecommunications satellites** are often placed in a GEO so that earth-based satellite antennas (located on Earth) do not have to rotate to track them but can be pointed permanently at the position in the sky where the satellites are located.
- It can also be used in **meteorology** to keep an eye on the weather in particular regions and track the development of local patterns.
- The downside of GEO type of spacecraft for real-time communication is the **longer signal delay caused** by their great distance from Earth.

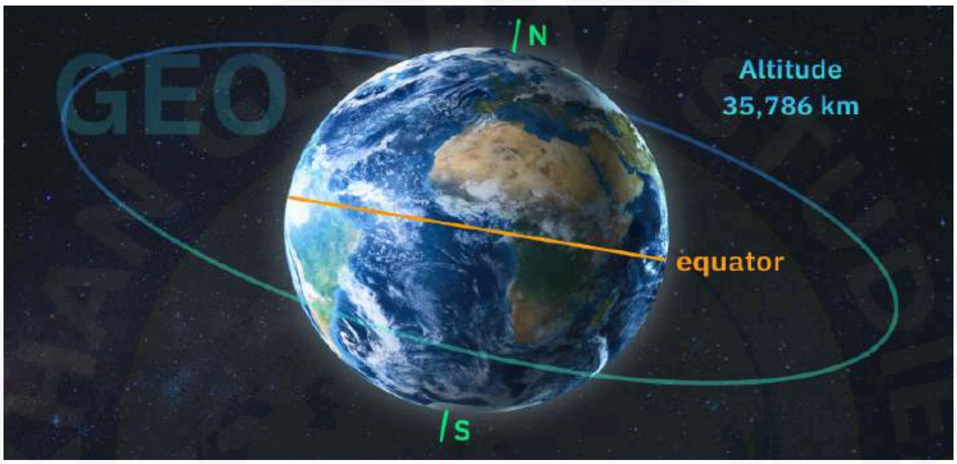


Figure.4. Geostationary Orbit

Sun-Synchronous Orbit (SSO)

- Satellites in Sun-synchronous orbit go from north to south across the polar regions at an altitude of 600 to 800 km above the Earth.
- The orbital inclination and altitude of SSO spacecraft are calibrated so that they **always cross any given location at precisely the same local solar time.**

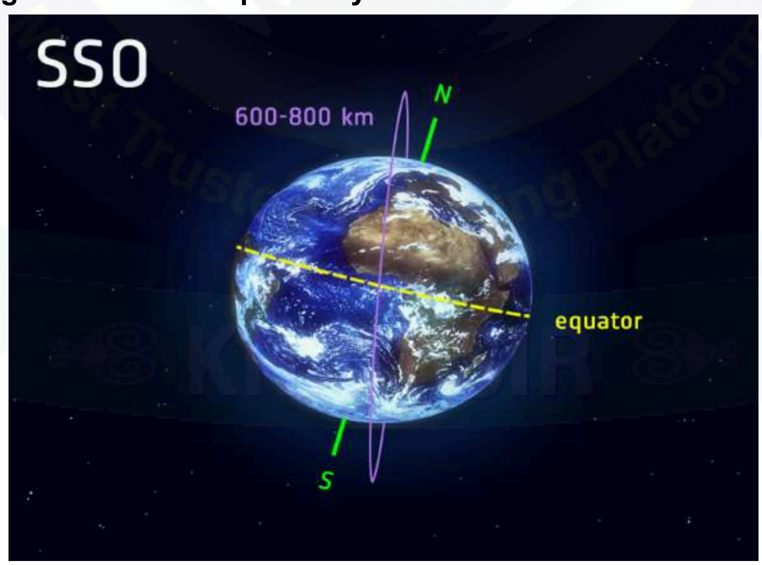


Figure.5. Sun-Synchronous Orbit

- Thus, the lighting conditions are consistent for imaging, making this type of satellite **ideal for earth observation and environmental monitoring.**

- Scientists use these image sequences to learn about the development of weather patterns, forecast cyclones, prevent wildfires and floods, and gather information on issues like deforestation and coastline changes.

Geostationary Transfer Orbit (GTO)

- Often, the satellites are placed on a transfer orbit; an orbit where, by using relatively little energy from built-in motors, the satellite or spacecraft can move from one orbit to another.
- This **allows a satellite to reach a high-altitude orbit** like GEO **without actually needing the launch vehicle** to go all the way to this altitude.
- Reaching GEO in this way is an example of one of the most common transfer orbits, called the geostationary transfer orbit (GTO).
- When the payload reaches the apogee at the GEO altitude of 35,786 km, it fires its engines in such a way that it enters onto the circular GEO orbit and stays there.

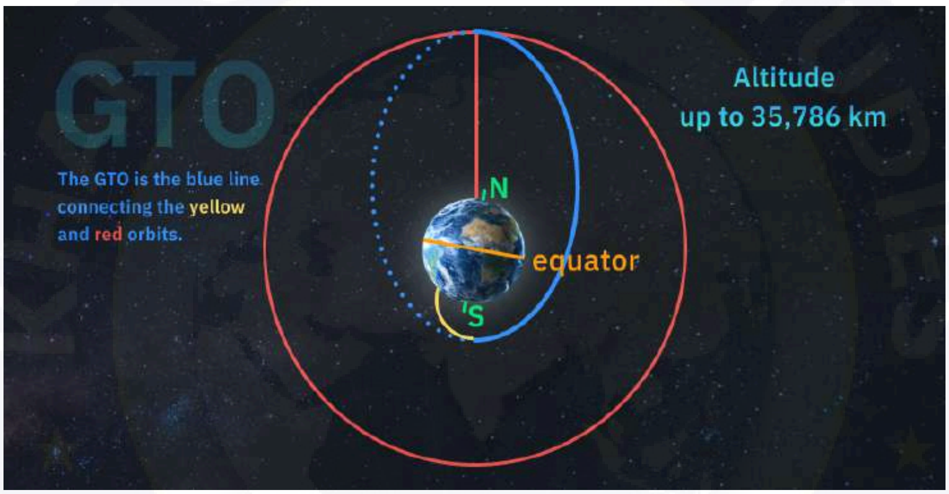


Figure.6. Geostationary Transfer Orbit

2.2.2. Other orbits

Lunar Orbit

- In astronomy, lunar orbit (also known as a selenocentric orbit) is the **orbit of an object around the Moon.**
- Orbital evolution in lunar orbit is primarily influenced by lunar gravity, gravity of the Sun and the Earth, and the Sun Radiation Pressure.
- **Lunar orbit insertion (LOI)** is the **adjustment to achieve lunar orbit.**
- The major types of lunar orbit include Halo orbit around Langrange's point, Nearly Rectilinear Halo Orbit (NRHO), Low Lunar Orbit (LLO), and Distant Retrograde Orbit (DRO).
- An example of a spacecraft in lunar orbit is Chandrayaan-3, the third lunar mission of ISRO, which circles the moon in an elliptical orbit. Another example is NASA's Lunar Reconnaissance Orbiter (LRO) which orbits the Moon in a nearly polar, slightly elliptical orbit.

Martian orbit

- It is the orbit of an object around planet Mars.

- The **orbit insertion phase** is the period of transition from the interplanetary trajectory to the mapping orbit around Mars.
    - This phase extends from the beginning of the Mars orbit insertion (MOI) sequence, until the spacecraft is established in the mapping orbit and declared ready to begin science data collection.
- Mars Orbiter Mission (MOM), India's first interplanetary mission is an example of a spacecraft that orbits Mars.

Lagrangian point

- A lagrangian point is also known as a **Lagrange point, Liberation point, or L-point.**
- These points are **locations in an orbital arrangement of two large bodies** where a third smaller body, affected solely by gravity, is capable of maintaining a stable position relative to the two larger bodies.
- The interaction of the forces creates a point of equilibrium where a spacecraft may be "parked" to make observations.

More about Lagrange point

- These points are named after **Joseph-Louis Lagrange,** an 18th-century mathematician who wrote about them in a 1772 paper concerning what he called the **"three-body problem."** They are also called **Lagrangian points and libration points.**
- There are **five special points** where a small mass can orbit in a constant pattern with two larger masses. Of the five Lagrange points, **three are unstable and two are stable.**
- The unstable Lagrange points – labelled L1, L2, and L3 – lie along the line connecting the two large masses.
- The stable Lagrange points – labelled L4 and L5 – form the apex of two equilateral triangles that have the large masses at their vertices.

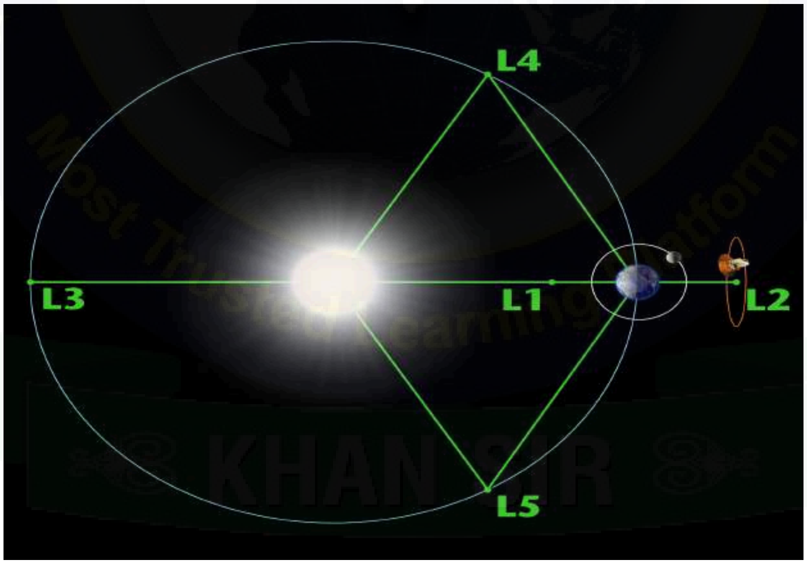


Figure.7. Lagrange Points

- **L1 point** of the Earth-Sun system affords an **uninterrupted view of the Sun,** and is currently home to the **Solar and Heliospheric Observatory Satellite** (SOHO). **Aditya-L1** of ISRO is positioned at the L1 point.

- **L2 point is ideal for astronomy** because a spacecraft is close enough to readily communicate with Earth, can keep Sun, Earth and Moon behind the spacecraft for solar power and provides a clear view of deep space for telescopes.
- **L3 lies behind the sun,** opposite Earth's orbit. For now, science has not found a use for this spot.
- **L4 and L5 points** are home to stable orbits so long as the **mass ratio between the two large masses exceeds 24.96.**

2.2.3. On the Basis of Shape

- The **eccentricity of an orbit** indicates the **deviation of the orbit from a perfect circle.** It governs the shape of an orbit.
- There are **two basic shapes** of an orbit: **circular and elliptical.** Some satellites start out elliptical and then, with corrective nudges from small onboard rockets, acquire circular paths.
- Others move permanently in elliptical paths known as **Molniya orbits.** These objects generally circle from north to south, over Earth's poles, and take about 12 hours to make one complete trip.
- A circular orbit has zero eccentricity, while a highly eccentric orbit is near to 1 (but always less).

2.3. Orbital Velocity

- The orbital velocity of a satellite refers to the **speed at which it must travel in order to maintain a stable orbit** around a celestial body, such as the Earth.
- Due to the inertia of the moving body, the body has a tendency to move on in a straight line. But, the gravitational force tends to pull it down.
- The orbital path, thus elliptical or circular in nature, represents a balance between gravity and inertia.
- For a satellite revolving around the Earth, the orbital velocity of the satellite **depends on its altitude above Earth.** The nearer to Earth, the faster the required orbital velocity.
- The **higher the orbit, the longer the satellite can stay** in orbit. At lower altitudes, a satellite runs into traces of Earth's atmosphere, which creates drag.
- The drag causes the orbit to decay until the satellite falls back into the atmosphere and burns up.
- At higher altitudes, where the vacuum of space is nearly complete, there is almost no drag and a satellite like the moon can stay in orbit for centuries.

3. About ISRO and India's Space Programmes

3.1. Institutional Structure Related to Space Programme in India

- Space activities in the country were initiated with the setting up of the **Indian National Committee for Space Research (INCOSPAR) in 1962.**
- In the same year, work on Thumba Equatorial Rocket Launching Station (TERLS) near Thiruvananthapuram was also started.
- Indian Space Research Organisation (ISRO) was established in August 1969.

- The Government of India constituted the Space Commission and established the **Department of Space (DOS) in June 1972** and brought ISRO under DOS in September 1972.
- The Space Commission formulates the policies and oversees the implementation of the Indian space programme to promote the development and application of space science and technology for the socio-economic benefit of the country.
- DOS implements these programmes through, mainly, ISRO, Physical Research Laboratory (PRL), National Atmospheric Research Laboratory (NARL), North Eastern-Space Applications Centre (NE-SAC) and Semi-Conductor Laboratory (SCL).
- **Antrix Corporation, established in 1992** as a government owned company, markets the space products and services.
- Programme offices at ISRO headquarters coordinate the programmes like satellite communication, earth observation, launch vehicle, space science, disaster management support, international cooperation, system reliability, safety, etc.

3.2. Indian Space Research Organisation (ISRO)

3.2.1. Introduction

- ISRO is the space agency of India.
- The organization is involved in science, engineering and technology to harvest the benefits of outer space for India and mankind.
- ISRO was previously the **Indian National Committee for Space Research** (INCOSPAR), **set up in 1962**, as envisioned by Dr. Vikram Sarabhai.
- ISRO was formed on **August 15, 1969** and superseded INCOSPAR.

3.2.2. Objective

- The prime objective of ISRO/DOS is the development and application of space technology for various national needs.
- To fulfill this objective, ISRO has established a major space system for
    - communication, television broadcasting and meteorological services;
    - resources monitoring and management;
    - space-based navigation services.
- ISRO has developed satellite launch vehicles, PSLV and GSLV, to place the satellites in the required orbits.

3.2.3. Headquarters

- ISRO has its headquarters in **Bengaluru.**
- Launch Vehicles are built at Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram.
- Satellites are designed and developed at U R Rao Satellite Centre (URSC), Bangalore.
- Integration and launching of satellites and launch vehicles are carried out from Satish Dhawan Space Centre (SDSC), Sriharikota.

3.2.4. Execution of Indian Space Programme

DOS, through its agency ISRO, has evolved the following programmes with the objective of promoting and developing application of space science and space technology:

- **Launch Vehicle programme** having indigenous capability for launching satellites.
- **INSAT Programme** for telecommunications, broadcasting, meteorology, development of education etc.

- **Remote Sensing Programme** for application of satellite imagery for various developmental purposes.
- Research and Development in Space Sciences and Technology for serving the end of applying them for national development.

4. India's Launch Vehicle Programme

4.1. What are Launch Vehicles?

- Launch vehicles or launch systems, as the names imply, are **used to carry spacecraft from the surface of the Earth into space.**
- Most launch vehicles operate from a launch pad, supported by a launch control center and systems such as vehicle assembly and fueling.
- They are classified by their orbital payload capacity, ranging from small-, medium-, heavy- to super-heavy lift.

4.1.1. Types of Satellite Launch Vehicle

The launch vehicles are basically multi-stage rockets and thus are mainly classified as:

Expendable Launch Vehicles (ELV)

- An expendable launch vehicle is a **single-use launch vehicle** usually used to launch a payload into space. Most satellites are launched into orbit using expendable launchers.
- Expendable launch vehicles typically consist of stages which are discarded one by one, in order not to have to carry and accelerate parts that are no longer needed.
- The ELV contains three stages. First and second stages of ELV raise the satellite to about 50 miles and 100 miles. Third stage of ELV places the satellite in transfer orbit.
- Once the satellite reaches the transfer orbit then the task of the launch vehicle will get completed and the various parts will get destroyed by themselves generally by falling to the earth.

Reusable Launch Vehicles (RLV)

- This category of launch vehicles **offers reusability** and so can be used various times for launching satellites in space.
- Generally, this type of launch vehicle will return back to earth after leaving the satellite in space. Sometimes it is given the name, space shuttle.
- Functions of RLV are similar to the functions of first and second stages of ELV.
- However, in the third stage, the satellite is inserted with a cargo bay and the satellite gets ejected from the cargo bay when the RLV attains an elevation of around 150 to 200 miles.
- Once this height is achieved then the shuttle will be fired thereby placing the satellite in the transfer orbit. After this, the space shuttle will return back to earth for reuse.

4.2. India's Launch Vehicles

4.2.1. Historic

4.2.1.1. Satellite Launch Vehicle-3 (SLV-3)

- The Satellite Launch Vehicle (SLV) program marked India's entry into the domain of satellite launch vehicles.

- Satellite Launch Vehicle-3 (SLV-3) was **India's first experimental satellite launch vehicle,** which was an **all solid, four stage** vehicle capable of placing 40 kg class payloads in Low Earth Orbit (LEO).
- The first experimental flight in August 1979 was partially successful. SLV-3 was successfully launched on July 18, 1980 from Sriharikota Range (SHAR), when Rohini satellite, RS-1, was placed in orbit, thereby making India the sixth member of an exclusive club of space-faring nations.
- Apart from the July 1980 launch, there were two more launches held in May 1981 and April 1983, orbiting Rohini satellites carrying remote sensing sensors.
- The successful culmination of the SLV-3 project showed the way to advanced launch vehicle projects such as the Augmented Satellite Launch Vehicle (ASLV), Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV).

4.2.1.2. Augmented Satellite Launch Vehicle (ASLV)

- The Augmented Satellite Launch Vehicle (ASLV) Programme was **designed to augment the payload capacity to 150 kg,** thrice that of SLV-3, for Low Earth Orbits (LEO). It was an advancement over the SLV.
- The ASLV was 24 meters tall, with a lift-off weight of 40 tonnes, featuring a five-stage, all-solid propellant design.
- Key technologies included strap-on technology, navigation, a heat shield etc.
- Under the ASLV programme four developmental flights were conducted. The first developmental flight took place on March 24, 1987 and the second on July 13, 1988.
- The third developmental flight, ASLV-D3 was successfully launched on May 20, 1992, when SROSS-C (106 kg) was put into an orbit of 255 x 430 km.
- ASLV-D4 on May 4, 1994, successfully orbited the SROSS-C2 satellite.

4.2.2. Operational

4.2.2.1. Polar Satellite Launch Vehicle (PSLV)

- PSLV is an **indigenously-developed expendable launch system** of the ISRO.
- It is the **third generation launch vehicle** of India and is the **first Indian launch vehicle** to be **equipped with liquid stages.**
- It comes in the category of **medium-lift launchers** with a reach up to various orbits. Used for launching satellites into Geosynchronous and Geostationary Orbits, including satellites from the IRNSS Constellation.
- After its first successful launch in October 1994, the vehicle has launched numerous Indian and foreign customer satellites.
- Besides, the vehicle successfully **launched** two spacecraft "**Chandrayaan-1** in 2008 and **Mars Orbiter Spacecraft** in 2013" that later travelled to Moon and Mars respectively.
- It also **launched India's first space observatory, Astrosat** in 2015 and Aditya L1 in 2023.
- PSLV-C48 marked the 50th launch of PSLV.
- PSLV has earned a title of 'Workhorse of ISRO' by consistently delivering satellites into low earth orbits, particularly the IRS Series of satellites.
- It is capable of placing multiple payloads into orbit, using multi-payload adaptors in the payload fairing.

- Its mission flexibility and performance is evident from multi-orbit and multi-satellite missions that showcased its versatility and reliability.
- In the global market, a long string of consecutive successes and multi-satellite launch capability reinforces its status as a reliable, versatile, and affordable launcher.
- All the operations of PSLV are controlled from the Satish Dhawan Space Center, Sriharikota, east coast, India.
- The most notable launch of the PSLV was the launch of PSLV-C37 on 15 February 2017 that successfully deployed 104 satellites in sun-synchronous orbit that included Cartosat-2 series satellites.

Stages of PSLV

PSLV is a four stage launch vehicle.

- **First Stage: PS1** - PSLV uses the **S139 solid rocket motor** that is augmented by **6 solid strap-on boosters.** PSLV uses 6 solid rocket strap-on motors to augment the thrust provided by the first stage in its PSLV-G and PSLV-XL variants. However, strap-ons are not used in the core alone version (PSLV-CA).
- **Second stage: PS 2** - PSLV uses an **Earth storable liquid rocket engine** for its second stage, known as the Vikas engine, developed by Liquid Propulsion Systems Centre.
- **Third stage: PS 3** - The third stage of PSLV is a **solid rocket motor** that provides the upper stages high thrust after the atmospheric phase of the launch.
- **Fourth stage: PS 4** - The PS4 is the **uppermost stage** of PSLV, comprising **two Earth storable liquid engines.**
- The first stage and third stage as well as the strap on boosters rocket motors use solid fuel Hydroxyl-terminated polybutadiene (HTPB) as a fuel.
- The second and fourth stages use liquid fuel. The second stage uses Unsymmetrical dimethyl hydrazine (UDMH) as a fuel along with nitrogen tetroxide (N_2O_4) as an oxidizer.
- The fourth uses Mono Methyl Hydrazine (MMH) fuel and Mixed Oxides of Nitrogen (MON-3-a mixture of dinitrogen tetroxide and approx. 3% Nitric oxide).

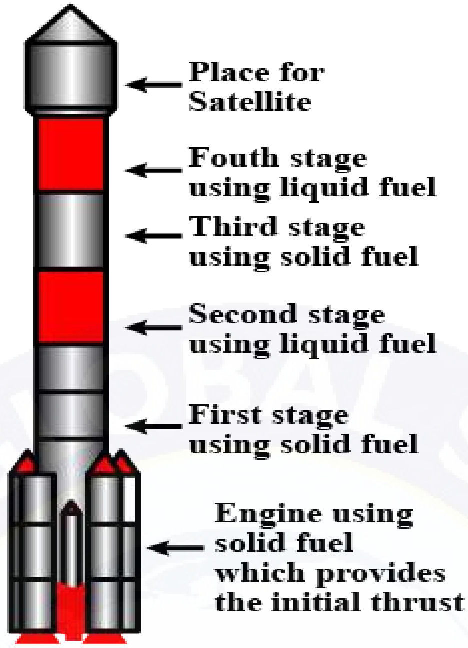


Figure.8. Structure of PSLV

Launch capacity

- PSLV is capable of launching **1750 kg satellites in 600 km sun-synchronous polar orbit.**
- It can launch **1425 kg satellites in geo-synchronous transfer orbit,** like satellites from the IRNSS constellation.
- With its variant configurations, PSLV has proved its multi-payload, multi-mission capability in a single launch and its geosynchronous launch capability.

PSLV Variants and Strap-on Motors

- PSLV-XL uses 6 solid rocket strap-on motors.
- PSLV-QL uses 4 solid rocket strap-on motors.
- PSLV-DL uses 2 solid rocket strap-on motors.
- PSLV-CA: The core alone version does not use strap-on motors.

4.2.2.2. Geosynchronous Satellite Launch Vehicle Mark II

- The Geosynchronous Satellite Launch Vehicle Mark II (GSLV Mk II) is an **Indian expendable launch system** that was developed and is operated by the ISRO to launch communication satellites in geo transfer orbit using cryogenic third stage.
- The GSLV project was **initiated back in 1990** when India determined that it needed its own launch capability for Geosynchronous Satellites to become independent from other launch providers.
- Initially, Russian GK supplied cryogenic stages were used. Later cryogenic stage was indigenously developed and inducted in January 2014 from GSLV D5 onwards.
    - This operational fourth generation launch vehicle is a **three stage vehicle with four liquid strap-ons.**
- The flight proven indigenously developed Cryogenic Upper Stage (CUS), forms the third stage of GSLV Mk II.
- GSLV MK II was used in fifteen launches from 2001 to 2023.

Stages of GSLV MK II

It is a three-stage launcher with strap-on motors.

- **First Stage: GS1** - The first stage of GSLV was also derived from the PSLV's PS1. The 138 tonne **solid rocket motor** is augmented by 4 liquid strap-ons. This stage uses HTPB as fuel.
- **Second Stage: GS2** - One **Vikas engine** is used in the second stage of GSLV. The stage was derived from the PS2 of PSLV where the Vikas engine has proved its reliability. **Fuel:** UH25 (a mixture of 75% Unsymmetrical dimethylhydrazine-UDMH and 25% hydrazine hydrate) + N_2O_4.
- **Third Stage: CUS** - Developed under the Cryogenic Upper Stage Project (CUSP), the **CE-7.5 is India's first cryogenic engine, developed by the Liquid Propulsion Systems Centre. Fuel:** LOX (Liquid oxygen) + LH_2 (Liquid hydrogen).

Technical Specifications

- **Payload to GTO: 2,500 kg:** GSLV's primary payloads are INSAT class of communication satellites that operate from Geostationary orbits and hence are placed in Geosynchronous Transfer Orbits by GSLV.
- **Payload to LEO: 6,000 kg:** Further, GSLV's capability of placing up to 6 tonnes in Low Earth Orbits broadens the scope of payloads from heavy satellites to multiple smaller satellites.

4.2.2.3. Geosynchronous Satellite Launch Vehicle Mk III (LVM3)

- It is a **three-stage medium-lift** launch vehicle developed by the Indian Space Research Organisation (ISRO).
- Primarily designed to launch communication satellites into geostationary orbit, it is also due to launch crewed missions under the Indian Human Spaceflight Programme.
- ISRO successfully conducted the first orbital test launch of LVM3 on 5 June 2017 from the Satish Dhawan Space Centre. LVM3 was used in total 7 launches till July 2023.
- The Chandrayaan-3 mission was launched into space by LVM3. It is also due to launch a crewed mission, Gaganyaan, under the Indian Human Spaceflight Programme.

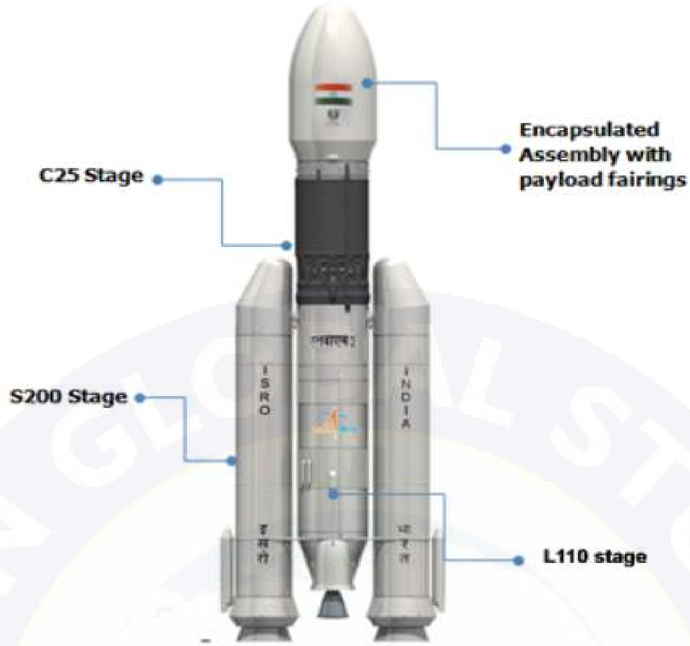


Figure.9. GSLV MK III

Stages of LVM3

- LVM3 is configured as a three stage vehicle with **two solid strap-on motors** (S200), **one liquid core stage** (L110) and a **high thrust cryogenic upper stage** (C25).
- **Core Stage: L110 Liquid Stage** - The L110 liquid stage is **powered by two Vikas engines** designed and developed at the Liquid Propulsion Systems Centre. Uses UDMH + H_2O as fuel.
- **Solid Rocket Boosters: S200** - LVM3 uses two S200 solid rocket boosters to provide the huge amount of thrust required for lift off. The S200 was developed at Vikram Sarabhai Space Centre. Uses HTPB as fuel.
- **Cryogenic Upper Stage: C25** - The C25 is powered by CE-20, India's largest cryogenic engine, designed and developed by the Liquid Propulsion Systems Centre. Uses LOX + LH_2 as fuel.

Technical Specification

- **Payload to GTO: 4,000 kg:** LVM3 will be capable of placing the 4 tonne class satellites of the GSAT series into Geosynchronous Transfer Orbits.
- **Payload to LEO (Low Earth Orbit) : 8,000 kg:** The powerful cryogenic stage of LVM3 enables it to place heavy payloads into Low Earth Orbits of 600 km altitude.

OneWeb

- LVM3 executed its first successful commercial mission on October 23, 2022 by launching 36 satellites for OneWeb into low-Earth orbit.
- ISRO's commercial arm NewSpace India Limited (NSIL) had signed a contract with OneWeb to launch 72 satellites in two phases. The first set of 36 satellites was launched in October 2022 and the second set of 36 satellites was launched in March 2023.
- OneWeb is a UK based firm that aims to build a global communication network from

space for governments, businesses, and communities.
- OneWeb implements Low Earth Orbit (LEO) satellite constellation of 618 satellites for its operation.
- Bharti Enterprises of India is a major investor and shareholder in OneWeb.

4.2.2.4. Small Satellite Launch Vehicle (SSLV)

- Small Satellite Launch Vehicle (SSLV) is a **small-lift launch vehicle** developed by ISRO with payload capacity to deliver 500 kg to low Earth orbit or 300 kg to Sun-synchronous orbit for launching small satellites, with the capability to support multiple orbital drop-offs.
- The maiden flight SSLV-D1 was conducted on 7 August 2022, from the First Launch Pad, but failed to orbit.
- A second flight SSLV D2 was conducted on 10 February 2023 that successfully delivered payloads to orbit.
- It is a **3 stage Launch Vehicle** configured with three Solid Propulsion Stages and liquid propulsion based Velocity Trimming Module (VTM) as a terminal stage.
- It is 2m in diameter and 34m in length with a lift off weight of ~120 tonnes.
- The key features of SSLV are low cost, with low turn-around time, flexibility in accommodating multiple satellites, launch on demand feasibility, minimal launch infrastructure requirements, etc.
- Capability: Launches Mini, Micro, or Nanosatellites (10 to 500 kg mass) into a 500km Low Earth Orbit on 'launch-on-demand' basis from SDSC/SHAR.

Payload Capability

- **Single Satellite:** Up to 500kg in 500km planar orbit.
- **Multiple Satellites:** Three satellites ranging from 10kg to 300kg into a 500km Planar Orbit.

Technical Specifications

- **Stage 1 (SS1):** HTPB based Solid Propellant
- **Stage 2 (SS2):** HTPB based Solid Propellant
- **Stage 3 (SS3):** HTPB based Solid Propellant
- **Velocity Trimming Module (VTM):** Fuel is MMH + MON-3 (Liquid). It achieves desired velocity for the insertion of the satellites into the intended orbit.

4.2.2.5. Reusable Launch Vehicle – Technology Demonstrator (RLV-TD)

- RLV-TD is one of the endeavours of ISRO towards developing essential technologies for a fully reusable launch vehicle to enable low cost access to space.
- Its configuration is similar to that of an aircraft and **combines the complexity of both launch vehicles and aircraft.**
- The winged RLV-TD has been configured to act as a flying test bed to evaluate various technologies, namely, hypersonic flight, autonomous landing and powered cruise flight.
- In future, this vehicle will be scaled up to become the first stage of India's reusable two stage orbital launch vehicle.
- It consists of a fuselage (body), a nose cap, double delta wings and twin vertical tails.
- It also features symmetrically placed active control surfaces called **Elevons and Rudder.**

- It was successfully flight tested on May 23, 2016, validating the critical technologies such as autonomous navigation, guidance & control, reusable thermal protection system and re-entry mission management.
- ISRO successfully carried out the landing experiment on April 2, 2023, executed at the Aeronautical Test Range in Challakere, Chitradurga.
- Final version is expected to take 10 to 15 years to develop.

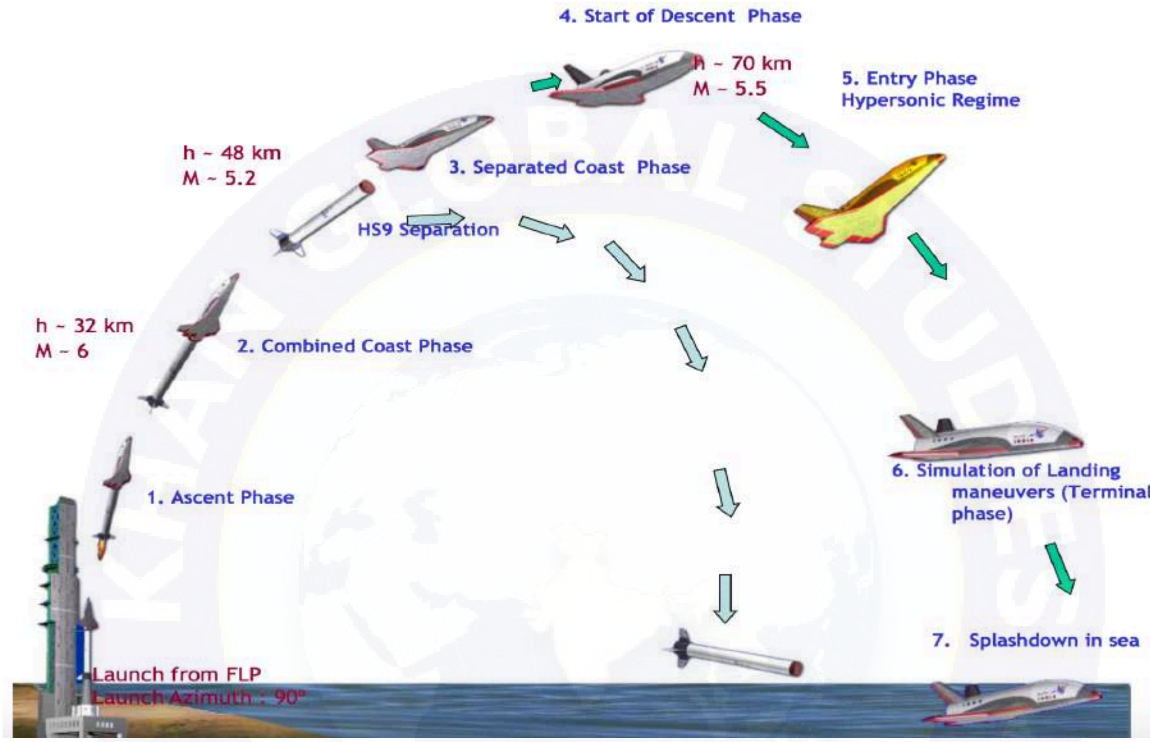


Figure.10. RLV-TD

Programme Objectives

- Develop a scalable version of a fully reusable Two Stage To Orbit (TSTO) system.
- Aims to reduce launch costs by a factor of 10.
- Contributes to making space exploration more accessible and sustainable.

Sounding Rockets

- Sounding rockets are one or two stage solid propellant rockets used for probing the upper atmospheric regions and for space research.
- They also serve as easily affordable platforms to test or prove prototypes of new components or subsystems intended for use in launch vehicles and satellites.
- The launch of the first sounding rocket from Thumba near Thiruvananthapuram, Kerala on 21 November 1963, marked the beginning of the Indian Space Programme.
- The first rockets were two-stage rockets imported from Russia (M-100) and France (Centaure).
- Indigenous sounding rockets were launched from 1965.
- Rohini Sounding Rocket (RSR) Programme consolidated all activities in 1975. RH-75 was the first truly Indian sounding rocket in 1967, followed by RH-100 and RH-125.
- The sounding rocket programme laid the foundation for advanced launch vehicle

technology in India.

- The ISRO has launched more than 1,600 RH-200 rockets so far.
- The rocket celebrated its 100th consecutive successful mission on July 15, 2015.
- It celebrated the 200th successful launch of the Rohini RH-200 sounding rocket in 2022.

Operational Capabilities

- Three versions: RH-200, RH-300-Mk-II, RH-560-MK-II.
- Payload range: from 8-100 Kg.
- Altitude range: from 80-475 km.

Launch Sites

- Thumba, Balasore, and SDSC-SHAR are primary launch pads.

5. India's Satellite Programme

5.1. What are Artificial Satellites?

- Artificial satellites are **human-built objects orbiting the Earth and other planets** in the Solar System.
- They are used to study the Earth, other planets, aiding communication, and even to observe the distant universe. Satellites can even have people in them, like the International Space Station.
- The first artificial satellite was the Soviet Sputnik 1 mission, launched in 1957.
- The most common types of artificial satellites based on their application are:
    - Communication
    - Weather monitoring and Earth observation
    - Navigation
    - Scientific research
- Artificial satellites orbit around the Earth in various types of orbits such as geostationary, polar, and sun-synchronous orbits, depending on their function.
- They are launched into the correct orbit using rockets.
- A typical satellite consists of:
    - Payload (which carries the instruments or technology to fulfill its mission)
    - Bus (which has the support systems like power supply, solar panels, communication, and propulsion systems)

5.2. Communication Satellites

5.2.1. What are Communication Satellites?

- Communication satellites are launched to orbit around the earth or any other planet to collect information and transmit it back to the planet.
- They are launched to **expand the ability of networks and connections** on the planet.
- Such a satellite can make long-distance communication and information transfer much more effortless.
- They enable wireless communication networks including public services like TV, radio, internet, long-distance telephony etc., and dedicated services like – communication networks for armed forces, seafaring, air-traffic, banking, stock exchanges etc.

- Also integral in connecting remote areas to communication networks for e-Governance, Tele-medicine, Remote education,support emergency communication during disasters etc.
- Examples: INSAT series, GSAT series (of India)

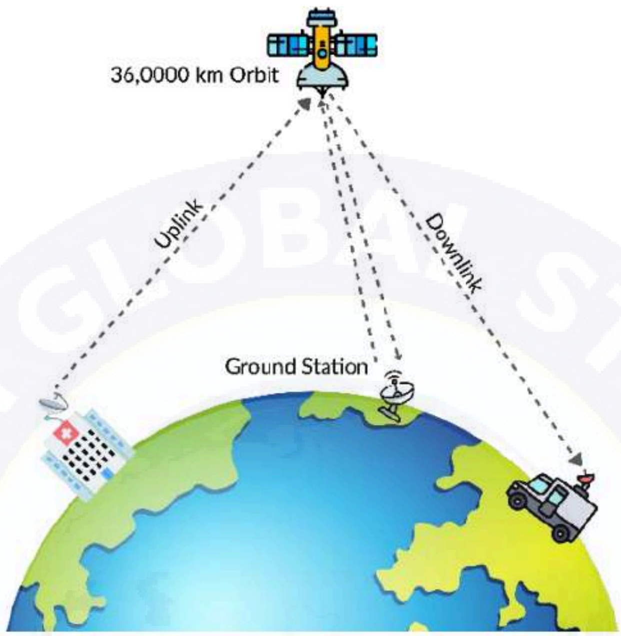


Figure.11. Working of Communication Satellite

5.2.2. Working of Communication Satellite

The process of communicating with satellites involves four significant steps:

- A **signal transmission** will occur from an **Uplink Earth station** or other equipment transmitting the desired signal to the satellite.
- The received signal is **amplified** by the satellite.
- The signal is transmitted back to the earth as a **downlink.**
- The antennas or **receiving equipment** will receive this signal.

5.2.3. Satellite Communication Spectrum

- Satellite communications are complex and rely on what is known as radiofrequency ('RF') spectrum. This spectrum is divided into many different frequency bands, with the choice of band depending on many factors—including the specific application at issue.
- The frequency of an RF signal refers to the number of times the underlying wave oscillates per second. It is measured in Hertz (Hz), with 1 Hz being equal to one cycle per second.
- This unit can be used for all the waveforms in the entire electromagnetic spectrum - which includes everything from gamma rays, x-rays, visible light, microwaves, and radio waves.

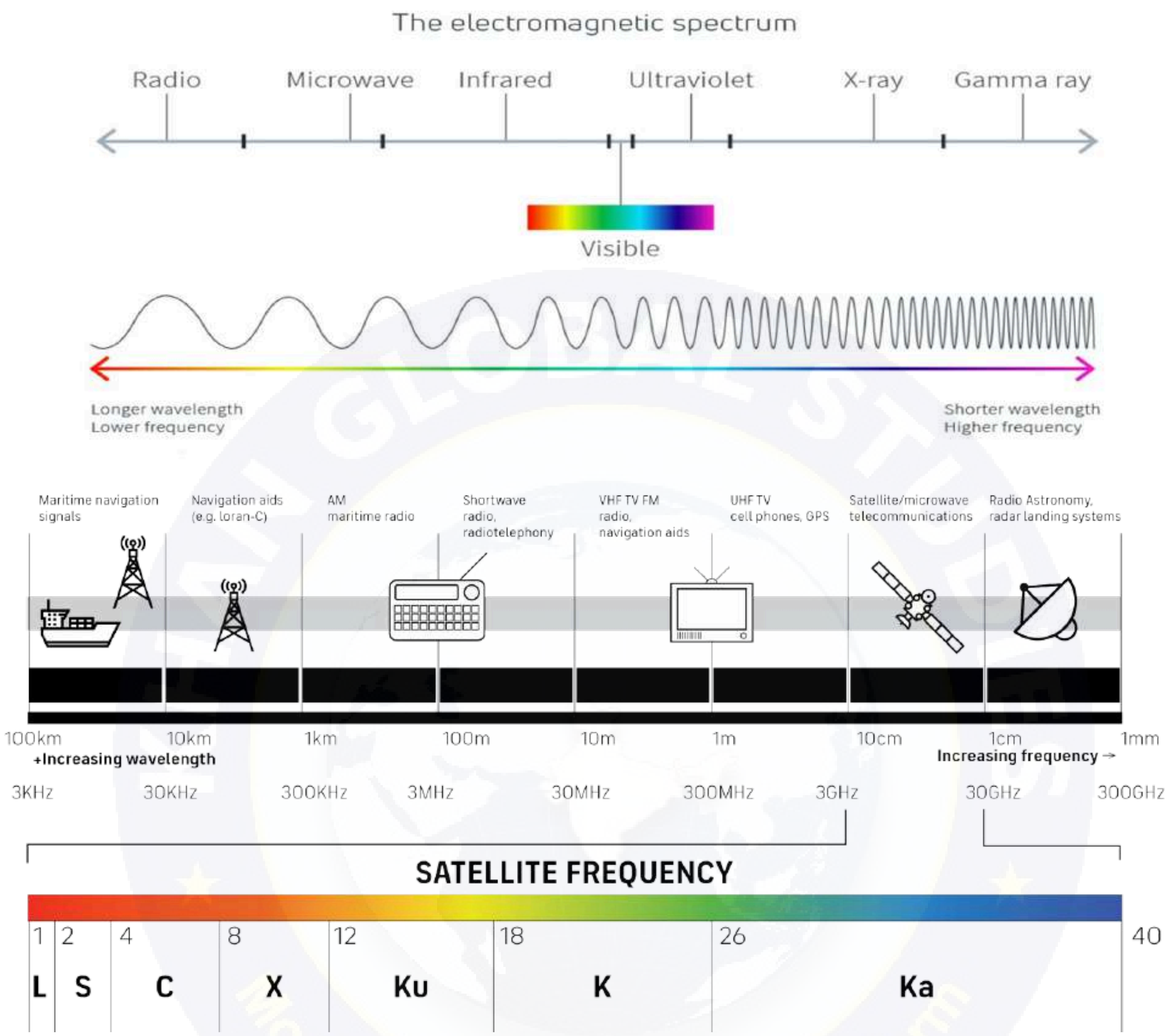


Figure.12. Types of satellite communication spectrum

C-Band (3 to 4 GHz)

- Used for traditional satellite television/radio broadcasting.
- Less susceptible to rain fade compared to higher frequency bands.
- Utilized for long-distance telecommunication.

Extended C-Band (4 to 8 GHz)

- Offers slightly extended frequency range compared to standard C-band.
- Used for direct-broadcast satellite services.
- Suitable for mobile communication and radar applications.

Ku-Band (12-18 GHz)

- Used for satellite TV broadcasting, especially for DTH (Direct to Home) services.
- Utilized in radar and satellite communication systems.
- More susceptible to rain fade compared to C-band, requiring larger antennas for compensation.

Applications and Use Cases

- **C-Band:** Ideal for rural area connectivity due to lower frequency and better penetration.
- **Extended C-Band:** Preferred for mobile and radar applications with a wider frequency range.
- **Ku-Band:** Commonly used for urban area connectivity and high-definition satellite TV broadcasting due to higher frequency and data transmission rate.

5.3. Indian National Satellite (INSAT) system

- The Indian National Satellite (INSAT) system is one of the largest domestic communication satellite systems in the Asia-Pacific region with nine operational communication satellites placed in Geo-stationary orbit.
- It was **established in 1983** with commissioning of the first satellite in the series, INSAT-1B.
- Currently has 9 operational satellites in geostationary orbit (ISRO: 12 September 2023).
- It is equipped with over 200 transponders in C, Extended C, and Ku-bands.

5.3.1. Impact of INSAT Programme on India

- The INSAT satellite system is one of the largest domestic communication satellite systems providing regular services in the areas of television, telecommunications, radio networking, business and personal communication and weather forecasting and meteorological services.
- Newer initiatives have been taken to expand the INSAT applications to newer areas like:
    - Tele-education
        - **EDUSAT**: used extensively to cater to a wide range of interactive educational delivery modes like one-way TV broadcast, video conferencing, web-based instructions, etc.
    - Tele-medicine
        - ISRO Telemedicine pilot project was started in the year 2001 as part of proof-of-concept demonstration programme.
    - Village Resource Centre (VRC)
        - VRCs have provided various space technology enabled services such as tele-healthcare, tele-education, natural resources information, etc.
    - Disaster Management Support (DMS)
        - ISRO disseminates relevant information in interactive **geo-spatial domains** through various geoportals like Bhuvan, National Database for Emergency Management and MOSDAC (Meteorological and Oceanographic Satellite Data Archival Centre).
    - Satellite news gathering
    - Satellite Aided Search and Rescue (SAS&R)
    - Internet services and e-governance
    - Financial service network, such as the banking, the stock exchanges etc.
    - Standard Time and Frequency Signal (STFS) Dissemination Services
- The INSAT system has also extended the outreach to less accessible areas like North-East, other far-flung areas and islands.

5.3.2. List of Important Communication Satellites

Satellite	Launch Date	Launch Vehicle	Application
CMS-01	Dec 17, 2020	PSLV-C50/CMS-01	Communication
GSAT-30	Jan 17, 2020	Ariane-5 VA-251	Communication
GSAT-31	Feb 06, 2019	Ariane-5 VA-247	Communication
GSAT-11 Mission	Dec 05, 2018	Ariane-5 VA-246	Communication
GSAT-17	Jun 29, 2017	Ariane-5 VA-238	Communication
GSAT-15	Nov 11, 2015	Ariane-5 VA-227	Communication, Navigation
GSAT-8	May 21, 2011	Ariane-5 VA-202	Communication, Navigation
EDUSAT	Sep 20, 2004	GSLV-F01 / EDUSAT(GSAT-3)	Communication
INSAT-3A	Apr 10, 2003	Ariane5-V160	Climate & Environment, Communication
KALPANA-1	Sep 12, 2002	PSLV-C4 /KALPANA-1	Climate & Environment, Communication

5.4. Earth Observation Systems

5.4.1. What are Earth Observation Satellites?

- The purpose of Earth observation type of satellites is to monitor the Earth from space and report back on any changes they observe.
- The equipped sensors are different depending on the purpose such as observation of natural phenomena, disaster monitoring, changes in the Earth caused by human activity and so on.
- They are mostly placed in SSPO. Some may be placed in LEO / GEO / GSO especially for weather monitoring and forecast purposes
- Observation results are provided as satellite images or observation data, and can be interpreted into various information regarding the Earth.
- Earth observation spacecraft can be classified as:

  - **Weather satellites:** employed for monitoring and forecasting weather trends and providing actual weather data.
  - **Remote sensing satellites:** its primary applications are all types of environmental monitoring and geographical mapping.

5.4.2. Applications of Earth Observation Satellites

- Monitor weather patterns and climate changes.
- Assist in urban planning and mapping.
- Help in disaster management and forecasting.
- Utilized in environmental monitoring and resource management.
- Contribute to scientific research on Earth's physical, chemical, and biological systems.
- Support military and security applications through surveillance and reconnaissance.
- Facilitate infrastructure development by providing data on topography and land use.
- Enhance agricultural planning through soil, crop, and water resource monitoring.

5.4.3. Working of Remote Sensing Satellites

- Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation energy without going physically into that particular area.
- Special cameras collect remotely sensed images, which help researchers sense things about the Earth.

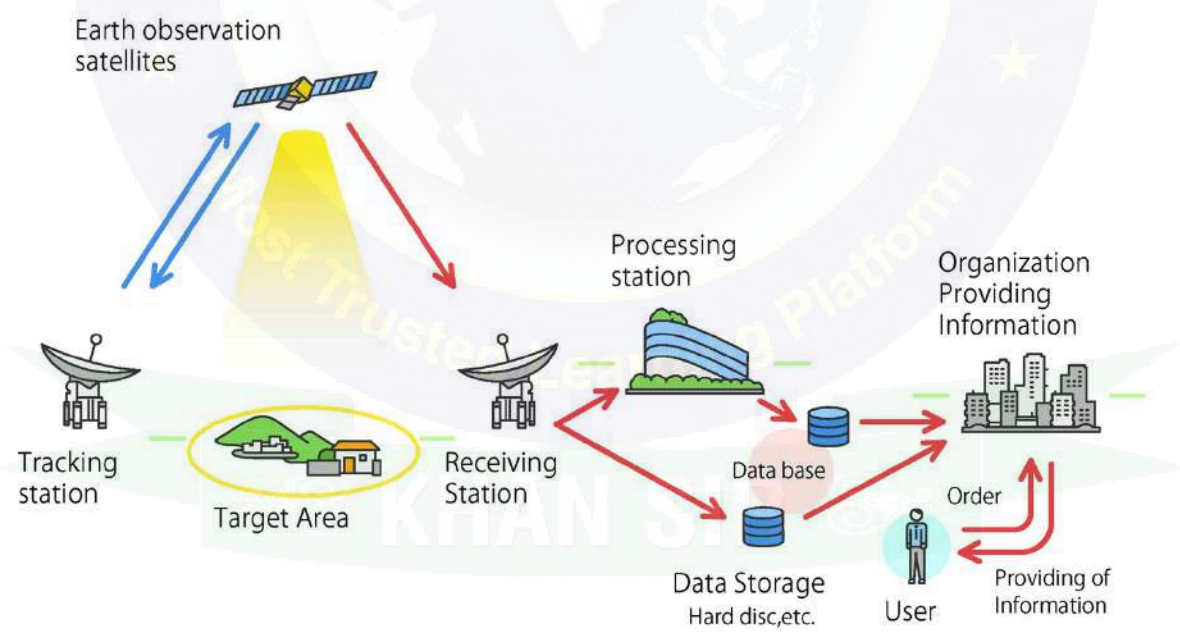


Figure.13. Remote Sensing Process

5.5. India's Earth Observation Programme

- Starting with IRS-1A in 1988, ISRO has launched many Earth Observation satellites.

- ISRO operates one of the largest remote sensing satellite constellations globally.
- India has a total of 23 Earth Observation Satellites in space (PIB, 11 August 2023). They are equipped with diverse instruments for varied spatial, spectral, and temporal resolutions.
- The data from these satellites are used for several applications covering agriculture, water resources, urban planning, rural development, mineral prospecting, environment, forestry, ocean resources and disaster management.

5.5.1. Important Indian Remote Sensing Satellites

Name		Launch Year	Importance
IRS	IRS-1A	1988	Used for remote sensing applications such as cartography, land use mapping, and forestry.
	IRS-1B	1991	
	IRS-1C	1995	Had improved capabilities. Used for a wide range of applications such as mineral exploration, coastal monitoring, and disaster management.
	IRS-1D	1997	
Resourcesat	Resourcesat-1	2003	Used for resource mapping and management applications such as soil moisture mapping, crop inventory, and forestry.
	Resourcesat-2	2011	
	Resourcesat-2A	2016	
Cartosat	Cartosat-1	2005	Used for cartography and high-resolution imaging applications. Cartosat-3 also has an additional capability of capturing hyperspectral images.
	Cartosat-2	2007	
	Cartosat-3	2019	
Oceansat	Oceansat-1	1999	Used for oceanographic applications such as sea surface temperature mapping, ocean color mapping, and ocean wind vector mapping.
	Oceansat-2	2009	
RISAT	RISAT-1	2012	These satellites had synthetic aperture radar (SAR) sensors that allowed them to capture images of the earth even in cloudy or dark conditions.
	RISAT-2	2009	

5.6. Satellite Navigation Systems

5.6.1. What is a Satellite Navigation System?

- Satellite navigation or SatNav system is a system of artificial **satellites capable of providing geo specific positioning** everywhere in the world.
- Satellite navigation allows satellite navigation devices to determine their location to high precision using time signals transmitted along a line of sight by radio from satellites.
- Global coverage for each system is generally achieved by a satellite constellation of 18–30 medium Earth orbit (MEO) satellites spread between several orbital planes.

5.6.2. Types of Space Navigation System

There are two major types of space navigation systems:

Global Navigation Satellite System (GNSS)

- The spacecraft of the Global Navigation Satellite System (GNSS) broadcast signals that GNSS receivers pick up and utilize for geolocation purposes, providing global coverage.
- As of 2023, four global systems are operational:
    - United States' Global Positioning System (GPS) (became fully operational in 1993) – 31 satellites,
    - Russia's Global Navigation Satellite System (GLONASS),
    - China's BeiDou Navigation Satellite System, and
    - European Union's Galileo.
- General features of GNSS:
    - 18-35 medium Earth orbit (MEO) satellites
    - Orbital inclinations >50°
    - Orbital periods: ~12 hours
    - Altitude: ~17,000 20,000 kilometers

Regional Navigation Satellite System (RNSS)

- The Regional Navigation Satellite System (RNSS) is an autonomous regional navigation system that provides coverage on a regional scale.
- RNSS in operation are:
    - Japan's Quasi-Zenith Satellite System (QZSS)
        - Enhances GPS accuracy
        - Independent navigation from GPS planned for 2023-24
    - Indian Regional Navigation Satellite System (IRNSS) or NavIC
        - Autonomous regional satellite navigation system, developed by ISRO
        - Provides accurate position information services
        - Coverage: India and up to 1500 km from its boundary
        - Offers reliable position, navigation, and timing services

5.6.3. Applications of Satellite Navigation

- Made travel to unknown places simple.
- It has become common to track a package location, whether a parcel or food delivery.
- Aircraft with SatNav services decrease the load on the pilot and decrease accidents.
- Buildings, roads and other construction companies used SatNav technologies for precise and accurate readings.
- Both mining and archaeology sectors use SatNav for 3D mapping of sites for excavation and detailed site features.
- Spacecraft with SatNav receivers enable orbit determination precisely. It also helps in performing autonomous navigation and rendezvous tasks.

- Unmanned Aerial Vehicles (UAV), missiles, and bombers are updated with guided technology that was achieved with the integration of SatNav technology.

5.7. Navigation Satellites of India

5.7.1. GPS Aided GEO Augmented Navigation (GAGAN)

- It is a **Space Based Augmentation System** (SBAS) **jointly developed by ISRO and Airport Authority of India** to provide the best possible **navigational services over Indian FIR** (Flight Information Region) with the capability of expanding to neighbouring FIRs.
- After launching the GAGAN on 13 July, 2015, India joined the select league comprising the United States, Europe Union (EU) and Japan which have similar systems.
- GAGAN is a system of satellites and ground stations that **provide GPS signal corrections.** It corrects for GPS signal errors caused by Ionospheric disturbances, timing and satellite orbit errors and also it provides vital information regarding the health of each satellite.

Working of GAGAN

- GAGAN consists of a set of ground reference stations positioned across various locations in India called **Indian Reference Station** (INRES), which gathers GPS satellite data.
- A master station, **Indian Master Control Centre** (INMCC) collects data from reference stations and creates GPS correction messages.
- The corrected differential messages are uplinked via **Indian Uplink Station** (INLUS) and then broadcasted on a signal from three geostationary satellites (GSAT-8, GSAT-10 and GSAT-15).
- The information on this signal is compatible with basic GPS signal structure, which means any SBAS enabled GPS receiver can read this signal.

Gagan Applications

- The GAGAN system is being used for effective management of wildlife resources and monitoring of forests.
- It can provide navigational support to the Indian railway for signaling when a train approaches a no man crossing and also for alignment of railway tracks.
- The Road Asset Management System (RAMS) is likely to be developed for all National Highways in the country and a modern management system that will use the GAGAN system.
- GAGAN signals can also be used to manage traffic in real time to avoid traffic jams.
- Other areas include scientific research for atmospheric studies, natural resource and land management, location based services, mobile and tourism.

5.7.2. Navigation with Indian Constellation (NavIC)

- To meet the **positioning, navigation and timing requirements** of the nation, ISRO has established a regional navigation satellite system called Navigation with Indian Constellation (NavIC).
- NavIC was **erstwhile known as Indian Regional Navigation Satellite System** (IRNSS).
- The main objective is to provide Reliable Position, Navigation and Timing services over India and its neighbourhood, and to provide fairly good accuracy to the user.

- NavIC offers two services:
    - **Standard Position Service** (SPS) for civilian users
    - **Restricted Service** (RS) for strategic users
- It operates during all weather conditions.

Organisation of the NavIC

- In the space segment, there are **three satellites in Geostationary orbit** (GEO) and **five satellites in Geosynchronous orbit** (GSO) with inclination of 29° to the equatorial plane. All the satellites are visible at all times in the Indian region.
- There are 2 additional stand-by satellites on ground. The ground network consists of a control centre, precise timing facility, range and integrity monitoring stations, two-way ranging stations, etc.
- Ground Segment is responsible for the maintenance and operation of the IRNSS constellation. It provides the monitoring of the constellation status, computation of the orbital and clock parameters and navigation data uploading.
- The system is intended to provide an absolute position accuracy of better than 10 meters throughout Indian landmass and better than 20 meters in the Indian Ocean as well as a region extending approximately 1,500 km around India.

Launch Timeline of IRNSS Satellites

- IRNSS-1A: July 2, 2013
- IRNSS-1B: April 4, 2014
- IRNSS-1C: October 16, 2014
- IRNSS-1D: March 28, 2015
- IRNSS-1E: January 20, 2016
- IRNSS-1F: March 10, 2016
- IRNSS-1G: April 28, 2016
- IRNSS-1I: April 12, 2018
- **Note:** The PSLV-39 / IRNSS-1H launch in 2017 was unsuccessful, and the satellite could not reach orbit.

Some applications of IRNSS

- Terrestrial, Aerial and Marine Navigation.
- Disaster Management.
- Vehicle tracking and fleet management.
- Integration with mobile phones.
- Precise Timing.
- Mapping and Geodetic data capture.
- Terrestrial navigation aid for hikers and travellers.
- Visual and voice navigation for drivers.

5.7.3. NVS-01

- ISRO, in May, 2023, launched a new NavIC satellite (NVS-01), that belongs to the second generation of the NavIC, to overcome some of the previous issues faced by NavIC.
- Its major role is to sustain and enhance NavIC with improved features.
- It incorporates L1 band signals for expanded services and carries the first indigenous atomic clock

- It marks a milestone in self-reliance and technological advancement for India's space program.

6. National Space Missions

6.1. Mangalyaan (Mars Orbiter Mission)

- Mars Orbiter Mission (MOM), popularly known as Mangalyaan, marks **India's first venture into interplanetary space.**
- The spacecraft launched on November 5, 2013, arrived safely into Mars orbit on September 24, 2014.
- ISRO has become the fourth space agency to reach Mars, after the Soviet space program, NASA, and the European Space Agency.
- As a result, India made history by becoming the **first-ever country to reach Mars on the first attempt** and it was done on a light budget.

Objectives

- To develop the technology required for interplanetary missions.
- To explore Mars' surface features, morphology, and atmosphere.
- Scientific analysis of Mars including its mineralogy and Martian atmosphere.

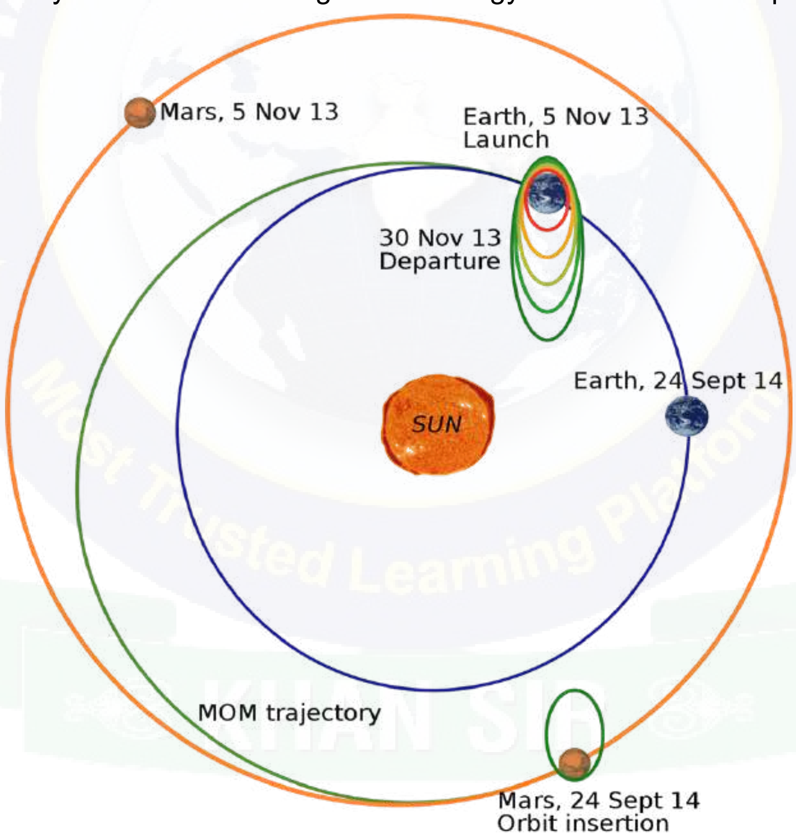


Figure.14. Travel of MOM

6.1.1. Equipment on board MOM

- **Lyman Alpha Photometer (LAP)** is an absorption cell photometer. It measures the relative abundance of Deuterium and Hydrogen from spectral studies of the Martian upper atmosphere (Exosphere and Exobase).

- **Methane Sensor for Mars (MSM)** was designed to measure methane in the Martian atmosphere with a particle-per-billion accuracy and also capacity to map the sources.
- **Mars Exospheric Neutral Composition Analyser (MENCA)** is a quadrupole mass spectrometer capable of analysing the neutral composition in the range of 1 to 300 amu, the range in which the bulk proportion of gases of the Martian atmosphere falls.
- **Mars Colour Camera (MCC)** images give useful inputs about the surface features and composition of the Martian surface and to monitor the dynamic events and weather of Mars.
- **Thermal Imaging Spectrometer (TIS)** is for surface and atmospheric exploration using thermal remote sensing and also detecting the sources of thermal radiation in the Martian environment.

6.1.2. Duration of Mars Mission

- Mangalyaan was planned for a mission life of six months. However, due to fuel-saving manoeuvres and accurate orbital injections and firings saved 20 Kg of fuel, making 40 Kg of fuel at the time of Mars's high elliptical orbit insertion.
- The functioning of instruments with no or less degradation even after six months of working under such harsh conditions is another great feat of the orbiter.
- ISRO utilized this opportunity to make use of the data and worked towards familiarizing the Martian conditions.
- On October 02, 2022, it was reported that the orbiter had irrecoverably lost communications with Earth after entering a seven-hour eclipse period in April 2022 that it was not designed to survive.
- The following day, ISRO released a statement that all attempts to revive MOM had failed and officially declared it dead.

6.1.3. Other Similar Projects

- **NASA's Mars Rovers** (Spirit, Opportunity, Curiosity, Perseverance): Robotic explorers studying the Martian surface.
- **European Space Agency's Mars Express:** Orbital mission providing high-resolution imagery of Mars' surface.
- **China's Tianwen-1:** Orbiter, lander, and rover mission studying Mars' geology and atmosphere.
- **UAE's Hope Probe:** Orbital mission studying Mars' atmosphere and climate.
- **Russia's Mars Program (Phobos-Grunt):** Intended to study Mars' moon Phobos
- **NASA's MAVEN:** Orbiter studying Mars' atmosphere and its interaction with the solar wind.
- **NASA's Mars Reconnaissance Orbiter:** Orbital mission providing detailed imagery of Mars' surface.
- **ESA's ExoMars:** A mission to search for signs of past life on Mars.
- **Japan's Martian Moons Exploration (MMX):** Upcoming mission to study Mars' moons, Phobos and Deimos.
- **India's Mangalyaan 2:** Planned follow-up mission to further study Mars.

6.1.4. Why Study Mars?

Search for Life

- Mars is the most Earth-like planet in our Solar System.

- Investigating Mars can help answer the fundamental question of life beyond Earth.
- The planet's history suggests it may have once supported ecosystems, and it could still harbour microbial life today.

Understanding Surface and Planet's Evolution

- Mars experienced significant climate change over its history.
- Planetary geologists study rocks, sediments, and soils to uncover its surface history.
- Understanding the history of water on Mars is crucial for assessing potential habitability.

Preparing for Future Human Exploration

- Robotic missions to Mars pave the way for human exploration.
- Look for resources and assess risks, reducing costs and enhancing safety.
- NASA aims to land humans on Mars by the 2030s.

Understanding Our Home

- Studying Martian geophysical processes offers insights into Earth's evolution and history.
- It provides knowledge about the broader processes shaping our Solar System.

Mars is Accessible

- Mars is the second most accessible destination in our Solar System after the Moon.
- Its relative proximity makes it a prime target for exploration missions.

6.2. Chandrayaan I

- Chandrayaan I was India's first Moon mission.
- The mission had 11 payloads built by India, the United Kingdom, the United States of America, Germany, Bulgaria and Sweden.
- Chandrayaan mission, launched on a PSLV rocket on October 22, 2008 from Sriharikota, was designed to collect data about the topography of the Moon.
- The spacecraft was orbiting around the Moon at the height of 100 km from the lunar surface.

Significance of Chandrayaan I Mission

- It collected data on chemical, mineralogical and photo-geologic mapping of the Moon.
- The data from Chandrayaan I helped discover the presence of water on the Moon in September 2009.

6.3. Chandrayaan II

- Chandrayaan II is the second lunar exploration mission of the ISRO after Chandrayaan I.
- It consisted of an orbiter, a lander named Vikram and a rover named Pragyan.
- The spacecraft was launched from the second launch pad at the Satish Dhawan Space Centre in Andhra Pradesh on 22 July 2019 by GSLV MkIII-M1.
- The lander and the rover were scheduled to land on the near side of the Moon, in the south polar region on 6 September 2019.
- A successful soft landing would have made India the fourth country to land on the moon after the Soviet Union, United States and China.
- However, the lander crashed when it deviated from its intended trajectory while attempting to land.

Mission Objectives

- To develop and demonstrate the key technologies for end-to-end lunar mission capability, including soft-landing and roving on the lunar surface.

Science Objectives

- To expand the lunar scientific knowledge through detailed study of topography, mineralogy, surface chemical composition, thermo-physical characteristics and tenuous lunar atmosphere leading to a better understanding of the origin and evolution of the Moon.

Relevance of Chandrayaan II Mission

- Despite the failure, the mission's orbiter and other parts had functioned normally and gathered information.
- The information included the presence of water molecules on the moon, information about solar flares and discovery of minor elements.

6.4. Chandrayaan III

- Chandrayaan III is a follow-on mission to Chandrayaan II to demonstrate end-to-end capability in safe landing and roving on the lunar surface.
- It was **launched on 14 July 2023 by LVM3 M4** from the Satish Dhawan Space Center, and the lander and rover **landed near the lunar south pole region on 23 August 2023.**
- With this, **India has become the fourth country** – after Russia, the United States and China – to land on the moon and **also the first to land on the moon's South Pole.**

6.4.1. Mission objectives of Chandrayaan III

- To demonstrate Safe and Soft Landing on the Lunar Surface.
- To demonstrate Rover roving on the moon.
- To conduct in-situ scientific experiments.

6.4.2. Components of Chandrayaan III

It consists of an **indigenous Lander module (LM), Propulsion module (PM) and a Rover.** The lander (Vikram) and rover payloads (Pragyan) of Chandrayaan III remain the same as the Chandrayaan II mission.

Propulsion module

- It is a box-like structure with one large solar panel mounted on one side and a large cylinder on top that acts as a mounting structure for the lander.
- It has one instrument called the **Spectropolarimetry of HAbitable Planet Earth** (SHAPE) to study Earth from lunar orbit.

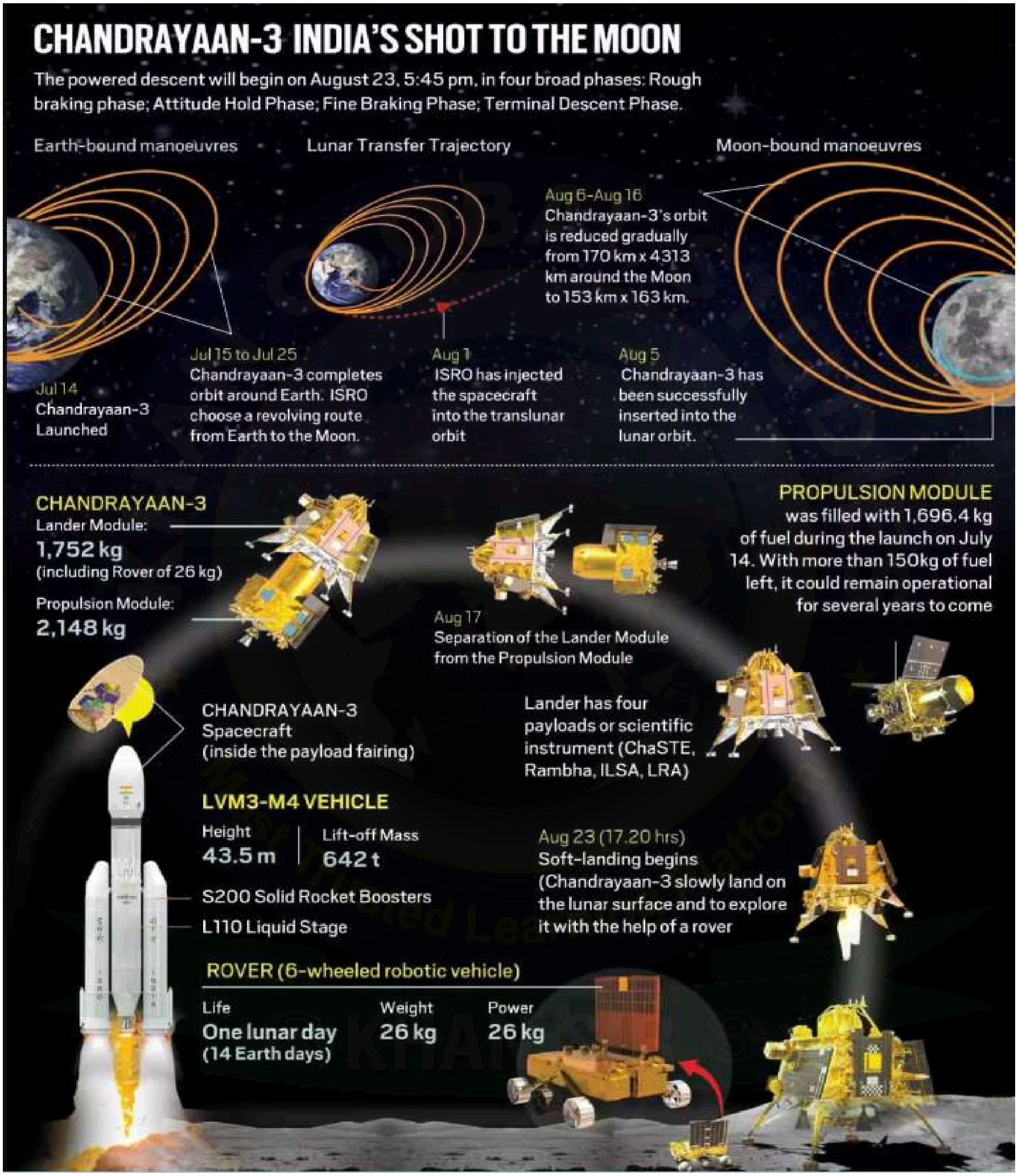
Vikram

- The Vikram lander is **responsible for the soft landing** on the Moon. It is box-shaped, with four landing legs and four landing thrusters capable of producing 800 newtons of thrust each.
- Payloads of Vikram lander are:
    - an instrument called **Chandra's Surface Thermophysical Experiment** (ChaSTE) to measure surface thermal properties,
    - the **Instrument for Lunar Seismic Activity** (ILSA) to measure seismicity around the landing site,
    - the **Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere** (RAMBHA) to study the gas and plasma environment, and
    - a passive **laser retroreflector array** provided by NASA for lunar ranging studies.

Pragyan

- Pragyan rover has navigation cameras and a solar panel that can generate 50 W.

- It has two instruments to study the local surface elemental composition, an **Alpha Particle X-ray Spectromete**r (APXS) and **Laser Induced Breakdown Spectroscopy** (LIBS).



Infographic: How the Chandrayaan III Reached the Lunar Orbit

6.4.3. Changes and Improvements in Chandrayaan III

Simplified Payload

- Unlike Chandrayaan II, which comprised the Vikram lander, Pragyan rover, and an orbiter, Chandrayaan III is **equipped with a lander and a rover only.**
- While Chandrayaan II's orbiter carried nine in-situ instruments, Chandrayaan III's propulsion module housed a single instrument called SHAPE.

Enhanced Lander Capabilities

- Chandrayaan III incorporates "lander hazard detection & avoidance cameras" to assist in coordination with the orbiter and mission control during the lander's descent to the lunar surface.

Strengthened Legs

- The legs of the new Vikram lander have been strengthened to ensure that it can land safely up to a speed of 10.8 kilometres per hour.

Bigger Fuel Tank

- The Chandrayaan III mission carries more fuel than its predecessor to make sure that it can make last-minute changes if necessary.

More Solar Panels

- The new Vikram lander has solar panels on all four of its faces instead of just two, as seen with its predecessor.

Additional Instruments and Improved Software

- The Chandrayaan III mission has additional instruments and improvements to its software to aid the soft-landing effort.

6.4.4. Why Do Space Agencies Want to Explore the Moon's South Pole?

- All of the previous spacecraft to have landed on the Moon have landed in the region near the Moon’s equator firstly because it is easier and safer there.
- The terrain and temperature are more conducive for a long and sustained operation of instruments.
- Sunlight is also present, offering a regular supply of energy to solar-powered instruments.
- The polar regions of the Moon, however, are different. Many parts lie in a completely dark region without sunlight, and temperatures can go below 230 degrees Celsius. This creates difficulty in the operation of instruments.
- In addition, there are large craters all over the place. As a result, the polar regions of the Moon have remained unexplored.
- Chandrayaan II also planned to land in that region in 2019, but it was not able to accomplish a soft landing and lost contact after it hit the surface.
- South pole of the Moon is of special interest to scientists because of the **occurrence of water ice in permanently shadowed areas** around it.
- The lunar south pole has **craters on its surface that contain a fossil record of hydrogen, water ice, and other volatiles** dating from the early Solar System.
- Considering these cold temperatures, the matter trapped in the southern lunar region would not have witnessed much change over the years and could thereby **hold clues to early life.**

6.5. Aditya L1 Mission

- ISRO launched the Aditya-L1 mission (Aditya in Sanskrit means the Sun), **India's first** dedicated scientific **mission to study the Sun,** on September 02, 2023.

- After four months (on January 06, 2024), the spacecraft was placed at Lagrange Point 1 (L1) of the Sun-Earth system, which is about 1.5 million km from Earth. It is carrying 7 distinct payloads, all developed indigenously that will study the Sun.
- ISRO became the **third space agency to station a solar observatory** at L1 after NASA and the European Space Agency.
- From L1, which serves as a special vantage point for the Sun, Aditya-L1's four payloads will directly view the Sun and three payloads will carry out in-situ studies of particles and fields at the Lagrange Point L1, thus providing important scientific studies of the propagatory effect of solar dynamics in the interplanetary medium.
- The suits of Aditya L1 payloads are expected to provide the information to understand the problem of coronal heating, coronal mass ejection (CME), pre-flare and flare activities, dynamics of space weather, propagation of particles etc.

6.5.1. Launch Vehicle

- The solar probe was carried into space by the Polar Satellite Launch Vehicle (PSLV) in **'XL' configuration.**
    - Missions like Chandrayaan-1 in 2008 and Mangalyaan in 2013 were also launched using PSLV.
- The rocket is most powerful in the 'XL' configuration as it is equipped with six extended strap-on boosters — they are larger than the boosters of other configurations and, therefore, can carry heavier payloads.
- PSLV-XL can lift 1,750 kg of payloads to the sun-synchronous polar orbit. As **Aditya L-1 weighs 1,472 kg,** it was launched aboard PSLV.
- The PSLV will initially place the Aditya L-1 in a lower Earth orbit. Subsequently, the spacecraft's orbit around the Earth will be raised multiple times before it is put on a path to a halo orbit around the L1 Lagrange point.

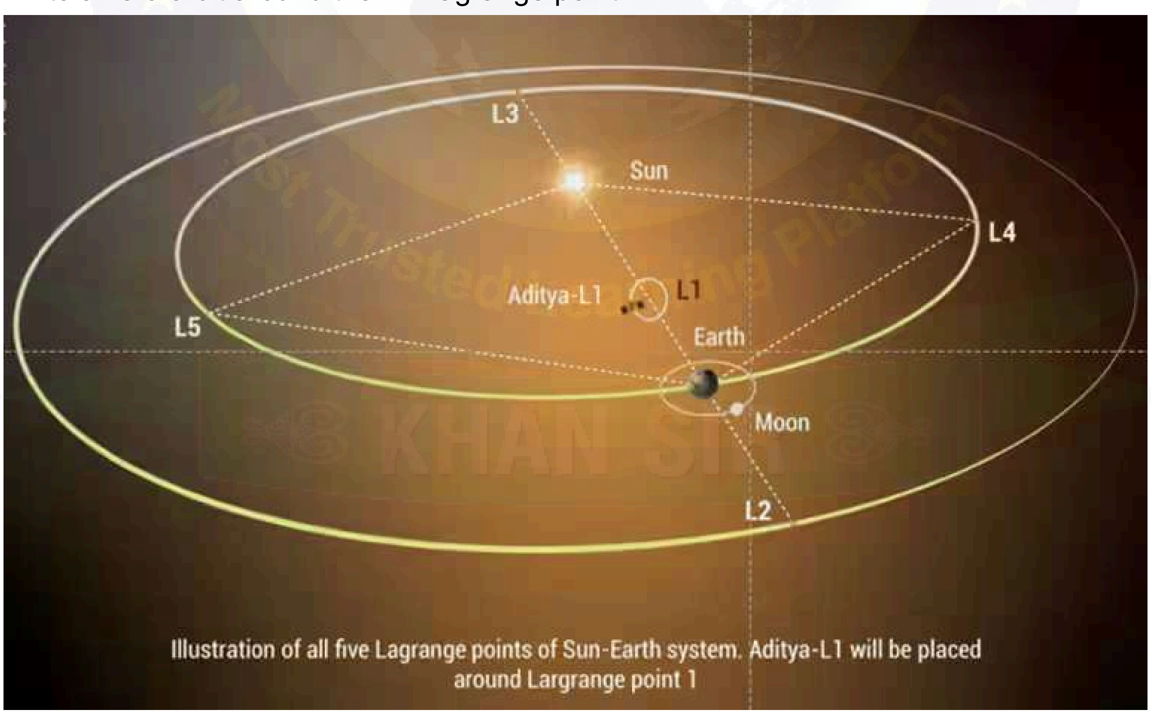


Figure.15. Aditya L1 and Lagrange Point 1

6.5.2. Major Objectives of Aditya-L1 mission

- Study of Solar upper atmospheric (chromosphere and corona) dynamics.
- Study of chromospheric and coronal heating, physics of the partially ionized plasma, initiation of the coronal mass ejections, and flares.
- Observe the in-situ particle and plasma environment providing data for the study of particle dynamics from the Sun.
- Physics of solar corona and its heating mechanism.
- Diagnostics of the coronal and coronal loops plasma: Temperature, velocity and density.
- Development, dynamics and origin of coronal mass ejections.
- Identify the sequence of processes that occur at multiple layers (chromosphere, base and extended corona) which eventually leads to solar eruptive events.
- Magnetic field topology and magnetic field measurements in the solar corona.
- Drivers for space weather (origin, composition and dynamics of solar wind.

6.5.3. Payloads

Remote Sensing Payloads

- **Visible Emission Line Coronagraph (VLEC):** the prime payload designed as a reflective coronagraph with a multi-slit spectrograph. The payload will send 1,440 images of the Sun every day to the ground station on Earth for analysis and research of the intended orbit.
- **Solar Ultraviolet Imaging Telescope (SUIT):** to picture the solar disk in the near ultraviolet wavelength range.
- **Solar Low Energy X-ray Spectrometer (SoLEXS):** to measure the solar soft X-ray flux to study solar flares.
- **High Energy L1 Orbiting X-ray Spectrometer (HEL1OS):** to observe the Sun and study solar flares in the high-energy X-rays.

In-Situ Payloads

- **Aditya Solar Wind Particle Experiment (ASPEX):** it consists of two subsystems – Solar Wind Ion Spectrometer (SWIS) and Suprathermal and Energetic Particle Spectrometer (STEPS).
    - SWIS is a low-energy spectrometer that will measure the proton and particles of the solar wind and STEPS is a high-energy version of it tasked with measuring high-energy ions of the solar wind.
- **Plasma Analyser Package For Aditya (PAPA):** the instrument will help scientists understand the solar winds and their composition. It will also carry out mass analysis of solar wind ions.
- **Advanced Triaxial High-Resolution Digital Magnetometers:** it will measure the low intensity interplanetary magnetic field in space.

6.5.4. Why Study the Sun From Space?

- The Sun emits radiation/light in nearly all wavelengths along with various energetic particles and magnetic fields.
- The atmosphere of the Earth as well as its magnetic field acts as a protective shield and blocks a number of harmful wavelength radiations including particles and fields.
- This means studying the Sun from Earth can't provide a complete picture and it becomes crucial to observations from outside the planet's atmosphere i.e., from space.

Space Weather Conditions

- Space weather refers to changing environmental conditions in space. It is mainly influenced by activity on the Sun's surface. In other words, the solar wind, magnetic field, as well as solar events like CME affect the nature of space.
- During such events, the nature of the magnetic field and charged particle environment near to the planet change.
- In the case of the Earth, the interaction of the Earth's magnetic field with the field carried by CME can trigger a magnetic disturbance near the Earth. Such events can affect the functioning of space assets.
- The mission hopes to generate user-friendly information that can help safeguard a range of satellite-dependent operations such as telecommunications, mobile-based Internet services, navigation, power grids, etc.

6.6. Gaganyaan

- Gaganyaan project envisages demonstration of human spaceflight capability by launching a crew of 3 members to an orbit of 400 km for a 3 days mission and bring them back safely to earth, by landing in Indian sea waters.
- The project is accomplished through an optimal strategy by considering inhouse expertise, experience of Indian industry, intellectual capabilities of Indian academia & research institutions along with cutting edge technologies available with international agencies.
- The pre-requisites for Gaganyaan mission include development of many critical technologies including human rated launch vehicle for carrying crew safely to space, Life Support System to provide an earth like environment to crew in space, crew emergency escape provision and evolving crew management aspects for training, recovery and rehabilitation of crew.
- Various precursor missions are planned for demonstrating the Technology Preparedness Levels before carrying out the actual Human Space Flight mission.
- These demonstrator missions include Integrated Air Drop Test (IADT), Pad Abort Test (PAT) and Test Vehicle (TV) flights. Safety and reliability of all systems will be proven in unmanned missions preceding manned missions.
- Crew training for Gaganyaan
- Astronaut Training Facility established in Bengaluru caters to Classroom training, Physical Fitness training, Simulator training and Flight suit training.

Planned launch

- The first trial (uncrewed flight) for Gaganyaan was planned to be launched by the end of 2023 but has been delayed.
- Launching of the uncrewed flight will be followed by sending Vyom Mitra, a humanoid, and then with the crew onboard (These dates are not yet announced).
- If successful, India would become the fourth nation to conduct a human space flight programme after USSR/Russia, USA and China.

Launcher

- The Gaganyaan Mission will be launched by the LVM3 Rocket.
- Type: Reconfigured to human-rated LVM3 (HLVM3) for Gaganyaan mission.
- Components of launcher: Solid Stage, Liquid Stage and Cryogenic Stage

- Capability: Launches the Orbital Module to a Low Earth Orbit of 400 km.
- Safety Feature: Equipped with a Crew Escape System (CES) for emergency evacuations during launch or ascent, powered by quick-acting, high burn rate solid motors.

Orbital Module

- It has 2 Components: Crew Module and Service Module
- **Crew Module (CM):** To develop a Habitable, Earth-like environment with double-walled construction (pressurized inner, unpressurized outer with Thermal Protection System).
    - Features: Human-centric products; Life support system; Avionics and deceleration systems; and Designed for safe re-entry and descent.
- **Service Module (SM):** Unpressurized support unit housing:
    - Thermal system
    - Propulsion system
    - Power systems
    - Avionics systems
    - Deployment mechanisms

Benefits

- **Scientific Advancement:** Elevates science and technology standards in India.
- **Economic Boost:** Anticipated to generate 15,000 new jobs and stimulate economic activities.
- **Industrial Growth:** Promotes industry development, especially in the private sector.
- **Youth Inspiration:** Aims to ignite young minds towards space science and technology.
- **Societal Benefits:** Spin-off technologies with potential benefits for society.
- **Global Collaboration:** Opens avenues for international partnerships in space exploration.

6.7. ASTROSAT

- PSLV-C30 successfully launched ASTROSAT, India's **Multi Wavelength Space Observatory** in lower earth orbit on September 28, 2015.
- ASTROSAT is designed to observe the universe in the Visible, Ultraviolet, low and high energy X-ray regions of the electromagnetic spectrum simultaneously with the help of its five payloads.
- With the success of this satellite, ISRO has proposed launching AstroSat-2 as a successor for ASTROSAT.
- The observatory had a planned lifespan of five years but completed its mission in 2022.
- With the successful launch of the space observatory, ASTROSAT, ISRO had put India in a select group of countries that have a space telescope to study celestial objects and processes.

Scientific Objectives of ASTROSAT

- To understand high energy processes in binary star systems containing neutron stars and black holes.
- Estimate magnetic fields of neutron stars.
- Study star birth regions and high energy processes in star systems lying beyond our galaxy.
- Detect new briefly bright X-ray sources in the sky.

- Perform a limited deep field survey of the Universe in the Ultraviolet region.