Science and Technology Class 05

Previous Class Topic

- **Types of satellite orbits** (LEO, MEO, GEO) and their relation to rocket launches
- Introduction to **space observation technologies** and **mission fuel types**

Rocket Launches, Satellite Orbits, and Fuel Types

Satellite Orbit Types and Launch Logistics

- A single rocket is typically not used to deploy satellites into vastly different orbits such as**LEO**(Low Earth Orbit),**MEO**(Medium Earth Orbit), and**GEO**(Geostationary Earth Orbit) in a single mission.
- Rockets are designed with fixed objectives; most multiple satellite launches deploy satellites in orbits of similar altitudes.
- Deploying satellites in different types of orbits from a single launch is theoretically possible but requires complex maneuvers and a lot of additional fuel post-separation.
- Engineering challenges, such as increased acceleration and fuel requirements, limit multi-orbit satellite deployment from a single launch vehicle.

Rocket Fuel Types and Environmental Considerations

- **Kerosene**is used in rockets but not exclusively;**hydrazine**is another common propellant but is not the only one used.
- **ISRO**uses different fuels, such as**semi-cryogenic**and**cryogenic**fuels, in their launch vehicles.
- Semi-cryogenic fuel consists of liquid fuel usable at normal temperatures, while cryogenic fuel (e.g., liquid hydrogen) is stored at extremely low temperatures.
- Environmental impact of rocket fuels is assessed based on the by-products produced; liquid hydrogen is viewed as environmentally friendly as it produces only water vapor upon combustion.
- Other liquid fuels at room temperature may result in nitrogen and carbon oxides, which are pollutants.
- The optimal environmental option for rocket launches is to use liquid hydrogen and liquid oxygen as propellants.

Aditya L1 Mission: Objectives and Significance

Key Features and Placement

- Aditya L1 is**ISRO's first dedicated solar observatory**.
- Placed 1.5 million km from Earth at**Lagrangian Point 1 (L1)**, it follows a halo orbit around L1.
- The mission operates in a heliospheric orbit (around the Sun, not Earth).
- Its unique placement allows continuous, unobstructed observation of the Sun.

Mission Objectives

- Imaging of the Sun's outer layers: photosphere, chromosphere, and corona, using diverse spectrums of light.
- Investigation into**coronal heating**—the process causing the Sun's corona to reach temperatures far higher than the photosphere.
- Study of the solar wind's genesis, properties, and variability.
- Monitoring dynamic solar events such as**coronal mass ejections (CMEs)**and solar flares.
- Analysis of interplanetary magnetic fields and the travel of charged particles from the Sun toward Earth.

The Sun: Structure, Layers, and Related Phenomena

Structure and Temperature Ranges

Layer	Approximate Temperature	Key Features
Core	15–20 million °C	Site of nuclear fusion; source of Sun's energy
Radiative Zone	Lower than the core	Energy transport via radiation
Convective Zone	Cooler than radiative zone	Energy transport through convection
Photosphere	5,700 K (approx. 5,500 °C)	Visible surface; source of most sunlight
Chromosphere	Above photosphere	Thin outer shell; seen as reddish rim in solar eclipse
Corona	1–3 million °C	Outermost tenuous layer; visible during total solar eclipse

- The Sun's energy is produced in the core via nuclear fusion where hydrogen fuses into helium.
- The photosphere emits visible light; it appears as the 'surface' of the Sun.
- The chromosphere and corona comprise the outer layers, with the corona exhibiting unexpectedly high temperatures.

Coronal Heating Mystery

- The corona is much hotter than the underlying photosphere, reaching 1–3 million degrees Celsius versus the photosphere's 5,500°C.
- The mechanisms behind this intense heating remain theoretical and not completely understood, necessitating more data.

Solar Observations and Eclipses

- The corona is not visible during regular daylight due to the photosphere’s bright light but can be observed during total solar eclipses.
- The unique alignment of Earth, Moon, and Sun during a total solar eclipse allows viewing the corona.

Solar Phenomena: Solar Wind, Solar Flares, and Coronal Mass Ejections (CMEs)

Solar Wind

- Consists mainly of charged particles (protons, electrons, some neutrons), continuously emitted from the Sun.
- Originate predominantly from**coronal holes**(regions in the corona with open magnetic field lines).
- Travel much slower than light; solar wind particles take about 15–20 hours to reach Earth compared to 8.3 minutes for sunlight.

Solar Flares

- Solar flares are sudden, intense bursts of radiation, including X-rays and ultraviolet light, usually emanating from magnetically active sunspot regions.
- These flares can release energy equivalent to thousands of atomic bombs.
- While most high-energy radiation is stopped by Earth's magnetic field or atmosphere, solar flares can impact satellite electronics and communication systems.

Coronal Mass Ejections (CMEs)

- CMEs are massive expulsions of plasma (charged particles) from the Sun's corona, often triggered in conjunction with solar flares.
- Billions of tons of matter can be ejected into the solar system at high speed.
- CMEs, solar flares, and solar wind collectively constitute what is called a**solar storm**.

Table: Solar Phenomena and Their Effects

Phenomenon	Mechanism/Origin	Primary Effects on Earth
Solar Wind	Continuous outflow from coronal holes	Causes auroras; increases satellite drag
Solar Flare	Magnetic realignment in sunspots	Disrupts comms and power, radiation exposure
Coronal Mass Ejection	Plasma ejected from corona (with/without flare)	Geomagnetic storms, satellite damage, blackouts

Earth's Protective Shield: Magnetic Field and the Van Allen Radiation Belt

Earth's Magnetic Field and Magnetosphere

- The movement of charged particles in Earth's outer liquid core generates a magnetic field (**magnetosphere**) acting as a shield.
- This shield deflects most solar particles, preventing them from reaching Earth's atmosphere.

Aurora Formation

- Charged solar particles spiral along magnetic field lines toward the poles, colliding with atmospheric gases.
- These collisions produce auroras—the*Northern and Southern Lights*—seen near magnetic poles but during strong storms, auroras can extend to lower latitudes.

Impact of Solar Storm on Earth :-

-> Earth has a very powerful magnetic field which act as a shield against solar storm, the disruption in Earth's magnetic field due to solar storm is called Geomagnetic storm. However depending upon the strength of solar storm various impacts can occur -

i) Aurora at lower latitude:

-> Interaction of solar particles from Earth's magnetic field leads to high concentration of charged particles in polar regions as these particles interact with gases in the outer atmosphere it produces beautiful simar of light at north pole and south pole is known as Aurora.
Powerful solar storm can cause aurora even at lower latitude.

ii) Malfunction of communication, navigation satellites as their electronics can suffer.

iii) Drag on satellite's orbit.

iv) Blackouts on Earth due to damage of power grids.

Effects of Solar Storms on Technology

- Auroras during geomagnetic storms can be observed as far as subtropical regions during powerful events.
- Satellite orbits can be disturbed due to increased drag from atmospheric expansion caused by charged particles.
- Power grids and GPS navigation can be disrupted or damaged in rare but intense geomagnetic storms.

Van Allen Radiation Belts

- Zones of energetic charged particles trapped by Earth's magnetic field, forming around the planet.
- Two main belts (sometimes a third forms transiently), with the inner belt starting about 500–600 km above Earth and the outer belt at around 40,000 km.
- **South Atlantic Anomaly (SAA)**: Region where the belts approach Earth's surface unusually closely (as near as 200 km), increasing radiation risk for satellites.

Sunspots and Coronal Holes

Sunspots: Nature and Impact

- Sunspots are magnetically active, cooler regions on the Sun's photosphere, appearing darker in thermal and ultraviolet imaging.
- These occur due to twisted and intertwined magnetic fields blocking heat transport from the Sun's interior.
- Upon realignment of these magnetic fields, energy is explosively released as solar flares and sometimes as CMEs.
- The number and area of sunspots fluctuate in a cyclical manner—the**11-year solar cycle**(sunspot cycle).
- Sunspot maxima correlate with increased solar activity, solar flares, and proton storms; minima with coronal hole expansion and increased solar wind but fewer flares.

-> Sunspots are dynamic they appear, grow and reach to a maximum and then gradually dissipate away and reach to a minimum.
-> Between two maximum 11 years passes which is called sunspot cycle or solar cycle.

Table: Sunspot Cycle

Stage	Description	Associated Activity
Solar Maximum	Greatest number and area of sunspots	High flare and CME activity
Solar Minimum	Fewest sunspots, coronal holes expand	Increased solar wind, fewer flares
Cycle Period	~11 years between two maxima or two minima	Solar activity follows this pattern

Coronal Holes: Structure and Role

- Darker regions in the corona observed in X-ray imaging where the Sun’s magnetic field opens outwards, allowing solar wind to escape more easily.
- Coronal holes tend to expand during solar minimum and contract during solar maximum.

Solar Storms and Their Impact on Earth

Geomagnetic and Technological Effects

- Solar storms' interaction with Earth’s magnetic field induces geomagnetic storms when disturbances are strong.
- Effects include:
- Enhanced auroras visible at lower latitudes
- Malfunction or loss of satellites (due to electronic damage or drag)
- Disruption of radio communications, particularly near poles
- Power grid failures and extensive blackouts if a very strong event occurs
- Increased exposure to radiation for astronauts

-> Van Allen Radiation Belt:
It is a zone of energetic charge particles which originating from sun that are captured and held around by Earth's magnetic field. Earth has two such belt sometimes others may be temporary created.

i) South Atlantic Anomaly-
It is a region where Earth's magnetic field is usually weak this allows charged particles from sun to much closer to earth surface to normal.

Frequency and Predictability

- Major solar storms are rare but not impossible; their likelihood follows the 11-year solar cycle.
- Technologies and observatories, such as Aditya L1, monitor and help predict these phenomena, aiming for better forecasting and preparedness.

Sunspot and Solar Cycle Observations

Nature of the Solar Cycle

- Variation in sunspot coverage and magnetic activity follows an approximately 11-year periodicity.
- Sunspot numbers and areas increase to a maximum (*solar maximum*), then decrease to a minimum (*solar minimum*).
- Causes and mechanics of the cycle remain topics of ongoing research and are not fully understood.

Relation to Solar Phenomena

- Solar maximum years (recently peaked in 2023–2024) correspond with elevated auroral displays and more frequent solar flares and CMEs.
- During solar minimum, more extensive coronal holes and solar wind events occur, though flare activity remains low.

* Objectives of Aditya L1 :-

-> Have 7 scientific instruments.
-> Trying to image outer layers (photosphere, chromosphere, corona).
-> To understand coronal heating.
-> To know about origin of solar wind and its composition.
-> To understand dynamic events in corona and CME.
-> To know solar flare.
-> To know about interplanetary magnetic field.

Lagrangian Points

Theory and Locations

Table: Lagrangian Points in the Sun-Earth System

Point	Location Relative to Earth and Sun	Typical Use	Stability Type
L1	Between Earth and Sun (~1.5 million km)	Solar observatories (e.g., Aditya L1, SOHO)	Semi-stable
L2	Opposite side of Earth from Sun (1.5 million km)	Space telescopes (e.g., James Webb, Gaia)	Semi-stable
L3	Opposite side of Sun, behind Sun from Earth	Not used	Semi-stable
L4	60° ahead of Earth in its orbit	Potential for future space stations; Trojan asteroids (Sun-Jupiter)	Stable
L5	60° behind Earth in its orbit	Similar uses to L4	Stable

- Lagrangian points are positions in the orbital configuration of two large bodies (like Earth and the Sun) where a smaller object affected only by gravity can maintain a stable or semi-stable position relative to the larger bodies.
- These points are derived from the solutions to the restricted three-body problem.

Types of Equilibrium

- L1, L2, and L3: Semi-stable (saddle point equilibrium) — require occasional correction to maintain stability.
- L4 and L5: Stable equilibrium — objects remain in place with minimal perturbation or fuel use.

Usage and Missions

- **L1**: Ideal for solar observatories, continually monitoring the Sun with uninterrupted views (e.g., Aditya L1).
- **L2**: Favored site for deep-space telescopes, offering continuous, unblocked observation of the universe without Earth's interference (e.g., James Webb Space Telescope, Gaia).
- **L3**: Not utilized due to being on the far side of the Sun from Earth.
- **L4**and**L5**: Stable zones; potentially advantageous for future large-scale space infrastructure and already home to natural objects (Trojan asteroids).

Halo Orbits

Nature and Advantages

- Halo orbits are three-dimensional elliptical orbits around Lagrangian points (typically L1 or L2).
- Missions such as Aditya L1 and James Webb Space Telescope leverage halo orbits for continuous observation while minimizing fuel usage.

Trojan Asteroids and Asteroid Belts

Asteroid Belt and Kuiper Belt

Table: Solar System Small Body Regions

Belt	Location	Composition/Noteworthy Objects
Asteroid Belt	Between Mars and Jupiter	Irregular rocky bodies, failed planetesimals
Kuiper Belt	Beyond Neptune (~30–50 AU)	Dwarf planets, icy and rocky objects
Oort Cloud	Outermost solar system edge	Hypothetical comet reservoir (2,000–200,000 AU)

Trojan Asteroids

- Large groups of asteroids located at**L4**and**L5**points of the Sun-Jupiter system; they precede and follow Jupiter in its orbit.
- Named after characters from the Trojan War in Greek mythology, alluding to hidden or unexpected influence.
- Jupiter's gravitational field, in concert with the Sun's, creates stable zones (L4 and L5) where these bodies cluster.
- These asteroids originate outside the immediate solar system but were captured and retained due to the Sun-Jupiter gravity interplay.
- Jupiter acts as a "cosmic shield," deflecting or capturing many potentially hazardous objects from the inner solar system.

Space Docking and Related Experiments

SPEDEX Mission (Space Docking Experiment)

- Demonstrated the capacity to autonomously dock two spacecraft in orbit.
- Involved two distinct modules: a "chaser" and a "target", both launched into orbit.
- The chaser, equipped with fuel and engines, synchronized speed with the target before docking and later detaching and re-docking.
- Docking technology is critical for complex missions, such as sample return missions and space stations, allowing two moving spacecraft to physically connect in orbit.

Future Applications

- Upcoming missions like**Chandrayaan-4**will rely on docking maneuvers for sample return from the Moon.
- Space stations and interplanetary missions require robust docking capability.

POEM (PSLV Orbital Experimental Module)

- The PSLV's fourth stage has been repurposed for orbital experiments after main mission completion.
- Used for scientific payloads, including space weather monitoring and the CROPS experiment (seed germination in space).
- Demonstrated Indian capability in conducting biological and physical experiments in microgravity.

Upcoming and Notable ISRO Missions

Shukriyaan Mission

- Target:**Venus**, Earth's similar-sized but harsh twin planet.
- Mission Type: Orbiter (not lander), to study atmospheric and surface composition.
- Noted for Venus' dense atmosphere, extreme surface temperatures, and acid rain making it inhospitable.

ExpoSat Mission (X-ray Polarimeter Satellite)

- Purpose: Study and measure the polarization of X-rays from cosmic sources such as supernovae, quasars, and neutron star mergers.
- Utilizes X-ray polarimetry to deduce geometry, magnetic fields, and the emission processes of cosmic objects.
- Focus: Dedicated exclusively to X-ray studies, differing from AstroSat, which observed multiple wavelengths.

-> Launched in LEO.
-> To know more about X-ray sources in the universe such as -
  -> Supernova
  -> Quasar
  -> Merger of neutron star to a blackhole.
-> This mission aims to measure the polarization of X-ray coming from these sources by studying polarization scientist can learn about the source, geometry, magnetic fields and the processes that produce X-ray.

Table: Indian Astronomical Observatories

Observatory	Main Focus	Orbit	Notable Features
AstroSat	Multi-wavelength	Low Earth Orbit	First dedicated space observatory
ExpoSat	X-ray polarization	Low Earth Orbit	Second dedicated astronomy mission

Polarization: Basic Explanation

- Polarization refers to the orientation of the electric field of light waves.
- Unpolarized light has electric fields in random directions; polarized light has them aligned in specific directions.
- Polarizing filters absorb all vibrations except those aligned with the filter orientation, reducing glare and eye strain (*applies in display tech and sunglasses*).
- Measurement of X-ray polarization informs about the environment and processes around high-energy cosmic phenomena.

Topic to be Discussed in the Next Class

- Nature of light, electromagnetic waves, and polarization in greater detail as part of the**ICT (Information and Communication Technology)**module.
- Communication and computing technology advancements with a focus on foundational physics concepts such as**electricity, magnetism, sound, and light**