SARRTHI IAS

LIVE

PRELIMS NAVIGATOR PROGRAM

UPSC PRELIMS 2026

SCIENCE &TECHNOLOGY

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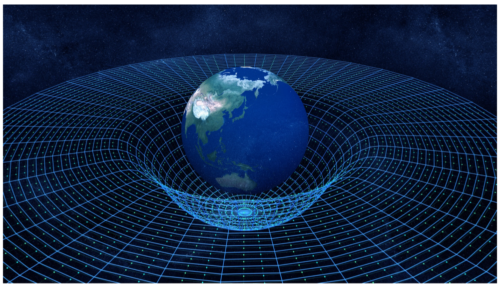
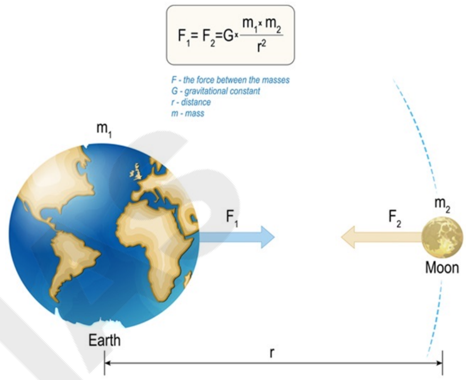
Space Technology



Gravity is bending of space time

$F_G = G\frac{m_1 m_2}{r^2}$; $G = 6.67\times10^{-11} m^3/kg/s^{-2}$

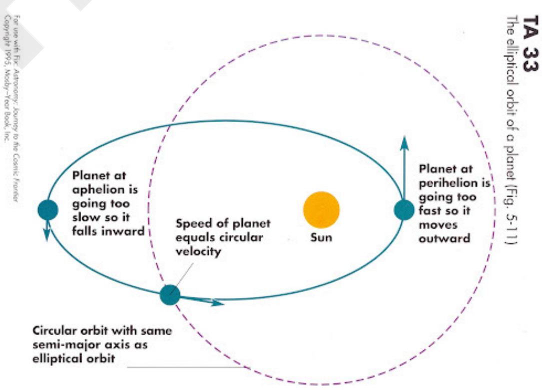
↳ for gravity to operate → we need a large mass



ORBITS

↳ Imaginary path taken by a celestial body / spacecraft centripetal due to gravitational force.

Types → Shape → Elliptical (planets orbits)
→ Circular Orbit (Geo stationary Orbit)



Elliptical Orbit	Circular Orbit
• Distance Variable	• Distance constant
• Speed Variable	• Speed constant
• Velocity Variable	• Velocity variable

Types → Revolution → Geosynchronous orbit
→ Sun-synchronous orbit

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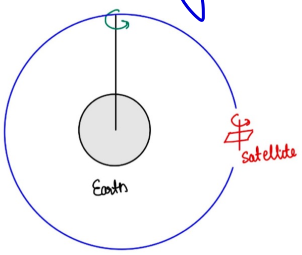
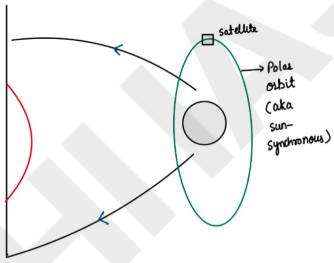
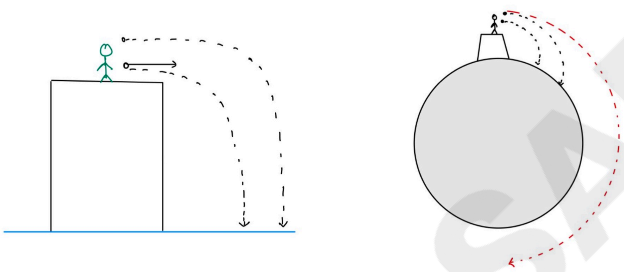
Geo-Synchronous	Sun-Synchronous
• Revolution is synchronized as per earth's rotation • Orbit: equitorial plane • Application:- ↳ Communication ↳ Navigation	• Revolution is synchronized as per earth's revolution • Orbit: polar plane • Application: ↳ Earth Observation ↳ Remote sensing



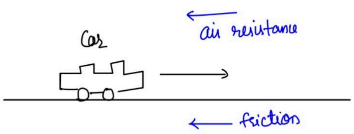


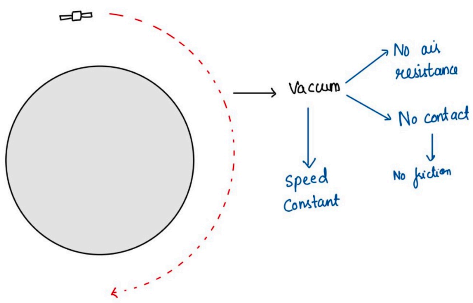
Why satellites don't fall

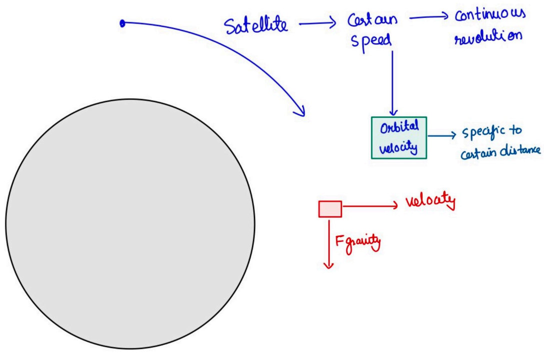


At certain speed ⟶ overcomes curvature

Movement of satellites







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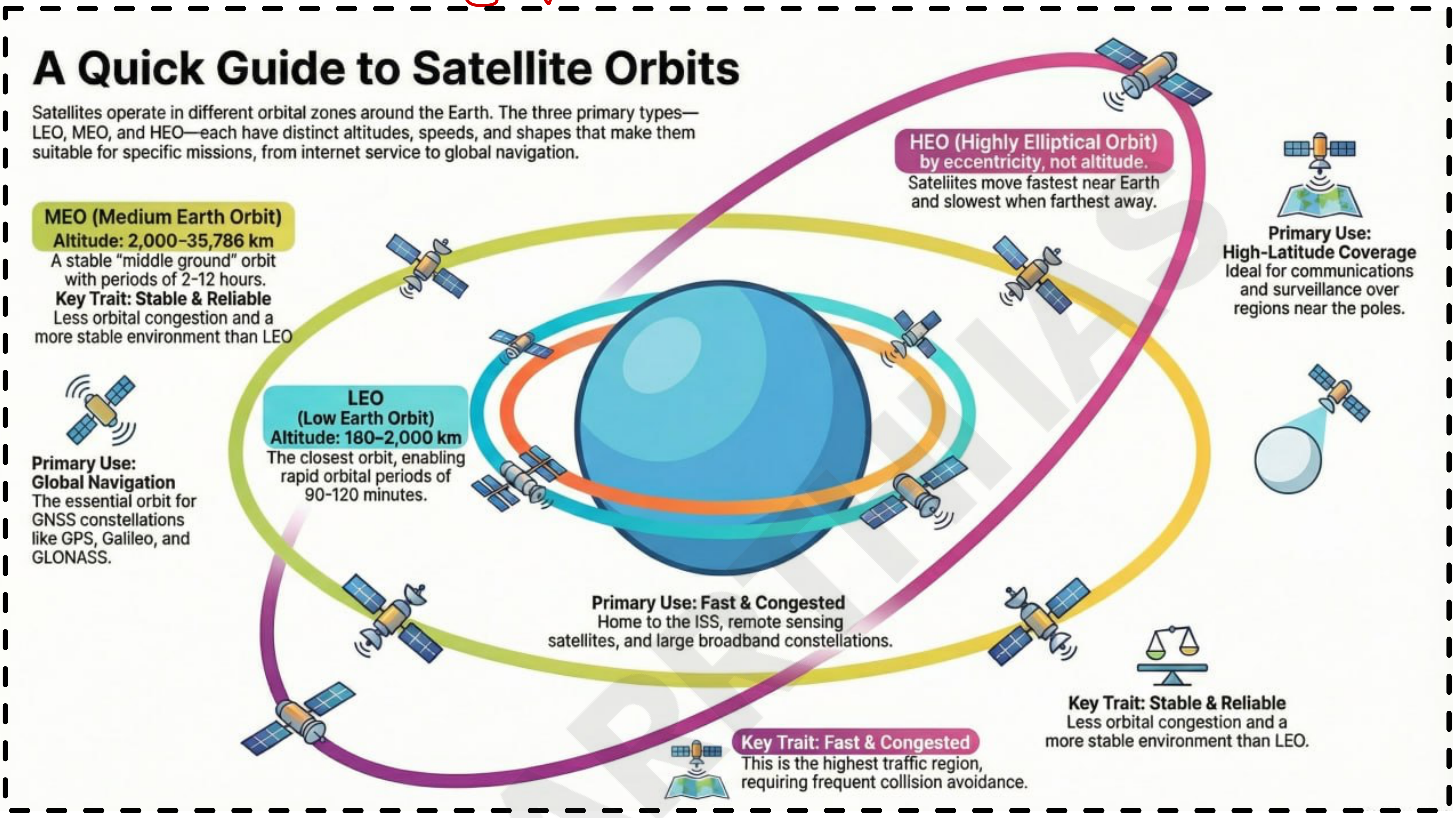
Types → Distance → Low earth orbit
→ Mid earth orbit
→ Highly eccentric orbit



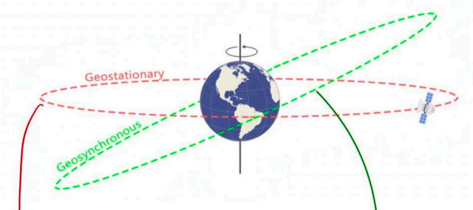
Applications of LEO

1.) Astronomical Observation
2.) Capture data such as radiation → Eg: Hubble, Keppler
3.) Space station
4.) Microgravity experiment
5.) Space Observation
6.) Space Voyage
7.) Service Workshop
8.) Space Tourism

Mid Earth Orbit (2000-36,000 Km)

Geostationary v/s Geosynchronous

→ Both are at 35,786 km above surface



geostationary are always parked at equator

geosynchronous can be at any inclination

Centripetal force is provided by gravitational force

$$\frac{GM_e m_s}{(R+h)^2} = m_s (R+h)\omega^2$$

$$\frac{GM_e}{\omega^2} = (R+h)^3$$

$$\left(\frac{GM_e}{\omega^2}\right)^{\frac{1}{3}} = R + h$$

$$h = -R + \left(\frac{GM_e}{\omega^2}\right)^{\frac{1}{3}}$$

$$h = -6.4 \times 10^6 + \left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{\frac{4\pi^2}{T^2}}\right)^{\frac{1}{3}}$$

$T = 24$ hours for geostationary satellite

$= 24 \times 60 \times 60$ second

$h = -6.4 \times 10^6 + 42.31 \times 10^6$

$= 35.911 \times 10^6$ m

$\simeq 36000$ km

Application of MEO:-

① Navigation Systems:-

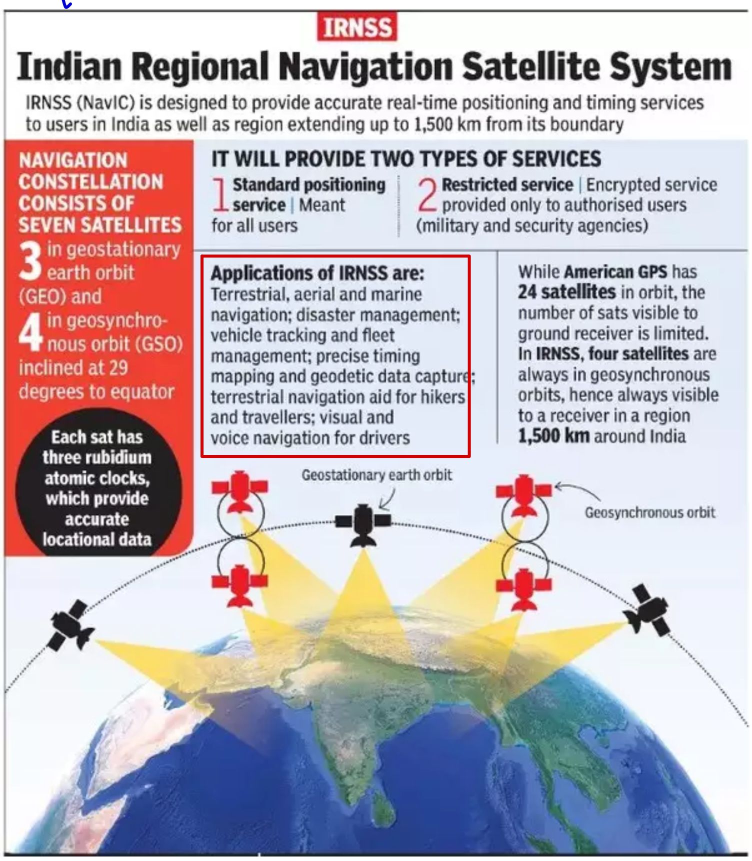
i) GPS → USA
ii) GLONASS → Russia
iii) GALILEO → European Union
iv) BEIDOU 1 & 2 → China
v) NAVIC → India
vi) Quasizenith → Japan

NAVIC → 4 satellites → Geosynchronous
NAVIC → 3 satellites → Geostationary

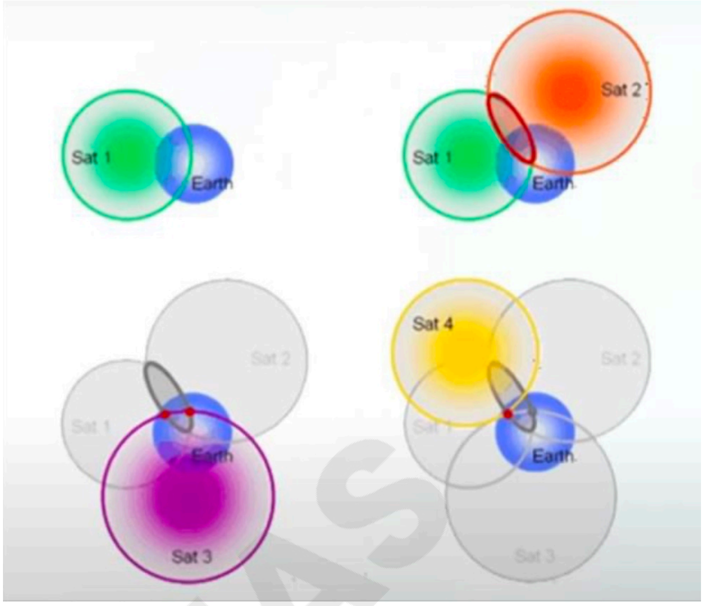
Coverage → India + 1500 km from border

Resolution 10 m

Integration with Mobile:
- Apps: NaviMaps: 3D GPS Navigation, MapmyIndia NavIC
- iPhone 15 Pro and 15 Pro Max models, equipped with the A17 Pro chipset, include NavIC support
- Qualcomm: Announced that its Location Suite now supports up to seven satellite constellations concurrently, including all of NavIC's L1 and L5 signals,
- MediaTek: Chipsets like the Dimensity 8000 and 9000 series are designed with NavIC compatibility



GPS → NAVSTAR of USA
↳ satellites in
semi-synchronous orbit
↳ 24 satellites



★ R = 20,200 Kms above surface
★ takes 12 hrs to complete the orbit.

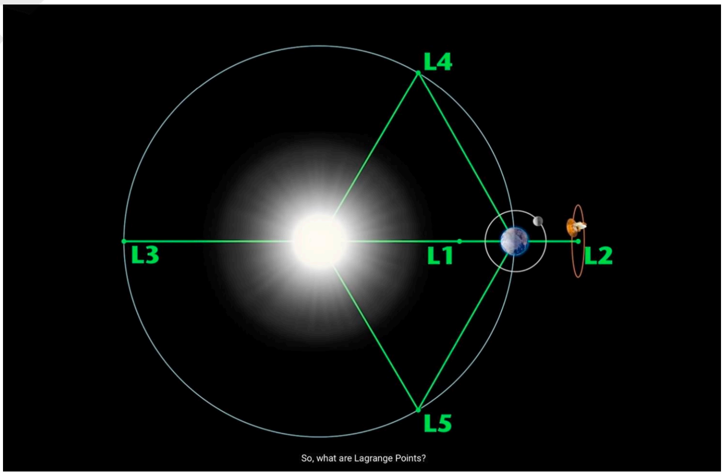
Application → Location service
→ Timing service

b) Geostationary → circular orbit (35,786 km)
→ 24 hour times (matches earth)
→ West to east rotation

High Earth Orbit

L_1 → 16 lakh km from surface

L_2 → same distance other side

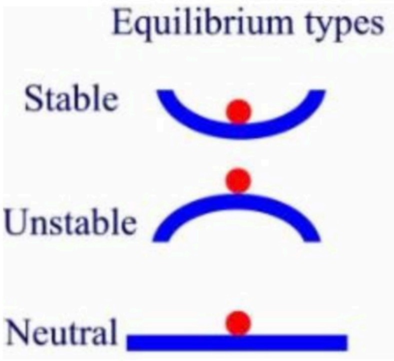


Satellite can constantly monitor sun.

If spacecraft on Lagrange point
↳ Halo Orbit

L_1, L_2 } unstable equilibrium

L_3, L_4 } stable equilibrium



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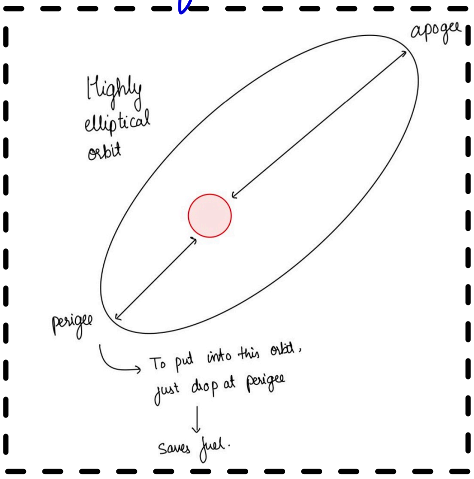
Applications of HEO

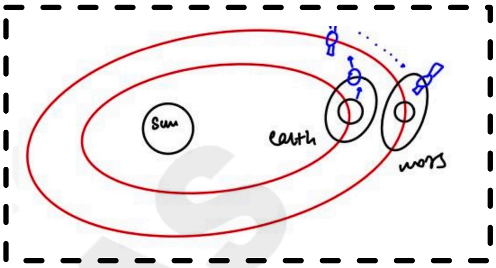
① Geosynchronous Transfer Orbit (GTO)
- Perigee (300 - 400 km)
- Apogee (36,000 km to 38,000 km)

★ Used for initial launch of communication satellite



Used by ISRO
↳ cost ₹7/km

Issues
- Geocentric → Heliocentric
- Shifting of Orbits



Satellite

Liquid Apogee Motor → to give thrust.

Small Newton Engines (to give thrust) → used to shift from one orbit to another.

Nowadays we have complete control of Satellite

LAUNCH VEHICLES

Types

Expendable launch Vehicle
- ✓ Used only once for space mission
- ✓ for unmanned mission
- ✓ space debris issues

Reusable launch Vehicle
- ✓ can be used multiple times (returns back → both manned & unmanned
- ✓ ISRO RLV :- Pushpak
- ✓ cost efficient

Major components of launch vehicle

I.) Engine:-

Reaction:-
- Fossil fuel + O_2 ⟶ CO_2 + Energy
- Oxidizes ⟶ Burn ⟶ CO_2

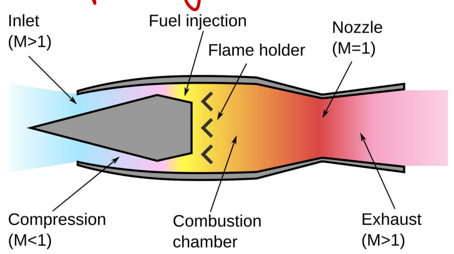
Conventional engine
- Fuel (H_2)
- Oxidizer (O_2) ⟶ compression ⟶ High concentration ⟶ Better energy

Types of Engine

Non air breathing propulsion system
- ✓ Use of oxidiser to burn fuel that is kept on the rocket
- ✓ Heavier due to mass of oxidizer.

Air breathing Propulsion system (Ramjet / Scramjet)
- Air breathing:- word breakdown
- Oxygen from air.
- Lighter.

Types of Jet Engine

Type	Details
① Ramjet Engine 	✓ form of air breathing jet engine that uses forward motion to produce thrust ✓ stationary ⟶ No thrust ↳ required assisted take off (rocket assist.) ✓ works efficiently at supersonic speed (~Mach 3)

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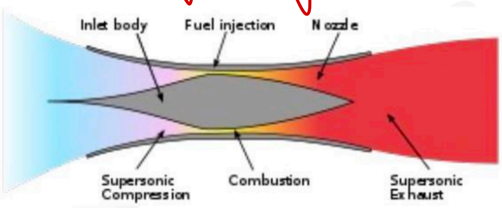
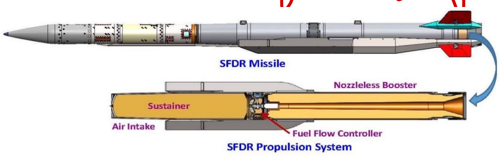
2.) Scramjet Engine



✓ Variant of ramjet air breathing jet engine in which combustion takes place in supersonic airflow.

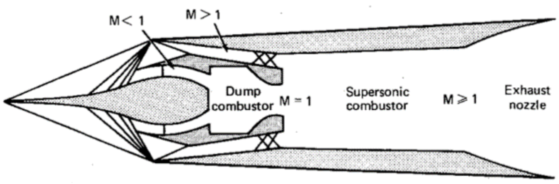
✓ No shock cone
↳ slow airflow using shockwaves produced by its ignition source in place of shock cone.

3.) Solid ducted fuel Ramjet



✓ includes a thrust modulated ducted rocket with reduced smoke nozzle less missile booster
✓ solid fuelled air breathing Ramjet
✓ Range → 70 – 340 Km.

4.) Dual Mode Ramjet



✓ speed > 4–8 mach range

Ramjet ⟶ Scramjet

* Operates both in subsonic & supersonic combuster modes

$\boxed{\text{Types of fuel}}$

1.) Solid fuel :- eg:- HTPB (Hydroxy terminated polybutadine)
used in PSLV & GSLV

Advantage:-
→ Easy to store and transfer
→ All rockets use solid fuel in 1st stage (as it gives more energy)

Disadvantage
→ Heavy weight → ⇑ in cost
→ Non uniform burning

2.) Liquid stage:- eg → UDMH (N_2O_4)
Unsymmetrical Dimethyl Hydrazine

↳ Used in GSLV and PSLV

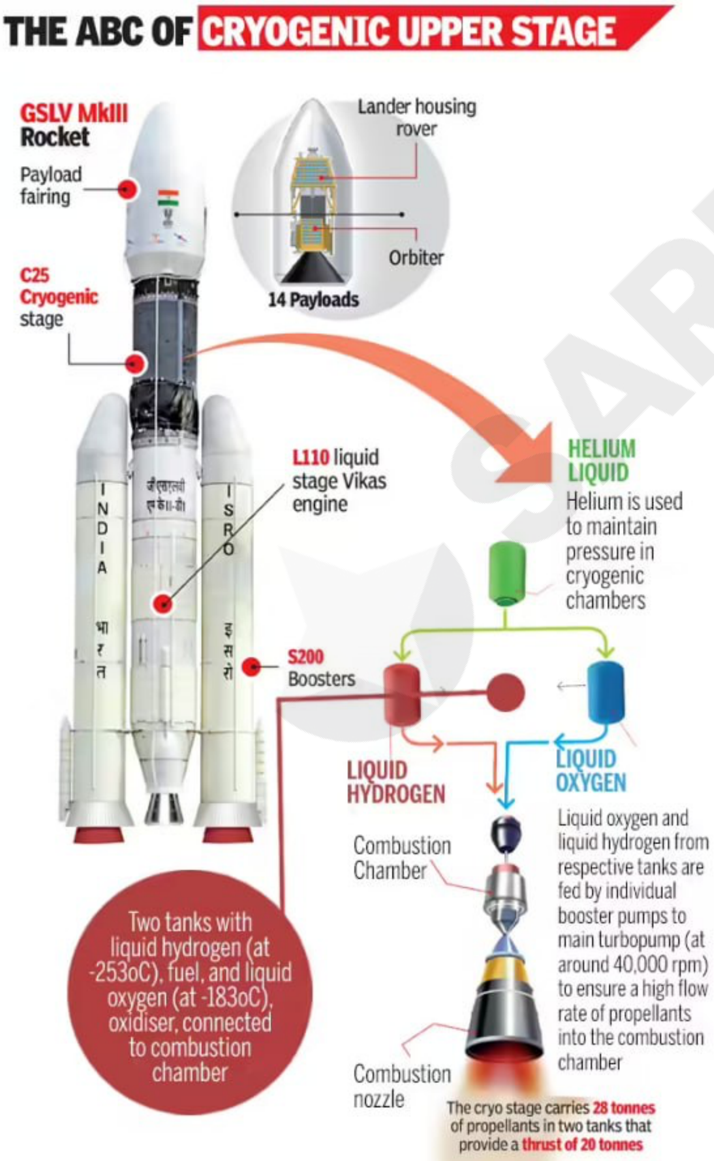
Advantage :- → High efficiency.
→ Uniform burning
→ Less weight → cheap storage
→ Difficulty in storage & transport.

3.) Cryogenic Engine :-
↳ Indigenously developed by India.
store fuel liq. H_2 and liq-O_2 at very low temperature.
generate → H_2O + high energy thrust

$\boxed{\text{Why cryogenic :-}}$

① $H_2 + O_2$ → stored as liquid
↳ highest efficiency
↓
Best thrust / kg of fuel combination.

Only 6 countries have cryogenic
→ US (1963)
→ Japan (1977)
→ France (1979)
→ China (1984)
→ Russia (1987)
→ India (2014)



➤ Two small steering engines provide for control of stage during its thrusting phase

➤ Thrust control and mixture ratio control are achieved by two independent regulators

➤ Main engine and two steering engines together develop a nominal thrust of 73.55 kN in vacuum

MAIN PROBLEMS

➤ Due to large temperature difference, heat transfer is very high. Therefore, lot of insulation needed

➤ Boiling causes sudden pressure rise in tanks. So proper venting is required

➤ Material properties vary at low temperatures. Most materials become brittle. So if valve seats or seals become brittle and break, it causes leaks

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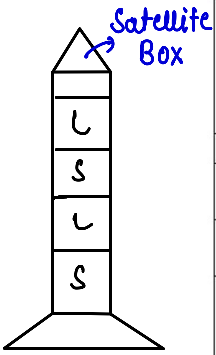
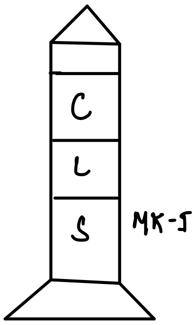
India's Launch Vehicles

Historical
- SLV → Satellite Launch Vehicle
- ASLV → Augmented Satellite Launch Vehicle

Operational:
- PSLV (1993)
- GSLV (2001) → MK-III (recently developed)



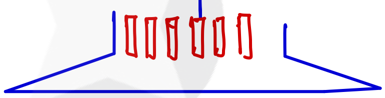
Parameter	PSLV (Polar Satellite Launch Vehicle)	GSLV (Geosynchronous Satellite Launch Vehicle)
Main purpose	• Launch satellites mainly to **Polar / Sun-Synchronous Orbit (SSO)** and other **LEO** missions	• Launch **heavier communication satellites** to **Geosynchronous Transfer Orbit (GTO)**, an elliptical orbit that serves as a pathway to a final Geostationary Orbit (GEO)
Stages	• **4 stages**	• **3 stages** (Mk-I/Mk-II)
Propellants	• Alternating **solid–liquid–solid–liquid**	• **solid + liquid + cryogenic** (cryogenic upper stage is the key feature)
Key engine highlight	• **Vikas engine** in **2nd stage (PS2)**	• **Vikas engine** in liquid stage; **cryogenic upper stage** (CE series)
Why it matters	• Best for **Earth observation**, remote sensing, navigation satellites in SSO/LEO; very reliable	• Enables India to place **heavier satellites** for telecom/meteorology into GTO (GEO capability)
Variants	• Configurations: **CA, DL, QL, XL** (0/2/4/6 strap-ons)	• Variants: **Mk-I, Mk-II** (and heavier class **LVM3** / ex **GSLV Mk-III** is separate)



Versions:-

i) Core alone → w/o strap on motor

ii) standard configuration (with strap on motor (6))



iii) Extra large
↳ 6 strap on motors but more fuel capacity.

Versions:-

i) MK-I

ii) Mark-II
(4 strap on motors) - 3 tons

iii) GSLV-MK-III (LVM III)
- heaviest launch vehicle of India (640 tonnes)
- Can launch 4000-5000 kg satellites.
- 3 stages
  → S-200 (booster solid)
  → L-110 (liquid)
  → CE-25 (Cryogenic)

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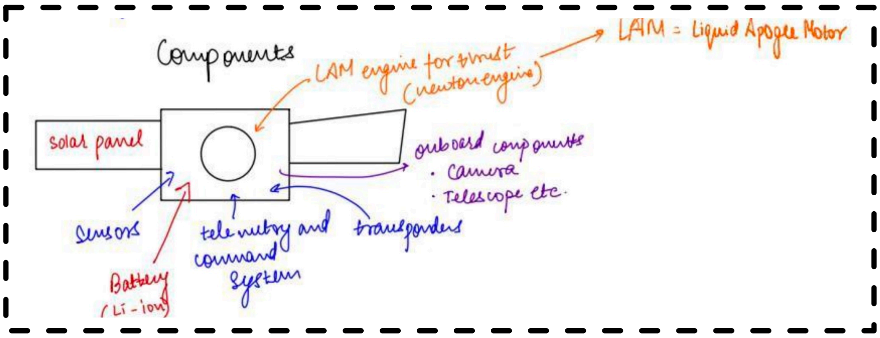
Satellites :- spacecraft designed to carry payloads such as transponders. Sensors and instruments for space application.

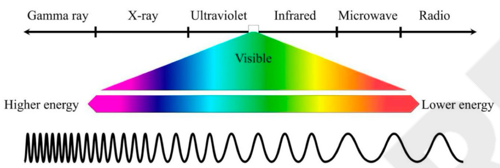


Types of Satellites Based on Applications:

- Communication Satellites
- Meteorological Satellites
- Astronomy Satellites
- Remote Sensing Satellites
- Navigation Satellites Defence and Reconnaissance Satellites
- Anti-Satellite Systems

Transponders :- Transmitter and Receivers
↳ many frequency bands.

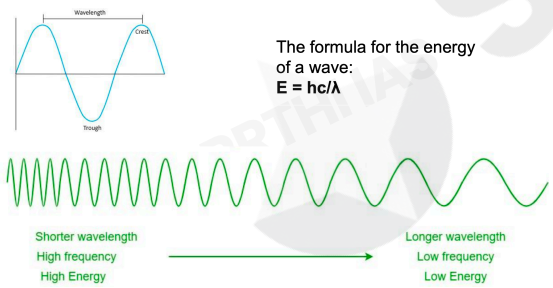
Electromagnetic Spectrum



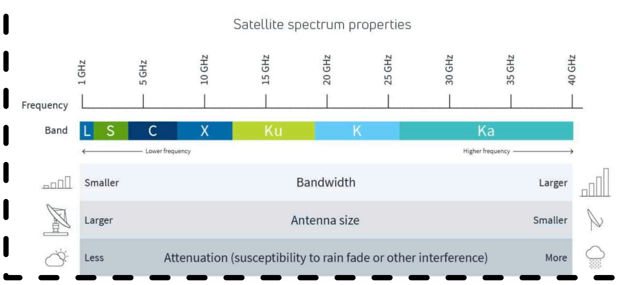
← frequency increasing
wavelength increasing.

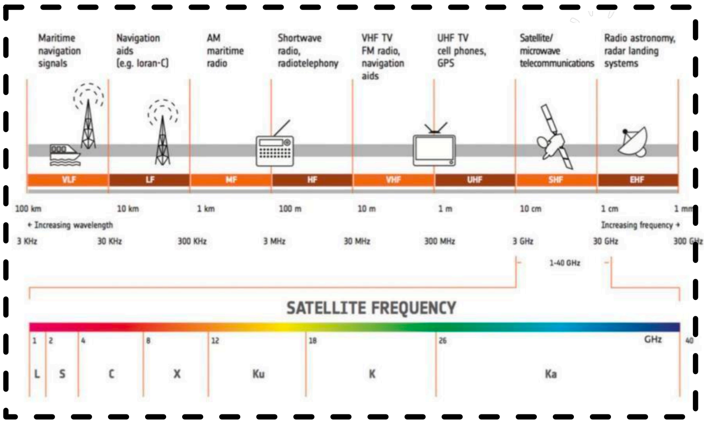
Stars emit a broad spectrum of electromagnetic radiation, including:

- Gamma Rays
- X-Rays
- Ultraviolet (UV) Rays
- Visible Light
- Infrared (IR) Rays
- Microwaves
- Radio Waves



Antenna size ∝ Wave length
frequency ↑ → more energy → more throughput





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Different types of Bands

Band	Frequency range	Typical uses	Key point to remember
L-band	1–2 GHz	**GNSS/GPS** signals, satellite navigation, some satellite phones, aircraft surveillance (ADS-B), telemetry	**Low frequency → penetrates clouds/rain better**, larger antennas
S-band	2–4 GHz	Weather radar, surface/marine radar, telemetry/telecommand, some satellite comms (incl. space/near-Earth links)	Good balance: **reliable links**, moderate antenna size
C-band	4–8 GHz	Satellite communications (TV distribution, raw feeds), VSAT links, some radars	**More rain-resistant than Ku/Ka** (lower rain fade)
X-band	8–12 GHz	**Military + government** satellite comms, imaging radars (SAR), tracking radars; also some civil radar uses	High utility for **radar & defence tracking**
Ku-band	12–18 GHz	DTH/Direct-to-Home TV, satellite broadband, VSAT, broadcasting	**Smaller dishes** than C-band but **more rain fade**
Ka-band	26–40 GHz	High-throughput satellite internet, high-resolution links, inter-satellite/feeder links; military targeting radars	**Highest bandwidth**, but **most affected by rain fade**

Space Debris:

Indian Space situational Assessment Report (ISSAR) for 2023 Released.

space debris → Natural (meteoroid)
→ Artificial (man made)

Maximum → LEO
36,500 large (>10 cm)
1 million medium (1-10 cm)
130 million small (1cm-1mm)

Tackling Space Debris:

1) Mitigation:- No. of countries Germany, France UK & USA

2) Situational Space Awareness:-
→ Project Netra → ISRO
→ Orbit computation of Resident Space Objects for space situation awareness → Indraprastha Institute of Information Tech.

3) Avoiding future Debris:- → UK's Tech Demo Sat-1
↓
Mission over → Re-entry in atmosphere burn up.

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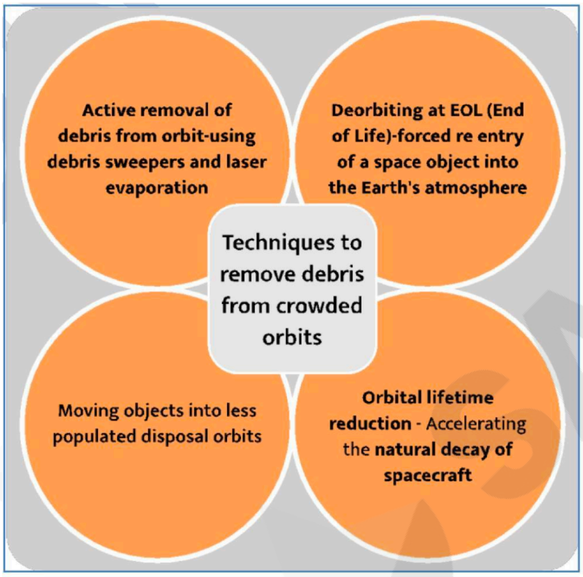
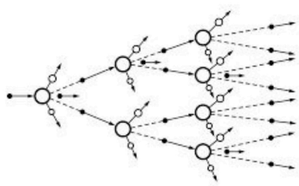
4) Removal of Debris:-

- End of life services by Astroscale Demonstration (ELSA-D)
- Remove Debris (EU) → Harpoon Satellite
- Kumotori Experiment (White Stork - JAXA)

- Global Initiatives
  - Inter-Agency Debris Coordination Committee (IADC): International forum for space debris coordination.
  - UN Space Debris Mitigation Guidelines: Framework for debris reduction by United Nations Office for Outer Space Affairs.
  - Zero Debris Charter: Signed by 12 nations, including Austria and Belgium.
- India's Initiatives
  - Debris Free Space Missions (DFSM) 2030 (by ISRO): Target for sustainable space operations.
  - Space Situational Awareness Control Centre (SSACC): Monitors and manages space debris (in Bengaluru).



Kessler Syndrome



Collision in space
↳ generate fragments (which will collide again)

Cascade of collision

★ Outer space treaty of UN

What happens to a star?

Nebula (Hydrogen + Helium, -173° C) → Gravity pulls particles together (Kinetic Energy (KE) & Temperature increase (10^7°C)) → Protostar (Non-illuminating and Sustained Fusion (Fusion and Fission)) → Main Sequence Star (Core has fusion reaction)

Red Yellow Blue

energy, size → increasing

↓

H_2 in core runs out. (Unstable)

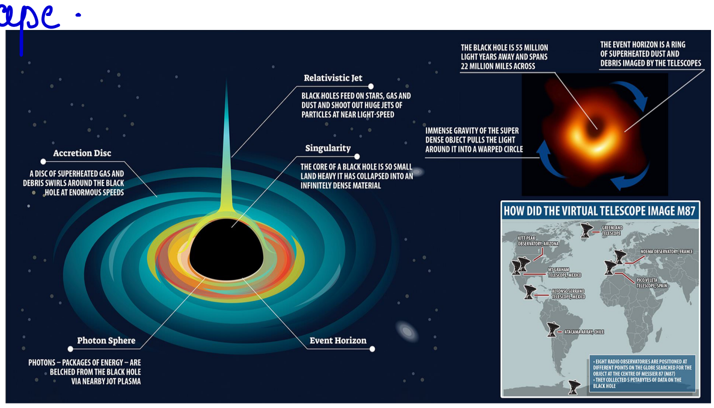
Main Sequence Star → Red Giant

Chandrashekhar Limit = 1.44 × Mass of Sun

- Mass < 1.44 (sun) → planetary nebula → white dwarf → Black dwarf
- Mass > 1.44 (sun) → Supernova Explosion
  - Mass > 3x sun → Black Hole
    - Stellar 5-50
    - Intermediate $10^2 - 10^5$
    - Supermassive $10^6 - 10^9$ → space tsunami
    - Miniature: 148 fm : hypothetical.
  - Mass < 3 (sun) → Neutron Star → Pulsar.

(★) = Lithium concentration increased due to Helium Flash.

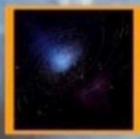
Black holes → region in space with an extremely strong gravitational pull so intense that even light can't escape.



- ★ Matter being compressed into tiny space
- ★ No light can escape
- ★ Center → singularity

Categories of Black Hole

Stellar
Formed by the gravitational collapse of a star. Masses ranging from about 5 to several tens of 5 solar masses.



Supermassive
The largest type of black hole, containing a mass of the order of hundreds of thousands, to billions of times, the mass of the sun.

Intermediate-mass
Mass in range 10^2 - 10^5 solar masses; significantly more than stellar black holes but less than 10^5- 10^9 solar mass supermassive black holes.

Miniture
Approximately 148 fm, Hypothetical tiny black holes, for which quantum mechanical efforts play an important role. The concept that black holes may exist that are smaller than stellar mass was introduced in 1971 by famous astrophysicist Stephen Hawking.

Taking Picture of black hole:-

↳ Event Horizon Telescope → Last Photo using

Sagittarius A* → 2nd black hole whose photo has been taken.

Significance:-

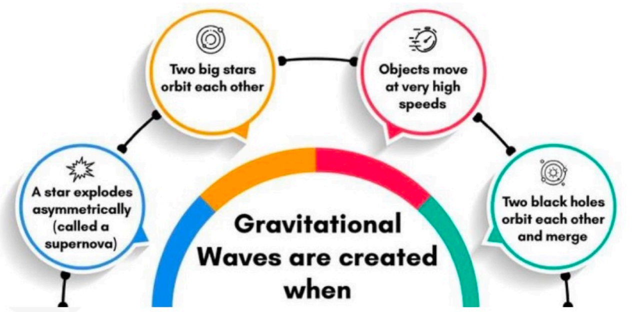
→ 1.) Evolution of galaxies
→ 2.) Distribution of Dark Matter
→ 3.) Star formation
→ 4.) Gravitational waves
→ 5.) Light bending
→ 6.) Testing theory of Relativity.

2020 NOBEL PRIZE

- Roger Penrose: Demonstrated that black hole formation is a direct consequence of General Theory of Relativity.
- Reinhard Genzel & Andrea Ghez: Discovered a supermassive compact object at the center of our galaxy, most likely a supermassive black hole (Sagittarius A*).

Gravitational Waves

- Produced by cataclysmic events
- Travel at speed of light, squeezing and stretching anything coming in path.
- Observed first time by LIGO



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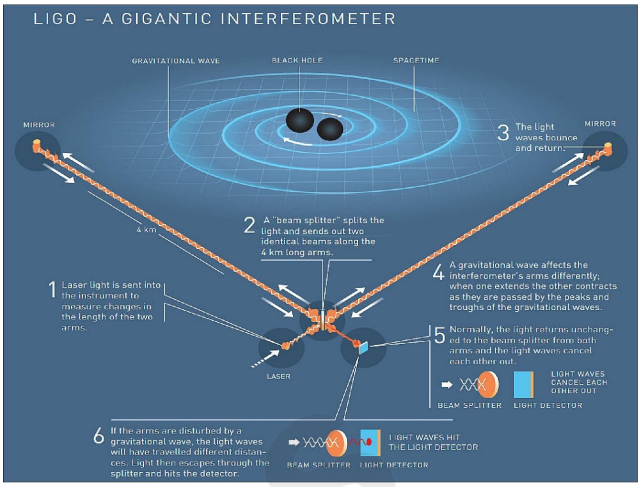
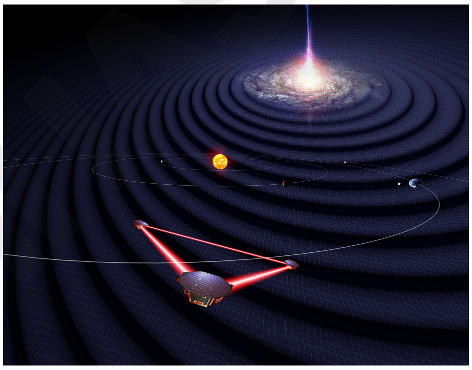
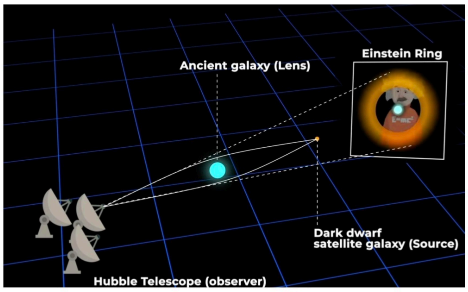
LIGO
↳ detects gravitational waves.
↳ Working Mechanism
  ↳ GW Detection → stretching the arm
  ↳ Signal Processing



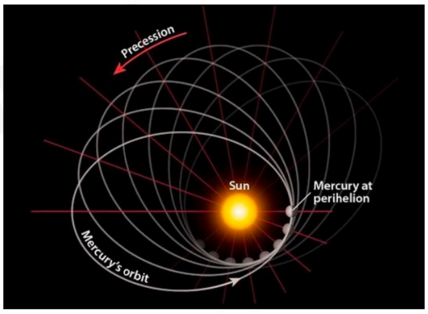
eLISA → mother and daughter spacecraft
↓
Orbit sun in triangular configuration
↓
forms a precision interferometer
↳ detects GW



gravitational lensing
↳ When gravity bends light rays
↓
enable observation of distance objects



General theory of relativity
↳ was proposed by Albert Einstein in 1915
↳ gravity is curving of space



Confirmed :-
→ 1919 : deflection of light from distant star
→ 2016 : Discovery of GW

Sun wraps space across solar system
↓
- elliptical path of planets
- precession of mercury

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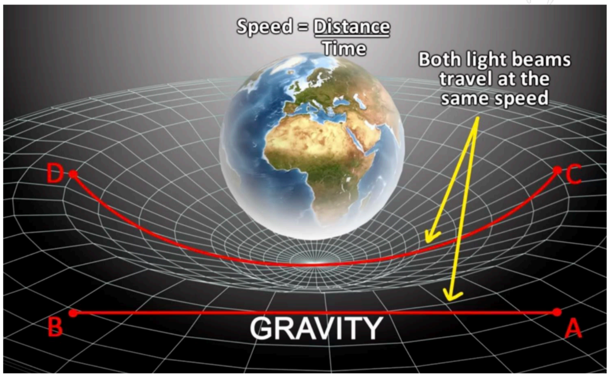
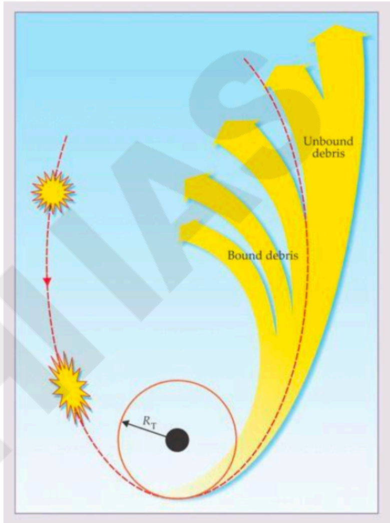
Special theory of Relativity

↳ gravity affects time
↓
slows it down in strong gravitational fields ensuring speed of light remains same



Tidal disruption events

↳ tearing apart of a star too close to a black hole
↓
spaghettification → produces intense radiation



Binary supermassive Black Hole

↳ discovered through gravitational blazing of pulsar

Pulsar:- most luminosent energetic objects in universe

Space Exploration

↳ Orbiter:- revolves around celestial body

↳ Lander:- soft landing Eg:- Pragyan of ISRO

↳ Rover:- Robotic device equipped with scientific instruments
↳ Eg:- Phoenix, Curiosity, Insight of NASA

Types of Mission:-

↳ Flyby:- passed a planet w/o entering the orbit

↳ Gravity Assist:- uses gravitational pull of celestial bodies to boost spacecraft speed & trajectory.

Prelims Navigator Program for 2026
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Space governance

DEPARTMENT OF SPACE			
ISRO	**INSPACE**	**CPSEs**	**Autonomous Bodies**
Core role: ISRO, as the **National Space Agency**, will focus primarily on research and development of new space technologies and applications, and for expanding **the human understanding of outer space**	**Core role:** Acts as a **single-window body** to: • **Promote** private participation in space activities • **Authorize** and **regulate** private space activities (non-government entities) • **Enable access** to ISRO facilities/technology on defined terms (testing, launch support, etc.)	These are **Government-owned companies** under DoS. **(a) Antrix Corporation Ltd. "International marketing/contracting arm** • **Core role:** Historically handled **commercial deals** for ISRO products/services, especially **international contracts** (marketing and customer interface). **(b) New Space India Ltd. (NSIL): "Commercialisation + production + PSLV/SSLV missions"** • **Core role:** Commercialising ISRO/DoS space products and services • **Industry consortium-based production** (e.g., outsourcing/ manufacturing ecosystem) • Handling **operational commercial missions** and capacity-building for launches/satellites	• **IIST**: **Indian Institute of Space Science and Technology:** premier academic institution dedicated to the study and research of Space science and technology in India • **NARL**: **National Atmospheric Research Laboratory:** Atmospheric science and related research • **NE-SAC**: **North Eastern Space Applications Centre:** Space applications for the North-East region (planning, monitoring, development support) • **PRL**: **Physical Research Laboratory:** Fundamental research in physics/space sciences

Space Sustainability

Ensure that all humanity can continue to use outer space for peaceful purpose.

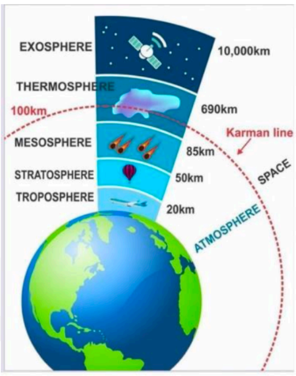
Global Initiatives	Conference on Disarmament (CD) - Focus on PAROS
	Guidelines on Space Sustainability (UNCOPUOS) → Overseas
	Space Sustainability Rating (SSR)
	ASAT Test-Ban Resolution (Non-binding, India abstained)
	United Nations General Assembly (UNGA) - Space security initiatives
Indian Initiatives	Space Situational Awareness (SSA) - Asset protection & tracking
	Space Weather Monitoring
	Near-Earth Objects (NEO) Monitoring
	Project NETRA - Space surveillance by ISRO
	Digantra - India's first commercial SSA observatory
	India-USA Bilateral SSA Agreement
	SPADEX - ISRO's in-orbit servicing platform
	Space Surveillance & Tracking (SST) - Risk mitigation

Overseas:
- Outer Space Treaty
- Moon Agreement
- Registration Convention
- Rescue Agreement
- Liability Convention

Space Tourism :- recreational, leisure & business purpose

Needs authorization → as per article VI of Outer Space Treaty.

Space Travel :- flight operation that takes 1 or more passenger beyond Karman line (altitude > 100 km)



Feature	Suborbital Tourism	Orbital Tourism
Altitude	About 100 kilometres	Over 400 kilometres
Duration in Space	Gives passengers a few minutes in space	Spend days or even more than a week in space
Velocity	Requires much lower speeds; does not achieve orbit; flies up to a certain height and then comes back down	Spacecraft must achieve orbital velocity to maintain orbit around a planet

James Webb Space Telescope → NASA, ESA, CSA

On sun earth Lagrange point (L2)

↳ successor of Hubble Space Telescope

Mission Goals are :

Search for first galaxies or luminous objects formed after Big Bang. (Big Bang is also called expanding universe hypothesis. It states that all of the current and past matter in the Universe came into existence at the same time, roughly 13.8 billion years ago.)

Determine how galaxies evolved.

Observe stars formation from the first stages to formation of planetary systems

Measure physical and chemical properties of planetary systems, including our own Solar System, and investigate potential for life in those systems.

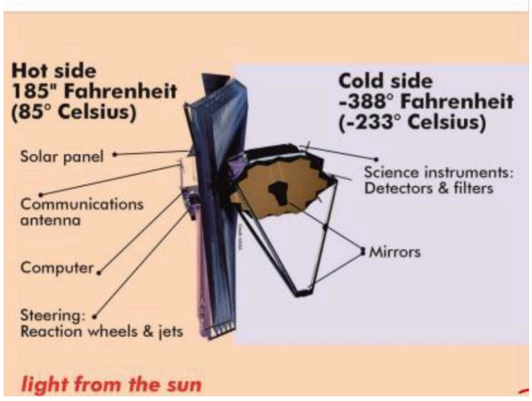
Features of James Webb :-

1.) Visibility of spectrum → infrared

2.) Primary mirror → 6.5 m dia. (also has secondary mirror)

3.) allows satellite's large sunshield to protect telescope from light & heat of sun & Earth

The Two Sides of the Webb Telescope



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The Integrated Science Instrument Module (ISIM) is one of the three major payloads of the system. The other two are:
Optical Telescope Element (OTE)
Spacecraft Element

ISIM – The Main Payload
ISIM houses four primary scientific instruments:

Near-Infrared Camera (NIRCam)
Near-Infrared Spectrograph (NIRSpec)
Mid-Infrared Instrument (MIRI)
Fine Guidance Sensor / Near InfraRed Imager and Slitless Spectrograph (FGS/NIRISS)

Parameter	Hubble Space Telescope (HST)	James Webb Space Telescope (JWST)	Herschel Space Observatory
Agency/partners	NASA + ESA	NASA + ESA + CSA	ESA (with NASA support)
Launch year	1990	2021	2009
Mission status	Retired? **No** (still operating, servicing ended)	Operating	**Ended** (2013; coolant exhausted)
Primary wavelength	**UV + Visible + Near-IR**	**Near-IR + Mid-IR**	**Far-IR + Submillimetre**
What it is best for	Sharp imaging of galaxies, nebulae; UV astronomy	Early universe/first galaxies, exoplanet atmospheres, dusty star-forming regions	Cold universe: dust clouds, star formation, molecular clouds, water chemistry
Mirror size	**2.4 m**	**6.5 m segmented**	**3.5 m**
Operating temperature	**~room temp (no deep cryogenic)**	Very cold (sunshield; instruments cryogenic)	**Cryogenic** telescope (liquid helium cooling)
Orbit/location	Low Earth Orbit (~550 km)	Sun–Earth **L2**	Sun–Earth **L2**
Key design feature	Serviceable by astronauts; long-lived	Huge segmented mirror + 5-layer sunshield	Largest space far-IR telescope; specialised detectors
Famous contributions	Hubble Deep Field; precise cosmology; star formation and nebula imaging	Early galaxy surveys; high-sensitivity IR spectra; exoplanet atmospheric signatures	Water in space; star-forming regions; cold dust mapping; ISM chemistry

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