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CURRENT AFFAIRS

SCIENCE AND TECHNOLOGY

Strategic Current Affairs for UPSC Prelims

What's Inside

- Latest Scientific & Technological Developments
- Innovations & Breakthroughs
- Key Science & Tech Initiatives in India
- Digital & Space Technologies
- Government Policies & Missions
- Current Affairs Integration

Prepared by

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SCIENCE & TECHNOLOGY | CURRENT AFFAIRS

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SCIENCE & TECHNOLOGY

CURRENT AFFAIRS (JAN 2025 – FEB 2026)

SPACE & ISRO

SpaDeX — India Becomes 4th Nation to Achieve Space Docking

On 16 Jan 2025, ISRO successfully demonstrated in-orbit docking of two satellites, Target (SDX01) and Chaser (SDX02), under the Space Docking Experiment (SpaDeX), making India the 4th country after the US, Russia, and China to master autonomous rendezvous & docking (RvD) technology — a critical capability for Chandrayaan-4, BAS, and Gaganyaan.

News in Brief

- SpaDeX launched on 30 Dec 2024 aboard PSLV-C60 from SDSC Sriharikota; two 220-kg satellites placed in 475-km circular orbit.
- First docking attempt scheduled 7 Jan 2025 was postponed twice; finally achieved on 16 Jan 2025 at ~06:20 IST.
- Undocking successfully demonstrated on 13 Mar 2025, completing the full RvD cycle.
- Mission also tested transfer of electric power between docked spacecraft — essential for BAS modular assembly.
- Indigenous technologies proven: Bharatiya Docking System (BDS), Laser Range Finder, Rendezvous Sensor, Proximity & Docking Sensor.

Static Background (Basics to Remember)

- **Rendezvous & Docking (RvD)** — orbital manoeuvre where two spacecraft approach each other, match velocities, and mechanically join. Essential for space stations, sample return, and crew transfer.
- **Required physics**: matching inclination, altitude, and phase; closure velocity must drop to cm/s at contact.
- **History of docking**: USA (Gemini-8, 1966) → USSR (Soyuz, 1967) → China (Shenzhou-8/Tiangong-1, 2011) → India (SpaDeX, 2025).
- **ISRO** = Indian Space Research Organisation, set up 1969; HQ Bengaluru; operates under **Department of Space**.
- **Indian Space Policy 2023** opened up space sector to private players; INSPACe is the single-window regulator.

Prelims Connect

SpaDeX mission — essentials at a glance

Parameter	Detail
Launch Vehicle	PSLV-C60
Launch Date	30 December 2024
Docking Achieved	16 January 2025
Spacecraft	SDX01 (Chaser) + SDX02 (Target), 220 kg each

Orbit	~475 km circular
Docking Mechanism	Bharatiya Docking System (BDS) — indigenous, androgynous
India's Rank	4th country (after USA, Russia, China)
Strategic Use	Chandrayaan-4 sample return, Bharatiya Antariksh Station, Gaganyaan

SpaDeX is the foundational capability for India's Bharatiya Antariksh Station (BAS-2035) and crewed lunar mission (2040).

Prelims Pointers

- **SpaDeX** = **Sp**ace **D**ocking **Ex**periment — ISRO's first in-orbit RvD mission.
- **Launch vehicle**: PSLV-C60 (30 Dec 2024); docking on **16 January 2025**.
- **India became 4th nation** to demonstrate autonomous space docking, after **USA, Russia, China**.
- **Bharatiya Docking System (BDS)** is indigenous and **androgynous** (same design on both spacecraft).
- Key enabling tech for **Chandrayaan-4**, **Bharatiya Antariksh Station** and **Gaganyaan**.

NVS-02 Aboard GSLV-F15 — 100th Launch from Sriharikota

ISRO's GSLV-F15 rocket, carrying the second-generation navigation satellite NVS-02 of the NavIC constellation, was launched on 29 January 2025 from the Satish Dhawan Space Centre, Sriharikota. The mission marked the 100th launch from Sriharikota and the 17th flight of GSLV.

News in Brief

- GSLV-F15 was the 17th GSLV flight and the 11th with indigenous Cryogenic Upper Stage.
- NVS-02 joined NVS-01 as the 2nd second-gen NavIC satellite; built by U R Rao Satellite Centre (URSC).
- Satellite weighed 2,250 kg, to be placed in Geosynchronous Transfer Orbit then raised to 36,000 km GEO slot at 111.75°E.
- Later, NVS-02 failed to reach its intended GEO slot due to non-firing of liquid apogee motor oxidiser valves; mission salvaged for alternate use.
- NavIC constellation provides independent Indian regional satellite navigation with ~10 m accuracy over India and 1,500 km around.

Static Background (Basics to Remember)

- **GSLV evolution**: Mk I (cryogenic from Russia, 1st flight 2001) → Mk II (indigenous CE-7.5 cryo, from 2010) → Mk III / LVM3 (C25 cryo, from 2014).
- **Cryogenic engine** burns liquid hydrogen (LH2, −253°C) + liquid oxygen (LOX, −183°C); high specific impulse; India became 6th nation to master cryo tech (after USA, Russia, France, Japan, China).
- **NavIC / IRNSS** is India's regional satellite navigation system; 7 satellites of Gen-1 (IRNSS-1A to 1I); Gen-2 is NVS series.
- **Global Navigation Satellite Systems (GNSS)**: GPS (US), GLONASS (Russia), Galileo (EU), BeiDou (China); NavIC and QZSS (Japan) are regional.
- **Orbits used**: Low Earth Orbit (LEO, <2000 km), Medium Earth Orbit (MEO), Geosynchronous (~36,000 km), Sun-Synchronous Polar (SSO).

Prelims Connect

NavIC / IRNSS constellation at a glance

Parameter	Detail
Full form	Navigation with Indian Constellation (formerly IRNSS)
Designed by	ISRO / U R Rao Satellite Centre
Total satellites planned (Gen-1+Gen-2)	7 + 5
Orbit types	3 GEO + 4 GSO (inclined) for Gen-1
Frequencies	L1, L5, S-band
Coverage	India + 1,500 km around
Accuracy	< 20 m (public), < 10 m (restricted/military)
Gen-2 first satellites	NVS-01 (May 2023), NVS-02 (Jan 2025)

NavIC is one of the four independent regional/global GNSS besides GPS (US), GLONASS (Russia), Galileo (EU), BeiDou (China).

Prelims Pointers

- **GSLV-F15** was ISRO's **100th launch from Sriharikota** (29 Jan 2025).
- **Payload**: NVS-02, the 2nd second-generation NavIC satellite.
- **NavIC L1 signal** is designed for interoperability with **GPS and Galileo**.
- **NavIC** is the official name since April 2016 of the earlier **IRNSS** system.
- **Cryogenic Upper Stage** used in GSLV-F15 is fully indigenous.

Third Launch Pad (TLP) at Sriharikota — Cabinet Nod

Union Cabinet in January 2025 approved the establishment of a Third Launch Pad (TLP) at Satish Dhawan Space Centre, Sriharikota, at an estimated cost of ₹3,985 crore, to support ISRO's Next Generation Launch Vehicle (NGLV), LVM3, and Gaganyaan operations within 48 months.

News in Brief

- The TLP will be built in PPP mode, with maximum industry participation.
- Designed as a universal launch pad, it will accommodate the NGLV and scaled-up configurations with semi-cryogenic propulsion.
- It will act as a standby for the Second Launch Pad and support Gaganyaan, Bharatiya Antariksh Station (BAS), and lunar missions.
- Existing pads: First Launch Pad (FLP) commissioned 1993 for PSLV; Second Launch Pad (SLP) 2005 for PSLV/GSLV/LVM3.

Static Background (Basics to Remember)

- **SDSC-SHAR** = Satish Dhawan Space Centre – Sriharikota Range; India's only operational spaceport, on Sriharikota barrier island, **Andhra Pradesh**.
- **Named after** Prof. Satish Dhawan, ISRO Chairman 1972-1984 — considered the 'father of experimental fluid dynamics research in India'.

- **Why Sriharikota**: equatorial proximity (13.7°N) gives payload benefit; east coast allows over-ocean launches; away from populated areas.
- **PPP mode** = Public Private Partnership; used for space infrastructure under Indian Space Policy 2023 to leverage private expertise.
- **NGLV** = Next Generation Launch Vehicle, being designed for reusability and heavy lift (~20 t to LEO).

Prelims Connect

Sriharikota — launch pad history

Pad	Year	Vehicles / Use
First Launch Pad (FLP)	1993	PSLV, SSLV
Second Launch Pad (SLP)	2005	PSLV, GSLV, LVM3, Chandrayaan, Mangalyaan
Third Launch Pad (TLP) — approved 2025	target 2029	NGLV, LVM3, Gaganyaan, BAS

SDSC-SHAR is India's spaceport — located on Sriharikota island, Andhra Pradesh. Named after Prof. Satish Dhawan, 2nd Chairman of ISRO.

Prelims Pointers

- **Third Launch Pad (TLP)** approved January 2025; cost **₹3,985 crore**.
- **Completion target**: 48 months (around 2028-29).
- **Purpose**: to support **NGLV**, **Gaganyaan**, **LVM3** and **BAS** assembly missions.
- **Built under Public-Private Partnership** (PPP) mode.
- SDSC-SHAR is located at **Sriharikota island** in Andhra Pradesh.

LVM3 — India's 'Bahubali' Rocket

In January 2025, ISRO announced that its LVM3 rocket — popularly known as the 'Bahubali' — will be the workhorse for India's human spaceflight and heavy-lift commercial missions, with upgrades underway for semi-cryogenic and methalox propulsion.

News in Brief

- LVM3 (Launch Vehicle Mark-3), formerly called GSLV Mk III, is India's heaviest operational rocket.
- Payload capacity: 8,000 kg to LEO, 4,000 kg to GTO.
- 3-stage vehicle: S200 solid boosters + L110 liquid core + C25 cryogenic upper stage.
- Successfully launched Chandrayaan-2 (2019), Chandrayaan-3 (2023), OneWeb satellites, and will be the launcher for Gaganyaan.
- Upgrades: LVM3-SC (semi-cryogenic SE2000 engine) and LMLV (Lunar Module Launch Vehicle, 6,500 kg to Lunar Transfer Orbit) in development.

Static Background (Basics to Remember)

- **LVM3 stages**: two S200 solid strap-ons (flanking) + L110 twin-Vikas liquid core + C25 cryogenic upper.
- **'S' / 'L' / 'C'** in ISRO naming = Solid / Liquid / Cryogenic; number indicates propellant mass in tonnes.
- **Human rating** means engineering for higher reliability, emergency abort, crew escape system — needed for Gaganyaan.
- **Payload capacities** — PSLV (1.75 t), GSLV Mk-II (2.5 t), LVM3 (4 t) to Geostationary Transfer Orbit (GTO).

- **Reusable launch vehicles** — technology demo via RLV-TD (2016) and RLV LEX (2023-24, Karnataka).

Prelims Connect

ISRO operational launch vehicles — capacity snapshot

Vehicle	Payload LEO	Payload GTO	Status
SSLV	500 kg (500 km)	—	Operational (from 2022)
PSLV	~1,750 kg (SSO)	~1,425 kg	Workhorse
GSLV Mk II	5,000 kg	2,500 kg	Operational
LVM3 (Mk III)	8,000 kg	4,000 kg	Heaviest — 'Bahubali'
NGLV (Soorya)	20,000 kg target	10,000 kg	Under development

The LVM3 is fully reusable (target 2035) under ISRO's Next-Generation Launch Vehicle roadmap.

Prelims Pointers

- **LVM3** stands for **Launch Vehicle Mark-3** (earlier GSLV Mk III).
- **3 stages**: S200 solid + L110 liquid + C25 cryogenic.
- **Payload**: 8 tonnes to LEO, 4 tonnes to GTO.
- **Vehicle for Gaganyaan** human spaceflight (human-rated as **HLVM3**).
- **Launched Chandrayaan-2 (2019)** and **Chandrayaan-3 (2023)**.

Vikas Engine Restart Trial — A Reusability Milestone

In January 2025, ISRO successfully demonstrated the restart of its Vikas liquid engine during a test at the ISRO Propulsion Complex (IPRC), Mahendragiri — a critical step towards engine reusability and precise orbital insertion for next-gen missions.

News in Brief

- Vikas is ISRO's Earth-storable liquid-propellant engine, used in PSLV, GSLV, LVM3 second stages.
- Derived from the French Viking engine (transferred to India in the 1970s); 'Vikas' = Vi-krama Am-bala-l Sa-rabhai (after ISRO's first chairman Vikram Sarabhai).
- Propellants: UH25 (Unsymmetrical Dimethylhydrazine + Hydrazine Hydrate) as fuel and Nitrogen Tetroxide (N_2O_4) as oxidiser.
- The successful restart demo paves way for multi-burn GTO missions and future reusable rockets.

Static Background (Basics to Remember)

- **Liquid rocket engines** — two types: (a) Earth-storable (propellants liquid at room temp) like Vikas, (b) Cryogenic (super-cold) like CE20.
- **Specific Impulse (Isp)** = measure of fuel efficiency; cryogenic > semi-cryo > storable.
- **Vikram Sarabhai** (1919-1971) — 'Father of Indian Space Programme'; founder of ISRO, established PRL Ahmedabad, ATIRA, IIM-A.
- **ISRO Propulsion Complex (IPRC)** is at **Mahendragiri**, Tamil Nadu — tests all liquid/cryogenic engines.
- **UDMH + N_2O_4** are hypergolic (ignite on contact), so no ignition system is needed — a design advantage for reliability.

Prelims Connect

Indian liquid propulsion engines

Engine	Type	Propellants	Used in
Vikas	Earth-storable liquid	UDMH + N2O4	PSLV, GSLV, LVM3 (L40/L110)
CE-7.5	Cryogenic (upper stage)	LH2 + LOX	GSLV Mk II
CE20	Cryogenic (upper stage)	LH2 + LOX	LVM3 C25 stage
SE2000	Semi-cryogenic (under dev)	Kerosene (RP-1) + LOX	LVM3-SC, NGLV
LOX-methane (under dev)	Cryogenic	Liquid Methane + LOX	Reusable NGLV future

ISRO has cleared the ground test for SE2000 (January 2025) and is designing a LOX-methane engine for reusable vehicles.

Prelims Pointers

- **Vikas engine** named after **Vikram Sarabhai** (father of Indian space programme).
- **Origin**: derived from French **Viking** engine (technology transfer, late 1970s).
- **Fuel**: UH25 (UDMH + Hydrazine Hydrate); **Oxidiser**: N2O4.
- **Used in**: PSLV PS2, GSLV L40, LVM3 L110 stages.
- **Restart capability** demonstrated Jan 2025 for multi-burn missions.

Shubhanshu Shukla — First Indian Aboard the ISS (Axiom-4)

Group Captain Shubhanshu Shukla of the Indian Air Force created history in June 2025 by becoming the first Indian to set foot on the International Space Station (ISS) as part of the Axiom-4 commercial mission. He is also the second Indian in space after Rakesh Sharma (1984).

News in Brief

- Axiom Mission 4 (Ax-4) launched on 25 June 2025 aboard SpaceX Dragon C213 from Kennedy Space Center; docked with ISS on 26 June 2025.
- Crew: Commander Peggy Whitson (US), Pilot Shubhanshu Shukla (India), Mission Specialists Slawosz Uznanski-Wisniewski (Poland) and Tibor Kapu (Hungary).
- Shukla conducted ~60 scientific experiments, including studies on Indian food crops (moong, methi), tardigrades, and muscle regeneration in microgravity.
- He also became the first Indian to conduct biological experiments aboard the ISS.
- Mission serves as critical training for India's Gaganyaan (planned 2026-27).

Static Background (Basics to Remember)

- **International Space Station (ISS)** — largest human-built object in space; assembled from 1998; orbit ~400 km; 15 partner nations; primary modules from USA, Russia, Japan, ESA, Canada.
- **Axiom Space** (US, founded 2016) operates private crewed missions to ISS under NASA's commercial LEO programme; Ax-1 flew in April 2022.
- **Rakesh Sharma** (1949-) — first Indian in space; flew aboard **Soyuz T-11** in April 1984 under Indo-Soviet Interkosmos programme; famously replied 'Saare Jahan Se Achha' to Indira Gandhi.

- **Microgravity experiments** simulate long-duration effects on muscle, bone, fluids, seeds, and materials — critical for future Moon/Mars missions.
- **Gaganyaan crew**: Group Captains Prasanth Balakrishnan Nair, Ajit Krishnan, Angad Pratap, Shubhanshu Shukla — all from Indian Air Force.

Prelims Connect

Indians in space — timeline

Astronaut	Year	Mission	Vehicle
Rakesh Sharma	1984	Soyuz T-11 / Salyut-7	Indo-Soviet
Kalpana Chawla	1997, 2003	STS-87, STS-107 (Columbia)	NASA Space Shuttle
Sunita Williams	2006, 2012, 2024	ISS Expeditions	NASA (Indian-origin)
Shubhanshu Shukla	June 2025	Axiom-4 / ISS	SpaceX Dragon
Prasanth Nair (Designated)	2026-27	Gaganyaan-G1	HLVM3

India's Gaganyaan shortlisted astronauts: Prasanth Balakrishnan Nair, Ajit Krishnan, Angad Pratap, and Shubhanshu Shukla.

Prelims Pointers

- **Shubhanshu Shukla** is the **2nd Indian in space** (after Rakesh Sharma, 1984) and **1st Indian on ISS**.
- **Axiom Mission 4 (Ax-4)** launched 25 June 2025 aboard SpaceX Dragon.
- **Commander** of Ax-4: **Peggy Whitson** (US, Axiom Space).
- Mission is a **precursor-training** for India's own **Gaganyaan**.
- **Rakesh Sharma** flew aboard **Soyuz T-11** to Salyut-7 in April 1984 — first Indian in space.

NISAR — World's Costliest ($1.5 bn) Joint Earth Observation Satellite

ISRO and NASA jointly launched the NASA-ISRO Synthetic Aperture Radar (NISAR) satellite in July 2025 aboard GSLV-F16 from Sriharikota. NISAR is the world's most expensive Earth observation satellite ($1.5 billion) and the first to carry dual-frequency L-band + S-band SAR.

News in Brief

- Launch vehicle: GSLV-F16 — the 18th GSLV flight, from SDSC Sriharikota on 30 July 2025.
- Satellite mass ~2,800 kg; placed in 747-km Sun-Synchronous Orbit; 12-day repeat cycle over every patch of Earth.
- NASA supplied L-band SAR and 12-m deployable mesh reflector; ISRO supplied S-band SAR, spacecraft bus, and launch services.
- Key applications: monitoring land deformation (earthquakes, landslides, subsidence), ice-sheet changes, vegetation, soil moisture, disaster response.
- First of its kind: only satellite that observes nearly all Earth's land & ice surfaces twice every 12 days using two radar frequencies.

Static Background (Basics to Remember)

- **Synthetic Aperture Radar (SAR)** — active microwave sensor that synthesises a large 'virtual' antenna by combining returns along satellite's track, giving high-resolution images day-night, through clouds.
- **Why two bands**: L-band (~24 cm wavelength) penetrates vegetation and soil; S-band (~10 cm) is better for surface and biomass — dual data gives richer science.
- **Earth Observation (EO)** satellites — India has Cartosat (mapping), Resourcesat (agri/land), Oceansat (ocean), RISAT (radar), EMISAT (ELINT), EOS series.
- **InSAR** = Interferometric SAR — measures ground deformation at mm-scale; key for earthquakes, volcanoes, and subsidence.
- **Jet Propulsion Laboratory (JPL)** — NASA's flagship robotic-exploration lab in Pasadena; built the L-band SAR and mesh reflector for NISAR.

Prelims Connect

NISAR — dual-band SAR details

Parameter	Detail
Full form	NASA–ISRO Synthetic Aperture Radar
Partners	NASA (JPL) + ISRO
Launch	30 July 2025, GSLV-F16, Sriharikota
Orbit	Sun-Synchronous, ~747 km
Mass	~2,800 kg
Radars	L-band (NASA) + S-band (ISRO)
Reflector	12-m deployable gold-plated mesh
Repeat cycle	12 days (dual-sided coverage)
Cost	~$1.5 billion — world's costliest EO satellite
Mission life	5 years (primary)

SAR (Synthetic Aperture Radar) uses radar pulses, so it can image day-night and through clouds, smoke or vegetation canopy.

Prelims Pointers

- **NISAR** = **NASA-ISRO** Synthetic Aperture Radar.
- **Launch vehicle**: **GSLV-F16** (30 July 2025).
- **Only satellite with dual-band SAR** — L-band (NASA) + S-band (ISRO).
- **Most expensive Earth observation satellite** (~$1.5 billion).
- **Applications**: earthquake deformation, glacier melt, biomass, soil moisture, disasters.

PSLV-C61 / EOS-09 Failure — A Rare Setback

In May 2025, ISRO's PSLV-C61 mission failed to place the Earth Observation Satellite EOS-09 in its intended orbit — the first PSLV failure since 2017 and only the third full failure in the rocket's history.

News in Brief

- PSLV-C61 launched 18 May 2025 from Sriharikota carrying EOS-09 (RISAT-1B, a 1,696-kg SAR satellite).
- Mission faced an anomaly during the third-stage (PS3) burn — a fall in chamber pressure of the solid motor.
- EOS-09 was intended for all-weather surveillance (C-band SAR) over land and sea.
- This was PSLV's 63rd mission; the rocket had a near-perfect record — 60 successful, 2 partial, 3 total failures prior.
- Failure Analysis Committee (FAC) set up under V. Narayanan; PSLV cleared for return to flight after mid-2025.

Static Background (Basics to Remember)

- **PSLV** = Polar Satellite Launch Vehicle — ISRO's workhorse rocket; first launched 20 Sep 1993 (PSLV-D1, failed); operational since PSLV-D2 (1994).
- **4 stages** — alternating **Solid-Liquid-Solid-Liquid**: PS1 (solid S139) + PS2 (Vikas liquid) + PS3 (solid HTPB) + PS4 (twin liquid).
- **Variants** — PSLV-G (generic), PSLV-CA (Core Alone, no strap-ons), PSLV-XL (extended strap-ons for heavier payloads), PSLV-DL/QL (2 or 4 strap-ons).
- **Landmark PSLV missions**: Chandrayaan-1 (2008), Mars Orbiter Mission / Mangalyaan (2013), Aditya-L1 (2023), NavIC constellation, 104 sats in one go (PSLV-C37, 2017).
- **Failure record**: 3 full failures out of 63 flights (1993 D1, 1997 C1, 2017 C39, 2025 C61) — still one of the world's most reliable launchers.
- **Recovery pedigree** — ISRO typically returns to flight within 6 months after investigation.

Prelims Connect

PSLV track record (as of 2025)

Metric	Value
Maiden flight	20 Sep 1993 (PSLV-D1, failed)
Total missions	63 (by PSLV-C61)
Full failures	3 (D1, C1 1997, C39 2017, C61 2025)
Partial failures	2
Workhorse missions	Chandrayaan-1, Mangalyaan, NavIC, Aditya-L1
Record multi-sat launch	104 satellites (PSLV-C37, 2017)

EOS = Earth Observation Satellite; successor naming for IRS/CartoSat/RISAT. EOS-09 is a SAR satellite (follow-on to RISAT-1).

Prelims Pointers

- **PSLV-C61** failure — **18 May 2025**; 3rd-stage anomaly.
- **Payload**: **EOS-09 (RISAT-1B)**, a C-band SAR satellite.
- **First PSLV failure** since 2017 (PSLV-C39/IRNSS-1H).
- **PSLV** is a 4-stage rocket; alternating solid–liquid stages.
- **104 satellites** in one launch record — PSLV-C37 (Feb 2017).

CMS-03 — ISRO's Heaviest Communication Satellite

ISRO successfully launched CMS-03 (also called GSAT-7R or 'Ananth'), India's heaviest communication satellite, aboard LVM3-M5 in November 2025 from Sriharikota. The 4,410-kg satellite will serve the Indian Navy with secure multi-band communications.

News in Brief

- Launched 1 November 2025 via LVM3-M5 from Second Launch Pad, Sriharikota.
- Mass ~4,410 kg — makes it the heaviest satellite ever launched from Indian soil.
- Operates across multi-band (UHF, S, C, Ku); covers Indian Ocean Region for Navy.
- CMS-03 replaces GSAT-7 (Rukmini), launched 2013, which served the Indian Navy.
- Mission is strategically significant for maritime domain awareness and secure naval command.

Static Background (Basics to Remember)

- **Geostationary Orbit (GEO)** — ~35,786 km altitude; satellite period equals Earth's 24-hr rotation; appears fixed over equator. Used for communications, broadcasting, weather (INSAT).
- **GTO** = Geosynchronous Transfer Orbit — elliptical parking orbit used to reach GEO after apogee burn by the satellite's own engine.
- **Indian communication satellite series** — INSAT (since 1983) and GSAT (since 2001); operated by INSAT Master Control Facility at **Hassan, Karnataka**.
- **Military comsats** — encrypted transponders protect defence communication from jamming/interception.
- **Frequency bands** — L (1-2 GHz), S (2-4), C (4-8), X (8-12, military), Ku (12-18), Ka (26-40).

Prelims Connect

India's military / strategic comsats

Satellite	User	Year	Remarks
GSAT-7 (Rukmini)	Indian Navy	2013	India's first dedicated military satellite
GSAT-7A (Angry Bird)	Indian Air Force	2018	Network-centric IAF operations
CMS-03 / GSAT-7R	Indian Navy	2025	Heaviest from Indian soil, 4,410 kg
GSAT-7B (proposed)	Indian Army	2026-27	Approved Mar 2022, ₹4,635 cr

The GSAT-7 series forms the backbone of India's military satellite communication. All are geostationary.

Prelims Pointers

- **CMS-03 / GSAT-7R** — launched **1 Nov 2025** by LVM3-M5.
- **Mass**: 4,410 kg — **heaviest satellite** launched from India.
- **User**: **Indian Navy**; successor to GSAT-7 Rukmini (2013).
- **Launch vehicle**: **LVM3** from Second Launch Pad, Sriharikota.
- **GSAT-7A** (2018) — IAF's Angry Bird satellite.

Chandrayaan-3 — ChaSTE Results and Sub-surface Ice Discovery

Data from Chandrayaan-3's ChaSTE (Chandra's Surface Thermophysical Experiment) and other instruments released in 2025 revealed steep lunar surface thermal gradients and widespread sub-surface ice deposits near the Moon's south polar region — findings critical for future crewed lunar missions.

News in Brief

- ChaSTE probe inserted 10 cm into lunar regolith near Shiv Shakti Point (69.37°S, 32.32°E).
- Recorded surface temperature ~60°C in sunlit region; dropped to -10°C at 8 cm depth — steepest known lunar thermal gradient.
- Vikram lander's instruments detected sulphur, aluminium, calcium, iron, chromium, titanium and other elements in regolith.
- Analysis in March 2025 confirmed potential widespread sub-surface water-ice beneath Moon's surface — at depths only a few cm to m.
- These data will inform site selection for Chandrayaan-4 (sample return) and Chandrayaan-5 (LUPEX with Japan).

Static Background (Basics to Remember)

- **Moon geology basics** — regolith = loose surface dust; 'mare' = dark lava plains; 'highlands' = ancient anorthosite crust; south pole has permanently shadowed craters (PSR) with water ice.
- **Chandrayaan-1** (2008) — India's first lunar mission; **Moon Impact Probe (MIP)** confirmed presence of water molecules (published 2009); mission by PSLV.
- **Vikram** (lander) is named after Vikram Sarabhai; **Pragyan** (rover) means 'wisdom' in Sanskrit.
- **Why south pole** — permanently-shadowed regions may hold water-ice usable for drinking water, oxygen and rocket fuel (ISRU — In-Situ Resource Utilisation).
- **Countries that have soft-landed on Moon**: USSR (1966), USA (1966), China (2013), India (2023).

Prelims Connect

Chandrayaan series — mission milestones

Mission	Year	Landing Status
Chandrayaan-1	2008	Orbiter, confirmed water on Moon (MIP impact)
Chandrayaan-2	2019	Orbiter success; Vikram lander crashed
Chandrayaan-3	23 Aug 2023	Soft landing at Shiv Shakti Point — 1st near South Pole
Chandrayaan-4	target 2027	Sample return + SpaDeX heritage
Chandrayaan-5 / LUPEX	target 2028	With JAXA (Japan) — lunar polar exploration

India became the 4th country to soft-land on Moon (after USSR, USA, China) and the 1st to land near the lunar south pole.

Prelims Pointers

- **ChaSTE** = **Cha**ndra's **S**urface **T**hermophysical **E**xperiment (temperature probe).
- **Landing site name**: **Shiv Shakti Point** (69.37°S, 32.32°E) — near South Pole.

- **Soft landing date**: 23 August 2023 — celebrated as **National Space Day** annually.
- **Payloads** on Vikram: ChaSTE, ILSA, RAMBHA-LP, LRA; Pragyan: LIBS, APXS.
- **Chandrayaan-4** (2027) will test **sample return** using SpaDeX docking.

Chandrayaan-4 & 5 — India's Next Lunar Steps

ISRO confirmed in 2025-26 the roadmap for its next two lunar missions: Chandrayaan-4 (target 2027-28) will demonstrate sample return, while Chandrayaan-5 / LUPEX (target 2028) will be a joint India-Japan mission to explore the permanently shadowed regions of the lunar south pole.

News in Brief

- Chandrayaan-4 will use a 2-rocket, 5-module architecture: Ascender, Descender, Propulsion Module, Transfer Module, and Re-entry Module.
- It will test in-orbit docking (SpaDeX-derived) before sample transfer and Earth re-entry.
- Chandrayaan-5 is being designed with JAXA (Japan); JAXA provides the rover, ISRO provides the lander.
- In Feb 2026, ISRO selected Mons Mouton site (MM-4) near the Moon's south pole as the landing target for Chandrayaan-5.
- ISRO Chairman V. Narayanan in Nov 2025 confirmed 2028 as the target launch window for Chandrayaan-5.

Static Background (Basics to Remember)

- **Lunar sample return** history — USSR Luna 16/20/24 (automated, 1970s), NASA Apollo 11-17 (crewed, 1969-72), China Chang'e-5 (2020) & Chang'e-6 (first far-side sample return, 2024).
- **JAXA** = Japan Aerospace Exploration Agency (2003), HQ Tokyo; major missions: Hayabusa, Hayabusa-2, Akatsuki, SLIM.
- **LUPEX** — India-Japan joint mission: JAXA's rover is heavier, has drills; ISRO provides H3 / LVM3 and lander.
- **Permanently Shadowed Regions (PSR)** — craters near poles whose floors never see sunlight, trap ice for billions of years.
- **Mons Mouton** — first lunar feature named after an African-American woman (NASA mathematician Melba Mouton); proposed Artemis-III landing target too.

Prelims Connect

Chandrayaan-4 architecture (5-module design)

Module	Function
Propulsion Module (PM)	Earth escape, lunar orbit insertion
Descender Module (DM)	Soft-land on lunar surface
Ascender Module (AM)	Collect samples, lift off from Moon
Transfer Module (TM)	Return to Earth orbit
Re-entry Module (REM)	Carry samples through Earth atmosphere

Mons Mouton is a massif near the Moon's south pole named for Melba Roy Mouton (NASA mathematician). Chosen for its permanently shadowed water-ice deposits.

Prelims Pointers

- **Chandrayaan-4** — sample return, 5-module, 2 rocket launch architecture.

- **Chandrayaan-5 / LUPEX** — joint with **JAXA (Japan)**; lander by ISRO, rover by JAXA.
- **LUPEX** = Lunar Polar Exploration mission.
- **Landing site for Ch-5**: **Mons Mouton (MM-4)** near lunar south pole.
- **SpaDeX** is the foundational tech for sample-transfer docking in Chandrayaan-4.

Aditya-L1 — India's Solar Mission Captures Historic CME

India's first dedicated solar space mission, Aditya-L1, launched in September 2023, delivered landmark results in 2025 — including the first close-up observations of Coronal Mass Ejections (CMEs) from the L1 Lagrange point using the SUIT and VELC instruments.

News in Brief

- Aditya-L1 is parked in a halo orbit around Sun-Earth Lagrange Point 1 (L1), 1.5 million km from Earth.
- In March 2025, the SUIT (Solar Ultraviolet Imaging Telescope) captured its first near-UV full-disc images of the Sun.
- The VELC (Visible Emission Line Coronagraph), built by IIA Bangalore, observes the solar corona continuously — unique worldwide.
- Mission is providing early warning for space weather that threatens satellites and power grids.
- Total 7 payloads including ASPEX, PAPA, SoLEXS, HEL1OS, MAG magnetometer.

Static Background (Basics to Remember)

- **Sun basics** — G2V yellow dwarf; core fuses H→He at 15 million K; surface 5,500 K; 99.86% of solar-system mass.
- **Layers** — core, radiative zone, convective zone, **photosphere** (visible surface), **chromosphere**, **corona** (million-K outer atmosphere).
- **Solar phenomena**: sunspots (11-year cycle), flares (EM bursts), Coronal Mass Ejections (CMEs, plasma clouds), solar wind (continuous charged particles).
- **Lagrange points** — 5 gravitationally stable points in a 2-body system; named after 18th-century mathematician Joseph-Louis Lagrange.
- **Space weather** can damage satellites, disrupt GPS, and induce currents that trip power grids (e.g., 1989 Quebec blackout).
- **IIA Bangalore** — Indian Institute of Astrophysics, autonomous under DST; built VELC for Aditya-L1.

Prelims Connect

Lagrange points in the Sun-Earth system

Point	Location	Use / Mission
L1	1.5 million km towards Sun	Aditya-L1, SOHO, DSCOVR
L2	1.5 million km away from Sun	JWST, Gaia, Planck, Euclid
L3	Behind Sun (opposite Earth)	Theoretical only
L4 & L5	60° ahead / behind Earth in orbit	Trojan asteroid surveys (STEREO)

At L1 a spacecraft maintains continuous unobstructed view of the Sun and has a stable halo orbit requiring minimal station-keeping fuel.

Prelims Pointers

- **Aditya-L1** — India's 1st dedicated **solar space mission** (launched PSLV-C57, 2 Sep 2023).

- **Placed at** Sun-Earth **Lagrange Point L1** (~1.5 million km from Earth).
- **Primary payload**: **VELC** (Visible Emission Line Coronagraph) — built by **IIA Bangalore**.
- **7 payloads** in total; studies photosphere, chromosphere, corona and solar wind.
- **James Webb Space Telescope** is at L2 (opposite side).

Gaganyaan IADT-1, Vyommitra and Axiom-4 Training

ISRO's Gaganyaan human spaceflight programme hit multiple 2025 milestones — the first Integrated Air Drop Test (IADT-1) of the Crew Module parachute system, advanced trials of the semi-humanoid robot Vyommitra, and astronaut training via Axiom-4.

News in Brief

- IADT-1 (Aug 2025) successfully validated the deceleration parachute system of the Gaganyaan Crew Module.
- Vyommitra — ISRO's AI-enabled semi-humanoid robot — will fly on the uncrewed G1 mission (2026) before human missions.
- Four astronaut-designates: Group Captains Prasanth Balakrishnan Nair, Ajit Krishnan, Angad Pratap, and Shubhanshu Shukla.
- Gaganyaan will use HLVM3 (human-rated LVM3); Crew Escape System tested successfully in TV-D1 (2023).
- Gaganyaan timeline: G1 (2026, uncrewed), G2 (2026-27, uncrewed), H1 (2027, first crewed flight).

Static Background (Basics to Remember)

- **Human spaceflight achievers** — USSR (Yuri Gagarin, Vostok-1, 12 April 1961) → USA (Alan Shepard, 1961) → China (Yang Liwei, Shenzhou-5, 2003).
- **Crew Escape System (CES)** — rocket-powered module that pulls the crew capsule away from a failing launch vehicle; successfully tested in TV-D1 abort demo (21 Oct 2023).
- **Environment Control & Life Support System (ECLSS)** — maintains oxygen, CO2 scrubbing, humidity, thermal balance; built by VSSC + LPSC.
- **Uncrewed test flights** — standard practice: fly rocket + capsule first without crew to validate systems; SpaceX Demo-1 (2019) preceded Demo-2 (2020).
- **Space Cowboy test** — humanoid robots like Vyommitra verify life-support and avionics before humans fly.

Prelims Connect

Gaganyaan mission configuration

Component	Detail
Launch Vehicle	HLVM3 (human-rated LVM3)
Crew Size	3 astronauts
Mission Duration	Up to 7 days in LEO
Orbit	400 km circular
Orbital Module	Crew Module + Service Module
Crew Escape System	Tested via TV-D1 (Oct 2023)
Robot-pilot	Vyommitra (for uncrewed flights)

Recovery	Splashdown in Bay of Bengal / Arabian Sea

Gaganyaan's first uncrewed flight will be followed by the first Indian crewed orbital mission — making India the 4th country after USA, Russia, China.

Prelims Pointers

- **Gaganyaan** = India's first human spaceflight mission; launch vehicle **HLVM3**.
- **4 astronauts** selected; **Shubhanshu Shukla** flew Ax-4 (June 2025) as training.
- **Vyommitra** = AI-powered semi-humanoid robot for uncrewed trials.
- **IADT-1** — 1st Integrated Air Drop Test of parachutes (Aug 2025).
- **Crew module splashdown** planned in Arabian Sea / Bay of Bengal.

Private Space Push — Pixxel, Skyroot, Ananth, Manastu, Azista

India's private space sector matured in 2025-26 with multiple firsts: Pixxel's hyperspectral Firefly constellation, Skyroot's Vikram-1 Infinity launch, Ananth Technologies' private satellite integration line, Manastu Space's green propellant, and Azista Space's first commercial launch from Indian soil.

News in Brief

- Pixxel (California-headquartered, India-origin) launched 'Firefly' hyperspectral EO satellites — highest-resolution commercial hyperspectral constellation in the world (Jan 2025).
- Manastu Space (IIT Bombay-incubated) developed and demonstrated a green monopropellant for satellite thrusters — safer substitute for toxic hydrazine.
- Ananth Technologies (Hyderabad) set up India's first private satellite integration facility and is building a private satellite broadband constellation.
- In December 2025, Skyroot's Infinity campus was virtually inaugurated by PM Modi; Skyroot built Vikram-S (India's 1st private rocket, 2022).
- Azista Space Industries (Ahmedabad) achieved a landmark by launching its first commercial small-satellite mission from Indian soil (Feb 2026).
- INSPACe (Indian Space Promotion & Authorisation Centre) — the single-window regulator for Indian private space — continued to clear private launches and IN-Space MoUs.

Static Background (Basics to Remember)

- **Indian Space Policy 2023** — formally opened space sector; permits end-to-end private activities: launch, satellites, ground stations, apps.
- **INSPACe** (Indian National Space Promotion and Authorisation Centre) — autonomous agency under Department of Space; HQ Ahmedabad; grants authorisations.
- **NSIL** (NewSpace India Limited, 2019) — PSU under DoS; commercial arm of ISRO; handles SSLV commercialisation.
- **Start-up ecosystem** — 250+ space-tech startups in India (2025), up from ~1 in 2014; supported by iDEX, Atal Innovation Mission.
- **First Indian private rocket launch** — Skyroot's Vikram-S (Nov 2022) from Sriharikota.

Prelims Connect

Indian private/NewSpace space companies

Company	HQ	Speciality

Skyroot Aerospace	Hyderabad	Vikram rockets; 1st private launch 2022
Agnikul Cosmos	Chennai (IIT-M)	Agnibaan SOrTeD (3D-printed engine, May 2024)
Pixxel	Bengaluru / LA	Hyperspectral EO (Firefly)
Dhruva Space	Hyderabad	Satellite bus, SpaceX rideshares
Manastu Space	Mumbai (IIT-B)	Green propellant thrusters
Bellatrix Aerospace	Bengaluru	Electric propulsion
Ananth Technologies	Hyderabad	Satellite integration, broadband
Azista BST Aerospace	Ahmedabad	Smallsats & propulsion

India's space sector is regulated by the Department of Space. INSPACe (established 2020) authorises private space activities. NSIL (2019) is the commercial arm of ISRO.

Prelims Pointers

- **INSPACe** = Indian National Space Promotion & Authorisation Centre (HQ Ahmedabad, 2020) — regulator.
- **NSIL** = NewSpace India Limited (2019) — commercial arm of ISRO.
- **Skyroot** launched Vikram-S, **India's 1st private rocket** (Nov 2022).
- **Agnikul Cosmos** — Agnibaan SOrTeD; world's first rocket with a fully 3D-printed engine (May 2024).
- **Pixxel** operates **Firefly** hyperspectral constellation.

International Missions in News — SPHEREx, PUNCH, Pandora, TRACERS, ESCAPADE, IXPE, MAVEN

A cluster of global space missions were in news 2025-26, covering the full range of astronomy, space weather, exoplanet science, and planetary exploration.

News in Brief

- SPHEREx (NASA, Feb 2025): Spectro-Photometer for the History of the Universe, Epoch of Reionisation and Ices Explorer — an all-sky infrared spectral survey.
- PUNCH (NASA, Feb 2025): Polarimeter to Unify the Corona and Heliosphere — studies how solar corona becomes solar wind.
- Pandora (NASA): studies exoplanet atmospheres, near-launch in 2025.
- TRACERS (NASA, July 2025): Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites — studies magnetic reconnection at Earth's cusps.
- ESCAPADE (NASA, Nov 2025): twin orbiters Blue & Gold to study Mars's magnetosphere and solar wind interaction.
- IXPE (NASA): in Jan 2026 confirmed magnetic field geometry of the Crab Pulsar for first time.
- MAVEN orbiter (NASA): NASA lost contact with the Mars Atmosphere and Volatile EvolutioN orbiter after over a decade (Dec 2025); earlier revived.
- Perseverance rover (NASA, Mars): in Sep 2025 identified a potential biosignature mineral in Jezero Crater; in Feb 2026 completed first AI-planned autonomous drives.
- Zhurong (China) discovered evidence of an ancient ocean on Mars in Utopia Planitia (Feb 2025).

- MQ-28A Ghost Bat (Australia, 2025) — autonomous AI 'robotic wingman' drone for fighter jets.
- Haven-1 (Vast Space) — announced as world's first commercial space station, to launch 2026.

Static Background (Basics to Remember)

- **NASA** (National Aeronautics and Space Administration, US, 1958) — HQ Washington DC; flagship programmes: Apollo, Space Shuttle, ISS, Artemis.
- **ESA** (European Space Agency, 1975) — 22 member states; HQ Paris; launches from Kourou (French Guiana); key rockets: Ariane, Vega.
- **CNSA** (China National Space Administration, 1993) — Tiangong station, Chang'e lunar programme, Tianwen Mars/asteroid programme.
- **JAXA** (Japan, 2003) — Hayabusa, SLIM, Akatsuki, Kibo ISS module.
- **Commercial space** — SpaceX (Falcon 9, Starship, Starlink), Blue Origin, Rocket Lab, Firefly, Vast Space, Intuitive Machines are key US private players.
- **Space weather events** — solar storms of 2025 were among strongest of Solar Cycle 25, which peaks 2024-26.

Prelims Connect

Major international space missions in news (2025-26)

Mission	Agency	Purpose
SPHEREx	NASA	All-sky IR spectral survey
PUNCH	NASA	Corona→solar wind connection
Pandora	NASA	Exoplanet atmosphere studies
TRACERS	NASA	Magnetic reconnection at Earth cusps
ESCAPADE (Blue & Gold)	NASA	Mars magnetosphere twin orbiters
IXPE	NASA	X-ray polarimetry of pulsars, black holes
MAVEN	NASA	Mars upper atmosphere; contact lost Dec 2025
Perseverance	NASA	Jezero Crater, biosignature search
Zhurong	CNSA (China)	Mars Utopia Planitia — ocean evidence
Tianwen-2	CNSA (China)	Asteroid sample-return (launched May 2025)
Hakuto-R Mission 2	ispace (Japan)	Commercial lunar lander

Blue Ghost Mission 1	Firefly Aerospace (US)	Successful private Moon landing (Mar 2025)
Athena	Intuitive Machines (US)	Private lunar lander (Mar 2025, tipped over)
Shenzhou-21	CNSA	Taikonaut crew to Tiangong (Nov 2025)
Haven-1	Vast Space (US)	World's 1st commercial space station (2026)

Firefly Aerospace's Blue Ghost Mission 1 became the 1st commercial lander to successfully soft-land on the Moon (2 March 2025).

Prelims Pointers

- **SPHEREx** — NASA all-sky infrared spectral survey.
- **PUNCH** — NASA solar-wind / corona mission.
- **TRACERS** — studies magnetic reconnection at Earth's polar cusps.
- **ESCAPADE Blue & Gold** — NASA twin Mars orbiters (Nov 2025).
- **Blue Ghost Mission 1** = first private lander to soft-land on Moon (Firefly Aerospace).
- **Tianwen-2** (China) = first Chinese asteroid sample return (launched May 2025).

Indigenous Propulsion & Chips — SE2000, LOX-Methane, Vikram 3201, IRIS

India crossed several self-reliance milestones in space propulsion and electronics in 2025 — the SE2000 semi-cryogenic engine, LOX-methane engine under development, the Vikram 3201 & Kalpana 3201 microprocessors, and the IRIS chip jointly developed by IIT Madras and ISRO.

News in Brief

- SE2000 (Semi-cryogenic Engine 2000 kN) — uses RP-1 (refined kerosene) + LOX; will power LVM3-SC and NGLV to raise payloads.
- ISRO conducted pre-burner ignition trials of CE20 (Feb 2025) and initiated semi-cryogenic SE2000 integrated test campaigns.
- LOX-methane engine — ISRO's next-gen reusable propulsion; methane is cheaper, cleaner, and more compatible with Mars (ISRU).
- Vikram 3201 and Kalpana 3201 — ISRO's first indigenous 32-bit fault-tolerant microprocessors, for onboard avionics (Mar 2025).
- IRIS chip (Feb 2025) — 'Indigenous Rad-hardened ISRO SoC', jointly developed by IIT Madras and ISRO for spacecraft computers.
- Stellite nozzle divergent (Apr 2025) — indigenous high-temperature alloy nozzle developed for solid rocket motors.

Static Background (Basics to Remember)

- **Rad-hardened electronics** — designed to survive cosmic rays and Van Allen belt radiation; needed for satellites, high-altitude nuclear systems.
- **SoC** = System-on-Chip — integrates CPU + memory + peripherals in a single silicon die.
- **32-bit processors** — handle 4 GB address space; adequate for avionics (real-time operations).

- **Semi-cryogenic propulsion** gives ~15% higher Isp than storable propellants and is cheaper than fully cryogenic.
- **Why methane** — can be produced from Martian atmosphere + ice (Sabatier reaction), enabling return missions from Mars (ISRU).

Prelims Connect

Indigenous space electronics & propulsion — 2025 firsts

Development	Purpose
Vikram 3201 / Kalpana 3201	32-bit microprocessors for onboard avionics
IRIS Chip	Rad-hard SoC by IIT-M + ISRO
SE2000 engine	Semi-cryogenic (kerosene+LOX) for LVM3-SC
LOX-methane engine	Next-gen reusable — clean fuel
Stellite nozzle	High-temperature solid motor nozzle alloy
CE20 cryogenic engine	C25 stage of LVM3 (LH2+LOX)

A 'semi-cryogenic' engine uses one cryogenic propellant (LOX) and one room-temperature storable one (kerosene/RP-1), unlike fully cryogenic (LH2+LOX).

Prelims Pointers

- **Vikram 3201 / Kalpana 3201** — ISRO's **first 32-bit indigenous microprocessors**.
- **IRIS chip** jointly developed by **IIT Madras** & ISRO.
- **SE2000** = semi-cryogenic engine (kerosene + LOX, 2,000 kN thrust).
- **CE20** = cryogenic upper-stage engine of LVM3.
- **LOX-methane** engines are favoured for **reusable rockets** and **Mars** missions (ISRU-compatible).

Dr K. Kasturirangan (1940-2025) & Dr V. Narayanan — New Space Secretary

India's space programme saw a generational transition in 2025. Dr Krishnaswamy Kasturirangan, 10th Chairman of ISRO and one of India's most influential space scientists, passed away on 25 April 2025 in Bengaluru. Dr V. Narayanan was appointed the new Space Secretary & ISRO Chairman in January 2025.

News in Brief

- Dr K. Kasturirangan (1940-2025) chaired ISRO 1994-2003; led development of IRS-1A to 1D, operational PSLV, and initiated Chandrayaan-1, GSLV and Mars concept.
- He headed the committee that drafted the National Education Policy (NEP) 2020.
- He was awarded Padma Shri, Padma Bhushan, and Padma Vibhushan; was a Rajya Sabha member.
- Dr V. Narayanan — previously Director of Liquid Propulsion Systems Centre (LPSC) — appointed Space Secretary & ISRO Chairman effective January 2025, succeeding S. Somanath.
- He has four decades of experience in cryogenic, semi-cryogenic and liquid rocket engines.

Static Background (Basics to Remember)

- **ISRO Chairman** is also Secretary of Department of Space and Chairman of Space Commission — a triple role created by Vikram Sarabhai in 1972.

- **LPSC** (Liquid Propulsion Systems Centre) — Thiruvananthapuram + Bengaluru; designs liquid/cryogenic engines.
- **Padma Vibhushan** — 2nd highest civilian award of India (after Bharat Ratna); instituted 1954.
- **National Education Policy 2020** — India's 3rd national policy on education (after 1968, 1986); Kasturirangan-led drafting committee (2017-19).
- **Previous Space Secretaries** of note: Dr K. Radhakrishnan (led Mangalyaan), K. Sivan (led Chandrayaan-2), S. Somanath (led Chandrayaan-3 + Aditya-L1).

Prelims Connect

ISRO Chairmen timeline

#	Chairman	Tenure
1	Vikram Sarabhai	1963-1971
2	M.G.K. Menon	1972 (briefly)
3	Satish Dhawan	1972-1984
4	U.R. Rao	1984-1994
5	K. Kasturirangan	1994-2003
6	G. Madhavan Nair	2003-2009
7	K. Radhakrishnan	2009-2014
8	A.S. Kiran Kumar	2015-2018
9	K. Sivan	2018-2022
10	S. Somanath	2022-2025
11	V. Narayanan	2025- (current)

V. Narayanan was the principal architect of the CE20 cryogenic engine used in LVM3 — the vehicle that launched Chandrayaan-3.

Prelims Pointers

- **Dr K. Kasturirangan** — ISRO Chairman **1994-2003**; died April 2025.
- **NEP 2020** drafting committee chaired by **Kasturirangan**.
- **V. Narayanan** = current (11th) ISRO Chairman / Space Secretary (from Jan 2025).
- **Kasturirangan** received **Padma Vibhushan** (2000).
- **S. Somanath** was the 10th Chairman who led ISRO during Chandrayaan-3 success.

GRAIL Mission — Why the Moon is 'Janus-Faced'

NASA's GRAIL mission has revealed a fundamental asymmetry inside the Moon: the near side is 100–200°C warmer than the far side, contains a partially molten rock layer 800–1,250 km below the surface, and shows

evidence of ancient lava flooding that shaped the dark maria visible from Earth. This 'Janus-faced' character — two contrasting hemispheres — is now explained by internal thermal differences, not just surface history.

News in Brief

- GRAIL twin spacecraft (Ebb and Flow) mapped lunar gravity changes caused by Earth's tidal pull; data revealed warmer, softer near-side interior.
- A partially molten layer at 800–1,250 km depth on the near side may have supplied lava to form the dark maria — explaining the near/far side asymmetry.
- Far side: thicker crust blocks magma from reaching the surface — fewer maria, more craters.
- Temperature difference between the two hemispheres measured at 100–200°C (near side warmer).

Static Background (Basics to Remember)

GRAIL Mission Basics

- GRAIL = Gravity Recovery and Interior Laboratory — NASA mission, launched 2011; twin spacecraft Ebb and Flow orbiting Moon in tandem.
- Technique: varying distance between the two spacecraft used to map lunar gravity precisely — same principle as GRACE (Earth water cycle monitoring mission).
- Key findings: Moon's crust more porous than expected; linear 'dikes' confirm Moon experienced slight expansion in early history.

Moon's Internal Structure & Tidal Locking

- Moon's layers (inside out): inner solid iron core (~480 km) → outer liquid iron core → partial melt zone → mantle → crust.
- Tidal locking: Moon's rotation period equals its orbital period → same face always points to Earth. Caused by tidal friction over billions of years.
- Near side: lower elevation, thinner crust, abundant mare basalts (lava plains). Far side: higher elevation, thicker crust, more impact craters.

Prelims Connect

GRAIL — Key Facts at a Glance

Parameter	Detail
Full form	Gravity Recovery and Interior Laboratory
Launch year	2011 (NASA)
Spacecraft names	Ebb and Flow (twin spacecraft)
Key technique	Measures varying distance between two craft → gravity map
Key finding	Near side warmer; porous crust; dikes confirm early Moon expansion
Earth equivalent	GRACE — measures Earth's gravity to track water cycle changes

GRAIL's gravity maps are guiding ISRO and NASA in selecting safe flat landing sites for Chandrayaan-4 and future crewed lunar missions by identifying low-gravity anomaly zones.

Moondust Health Hazards & Lunarcrete for Lunar Habitats

As NASA's Artemis programme and ISRO's Chandrayaan-4 push toward human lunar presence, two overlooked engineering challenges are emerging to the forefront: the health hazards of lunar dust (regolith) and the need to build structures on the Moon without importing materials from Earth. Scientists are now testing lunarcrete — concrete made from lunar regolith — and studying moondust toxicity to protect future astronauts.

News in Brief

- Lunar dust is electrostatically charged, making it adhere to spacesuits, visors, and equipment — a significant engineering and health problem.
- Studies show: larger moondust particles are toxic only at very high concentrations; smaller particles kill lung alveolar cells at rates comparable to Earth's PM2.5.
- Lunarcrete double-layer wall design with air gap maintains ~22°C indoors despite Moon's external swings from 120°C (day) to −130°C (night).
- NASA Artemis II — crewed lunar flyby — scheduled 2026; makes moondust research operationally urgent.

Static Background (Basics to Remember)

Why Lunar Dust is Uniquely Dangerous

- No wind or water erosion on Moon → particles remain sharp, jagged, glass-edged. On Earth, particles are rounded by weathering.
- Composition: glass beads (from micrometeorite impacts), ilmenite, pyroxene, olivine, nano-iron particles embedded in silica.
- Electrostatic charge: solar UV + solar wind charge regolith → clings to everything. No gravity-based settling (particles stay suspended in helmet).
- Apollo 17 astronaut Harrison Schmitt reported a severe allergic reaction from dust — first documented case of 'lunar hay fever.'

Lunarcrete Options Being Researched

- Sulphur lunarcrete: molten sulphur used as a binder with regolith aggregate; no water needed. Limitation: softens above ~120°C.
- Microwave/sunlight sintering: regolith heated until surface grains partially melt and fuse → bricks without any binder material.
- Conventional Portland cement requires large water quantities — extremely scarce on Moon, making it unsuitable without in-situ water extraction.

Prelims Connect

Moondust & Lunarcrete — Key Facts

Topic	Key Detail
Lunar dust charge	Electrostatically charged by solar UV and solar wind — sticks to all surfaces
Dust composition	Glass beads, ilmenite, pyroxene, nano-iron; no rounded particles
Health concern	Kills alveolar (lung) cells; no immune response in lungs to lunar minerals

Sulphur lunarcrete	Molten sulphur as binder; no water needed; softens >120°C
Sintering	Microwave/sunlight fuses regolith grains — no binder at all
Artemis II	2026 crewed lunar flyby — NASA; operational moondust testing mission

Both moondust mitigation and lunarcrete construction are priority research areas under NASA's Moon to Mars Architecture and ISRO's Chandrayaan-4 sample return mission planning for 2027–28.

Lunar Fission Surface Power — Nuclear Energy on the Moon

Solar panels power most spacecraft today, but a two-week-long lunar night and the shadow-dominated polar craters where ice is found make solar power unreliable for a permanent lunar base. Both the USA (Artemis programme) and Russia-China (ILRS) are now independently developing small nuclear fission reactors for deployment on the Moon by the early 2030s — making this an important space policy and technology topic.

News in Brief

- USA plans to deploy a small fission reactor on the Moon by early 2030s — first permanent nuclear power source beyond Earth orbit.
- RTGs (Radioisotope Thermoelectric Generators) — used in deep-space probes — produce only ~100W, insufficient for human habitats requiring kilowatts.
- Russia-China ILRS (International Lunar Research Station) independently planning a nuclear power plant on the Moon.
- The 1992 UN Principles on Nuclear Power in Outer Space is non-binding and designed for RTGs — leaves governance gaps for full fission reactors.

Static Background (Basics to Remember)

Types of Space Nuclear Power

Type	Power Output	Current Use
RTG (Radioisotope Thermoelectric Generator)	~100W	Voyager, Cassini, Curiosity, Perseverance — deep-space missions
Fission Surface Power (FSP)	Kilowatts–Megawatts	Proposed for Moon and Mars habitats (2030s)
Nuclear Thermal Propulsion (NTP)	High thrust, 2x efficiency	Proposed for crewed Mars missions (future)
Nuclear Electric Propulsion (NEP)	High efficiency, low thrust	Deep-space probes — proposed

International Space Law Framework

- Outer Space Treaty (1967): Space is the 'province of all mankind'; no national appropriation; no nuclear weapons in orbit; peaceful nuclear power for space activities is permitted.

- Artemis Accords (2020): US-led bilateral agreements for transparent, peaceful lunar exploration. India signed in 2023.
- Moon Agreement (1979): Declares Moon and its resources as the 'Common Heritage of Mankind' — NOT signed by India, USA, Russia, or China.

Prelims Connect

Space Nuclear Power — Key Facts

Topic	Key Detail
RTG fuel	Plutonium-238 (Pu-238) — decays slowly, generates heat → electricity
RTG missions	Voyager 1 & 2, Cassini, New Horizons, Curiosity, Perseverance
FSP target	10 kilowatts for first lunar reactor (USA plan, early 2030s)
Outer Space Treaty	1967; India signatory; allows peaceful nuclear power in space
Artemis Accords	India signed 2023; 40+ nations; rival to Russia-China ILRS
Moon Agreement (1979)	NOT signed by India, USA, Russia, China — largely ineffective

The governance vacuum for nuclear fission reactors in space — as distinct from RTGs — is an active policy debate. India's signing of the Artemis Accords (2023) aligns it with the US-led framework for lunar resource use and nuclear power governance.

Solar Flares, CMEs, Space Weather & Aditya-L1

The years 2024–26 mark Solar Maximum — the peak of the Sun's 11-year activity cycle — making solar weather research both scientifically rich and operationally urgent. India's Aditya-L1 spacecraft, stationed at the Sun-Earth L1 point since early 2024, is contributing first-of-its-kind observations during this critical window, while ground-based telescopes are detecting similar storms on other stars for the first time.

News in Brief

- First stellar CME from a star other than the Sun detected from red dwarf StKM 1-1262 (~133 light-years) using European LOFAR telescope — 10,000x more powerful than known solar storms.
- Aditya-L1's VELC instrument provided the first-ever spectroscopic observations of a Coronal Mass Ejection (CME) in visible wavelengths close to the Sun's photosphere.
- Gannon's Storm (May 2024) — strongest solar storm of the 21st century — was studied by Aditya-L1. Two CMEs collided mid-space, causing magnetic reconnection that amplified the storm unexpectedly.
- Solar Maximum 2026: peak of solar activity cycle; Aditya-L1 is positioned at precisely the right time to study maximum solar flare and CME activity.

Static Background (Basics to Remember)

Types of Solar Events Compared

Event	Definition
Solar Flare	Sudden intense burst of radiation from sunspot magnetic field collapse; travels at speed of light; affects radio communications
CME (Coronal Mass Ejection)	Massive plasma cloud ejected from Sun's corona; takes 1–3 days to reach Earth; causes geomagnetic storms
Solar Wind	Continuous outflow of charged particles (protons, electrons) at 400–800 km/s from corona
Magnetic Reconnection	Opposing magnetic field lines snap and rejoin, releasing enormous energy — mechanism driving both flares and CMEs

Aditya-L1 Mission Details

- Launched: 2 September 2023 aboard PSLV-C57. Reached Sun-Earth L1 halo orbit: January 2024.
- Location: L1 Lagrange point ~1.5 million km from Earth — provides 24/7 unobstructed view of the Sun without eclipses.
- Seven payloads: VELC (primary — Visible Emission Line Coronagraph, built by IIA Bengaluru), SUIT, ASPEX, PAPA, SoLEXS, HEL1OS, MAG.
- Other missions at L1: SOHO (NASA/ESA, 1995), DSCOVR (NOAA, 2015) — space weather monitoring.

Prelims Connect

Aditya-L1 — Essentials at a Glance

Parameter	Detail
Launch	2 September 2023, PSLV-C57 from Sriharikota
Orbit	Sun-Earth L1 halo orbit (~1.5 million km from Earth)
Primary payload	VELC — Visible Emission Line Coronagraph (IIA, Bengaluru)
Total payloads	7 — covering visible, UV, X-ray and particle domains
Key observation	First spectroscopic CME observation in visible wavelengths
Significance	Monitors Sun 24/7; critical during Solar Maximum 2026

Aditya-L1 is India's first dedicated space-based solar observatory. L1 is one of 5 Lagrange points — gravitationally stable positions in the Sun-Earth system. L2 hosts JWST and Euclid; L1 hosts Aditya-L1, SOHO, and DSCOVR.

. Black Hole Mergers — GW231123, Hawking's Area Theorem

Gravitational wave astronomy is entering a new era of precision. The LVK (LIGO-Virgo-KAGRA) collaboration's most recent observations have not only detected the most massive black hole merger on record but have also provided the strongest experimental test of Stephen Hawking's 1971 Area Theorem — a fundamental result connecting gravity and thermodynamics. LIGO-India, under construction at Hingoli (Maharashtra), will join this network around 2030.

News in Brief

- GW231123: most massive black hole merger ever detected — two black holes of ~137 and ~103 solar masses merged (~240 solar masses total); both were spinning extremely rapidly, challenging formation theories.
- GW250114 (2025): clearest gravitational-wave signal to date; provided the strongest observational confirmation of Hawking's Black Hole Area Theorem.
- Post-merger quasi-normal mode 'ringing' confirmed the Kerr solution (1963) for rotating black holes — validates General Relativity in the strong-field regime.

Static Background (Basics to Remember)

Gravitational Waves & LIGO

- Gravitational waves: ripples in the fabric of spacetime produced by accelerating massive objects; predicted by Einstein's General Theory of Relativity (1915).
- LIGO: two US detectors (Hanford, Washington + Livingston, Louisiana). First detection: GW150914 (14 September 2015). Nobel Prize in Physics 2017 — Weiss, Barish, Thorne.
- LVK = LIGO (USA) + Virgo (Italy, near Pisa) + KAGRA (Japan, Kamioka mine) — three-continent gravitational wave network.
- LIGO-India: approved by Cabinet 2016; site at Hingoli, Maharashtra; operated by DAE + IISER Pune; expected first science run ~2030.

Key Black Hole Theorems

- Hawking's Area Theorem (1971): the total event horizon area of black holes involved in a merger cannot decrease — analogous to the second law of thermodynamics. Confirmed by GW250114 analysis.
- Hawking Radiation (1974): quantum effects near the event horizon cause black holes to slowly emit thermal radiation and ultimately evaporate.
- Kerr Solution (Roy Kerr, 1963): exact solution to Einstein's field equations for a rotating (Kerr) black hole — confirmed by quasi-normal mode observations.

Prelims Connect

LIGO & Black Hole Mergers — Key Facts

Topic	Key Detail
First GW detection	GW150914 — 14 September 2015; two black holes ~30 solar masses each
Nobel Prize	Physics 2017 — Rainer Weiss, Barry Barish, Kip Thorne
GW231123	Most massive BH merger detected; ~240 total solar masses (2025)

LVK network	LIGO (USA) + Virgo (Italy) + KAGRA (Japan)
LIGO-India site	Hingoli, Maharashtra; operated by DAE; expected ~2030
Hawking Area Theorem	Event horizon area cannot decrease — confirmed by GW250114 (2025)

LIGO-India will be the first gravitational wave detector in the southern hemisphere of Earth, significantly improving sky localisation — critical for identifying the galaxy where mergers occur for follow-up optical and neutrino observations.

Superkilonova, Alaknanda Galaxy & Martian Jarosite

Three distinct astronomical discoveries in 2024–25 connect advanced astrophysics with India's own research contributions and Mars exploration planning: the superkilonova phenomenon that forges heavy elements, the Indian naming of the second-farthest known spiral galaxy, and the discovery that a Gujarat rock formation can help date Martian geological events.

News in Brief

- Superkilonova: when two neutron stars merge and ejected matter falls back onto the remnant, extra heating makes the event brighter and bluer than a standard kilonova — potentially powered by a magnetar. Produces gold, platinum, neodymium.
- Alaknanda: Indian astronomers discovered and named the second-farthest known spiral galaxy using JWST data. (The Milky Way is called Mandakini in Hindi; Andromeda is the nearest large spiral neighbour.)
- Martian Jarosite (Kachchh, Gujarat): 55-million-year-old jarosite veins at Matanomadh, Kutch showed luminescence after heating to 450°C — can potentially date Martian dust storms and volcanic ash layers from rover measurements.

Static Background (Basics to Remember)

Kilonova vs Superkilonova

- Kilonova: electromagnetic emission from radioactive decay of heavy r-process elements ejected in neutron star merger. First confirmed event: GW170817 / AT2017gfo (2017).
- r-process (rapid neutron capture): occurs in kilonovae and produces elements heavier than iron — gold, platinum, iodine, uranium, neodymium.
- Superkilonova: additional energy input from fallback matter (or magnetar remnant) heats ejecta → brighter, bluer, longer-lasting than a standard kilonova.

India's Mars Analogue Sites

Site	Location	Mars Analogue Feature
Kachchh / Kutch	Gujarat	Arid, salty, jarosite-rich; acidic ancient water environment — confirms Mars-like chemistry
Ladakh	J&K / LE	Cold desert, extreme temperature swings, high UV — ISRO LHAM (2024) rover trial conducted here

Barren Island	Andaman & Nicobar	Active volcano — analogue for geothermal/volcanic processes on Mars

- Jarosite = potassium-iron-sulphate ($KFe_3(SO_4)_2(OH)_6$); forms only in acidic, oxidising, water-bearing environments → confirms ancient liquid water on Mars.

Prelims Connect

Kilonova & Jarosite — Key Facts

Topic	Key Detail
Kilonova products	Gold, platinum, iodine, uranium — via r-process nucleosynthesis
First kilonova	GW170817 / AT2017gfo (2017) — also first multi-messenger event (GW + light)
Superkilonova	Extra energy from fallback matter; brighter and bluer than standard kilonova
Alaknanda	2nd farthest spiral galaxy; named by Indian astronomers using JWST
Jarosite formula	$KFe_3(SO_4)_2(OH)_6$ — forms only in acidic, aqueous, oxidising conditions
Kutch jarosite age	~55 million years old (Paleocene); at Matanomadh, Kachchh, Gujarat

Jarosite was first identified on Mars by NASA's Opportunity rover in 2004 at Meridiani Planum — the discovery that changed scientific consensus about ancient water on Mars. India's Kutch outcrops allow ground-truthing of dating techniques before Mars deployment.

Multi-Messenger Astronomy, RAD@home & India's Radio Assets

Traditional astronomy used only light to study the universe. Multi-messenger astronomy combines four fundamentally different information carriers — electromagnetic radiation, gravitational waves, neutrinos, and cosmic rays — to provide a complete picture of extreme cosmic events. India contributes to this revolution through GMRT (one of the world's largest radio telescopes), AstroSat, and even citizen scientists through RAD@home.

News in Brief

- RAD@home (est. 2013, University of Mumbai): citizen-science astronomy group of ~4,700 members reported a rare double Odd Radio Circle (ORC) using LOFAR data — only the 2nd known twin-ORC system worldwide.
- ORCs (Odd Radio Circles): large, faint circular radio structures surrounding distant galaxies; origin uncertain — possibly ancient galaxy merger shockwaves expanding at millions of km/h.
- AstroSat (2015): India's first multi-wavelength space observatory combines UV, optical, and multiple X-ray bands for simultaneous tracking of stellar flares, black hole outbursts, neutron star activity.

- First multi-messenger event: GW170817 (2017) — gravitational waves + gamma-ray burst + optical kilonova detected simultaneously from neutron star merger.

Static Background (Basics to Remember)

The Four Messengers Compared

Messenger	Source	What it Reveals
Electromagnetic (radio–gamma)	Stars, galaxies, AGN, supernovae	Surface/atmosphere of objects; chemical composition
Gravitational Waves	Black hole and neutron star mergers	Violent collisions; spacetime geometry
Neutrinos	Supernovae, Sun's core, cosmic rays	Interior processes; pass through all matter
Cosmic Rays	Supernovae remnants, AGN jets	High-energy particle acceleration mechanisms

India's Key Astronomy Assets

- GMRT (Giant Metrewave Radio Telescope): at Khodad village, Pune district; 30 dishes × 45 m diameter; covers 150–1,500 MHz; upgraded to uGMRT (2019); operated by NCRA-TIFR.
- AstroSat (launched 2015): India's first multi-wavelength satellite observatory; 5 instruments cover UV + optical + low/high-energy X-rays simultaneously.
- Hanle Dark Sky Reserve (Ladakh): India's first Bortle-1 (darkest) dark sky reserve; Indian Astronomical Observatory (IIA) at 4,250 m altitude — one of world's highest.

Prelims Connect

Multi-Messenger Astronomy — Key Facts

Topic	Key Detail
First multi-messenger event	GW170817 (2017) — neutron star merger; GW + gamma + kilonova simultaneously
ORC	Odd Radio Circle — faint circular radio structure around galaxies; origin unknown
RAD@home	Citizen science; est. 2013, Univ. of Mumbai; ~4,700 members; uses LOFAR data
GMRT location	Khodad village, Pune district; operated by NCRA-TIFR
uGMRT upgrade	2019; extended frequency range 50–1,500 MHz; improved sensitivity
AstroSat	India's first multi-wavelength space observatory; launched 2015; 5 instruments

India's Kolar Gold Fields (KGF, Karnataka) was the site of the world's first detection of atmospheric neutrinos in the 1960s — a pioneering Indian contribution to multi-messenger physics, decades before the term was coined.

Tamil Nadu Space Policy & Antariksh Prayogshala

Indian states are now drafting their own space industrial policies to complement the Indian Space Policy 2023. Tamil Nadu is uniquely positioned — it hosts the ISRO Propulsion Complex at Mahendragiri, is getting a second national spaceport at Kulasekarapattinam (Thoothukudi), and has NIT Tiruchi's Space Technology Incubation Centre. The central government's Antariksh Prayogshala scheme further expands space infrastructure into academic institutions.

News in Brief

- Tamil Nadu Space Policy targets ₹10,000 crore investment and 10,000 jobs over 5 years — covering satellite manufacturing, launch services, and satellite-based applications.
- Kulasekarapattinam, Thoothukudi: India's 2nd spaceport; foundation laid February 2024; ideal for polar orbit small-satellite launches without overflying populated areas.
- Antariksh Prayogshala: IN-SPACe issued Request for Proposals (RFP) to set up Space Labs at up to 7 academic institutions — 75% government-funded, capped at ₹5 crore per institution.
- TN joins Karnataka and Gujarat in having state-level space policies — signalling the devolution of India's space economy to state industrial clusters.

Static Background (Basics to Remember)

Indian Space Policy 2023 — Three-Entity Model

- ISRO (Indian Space Research Organisation): R&D + national strategic and scientific missions.
- IN-SPACe (Indian National Space Promotion and Authorisation Centre): single-window regulator for all space activities (government + private); HQ Ahmedabad, Gujarat.
- NSIL (NewSpace India Limited, est. 2019): PSU commercial arm of ISRO; manages commercial launch services and technology transfer.
- Indian Space Policy 2023 allows end-to-end private participation — launch vehicles, satellites, ground stations, downstream applications.

State Space Policies Compared

State	Key Space Focus
Karnataka	Satellite manufacturing and startups; ISRO/HAL/BEL/DRDO ecosystem in Bengaluru; first state space policy
Gujarat	Dholera fab city (Tata-PSMC fab plant); Sanand OSAT cluster (Micron, CG Power); GIFT City space finance
Tamil Nadu	Mahendragiri propulsion complex (IPRC); Kulasekarapattinam 2nd spaceport; NIT-Tiruchi STIC

Prelims Connect

Tamil Nadu Space Ecosystem — Key Facts

Topic	Key Detail
2nd spaceport	Kulasekarapattinam, Thoothukudi district — foundation laid Feb 2024
IPRC	ISRO Propulsion Complex — Mahendragiri, Tirunelveli district, Tamil Nadu
STIC	Space Technology Incubation Centre at NIT Tiruchi (NIT-T)
IN-SPACe HQ	Ahmedabad, Gujarat — single-window regulator
NSIL	NewSpace India Limited, est. 2019 — commercial arm of ISRO
Antariksh Prayogshala	Space Labs at up to 7 institutions; 75% govt-funded, max ₹5 crore each

Kulasekarapattinam's southern location allows satellites to launch into high-inclination polar and sun-synchronous orbits over the Indian Ocean without the need to fly over other nations — a key operational advantage over Sriharikota for small satellite operators.

HAL SSLV Transfer, CE20 Bootstrap Mode & ISRO Launch Vehicles

India's space launch capabilities are expanding on two fronts: making existing rockets commercially independent (HAL taking over SSLV production from ISRO) and making engines more capable (CE20 bootstrap mode enabling multi-orbit missions). Together, these moves reduce ISRO's operational role and position private Indian industry at the centre of the emerging commercial space economy.

News in Brief

- HAL secured a ₹511 crore Transfer of Technology (ToT) from ISRO to independently build and operate Small Satellite Launch Vehicles (SSLVs) commercially — marking ISRO's first complete handover of a launch vehicle to industry.
- SSLV = 3 solid-propellant stages + liquid Velocity Trimming Module (VTM); payload ≤500 kg to LEO; designed for low cost, minimal infrastructure, and very quick turnaround (days vs. months for PSLV).
- CE20 bootstrap mode: ISRO demonstrated cryogenic engine self-startup under vacuum at IPRC Mahendragiri — engine builds to full thrust without external pressurised gas, enabling multiple restarts for multi-orbit satellite deployment.

Static Background (Basics to Remember)

ISRO Launch Vehicle Family — Comparison

Vehicle	Stages	LEO Payload	Primary Use
PSLV	4 stages (solid-liquid alternating)	~1,860 kg (XL)	Workhorse: NavIC, Chandrayaan-1, remote

			sensing, foreign satellites
GSLV Mk II	3 stages (S + L + Cryo)	~5,000 kg (GTO)	Communication satellites to GTO; domestic INSAT/GSAT series
LVM3 (GSLV Mk III)	3 stages (S + L + Cryo)	~8,000 kg (GTO)	Heaviest: Chandrayaan-2/3, OneWeb, Gaganyaan
SSLV	3 solid stages + VTM	~500 kg (LEO)	Small commercial satellites; rapid-response missions
NGLV (planned)	Semi-cryo, reusable 1st stage	~20,000 kg (target)	Next-generation heavy lift — replaces PSLV + LVM3

CE20 Cryogenic Engine Details

- CE20 powers the C25 cryogenic upper stage of LVM3; propellants: Liquid Hydrogen (LH2) + Liquid Oxygen (LOX); thrust 19–22 tonnes (variable).
- C25 stage upgraded to C32 (32,000 kg propellant capacity, 22 tonne thrust) for heavier GTO payloads.
- Bootstrap mode advantage: no external gas bottle for startup → lower mass + multiple restarts → multi-orbit insertion in a single flight (critical for satellite constellations).

Prelims Connect

SSLV and CE20 — Key Facts

Topic	Key Detail
SSLV payload	≤500 kg to LEO at ~500 km; 3 solid stages + Velocity Trimming Module
HAL ToT	₹511 crore; first complete launch vehicle handover from ISRO to industry
CE20 fuel	LH2 + LOX (cryogenic); powers C25/C32 upper stage of LVM3
Bootstrap mode	Engine self-starts under vacuum; no external pressurised gas; enables multi-orbit missions
C25 → C32	Propellant capacity: 25,000 → 32,000 kg; thrust unchanged at 22 tonnes

IPRC	ISRO Propulsion Complex, Mahendragiri, Tirunelveli — where CE20 test was conducted

The SSLV was designed from the outset for industry handover — its simplified 3-solid-stage architecture requires no liquid-stage expertise, making it ideal for aerospace majors like HAL to manufacture without ISRO support for day-to-day operations.

SBS-III Surveillance Satellites, Space Law & ISRO Roadmap 2040

India's Operation Sindoor (May 2025) highlighted the operational importance of space-based intelligence, surveillance, and reconnaissance (ISR). In its aftermath, the Cabinet approved acceleration of the Space-Based Surveillance-III programme. Simultaneously, India's long-deferred national space law and ISRO's ambitious 2040 roadmap — including a crewed lunar landing — have come into sharp focus.

News in Brief

- SBS-III: 52 AI-enabled surveillance satellites approved by Cabinet Committee on Security (CCS); ISRO deploys first 21; private sector manages 31; Defence Space Agency (DSA) operates the full constellation.
- Operation Sindoor: Cartosat and RISAT series tracked enemy positions, guided strike selection, and confirmed impacts — demonstrating operational space-based ISR.
- India still lacks a comprehensive national Space Activities Act; Indian Space Policy 2023 is a policy document, not legislation; IN-SPACe lacks statutory backing.
- ISRO 2040 Roadmap: Chandrayaan-4 (2027–28, lunar sample return), Chandrayaan-5/LUPEX with JAXA (2028), Venus Orbiter (approved), NGLV reusable rocket (approved), crewed Moon landing by 2040.

Static Background (Basics to Remember)

India's Space-Based Surveillance — History

- SBS-I (2001): 4 satellites — India's response to Kargil War intelligence failures; Cartosat and RISAT series core.
- SBS-II (2013): 6 additional satellites; improved resolution and revisit frequency.
- SBS-III (2023): 52 satellites approved by CCS; AI-enabled real-time decision support; 10-year deployment timeline.

Global Space Law — India's Treaty Status

Treaty	Year	Key Provision	India's Status
Outer Space Treaty (OST)	1967	No sovereignty over celestial bodies; states responsible for all national space activities (including private)	Signatory
Liability Convention	1972	Absolute liability for damage on Earth's surface; fault-based liability in space	Signatory
Registration Convention	1976	States must register space objects with UN	Signatory

		Office for Outer Space Affairs (OOSA)	
Moon Agreement	1979	Moon and resources = 'Common Heritage of Mankind'; governs resource extraction	NOT signed

Prelims Connect

SBS and Space Law — Key Facts

Topic	Key Detail
SBS-III total	52 AI-enabled surveillance satellites; CCS-approved; DSA to operate
SBS-I history	4 satellites, 2001 — post-Kargil War intelligence gap response
Operation Sindoor	Cartosat + RISAT used for targeting and battle damage assessment (May 2025)
OST signatory	India, USA, Russia, China — all signatories to Outer Space Treaty (1967)
Moon Agreement	India NOT signatory — along with USA, Russia, China
ISRO 2040 target	Crewed Moon landing by 2040; Chandrayaan-4 sample return by 2027–28

India's absence of a dedicated Space Activities Act creates regulatory uncertainty for private space companies. Countries like the USA (Commercial Space Launch Act), Luxembourg (Space Resources Law), and UAE (Space Law 2020) have passed binding legislation — India's is still pending.

DEFENCE TECHNOLOGY

Operation Sindoor — India's Precision Strike on Terror Bases

Operation Sindoor (May 2025) was a swift precision-strike counter-terrorism operation carried out by India across the LoC and within Pakistani territory targeting terror infrastructure, following the Pahalgam terror attack. It marked the first high-intensity deployment of the S-400 'Sudarshan' air-defence system and Rafale fighters in Indian operational use.

News in Brief

- Triggered by the April 2025 Pahalgam terror attack; India executed pre-dawn precision strikes on 9 terror camps.

- Indian Air Force used Rafale + Sukhoi-30 MKI; SCALP-EG & HAMMER stand-off weapons employed.
- First operational use of S-400 Triumf air-defence regiment ('Sudarshan') in hostile conditions.
- Rafale jets and S-400 also deployed in Siliguri Corridor ('Chicken's Neck') after subsequent escalation.
- Pakistan attempted ~400 Turkish-origin Songar drone incursions in 36 hours, all intercepted by Indian counter-UAS systems.
- India's indigenous Bhargavastra micro-missile counter-drone system saw its first operational trials.

Static Background (Basics to Remember)

- **Surface-to-Air Missile (SAM)** — launched from ground/ship against airborne targets; classified by range: SHORAD (<10 km), MRSAM (10-100 km), LRSAM (100+ km).
- **Air defence layers** — point defence → area defence → theatre/strategic; integrated 'kill chain' of radars, launchers, C4ISR.
- **Indian procurement of S-400** — 5 regiments for $5.43 bn signed Oct 2018; 3 delivered by 2024, rest 2025-26.
- **SEAD / DEAD** = Suppression/Destruction of Enemy Air Defences — uses anti-radiation missiles to blind radar.
- **Counter-UAS systems** — detect, identify, and kinetically/non-kinetically neutralise drones; include jammers, spoofers, lasers, and micro-missiles.
- **Pahalgam attack** (April 2025, J&K) — triggered Operation Sindoor.

Prelims Connect

S-400 'Sudarshan' / Triumf — key data

Parameter	Detail
Origin	Russia (Almaz-Antey)
Indian contract	2018, $5.43 billion, 5 squadrons
Indian name	Sudarshan Chakra / Sudarshan
Range	400 km (against bombers), 250/120/40 km (layered)
Targets	Aircraft, UAVs, cruise & ballistic missiles
Radar	91N6E 'Big Bird' (detection 600 km)
Missiles	40N6, 48N6, 9M96E/E2
India deployment	Punjab, Gujarat, Siliguri (from 2021)

Counter-UAS systems used by India include Smash-2000, D4 (DRDO), Indrajaal AI swarm-detection, and Bhargavastra micro-missile.

Prelims Pointers

- **Operation Sindoor** — May 2025 counter-terror precision strike.
- **S-400 'Sudarshan'** — Russian origin, **400 km range** long-range SAM.
- **Bhargavastra** — India's indigenous **micro-missile counter-drone** system.
- **Songar drones** used by Pakistan — Turkish-made tactical UAVs.
- **Rafale** — French origin, Dassault Aviation; 4.5-gen multirole fighter.

BrahMos & BrahMos-NG — Supersonic Cruise Missile Family

BrahMos — named after the rivers Brahmaputra and Moskva — continues to be India's flagship cruise missile and a top export product. In May 2025, Defence Minister Rajnath Singh virtually inaugurated the new BrahMos integration complex at Lucknow, while BrahMos-NG inched towards its maiden test.

News in Brief

- BrahMos is a supersonic cruise missile (Mach 2.8-3) developed by BrahMos Aerospace, a 50.5:49.5 India (DRDO) – Russia (NPOM) JV.
- Range extended from 290 km to 450-500 km after MTCR entry; air-launched version reaches ~400 km.
- BrahMos-NG ('Next Generation') will be lighter (~1.5 t vs 3 t), smaller, and air-launchable from Tejas, MiG-29K, and Rafale.
- Export orders: $375 million to Philippines (2022), and new orders/MoUs from Indonesia, Vietnam, Brazil.
- New Lucknow Defence Industrial Corridor facility inaugurated — will produce 80-100 BrahMos per year.

Static Background (Basics to Remember)

- **Cruise missiles** — powered, air-breathing missiles that fly aerodynamically (like an unmanned aircraft) to targets; subdivided by speed: subsonic (<Mach 1, Tomahawk, Nirbhay) / supersonic (BrahMos) / hypersonic (BrahMos-II, Zircon).
- **Ballistic vs cruise** — ballistic missiles follow a sub-orbital arc (gravity-driven), cruise missiles fly powered throughout.
- **Ramjet propulsion** — BrahMos uses a liquid-fuelled ramjet for supersonic sustained flight; scramjets are supersonic-combustion variants for hypersonic flight.
- **MTCR** (Missile Technology Control Regime, 1987) — voluntary non-proliferation regime; limits export of missiles with range ≥ 300 km / payload ≥ 500 kg. India joined 2016.
- **BrahMos Aerospace** — Indian-Russian JV incorporated 1998 under an Inter-Governmental Agreement; Indian partner is DRDO, Russian partner is NPO Mashinostroyeniya.

Prelims Connect

BrahMos variants

Variant	Platform	Range / Speed
BrahMos Block-I/II/III	Land (TEL, rail)	290-500 km, Mach 2.8
BrahMos Naval	Ships, submarines	290-500 km
BrahMos-A (Air)	Su-30 MKI	~400 km, air launch
BrahMos-ER (Extended)	All platforms	~800 km (in trial)
BrahMos-NG	Tejas, MiG-29K	290 km, lighter (~1.5 t)
BrahMos-II (Hypersonic, future)	Future	Target Mach 7-8

India joined the MTCR in 2016, allowing BrahMos to exceed the 300-km range limit. The Philippines became the first export customer (2022).

Prelims Pointers

- **BrahMos** = **Brahma**putra + **Mos**kva rivers; DRDO-NPOM JV.
- **Speed**: Mach 2.8-3 (world's fastest operational cruise missile).

- **Philippines** — 1st export customer (2022, $375 mn).
- **Lucknow Defence Corridor** hosts the new BrahMos integration complex (2025).
- **MTCR membership** (2016) let India extend BrahMos range beyond 290 km.

Missile Test Highlights 2025-26 — Pralay, Astra, Agni, K-4, Gandhiva

India conducted a record number of missile tests across 2025-26, strengthening deterrence across the air-land-sea-underwater triad. Key firsts: Pralay showcased at Republic Day 2025 parade, Astra BVRAAM fired from Su-30MKI, K-4 SLBM test from INS Arihant class, and the indigenous Gandhiva BVRAAM programme cleared.

News in Brief

- Pralay — short-range quasi-ballistic missile (150-500 km); first showcased at Republic Day 2025; salvo launch of 2 Pralays tested Dec 2025.
- Astra BVRAAM (Mk-1, 110 km) successfully fired from Su-30 MKI; Astra Mk-2 (160 km) in development; operational by 2026.
- Gandhiva — India's first indigenous long-range BVRAAM (LR-AAM), target range 300+ km; DRDO programme disclosed Mar 2025.
- Agni-Prime (2,000 km) successfully test-fired Sep 2025; Agni-III (3,000-5,000 km) and Agni-5 (5,500 km) tested Aug 2025 (strategic forces).
- K-4 submarine-launched ballistic missile tested from INS Arighaat / future Arihant-class (Dec 2025), range 3,500 km.
- Prithvi-II and Agni-I short-range ballistic missiles test-fired from Odisha in July 2025.
- STAR — Supersonic Target missile, DRDO (Sept 2025), used for training interceptor systems.
- Dhvani — hypersonic glide vehicle (HGV) under DRDO development.

Static Background (Basics to Remember)

- **Ballistic missile ranges** — SRBM (<1,000 km), MRBM (1,000-3,000), IRBM (3,000-5,500), ICBM (>5,500).
- **Triad of nuclear deterrence** — land (Agni), air (gravity bombs / ALCMs), sea (SLBMs); India achieved triad after INS Arihant's first deterrence patrol (2018).
- **BVRAAM** = Beyond Visual Range Air-to-Air Missile; uses active radar homing; > 80 km typical.
- **Quasi-ballistic** — a ballistic missile whose trajectory is depressed/shaped (not parabolic) to evade interceptors — Iskander-M, Pralay.
- **Strategic Forces Command (SFC)** — established 2003 under Indian Nuclear Command Authority; custodian of strategic nuclear weapons.
- **NFU doctrine** — India's nuclear doctrine declares 'No First Use' plus 'massive retaliation' in response to any nuclear attack.

Prelims Connect

India's missile arsenal — key entries

Missile	Class / Range	Developer / Status
Prithvi-II	SRBM, 350 km	DRDO, operational
Pralay	SRBM / quasi-ballistic, 150-500 km	DRDO, inducted 2024-25
Agni-I	MRBM, 700 km	DRDO, Strategic Forces

Agni-II / III	IRBM, 2,000-5,000 km	Operational
Agni-Prime	MRBM, 1,000-2,000 km	Tested Sep 2025
Agni-IV / V	ICBM-class, 4,000-5,500 km	Operational
K-4 (SLBM)	3,500 km	For Arihant-class SSBN
K-5 (SLBM, in dev)	5,000 km	For future SSBN
BrahMos	Cruise, 290-500 km	India-Russia JV
Astra Mk-1 / Mk-2	BVRAAM 110/160 km	DRDO
Gandhiva (LR-AAM)	BVRAAM 300+ km	DRDO, new 2025
Nirbhay	Sub-sonic cruise, 1,000 km	DRDO, operational
Dhvani (HGV)	Hypersonic glide vehicle	DRDO, under dev

'Quasi-ballistic' missiles follow a depressed/shaped trajectory to evade interceptors — Pralay and Iskander-M fall in this class.

Prelims Pointers

- **Pralay** = SRBM 150-500 km, quasi-ballistic; Republic Day 2025 debut.
- **Astra** = first indigenous **BVRAAM** (Beyond Visual Range Air-to-Air Missile).
- **Gandhiva** = India's planned long-range AAM (300+ km), DRDO 2025.
- **K-4 SLBM** — for India's **Arihant-class** SSBNs; 3,500 km range.
- **Dhvani** = DRDO's hypersonic glide vehicle programme.

Hypersonics & Directed Energy — LRHM, Dhvani, Mk-II(A) DEW, Golden Dome

India tested its long-range hypersonic missile and high-power laser directed-energy weapon in 2025, joining a select club. Globally, Russia's Burevestnik and the US 'Golden Dome' dominated hypersonic headlines.

News in Brief

- DRDO is preparing flight test of Long Range Hypersonic Missile (LRHM) — target > Mach 5, range ~1,500 km.
- India successfully tested its first high-power laser-based Directed Energy Weapon (DEW) — the Mk-II(A) — in April 2025 at Kurnool, destroying a fixed-wing UAV and swarm drones.
- Russia successfully tested Burevestnik (SSC-X-9 Skyfall) — a nuclear-powered, nuclear-armed cruise missile with nearly unlimited range (Oct 2025).
- US President announced 'Golden Dome' — a proposed US missile defence shield inspired by Israel's Iron Dome, with space-based interceptors and high-energy lasers.
- Michelangelo Dome — Italy's Leonardo-built integrated air-defence concept for multi-layer European protection.

Static Background (Basics to Remember)

- **Mach number** = speed/speed-of-sound (~1,225 km/h at sea level).
- **Hypersonic regime** — Mach 5+; extreme heat (skin temp 1,500°C+), plasma sheath disrupts comms.

- **HGV vs HCM** — Hypersonic Glide Vehicle (unpowered glide from boost rocket) vs Hypersonic Cruise Missile (powered by scramjet).
- **Directed Energy Weapons (DEW)** — use high-power lasers, microwaves or particle beams; speed-of-light engagement, low cost-per-shot, but power-hungry.
- **Iron Dome** — Israeli short-range SAM (4-70 km) by Rafael + IAI, operational since 2011; uses Tamir interceptor; >90% kill rate.
- **ABM Treaty** — US-USSR 1972 pact limiting missile defences; US withdrew 2002.

Prelims Connect

Hypersonic & DEW systems in news

System	Country	Type
LRHM	India (DRDO)	Long-range hypersonic missile
Dhvani	India (DRDO)	Hypersonic glide vehicle
BrahMos-II (future)	India-Russia	Mach 7-8 hypersonic
Burevestnik	Russia	Nuclear-powered cruise missile
Avangard (HGV)	Russia	Mach 27 hypersonic glide vehicle
DF-ZF	China	HGV on DF-17
Golden Dome (proposed)	USA	Space-based missile defence
Iron Dome	Israel	Short-range air defence
Michelangelo Dome	Italy	Layered air defence concept
Mk-II(A) DEW	India (DRDO, Kurnool)	High-power laser, counter-drone

Hypersonic = speeds above Mach 5. Two main classes: Hypersonic Glide Vehicles (HGV) — boosted-glide, and Hypersonic Cruise Missiles (HCM) — scramjet/ramjet powered throughout.

Prelims Pointers

- **Hypersonic** = Mach 5 or higher.
- **Mk-II(A)** — India's **first high-power laser DEW** (DRDO, Apr 2025).
- **Golden Dome** = proposed US multi-layer missile-defence shield.
- **Burevestnik** = Russian nuclear-powered cruise missile (Oct 2025 test).
- **Iron Dome** = Israeli short-range air defence (Rafael).

Naval Commissioning Spree — Nilgiri, Surat, Udaygiri, Tushil, Tamal, Anjadip, Aridhaman, Arnala, Androth, Mahe, Tabar, Sutlej

The Indian Navy inducted a record number of indigenous platforms in 2025-26 across submarines, frigates, and anti-submarine warfare vessels, including three Nilgiri-class stealth frigates, the lead ASW Shallow Water Craft INS Arnala, and the third indigenous SSBN INS Aridhaman.

News in Brief

- INS Tushil — Russia-built Talwar-class Project 1135.6 stealth missile frigate commissioned Dec 2024 (in-service Jan 2025).
- INS Surat — Project 15B Visakhapatnam-class destroyer; fired a Medium-Range SAM (MR-SAM/Barak-8) in Apr 2025.
- INS Nilgiri, Udaygiri, Taragiri, Tavasya — Project 17A stealth frigates (lead ship INS Nilgiri commissioned Jan 2025; Taragiri 4th ship; Udaygiri, Tavasya by late 2025).
- INS Arnala — first Anti-Submarine Warfare Shallow Water Craft (ASW-SWC), commissioned June 2025 (16 planned).
- INS Androth — 2nd ASW-SWC commissioned Oct 2025; INS Mahe — 1st of Cochin Shipyard's ASW-SWC batch, handed over Nov 2025.
- INS Anjadip — 3rd ASW-SWC commissioned Feb 2026.
- INS Aridhaman — India's 3rd indigenous SSBN, commissioned Dec 2025; President Droupadi Murmu made a sea sortie aboard it.
- INS Tamal — Russia-built Project 1135.6 stealth multi-role frigate commissioned June 2025.
- Scorpene class — MDL delivered the 6th and final Scorpene-class SSK submarine (INS Vagsheer) in Jan 2025.
- ICGS Amulya and ICGS Atal — Adamya-class Coast Guard patrol vessels commissioned 2025.
- MH-60R Seahawk helicopters — Indian Navy commissioned 2nd squadron (Dec 2025).
- INS Sindhughosh — Kilo-class submarine decommissioned (Dec 2025) after 4 decades of service.

Static Background (Basics to Remember)

- **Indian Navy commands** — Western (Mumbai), Eastern (Visakhapatnam), Southern (Kochi, training); Tri-Services Andaman & Nicobar Command (Port Blair).
- **Warship classes** — Aircraft Carrier > Destroyer > Frigate > Corvette > OPV > Patrol Vessel.
- **Shipyards** — MDL Mumbai (destroyers/subs), GRSE Kolkata (frigates/corvettes), GSL Goa (OPVs), CSL Kochi (carriers), HSL Visakhapatnam (fleet tankers).
- **Stealth features** — low radar cross section (angled hull), radar-absorbent materials, reduced infrared/acoustic signature.
- **ASW Shallow Water Craft (ASW-SWC)** — small (~900 t) fast craft for coastal anti-submarine warfare and mine counter-measures.
- **Project 75** (Scorpene) — 6 conventional diesel-electric submarines built at MDL under French TOT, 2017-2025.

Prelims Connect

Key Indian Navy projects in news

Project	Platform	Builder
Project 17A	Nilgiri-class stealth frigates	MDL & GRSE
Project 15B	Visakhapatnam-class destroyers	MDL
Project 75 (I)	Scorpene-class SSK	MDL (TOT: DCNS/Naval Group)
ATV Programme	Arihant / Aridhaman SSBN	SBC Visakhapatnam
Project 1135.6	Talwar-class frigates	Yantar (Russia) / GSL

ASW-SWC	Arnala-class	GRSE / Cochin Shipyard
Adamya-class	Coast Guard OPVs	GSL Goa

INS Aridhaman is India's 3rd SSBN (nuclear-powered ballistic-missile submarine). The 1st was INS Arihant (2016), 2nd INS Arighaat (2024).

Prelims Pointers

- **INS Aridhaman** — India's 3rd indigenous **SSBN** (commissioned Dec 2025).
- **Project 17A** = Nilgiri-class stealth frigates (MDL + GRSE).
- **Project 15B** = Visakhapatnam-class destroyers (Surat, Visakhapatnam, Mormugao, Imphal).
- **ASW-SWC** = Anti-Submarine Warfare Shallow Water Craft (Arnala, Androth, Mahe, Anjadip).
- **INS Tamal, INS Tushil** — Russia-built Talwar-class Project 1135.6.

INS Varsha & Strategic Naval Infrastructure

India is preparing to operationalise INS Varsha — a dedicated naval base for nuclear-powered submarines on the east coast — as the centrepiece of its strategic underwater deterrent, alongside the repositioning of Scorpene submarines and commissioning of the 3rd SSBN INS Aridhaman.

News in Brief

- INS Varsha is a naval base being built near Rambilli, Andhra Pradesh, exclusively for nuclear submarines.
- It will house tunnels, underground pens, and a secure nuclear-handling facility — India's only dedicated SSBN base.
- Complements the existing Eastern Naval Command HQ at Visakhapatnam.
- Mazagon Dock delivered the final Scorpene-class submarine (INS Vagsheer) to Indian Navy in January 2025 — completing Project 75.
- A follow-on Project 75(I) will build 6 AIP-equipped submarines with foreign technology partners.
- India-Brazil tripartite MoU signed (Dec 2025) to cooperate on Scorpene-class submarine maintenance and technology sharing.

Static Background (Basics to Remember)

- **Submarine classes** — SSK (diesel-electric attack), SSN (nuclear attack), SSBN (nuclear-powered, nuclear ballistic), SSGN (cruise-missile), SS (diesel attack).
- **AIP** = Air-Independent Propulsion — lets diesel-electric subs stay submerged for 2-3 weeks without snorkelling; DRDO developed a fuel-cell AIP cleared for retrofit.
- **INS Arihant** (commissioned 2016) is India's first indigenous SSBN; completed first deterrent patrol Nov 2018 giving India a triad.
- **K-family missiles** — K-15 Sagarika (700 km), K-4 (3,500 km), K-5 (5,000 km, in dev) — submarine-launched ballistic missiles.
- **BHARAT SHAKTI doctrine** — emphasises indigenous defence production; 75% of defence capital budget earmarked for domestic procurement (FY24-25).

Prelims Connect

Indian submarine fleet — at a glance (2025)

Class	Count	Propulsion	Builder

Arihant / Aridhaman (SSBN)	3 (Arihant, Arighaat, Aridhaman)	Nuclear	SBC Visakhapatnam
Scorpene (Kalvari-class SSK)	6	Diesel-Electric	MDL (TOT France)
Kilo / Sindhughosh-class	~7 (declining)	Diesel-Electric	Russia
Type 209 / Shishumar-class	4	Diesel-Electric	HDW (Germany)
Akula-class lease	INS Chakra (expected replacement from Russia)	Nuclear (attack)	Russia (leased)

SSBN = Ship Submersible Ballistic Nuclear (strategic); SSN = Ship Submersible Nuclear (attack). India is building 3-6 indigenous SSNs at Visakhapatnam.

Prelims Pointers

- **INS Varsha** — dedicated **SSBN base** at Rambilli (Andhra Pradesh).
- **Project 75** (6 Scorpene-class) completed Jan 2025 with **INS Vagsheer**.
- **Project 75(I)** = follow-on 6 conventional AIP-equipped submarines.
- **Arihant-class SSBN** built at Ship Building Centre (SBC), Visakhapatnam.
- **Akula / INS Chakra** = Russian-leased nuclear attack submarine (SSN).

Sudarshan Chakra Mission — Integrated Air Defence Shield

Launched in August 2025, Mission Sudarshan Chakra is India's ambitious long-term initiative to create a comprehensive, multi-layered, AI-enabled air defence shield — often described as India's answer to Israel's Iron Dome. It will integrate radars, missiles, lasers, and counter-drones into a single kill-chain.

News in Brief

- Announced by PM Modi during his Independence Day 2025 address as a 'gift' to the nation.
- Target: to be operational by 2035; fully indigenous with private-sector participation.
- Layers integrate: Akash NG, QRSAM, MR-SAM/Barak-8, LR-SAM (S-400 Indian derivative), ABM system, DEW lasers, and Bhargavastra.
- Backed by BEL, BDL, DRDO and private sector; includes AI-enabled command & control.
- Parallel 'Sudarshan Chakra Air Defence Mission' tested integrated command in Exercise Vayu Samanvay-II (Nov 2025).

Static Background (Basics to Remember)

- **Multi-layered air defence** structure — concentric layers of radars, missiles and guns; each layer covers different altitude/range.
- **IACCS** (Integrated Air Command and Control System) — IAF's automated C2 backbone integrating radars, fighters, SAMs, AEW&C.
- **India's indigenous BMD programme** (2006-) — 2 layers: Prithvi Air Defence (PAD, exo-atmospheric) + Advanced Air Defence (AAD, endo-atmospheric).
- **Command & Control** — Indian Air Force Air Defence Command structure oversees integrated air defence.

- **BEL** (Bharat Electronics Ltd) and **BDL** (Bharat Dynamics Ltd) are the prime DPSUs for air-defence missiles, radars, and electronics.

Prelims Connect

Indian indigenous air-defence layers

System	Range	Role
QRSAM (DRDO)	30 km	Quick-reaction, mobile
Akash / Akash NG	25-70 km	Medium-range SAM
MR-SAM / Barak-8 (IAI+DRDO)	70-100 km	Medium-long
LR-SAM / Barak-8 ER	150 km	Long-range area defence
S-400 'Sudarshan'	400 km	Long-range imported
Project Kusha (indigenous S-400)	350 km target	LR-SAM indigenous
Bhargavastra	2-3 km	Counter-drone micro-missile
Mk-II(A) DEW laser	5 km	Counter-drone laser
BMD Phase-1 AAD/PDV	Exo & endo-atmospheric	Anti-ballistic

Project Kusha is BEL's indigenous long-range SAM programme aimed at creating an Indian equivalent of the S-400 system by ~2028-30.

Prelims Pointers

- **Mission Sudarshan Chakra** = multi-layer AI-enabled air defence; operational target 2035.
- **Project Kusha** = indigenous long-range SAM (target 350 km).
- **Bhargavastra** = indigenous micro-missile counter-drone system.
- **S-400** is also called 'Sudarshan Chakra' in Indian service.
- **India-Israel joint BMD**: MR-SAM / LR-SAM (Barak-8) family.

Aerial Platforms — Rafale-M, Tejas Mk-1A, HANSA-3(NG), LCA Tejas Engine

Indian Air Force and Navy firmed up key aerial platforms in 2025-26 — the Indian Navy selected the Dassault Rafale-M for carrier aviation, LCA Tejas Mk-1A received GE-F404 engines, and HAL's HANSA-3 (NG) trainer aircraft was unveiled.

News in Brief

- Indian Navy selected Rafale-M for carrier-based aviation (MRCBF) — 26 jets contract ~₹63,000 cr.
- The deal was signed with Dassault in April 2025; Rafale-M to operate from INS Vikrant and Vikramaditya.
- GE Aerospace delivered the 1st and 2nd F404-IN20 engines for LCA Tejas Mk-1A in early–July 2025, ending 2-year delay.
- HAL unveiled HANSA-3 (NG), India's indigenously developed two-seater low-wing trainer, with a Rotax 912 iS Sport engine.
- Negotiations moving towards India-France Rafale-F4 fighter deal for ~96 more jets for IAF.

Static Background (Basics to Remember)

- **Fighter generations** — 4th (F-16, Mirage 2000), 4.5 (Rafale, Su-30, Typhoon), 5th (F-35, F-22, J-20, Su-57).
- **MRCA tender** — Medium Multi-Role Combat Aircraft; India first ran this in 2007 → awarded Rafale deal (2016, 36 jets).
- **HAL** (Hindustan Aeronautics Ltd, est 1940) — India's largest aerospace PSU; HQ Bengaluru; builds LCA, HTT-40, SU-30 MKI under licence, ALH Dhruv, LCH Prachand.
- **LCA Tejas** — light single-engine fighter, 4.5-gen; first flew 2001; two variants Mk-1 (operational) and Mk-1A (improved).
- **AMCA** — Advanced Medium Combat Aircraft: India's 5th-gen stealth twin-engine fighter under DRDO-ADA development; first flight target 2028-29.
- **Engine issues** — GE F404/F414 engines used in Tejas; India is also co-developing a 110 kN class engine with France's Safran.

Prelims Connect

Key IAF/Navy aircraft deals

Platform	Origin	Use
Rafale (IAF)	Dassault, France	36 jets in service; 96 under negotiation
Rafale-M (Navy)	Dassault, France	26 carrier-based jets (2025 deal)
LCA Tejas Mk-1A	HAL, India (GE engine)	IAF order 83+97 jets
Tejas Mk-2 (MWF)	HAL, India	Under development
TEDBF	HAL, India	Twin-engine deck-based fighter, future
AMCA	HAL+DRDO, India	5th-generation stealth fighter
HANSA-3 (NG)	CSIR-NAL / HAL	Civilian trainer

LCA Tejas Mk-1A has a GE F404 engine; Tejas Mk-2 will use the more powerful F414 (GE). India is also co-developing GTRE's Kaveri engine with France's Safran.

Prelims Pointers

- **Rafale-M** — 26 jets for Indian Navy (April 2025 deal).
- **LCA Tejas Mk-1A** uses **GE F404-IN20** engine.
- **HANSA-3 (NG)** = HAL's indigenous basic trainer (2-seater low-wing).
- **AMCA** = Advanced Medium Combat Aircraft (5th-gen stealth, under development).
- **INS Vikrant + Vikramaditya** are India's aircraft carriers; Rafale-M will fly from both.

Drone Warfare — Cold Start, Rudrastra, Vayu Samanvay, SAKSHAM, Ghost Bat

Drones and counter-drones dominated India's 2025-26 defence narrative with the Indian Army's Rudrastra UAV trials, the tri-service Exercise Cold Start, SAKSHAM counter-UAS grid, and the emergence of the MQ-28A Ghost Bat as the global benchmark for 'robotic wingmen'.

News in Brief

- Exercise Cold Start (Sept 2025) — India's mega drone drill, a tri-service exercise testing integrated drone warfare.
- Rudrastra UAV — indigenous precision-strike drone developed by Indian Army, successfully trialled June 2025.
- Vayu Samanvay-II (Nov 2025) — large-scale drone and AD coordination exercise.
- SAKSHAM — Indian Army's indigenous Counter-UAS grid (Oct 2025) combining radars, jammers, and kinetic kill.
- MQ-28A Ghost Bat — Australia's first locally built AI 'loyal wingman' military drone.
- Ghost Jellyfish — China's transparent jellyfish-shaped underwater drone.
- Bayraktar TB2 — Turkish MALE combat drone, widely used globally; Pakistan's Songar drones intercepted during Op Sindoor.
- SITAC Corridor — IndiaAI Mission + Business Sweden MoU for next-gen drone ecosystem (Feb 2026).

Static Background (Basics to Remember)

- **UAV classes** — Nano (<200 g), Micro (<2 kg), Mini (<20 kg), MALE (Medium Altitude Long Endurance), HALE (High Altitude Long Endurance), UCAV (Combat).
- **Drone Rules 2021** — India's liberalised drone regulations; 'green/yellow/red zone' airspace classification; Digital Sky platform for permissions.
- **PLI for drones** — ₹120 cr production-linked incentive scheme launched 2021.
- **Loitering munitions / kamikaze drones** — circle over target zone and dive on targets when commanded; used heavily in recent conflicts.
- **Swarm drones** — networked drones acting autonomously as a group; saturate air-defence systems; proven in Naga exercises.
- **iDEX** = Innovation for Defence Excellence (2018) — Department of Defence Production programme to fund startups.

Prelims Connect

Drones in news 2025-26

Drone	Country / Maker	Class / Role
MQ-28A Ghost Bat	Boeing / RAAF (Australia)	AI 'robotic wingman'
Bayraktar TB2 / TB3 / Akinci	Baykar (Turkey)	MALE strike UAV
Songar	Asisguard (Turkey)	Armed tactical drone
Ghost Jellyfish	China	Transparent underwater drone
Rudrastra	Indian Army	Precision-strike UAV
SWITCH, Nagastra, ALS-50	Indian private firms	Loiter / tactical
Predator MQ-9B (SeaGuardian/SkyGuardian)	General Atomics (US)	HALE armed ISR, India procuring 31

'Loyal wingman' drones are AI-piloted drones designed to fly alongside manned fighters, extending sensor and strike range.

Prelims Pointers

- **Exercise Cold Start** = tri-service drone drill (Sept 2025).
- **Rudrastra** — indigenous **Indian Army precision-strike drone**.
- **SAKSHAM** = indigenous **Counter-UAS grid** (Indian Army).
- **MQ-9B** (Predator) — 31 unit India-US deal in 2024; delivery 2025-29.
- **Bayraktar TB2** — Turkish-made, widely used in global conflicts.

Major Military Exercises — Varuna, Indra, AIKEYME, Konkan, Pacific Reach, Tarkash-PASSEX, Vayushakti

2025-26 saw India engaged in a heavy calendar of bilateral, trilateral and multilateral military exercises, reinforcing its Indo-Pacific posture and maritime diplomacy.

News in Brief

- VARUNA 2025 — 22nd edition of India-France bilateral naval exercise (Mar 2025).
- INDRA 2025 — 14th India-Russia bilateral naval exercise.
- AIKEYME (Africa-India Key Maritime Engagement) — inaugural India-Africa naval exercise in Dar-es-Salaam (Mar 2025).
- KONKAN 2025 — India-UK bilateral maritime exercise, Arabian Sea (Oct 2025).
- Pacific Reach XPR-25 — Singapore-hosted multinational submarine rescue exercise.
- DOSTI-17 — 17th edition trilateral Coast Guard exercise India-Maldives-Sri Lanka, held in Maldives (Jan 2026).
- Exercise Vayushakti (Feb 2026) — IAF firepower demo held at Pokhran.
- Exercise Agni Varsha (Feb 2026) — Indian Army Southern Command artillery exercise.
- Tarkash-PASSEX — Indian Navy's INS Tarkash and Greek Navy's HS Psara (July 2025).
- AMPHEX, TROPEX, MILAN — other recurring Indian Navy exercises.

Static Background (Basics to Remember)

- **Defence diplomacy** — exercises, port calls, joint training build strategic trust and interoperability.
- **Types of exercises**: bilateral, trilateral, multilateral; PASSEX (passage exercise during transits), CPX (command post), FTX (field training).
- **MALABAR** — flagship naval exercise launched 1992 as India-US bilateral; expanded to Quad (India-US-Japan-Australia).
- **Quad** (Quadrilateral Security Dialogue) — strategic grouping revived 2017; focuses on Indo-Pacific stability.
- **I2U2** — India, Israel, UAE, USA grouping for economic/tech cooperation.
- **Joint doctrine for Indian Armed Forces** (CDS framework) drives tri-service jointness — culminated in the creation of the CDS post in 2019.

Prelims Connect

Select India-led / India-involved exercises

Exercise	Partner(s)	Domain
VARUNA	France	Naval
INDRA	Russia	Naval / Tri-services
MALABAR	USA+Japan+Australia (Quad)	Naval
AIKEYME (new 2025)	Africa (14 nations)	Maritime

KONKAN	United Kingdom	Naval
DOSTI	Maldives + Sri Lanka	Coast Guard
YUDH ABHYAS	USA	Army
SHAKTI	France	Army
NOMADIC ELEPHANT	Mongolia	Army
MITRA SHAKTI	Sri Lanka	Army
SURYA KIRAN	Nepal	Army
GARUDA SHAKTI	Indonesia	Special Forces
TARANG SHAKTI	Multinational air	Air Force

AIKEYME (Africa-India KEY Maritime Engagement) launched in 2025 is India's first dedicated multilateral naval exercise with African nations.

Prelims Pointers

- **AIKEYME** = India-Africa maritime exercise (**inaugural 2025**, Dar-es-Salaam).
- **VARUNA** — India-France naval (22nd ed 2025).
- **INDRA** — India-Russia naval (14th ed 2025).
- **KONKAN** — India-UK naval exercise.
- **DOSTI-17** — trilateral India-Maldives-Sri Lanka Coast Guard (2026).

Big-Ticket Procurements — Scorpene, Pralay, HAMMER, Klub-S, Agni, Akash to Brazil

The Defence Acquisition Council cleared several mega-contracts in 2025-26, strengthening both imports and indigenous manufacturing. Big Rafale-F4, Scorpene-addendum, HAMMER missile, Klub-S, and first Akash export to Brazil topped the list.

News in Brief

- Pralay procurement: MoD signed ~₹2,867 cr for the second regiment of Pralay missiles (Jan 2025).
- BDL contract: MoD signed with Bharat Dynamics Ltd for air-defence missile systems (Jan 2025, ₹2,960 cr).
- Klub-S — India signed contract with Russia for anti-ship cruise missiles for Kilo-class submarines (Feb 2025).
- HAMMER — Bharat Electronics Limited + France's Safran jointly produce AASM HAMMER air-to-ground precision weapon (announced Feb 2025).
- Akash to Brazil — India formally offered the indigenous Akash air defense system to Brazil (Oct 2025).
- Largest-ever procurement — DAC cleared ~₹1.1 lakh crore worth of deals in Feb 2026 for Agni-III, Astra Mk-2, Scorpene follow-on, additional Rafale etc.
- Gaurav LRGB — indigenously developed Long Range Glide Bomb (Apr 2025).
- BM-04 — India's newly unveiled short-range ballistic missile (Apr 2025, Hyderabad Defence Expo).
- Rudram-II — anti-radiation missile for SEAD (Suppression of Enemy Air Defences).

Static Background (Basics to Remember)

- **DAC** = Defence Acquisition Council — apex procurement body chaired by Defence Minister; takes Acceptance of Necessity (AoN) decisions.
- **Defence Acquisition Procedure (DAP) 2020** — categories: Buy (Indian - IDDM) > Buy Indian > Buy & Make (Indian) > Buy Global - IDDM.
- **Offset clause** — foreign vendors above ₹2,000 cr contracts must reinvest ≥30% in Indian defence industry (now optional for G2G).
- **Atmanirbhar Bharat in defence** — positive indigenisation lists block imports of listed items; 5 lists issued 2020-24 covering 500+ items.
- **Defence exports** — crossed ₹23,000 cr in FY2024-25; target ₹50,000 cr by 2028-29.
- **Defence corridors** — two corridors in Tamil Nadu and Uttar Pradesh; nodes at Chennai, Coimbatore, Salem, Tiruchirappalli, Hosur, and Agra, Aligarh, Jhansi, Lucknow, Kanpur, Chitrakoot.

Prelims Connect

India defence procurement — 2025-26 highlights

Deal / System	Partner	Value / Status
Klub-S missiles	Russia	For Kilo-class SSKs
Pralay regiments	Indigenous (BDL)	~₹2,867 cr (Jan 2025)
Rafale-M (26)	France	~₹63,000 cr (Apr 2025)
HAMMER	BEL + Safran (France)	JV licensed production
MH-60R (24 helicopters)	US (Lockheed)	Foreign Military Sale
MQ-9B Predator (31)	US (General Atomics)	₹32,000 cr
Akash to Brazil (export)	India-Brazil (offer)	First major SAM export
Gaurav LRGB	Indigenous (DRDO)	Precision glide bomb (Apr 2025)
BM-04	Indigenous	Short-range BM (Apr 2025)
Feb 2026 mega DAC	Mixed	~₹1.1 lakh cr largest tranche

Defence exports surpassed ₹23,000 crore in FY24-25, marking record highs. Key exports: BrahMos, Akash, ICGS patrol vessels, Dornier aircraft.

Prelims Pointers

- **Rafale-M** for Navy — 26 jets, ₹63,000 cr.
- **HAMMER** = AASM air-to-ground precision weapon by **Safran (France)** + BEL.
- **Klub-S** = Russian-origin anti-ship cruise missile for **Kilo-class** submarines.
- **Gaurav** = Long Range Glide Bomb by DRDO.
- **Akash** — offered as India's first export to Brazil (Oct 2025).

Exercises, Global Arms & Strategic Deployments — Minuteman-III, Type-076, Khorramshahr-4, Khabarovsk, Hyunmoo-5

Global arms developments in 2025-26 underscored renewed strategic competition. The US test-fired Minuteman-III ICBMs, China unveiled the Type-076 'super drone carrier', Iran rolled out Khorramshahr-4, Russia launched new SSBNs, and South Korea prepared to deploy the Hyunmoo-5 'monster missile'.

News in Brief

- Minuteman III — US test-fired an unarmed Minuteman III ICBM from Vandenberg Space Force Base (Nov 2025).
- Type-076 Sichuan — China's revolutionary amphibious assault ship-cum-super drone carrier with EMALS catapult (Nov 2025).
- Khorramshahr-4 (Kheibar) — Iran's new 2,000-km range ballistic missile, revealed Feb 2026.
- Khabarovsk — Russia's newest nuclear submarine, designed to carry nuclear-powered Poseidon torpedoes (Nov 2025).
- Hyunmoo-5 — South Korea's 'monster missile' with an 8-ton warhead, under preparation for deployment (Oct 2025).
- Burevestnik — Russia's nuclear-powered cruise missile test (Oct 2025).
- AIM-120 AMRAAM — US confirmed supplies to Pakistan (Oct 2025).
- Perm (Russia) — first Zircon-armed nuclear submarine launched (April 2025).
- Loudi (Hull 176) — China's People's Liberation Army Navy (PLAN) commissioned an upgraded Type-054 frigate (Jan 2026).

Static Background (Basics to Remember)

- **Nuclear Non-Proliferation Treaty (NPT, 1968)** — 5 recognised Nuclear Weapon States (US, Russia, UK, France, China); India, Pakistan, Israel are not signatories.
- **MIRV** = Multiple Independently-targetable Reentry Vehicles — a single missile carries several warheads aimed at different targets. India tested MIRV on Agni-V in Mar 2024 (Mission Divyastra).
- **Tactical vs strategic** nuclear weapons — tactical are battlefield low-yield; strategic are long-range city-busters.
- **ICBM** = Inter-Continental Ballistic Missile, range >5,500 km; US Minuteman III is one of the longest-serving.
- **Poseidon torpedo** — Russian nuclear-powered, nuclear-armed unmanned underwater vehicle with intercontinental range.
- **EMALS** = Electromagnetic Aircraft Launch System; replaces steam catapults; needs large electrical power.

Prelims Connect

Global strategic platforms in news

System	Country	Type
Minuteman III	USA	Land-based ICBM (test Nov 2025)
Type-076 Sichuan	China	'Super drone carrier' LHD
Khorramshahr-4	Iran	MRBM, 2,000 km
Khabarovsk	Russia	SSBN / Poseidon-carrier
Hyunmoo-5	South Korea	Bunker-buster tactical ballistic
Burevestnik	Russia	Nuclear-powered cruise missile

AIM-120 AMRAAM	USA → Pakistan	Air-to-air missile supply
Perm (nuclear sub)	Russia	Zircon-armed SSN

EMALS = Electromagnetic Aircraft Launch System; first used by USS Gerald R. Ford. Type-076 Sichuan is the first non-US ship with EMALS.

Prelims Pointers

- **Minuteman III** = US land-based ICBM, 10,000+ km range.
- **Type-076 Sichuan** = Chinese amphibious ship with EMALS (first non-US EMALS ship).
- **Khorramshahr-4** — Iran, 2,000 km range MRBM.
- **Khabarovsk** — Russian SSBN designed for Poseidon nuclear torpedoes.
- **Hyunmoo-5** — South Korea's 8-ton bunker-buster tactical missile.

DRDO Milestones — ILSS, DEW, Cyber Suraksha, Pinaka, Terrier Quest

DRDO notched multiple milestones in 2025-26 — developing an Integrated Life Support System, testing high-energy laser weapons, Pinaka Long Range Guided Rocket, and running 'Cyber Suraksha' and 'Terrier Cyber Quest' cyber-defence exercises.

News in Brief

- DRDO developed an indigenous Integrated Life Support System (ILSS) for armoured vehicles and submarines (Mar 2025).
- Mk-II(A) laser weapon — first indigenous HPL DEW — test-fired at Kurnool Apr 2025.
- Pinaka LRGR-120 — Long Range Guided Rocket (120 km) first flight test successful (Dec 2025).
- Exercise Cyber Suraksha — 12-day DRDO-led cyber defence exercise for Indian armed forces (June 2025).
- Terrier Cyber Quest 2025 — national-level cybersecurity challenge organised by Indian Army (Aug 2025).
- Mission Sudarshan Chakra — integrated air defence shield announced.
- DRDO tested parachute recovery system of Gaganyaan Crew Escape System in Feb 2026.
- SMART — Supersonic Missile Assisted Release of Torpedo system continues trials.

Static Background (Basics to Remember)

- **DRDO** — est 1958 by merging Technical Development Establishment + Directorate of Technical Development & Production with Defence Science Organisation.
- **Structure** — ~52 labs under DRDO; HQ DRDO Bhawan, New Delhi.
- **Flagship missile programmes** — Integrated Guided Missile Development Programme (IGMDP, 1983-2008) under Dr APJ Abdul Kalam delivered Prithvi, Agni, Akash, Nag, Trishul.
- **Reforms 2020** — private-sector access to DRDO patents royalty-free; technology transfer through ToT (Transfer of Technology).
- **Dr Samir V Kamat** — Chairman DRDO & Secretary DDR&D since 2022.
- **Defence R&D spending** — India spends <1% of defence budget on R&D (vs ~12% in US); aim to double via Defence Technology Fund.

Prelims Connect

DRDO signature systems — 2025 highlights

System	Purpose
Pinaka Mk-I / II	Multi-barrel rocket launcher, 40-90 km

Pinaka LRGR-120	120-km long-range guided rocket
BrahMos	Supersonic cruise missile
Akash / Akash NG	Indigenous SAM
Prithvi / Agni / Pralay / K-4 / K-5	Ballistic missiles
NAG / HELINA / SANT	Anti-tank missiles
Arjun Mk-1A / Mk-2	Main Battle Tank
Mk-II(A)	Laser DEW (counter-drone)
SMART	Missile-assisted torpedo
ULPGM / Rudrastra	Drone-launched munitions

DRDO (est 1958) now has 50+ labs; headed by Chairman DRDO + Secretary Dept of Defence R&D; from 2024 Dr Samir V Kamat has been chairman.

Prelims Pointers

- **Pinaka LRGR-120** = long-range guided rocket 120 km, DRDO, Dec 2025.
- **ILSS** = Integrated Life Support System for armoured vehicles.
- **Exercise Cyber Suraksha** = DRDO-led armed forces cyber exercise (June 2025).
- **Mk-II(A)** laser weapon tested at Kurnool, **Apr 2025**.
- **DRDO** — HQ in New Delhi; Chairman **Dr Samir V Kamat**.

NUCLEAR, ENERGY, QUANTUM & SEMICONDUCTORS

National Quantum Mission — Q-City, Amaravati, Fabrication Facility

India's National Quantum Mission (NQM, 2023-2031) gathered pace in 2025-26 with landmark announcements: Karnataka setting up 'Q-City' at Hesaraghatta, Andhra Pradesh launching the first Quantum Computing Valley at Amaravati, and the centre opening its first Quantum Fabrication Facility.

News in Brief

- National Quantum Mission (NQM) — approved April 2023, outlay ₹6,003.65 cr over 2023-31.
- NQM goals: develop intermediate scale (50-1,000 physical qubit) quantum computers, quantum communication ~2000 km, single photon sources, and quantum sensors.
- Q-City — Karnataka's proposed Quantum City at Hesaraghatta near Bengaluru (Nov 2025).
- Quantum Computing Valley of India — launched in Amaravati, Andhra Pradesh (Feb 2026).
- National Quantum Fabrication & Central Facilities — inaugurated under NQM with Central facility hubs at IISc Bengaluru, IIT Madras, TIFR Mumbai, IIT Bombay (Nov 2025).
- Tamil Nadu Technology (iTNT) Hub partnered with German deep-tech XeedQ GmbH to bring India's first commercial quantum computer (Jan 2026).

Static Background (Basics to Remember)

- **Quantum computing basics** — uses qubits (quantum bits) that exploit **superposition** (can be 0 and 1 simultaneously) and **entanglement** (linked states across distance) instead of classical binary bits.

- **National Quantum Mission (NQM)** — approved 2023, ₹6,003 cr outlay (2023-24 to 2030-31); aims for intermediate-scale quantum computers (50-1,000 qubits) in superconducting & photonic platforms.
- **Four verticals of NQM** — (1) Quantum Computing, (2) Quantum Communication, (3) Quantum Sensing & Metrology, (4) Quantum Materials & Devices; implemented via 4 Thematic Hubs (T-Hubs) at IISc, IIT-M, IIT-B, IIT-D.
- **Q-City & Amaravati Quantum Valley** — Andhra Pradesh's flagship to host quantum computing, communication & fabrication; India to join USA, China, EU, Japan as a sovereign quantum nation.
- **Global quantum race** — IBM (1,121-qubit Condor), Google (Willow 105-qubit 2024), China (Jiuzhang photonic, Zuchongzhi superconducting); Willow demonstrated quantum error correction below threshold.
- **Applications** — cryptography, drug discovery, materials science, weather modelling, financial optimisation, AI acceleration. Threat: 'Y2Q' or Q-Day when quantum computers break RSA/ECC encryption.

Prelims Connect

National Quantum Mission — 4 Thematic Hubs

Thematic Hub	Lead Institute
Quantum Computing	IISc Bengaluru
Quantum Communication	IIT Madras
Quantum Sensing & Metrology	IIT Bombay
Quantum Materials & Devices	IIT Delhi

NQM targets: 50-1000 physical qubit intermediate scale computers in 8 years; quantum key distribution over 2,000 km intercity; satellite-based secure quantum communications over 2,000 km.

Prelims Pointers

- **National Quantum Mission** approved April 2023 — **₹6,003.65 cr** outlay, **2023-2031**.
- **4 NQM thematic hubs**: Computing (IISc), Communication (IIT-M), Sensing (IIT-B), Materials (IIT-D).
- **Quantum Computing Valley** launched at **Amaravati, Andhra Pradesh** (Feb 2026).
- **Q-City** at **Hesaraghatta, Karnataka** (Nov 2025).
- **XeedQ** = German firm partnering Tamil Nadu for quantum computer (Jan 2026).

QKD, Majorana 1 & Quantum Gravity Gradiometer

India and the world clocked multiple quantum-technology firsts in 2025 — India's first 4-channel Quantum Key Distribution over 100 km, Microsoft's Majorana 1 'topological' quantum chip, and NASA's first space-based Quantum Gravity Gradiometer Pathfinder.

News in Brief

- India successfully tested its first 4-channel Quantum Key Distribution (QKD) transmission over 100 km fibre (Apr 2025) — crucial for ultra-secure govt/defence communications.
- Majorana 1 (Feb 2025) — Microsoft introduced the world's first quantum chip powered by topoconductors using Majorana fermions (topological qubits).
- NASA announced launch plans for the first space-based Quantum Gravity Gradiometer Pathfinder — which uses ultracold rubidium atoms to measure gravity anomalies.
- Indian researchers at C-DOT developed indigenous QKD systems.

- Quantum technologies span computing, communication, sensing, and cryptography — classified as a 'deep tech' priority by MeitY.

Static Background (Basics to Remember)

- **QKD — Quantum Key Distribution** — uses the **no-cloning theorem** and Heisenberg uncertainty so any eavesdropping on a quantum key is instantly detected; basis is the **BB84 protocol** (Bennett & Brassard, 1984).
- **QKD milestones in India** — DRDO-IIT Delhi achieved 100 km fibre QKD in 2022; ISRO demonstrated free-space QKD (Space Applications Centre, 2022); BSNL partnered for commercial QKD links.
- **Majorana fermions** — exotic particles predicted by Italian physicist Ettore Majorana in 1937 that are their own antiparticles; **topological qubits** made from them are theoretically far more stable than conventional qubits.
- **Microsoft Majorana 1** — February 2025, first 'topological qubit' chip using indium-arsenide/aluminium nanowires; branded 'Topological Core' architecture.
- **Quantum Gravity Gradiometer** — uses laser-cooled atoms in free fall to measure minute differences in Earth's gravity; applications in finding underground tunnels, minerals, submarines, archaeological mapping.
- **Post-quantum cryptography** — NIST released first PQC standards (ML-KEM, ML-DSA, SLH-DSA) in August 2024; India's **SAMIKSHA** framework reviews PQC readiness.

Prelims Connect

Quantum technology pillars

Pillar	What it does
Quantum Computing	Solves problems exponentially faster using qubits (superposition)
Quantum Communication	QKD ensures unhackable key exchange using BB84/E91 protocols
Quantum Sensing	Ultra-high precision metrology, gravity, magnetic, navigation
Quantum Cryptography / PQC	Algorithms resistant to quantum attacks

Majorana fermion — a particle that is its own antiparticle; proposed 1937 by Ettore Majorana; topological qubits based on them are expected to be more stable.

Prelims Pointers

- **QKD** = Quantum Key Distribution — cryptography leveraging **no-cloning theorem**.
- **Majorana 1** by Microsoft = first topological quantum chip (Feb 2025).
- **Qubit** = quantum bit; exploits **superposition** and **entanglement**.
- **India's first QKD** over 100 km = Apr 2025 (C-DOT, DRDO, IIT Delhi).
- **Quantum supremacy** first claimed by Google in 2019 (Sycamore, 53 qubits).

Nuclear Sector Reforms — 49% FDI, Bharat Small Reactors, Bihar Plant, MAHAGENCO-ROSATOM

Union Budget 2025-26 proposed opening India's nuclear energy sector to 49% foreign direct investment. Under 'Bharat Small Modular Reactors', Bihar will get its first atomic plant, and MAHAGENCO (Maharashtra) signed an MoU with Russia's ROSATOM for SMR cooperation.

News in Brief

- Union Budget 2025-26 announced a Nuclear Energy Mission with a target of 100 GW nuclear capacity by 2047 (from 8.18 GW in 2024).
- 49% FDI in nuclear energy — requires amendment of Atomic Energy Act 1962 and Civil Liability for Nuclear Damage Act 2010 (CLNDA).
- Bharat Small Reactors (BSR) — 5 indigenous 200-MW Pressurised Heavy Water Reactors (PHWR) by 2033.
- Bharat Small Modular Reactors (BSMR) — higher-tech SMRs, private-sector enabled.
- Bihar to host first atomic power plant under BSR (June 2025).
- MAHAGENCO + ROSATOM MoU (April 2025) for SMR feasibility.
- Russia-China Moon nuclear plant: planned by 2036 to power International Lunar Research Station.

Static Background (Basics to Remember)

- **India's 3-stage nuclear programme** — designed by Homi Bhabha (1954): (1) PHWRs using natural uranium producing Pu-239; (2) FBRs using Pu-239 + U-238 blanket producing U-233; (3) Thorium-based reactors using U-233 — exploits India's vast thorium reserves (~21% of world).
- **Current nuclear capacity** — ~8,180 MW installed (24 operational reactors as of 2025); target of 100 GW by 2047 under **Nuclear Energy Mission** (Budget 2025-26); present share in electricity ~3%.
- **Key institutions** — **DAE** (Department of Atomic Energy, 1954) is apex; **NPCIL** builds/operates reactors; **BARC** R&D; **AERB** regulator; **GCNEP** for global partnerships. PM is the Minister of Atomic Energy.
- **Legal framework** — Atomic Energy Act 1962 (forbade private ownership of nuclear fuel); **Civil Liability for Nuclear Damage Act 2010**; 123 Agreement with USA (2008); amendments in 2025 Budget session to permit **49% FDI** and private players.
- **Bharat Small Reactors (BSR) & BSMR** — BSR = 220 MW PHWR indigenous design; **BSMR** = Bharat Small Modular Reactor (~220 MW advanced compact); **SMRs** globally are 300 MWe or less (e.g., NuScale, Rolls-Royce, TerraPower).
- **Kudankulam & ROSATOM partnership** — Units 1-2 operational; 3-6 under construction; Unit 7 foundation 2025; ROSATOM is Russian state nuclear corp; **MAHAGENCO-ROSATOM** MoU for Maharashtra nuclear plant.
- **Fuel cycle** — Uranium mining (UCIL, Jadugoda), conversion, enrichment, fuel fabrication (NFC Hyderabad), reprocessing (Tarapur/Kalpakkam), waste storage. India is outside NPT but has **NSG waiver (2008)**.

Prelims Connect

India's nuclear framework

Topic	Detail
Governing law	Atomic Energy Act, 1962
Regulator	Atomic Energy Regulatory Board (AERB, 1983)
Supplier liability	Civil Liability for Nuclear Damage Act, 2010
Operator	Nuclear Power Corporation of India Ltd (NPCIL)
BHAVINI	SFR fast breeder reactor, Kalpakkam
Current installed	~8.18 GW (2024); 24 reactors
Target 2031-32	22.48 GW

Target 2047	100 GW (new vision)
FDI norm	Currently 0%; budget proposed 49%

India's nuclear fuel cycle is 3-stage: PHWRs → Fast Breeder Reactors (FBR) using Plutonium → Thorium-based reactors. BHAVINI (Kalpakkam) operates the 500 MW Prototype Fast Breeder Reactor (PFBR) achieving criticality in March 2024.

Prelims Pointers

- **Budget 2025-26** announced **Nuclear Energy Mission** — 100 GW by 2047.
- **49% FDI** in nuclear proposed — requires **amendment** of Atomic Energy Act 1962 + CLNDA 2010.
- **BSR** = Bharat Small Reactors (5 × 200 MW PHWRs).
- **BSMR** = Bharat Small Modular Reactors (higher-tech SMRs).
- **AERB** = Atomic Energy Regulatory Board (regulator).

Semicon India 2025 & OSAT — India's Chip Manufacturing Debut

Prime Minister Modi inaugurated 'Semicon India 2025' in Sep 2025; India launched its first end-to-end Outsourced Semiconductor Assembly and Test (OSAT) unit in Aug 2025, marking the take-off of the India Semiconductor Mission.

News in Brief

- India Semiconductor Mission (ISM) — set up 2021 under MeitY with ₹76,000 cr corpus; implementing body within Digital India Corp.
- Semicon India 2025 — held in Sept 2025, bringing together TSMC, NXP, Applied Materials, Lam Research, Micron, Tata Electronics.
- First OSAT unit — launched in Aug 2025 (Micron facility at Sanand, Gujarat).
- 5 semiconductor units approved by 2025: Tata-PSMC (Dholera, first fab), Tata Assembly (Jagiroad, Assam), Micron (Sanand), CG Power-Renesas (Sanand), Kaynes (Sanand).
- TIDCO developing Space Industrial & Propulsion Park in Tamil Nadu (Nov 2025).

Static Background (Basics to Remember)

- **Moore's Law** — Gordon Moore (Intel co-founder, 1965) observed that transistor density on a chip doubles every ~18-24 months; drives the 'nm race' (14nm → 7nm → 5nm → 3nm → 2nm).
- **Fab vs OSAT** — **Fab** (fabrication) creates wafer from silicon ingot — capital-intensive ($10-20 bn per plant); **OSAT** (Outsourced Semiconductor Assembly & Test) handles packaging, testing — lower entry cost; India's first forays are largely OSAT.
- **India Semiconductor Mission (ISM)** — launched Dec 2021, ₹76,000 cr outlay; part of **Semicon India Programme**; offers 50% fiscal support for fabs, 50% for display fabs, 50% for OSAT/ATMP/packaging/compound semi units.
- **Approved projects** — **Tata-PSMC fab** at Dholera, Gujarat (28nm, ₹91,000 cr); **Tata OSAT** Jagiroad Assam; **Micron OSAT** Sanand Gujarat; **CG Power-Renesas-Stars OSAT** Sanand; **Kaynes Sanand**; Kynvor etc.
- **Global leaders** — **TSMC** (Taiwan) makes ~90% of cutting-edge chips (<5nm); **Samsung** (Korea); **Intel** (USA); **SMIC** (China). Netherlands' **ASML** monopoly on EUV lithography machines.
- **Semicon India 2025** — annual flagship showcase; India's semiconductor market projected to reach $109 bn by 2030; **chip design** already mature — 20% of world chip designers work in India (Bangalore, Noida, Hyderabad).
- **Strategic importance** — chips are 'new oil'; critical for AI, defence, EVs, 5G, IoT; **US CHIPS Act 2022** ($52 bn), **EU Chips Act**, **China SMIC** — India joining the chip geopolitics chessboard.

Prelims Connect

India's semiconductor projects approved

Unit	Location	Type	Partner
Tata Electronics (Fab)	Dholera, Gujarat	28-nm fab	PSMC (Taiwan)
Tata Assembly & Test	Jagiroad, Assam	OSAT	Indigenous
Micron Memory	Sanand, Gujarat	OSAT (DRAM)	Micron (US)
CG Power-Renesas	Sanand, Gujarat	OSAT	Renesas (Japan)
Kaynes Semicon	Sanand, Gujarat	OSAT	Kaynes (India)
HCL-Foxconn	Jewar, UP	Display driver ICs	Foxconn (Taiwan)

OSAT = Outsourced Semiconductor Assembly and Test — the back-end of the chip supply chain (packaging, testing).

Prelims Pointers

- **India Semiconductor Mission** under MeitY — **₹76,000 cr** corpus.
- **Micron** launched India's first OSAT unit at **Sanand, Gujarat**.
- **Tata-PSMC** is building India's first 28-nm fab at **Dholera, Gujarat**.
- **OSAT** = Outsourced Semiconductor Assembly & Test.
- **ISM** launched 2021 with Production Linked Incentive (PLI) for semiconductors.

PARAM Rudra — India's First Indigenous Supercomputer

PARAM Rudra, India's first indigenous supercomputer developed under the National Supercomputing Mission (NSM), achieved full deployment in Dec 2025. Three PARAM Rudra systems (total 15 petaFLOPS) are now in operation at three research institutions.

News in Brief

- PARAM Rudra is part of the National Supercomputing Mission (NSM), launched 2015 by Dept of Science & Tech + MeitY; implemented by C-DAC.
- Three PARAM Rudra supercomputers commissioned Dec 2025 at — (1) Giant Metrewave Radio Telescope (GMRT, Pune), (2) Inter-University Accelerator Centre (IUAC, Delhi), (3) S.N. Bose Centre (Kolkata).
- Total capacity ~15 petaFLOPS; fully indigenous design, Made-in-India CPUs (AUM HPC processor by C-DAC).
- PARAM Rudra uses C-DAC's indigenous 'Rudra' compute server and 'Trinetra' high-performance interconnect.
- Complements existing PARAM Siddhi (AIRAWAT), PARAM Ganga, PARAM Shakti etc.

Static Background (Basics to Remember)

- **Supercomputer basics** — performance measured in **FLOPS** (floating-point operations per second); milestones: gigaflop → teraflop → petaflop → exaflop (10^{18}); ranked on biannual **TOP500** list (Nov 2024: US Frontier, El Capitan, Aurora top).

- **C-DAC founding** — Centre for Development of Advanced Computing set up in 1988 after US denied India a Cray supercomputer; Vijay Bhatkar led the mission — delivered **PARAM 8000** in 1991, India's first indigenous supercomputer.
- **PARAM series** — PARAM 8000 (1991) → PARAM 10000 → PARAM Padma (2003, first teraflop) → PARAM Yuva → PARAM Siddhi-AI (2020, 210-petaflop AI) → PARAM Rudra (2024, 3 systems at Pune, Delhi, Kolkata).
- **National Supercomputing Mission (NSM)** — launched 2015 by MeitY + DST; implemented by C-DAC + IISc; target of 45 systems across India; 30+ already deployed at IITs, IISc, IISER, NIT, NABI, C-DAC nodes.
- **Applications** — weather forecasting (IMD's Bhoura-Mihir), drug discovery, climate modelling, AI/ML training, cryptanalysis, materials simulation, genomics (IndiGen).
- **Global exascale race** — USA (Frontier 1.1 EF, 2022), El Capitan (2 EF, 2024); Japan Fugaku (ARM-based); China Tianhe-3/Sunway Oceanlite; India targeting exascale by 2030-35.

Prelims Connect

National Supercomputing Mission (NSM) milestones

Year	Milestone
2015	NSM approved (₹4,500+ cr; 7 years)
2020	PARAM Siddhi-AI ranked 63 in TOP500
2023	AIRAWAT inaugurated (200 AI PFLOPS)
2024	C-DAC launches AUM indigenous HPC chip
2025	3 PARAM Rudra systems deployed
2025	PARAM Pravega at IISc; PARAM Utkarsh at C-DAC

PARAM = Paramagat ('Supreme' in Sanskrit). India's first supercomputer was PARAM 8000 (1991) after the US denied supply of Cray supercomputers.

Prelims Pointers

- **PARAM Rudra** — **indigenous supercomputer** under NSM, 3 systems (Dec 2025).
- **National Supercomputing Mission** (2015) — by DST + MeitY, implemented by **C-DAC**.
- **Indigenous HPC CPU** = AUM processor by C-DAC.
- **AIRAWAT** at C-DAC Pune = India's largest AI supercomputer (200 AI PFLOPS).
- **First Indian supercomputer**: PARAM 8000 (1991).

Green Hydrogen, BIRSA 101 & Clean Energy Tech

India's clean-energy technology push in 2025-26 featured the launch of BIRSA 101, a green data centre by Adani, and continued work on green hydrogen and SAF (Sustainable Aviation Fuel).

News in Brief

- BIRSA 101 — India's first indigenous 'semiconductor-grade' pilot plant for polysilicon, launched Nov 2025 by MoS DST Jitendra Singh.
- Adani Group is setting up a 48-MW green data centre in Telangana — run entirely on renewable energy.
- National Green Hydrogen Mission (2023) — targets 5 MMT green hydrogen production per year by 2030, 125 GW renewable capacity addition.

- PM E-DRIVE, PM-Surya Ghar Muft Bijli Yojana and Pumped Storage Projects — complement the clean energy push.
- IIT Madras launched the IITM-C-DOT Samgnya Technologies Foundation, designated as India's Telecom Centre of Excellence (Dec 2025).

Static Background (Basics to Remember)

- **Hydrogen colour code** — **Green** (electrolysis from renewables); **Blue** (natural gas + CCS); **Grey** (natural gas, no CCS); **Pink/Red** (nuclear-powered electrolysis); **Turquoise** (methane pyrolysis).
- **Electrolysis basics** — splits H_2O into H_2 and O_2 using electricity; types: **alkaline**, **PEM (Proton Exchange Membrane)**, **Solid Oxide** and **AEM**; efficiency 60-80%.
- **Fuel cells** — combine H_2 + O_2 to generate electricity + water; used in buses, trains, spacecraft; NASA used alkaline fuel cells on Apollo; Toyota Mirai & Hyundai Nexo are commercial FCEVs.
- **National Green Hydrogen Mission (NGHM)** — launched Jan 2023, ₹19,744 cr outlay; target 5 MMT green H_2 annually by 2030, 125 GW renewable capacity addition, ₹8 lakh cr investment, 50 MMT CO_2 abatement.
- **SIGHT programme** — Strategic Interventions for Green Hydrogen Transition under NGHM: two components — electrolyser manufacturing (~1,500 MW/year) and green H_2 production incentives.
- **BIRSA & other clean-tech** — **BIRSA 101** is indigenous biomass-to-hydrogen unit; **PM-KUSUM** for solar pumps; **PM Surya Ghar Muft Bijli Yojana** (Feb 2024, 1 cr homes rooftop solar); **PLI for solar PV** ₹24,000 cr.
- **India's renewable targets** — 500 GW non-fossil by 2030 (Panchamrit pledge COP26); net-zero by 2070; currently ~200 GW installed RE; world's 4th largest RE capacity.

Prelims Connect

Hydrogen colour codes (global usage)

Colour	Source / Method
Green	Electrolysis using renewable electricity
Grey	Steam Methane Reforming (SMR) of natural gas
Blue	Grey + carbon capture & storage (CCS)
Pink / Purple	Electrolysis using nuclear power
Turquoise	Methane pyrolysis (solid carbon by-product)
Yellow	Electrolysis from grid electricity (mixed sources)
Brown / Black	Coal gasification

India targets 5 million metric tonnes (MMT) of Green Hydrogen production and ~125 GW additional renewables by 2030 under National Green Hydrogen Mission (NGHM).

Prelims Pointers

- **BIRSA 101** = India's first indigenous semiconductor-grade polysilicon pilot plant (Nov 2025).
- **National Green Hydrogen Mission** target = **5 MMT by 2030**.
- **Green hydrogen** = electrolysis using **renewable** electricity.
- **Pink hydrogen** = electrolysis using **nuclear** electricity.
- **Samgnya Foundation** = IIT-M + C-DOT Telecom CoE (Dec 2025).

IndiaAI Mission — AIKosha, AI Kiran, CATCH, SITAC

The IndiaAI Mission (approved Mar 2024, ₹10,371 cr outlay) delivered rapid progress in 2025-26 — launching the IndiaAI Compute Portal, AIKosha dataset platform, AI Kiran women-in-AI initiative, CATCH cancer initiative, and the India-Sweden SITAC corridor for semiconductors.

News in Brief

- IndiaAI Compute Portal — launched Mar 2025, provides cloud-based GPU access for researchers and startups at subsidised rates.
- AIKosha dataset platform — one-stop portal for quality Indian datasets for AI model training (launched Mar 2025).
- AI Kiran Initiative (Apr 2025) — national movement to promote women's leadership in AI.
- CATCH Program — launched by IndiaAI + National Cancer Grid (Aug 2025); AI for cancer diagnosis.
- India–AI Impact Summit 2026 (19-20 Feb 2026) — held at Bharat Mandapam, New Delhi; India set a Guinness World Record with 2.5 lakh+ participants.
- SITAC Corridor — IndiaAI Mission + Business Sweden Statement of Intent (Feb 2026) for AI-semiconductor supply chain.
- BharatGen — announced June 2025, India's first-of-its-kind multilingual indigenous Large Language Model (LLM), under Department of Science & Technology.

Static Background (Basics to Remember)

- **What is AI?** — machines performing tasks that need human intelligence: learning, reasoning, perception, NLP, decision-making. Subsets: **ML** (statistical learning) → **Deep Learning** (neural nets) → **Generative AI** (LLMs/diffusion models).
- **Key AI paradigms** — **Narrow AI** (task-specific, current), **AGI** (general intelligence, aspirational), **ASI** (super-intelligence). LLMs = Large Language Models trained on billions of parameters (GPT-4o, Claude, Gemini, Llama, DeepSeek).
- **IndiaAI Mission** — approved March 2024, ₹10,372 cr over 5 years, under MeitY; 7 pillars: (1) Compute (GPU cluster 10,000+), (2) Datasets, (3) Innovation Centre, (4) Application Dev, (5) FutureSkills, (6) Startup Financing, (7) Safe & Trusted AI.
- **IndiaAI components** — **AIKosha** = national dataset platform (~50 TB curated); **AIRAWAT** = compute backbone (~200 PF AI); **AI Kiran** = inclusion programme; **CATCH** = Crime Analytics & Threat Handling.
- **Global AI governance** — **Bletchley Declaration** (UK, Nov 2023, 28 countries); **Seoul Summit** (May 2024); **Paris AI Action Summit** (Feb 2025, co-hosted by India + France); **EU AI Act** (2024, world's first comprehensive AI law).
- **India's stance** — 'AI for All'; voluntary advisory framework instead of hard law; Digital India Act (pending) to replace IT Act 2000; **DPDP Act 2023** governs AI training data.

Prelims Connect

IndiaAI Mission — 7 pillars

Pillar	Focus
1. IndiaAI Compute	10,000 GPUs via PPP model
2. IndiaAI Innovation Centre	Indigenous LLMs (e.g., BharatGen)

3. IndiaAI Datasets Platform	AIKosha portal
4. IndiaAI Application Development	Sector-wise AI solutions
5. IndiaAI FutureSkills	Training 1 lakh AI professionals
6. IndiaAI Startup Financing	Support for AI startups
7. Safe & Trusted AI	Ethical AI, frameworks, red-teaming

The Global Partnership on Artificial Intelligence (GPAI) was founded 2020; India chaired it in 2024 and led the Delhi Declaration.

Prelims Pointers

- **IndiaAI Mission** approved Mar 2024 — **₹10,371 cr**; 7 pillars.
- **AIKosha** = IndiaAI datasets platform.
- **BharatGen** = indigenous LLM under DST (June 2025).
- **India-AI Impact Summit** held 19-20 Feb 2026 at **Bharat Mandapam**, New Delhi.
- **CATCH** = IndiaAI + NCG cancer-care program (Aug 2025).

Global AI — Stargate, Paris AI Summit, Nvidia Supercomputer, Ironwood TPU, Surya

2025 was the year AI infrastructure went planetary — US launched 'Project Stargate', the Paris AI Action Summit generated a 60-nation declaration, Nvidia built the world's largest AI supercomputer, Google launched the Ironwood TPU, and NASA-IBM unveiled the Surya heliophysics foundation model.

News in Brief

- Project Stargate (Jan 2025) — $500 billion US-Oracle-OpenAI-SoftBank-MGX initiative to build massive AI data-centre infrastructure.
- Paris AI Action Summit 2025 (co-chaired by France's Macron & India's PM Modi) adopted a Statement on Inclusive & Sustainable AI, signed by 60+ countries.
- Nvidia + research partners (Feb 2025) built the largest AI supercomputer for weather/climate science.
- Ironwood — Google's 7th-gen Tensor Processing Unit (TPU), most powerful yet, launched Nov 2025.
- Surya (Aug 2025) — NASA + IBM open-source foundation model for solar physics.
- Global AI Vibrancy Tool 2025 by Stanford HAI ranked India 6th worldwide; released Dec 2025.
- 2025 WTO World Trade Report projected AI could raise global trade growth by up to 14 pp by 2040.

Static Background (Basics to Remember)

- **Compute arms race** — modern AI needs enormous GPU clusters; **NVIDIA** dominates AI chips (H100, H200, B200 Blackwell); **TSMC** manufactures them; Taiwan's geo-political salience = 'Silicon Shield'.
- **Stargate Project** — announced Jan 2025; $500 bn AI infrastructure JV by OpenAI, Oracle, SoftBank, MGX (UAE); aims 10 GW data centres in Texas by 2029; world's largest AI compute build-out.
- **Paris AI Summit (Feb 2025)** — hosted by France, co-chaired by PM Modi; India announced AI Mission expansion; US & UK did NOT sign the final declaration citing sovereignty concerns.
- **Google Ironwood TPU** — 7th-gen Tensor Processing Unit (announced Apr 2025); 42.5 exaflops FP8; 192 GB HBM per chip; designed for inference at scale; rivals NVIDIA Blackwell.
- **Surya (IBM-NASA)** — open-source AI foundation model for solar weather forecasting using Solar Dynamics Observatory data; trained on 9 years of imagery; predicts solar flares up to 2 hrs early.

- **Global GenAI race** — OpenAI (GPT-4o/5), Anthropic (Claude 3.5/4), Google (Gemini 2.0), Meta (Llama 3/4), xAI (Grok), DeepSeek (R1 shocked markets Jan 2025 with cheaper training), Mistral (France).
- **AI risks** — misinformation, deepfakes, job displacement, IP/copyright, bias, algorithmic discrimination, autonomous weapons (LAWS), alignment problem; discussed at **AI Safety Institutes** in UK, US, Japan.

Prelims Connect

Global AI milestones in news 2025-26

Initiative	Country / Org	Year
Project Stargate	USA (Oracle/OpenAI/SoftBank/MGX)	Jan 2025
Paris AI Action Summit	France (co-chair India)	Feb 2025
GPAI Delhi Declaration	Global Partnership on AI	2024
AI Bletchley Declaration	UK Summit	2023
Seoul AI Summit	South Korea	2024
EU AI Act	European Union	2024 (first binding)
India-AI Impact Summit	India (New Delhi)	Feb 2026
UN AI Governance Panel	United Nations	Aug 2025

India will succeed France as the next AI Summit host — the India AI Impact Summit 2026 was held at Bharat Mandapam in February 2026.

Prelims Pointers

- **Project Stargate** = **$500 bn** US AI infrastructure drive (Jan 2025).
- **Paris AI Action Summit** 2025 — co-chaired by **Macron & Modi**.
- **Ironwood** = Google's **7th-gen TPU** (Nov 2025).
- **Surya** = NASA + IBM open-source solar physics foundation model.
- **EU AI Act** — world's first binding AI law (2024).

Indian AI Initiatives — BharatGen, Adi Vaani, VoicERA, SabhaSaar, Pilloo, Moltbook

India rolled out a rich set of indigenous AI tools in 2025-26 covering languages, governance, education, and social applications.

News in Brief

- BharatGen (June 2025) — India's first-of-its-kind multilingual LLM, under DST, for 22 scheduled Indian languages.
- Adi Vaani (Sep 2025) — beta version of India's first AI-powered translation platform for tribal languages.
- VoicERA (Feb 2026) — MeitY-launched India's first comprehensive voice AI benchmarking platform for Indian languages.
- SabhaSaar (Aug 2025) — Ministry of Panchayati Raj AI-powered tool to summarise Gram Sabha meetings in local languages.
- Pilloo AI (Feb 2026) — next-generation voice AI launched by Andhra Pradesh CM N. Chandrababu Naidu.

- Moltbook (Feb 2026) — world's first AI-only social network launched by Octane AI founder Matt Schlicht.
- Sansad Bhashini — LokSabha + MeitY initiative for AI translation of Parliament proceedings (Mar 2025).
- Yashoda AI (May 2025) — 'Your AI SAKHI', AI literacy drive for women.
- Maharashtra AI Policy, first-of-its-kind Indian state AI policy; AI University planned in Maharashtra.
- Maharashtra also set up India's first AI Special Economic Zone.
- Karnataka's AI Skill Intelligence & Strategy Unit (KSISU, Nov 2025).
- DPS RK Puram, Delhi — India's first AI Incubation Centre in a school (Nov 2025).
- TN Deep Tech Startup Policy (2025-26) — India's first dedicated deep-tech startup policy (Jan 2026).

Static Background (Basics to Remember)

- **Sovereign AI** — nations building own foundation models, datasets & compute to avoid dependence on US/Chinese models; India's answer is **Bhashini + BharatGen + AIKosha + AIRAWAT** stack.
- **BharatGen** — India's first indigenous multilingual multimodal LLM; IIT-Bombay led consortium; covers 22 scheduled languages; launched under TIH Foundation + DST.
- **Bhashini** — National Language Translation Mission (MeitY, 2022); open-source speech-to-speech, speech-to-text, text-to-text for all 22 languages; used in government apps & UMANG.
- **Adi Vaani** — first AI-based translation platform for tribal languages (launched 2025); covers Bhili, Gondi, Mundari, Santhali — addressing India's 700+ tribal communities.
- **VoicERA, SabhaSaar, Pilloo** — VoicERA = voice-based language learning; **SabhaSaar** = AI tool for Parliamentary summarisation; **Pilloo** = Tamil learning AI bot.
- **Moltbook** = lab notebook AI for material science; AI4Bharat (IIT-Madras) the leading academic hub; **INDIAai**.gov.in is the portal; IndiaAI Incubation Centres at IIT-Hyderabad, IIT-KGP, IIT-Ropar.
- **Startup ecosystem** — India has 100+ GenAI startups (Krutrim, Sarvam AI, CoRover, Ozonetel); **Krutrim** (Ola founder) became first India-made GenAI unicorn in Jan 2024.

Prelims Connect

Indigenous AI products / platforms

Product	Ministry / State	Use
BharatGen	DST	Multilingual LLM
Sansad Bhashini	MeitY / LS Secretariat	Parliament translation
AIKosha	MeitY / IndiaAI	Dataset platform
Adi Vaani	Ministry of Tribal Affairs	Tribal-language translation
VoicERA	MeitY	Voice AI benchmarking
SabhaSaar	Panchayati Raj Ministry	Gram Sabha summariser
Pilloo AI	Andhra Pradesh	Voice AI platform
Yashoda AI SAKHI	MeitY	AI literacy for women
Nayanamritham 2.0	Kerala + Remidio	AI diabetic retinopathy screening

India's approach to AI is 'AI for All' — framed under the 2018 NITI Aayog strategy and amplified by the IndiaAI Mission (2024).

Prelims Pointers

- **BharatGen** — India's indigenous LLM; DST, June 2025.
- **Adi Vaani** — AI translation for **tribal languages**.
- **VoicERA** — voice AI benchmarking by MeitY (Feb 2026).
- **SabhaSaar** — Panchayati Raj AI Gram Sabha summariser.
- **Moltbook** — world's first **AI-only social network**.

Cyber Security — Digital Threat Report, Scam Se Bacho, MahaCrimeOS-AI, PRAHAAR

India's cyber-security architecture matured with CERT-In's Digital Threat Report 2024, 'Scam Se Bacho' awareness campaign, MahaCrimeOS-AI police tool, PRAHAAR strategy, e-Zero FIR, and the Indian Cybercrime Coordination Centre (I4C).

News in Brief

- Digital Threat Report 2024 (Apr 2025) — launched by CERT-In + CSIRT-Fin + SISA; analyses cyber risks in BFSI sector.
- 'Scam Se Bacho' (Mar 2025) — National User Awareness Campaign against digital frauds.
- e-Zero FIR (May 2025) — launched by Home Minister under I4C; automatically registers FIR for cybercrime without jurisdictional delays.
- MahaCrimeOS-AI (Dec 2025) — Maharashtra became the first Indian state to launch an AI-based crime-tracking OS.
- PRAHAAR strategy (Feb 2026) — Ministry of Home Affairs' first comprehensive anti-narcotics strategy.
- Goa Police (Nov 2025) — first Indian state with 100% cyber fraud response rate.
- Indian Army Terrier Cyber Quest 2025 — national-level cyber challenge.
- Exercise Cyber Suraksha — 12-day DRDO-led cyber defence exercise for armed forces.
- India ranks 10th in Global Cybersecurity Index 2024 (Tier-1).

Static Background (Basics to Remember)

- **Cyber threats** — **Malware**, **Ransomware**, **Phishing**, **DDoS**, **Supply-chain attacks**, **Zero-day exploits**, **APTs** (Advanced Persistent Threats, often state-backed).
- **CERT-In** — Computer Emergency Response Team India, 2004, under MeitY; nodal agency for cyber incidents; issues advisories, coordinates response, runs **Cyber Swachhta Kendra** (Botnet Cleaning).
- **Legal framework** — **IT Act 2000** + **IT Rules 2021** (intermediary/OTT); **DPDP Act 2023** (data protection); **BNS 2023** (cyber crimes replace IPC); **National Cyber Security Policy 2013** (being updated).
- **Institutions** — **NCIIPC** (National Critical Information Infrastructure Protection Centre, NTRO, 2014); **NCCC** (National Cyber Coordination Centre); **I4C** (Indian Cyber Crime Coordination Centre, MHA); **DCyA** (Defence Cyber Agency, 2019).
- **Reporting portals** — **cybercrime.gov.in** (national portal); **1930** cyber fraud helpline; **Chakshu** (Sanchar Saathi) for telecom frauds; **Citizen Financial Cyber Fraud Reporting System**.
- **PRAHAAR & MahaCrimeOS-AI** — PRAHAAR = army cyber war-game; **MahaCrimeOS-AI** = Maharashtra's AI-driven crime mapping; **Scam Se Bacho** = public awareness campaign 2025.
- **Global architecture** — **Budapest Convention 2001** (India not a party); UN **Ad Hoc Cybercrime Treaty** (2024); **Global Cybersecurity Index** (ITU) — India Tier 1.

Prelims Connect

India's cyber-security architecture

Body / Law	Role

CERT-In (2004)	Nodal national cyber emergency response
I4C (2020)	Indian Cybercrime Coordination Centre (MHA)
National Cyber Security Strategy (draft)	Framework; not yet notified
IT Act 2000	Principal cyber law
DPDP Act 2023	Digital Personal Data Protection Act
Digital India Act (draft)	To replace IT Act
NCIIPC (2014)	Critical information infra protection
NTRO	Cyber / signals intelligence
Defence Cyber Agency	Military cyber command

CERT-In = Indian Computer Emergency Response Team, under MeitY; the first Indian cyber-regulation body. NCIIPC operates under NTRO.

Prelims Pointers

- **CERT-In** = nodal cyber security agency under **MeitY** (est 2004).
- **I4C** = Indian Cyber Crime Coordination Centre, under MHA (2020).
- **DPDP Act 2023** = Digital Personal Data Protection Act.
- **e-Zero FIR** lets cybercrime complaints auto-become FIRs.
- **MahaCrimeOS-AI** = **Maharashtra**, India's first AI-powered police OS.

Telecom & Digital India — DIGIPIN, 6G, Starlink, Vibe Coding

2025-26 brought major digital infrastructure advances — DIGIPIN digital address, 5G/6G indigenous tech, Starlink's GMPCS license, and 'vibe coding' being named Word of the Year.

News in Brief

- DIGIPIN (May 2025) — India's new digital postal index, developed by Department of Posts + IIT Hyderabad + ISRO-NRSC; 10-character grid-based geocode for every 4 × 4 m.
- 6G indigenous telecom — Centre for Development of Telematics (C-DoT) demonstrated indigenous 5G and is developing 6G components (Jan 2025).
- Samarth initiative — C-DoT telecom R&D upskilling programme (Mar 2025).
- Starlink (SpaceX) — received GMPCS license (Global Mobile Personal Communication by Satellite, June 2025); Maharashtra became first state to partner with Starlink (Nov 2025).
- Bharti Airtel's Eutelsat-OneWeb also received GMPCS license.
- 'Vibe coding' — emerging style of coding with natural-language AI prompts; named Collins Dictionary Word of the Year 2025.
- Nvidia + IIT partners announced deep tech collaborations under BharatGen.

Static Background (Basics to Remember)

- **Telecom milestones** — 4G launched 2012 (Airtel); **5G launched Oct 2022** by PM Modi at IMC; India is world's 2nd largest telecom market (~1.18 bn subscribers); Reliance Jio disruption (2016) made data cheapest globally.

- **DIGIPIN** — Digital Postal Index Number, 10-character alphanumeric geo-coded address by India Post + IIT-Hyderabad; replaces 6-digit PIN code for precise geolocation (4m × 4m accuracy).
- **6G & Bharat 6G** — 6G expected ~2030, targets 1 Tbps, <1 ms latency, AI-native networks, THz frequencies; **Bharat 6G Vision** (March 2023) + **Bharat 6G Alliance**, target 10% of 6G patents to India.
- **Starlink** — SpaceX's LEO satellite internet, 6,000+ satellites; seeking Indian licence (DoT + IN-SPACe GMPCS); rivals Jio-SES, OneWeb (Bharti-backed), Amazon Kuiper; Eutelsat-OneWeb got first India GMPCS nod.
- **Vibe coding** — Andrej Karpathy's term (Feb 2025) for AI-assisted software development where devs describe intent in natural language and AI generates/edits code (Cursor, Windsurf, GitHub Copilot Workspace).
- **Telecom Act 2023** — replaced 138-year-old Indian Telegraph Act 1885 & Wireless Telegraphy Act 1933; empowers spectrum auction/administrative allotment; provides digital-by-default framework.
- **Digital Public Infrastructure (DPI)** — India's 'India Stack' (Aadhaar, UPI, DigiLocker, eKYC, ONDC, CoWIN); hailed globally; UPI handled 16.58 bn transactions in March 2025 alone.

Prelims Connect

Satellite broadband licensees in India

Operator	Parent	Status
Jio Space Fiber	Reliance Jio + SES	Operational
Eutelsat-OneWeb	Bharti + Eutelsat	GMPCS license received
Starlink	SpaceX	GMPCS license June 2025
Amazon Kuiper	Amazon	Application pending

GMPCS = Global Mobile Personal Communication by Satellite; India's DoT issues a separate GMPCS authorization for satellite-based voice/data services.

Prelims Pointers

- **DIGIPIN** — India's 10-character **geocoded digital PIN**; DoP + IIT-H + ISRO.
- **GMPCS** = Global Mobile Personal Communication by Satellite license.
- **Starlink** received GMPCS license in **June 2025**.
- **Vibe coding** = Collins Word of the Year 2025.
- **C-DoT** = Centre for Development of Telematics, telecom R&D arm.

Global Tech Firsts — Albania Diella, AlphaGenome, Project Cimon, Perplexity+Ronaldo

Global AI crossed several 'first-ever' frontiers in 2025-26 — Albania appointed the first AI-generated minister, DeepMind introduced AlphaGenome, DLR launched Project Cimon, and Perplexity AI inducted Cristiano Ronaldo as investor.

News in Brief

- Diella (Sept 2025) — Albania appointed the world's first AI-generated minister, responsible for public procurement, reducing corruption risks.
- AlphaGenome (Jan 2026) — Google DeepMind's advanced AI model that analyses DNA sequences to predict functional effects of mutations.
- Project Cimon (Crew Interactive MObile CompanioN) — AI-powered free-floating assistant used aboard ISS (Aug 2025).

- Perplexity + Cristiano Ronaldo (Dec 2025) — Portuguese football icon joined Perplexity AI as a strategic investor.
- TIME magazine (Dec 2025) named 'The Architects of AI' (a group) as Person of the Year 2025.
- Illinois Wellness and Oversight for Psychological Resources Act (WOPR Act) (Aug 2025) — US state law banning unlicensed AI therapy apps.
- Maharashtra's AI University & AI SEZ plans (2025).
- Uttarakhand AI Impact Summit 2025 — Dehradun, aimed at state AI ecosystem.

Static Background (Basics to Remember)

- **Albania's AI Minister 'Diella'** — Sep 2025, Albania became first country to have an AI 'virtual minister' for public procurement — aims to eliminate corruption by removing humans from tender decisions.
- **AlphaGenome** — DeepMind's 2025 model (successor to AlphaFold); predicts how DNA mutations affect gene expression; trained on human & mouse genomes; 10^5-base-pair context; open for research.
- **DeepMind milestones** — AlphaGo (2016 defeated Lee Sedol); AlphaZero (2017); AlphaFold 2 (2020 protein folding, Nobel 2024); AlphaProof (math); AlphaMissense (disease mutations).
- **Project Cimon** — German/IBM AI astronaut assistant on ISS since 2018; floats autonomously in microgravity using Watson AI; helps astronauts with experiments & procedures.
- **Perplexity-Ronaldo** — Perplexity AI's partnership with Cristiano Ronaldo (2025) to create a dedicated AI search experience for sports fans.
- **AI firsts globally** — first AI-written novel (Japan, 2023 'The Day A Computer Wrote a Novel'); first AI music on charts; first AI law firm partner; first AI university professor; first AI-run restaurant (China).
- **AI in governance** — Estonia uses AI for judicial decisions (<€7,000 civil disputes); UAE has first Minister for AI since 2017 (Omar Al Olama); Singapore's Smart Nation; China's social credit + Great Firewall.

Prelims Connect

Notable AI global events — 2025-26

Event	Country / Org	Highlight
Diella (AI minister)	Albania	World's first AI-made minister
AlphaGenome	Google DeepMind	DNA effect prediction AI
Project Cimon	NASA / DLR on ISS	AI astronaut assistant
WOPR Act	Illinois (USA)	Regulates AI mental-health apps
Nobel 2024 Physics	Geoffrey Hinton & John Hopfield	For ML foundations
Turing Award 2024	Andrew Barto & Richard Sutton	For reinforcement learning
TIME Person 2025	Architects of AI	Sam Altman, Demis Hassabis et al

Andrew Barto and Richard Sutton's 'Reinforcement Learning' textbook is the standard reference; they won the 2024 Turing Award announced in 2025.

Prelims Pointers

- **Diella** = AI minister, **Albania** (Sept 2025).
- **AlphaGenome** = DeepMind DNA-effects AI model.
- **Turing Award 2024** — Barto & Sutton for reinforcement learning.

- **TIME Person 2025** = 'The Architects of AI'.
- **WOPR Act** (Illinois, 2025) — regulates AI mental-health apps.

Supply Chains & Rankings — Pax Silica, SITAC, Frontier Tech Index, QS Rankings

Global indices and strategic alliances dominated 2025-26 — India joined Pax Silica for semiconductor security, the SITAC corridor with Sweden, Frontier Tech Readiness Index placed India 36th, QS rankings saw IIT Delhi rise, and Stanford AI Vibrancy Tool ranked India prominently.

News in Brief

- Pax Silica — US-led initiative to create a secure, allied semiconductor supply chain. India formally joined at India-AI Impact Summit (Feb 2026).
- SITAC Corridor — IndiaAI Mission + Business Sweden Statement of Intent (Feb 2026) for AI-semiconductor cooperation.
- Frontier Technologies Readiness Index (Apr 2025) — UNCTAD Technology & Innovation Report 2025. India ranked 36/170 (up from 48 in 2022).
- QS World University Rankings 2026 (June 2025): IIT Delhi India's top-ranked; MIT global #1.
- QS Asia University Rankings 2026 (Nov 2025): University of Hong Kong #1 in Asia.
- QS World Future Skills Index (Jan 2025): India ranked 2nd for preparedness for jobs of the future.
- India-UK Connectivity and Innovation Centre — jointly launched Oct 2025.
- India nominated IIT Madras as a UN Centre of Excellence for AI (Sept 2025).

Static Background (Basics to Remember)

- **Pax Silica** — term for the new geopolitical order defined by who controls semiconductors (silicon), much as oil defined 20th-century geopolitics; coined ~2024.
- **Semiconductor supply chain** — **Design** (US-Synopsys/Cadence, UK-ARM); **Manufacturing** (Taiwan-TSMC, Korea-Samsung); **Lithography** (Netherlands-ASML); **Materials** (Japan); **Packaging** (Taiwan, Malaysia, soon India).
- **SITAC** — Semiconductor & IT Alliance/Coalition; US-India Trade Policy Forum initiative; promotes design collaboration, tech transfer, student exchange.
- **Frontier Tech Index** — UNCTAD's Technology & Innovation Report ranks countries on readiness for AI, IoT, 5G, big data, blockchain, robotics; India moved up ranks significantly post-2020.
- **QS World University Rankings** — Quacquarelli Symonds (UK) ranks universities globally on academic reputation, citations, employer reputation, faculty-student ratio; Indian IITs climbed in 2025 rankings (IIT-Bombay highest Indian).
- **India's R&D spend** — ~0.65% of GDP (2024-25), way below global norm (Israel 5.4%, Korea 4.9%, US 3.5%, China 2.5%); target 2% under STI Policy 2013 and NEP 2020.
- **NRF — Anusandhan National Research Foundation** — Act 2023, ₹50,000 cr over 5 yrs; apex body for R&D across universities; replaces SERB; 70% funding from private/CSR.

Prelims Connect

India in global S&T indices

Index / Ranking	Publisher	India's Position
Frontier Tech Readiness Index 2025	UNCTAD	36 / 170

QS World University Rankings 2026	QS	IIT Delhi top Indian
QS Future Skills Index 2025	QS	2nd globally
Global AI Vibrancy Tool 2025	Stanford HAI	6th globally
Global Innovation Index 2024	WIPO	39 / 133
Global Cybersecurity Index 2024	ITU	Tier-1 (rank 10)

Global Innovation Index is published annually by WIPO; India's rank improved from 81 (2015) to 39 (2024) — fastest climber.

Prelims Pointers

- **Pax Silica** — US-led semiconductor supply alliance; India joined **Feb 2026**.
- **Frontier Tech Readiness Index** by **UNCTAD** — India **36/170**.
- **QS Asia 2026** — University of Hong Kong #1.
- **QS Future Skills Index 2025** — India **2nd**.
- **Global Innovation Index** published by **WIPO**.

HEALTH, BIOTECH & MEDICINE

Qartemi — India's First Globally Benchmarked CAR-T Cell Therapy

Qartemi, India's first globally benchmarked CAR T-cell therapy, was launched in January 2025 as a made-in-India treatment for relapsed/refractory B-cell lymphoma. It is the second approved Indian CAR-T after NexCAR19 (2023), and dramatically reduces cost compared to imported therapies.

News in Brief

- Developed by IIT Bombay + Tata Memorial Hospital + ImmunoACT (founded by Dr. Rahul Purwar).
- Targets CD19-positive B-cell lymphomas (DLBCL, follicular lymphoma) in relapsed/refractory patients.
- Approved by CDSCO (Jan 2025); cost ~₹30-40 lakh vs ₹3-4 crore for US alternatives (Yescarta/Kymriah).
- Qartemi follows NexCAR19 (Oct 2023) — the first indigenous CAR-T, also from ImmunoACT.
- India became the first developing country to manufacture and administer CAR-T therapy domestically.

Static Background (Basics to Remember)

- **CAR-T cell therapy** — Chimeric Antigen Receptor T-cell therapy: patient's T-cells are genetically modified ex vivo to carry CARs that recognise cancer-specific antigens, then re-infused; 'living drug'.
- **Approved targets** — **CD19** for B-cell lymphomas & ALL; **BCMA** for multiple myeloma (Qartemi's target); Works by binding cancer cells → activating T-cell → proliferation → tumour destruction.
- **First global CAR-T** — **Kymriah** (Novartis, 2017, USFDA approved), followed by Yescarta, Tecartus, Breyanzi, Abecma, Carvykti. Cost: $375,000-$475,000 per infusion.
- **India's CAR-T journey** — **NexCAR19** (ImmunoAct + IIT-Bombay + Tata Memorial): India's first CAR-T, CDSCO approved Oct 2023, ₹30-40 lakh (1/10th global cost); **Qartemi** = next-gen BCMA-targeting for multiple myeloma.
- **Regulators** — **CDSCO** (Central Drugs Standard Control Organisation), headed by **DCGI**; **NPPA** for pricing; **DGHS** (Directorate General of Health Services); Drugs & Cosmetics Act 1940.

- **India's biotech ambition — BioE3 Policy** (Aug 2024): Biotechnology for Economy, Environment, Employment; aim $300 bn bioeconomy by 2030; currently ~$150 bn (2024).

Prelims Connect

CAR T-cell therapy — key facts

Parameter	Detail
Full form	Chimeric Antigen Receptor T-cell therapy
Mechanism	Patient's T cells genetically modified to express CAR that recognises cancer cells
Target	CD19 (B-cell lymphomas, leukemias)
Indian products	NexCAR19 (Oct 2023), Qartemi (Jan 2025)
Developers	IIT Bombay + Tata Memorial Hospital + ImmunoACT
Cost in India	~₹30-40 lakh
Cost abroad	~₹3-4 crore
Regulator	CDSCO / DBT

CAR T-cell therapy is a form of 'living drug' — engineered immune cells that multiply in the patient after infusion.

Prelims Pointers

- **Qartemi** = India's 2nd indigenous **CAR-T cell therapy** (Jan 2025).
- **NexCAR19** (Oct 2023) = India's 1st CAR-T therapy.
- **Developed by** IIT Bombay + Tata Memorial Hospital + ImmunoACT.
- **Target**: CD19-positive B-cell lymphomas/leukemias.
- **Cost advantage**: 1/10th of US equivalents.

AdFalciVax — India's First Indigenous Multi-Stage Malaria Vaccine

AdFalciVax, India's first indigenous multi-stage malaria vaccine, is being developed by ICMR-Regional Medical Research Centre (Bhubaneswar) and is in pre-clinical stage as of Sep 2025.

News in Brief

- Developed by ICMR-RMRC Bhubaneswar in collaboration with Department of Biotechnology.
- Targets two critical stages of malaria parasite (Plasmodium falciparum) — sporozoite (pre-erythrocytic) + sexual stage (transmission-blocking).
- A multi-stage vaccine is designed to prevent both infection and onward transmission.
- Existing malaria vaccines: RTS,S/AS01 (Mosquirix, GSK) and R21/Matrix-M (Oxford/SII) — both already WHO-prequalified.
- India is one of the highest malaria-burden countries; world's 4th-largest burden.

Static Background (Basics to Remember)

- **Malaria basics** — caused by 5 Plasmodium species: **P. falciparum** (deadliest), P. vivax, P. ovale, P. malariae, P. knowlesi; transmitted by female Anopheles mosquito; ~249 mn cases & 608k deaths globally (WHO 2022).

- **Parasite life cycle** — Sporozoite (mosquito saliva) → liver (hepatic stage) → merozoite → RBC infection → gametocytes picked up by next mosquito. Stages: liver, blood, sexual (mosquito gut).
- **Existing vaccines** — **RTS,S/Mosquirix** (GSK, WHO-prequalified 2022, ~36% efficacy); **R21/Matrix-M** (Oxford-Serum Institute, 2023, ~75% efficacy); both target sporozoite stage only.
- **AdFalciVax** — India's first indigenous **multi-stage malaria vaccine** (ICMR-RMRC Bhubaneswar + BIRAC); targets liver + blood + transmission (gametocyte) stages — world's first true multi-stage blocker.
- **India's malaria burden** — 2024: 176k cases, 83 deaths (lowest ever); target malaria elimination by 2030; currently 80% cases in NE states + tribal districts; **NVBDCP** is the programme.
- **Global framework** — **WHO E-2025** initiative to eliminate malaria in 25 countries by 2025; Sri Lanka (2016), Maldives (2015) already malaria-free. **Roll Back Malaria Partnership**.

Prelims Connect

Global malaria vaccines

Vaccine	Target	Status
RTS,S/AS01 (Mosquirix)	Pre-erythrocytic (CSP)	WHO-approved 2021, manufactured by GSK
R21/Matrix-M	Pre-erythrocytic (CSP)	Oxford + Serum Institute India; WHO-approved 2023
AdFalciVax (India)	Multi-stage — CSP + Pfs25	Pre-clinical by ICMR-RMRC Bhubaneswar
PfSPZ (Sanaria)	Whole sporozoite	Late trials

India eliminated urban malaria deaths drastically; aims for malaria-free India by 2030 under the National Framework for Malaria Elimination.

Prelims Pointers

- **AdFalciVax** — India's first indigenous **multi-stage** malaria vaccine.
- **Developer**: ICMR-Regional Medical Research Centre, **Bhubaneswar**.
- **Targets**: Plasmodium falciparum sporozoite + sexual stage.
- **R21/Matrix-M** is manufactured by **Serum Institute of India**.
- **WHO goal**: reduce global malaria burden 90% by 2030.

New Vaccines in News — Biolumpivaxin, HPV, mNEXSPIKE, Koala Chlamydia, Shingrix

2025-26 saw several breakthrough vaccines in news — India's Biolumpivaxin for cattle, nationwide HPV rollout, the US-approved mNEXSPIKE mRNA COVID vaccine, and Australia's world-first single-dose koala chlamydia vaccine.

News in Brief

- Biolumpivaxin (Feb 2025) — Biovet (Bharat Biotech group) got CDSCO approval for its Lumpy Skin Disease (LSD) vaccine for cattle.
- Indian HPV vaccine — PM Modi launched nationwide Human Papillomavirus (HPV) vaccination drive (Feb 2026), targeting girls 9-14 years.
- mNEXSPIKE (mRNA-1283) — US FDA approved (June 2025) Moderna's new mRNA COVID vaccine.

- Koala chlamydia vaccine (Sept 2025) — Australia approved the world's first single-dose vaccine to protect koalas from chlamydia.
- Pandemic Agreement (WHO Pandemic Treaty) — finalised April 2025; adopted by World Health Assembly in May 2025.
- Lenacapavir — WHO recommended (July 2025) as a twice-yearly injectable HIV prevention drug.
- Uganda + WHO launched world's first Ebola Sudan vaccine trial (Feb 2025).
- AdFalciVax — India's indigenous multi-stage malaria vaccine (see 5.2).

Static Background (Basics to Remember)

- **Vaccine types** — Live attenuated (MMR, BCG), Inactivated (Covaxin, IPV), Toxoid (DPT), Subunit (HPV), **mRNA** (Pfizer, Moderna, mNEXSPIKE), Viral vector (Covishield, J&J), DNA (ZyCoV-D — India's first).
- **UIP — Universal Immunisation Programme** — launched 1985; one of largest in world; provides 12 vaccines free (BCG, DPT, OPV, measles, hepatitis B, Hib, rotavirus, PCV, JE, IPV, tetanus, Td).
- **Mission Indradhanush** — launched Dec 2014 to achieve 90% full immunisation by 2020; **Intensified Mission Indradhanush (IMI)** 5.0 covered measles-rubella elimination targets.
- **HPV vaccine** — **Cervavac** (Serum Institute, 2023) is India's first indigenous qHPV; covers HPV 6/11/16/18; targets cervical cancer (2nd most common cancer in Indian women); added to UIP 2024.
- **Biolumpivaxin** — India's first indigenous vaccine for **Lumpy Skin Disease** in cattle (ICAR-NRCE, Hisar + IVRI, Izatnagar); launched Aug 2022, commercialised 2024 via Hester Biosciences.
- **mNEXSPIKE** — Moderna's next-gen mRNA COVID vaccine (May 2025 USFDA approved); 20% more effective than Spikevax in adults 65+; smaller 10 µg dose.
- **Koala Chlamydia vaccine** — University of Sunshine Coast (Australia) 2025; first vaccine for non-human species to combat a disease threatening extinction (koala populations); precedent for **One Health** concept.
- **Shingrix** — GSK's recombinant Herpes Zoster (shingles) vaccine; 97% efficacy in adults 50+; approved in India 2023 for adults ≥50 or immunocompromised.

Prelims Connect

Notable vaccines in news 2025-26

Vaccine	Disease	Maker / Country
Cervavac	HPV / cervical cancer	Serum Institute India (launched 2023)
Biolumpivaxin	Lumpy Skin Disease (cattle)	Biovet (Bharat Biotech)
mNEXSPIKE (mRNA-1283)	COVID-19	Moderna (US)
Lenacapavir	HIV prevention	Gilead; WHO recommended
AdFalciVax	Malaria (multi-stage)	ICMR-RMRC India
RTS,S / R21	Malaria (pre-erythrocytic)	GSK / Oxford-SII
Koala Chlamydia Vaccine	Koala chlamydia	Australia
Ebola Sudan Vaccine	Ebola Sudan strain	Uganda-WHO trial
Indogen (ZyCoV-D)	COVID-19 DNA	Zydus (India)

WHO's Pandemic Treaty finalised in April 2025 obliges members to share vaccines and diagnostic technologies during pandemics via PABS system (Pathogen Access & Benefit Sharing).

Prelims Pointers

- **Biolumpivaxin** = India's Lumpy Skin Disease (**LSD**) vaccine for cattle, by Biovet.
- **HPV vaccine nationwide rollout** = Feb 2026 for girls 9-14.
- **Lenacapavir** — twice-yearly injectable **HIV prevention** drug; WHO-recommended 2025.
- **Pandemic Agreement** (WHO) finalised **April 2025**.
- **Cervavac** = Serum Institute's HPV vaccine (world's cheapest).

Nafithromycin — India's First Indigenous Macrolide Antibiotic

Nafithromycin, India's first domestically developed macrolide antibiotic, was launched in October 2025. Branded 'Miqnaf', it treats Community-Acquired Bacterial Pneumonia (CABP) caused by multi-drug-resistant Streptococcus pneumoniae.

News in Brief

- Developed by Wockhardt (Mumbai); ~14 years of R&D supported under BIRAC-BIPP (Biotechnology Industry Research Assistance Council's Biotechnology Industry Partnership Programme).
- India's first new-chemical-entity macrolide, approved by CDSCO (Oct 2025).
- 10× more effective than azithromycin; needs only a 3-day course.
- Addresses a pressing gap — antimicrobial resistance (AMR) is the world's silent pandemic; CABP kills > 2 million annually.
- Part of India's push for 'Atmanirbhar' antibiotics and new-chemical-entity innovation.

Static Background (Basics to Remember)

- **Antibiotic classes** — **β-lactams** (penicillin, cephalosporins); **Macrolides** (erythromycin, azithromycin); **Tetracyclines**; **Fluoroquinolones**; **Aminoglycosides**; **Glycopeptides** (vancomycin); **Oxazolidinones** (linezolid).
- **Macrolides** — inhibit bacterial 50S ribosomal subunit; used for community-acquired pneumonia, STIs, atypical pathogens; azithromycin is most famous; developed by Russian scientists 1952 (erythromycin).
- **Nafithromycin** — India's first **indigenous macrolide**; developed by Wockhardt (Pune); 14 years R&D, ₹500 cr investment; 8× more potent than azithromycin against resistant pneumonia; branded **Miqnaf**.
- **AMR — Antimicrobial Resistance** — WHO calls it silent pandemic; ~1.27 mn direct deaths globally (2019), projected 10 mn/year by 2050; India is epicentre due to OTC sale, poultry use, under-regulation.
- **National Action Plan on AMR** — 2017 (NAP-AMR); Kayakalp, Swachh Bharat, Red Line campaign (red line on Rx-only antibiotics); **ICMR AMR surveillance network** of 30+ labs.
- **Global frameworks** — **WHO GLASS** (Global AMR Surveillance); **GAP-AMR** 2015; UN High-Level Meeting Sep 2024 (100 countries committed to 10% AMR death reduction by 2030); **One Health** approach.
- **India's pharma strength** — world's largest generic drugs supplier (~20% by volume), 60% of global vaccines, largest supplier to UNICEF; known as 'pharmacy of the world'.

Prelims Connect

Selected new indigenous Indian drugs

Drug	Purpose	Developer
Nafithromycin	Macrolide antibiotic (CABP)	Wockhardt

NexCAR19 / Qartemi	CAR T-cell therapy	ImmunoACT / IIT Bombay
Cervavac	HPV vaccine	Serum Institute
ZyCoV-D	DNA COVID vaccine	Zydus
Covaxin	Inactivated COVID vaccine	Bharat Biotech + ICMR
AdFalciVax	Malaria vaccine	ICMR-RMRC Bhubaneswar
IndOss	Indigenous bone substitute	CSIR-NCL

Macrolide antibiotics include azithromycin, erythromycin, clarithromycin — they target bacterial ribosomes. AMR-Safe new macrolides are rare because big pharma has deprioritised antibiotic R&D.

Prelims Pointers

- **Nafithromycin** = India's first indigenous **macrolide antibiotic** (Oct 2025).
- **Developer**: **Wockhardt**, supported by BIRAC-BIPP.
- **Treats**: Community-Acquired Bacterial Pneumonia (CABP).
- **10× more effective** than azithromycin; 3-day course.
- **BIRAC** = Biotechnology Industry Research Assistance Council, under **DBT**.

Viral Outbreaks — HMPV, HKU5-CoV-2, NB.1.8.1, Zika, Mpox, Nipah, Chandipura

2025-26 brought waves of viral outbreaks in India and globally — HMPV in India, HKU5-CoV-2 bat coronavirus in China, NB.1.8.1 Omicron subvariant, Zika in Pune, Mpox in Africa, and continued Nipah and Chandipura alerts.

News in Brief

- HMPV (Human Metapneumovirus, Jan 2025) — 15+ cases detected in India; causes flu-like illness.
- HKU5-CoV-2 (Feb 2025) — new bat coronavirus discovered in China by Wuhan Institute of Virology; similar to SARS-CoV-2 but lower pathogenicity.
- NB.1.8.1 (May 2025) — new Omicron subvariant spreading in India and China; described by WHO as 'variant under monitoring'.
- Zika virus (Feb 2025) — Pune district, Maharashtra, declared hotspot.
- West Nile Virus (WNV, May 2025) — detected in UK mosquitoes for the first time.
- Chandipura virus — June 2025, Favipiravir shown to be effective in preclinical studies.
- Mpox (Monkeypox) — Uganda + WHO launched new Ebola Sudan vaccine trials (Feb 2025); Mpox clade 1b still a PHEIC.
- GBS (Guillain-Barré Syndrome) — Pune outbreak Jan 2025 linked to contaminated water.
- Avian influenza H5N1 — tigers and a leopard died at Nagpur rescue centre (Jan 2025).

Static Background (Basics to Remember)

- **Virus classification** — DNA (e.g., herpes, smallpox) vs RNA (influenza, coronaviruses, HIV, Zika); RNA mutate faster. Envelope vs non-envelope. **Zoonotic** = jumps from animals to humans (60%+ of new diseases).
- **HMPV** — Human Metapneumovirus, discovered 2001 (Netherlands); respiratory virus like RSV; affects children, elderly, immunocompromised; China outbreak Jan 2025 caused panic but WHO said it was routine seasonal surge.
- **HKU5-CoV-2** — bat coronavirus found by Shi Zhengli (China, Wuhan Institute of Virology, Feb 2025); uses ACE2 receptor like SARS-CoV-2; no human cases yet but raised pandemic concerns.

- **NB.1.8.1** — SARS-CoV-2 subvariant (late 2024); descendant of Omicron JN.1 lineage; dubbed 'Nimbus'; detected in India mid-2025; symptoms include hoarseness.
- **Zika virus** — Flavivirus transmitted by Aedes aegypti (same as dengue/chikungunya); causes microcephaly in foetuses, Guillain-Barré; 2015-16 Americas outbreak; India reports sporadic cases (Maharashtra, Karnataka, Kerala).
- **Mpox (monkeypox)** — Orthopoxvirus; 2 clades (I & II); WHO declared PHEIC in 2022 (clade II) and 2024 (clade I in DRC); India's first case 2022. Vaccines: JYNNEOS, ACAM2000.
- **Nipah virus** — henipavirus from fruit bats (Pteropus); outbreaks in Kerala (2018, 2021, 2023, 2024); fatality 40-75%; no vaccine yet. ICMR developed monoclonal antibody.
- **Chandipura virus** — Vesiculovirus (Rhabdoviridae) transmitted by sand flies; causes encephalitis in children; 2024 Gujarat outbreak killed 70+; named after Chandipura village, Maharashtra (where first identified 1965).
- **WHO pandemic preparedness** — **Disease X** concept; **Pandemic Agreement** negotiated 2024-25; **IHR 2005** amendments; India's **PM-ABHIM** health infrastructure mission.

Prelims Connect

Major viruses in news 2025-26

Virus	Family	Transmission
HMPV	Pneumoviridae	Respiratory droplets
HKU5-CoV-2	Coronaviridae (β)	Bats (potential spillover)
NB.1.8.1	Coronaviridae (Omicron)	Respiratory
Zika	Flaviviridae	Aedes aegypti mosquito
West Nile Virus	Flaviviridae	Culex mosquito
Chandipura Virus	Rhabdoviridae	Sandfly vector
Mpox (MPXV)	Poxviridae	Close contact, fomites
Nipah Virus	Paramyxoviridae	Fruit bats → humans
Avian Influenza H5N1	Orthomyxoviridae	Wild birds → mammals
Rift Valley Fever	Phenuiviridae	Mosquito, livestock

A PHEIC — Public Health Emergency of International Concern — is declared by WHO under the International Health Regulations 2005. Mpox clade 1b was declared PHEIC in 2024.

Prelims Pointers

- **HMPV** = Human Metapneumovirus (family Pneumoviridae).
- **HKU5-CoV-2** = bat-origin beta-coronavirus discovered Feb 2025.
- **NB.1.8.1** = Omicron subvariant in news 2025.
- **Zika** and **West Nile** are both **flaviviruses**.
- **Chandipura virus** — transmitted by **sandflies**; causes encephalitis.

Trachoma Elimination, Malaria-Free Georgia, Rubella-Free Nepal

India earned a major global public health milestone in 2025 — WHO certification for eliminating trachoma as a public health problem. Georgia was certified malaria-free, and Nepal eliminated rubella.

News in Brief

- India received WHO Certificate of Elimination of Trachoma as a Public Health Problem (May 2025).
- India becomes 3rd SEAR country to eliminate trachoma (after Nepal and Myanmar).
- Trachoma is a bacterial eye infection (Chlamydia trachomatis) — leading cause of infectious blindness.
- Georgia (WHO-certified malaria-free, Jan 2025) — 44th country globally.
- Nepal (Aug 2025) — officially achieved elimination of rubella as public health problem.
- India eliminated polio (certified 2014), yaws (2016), and maternal-neonatal tetanus (2015).
- Uganda (Feb 2025) — launched world's first Sudan Ebola virus vaccine trial.

Static Background (Basics to Remember)

- **Trachoma** — bacterial eye infection by **Chlamydia trachomatis**; world's leading infectious cause of blindness; spreads via flies, shared towels, hand-to-eye contact; SAFE strategy (Surgery, Antibiotics, Face washing, Environmental improvement).
- **India trachoma elimination** — WHO certified in October 2024 as free from trachoma as a public-health problem; achieved through **National Trachoma Control Programme** integrated with **NPCB&VI** (National Programme for Control of Blindness & Visual Impairment).
- **Diseases India eliminated** — Smallpox (1977, world 1980), Polio (2014), Maternal & Neonatal Tetanus (2015), Yaws (2016), Guinea Worm (2000). Pending: TB, Leprosy, Kala-azar, Lymphatic Filariasis, Malaria.
- **Malaria-free Georgia** — 2025; WHO certification requires zero indigenous cases for 3 consecutive years + robust surveillance. Georgia joined Argentina, Paraguay, El Salvador, China, etc.
- **Rubella-free Nepal** — 2025; rubella (German measles) causes Congenital Rubella Syndrome (CRS) — blindness, deafness, heart defects; MR vaccine under UIP of India since 2017.
- **Measles elimination** — India missed the 2023 target; WHO SEARO region aims for 2026; MR vaccination drive added to UIP. **Measles & Rubella Elimination Initiative** (IMI 5.0 coverage).
- **WHO health certifications** — certification ≠ eradication. **Eradication** = global permanent zero (smallpox only so far); **Elimination** = zero in a defined area; **Control** = reduced to acceptable level.

Prelims Connect

India's disease elimination milestones

Disease	Year Eliminated	Status
Smallpox	1980 (globally)	Eradicated
Guinea worm (dracunculiasis)	2000	Eliminated from India
Polio	2014	Certified polio-free
Maternal-Neonatal Tetanus	2015	WHO-validated
Yaws	2016	First country to eliminate
Leprosy	2005 (as public-health problem)	Low-prev target ongoing
Trachoma	May 2025	WHO-certified elimination

WHO's 'Elimination as a Public Health Problem' (EPHP) means prevalence below a defined threshold, not necessarily zero cases. 'Eradication' means global permanent zero incidence.

Prelims Pointers

- **India** received WHO certification of **trachoma elimination** in **May 2025**.
- **Trachoma** causative agent: **Chlamydia trachomatis** (bacterium).
- **Georgia** certified malaria-free **Jan 2025** — 44th country globally.
- **Nepal** eliminated rubella (Aug 2025).
- **First disease eradicated** globally: **Smallpox** (1980).

Biotech & Genetic Research — BharatGen (?) / Biobank / AlphaGenome / Bloom / Huntington's

India's biotech sector deepened with the Phenome India National Biobank, the Gujarat Tribal Genome Sequencing Project, IIT Madras breakthroughs, while global genetic research was marked by AlphaGenome and the 'de-extinction' of the dire wolf.

News in Brief

- Phenome India 'National Biobank' — inaugurated by Dr Jitendra Singh at IIT Madras (July 2025); CSIR-IGIB-led.
- Gujarat (July 2025) — launched India's first Tribal Genome Sequencing Project.
- AlphaGenome (Jan 2026) — Google DeepMind AI model that predicts functional effects of DNA mutations.
- 'De-extinction' — Colossal Biosciences (US) announced the resurrection of the dire wolf (April 2025) — 3 pups born using gene editing of grey wolves.
- Huntington's disease (Jan 2025) — IIT Madras researchers used stem cells for advanced treatment.
- SUJVIKA — Jitendra Singh launched this AI-driven biotech data portal (Feb 2026).
- BioE3 initiative — DBT's Biotechnology for Economy, Environment and Employment policy (2024).
- BioAsia 2026 — 23rd edition inaugurated in Hyderabad (Feb 2026).
- Bloom syndrome (Aug 2025) — rare autosomal recessive genetic disorder (BLM gene) highlighted.
- Luxembourg prince died of POLG-related disease (Mar 2025) — a rare mitochondrial DNA polymerase disorder.

Static Background (Basics to Remember)

- **Genomics basics** — Human genome has ~3 billion base pairs & ~20,000 genes; Human Genome Project completed 2003 ($3 bn, 13 years); today's sequencing is <$200, under a day.
- **India's genome missions** — **GenomeIndia project** (2020, DBT); sequenced 10,000 Indian genomes (Jan 2025 announcement); **IndiGen** (CSIR) sequenced 1,000 genomes earlier; data housed at Indian Biological Data Centre (IBDC), Faridabad.
- **Biobanks** — collections of biological samples (blood, DNA, tissue) + clinical data for research; **UK Biobank** has 500k participants; India's **Phenome India Project** (CSIR) is similar; builds personalised medicine base.
- **Tribal Genome Project** — ICMR + DBT sequencing indigenous tribal populations for unique genetic variants; covers ~700 tribes (8.6% of India's population); vital for rare-disease research.
- **AlphaGenome (DeepMind 2025)** — predicts effects of DNA variants on gene regulation; handles 1 million base-pair context windows; successor to AlphaFold & AlphaMissense; major leap for genomics.
- **CRISPR-Cas9** — gene-editing tool discovered by Emmanuelle Charpentier & Jennifer Doudna (Nobel 2020); allows precise DNA cuts; **Casgevy** (CRISPR therapy for sickle-cell) approved UK 2023, India eyeing.
- **De-extinction / Dire wolf** — Colossal Biosciences (April 2025) claimed to resurrect **Aenocyon dirus** (dire wolf, extinct 10,000 yrs ago) using grey wolf genome editing; ethical debate over de-extinction.

- **Bloom / Huntington's** — Huntington's disease: autosomal dominant neurodegenerative disorder from CAG repeat expansion in HTT gene; first gene therapy (AMT-130) showing promise 2024-25.

Prelims Connect

Biotech / genomics milestones in news

Item	Agency / Country
Phenome India National Biobank	CSIR-IGIB / IIT Madras
Tribal Genome Sequencing	Gujarat Biotech Research Centre
AlphaGenome	Google DeepMind
Dire wolf 'de-extinction'	Colossal Biosciences (US)
SUJVIKA biotech portal	DBT / Jitendra Singh
BioE3 Policy	DBT India (2024)
BioAsia 2026 (23rd)	Telangana Life Sciences

BioE3 = 'Biotechnology for Economy, Environment, and Employment' — India's flagship biotech policy, envisioning bio-manufacturing hubs, research parks and climate-resilient agri-biotech.

Prelims Pointers

- **Phenome India National Biobank** — at IIT Madras; led by **CSIR-IGIB**.
- **AlphaGenome** = Google DeepMind DNA-effects AI.
- **Colossal Biosciences** — announced dire wolf 'de-extinction' (April 2025).
- **BioE3 policy** — DBT, 2024 — Biotechnology for Economy, Environment, Employment.
- **BioAsia 2026** — held in **Hyderabad**, Telangana (23rd edition).

Preventive Care & Public-Health Programmes — Nayanamritham, Obesity Guidelines, CATCH

India's preventive and precision healthcare expanded in 2025-26 with AI-based diabetic retinopathy screening (Nayanamritham 2.0), WHO's first obesity guidelines endorsing GLP-1 drugs, cancer AI via CATCH, and national biobanks.

News in Brief

- Nayanamritham 2.0 (Feb 2025) — launched by Kerala government with Remidio; world's first AI-enabled state-wide diabetic-retinopathy screening programme.
- WHO Guidelines on GLP-1 drugs (Dec 2025) — first conditional recommendation of GLP-1 receptor agonists (semaglutide, tirzepatide) for adult obesity treatment.
- CATCH Program (Aug 2025) — IndiaAI + National Cancer Grid; applies AI to cancer diagnostics.
- IARC (International Agency for Research on Cancer, WHO sub-body) released updates on cancer burden; India among highest-growth cancer countries.
- Phenome India National Biobank and Tribal Genome Sequencing Project (see 5.7).
- SUJVIKA biotech portal (Feb 2026).
- Dengue, Zika, Nipah, and AMR remain core challenges.
- Pushkar Kumbh Mela 2025 (May 2025) health planning in Keshav Prayag, Uttarakhand.

Static Background (Basics to Remember)

- **Preventive public health** — per WHO, 80% of premature heart disease, stroke & Type-2 diabetes can be prevented through diet, exercise & not smoking; **Ayushman Arogya Mandir** (formerly HWC) rolled out 1.75 lakh centres.
- **Ayushman Bharat** — launched 2018 with two pillars: (1) **PM-JAY** (health insurance, ₹5 lakh/family/year); (2) **Health & Wellness Centres** (HWCs). Extended to all seniors 70+ (Oct 2024).
- **Nayanamritham (Kerala)** — cataract elimination programme; Kerala declared cataract-blindness-free in 2025. India's **National Programme for Control of Blindness** targets prevalence <0.25% by 2025.
- **NCDs burden** — non-communicable diseases (CVD, cancer, diabetes, CRD) account for 66% of deaths in India; **NP-NCD** programme covers 700+ districts; HbA1c screening for diabetes.
- **GLP-1 agonists** — semaglutide (Ozempic, Wegovy, Rybelsus); originally diabetes drug, now blockbuster for obesity; mimics gut hormone reducing appetite. **Tirzepatide** (Mounjaro) dual GIP/GLP-1 agonist.
- **Obesity crisis** — WHO: 1 bn people obese globally (2022); India: ~44 mn obese women, 26 mn obese men; childhood obesity rising. Obesity linked to 13 cancers. BMI ≥25 = overweight, ≥30 = obese (WHO); India-specific cut-offs lower.
- **PMBJP — Jan Aushadhi** — Pradhan Mantri Bhartiya Janaushadhi Pariyojana; 14,000+ Kendras selling generic drugs at 50-90% discount; under BPPI (Bureau of Pharma PSUs of India).
- **National Health Policy 2017** — target health spend 2.5% of GDP by 2025 (currently ~2.1%); UHC goal; free drugs & diagnostics; **Ayushman Bharat Digital Mission (ABDM)** launched 2021 — ABHA health ID.

Prelims Connect

Public-health institutional framework

Body	Role
ICMR	Apex medical research body (under MoHFW)
CDSCO	Drug regulator (Central Drugs Standard Control Organisation)
NCDC	National Centre for Disease Control
NPPA	National Pharmaceutical Pricing Authority
NITI Aayog NCD Cell	Non-communicable disease strategy
DBT / BIRAC	Biotechnology research funding
IARC	Cancer research — WHO agency (Lyon)
WHO SEAR Office	New Delhi (Regional HQ)

GLP-1 receptor agonists (like semaglutide, marketed as Ozempic/Wegovy) were originally diabetes drugs now widely used for obesity. WHO recommended them conditionally in Dec 2025.

Prelims Pointers

- **Nayanamritham 2.0** — Kerala's AI-based retinopathy screening, with Remidio.
- **GLP-1 receptor agonists** (semaglutide, tirzepatide) — for **obesity**; WHO-recommended Dec 2025.
- **CATCH** = IndiaAI + National Cancer Grid.

- **IARC** = International Agency for Research on Cancer (WHO), HQ **Lyon, France**.
- **ICMR** is headquartered in **New Delhi**; oldest medical research body (est 1911 as IRFA).

Synthetic Human Genome Project, TnpB Editing & Gene-Edited Rice

Three developments in 2025 mark a new frontier in genetic science: the launch of a project to 'write' the entire human genome from scratch (SynHG), an ICAR-patented miniature genome editing tool smaller and easier to deliver than CRISPR-Cas9 (TnpB), and a CRISPR-edited rice variety from NIPGR that dramatically improves phosphate absorption — directly relevant to India's fertiliser subsidy bill and agricultural productivity.

News in Brief

- Synthetic Human Genome Project (SynHG, UK — Oxford/Cambridge): launched 2025 to synthesise (write) the entire human genome from scratch over 5 years — unlike the Human Genome Project (1990–2003) which only sequenced (read) it.
- NIPGR Gene-Edited Rice: CRISPR-Cas9 used to enhance phosphate uptake efficiency in japonica rice at National Institute of Plant Genome Research, New Delhi. Only 15–20% of applied phosphate fertiliser is currently absorbed — new variety significantly increases this.
- TnpB Genome Editing (ICAR): received patent for a miniature CRISPR-alternative tool — TnpB protein from Deinococcus radiodurans, an extremophile bacterium. Only 408 amino acids vs. Cas9's 1,368 — far easier to package into viral delivery vectors.

Static Background (Basics to Remember)

HGP vs Synthetic Human Genome Project — Comparison

Feature	Human Genome Project (1990–2003)	Synthetic Human Genome Project (2025–)
Goal	READ: sequence all 3.1 billion base pairs of the human genome	WRITE: chemically synthesise the complete human genome
Cost	$2.7 billion (initial estimate)	~$100 million (modern synthesis technology)
Duration	13 years (1990–2003)	~5 years (estimated, 2025–2030)
Output	Reference genome; ~20,000 protein-coding genes identified	Synthetic DNA segments → eventually full working genome in a cell
Key ethical concern	Data privacy; genetic discrimination; IP over genome sequence	Designer babies; eugenics; dual-use biosecurity risks

CRISPR and Genome Editing Tools — India's Position

- CRISPR-Cas9: Charpentier and Doudna (Nobel Chemistry 2020); uses guide RNA to direct Cas9 'molecular scissors' to specific DNA sequence.
- TnpB (ICAR, 2025): 3x smaller than Cas9; sourced from Deinococcus radiodurans (highly radiation-resistant extremophile); could fit into AAV viral delivery vectors currently too small for Cas9.

- India's genome editing regulation: SDN-1 (no foreign DNA insertion, site-directed nuclease only) — treated as non-GMO. NIPGR rice falls under SDN-1/SDN-2 — no foreign gene, only endogenous gene modification.

Prelims Connect

Genome Editing — Key Facts

Topic	Key Detail
HGP completion	2003; $2.7 billion; 3.1 billion base pairs; ~20,000 genes
SynHG	UK (Oxford + Cambridge); 2025–; writes genome from scratch; ~$100 million
NIPGR	National Institute of Plant Genome Research, New Delhi — under DBT
NIPGR rice	CRISPR-Cas9 enhanced phosphate uptake; SDN-1/SDN-2 (non-GMO category)
TnpB	ICAR patent 2025; 408 amino acids (vs Cas9 1,368); from Deinococcus radiodurans
Nobel Chemistry 2020	Charpentier + Doudna — CRISPR-Cas9 genome editing tool

India's SDN-1/SDN-2 gene-edited crops regime — which treats edited crops without foreign DNA as non-GMO — has significant implications for the fertiliser subsidy bill. If NIPGR's phosphate-efficient rice is widely adopted, India's phosphate fertiliser import bill (~$2 billion/year) could be significantly reduced.

BASIC SCIENCE, MISSIONS & INSTITUTIONS

Nobel Prizes 2025 — Physics, Chemistry, Medicine, Literature, Peace, Economics

The 2025 Nobel Prizes honoured scientific breakthroughs in quantum mechanics, metal-organic frameworks, and immune tolerance; literary excellence by László Krasznahorkai; human-rights activism by María Corina Machado; and economic work on innovation-led growth by three economists.

News in Brief

- Physics 2025 — John Clarke, Michel H. Devoret, John M. Martinis — for macroscopic quantum tunnelling and quantisation of energy in superconducting circuits (foundations of quantum computing).
- Chemistry 2025 — Susumu Kitagawa, Richard Robson, Omar M. Yaghi — for development of metal-organic frameworks (MOFs).
- Physiology or Medicine 2025 — Mary E. Brunkow, Fred Ramsdell, Shimon Sakaguchi — for discoveries on peripheral immune tolerance (regulatory T cells / Foxp3).
- Literature 2025 — László Krasznahorkai (Hungary).
- Peace 2025 — María Corina Machado (Venezuela) for democratic rights. The Norwegian Nobel Committee rejected her attempt to dedicate the prize to President Trump (Jan 2026).

- Economics 2025 — Joel Mokyr, Philippe Aghion, Peter Howitt — for theories of innovation-driven economic growth.

Static Background (Basics to Remember)

- **Nobel Prize basics** — instituted by will of Alfred Nobel (1895 will; first awards 1901); 6 categories: Physics, Chemistry, Physiology/Medicine, Literature, Peace, Economics (added 1968 by Sweden's Riksbank).
- **Indian Nobel laureates** — Rabindranath Tagore (Literature 1913), C.V. Raman (Physics 1930 — for Raman effect, only India-born science Nobel), Mother Teresa (Peace 1979), Amartya Sen (Economics 1998), Kailash Satyarthi (Peace 2014), Abhijit Banerjee (Economics 2019); Hargobind Khorana (Medicine 1968), S. Chandrasekhar (Physics 1983), Venki Ramakrishnan (Chemistry 2009) — Indian-origin.
- **2024 Nobel highlights** — Physics: Hopfield & Hinton (neural nets); Chemistry: Baker + Hassabis & Jumper (AlphaFold); Medicine: Ambros & Ruvkun (microRNA); Peace: Nihon Hidankyo (A-bomb survivors).
- **2025 Nobel highlights** — Physics: macroscopic quantum tunnelling; Chemistry: metal-organic frameworks; Medicine: peripheral immune tolerance; Literature: László Krasznahorkai (Hungary); Peace: María Corina Machado (Venezuela).
- **Prize mechanics** — Sweden awards all except Peace (awarded in Oslo, Norway); cash prize ~11 mn SEK (~₹8 cr); can be shared by up to 3 laureates; not awarded posthumously (since 1974).
- **Breakthrough Prize** — 'Oscars of Science' $3 mn; Silicon Valley–backed (Zuckerberg, Milner); in Life Sciences, Fundamental Physics & Math.

Prelims Connect

Nobel Prize 2025 laureates — at a glance

Category	Laureates	Field
Physics	Clarke, Devoret, Martinis	Quantum tunnelling in superconductors
Chemistry	Kitagawa, Robson, Yaghi	Metal-organic frameworks (MOFs)
Medicine	Brunkow, Ramsdell, Sakaguchi	Peripheral immune tolerance
Literature	László Krasznahorkai	Hungarian novelist
Peace	María Corina Machado	Venezuelan democracy activist
Economics	Mokyr, Aghion, Howitt	Innovation-driven growth

Metal-organic frameworks (MOFs) are crystalline porous materials formed by metal ions connected by organic ligands — widely used in gas storage, catalysis, drug delivery, and water harvesting.

Prelims Pointers

- **Physics Nobel 2025** — for **macroscopic quantum tunnelling** in superconducting circuits.
- **Chemistry Nobel 2025** — for **Metal-Organic Frameworks (MOFs)**.
- **Medicine Nobel 2025** — for discovery of **peripheral immune tolerance** (Treg cells).
- **Peace Nobel 2025** — **María Corina Machado** (Venezuela).
- **Literature Nobel 2025** — László Krasznahorkai (Hungary).

Turing, Crafoord & Other S&T Awards

Several top science awards made news in 2025-26 — the ACM Turing Award for reinforcement learning, the Crafoord Prize to an Indian-origin climate scientist, the Wiley Research Heroes Prize, and the Paulos Mar Gregorios Award.

News in Brief

- ACM A.M. Turing Award 2024 (announced 2025) — Andrew G. Barto and Richard S. Sutton — for foundational work on reinforcement learning.
- Crafoord Prize 2026 — Indian-origin atmospheric scientist Veerabhadran Ramanathan for climate science work.
- Wiley Research Heroes Prize 2025 — won by Soumya Swaminathan (former WHO Chief Scientist) — first Indian recipient.
- Dr Paulos Mar Gregorios Award 2025 — Tessy Thomas, 'Missile Woman of India', for contributions to science & technology.
- Padma Vibhushan 2025 — awarded to S. M. Krishna (posthumously), Suresh Bhardwaj, Dr D. Nageshwar Reddy, Justice J. S. Khehar, Kumudini Lakhia (posthumously).

Static Background (Basics to Remember)

- **Turing Award** — 'Nobel of computing'; instituted 1966 by ACM; named after Alan Turing (father of CS); $1 mn prize sponsored by Google; 2024: Barto & Sutton (reinforcement learning, the foundation of modern AI).
- **Crafoord Prize** — Royal Swedish Academy of Sciences, 1982; for fields NOT covered by Nobels (astronomy, mathematics, geosciences, biosciences, polyarthritis); ~6 mn SEK.
- **Fields Medal** — highest award in Mathematics, awarded every 4 years at ICM to mathematicians ≤40; Indian-origin winners: Manjul Bhargava (2014), Akshay Venkatesh (2018).
- **Abel Prize** — Math Nobel equivalent, awarded annually by Norwegian Academy since 2003; no age limit; 6 mn NOK; Sreenivasa Varadhan won in 2007.
- **Wiley Prize** — in Biomedical Sciences; by John Wiley & Sons publisher; recognises contributions to basic medical research.
- **Paulos Gregorios Prize** — for outstanding contributions to science & spirituality; named after Indian Orthodox Metropolitan & philosopher; awarded at Kerala events.
- **Indian science awards** — **Shanti Swarup Bhatnagar Prize** (CSIR, since 1957, for scientists ≤45, ₹5 lakh); **Rashtriya Vigyan Puraskar** (2024 new apex award replacing older awards): Vigyan Ratna/Shri/Yuva/Team categories.
- **Bharat Ratna** — instituted 1954; awarded to scientists like C.V. Raman (1954), M. Visvesvaraya (1955), A.P.J. Abdul Kalam (1997), C.N.R. Rao (2014).

Prelims Connect

Top science-tech awards — 2025-26 in news

Award	Field	Winner(s) 2025
Turing Award 2024	Computer science	Barto & Sutton (Reinforcement Learning)
Crafoord Prize 2026	Geosciences / Bio / Maths (rotating)	V. Ramanathan (Climate, Indian-origin)
Wiley Research Heroes 2025	Biomedical research	Soumya Swaminathan

Paulos Mar Gregorios Award	S&T contributions	Tessy Thomas
Nobel Physics 2025	Quantum circuits	Clarke, Devoret, Martinis
Nobel Chemistry 2025	MOFs	Kitagawa, Robson, Yaghi

Turing Award (ACM, since 1966) is often called the 'Nobel Prize of Computing' — carries a US$1 million prize sponsored by Google.

Prelims Pointers

- **Turing Award 2024** — Barto & Sutton, for **reinforcement learning**.
- **Crafoord Prize 2026** — V. Ramanathan (climate).
- **Tessy Thomas** — 'Missile Woman of India', Dr Paulos Mar Gregorios Award 2025.
- **Soumya Swaminathan** — 1st Indian to win **Wiley Research Heroes Prize**.
- **Turing Award** awarded by ACM, called **'Nobel Prize of Computing'**.

6.3 Deaths / Tributes — K. Kasturirangan, Chen-Ning Yang, G.G. Parikh

Several towering scientific figures were lost in 2025 — Dr K. Kasturirangan (ISRO 10th Chairman), Chen-Ning Yang (Nobel physicist) and G.G. Parikh (freedom fighter), along with other Indian science greats.

News in Brief

- Dr K. Kasturirangan (25 April 2025) — ISRO Chairman 1994-2003; led PSLV operationalisation, IRS-1C/1D; chaired NEP 2020 drafting committee. Padma Vibhushan.
- Chen-Ning Yang (Oct 2025) — Chinese theoretical physicist; Nobel Prize Physics 1957 with Tsung-Dao Lee for work on parity violation in weak interactions.
- G.G. Parikh (Oct 2025) — Gandhian freedom fighter imprisoned during Quit India movement.
- Tessy Thomas — 'Missile Woman' — received Paulos Mar Gregorios Award 2025 (alive but honored).
- Ustad Zakir Hussain (died 2024, tributes continued in 2025).

Static Background (Basics to Remember)

- **K. Kasturirangan (1940-2025)** — former ISRO chairman (1994-2003); presided over PSLV operationalisation, GSLV first successful flight, IRS, INSAT series; chaired drafting of **National Education Policy 2020**; awarded Padma Vibhushan 2000.
- **Chen-Ning Yang (1922-2025)** — Chinese-American theoretical physicist; shared 1957 Physics Nobel with T.D. Lee for **parity non-conservation** in weak interactions; co-developer of Yang-Mills theory (foundation of Standard Model); longest-lived Nobel laureate.
- **G.G. Parikh** — veteran Indian socialist, freedom fighter, medical practitioner; associated with Janata Weekly; lived ~100 years; icon of Gandhian values.
- **Tribute custom** — UPSC often asks recently deceased scientists; **Vikram Sarabhai** (father of Indian space 1919-71), **Homi Bhabha** (father of Indian nuclear 1909-66), **Satish Dhawan** (1920-2002), **APJ Abdul Kalam** (1931-2015), **UR Rao** (1932-2017), **Roddam Narasimha** (2020).
- **Padma awards** — instituted 1954 (Padma Vibhushan, Padma Bhushan, Padma Shri); scientists routinely honoured; announced on Republic Day.
- **Bharat Ratna in science** — C.V. Raman, Visvesvaraya, Kalam, C.N.R. Rao — only 4 science laureates in the 50+ awardees.

Prelims Connect

Nobel laureates of Indian origin

Name	Prize	Year
Rabindranath Tagore	Literature	1913
C.V. Raman	Physics	1930
Hargobind Khorana	Medicine	1968
Mother Teresa	Peace	1979
Subrahmanyan Chandrasekhar	Physics	1983
Amartya Sen	Economics	1998
Venkatraman Ramakrishnan	Chemistry	2009
Kailash Satyarthi	Peace	2014
Abhijit Banerjee	Economics	2019

Chen-Ning Yang's Yang-Mills theory (with Robert Mills, 1954) is the foundation of modern gauge theories describing strong & weak nuclear forces and electroweak unification.

Prelims Pointers

- **Dr K. Kasturirangan** — 10th ISRO Chairman; died April 2025.
- **Chen-Ning Yang** — Nobel Physics 1957 for parity violation; died Oct 2025.
- **Yang-Mills theory** underpins modern particle physics.
- **Tessy Thomas** is called **'Missile Woman of India'** — first woman to head a missile project.

Global Space / Planetary Discoveries — Enceladus, 2025 PN7, GW231123, Beryllium-10, Jarosite Mars

Global astronomy brought spectacular 2025-26 headlines — water ingredients on Enceladus, a new quasi-moon (2025 PN7), the most massive black-hole merger ever (GW231123), a rare Be-10 spike, and the first Mars jarosite discovery.

News in Brief

- Enceladus (Saturn's moon, Oct 2025) — new studies confirm all essential ingredients for life (phosphorus, hydrogen, organics).
- 2025 PN7 (Oct 2025) — newly discovered asteroid, a 'quasi-moon' of Earth; shares Earth's orbit but not gravitationally bound.
- GW231123 (July 2025) — LIGO detected the most massive black hole merger ever via gravitational waves (≈150 + 90 solar masses).
- Beryllium-10 spike (Feb 2025) — sharp rise in radioactive isotope Be-10 in ice cores ~12,000 years ago — points to a major solar event.
- Jarosite on Mars (Sep 2025) — Perseverance discovered this iron-sulphate mineral (~55 million years old) in Jezero Crater; jarosite only forms in acidic water.
- Mars Chopper (Jan 2025) — NASA revealed design of the successor to Ingenuity helicopter.
- Vera C. Rubin Observatory (June 2025) — began asteroid discovery; already cataloguing millions of objects.

- Tiangong Space Station bacteria (May 2025) — new species of bacteria discovered on board by Chinese astronauts.
- 'Artificial photosynthesis' (Feb 2025) — Chinese astronauts produced oxygen + organic molecules on Tiangong, first of its kind in space.
- Three Gorges Antarctic Eye (April 2025) — 3.2 m radio telescope installed at China's Zhongshan station.

Static Background (Basics to Remember)

- **Enceladus** — Saturn's icy moon (504 km diameter); discovered 1789 by William Herschel; **Cassini mission** (2005-17) found subsurface liquid ocean, cryo-volcanic plumes (tiger stripes near south pole) and organic molecules — prime target for life hunt.
- **Asteroid naming — 2025 PN7** = P (second half March) + N (14th asteroid) + year 2025; near-Earth asteroid (NEA); near-Earth objects classified into Atira, Aten, Apollo, Amor.
- **Gravitational waves** — predicted by Einstein 1915 General Relativity; first detected 2015 by LIGO (GW150914, black-hole merger); Nobel 2017; **GW231123** was an unusually massive binary BH merger event; LIGO-Virgo-KAGRA collaboration; India building **LIGO-India** at Hingoli, Maharashtra.
- **Beryllium-10 (^{10}Be)** — cosmogenic radioisotope; produced when cosmic rays hit nitrogen in atmosphere; half-life 1.4 mn years; used in palaeoclimatology & cosmic-ray intensity studies (Miyake events).
- **Jarosite** — yellow/brown iron sulphate mineral; forms in acidic, oxidising, water-limited conditions; found on Mars by NASA's Opportunity rover (2004); its discovery confirmed Mars once had liquid water.
- **Planetary classification** — IAU 2006: planet must (1) orbit Sun, (2) be round, (3) clear its orbital neighbourhood. Pluto failed #3, reclassified as 'dwarf planet'. Other dwarf planets: Ceres, Eris, Haumea, Makemake.
- **Exoplanet counts** — ~5,800 confirmed (2025) via Kepler (2009-18) + TESS missions; methods: transit, radial velocity, direct imaging, microlensing; **habitable zone** (Goldilocks zone) concept.
- **Recent missions** — JWST (2021), Euclid (2023), Psyche (2023), JUICE (2023), Europa Clipper (2024), Hera (2024), Artemis-II (2026 planned).

Prelims Connect

Astronomy / planetary science headlines 2025-26

Discovery / Event	Agency / Facility
Enceladus life ingredients	ESO / Cassini data re-analysis
2025 PN7 quasi-moon	Pan-STARRS / MPC
GW231123 black hole merger	LIGO-Virgo-KAGRA
Beryllium-10 spike in ice cores	University of Arizona
Jarosite on Mars	NASA Perseverance
Mars Chopper (successor)	NASA JPL
Vera C. Rubin Observatory	NSF / DOE (Chile)
Tiangong bacteria	CNSA (China)
Three Gorges Antarctic Eye	China — radio telescope at Antarctica

Jarosite is a potassium-iron-sulfate mineral that forms only in acidic aqueous environments — its presence is strong evidence that liquid acidic water existed on Mars.

Prelims Pointers

- **Enceladus** = Saturn's icy moon with ocean under ice shell; candidate for life.
- **2025 PN7** = **quasi-moon** of Earth (not gravitationally bound).
- **GW231123** = most massive black-hole merger detected (by LIGO).
- **Be-10 spike** in ice cores points to ancient **solar storm / supernova**.
- **Jarosite** on Mars = potassium-iron-sulfate, needs acidic water.

Indian R&D Institutions & Facilities — CSIR-NPL, IIT-Madras CoE, ACEN, Samgnya

India's scientific infrastructure broadened in 2025-26 with the CSIR-NPL opening new apex calibration facilities, IIT Madras designated UN Centre of Excellence for AI, ACEN navigation centre inaugurated, and the IITM-Samgnya Telecom CoE formed.

News in Brief

- CSIR-NPL (Jan 2026) — National Physical Laboratory inaugurated two apex-level calibration facilities — India's most accurate measurement standards.
- IIT Madras (Sept 2025) — nominated as UN Centre of Excellence for Artificial Intelligence.
- Ananth Centre of Excellence for Navigation (ACEN, Dec 2025) — inaugurated by ISRO Chairman V. Narayanan.
- IITM-C-DOT Samgnya Foundation (Dec 2025) — India's Telecom CoE, under Bharat 6G vision.
- INSA (Indian National Science Academy) — most prestigious science academy, highlighted Jan 2025.
- Indian Institute of Science Education and Research (IISERs), BHU, IISc — featured in QS/Nature rankings.
- IIT Palakkad (Oct 2025) — MoU with Ministry of Minority Affairs.
- Uttarakhand AI Impact Summit 2025 and TN Deep Tech Policy — state-level initiatives.

Static Background (Basics to Remember)

- **CSIR** — Council of Scientific & Industrial Research, 1942; 37 labs across India; DG is also the Secretary DSIR; PM is CSIR President; CSIR-NPL (Delhi), CSIR-NCL (Pune), CSIR-IICT, CSIR-CDRI are famous.
- **CSIR-NPL** — National Physical Laboratory, 1947; custodian of **India's national standards** (time, length, mass, current etc.); maintains Indian Standard Time via atomic clocks; operates **Bhartiya Nirdeshak Dravya** reference materials.
- **IIT & IISc ecosystem** — 23 IITs (oldest: Kharagpur 1951); IISc Bangalore (1909, J.N. Tata); 7 IISERs; NITs (31); NIAS; TIFR; IIA; PRL; IUCAA; all major research institutions across the country.
- **DBT institutions** — **NCBS** (Bengaluru), **inStem**, **ILS** (Bhubaneswar), **NII** (Delhi), **CDFD** (Hyderabad), **Translational Health Science & Technology Institute** (Faridabad).
- **ACEN** — **Advanced Centre for Energy & Nanoscience** type of CoEs; India now has multiple DST-funded Centres of Excellence in thematic areas like quantum, AI, battery, green hydrogen.
- **NRF (2023)** — Anusandhan National Research Foundation; ₹50,000 cr over 5 yrs; 70% from private/CSR; replaces SERB; aims to drive R&D from 0.65% to 2% of GDP.
- **Samgnya / Samagra** — government AI/quantum/biotech integrated programmes; also refers to 'Samagra' family of schemes for integrated planning.
- **IIT-Madras DST CoE** — multiple CoEs hosted at IITM: Robert Bosch, Ericsson 5G, IITM Pravartak, RBCCPS (IISc); serves as India's tech-transfer backbone.

Prelims Connect

India's apex scientific institutions

Body	Purpose	Year / Notes
ISRO	Space programme	1969 (Bengaluru)
DRDO	Defence R&D	1958
CSIR	Industrial research (37 labs)	1942
ICMR	Medical research	1911 (as IRFA)
DAE + BARC	Atomic energy	1954 / 1957
DBT + BIRAC	Biotechnology	DBT 1986
DST	Science & Tech policy + funding	1971
INSA	Science academy	1935
MeitY	Electronics & IT	2016 (renamed)
Anusandhan NRF	National Research Foundation	2023 Act

The Anusandhan National Research Foundation (2023) is the new apex funding body for research, replacing SERB, with ₹50,000 cr outlay.

Prelims Pointers

- **CSIR-NPL** — National Physical Laboratory; maintains India's primary standards.
- **IIT Madras** — UN Centre of Excellence for AI (Sept 2025).
- **Anusandhan NRF** = National Research Foundation Act 2023; apex funding body.
- **INSA** = Indian National Science Academy (est 1935).
- **ACEN** = Ananth Centre of Excellence for Navigation (Dec 2025).

Collaborations, Summits & Innovation — India-UK CIC, TIDCO Space Park, iTNT-XeedQ

India's innovation partnerships expanded with the India-UK Connectivity & Innovation Centre, Tamil Nadu's Space Industrial & Propulsion Park, the Tamil Nadu iTNT-XeedQ quantum tie-up, and new MoUs with Germany, Sweden and the US.

News in Brief

- India-UK Connectivity and Innovation Centre (Oct 2025) — jointly launched for joint R&D.
- TIDCO (Tamil Nadu Industrial Development Corporation, Nov 2025) is developing India's first Space Industrial & Propulsion Park.
- iTNT Hub (Tamil Nadu) partnered with XeedQ GmbH (Germany) — commercial quantum computer (Jan 2026).
- Odisha establishing India's first commercial airport-based National UAV Test & Innovation Centre (Jan 2026).
- Ministry of Mines + Government of Goa (Mar 2025) — launched India's first offshore mineral exploration tender.
- Andhra Pradesh — AI-powered Chief Minister's Office inaugurated (Sept 2025).
- IIT-M multinational engineering establishing as world's 1st multinational engineering institute (Jan 2026).

- SITAC Corridor with Sweden (Feb 2026, IndiaAI Mission).
- BioAsia 2026 — international biotech summit in Hyderabad.

Static Background (Basics to Remember)

- **Science diplomacy** — use of science cooperation for foreign policy; India engages via ITER, CERN, LIGO, SKA (Square Kilometre Array), Human Frontier Science Program, Antarctic Treaty.
- **India-UK CIC** — Critical Infrastructure Collaboration / Connectivity, Innovation and Commerce; announced under Technology Security Initiative (TSI, May 2024); covers AI, quantum, semiconductors, telecoms, biotech.
- **India's major S&T bilateral partners** — USA (iCET, INDUS-X, TRUST, NISAR); UK (TSI); EU (Horizon Europe); Japan (India-Japan Digital Partnership); Germany; France (Paris AI Summit co-host); Australia (AIRIS).
- **iCET** — Initiative on Critical & Emerging Technologies (USA + India, NSA-led, 2022); covers AI, quantum, space, semiconductors, biotech, telecom, 5G/6G; upgraded to **TRUST** (Feb 2025 — Transforming Relationships Using Strategic Tech).
- **TIDCO Space Park** — Tamil Nadu's space-industrial park at Kulasekarapattinam (near Thoothukudi) — India's 2nd spaceport for SSLV polar launches; TIDCO = Tamil Nadu Industrial Development Corp.
- **Kulasekarapattinam Spaceport** — foundation laid Feb 2024; advantages: near-equatorial, south-facing launches avoid Sri Lanka overflight, ideal for SSLV & small satellites.
- **iTNT** — Indian Technology Transfer Network; part of MeitY's tech transfer mechanism; **XeedQ** = German quantum computing startup; joint India-Germany quantum collab.
- **Vision 2047** — Viksit Bharat; DST & PSA's office prepared Decadal Vision Document for India's science priorities; aims 2% R&D spend, global top-3 in AI & quantum, semicon leadership.

Prelims Connect

Global S&T ranks & collaborations 2025-26

Initiative	Partner	Year
India-UK CIC	UK	Oct 2025
SITAC Corridor	Sweden	Feb 2026
iTNT + XeedQ	Germany	Jan 2026
Pax Silica	USA + allies	Feb 2026
India-France Rafale F4 deal	France	Ongoing
India-JAXA LUPEX	Japan	Ongoing
NASA-ISRO NISAR	USA	July 2025
India-Brazil submarine MoU	Brazil	Dec 2025

Pax Silica is a US-led minilateral aimed at de-risking global semiconductor supply chains from Chinese dependency. Similar to AUKUS-Pillar II for technology transfers.

Prelims Pointers

- **India-UK CIC** = India-UK Connectivity and Innovation Centre (Oct 2025).
- **Pax Silica** = US-led semiconductor supply alliance; India joined Feb 2026.

- **iTNT + XeedQ** = Tamil Nadu quantum computer deal with German firm.
- **NISAR** = joint NASA-ISRO EO satellite (July 2025).
- **LUPEX** = joint India (ISRO) – Japan (JAXA) lunar mission.

C2. Sodium-Ion Battery Breakthrough — JNCASR, Bengaluru

Lithium-ion batteries power everything from smartphones to electric vehicles, but lithium is scarce, expensive, and geographically concentrated in South America. Sodium-ion (Na-ion) batteries offer a potentially transformative alternative using one of Earth's most abundant elements — and a breakthrough from Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bengaluru, in 2025 has brought Na-ion performance close to Li-ion, with 6-minute fast charging and over 3,000 charge cycles.

News in Brief

- JNCASR (Bengaluru) developed a Na-ion battery that charges to 80% in 6 minutes and lasts >3,000 cycles — approaching commercial Li-ion performance thresholds.
- Key innovations: NASICON-type cathode chemistry; nanoparticle downsizing (faster diffusion) + carbon coating (better conductivity) + aluminium doping (structural stability) in the anode.
- CATL (China) launching 'Naxtra' commercial Na-ion EV battery by end 2025 — targeting 500 km range per charge.
- India's ACC Battery PLI scheme: ₹18,100 crore; target 50 GWh manufacturing capacity; Na-ion route could reduce dependence on imported lithium.

Static Background (Basics to Remember)

Na-Ion vs Li-Ion — Detailed Comparison

Feature	Lithium-Ion (Li-ion)	Sodium-Ion (Na-ion)
Raw material	Lithium (scarce; 60%+ from Li Triangle: Chile-Bolivia-Argentina)	Sodium (4th most abundant element; from seawater or salt)
Anode current collector	Copper foil (expensive, heavier)	Aluminium foil (cheaper, lighter — no Cu–Li alloy risk)
Energy density	150–250 Wh/kg (higher)	90–160 Wh/kg (lower but improving)
Safety	Thermal runaway / fire risk at high charge rates	Safer — can be discharged to 0V; shippable without special precautions
Temperature range	Performance drops below −20°C	Better low-temperature performance
Cycle life	LiFePO4 cells: 8,000+ cycles	3,000+ cycles (JNCASR 2025 result)

NASICON Chemistry & India's Battery Policy

- NASICON = Sodium Super Ionic CONductor — crystalline framework solid with very high Na+ ion mobility. Originally developed at MIT in the 1970s.

- JNCASR innovation: nanoparticle downsizing reduces ion diffusion path; carbon coating improves electron transport; Al doping stabilises crystal structure during charge-discharge cycles.
- India imports ~90% of Li-ion cells — a strategic vulnerability. Na-ion batteries using domestic sodium can reduce this dependence significantly.

Prelims Connect

Na-Ion Battery — Key Facts

Topic	Key Detail
JNCASR	Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru — under DST
NASICON	Sodium Super Ionic CONductor — high Na+ mobility crystal lattice; MIT origin (1970s)
JNCASR result	80% charge in 6 minutes; >3,000 cycles — using nanoparticle + carbon + Al-doped anode
Na-ion advantage	Aluminium anode (vs copper in Li-ion); safer; sodium is abundant and cheap
CATL Naxtra	China's commercial Na-ion EV battery; 500 km range; launch end 2025
India ACC PLI	₹18,100 crore; 50 GWh manufacturing capacity target; battery sovereignty

Na-ion batteries shipped at zero volts (fully discharged) do not require the dangerous-goods classification mandated for Li-ion cells — a significant supply chain and export logistics advantage for Indian manufacturers supplying global markets.

Altermagnetism — India Discovers Third Form of Magnetism

For over a century, magnetic materials were classified into two categories: ferromagnets (permanent magnets like iron) and antiferromagnets (opposing spins that cancel out). In 2024–25, a new category — altermagnetism — was experimentally confirmed, and Indian scientists at S.N. Bose National Centre and IACS (Kolkata) made the breakthrough discovery that the altermagnetic material CrSb displays a unique phenomenon that could enable entirely new single-crystal circuit architectures.

News in Brief

- Altermagnetism: third form of magnetism with zero net external magnetisation (like antiferromagnets) but spin-split electronic energy bands (like ferromagnets) — arising from crystal symmetry, not spin alignment.
- CrSb (chromium-antimony): SN Bose National Centre + IACS Kolkata discovered the first altermagnet showing Direction-Dependent Conduction Polarity (DDCP) — electron-type conduction in one direction, hole-type in the opposite direction.
- CrSb can function as both the p-type and n-type halves of a p-n junction within a single crystal — potentially enabling ultra-compact, single-crystal electronic circuits without multiple material layers.

Static Background (Basics to Remember)

Three Types of Magnetism — Comprehensive Comparison

Property	Ferromagnetism	Antiferromagnetism	Altermagnetism (new)
Net magnetisation	Strong (non-zero)	Zero (spins cancel perfectly)	Zero (like AFM — compensated)
Spin order	All spins parallel	Alternating antiparallel spins	Compensated but related by crystal rotation (not inversion)
External field	Yes — forms permanent magnet	No external field	No external field
Key property	Permanent magnet; memory storage	Exchange bias in spintronic devices	Spin-split bands; DDCP; anomalous Hall effect
Examples	Fe, Ni, Co, Nd2Fe14B	MnO, FeO, NiO	CrSb (first DDCP altermagnet)

Spintronics & Future Applications

- Spintronics: uses electron spin (not just charge) as information carrier — inherently faster, lower power than charge-based electronics.
- Giant Magnetoresistance (GMR): discovered 1988 (Fert + Grünberg); Nobel Prize 2007; principle used in every modern hard drive and MRAM.
- Altermagnetic spintronics advantages: terahertz-range spin switching (1,000x faster than GHz devices); anomalous Hall effect without external field; dense magnetic memory without magnetic crosstalk between adjacent bits.

Prelims Connect

Altermagnetism — Key Facts

Topic	Key Detail
Discovery	3rd form of magnetism; theorised ~2019; experimentally confirmed 2024–25
Key material	CrSb (chromium-antimony) — first DDCP altermagnet; Indian discovery
DDCP	Direction-Dependent Conduction Polarity — electrons one way, holes the other in same crystal
Institutions	SN Bose National Centre for Basic Sciences + IACS (Indian Association for the Cultivation of Science), Kolkata
Application	Single-crystal p-n junction; terahertz spintronics; anomalous Hall effect devices

GMR (reference)	1988; Nobel 2007 (Fert + Grünberg); used in all hard drives — earlier spintronics milestone

CrSb is easy to synthesise, stable at room temperature, and does not require rare-earth elements — making it commercially attractive. The Indian team's discovery of DDCP in an altermagnetic material positions Indian institutions at the forefront of a new sub-field in condensed matter physics.

LHC Alchemy, Parrondo's Paradox, Lactose Persistence & Mithridatism

Some of 2025's most interesting science stories are conceptual breakthroughs that reframe long-held assumptions: medieval alchemy vindicated in a particle accelerator, a mathematical paradox where losing leads to winning, evolutionary genetics explaining why most of humanity can't drink milk comfortably, and ancient poison immunity as a precursor to modern vaccination. Each is a high-probability Prelims topic dressed in the language of 'weird science.'

News in Brief

- LHC Alchemy: CERN scientists briefly converted lead atoms (82 protons) into gold atoms (79 protons) via ultra-peripheral collisions — electromagnetic fields from near-miss lead nuclei stripped 3 protons. Medieval alchemists' dream realised in a 27 km tunnel — but creating only picograms, far from commercial viability.
- Parrondo's Paradox: alternating between two individually losing strategies in the right sequence produces a winning outcome. Applied in oncology — two drugs, each individually unable to cure, administered in an alternating sequence prevented cancer cells from evolving resistance.
- Lactose Persistence: ability to digest milk sugar (lactose) as an adult evolved independently in multiple human populations ~11,000 years ago — linked to domestication of cattle and goats. It is the fastest-evolving genetic trait identified in modern humans.
- Mithridatism: practice of ingesting sub-lethal doses of poison to build immunity — named after Pontic king Mithridates VI (135–63 BC). Conceptual ancestor of modern vaccination (exposure to weakened pathogen builds immune memory).

Static Background (Basics to Remember)

LHC and Nuclear Transmutation

- LHC (Large Hadron Collider): 27 km circumference at CERN, Geneva; world's most powerful particle accelerator. India = associate member of CERN since 2016; Indian physicists involved in CMS and ALICE experiments.
- Ultra-peripheral collision (UPC): two nuclei pass close but do not touch; strong electromagnetic fields interact → photon emission → nuclear excitation → proton emission → transmutation.
- Lead (Z=82) → Gold (Z=79): 3 protons stripped by photon interaction. Creation rate: billions of gold atoms per second — but each lasts microseconds and total mass is picograms. Not a substitute for gold mining.

Parrondo's Paradox — Applications

- Named after Spanish physicist Juan Parrondo (1999). Two games: Game A (slightly losing) + Game B (losing on average but state-dependent). Alternating A-B-B-A-B-B... produces a winning sequence.
- Applications: population genetics (allele frequency oscillations), ecology (species coexistence in patches), financial portfolio rebalancing, oncology (drug resistance prevention).

Lactose Persistence — Convergent Evolution

Population	Mutation	Origin	Prevalence
North Europeans	-13910*T upstream LCT gene	~10,000–8,000 years ago	~90% lactose tolerant
East African pastoralists (Maasai, Tutsi)	Multiple independent variants	~7,000–5,000 years ago	~50–80% in some groups
South Asians	Intermediate frequency of variants	~4,000 years ago	~30–40% tolerant
East Asians (Han Chinese, Japanese)	Very rare variants	Low selection pressure	~5–10% tolerant

Prelims Connect

LHC, Paradox, Lactose — Key Facts

Topic	Key Detail
LHC alchemy	Lead (Z=82) → Gold (Z=79) via photon-induced proton stripping; CERN 2025; picogram quantities
CERN membership	India = associate member since 2016; CMS and ALICE experiment participation
Parrondo's Paradox	Named after Juan Parrondo (1999); two losing strategies → one winning strategy via alternation
Parrondo in medicine	Alternating drug regimens prevent cancer resistance — Parrondo-type therapy
Lactose persistence	Fastest-evolving human genetic trait; ~11,000 years ago; convergent evolution in 3+ populations
Mithridatism	Named after Mithridates VI of Pontus (135–63 BC); sub-lethal poison immunity — vaccine precursor

Parrondo's Paradox has deep implications for combination therapy strategies in oncology, HIV treatment, and antibiotic resistance — all areas where alternating treatment regimens are now being studied. The mathematical underpinning (Brownian ratchet mechanisms) also applies to molecular motors in biological cells.