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THE HINDU
INDIA'S NATIONAL NEWSPAPER SINCE 1878

Daily News Analysis

The Hindu Important News Articles & Editorial For UPSC CSE

Thursday,09 April, 2026

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Page 03 : GS III : Science and Tech / Prelims Exam

The Indian Space Situational Assessment Report (ISSAR) is an annual publication by the **ISRO System for Safe and Sustainable Space Operations Management (IS4OM)**. It provides a comprehensive audit of the orbital environment, tracking the health of national space assets and the growing threat of space debris. In 2025, the report underscores a paradox: while space accessibility has reached record highs, the resulting "orbital crowding" poses significant risks to long-term space sustainability.

Over 4,600 objects placed in orbit in 2025 after 315 space launches: report

The Hindu Bureau
BENGALURU

The year 2025 saw 315 successful space launches globally, with about 4,651 objects placed in orbit. According to the Indian Space Situational Assessment Report (ISSAR) for 2025 released on Wednesday, a maximum number of payloads were deployed during 2025.

The report stated that 4,651 objects were launched to orbits and 1,911 re-entered the atmosphere with a net annual growth of 74.5%.

27 satellites operational

With regard to the Indian space assets in 2025, eight satellites were launched and four rocket bodies were placed in orbit. The report said that 12 Indian objects re-entered the atmosphere.

It added that the IRNSS-1 D satellite was decommissioned 600 km above geosynchronous orbit.

In total, there are 86 Indian satellites in orbit of which 27 are operational, 23 are defunct (still in orbit), and 36 decayed.

In 2025, eight Indian satellites were launched and four rocket bodies placed in orbit. -FILE PHOTO

Among the Indian rocket bodies, three Launch Vehicle Mark-3 (LVM-3) are still in orbit and five are decayed; four Small Satellite Launch Vehicles are decayed; four Geosynchronous Satellite Launch Vehicles (GSLV) are in orbit and 10 have decayed, and 42 Polar Satellite Launch Vehicles (PSLV) are in orbit and 19 have decayed.

The report also said that 563 and 519 orbital manoeuvres were carried out in low-earth orbit and geostationary orbit, respectively.

Fourteen collision avoidance measures were carried out in low-earth orbit along with four in geostationary orbit, the ISSAR report said.

Key Highlights & Data Points

1. Global Orbital Trends

Launch Surge: 2025 saw a record-breaking **315 successful launches**, deploying **4,651 objects** into orbit—a massive jump from previous years, driven largely by commercial mega-constellations (like Starlink and Kuiper).

Re-entry & Growth: While 4,651 objects were added, **1,911 objects re-entered** the atmosphere. This resulted in a **74.5% net annual growth** in the population of space objects.

2. The Indian Scenario

Asset Breakdown: India currently maintains **86 satellites** in orbit, but only **27 are operational**. The remaining consist of 23 defunct satellites and 36 decayed objects.

Rocket Bodies: The PSLV remains India's "workhorse," with 42 rocket bodies still in orbit. In contrast, the newer **LVM-3** has only 3 bodies in orbit, reflecting modern efforts to minimize long-term debris.

Decommissioning: India demonstrated responsible behavior by decommissioning **IRNSS-1D** to a "graveyard orbit" 600 km above the Geostationary orbit, preventing it from becoming a collision hazard.

3. Space Situational Awareness (SSA) in Action

Collision Avoidance: ISRO performed **18 Collision Avoidance Manoeuvres (CAMs)** (14 in LEO, 4 in GEO). This reflects the high density of Resident Space Objects (RSOs) that threaten active missions.

Orbital Manoeuvres: A total of **1,082 manoeuvres** (LEO + GEO) were executed to maintain satellite health and mission parameters against orbital decay and solar activity.

Strategic Significance for India

Project NETRA: The data from ISSAR feeds into Project NETRA (Network for space object Tracking and Analysis), India's early warning system to protect satellites from debris and other hazards.

Space Diplomacy: India currently chairs the UN working group on the **Long-term Sustainability (LTS) of Outer Space Activities**. This report bolsters India's image as a "responsible space power."

Debris Free Space Mission (DFSM) 2030: The report tracks progress toward India's goal of achieving debris-free missions by 2030, which involves using de-orbiting technologies and "zero debris" launch stages (like the POEM platform).

Challenges Highlighted

Kessler Syndrome: The exponential growth of objects (74.5% net growth) brings us closer to a scenario where one collision triggers a chain reaction of debris, making certain orbits unusable.

Resource Intensity: Performing over 1,000 manoeuvres annually requires significant ground station coordination and fuel consumption, shortening the lifespan of satellites.

Solar Cycle 25: Intense solar activity in 2025 accelerated orbital decay, increasing the frequency of re-entries and necessitating more active tracking.

Conclusion

The ISSAR 2025 report is not just a statistical summary but a call to action for global space governance. For India, it marks a transition from being a mere "launch provider" to a "custodian of the space environment." As India opens its space sector to private players (NGEs) through **IN-SPACe**, maintaining a clean and predictable orbital environment will be the bedrock of future commercial and strategic success. To ensure the "Final Frontier" remains a global common, India must continue leading by example through transparent reporting and technological innovations in debris mitigation.

UPSC Prelims Exam Practice Question

Ques: Which of the following statements best describes Kessler Syndrome?

(a) A phenomenon of solar storms affecting satellites

(b) A cascading collision of space debris increasing exponentially

(c) A method of satellite de-orbiting

(d) A technique for collision avoidance

Ans: b)

UPSC Mains Exam Practice Question

Ques: The rapid commercialization of outer space has transformed orbital space into a congested domain. Discuss in the context of ISSAR 2025 findings. Suggest measures for sustainable space governance. **(150 Words)**

Page 04 : GS III : Science and Tech / Prelims Exam

Biotechnology in agriculture—often termed **"Green Biotechnology"**—involves using scientific techniques like genetic engineering, molecular markers, and tissue culture to modify living organisms for better productivity. In the era of **Industry 5.0**, the focus has shifted from mere mass production to **human-centric, sustainable, and resilient** innovation.

Webinar to discuss biotech's role in sustainable agriculture

The Hindu Bureau
CHENNAI

The VIT-Chennai, in association with *The Hindu*, will organise a webinar on "Biotech for Sustainable Agriculture and Crop Productivity" on Sunday.

It will explore how biotechnology is reshaping modern agriculture by supporting modern farming practices, improving crop productivity, and addressing critical challenges related to food security and climate resilience.

The webinar is the fifth in a series on "Biotechnology: Role in Industry 5.0 – Sustainable Future Pathways", focusing on the evolving role of biotechnology in an industry 5.0 era driven by human-centric innovation, sustainability, and advanced technological integration.

The discussion will focus on the role of biotech in sustainable and efficient agricultural systems.

The event will feature G. Jayaraman, Professor and Dean, School of Bio Sciences and Technology, VIT-Chennai; Gayatri Venkataraman, Senior Principal Scientist, M.S. Swaminathan Research Foundation; Dolly Wattal Dhar, Dean, Sharda School of Agriculture Sciences, Greater Noida; and Lipin Dev, Director and partner, VT Ecogreen Technologies Pvt. Ltd., Coimbatore. The session will be moderated by journalist Soma Basu. It will be held at 11.30 a.m. Those interested may register at *newsth.live/THVITSE*

Core Pillars of Biotech in Agriculture

1. Responding to Climate Change

Abiotic Stress Tolerance: Developing crops that can survive "climate shocks" such as extreme heat, prolonged drought, and soil salinity.

Carbon Sequestration: Research into "Carbon-Smart" crops that can trap more atmospheric CO_2 into the soil.

2. Enhancing Crop Productivity & Nutrition

Biofortification: Increasing the nutritional value of crops at the source (e.g., **Golden Rice** for Vitamin A, **Dhanashakti** pearl millet for Iron).

Pest & Disease Resistance: Reducing dependency on chemical pesticides through built-in resistance (e.g., **Bt Cotton**), which protects biodiversity and reduces farmer input costs.

3. Transition to Industry 5.0

Precision Farming: Integrating biotech with AI and IoT to provide real-time data on soil health and crop needs.

Bio-Foundries: The recent **BioE3 Policy (2024)** emphasizes "Biomanufacturing & Bio-AI hubs" to accelerate the commercialization of lab-grown agricultural solutions.

Government Initiatives in India

BioE3 Policy (2024): Stands for "Biotechnology for Economy, Environment, and Employment." It targets high-performance biomanufacturing and climate-resilient agriculture.

Biotech-KISAN: A farmer-centric scheme that connects scientists with farmers to understand ground-level problems and provide biotech solutions.

Bio-RIDE Scheme: A unified program (₹9,197 crore) designed to support biotech R&D and entrepreneurship.

GEAC (Genetic Engineering Appraisal Committee): The apex body under the Ministry of Environment that regulates the commercial release of GM crops in India.

Challenges and Ethical Concerns

While the benefits are vast, several "red flags" remain central to the UPSC discourse:

Biosafety: Concerns regarding "gene flow" where modified genes might escape into wild plant relatives.

Monopoly & IP Rights: The dominance of large seed corporations can impact the "Seed Sovereignty" of small-scale farmers.

Regulatory Delays: India's cautious approach (as seen with GM Mustard) stems from a lack of long-term ecological impact data.

Conclusion

Biotechnology is the "force multiplier" required to achieve **Sustainable Development Goal 2 (Zero Hunger)**. However, the transition to a biotech-led agricultural system must be inclusive. As the webinar aims to discuss, the future lies in balancing **high-tech innovation** with **traditional farming wisdom**, ensuring that the benefits of Industry 5.0 reach the last mile—the marginal farmer.

UPSC Prelims Exam Practice Question

Ques: Which of the following best describes Biofortification?

(a) Increasing crop yield using fertilizers

(b) Enhancing nutritional quality of crops through biological processes

(c) Genetic modification for pest resistance

(d) Use of microbes to improve soil fertility

Ans: b)

UPSC Mains Exam Practice Question

Ques: Green Biotechnology is central to achieving climate-resilient agriculture in India. Discuss with suitable examples. **150 Words)**

Page 06 : GS III : Science and Tech / Prelims Exam

India has officially withdrawn its candidacy to host the 33rd Conference of Parties (COP33) in 2028. Prime Minister Narendra Modi had originally proposed hosting the summit during COP28 in Dubai (2023) as a way to champion the "Global South." However, a formal communication to the UNFCCC on April 2, 2026, cited a "review of commitments for 2028" as the primary reason for the reversal.

Why the Withdrawal? (Analysis of the "Review")

While the government hasn't issued a detailed public statement, several strategic factors emerge from the 2026 context:

- **Geopolitical & Energy Volatility:** Experts point toward the ongoing **global conflicts** (specifically the ripple effects of the US-Iran tensions in 2026) which have prioritized **short-term energy security**. Hosting a COP requires a country to lead by example with aggressive green targets—commitments that may conflict with India's current need to rely on traditional fuels to stabilize its economy.
- **Logistical & Financial Overlap:** In 2028, South Korea is expected to host the **G20 Summit**. If India were to host COP33 in the same year, the diplomatic and financial strain would be immense.
- **Shift in NDC Focus:** On March 25, 2026, India updated its **Nationally Determined Contributions (NDCs)**. The new targets are "implementation-focused" rather than "announcement-focused," signaling a move toward steady domestic progress over high-profile global posturing.

India's Updated NDCs (March 2025/26)

The withdrawal comes on the heels of India raising its climate ambitions for the **2031–2035 cycle**:

- **Non-Fossil Fuel Capacity:** Target increased to **60%** of total installed capacity by 2035. (India achieved its 50% goal in 2025, five years early).
- **Emissions Intensity:** Committed to a **47% reduction** in GDP emissions intensity by 2035 (from 2005 levels).
- **Carbon Sink:** Target raised to **3.5–4 billion tonnes** of CO_2 equivalent.

India withdraws bid to host climate summit in 2028

The government cites a review of its 2028 commitments, says report; the country had last hosted the summit in 2002, when it was a low-key affair

Jacob Koshy
NEW DELHI

The COP30 was held in Brazil and the COP31 is to be jointly hosted by Turkiye and Australia this year. AP

India has withdrawn its bid to host the 33rd edition of the Conference of Parties (COP 33) in 2028 – the annual United Nations climate talks, according to a report by Climate Home News (CHN) on Wednesday.

Prime Minister Narendra Modi had announced India's interest in hosting the COP33 at the COP28 in Dubai in 2023.

The Ministry for Environment, Forests and Climate Change did not comment on the report, but *The Hindu* has independently confirmed its veracity.

According to the CHN report, an April 2 letter by Rajat Agrawal, Joint Secretary in the Environment Ministry, to the United Nations Framework Convention on Climate Change (UNFCCC) stated that India was withdrawing its candidacy following a "review of its commitments for 2028".

In July 2025, the Environment Ministry set up a dedicated cell for the "professional and logistical requirements" for organising the COP33. This followed a joint declaration at the 17th BRICS summit on July 7, where the member countries "welcomed" India's candidacy.

The hosting of the COP rotates among the UN's five regional groups, with India belonging to the Asia Pacific group.

The COP30 was held in Brazil. The edition this year is to be jointly hosted by Turkiye and Australia and the 2027 summit (COP32) is scheduled to be held in Ethiopia. With India withdrawing, South Korea is the only country that has so far expressed interest in hosting the COP33. India has hosted the summit only once – in 2002 (COP8) – when it was a relatively low-key affair.

On March 25, India announced its updated Nationally Determined Contributions (NDCs), committing by 2035 to source 60% of its installed electricity capacity from non-fossil sources, reduce emissions intensity of GDP by 47%, and increase its carbon sink by 3.5-4 billion tonnes of CO_2 equivalent.

Global Hosting Roadmap (2025–2028)

Year	Edition	Host Country	Status
2025	**COP30**	**Brazil** (Belém)	Focused on the "Amazon " and Climate Finance.
2026	**COP31**	**Turkiye & Australia**	**Shared Presidency:** Turkiye hosts in Antalya; Australia leads negotiations.
2027	**COP32**	**Ethiopia**	African Group representative.
2028	**COP33**	**TBD (Likely South Korea)**	India has withdrawn; South Korea is the frontrunner.

Strategic Implications for India

Missed Leadership Opportunity: Critics argue India has lost a chance to replicate its "G20 Success" in the climate arena, where it could have demanded accountability from developed nations for historical emissions.

Pragmatic Realism: Conversely, by stepping back, India avoids the "host's burden"—the pressure to sign onto global pledges (like the "Global Cooling Pledge" or strict methane curbs) that might hinder its industrial growth.

The "Viksit Bharat" Goal: The government seems to be aligning climate action with the **Viksit Bharat @2047** vision, ensuring that green transitions do not compromise the goal of becoming a developed economy.

Conclusion

India's decision to withdraw reflects a "Pragmatic Green Strategy." While it steps back from the logistical spotlight of 2028, its updated NDCs show that it remains committed to the Paris Agreement. For India, the focus has shifted from hosting the conversation to executing the transition. As a "Responsible Power," India's challenge will now be to maintain its influence in climate negotiations without the leverage of the hosting chair.

UPSC Prelims Exam Practice Question

Ques : **Which of the following best describes the term "Emissions Intensity"?**

(a) Total emissions per capita

(b) Emissions per unit of GDP
(c) Emissions from industrial sector only
(d) Total greenhouse gas emissions
Ans: b)

UPSC Mains Exam Practice Question

Ques: India's withdrawal from COP33 reflects a shift from climate diplomacy to climate pragmatism. Critically analyze. **(150 Words)**

Page 07 : GS III : Science and Tech / Prelims Exam

Measuring distances in the "Deep Space" of our own galaxy is notoriously difficult because we cannot use physical rulers. Historically, astronomers used **Pulsars**—the dense, spinning remnants of dead stars—as "Cosmic Lighthouses." However, the "fog" of the Interstellar Medium (ISM) often distorts these signals. The new Indian study provides a way to see through this fog by combining two specific physical phenomena: **Dispersion** and **Scattering**.

Indian scientists find new way to measure distances in deep space

The dense and rapidly spinning remnant cores of dead stars are called pulsars; they emit beams of radio waves that sweep across the earth like light from a lighthouse sweeps across ships at sea; pulsars have an extraordinarily fixed spinning rate, so the pulses arrive very regularly

Shreejaya Karantha

Indian astronomers, including from IIT-Kanpur, have developed a new way to measure distances in the universe using the pulsating cores of dead stars, by studying how their radio emissions are distorted as they travel through space. The technique combines a pair of subtle effects that occur when pulsar signals pass through clouds of ionised gas in the Milky Way.

The dense and rapidly spinning remnant cores of dead stars are called pulsars. They emit beams of radio waves that sweep across the earth like light from a lighthouse sweeps across ships at sea. Pulsars have an extraordinarily fixed spinning rate, so the pulses arrive very regularly. So astronomers have used them as cosmic clocks.

Pulsar timing experiments use millisecond pulsars, which spin hundreds of times per second, to create precise timing models that predict the arrival of following pulses. Any difference in arrival time indicates the presence of another astrophysical event, such as those producing gravitational waves.

But as these radio waves travel through the galaxy before reaching the earth, they also pass through clouds of ionised gas, or plasma, that contain free electrons that slightly alter the radio signal.

Way of light

Astronomers measure one of these effects using a quantity called the dispersion measure (DM). As radio waves travel through the interstellar medium, free electrons slow down lower frequency waves more than higher frequency ones. This causes different frequencies to arrive at the earth at slightly different times. By measuring the delay caused by dispersion, astronomers can estimate how many electrons lie between the earth and the pulsar.

In general, signals from more distant pulsars pass through more interstellar plasma and encounter more electrons. As a result, DM provides a rough estimate of how far away the pulsar is.

Astronomers have long used DM to estimate the distance to pulsars. However, this method relies on models of electron distribution throughout the Milky Way that can be unreliable in complex regions such as the Gum Nebula, a vast region of ionised gas and one of the largest known nebulae in our galaxy. Possibly associated with a supernova explosion or ionisation by hot stars, the nebula contains the Vela Pulsar and regions that can strongly influence radio signals passing through it.

Wobbling signals

The interstellar medium also affects pulsar signals in another way. As plasma is not perfectly smooth, its irregularities scatter radio waves as they travel through it. This scattering causes the signals to follow multiple paths before reaching the earth. The scattered waves interfere with each other, causing the pulsar's brightness to vary with time.

The term for this is scintillation, similar to the twinkling of stars in the night sky. Since the signals arrive by different paths and at slightly different times, the signal appears stretched out or smeared. This effect is known as scatter broadening.

In the new study, published in the *Monthly Notices of Royal Astronomical Society*, the team combined DM with scatter broadening to refine the distance estimates. As scattering depends on how turbulent the plasma is, the electron density, and the location of the scattering region along the line of sight, the joint method revealed where the turbulent plasma is located between the earth and the pulsar much more accurately.

The Vela pulsar wind nebula. Light blue represents X-ray polarisation data from the NASA Imaging X-ray Polarimetry Explorer. Pink and purple colours correspond to data from the NASA Chandra X-Ray observatory. NASA

In the new study, published in the Monthly Notices of Royal Astronomical Society, the team combined dispersion measure with scatter broadening to refine the distance estimates

"Previously, we had only one 'soldier'—dispersion—to solve the problem," the study's lead author Ashish Kumar, formerly at IIT-Kanpur and now at the National Centre for Radio Astrophysics, said. "Now we have two: dispersion and scattering."

The study was carried out with co-authors Avinash Deshpande, former professor at the Raman Research Institute, and Pankaj Jain, a professor at IIT-Kanpur.

Systematic application

"The authors have done a careful job of utilising a variety of measurements on 10 pulsars to constrain the structure of the interstellar medium in this region, including the distance to the dominant scattering region [the Gum Nebula]," Cornell University professor James Cordes, who wasn't involved in the study, said. He also said combining scattering and dispersion to estimate pulsar distances is not entirely new and has been explored in pulsar studies for decades. In this study, however, the team applied the approach in a systematic way: they used both dispersion and scattering measurements together and adjusted their model step by step until it matched both the observed DM and the scatter broadening.

The distance where the model and observations agreed was then taken to be the pulsar's distance.

Their work shows that much of the scattering affecting pulsars in this direction likely comes from turbulent layers of the Gum Nebula. Using observations of 10 pulsars in the same region of the sky as Gum Nebula, researchers also developed a refined model of the nebula's electron distribution. Results showed that the Vela pulsar lies behind the nebula's front shell.

No hard limit

Scatter broadening depends on how strongly a pulsar's signal is scattered along the line of sight. Calculating this exactly requires extensive analysis. So to simplify it, researchers combined the dependencies into a single parameter, called the *k*-factor, at a given frequency.

Estimating the *k*-factor was the main technical challenge of the study, Dr. Kumar said, as it varies significantly in complex regions. However, one can determine its value for the target pulsar from a nearby pulsar at a known distance.

For the Gum Nebula, the team analysed several pulsars in the region and calculated their individual *k*-factors. Instead of adopting a single number, they used a range of possible values to account for uncertainties in the scattering properties of the plasma. The team is now working on a follow-up study of roughly 300 pulsars across our galaxy to determine how the *k*-factor varies in different directions.

Parallax-based measurements are extensively used in distance measurements. While the novel method offers several advantages over DM-only estimates, it cannot beat the "gold standards" of the parallax method in terms of accuracy, Dr. Kumar said.

However, while certain parallax techniques have a "hard limit" on distance, the new method has no specific distance limitation. It could even be used to measure distances to objects outside the Milky Way, like the enigmatic fast radio bursts.

(Shreejaya Karantha is a freelance science writer)

The Science Behind the Innovation

1. The "Single Soldier" Approach: Dispersion Measure (DM)

Traditionally, distance was estimated using **Dispersion**.

The Physics: Space is not empty; it is filled with **plasma** (ionized gas and free electrons).

The Effect: Low-frequency radio waves from a pulsar are slowed down more than high-frequency waves by these electrons.

The Calculation: By measuring the time delay between frequencies, scientists calculate the **Dispersion Measure (DM)**—the total number of electrons between Earth and the Pulsar.

The Flaw: This assumes electrons are spread evenly. In reality, regions like the **Gum Nebula** have dense "clumps" of electrons that make a pulsar look much farther away than it actually is.

2. The New "Two-Soldier" Approach: Combining Scattering

The Indian team added **Scatter Broadening** to the equation.

The Physics: Plasma is turbulent. As radio waves pass through it, they bounce off irregularities (like light through a frosted glass).

The Effect (Scintillation): The waves take multiple paths to reach Earth, causing the pulse to "smear" or broaden in time.

The Breakthrough: By combining the **DM** (how many electrons) with **Scattering** (how turbulent/clumpy the electrons are), the researchers could pinpoint exactly where the "clumps" are located. This allowed them to correct the distance errors caused by the Gum Nebula.

Key Technical Terms

Pulsars: Highly magnetized, rotating neutron stars that emit a beam of electromagnetic radiation.

Interstellar Medium (ISM): The matter and radiation that exist in the space between the star systems in a galaxy.

Gum Nebula: A massive emission nebula in the southern sky (constellations Vela and Puppis) that acts as a major source of signal distortion for Indian astronomers.

Parallax Method: The "Gold Standard" of distance measurement based on trigonometry. While accurate, it has a distance limit; the new Indian method has **no hard distance limit**.

Significance of the Study

Mapping the Milky Way: It helps create a 3D map of the electron density in our galaxy, which is crucial for all radio astronomy.

Gravitational Wave Research: To detect gravitational waves using "Pulsar Timing Arrays," we need to know the exact distance of pulsars. Any error in distance leads to an error in detecting the "ripples" in spacetime.

Extragalactic Potential: The method can be applied to **Fast Radio Bursts (FRBs)**—mysterious signals from other galaxies—potentially helping us map the "web" of the entire universe.

Indigenous Capability: The study showcases the analytical depth of Indian institutions (IIT-K, RRI, NCRA) in handling complex astrophysical data without relying solely on foreign models.

Conclusion

The work of Ashish Kumar and his team represents a move toward "High-Precision Astronomy." By systematically applying the k-factor (a parameter that accounts for scattering variations), they have turned a "noise" problem (scattering) into a "signal" solution. As India prepares for mega-projects like the Square Kilometre Array (SKA), such mathematical refinements in signal processing will be the backbone of our contribution to global space science.

UPSC Prelims Exam Practice Question

Ques: With reference to Pulsars, consider the following statements:

1. They are rapidly rotating neutron stars.

2. They emit beams of electromagnetic radiation.

3. They are used as standard candles like Cepheid variables.

Which of the statements given above is/are correct?

(a) 1 and 2 only

(b) 2 only

(c) 1, 2 and 3

(d) 1 only

Ans: b)

UPSC Mains Exam Practice Question

Ques: Interstellar Medium acts both as an obstacle and a tool in astrophysics. Discuss in the context of recent Indian research. **(150 Words)**

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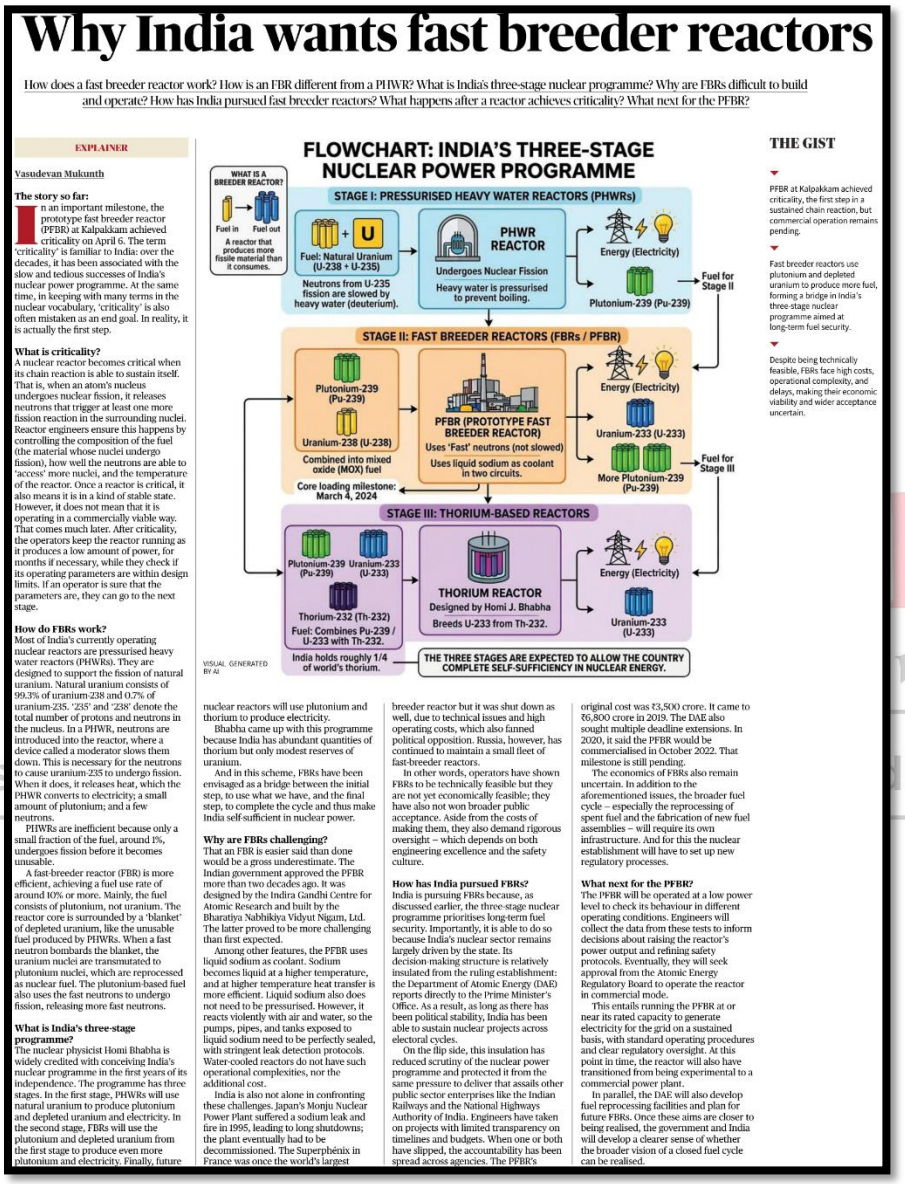
The achievement of **criticality** at the **Prototype Fast Breeder Reactor (PFBR)** in Kalpakkam on April 6, 2026, marks one of the most significant milestones in India's scientific history.



Why India wants fast breeder reactors

How does a fast breeder reactor work? How is an FBR different from a PHWR? What is India's three-stage nuclear programme? Why are FBRs difficult to build and operate? How has India pursued fast breeder reactors? What happens after a reactor achieves criticality? What next for the PFBR?

EXPLAINER

Vasudevan Mukunth

The story so far:

In an important milestone, the prototype fast breeder reactor (PFBR) at Kalpakkam achieved criticality on April 6. The term 'criticality' is familiar to India: over the decades, it has been associated with the slow and tedious successes of India's nuclear power programme. At the same time, in keeping with many terms in the nuclear vocabulary, 'criticality' is also often mistaken as an end goal. In reality, it is actually the first step.

What is criticality?

A nuclear reactor becomes critical when its chain reaction is able to sustain itself. That is, when an atom's nucleus undergoes nuclear fission, it releases neutrons that trigger at least one more fission reaction in the surrounding nuclei. Reactor engineers ensure this happens by controlling the composition of the fuel (the material whose nuclei undergo fission), how well the neutrons are able to 'access' more nuclei, and the temperature of the reactor. Once a reactor is critical, it also means it is in a kind of stable state. However, it does not mean that it is operating in a commercially viable way. That comes much later. After criticality, the operators keep the reactor running as it produces a low amount of power, for months if necessary, while they check if its operating parameters are within design limits. If an operator is sure that the parameters are, they can go to the next stage.

How do FBRs work?

Most of India's currently operating nuclear reactors are pressurised heavy water reactors (PHWRs). They are designed to support the fission of natural uranium. Natural uranium consists of 99.3% of uranium-238 and 0.7% of uranium-235. '235' and '238' denote the total number of protons and neutrons in the nucleus. In a PHWR, neutrons are introduced into the reactor, where a device called a moderator slows them down. This is necessary for the neutrons to cause uranium-235 to undergo fission. When it does, it releases heat, which the PHWR converts to electricity; a small amount of plutonium; and a few neutrons.

PHWRs are inefficient because only a small fraction of the fuel, around 1%, undergoes fission before it becomes unusable.

A fast-breeder reactor (FBR) is more efficient, achieving a fuel use rate of around 10% or more. Mainly, the fuel consists of plutonium, not uranium. The reactor core is surrounded by a 'blanket' of depleted uranium, like the unusable fuel produced by PHWRs. When a fast neutron bombards the blanket, the uranium nuclei are transmutated to plutonium nuclei, which are reprocessed as nuclear fuel. The plutonium-based fuel also uses the fast neutrons to undergo fission, releasing more fast neutrons.

What is India's three-stage programme?

The nuclear physicist Homi Bhabha is widely credited with conceiving India's nuclear programme in the first years of its independence. The programme has three stages. In the first stage, PHWRs will use natural uranium to produce plutonium and depleted uranium and electricity. In the second stage, FBRs will use the plutonium and depleted uranium from the first stage to produce even more plutonium and electricity. Finally, future nuclear reactors will use plutonium and thorium to produce electricity.

Bhabha came up with this programme because India has abundant quantities of thorium but only modest reserves of uranium.

And in this scheme, FBRs have been envisaged as a bridge between the initial step, to use what we have, and the final step, to complete the cycle and thus make India self-sufficient in nuclear power.

Why are FBRs challenging?

That an FBR is easier said than done would be a gross underestimate. The Indian government approved the PFBR more than two decades ago. It was designed by the Indira Gandhi Centre for Atomic Research and built by the Bharatiya Nabhikiya Vidyut Nigam, Ltd. The latter proved to be more challenging than first expected.

Among other features, the PFBR uses liquid sodium as coolant. Sodium becomes liquid at a higher temperature, and at higher temperature heat transfer is more efficient. Liquid sodium also does not need to be pressurised. However, it reacts violently with air and water, so the pumps, pipes, and tanks exposed to liquid sodium need to be perfectly sealed, with stringent leak detection protocols. Water-cooled reactors do not have such operational complexities, nor the additional cost.

India is also not alone in confronting these challenges. Japan's Monju Nuclear Power Plant suffered a sodium leak and fire in 1995, leading to long shutdowns; the plant eventually had to be decommissioned. The Superphénix in France was once the world's largest breeder reactor but it was shut down as well, due to technical issues and high operating costs, which also fanned political opposition. Russia, however, has continued to maintain a small fleet of fast-breeder reactors.

In other words, operators have shown FBRs to be technically feasible but they are not yet economically feasible; they have also not won broader public acceptance. Aside from the costs of making them, they also demand rigorous oversight – which depends on both engineering excellence and the safety culture.

How has India pursued FBRs?

India is pursuing FBRs because, as discussed earlier, the three-stage nuclear programme prioritises long-term fuel security. Importantly, it is able to do so because India's nuclear sector remains largely driven by the state. Its decision-making structure is relatively insulated from the ruling establishment: the Department of Atomic Energy (DAE) reports directly to the Prime Minister's Office. As a result, as long as there has been political stability, India has been able to sustain nuclear projects across electoral cycles.

On the flip side, this insulation has reduced scrutiny of the nuclear power programme and protected it from the same pressure to deliver that assails other public sector enterprises like the Indian Railways and the National Highways Authority of India. Engineers have taken on projects with limited transparency on timelines and budgets. When one or both have slipped, the accountability has been spread across agencies. The PFBR's original cost was ₹3,500 crore. It came to ₹6,800 crore in 2019. The DAE also sought multiple deadline extensions. In 2020, it said the PFBR would be commercialised in October 2022. That milestone is still pending.

The economics of FBRs also remain uncertain. In addition to the aforementioned issues, the broader fuel cycle – especially the reprocessing of spent fuel and the fabrication of new fuel assemblies – will require its own infrastructure. And for this the nuclear establishment will have to set up new regulatory processes.

What next for the PFBR?

The PFBR will be operated at a low power level to check its behaviour in different operating conditions. Engineers will collect the data from these tests to inform decisions about raising the reactor's power output and refining safety protocols. Eventually, they will seek approval from the Atomic Energy Regulatory Board to operate the reactor in commercial mode.

This entails running the PFBR at or near its rated capacity to generate electricity for the grid on a sustained basis, with standard operating procedures and clear regulatory oversight. At this point in time, the reactor will also have transitioned from being experimental to a commercial power plant.

In parallel, the DAE will also develop fuel reprocessing facilities and plan for future FBRs. Once these aims are closer to being realised, the government and India will develop a clearer sense of whether the broader vision of a closed fuel cycle can be realised.

FLOWCHART: INDIA'S THREE-STAGE NUCLEAR POWER PROGRAMME

WHAT IS A BREEDER REACTOR? Fuel in, Fuel out. A reactor that produces more fissile material than it consumes.

STAGE I: PRESSURISED HEAVY WATER REACTORS (PHWRs)
Fuel: Natural Uranium (U-238 + U-235)
Neutrons from U-235 fission are slowed by heavy water (deuterium).
PHWR REACTOR
Undergoes Nuclear Fission
Heavy water is pressurised to prevent boiling.
Energy (Electricity)
Plutonium-239 (Pu-239)
Fuel for Stage II

STAGE II: FAST BREEDER REACTORS (FBRs / PFBR)
Plutonium-239 (Pu-239)
Uranium-238 (U-238)
Combined into mixed oxide (MOX) fuel
PFBR (PROTOTYPE FAST BREEDER REACTOR)
Uses 'Fast' neutrons (not slowed)
Uses liquid sodium as coolant in two circuits.
Energy (Electricity)
Uranium-233 (U-233)
More Plutonium-239 (Pu-239)
Fuel for Stage III
Core loading milestone: March 4, 2024

STAGE III: THORIUM-BASED REACTORS
Plutonium-239 (Pu-239)
Uranium-233 (U-233)
Thorium-232 (Th-232)
Fuel: Combines Pu-239 / U-233 with Th-232.
THORIUM REACTOR
Designed by Homi J. Bhabha
Breeds U-233 from Th-232.
Energy (Electricity)
Uranium-233 (U-233)
India holds roughly 1/4 of world's thorium.

THE THREE STAGES ARE EXPECTED TO ALLOW THE COUNTRY COMPLETE SELF-SUFFICIENCY IN NUCLEAR ENERGY.

VISUAL GENERATED BY AI

THE GIST

- PFBR at Kalpakkam achieved criticality, the first step in a sustained chain reaction, but commercial operation remains pending.
- Fast breeder reactors use plutonium and depleted uranium to produce more fuel, forming a bridge in India's three-stage nuclear programme aimed at long-term fuel security.
- Despite being technically feasible, FBRs face high costs, operational complexity, and delays, making their economic viability and wider acceptance uncertain.

Why India Wants Fast Breeder Reactors (FBRs)

1. Understanding the Three-Stage Nuclear Programme

The FBR is the second stage of the vision formulated by Dr. Homi J. Bhabha. This strategy is dictated by India's natural resource constraints: India holds roughly 25% of the world's Thorium reserves but has very limited Uranium.

Stage	Reactor Type	Fuel Used	Key Output
Stage I	**PHWR**	Natural Uranium	Electricity + **Plutonium-239**
Stage II	**FBR**	Mixed Oxide (MOX) Fuel (Plutonium + U-238)	Electricity + **More Plutonium** + Uranium-233
Stage III	**AHWR**	Thorium-232 + U-233	Electricity + Sustainable Fuel Cycle

2. How an FBR Works: The "Breeding" Mechanism

In a standard reactor (PHWR), neutrons are slowed down by a **moderator** (like heavy water) to sustain fission. In an **FBR**:

No Moderator: It uses "fast" neutrons.

The Blanket: The core (Plutonium) is surrounded by a "blanket" of fertile material (Uranium-238).

Breeding: As the reactor runs, the fast neutrons convert the U-238 in the blanket into **Plutonium-239**.

Efficiency: It "breeds" more fuel than it consumes. While a PHWR uses only about 1% of uranium energy, an FBR can extract **60-70%**.

3. FBR vs. PHWR: Key Differences

Feature	Pressurised Heavy Water Reactor (PHWR)	Fast Breeder Reactor (FBR)
Neutron Speed	Slow (Thermal)	Fast
Moderator	Heavy Water (D_2O)	**None**
Coolant	Heavy Water	**Liquid Sodium**
Fuel Efficiency	Low (~1%)	High (10% to 60%)
Primary Goal	Power + Initial Plutonium production	Power + **Fuel Multiplication**

4. Why are FBRs Difficult to Build and Operate?

The technical complexity is the reason only a few countries (like Russia) operate them commercially:

Liquid Sodium Challenges: Unlike water, sodium is highly reactive. It catches fire upon contact with air and explodes upon contact with water. This requires high-precision engineering and "double-walled" heat exchangers.

Corrosion: Liquid metal can be corrosive to the reactor's internal components over long periods.

Cost: The PFBR cost jumped from ₹3,500 crore to over **₹6,800 crore**, reflecting the expensive safety systems required.

5. The Significance of "Criticality"

Criticality is the state where a nuclear chain reaction becomes **self-sustaining**.

It means for every fission event, exactly one released neutron goes on to cause another fission.

It is not the end: After criticality, the reactor undergoes months of low-power testing to ensure the "liquid sodium" systems and "control rods" behave as predicted before it is connected to the grid.

6. The Road Ahead: What's next for PFBR?

Now that the PFBR at Kalpakkam has achieved criticality, the next steps involve:

Low-Power Physics Experiments: Testing the reactor's stability.

AERB Approval: The Atomic Energy Regulatory Board must clear the transition to commercial operation.

Grid Integration: Eventually, the 500 MWe plant will start feeding electricity into the national grid.

Scaling Up: Success here will pave the way for two more commercial FBRs, accelerating India's transition to the **Thorium Stage (Stage III)**.

Conclusion

The FBR is India's "Strategic Bridge." It allows India to turn its limited Uranium into a vast pool of Plutonium, which is the only key to unlocking the massive energy potential of Thorium. While the delays and costs have been significant, the successful criticality of the PFBR is a testament to India's technological sovereignty and its commitment to a "closed fuel cycle" that ensures long-term energy security without relying on volatile global uranium markets.

UPSC Prelims Exam Practice Question

Ques: With reference to the Prototype Fast Breeder Reactor (PFBR), consider the following statements:

1. It is part of India's second stage of the nuclear programme.

2. It uses slow neutrons moderated by heavy water.

3. It produces more fissile material than it consumes.

Which of the statements given above is/are correct?

(a) 1 and 3 only

(b) 2 only

(c) 1, 2 and 3

(d) 1 only

Ans: a)

UPSC Mains Exam Practice Question

Ques: Explain the working principle of a Fast Breeder Reactor (FBR). How does it differ from a Pressurised Heavy Water Reactor (PHWR)? **(250 Words)**

Jan Vishwas 2.0 is all about trust-based compliance

Chandrajit Banerjee

Director General, The Confederation of Indian Industry (CII)

Driven by clarity and proportionality, Jan Vishwas 2.0 will help shift Indian businesses toward a trust-based compliance culture

The passage of the Jan Vishwas (Amendment of Provisions) Bill, 2026 by Parliament reflects a conscious and forward-looking policy choice by the Government of India to recalibrate the balance between enforcement and facilitation, and to embed trust as a central pillar of the regulatory framework. The reform signals a clear departure from over-reliance on criminal sanctions toward a more proportionate, predictable, and facilitative approach to compliance.

In recent years, the decriminalisation of minor business-related offences has emerged as a core element of India's reform agenda. The underlying objective has been consistent: to rationalise compliance requirements, enhance ease of doing business and foster a regulatory culture that promotes voluntary compliance rather than fear-driven adherence. Excessive criminalisation of technical and procedural lapses had created compliance anxiety, discouraged entrepreneurship, and diverted administrative and judicial resources from more serious violations.

A journey of reform

This reform journey began with the Jan Vishwas (Amendment of Provisions) Act, 2023, which decriminalised minor offences by amending 183 provisions across 42 Central Acts administered by 19 Ministries and Departments. By replacing criminal penalties for technical and procedural non-compliances with civil penalties or administrative measures, it significantly reduced the compliance burden on businesses and citizens, improving both ease of doing business and ease of living.

Building on this foundation, the 2026 Bill, commonly referred to as the Jan Vishwas 2.0, represents a decisive scale-up of this reform effort. The Bill proposes amendments to 784 provisions across 79 Central Acts administered by 23 Ministries and Departments, including the decriminalisation of 717 provisions. It also rationalises the statute book by removing obsolete and redundant offences, thereby strengthening the coherence and credibility of India's overall regulatory architecture.

Extensive engagement between government, industry bodies, experts and other stakeholders has helped identify provisions where criminal liability was disproportionate to the nature of the offence. Such sustained dialogue has been critical in ensuring that regulatory objectives are preserved even as enforcement mechanisms are made more facilitative. Going forward, continued consultation will remain essential to keep regulation aligned with evolving economic realities.

A process of engagement

The Confederation of Indian Industry (CII) has shaped this reform agenda through sustained, evidence-based policymaker engagement. Industry representations consistently highlighted a large number of statutory offences related to minor and procedural lapses – delays in filings, documentation gaps or clerical errors – that did not warrant criminal prosecution. The CII has emphasised that decriminalisation of such offences strengthens compliance rather than diluting enforcement.

The CII's advocacy has gone beyond decriminalisation alone. A persistent industry recommendation has been to move away from court-imposed 'fines' toward a system of regulatory 'penalties' administered by executive authorities, with clear rules, proportionality, and time-bound resolution. The CII has also stressed the need for the retrospective application of decriminalisation reforms, covering cases currently pending in criminal courts. The Jan Vishwas 2.0 seems to address these long-standing concerns very well.

At a broader level, the Jan Vishwas 2.0 reflects a fundamental shift in regulatory philosophy, from criminalisation to trust, proportionality and economic efficiency. It recognises that most technical or procedural violations occur without *mala fide* intent and are better resolved through civil or administrative mechanisms. The reform explicitly retains stringent enforcement for serious offences where public interest, safety, environmental protection or national priorities are involved. The amendments span key sectors such as exports, textiles, the environment, and transport, and introduce graded enforcement mechanisms, including warnings and lower penalties for first-time or minor violations. Such measures should reduce regulatory uncertainty and boost confidence, especially for micro, small and medium enterprises (MSME) facing high compliance burdens.

Reduces 'court congestion'

These reforms could significantly help India's overburdened judiciary. With nearly 50 million cases pending in courts – many for minor procedural or technical violations – shifting such matters out of criminal courts can reduce congestion and improve efficiency. Government indications, post the passing of the Bill in Parliament, suggest many pending minor cases may be reviewed for closure under the revised framework.

The Bill also advances trust-based regulation by introducing tools such as improvement notices and proportionate penalties for first-time contraventions. This approach recognises the reality that most businesses and citizens act in good faith and comply more effectively in a regulatory environment that is clear, predictable and fair.

The success of the Jan Vishwas 2.0 will depend on effective implementation. Strengthening institutional capacity for administrative adjudication, ensuring uniform enforcement practices, and issuing clear guidance to regulated entities will be critical to realising the full benefits of the reform for industry and citizens.

By decisively moving towards a trust-based, proportionate and growth-oriented framework, The Jan Vishwas 2.0 has the potential to create a more predictable, transparent and investor-friendly environment. Ultimately, the reform reinforces a simple yet powerful principle: compliance works best when driven by clarity, proportionality, and – above all – trust.

GS Paper II: Governance

UPSC Mains Exam Practice Question: Decriminalization of minor economic offences is a necessary but not sufficient condition for the 'Ease of Doing Business' in India. Critically analyze in the context of the Jan Vishwas 2.0 Bill. **(150 Words)**

Context : Jan Vishwas 2.0 is the second iteration of a reform process aimed at **decriminalizing minor, technical, and procedural defaults**. By moving away from a "fear-based" compliance model to a "trust-based" one, the government aims to reduce the compliance burden on businesses (especially MSMEs) and unclog the judicial system.

Comparison: Jan Vishwas 1.0 vs. 2.0

The 2026 Bill represents a massive scaling up of the initial 2023 Act:

Feature	Jan Vishwas Act, 2023 (1.0)	Jan Vishwas Bill, 2026 (2.0)
Scope	183 provisions across 42 Acts	**784 provisions across 79 Acts**
Ministries involved	19 Ministries	**23 Ministries**
Core Action	Decriminalized minor offences	Decriminalized **717 provisions**; removed obsolete laws.
Approach	Replaced fines with penalties	Introduced **graded enforcement** (warnings, lower penalties for 1st timers).

Key Pillars of the Reform

1. Decriminalization vs. Dilution

The Bill distinguishes between **technical lapses** (e.g., clerical errors, delayed filings) and **serious violations** (e.g., public safety, environmental damage).

Trust-Based: Assumes that most businesses act in good faith.

Proportionality: Instead of criminal "fines" (decided by courts), it uses administrative "penalties" (decided by executive officers), which are faster and less stigmatizing.

2. Strengthening MSMEs and Entrepreneurship

Small businesses often lack the legal resources to handle criminal litigation for minor errors. Jan Vishwas 2.0 introduces:

Improvement Notices: Giving businesses a chance to fix errors before being penalized.

Reduced Compliance Anxiety: Encouraging entrepreneurs to take risks without the fear of jail time for procedural mistakes.

3. Judicial Efficiency (The "50 Million" Challenge)

With nearly **5 crore (50 million)** cases pending in Indian courts, a large chunk involves minor business defaults.

Shifting these to **administrative adjudication** (Executive branch) removes them from the criminal court docket.

The government has signaled a **retrospective review** of pending cases, which could lead to the mass closure of thousands of petty litigations.

Key Concepts

Administrative Adjudication: The process by which an executive agency issues an order/penalty without going to a traditional court.

Ease of Living & Ease of Doing Business: Two core governance objectives aimed at reducing the "Inspector Raj" and making life simpler for citizens and investors.

Mala Fide vs. Bona Fide: The Bill assumes "Bona Fide" (good faith) intent for procedural errors, reserving criminal law only for "Mala Fide" (bad faith/intentional) crimes.

Challenges in Implementation

Institutional Capacity: Executive officers must be trained to act as fair adjudicators to ensure "penalties" don't become a new tool for harassment.

Uniformity: Ensuring that different ministries and states apply these decriminalized rules consistently.

Retrospective Clarity: Clear guidelines are needed on how exactly pending court cases will be transferred or closed.

Conclusion

Jan Vishwas 2.0 is more than just a legal amendment; it is a **behavioral shift** in the state-citizen relationship. By removing the "shadow of the jailhouse" from the boardroom, India is positioning itself as a modern, investor-friendly economy. However, the true success of this reform will lie in its **ground-level implementation**—ensuring that the reduction in "criminalization" is matched by an increase in "regulatory clarity."