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Integrated Innovation with Lunar Exploration using Artificial Intelligence in Chandrayaan-3

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Abstract: The third lunar exploration mission of ISRO Chandrayaan-3 has both robotics and lunar exploration and focuses on important terms such as “lunar exploration”, “robotic technology”,“ISRO”, and “Chandrayaan-3”, which emphasizes the mission’s goals, scientific endeavors, and technical advancements. This work’s goal is to monitor ISRO’s effort to perform a soft landing near the lunar South Pole, which is of significant scientific interest due to its potential for water ice deposits and constantly shadowed craters. An integrated orbiter, lander, and rover system called Chandrayaan-3 will be outfitted with state-of-the-art scientific tools to investigate the lunar surface, identify elements, and research the geology and chemistry of the moon. The development of robotic technology crucial to strengthening the mission’s capabilities is emphasized. The rover can navigate hard terrain with the help of cutting-edge autonomous navigation technologies, eliminating the need for direct human interaction. Additionally, artificial intelligence and machine learning are combined to promote intelligent decision-making, mission planning optimization, and increased mission success. This review article explores the ISRO’s dedication to global cooperation, and building alliances to exchange materials, information, and experience about lunar exploration. This collaboration improves India’s standing in the international space community and adds to our developing understanding of the moon.

Keywords: Autonomous navigation technology, Integrated orbiter, Lander, Rover.

I. Introduction

The Indian Space Research Organization (ISRO) is the third lunar research mission, Chandrayaan-3, which is proof of the country’s unwavering dedication to space exploration and scientific advancement. Building on Chandrayaan-1 and Chandrayaan-2’s achievements and lessons learned, this ambitious project offers a huge leap in technological capability and lunar exploration. The objective of Chandrayaan-3 is to do a gentle landing on the moon with a focus on the area close to the South Pole. It contains water ice deposits and craters that are always in darkness, this landing location was chosen for its scientific value. Chandrayaan-3 intends to arrive in an uncharted region to gather crucial information on the moon’s geological history, composition, and resources. An integrated orbiter, lander, and rover system will make up the mission, and each will be furnished with cutting-edge scientific tools to perform an extensive investigation of the lunar environment. The orbiter will serve as a crucial link, enabling interaction between the lander-rover module and mission control on Earth as well as remote sensing investigations of the moon’s surface.

Chandrayaan-3 unquestionably represents a huge advancement in “lunar exploration” to solve the puzzles surrounding our planetary neighbor and broaden our comprehension of the moon’s history. To understand the moon’s origins and its possible role in future human space exploration missions, it explores the lunar South Pole and provides crucial data to the international scientific community. ISRO developed creative solutions to make the landing and exploration mission successful to encourage international cooperation in lunar exploration. It has the chance to observe India’s pursuit of scientific brilliance, technological innovation, and its drive to uncover the mysteries of the moon as sets off on this intriguing voyage into the world of Chandrayaan-3. The knowledge gleaned from this mission transforms the conception of the universe and motivates future generations to imagine possibilities beyond the boundaries of our planet. The persistence of Chandrayaan-3’s lander, rover, and indigenous propulsion module is to test and advance the new technologies needed for interplanetary travel as shown in Fig. 1. The lander will be propelled up to 100 miles above the moon by the propulsion module, which lifts it out of injection orbit. It also carries the Planetary Spectro-Polarimetry of Habitable Earth (SHAPE) payload, which measures the polarization of the earth by doing spectral analysis from the moon’s route. The Lander Module (LM) must be moved from the injection launch vehicle to the landing site until the Lander separates from its orbit, and this is the main responsibility of the Propulsion Module.

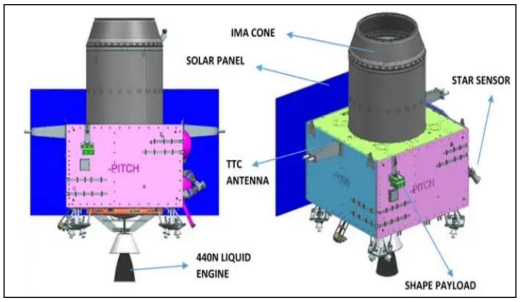

Fig. 1: Transporting the Lander-Rover Payloads to the Moon is the Primary Function of the Propulsion Module [1]

LANDER

Hypersensitive Ionosphere and Atmosphere Bound by the Moon Radio Anatomy (RAMBHA): RAMBHA monitors the local plasma and gas environment's temporal evolution. The Chandra Surface Thermophysical Experiment, or ChaSTE, examines the thermal characteristics of the surface and detects seismic activity at the landing location to help differentiate between the sub-surface's crust and mantle. The NASA-sponsored Laser Retroreflector Array (LRA) is a retroreflector that enables lunar range investigations as shown in Fig. 2. The laser ranging involves firing a laser at a reflector and timing how long it takes for the signal to return. Using retroreflectors that were left over from the Apollo program, NASA continues to estimate the distance to the moon's South pole.

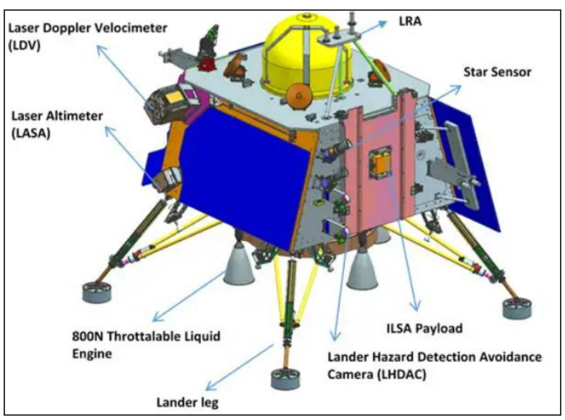

Fig. 2: The Lander will be Able to Gently Touch Down at a Designated Lunar Location [2]

ROVER

Rover is carrying the next two payloads that use Laser Induced Breakdown Spectroscope (LIBS) to determine the surface's chemical and mineralogical makeup as shown in Fig. 3. The elements that comprise the surface are identified by the Beta Particle X-ray Spectrometer or APXS. The elements that the rover will specifically look for are magnesium, aluminum, silica, potassium, calcium, titanium, and iron, according to ISRO.

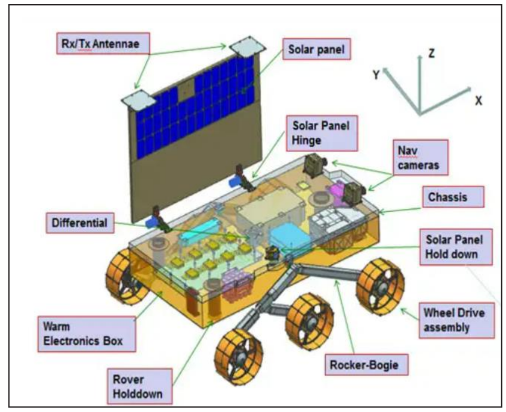

Fig. 3: Rover Uses its Mobility to Conduct In-Situ Chemical Research on the Lunar Surface [3]

A. *Major Process Involved in Flighting and Landing of Chandrayaan-3*

i. A.1 Flighting Part

The two primary parts of any space mission are the spacecraft, which might be a satellite or any other type of payload, and the rocket, or carrier as shown in Fig. 4. The rocket is all that is needed to launch the spacecraft into orbit. In most missions, the rockets are destroyed once they accomplish their goal. According to NASA, the launch of a spacecraft comprises an initial phase of powered flight during which the vehicle rises above Earth's atmosphere and accelerates. Propeller, a mixture of fuel and oxidizers that promote combustion, powers the rocket. Its goal is to provide enough energy to keep the spaceship moving upward. The powered flight continues after that and only concludes when the spacecraft separates and the rocket's last stage burns out. At this juncture, the payload ought to be within the orbit of the target planetary body.

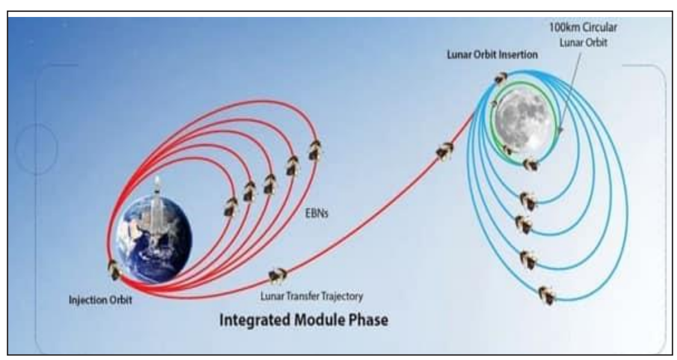

Fig. 4: ISRO Graphic Payload (Chandrayaan-3 Traveling from Earth to Space) [4]

ii. A.2 Landing Part

The goals of the mission were to deploy a lunar rover to explore the moon, do in-situ scientific research, and show a safe and gentle lunar surface landing, according to ISRO. In brief, a soft landing is a landing at a controlled, moderate speed to prevent spaceship damage. Regarding NASA's Rover mission to Mars, scientist Amitabha Ghosh stated, imagine if in a matter of minutes and, more crucially, without the need for human intervention, a spaceship speeding through space at ten times the speed of an airliner would need to almost completely halt to land gently on Earth.

B. Novelties in Chandrayaan-3 as Comparison to Chancdrayaan-2

Chandrayaan-3 uses high-resolution photos from Chandrayaan-2's orbit, and the lander's landing site determination has been improved. The central thruster was removed from the lander, the legs were made stronger for faster landings, and there were more solar panels added for more power generation. SHAPE payload, which uses Spectro-Polarimetry to look for habitable planets, is carried by Chandrayaan-3's propulsion module which hasn't been installed in Chandrayaan-2. The laser doppler velocity meter, an additional sensor from ISRO, examines the lunar surface. Additionally, able to obtain the elements of three velocity vectors by laser source sounding. It's able to combine the other instruments on hand, resulting in measurement redundancy. Laser Retroreflector Array (LRA) is a passive experiment being deployed with the lander as an add-on to the Chandrayaan-3 mission to investigate the dynamics of the Moon system.

C. Advancement of AI in Chandrayaan-3

Artificial Intelligence (AI) is rapidly becoming essential in many fields, including space exploration to analyze huge amounts of data, identify trends, and make forecasts making it a useful tool in the space industry. AI has been used in the Chandrayaan-3 mission in several ways, from the spacecraft's design to data processing and decision-making such as:

- AI is used in the design and development of the lander, rover, and the entire ship. Its algorithms are being used to optimize the spacecraft's design for weight, efficiency, and security.
- The lander's safe lunar surface landing was aided by AI. To predict the topography, spot potential dangers, and control the lander's descent, AI systems are being used.
- The rover is helped by AI as it explores the lunar surface. The rover's route is being mapped out as well and interesting things are being found and mapped using AI techniques.
- The data collected by the spacecraft is analyzed using AI. AI algorithms can be used to extract insights from data that would be challenging or impossible to obtain using traditional methods.

II. Literature Survey

J. N. Goswai *et al.* [1] proposed a report to better comprehend the Moon's origins and development, Chandrayaan-1, India's first planetary exploration mission, will carry out extensive remote sensing observations of the Moon. To offer information on chemical composition and mineralogy, it will make use of low-energy X-ray spectrometers, a trometer, and hyperspectral imaging in the UV-VIS-NIR area. Additionally, it will capture high-resolution images of the lunar surface and provide three-dimensional photographs through a mapping camera. Furthermore, a laser ranging device for lunar altimetry will be utilized in conjunction with three payloads, including a potent X-ray spectrometer, an atom-reflecting light spectrometer at sub-keV, and a compact imaging radar. These studies, which look at the presence of a localized lunar mini-magnetosphere, volatile mobility on the lunar surface, and the possibility of water ice in the region's continuously shadowed polar zone, represent the first attempts at remote sensing observations of a planet or moon. Carle M. Piet *et al.*, [2] proposed a study conducted on the NASA-backed Moon Mineralogy Mapper (M3) has revealed that this instrument, hosted on Chandrayaan-1, the remote sensing mission to the moon by ISRO, is an imaging spectrometer. The M3 functions across a range extending from visible light to near-infrared (0.42-3.0 micrometers), enabling the observation of mineral absorption bands that hold significant diagnostic importance. M3 intends to deliver high-resolution scientific data covering 25-50% of the lunar surface at a spectral resolution of 80 meters per pixel, or 260 spectral channels, during the mission's duration. It will also provide low-resolution spectroscopic data at 140 meters per pixel (86 spectral channels) covering the whole lunar surface to create a base map for additional investigation. Arup Roy Chowdhury *et al.* [3] proposed - It includes a thorough examination of the camera's payload characterization, scientific objectives, system and subsystem setup, as well as its achieved performance. The Terrain Mapping Camera (TMC) present on Chandrayaan-1 has been superseded by the TMC-2 installed on the orbiter-craft Chandrayaan-2. This camera functions within the panchromatic visible band. It comprises three identical electro-optical chains aligned to capture three distinct views (-25, 0, and +25 degrees) along the path of the craft for the formation of stereo images. The aim is to generate a digital elevation model using data with a 5-meter horizontal ground sample distance. Amitabh *et al.* [4] proposed - Performing a safe and gentle touchdown of a lander on the lunar surface near the southpole is the main goal of the Chandrayaan-3 mission. Precise navigation, guiding, and control are crucial for achieving this aim, as is a suitable trajectory for the lander's descent. Picking a landing location with the attention that satisfies all engineering specifications and limitations is essential to ensuring a safe touchdown. Chandrayaan-3 Prime Landing site spans approximately 4 kilometers in length and is situated at coordinates 69.367621 S and 32.348126 E. This site is within the south polar zone, covering an area of 2.4 square kilometers lying between Manzinus and the designated landing zone. It was chosen due to engineering limitations and specific parameters set by the terrain, taking into account the U and Boguslawsky M craters on the lunar surface. A. R. Rekha *et al.* [5] proposed the moon stands as a pivotal location for space exploration and scientific endeavors. Since the lunar missions of the late 1950s and early 1960s, various nations have initiated endeavors to land spacecraft on the moon. Achieving precise and gentle unmanned lunar landings is crucial for providing essential support for future manned lunar missions. The mission's central focus revolves around design and development, emphasizing the necessity for landing with an assured 100% success rate and minimizing risks. The lander's design prioritizes a high degree of autonomy, reliability, and advanced guidance, navigation, and control (GNC) capabilities. The primary technological objectives of achieving a soft moon landing aim to ensure a gentle and accurate landing while also enabling retargeting strategies to mitigate risks. Vadawale *et al.* [6] proposed Remote X-ray fluorescence spectroscopy is a reliable technique to study the elemental makeup of planets without an atmosphere. In this experiment, a low-energy X-ray detector aboard a spacecraft in lunar orbit is used to analyze fluorescence X-ray spectra from the lunar surface. Since the fluorescence of X-ray lines much depends on the incident solar X-ray flux and spectrum, precise measurements of both lunar and solar X-rays are essential. Despite its historical use in exploring space and determining the lunar surface's elemental composition, the technique has not been fully optimized due to several constraints. Thus, the experiment of remote X-ray fluorescence spectroscopy on Chandrayaan-2 is expected to continue, with different payloads for solar and lunar X-ray studies. The Solar X-ray Monitor (XSM) experiment will observe the sun, while the Chandra Large Area Soft X-ray Spectrometer (CLASS) experiment is dedicated to X-ray studies of the moon. The XSM electronics package and the XSM sensor package make up the XSM instrument. The XSM aims to offer thorough solar X-ray observations by correctly measuring the solar X-ray spectrum across the energy range of 1-15 keV with an energy resolution of around 200 eV @ 5.9 keV. Deepak Putrevu *et al.* [7] proposeda key division of ISRO, the Space Applications Centre (SAC) is working on the development of a high-resolution, dual-frequency Synthetic Aperture Radar (SAR). This cutting-edge technology is intended to be used as a research payload on ISRO's second lunar mission, Chandrayaan-2. With the use of this recently created equipment, ISRO hopes to further scientific research by utilizing data from the MiniRF on the Lunar Reconnaissance Orbiter (USA) and the S-band MiniSAR on Chandrayaan-1 (India). Configured with a single antenna, this SAR tool is designed to function in both the L- and S-bands. While the S-band SAR will preserve consistency with the MiniSAR data, the L-band is anticipated to allow greater penetration of the lunar regolith. This system will provide variable slant-range resolution from 2 meters to 75 meters, and it will offer both simultaneous (L and S) and standalone (L or S) imaging modes. It anticipates an instrument that understands surface characteristics, especially in the polar regions of the moon. Its features include hybrid and full polarimetry, a wide range of image incidence angles (from 10° to 35°), and the provision of high spatial resolution. S. Narendranath *et al.* [8] proposed that observing x-ray spectra remotely from a satellite orbiting a planet can assist in ascertaining the surface composition of airless celestial bodies within the solar system. Solar X-rays play a pivotal role in stimulating X-ray emissions from the surfaces of these celestial bodies. This method, known as X-ray fluorescence, has been applied in various experiments in the past to determine the quantities of essential elements forming the rocks. An x-ray fluorescence experiment, referred to as CLASS and installed on the Chandrayaan-2 orbiter, has been developed based on the insights gained from its predecessor, C1XS, which was part of the Chandrayaan-1 mission. This discussion centers on the innovative prospects in lunar science that might be facilitated by the capabilities of CLASS. G. Manju *et al.* [9] proposed a report on several crucial factors such as the photoelectron sheath, solar wind, and lunar surface potential, among others, significantly impact the nearby lunar plasma environment. As of right now, no direct in-situ observations of the plasma have been made in the near region of the moon. Estimates of lunar photoelectron densities have been provided by previous lunar missions, mostly by study of returning lunar samples, providing insight into the environment near the surface.Chandrayaan-2 lunar mission presents a unique opportunity to explore the lunar near-surface plasma environment from the platform of the lunar lander. To investigate this, a locally developed Langmuir probe has been designed to study the dynamic lunar near-surface plasma environment from the upper part of the lunar lander. This probe is engineered to cover a broad range of densities, from 10/cc to 10,000/cc. Assessing the probe's behavior in standard room conditions using a current source and determining its sensitivity to incoming ionized species in a vacuum chamber is crucial. The Langmuir probe's response has been tailored to accurately interpret the input current throughout the mission duration. Utilizing a reference calibrated Langmuir probe, the current Langmuir probe is calibrated.

III. Why ISRO Launching Chandrayaan-3

Since it is simpler and safer to land here, every previous spacecraft that has touched down on the Moon has done so close to the equator. For a prolonged and sustained operation of instruments, the terrain and temperature are more favorable. Sunlight is also available, providing solar-powered devices with a consistent source of energy. Variations exist in the

Moon's polar regions, where temperatures can plummet below 230 degrees Celsius in entirely sunless areas. This extreme cold makes operating instruments difficult. These regions feature numerous large craters across the landscape.The Moon's polar regions are still mostly unexplored. Because of the extremely low temperatures, objects trapped in these locations can be maintained, effectively frozen in time. Therefore, significant hints regarding the Solar System's beginnings may be found inthe rocks and soil found in the moon's north and south poles. For instance, Chandrayaan-2 had difficulties on its 2019 attempt to land there, losing contact after touchdown and failing to perform a soft landing.

IV. Benefits of Chandrayaan-3 for India

The benefits of Chandrayaan-3 are as follows:

- With Vikram's successful landing, India joins an exclusive group of nations. So far, only the US, Russia, and China have been successful in pulling this off.
- A huge stride for India when Chandrayaan-3 soft lands on the moon, and it's also a tremendous boost for business.
- India's entry into the moon economy, an expanding industry with billions of dollars in potential, will be made possible by Chandrayaan-3.
- The private space-tech industry in India is currently brimming with unending possibilities. India's space industry was estimated to be worth over $9.6 billion in 2020 just a few short years ago. According to EY India, this might increase to $13 billion by 2025. Chandrayaan-3's launch will have a significant positive impact on this industry.
- Chandrayaan-3's successful launch may increase investor confidence and spur additional private investment in space technologies.

V. Comparative Analysis among Chandrayaan-1,2 and 3

The comparative analysis of Chandrayaan 1, 2, and 3 is given in Table I.

Table I: Comparative Analysis of Chandrayaan-1, 2, and 3

Classification	*Chandrayaan-1*	*Chandrayaan-2*	*Chandrayaan-3*
Launch Date	22 October 2008	22 July 2019	14 July 2023
Objectives	To orbit the Moon and send an impactor to the surface, the first Indian deep space mission was undertaken.	Moon exploration and knowledge expansion.	Earth's spectrum and polarimetric measurements were used to assess the habitability of exoplanets.
Launch Vehicle	India launched the spacecraft using a PSLV-XL.	The expedition was initiated using a GSLV Mk III M1 rocket.	The Chandrayaan-3 mission was effectively launched by the Indian Space Research Organisation (ISRO) using an LVM3-M4 rocket.
Payload	Chandrayaan-1 featured five domestically developed essential payloads/experiments: TMC, HySI, LLRI, and HEX, along with a Moon Impact Probe (MIP) designed to impact a predetermined location on the lunar surface.	One of the payloads aboard the orbiter is the Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) developed by the ISRO Satellite Center (ISAC).	The Lander's payloads, such as RAMBHA, ILSA, LRA, and ChaSTE, have diverse goals, while the Rover's payloads consist of the Alpha Particle X-ray Spectrometer (APXS) and the LIBS. Additionally, the propulsion module includes the SHAPE.
Mission Components	It only consists of a lunar probe.	Orbiter, Lander (Vikram), Rover (Pragyan).	No Orbiter, Lander (Vikram), Rover (Pragyan).
Cameras	The Terrain Mapping camera (TMC) aboard the Chandrayaan-1 spacecraft functioned effectively.	Extremely high spatial resolution camera that operates in the visible panchromatic band is the Orbiter High Resolution Camera (OHRC) onboard the Chandrayaan-2 Orbiter-craft.	Chandrayaan-3 is equipped with a pair of cameras for detecting and avoiding potential hazards on the lander.
Lander Configuration	Lander wasn't installed.	It comprises the Vikram Lander and Pragyan Rover.	Chandrayaan-3 consists of distinct modules: A Lander, a Propulsion module, and a Rover.

VI. Result and Discussions

Chandrayaan-3 is the first mission to soft land on the moon's unexplored south pole. A safe and controlled lunar landing, on-site scientific investigation, and rover mobility were the mission's goals. One lunar day, or fourteen days on Earth, is what Chandrayaan-3 is anticipated to run on lunar soil for. The orbiter will return with the information and pictures it received from the Vikram lander. With a 500-meter circle surrounding the landing site, the Pragyan rover will move while carrying out experiments and transmitting data and pictures to the lander as shown in Fig. 5. Advanced scientific payloads are combined between the Rover and Lander modules.

Fig. 5: An Image Captured by Pragyan Rover [14]

These tools are made to undertake thorough examinations into a variety of lunar properties, including terrain analysis, surface chemistry, mineralogical composition, atmospheric parameters, and, most importantly, the search for water and prospective resource reserves.

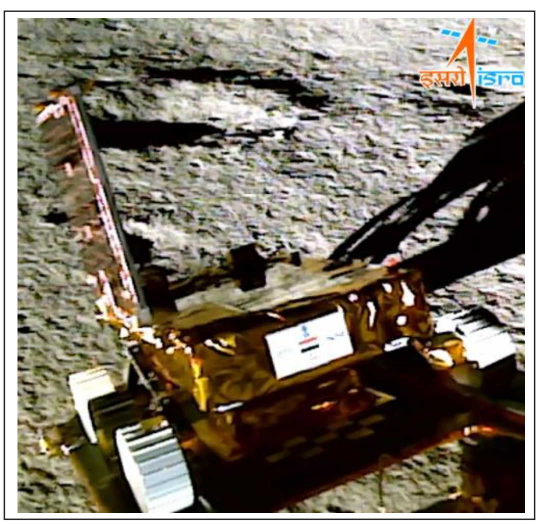

Fig. 6: An Image Captured by Lander Module [15]

A payload called SHAPE is a component of the propulsion module that launches the lander and rover into a 100-kilometer lunar orbit. Its purpose is to analyze the spectral and polarimetric data of Earth from the lunar orbit.

VII. Conclusion and Future Scope

This article provides an overview of India's third lunar exploration effort, Chandrayaan-3. India has made two efforts to soft-land a lander and rover on the lunar surface as part of this mission. Moreover, the country's second in-house lunar exploration project, Chandrayaan-3, is focused on the Moon's unexplored South Pole. The article describes the goals and characteristics of Chandrayaan-3, emphasizing the lander (Vikram) and rover (Pragyan) It also sheds light on the scientific equipment that the lander and rover brought with them to conduct on-site investigations on the lunar surface. The paper also describes how artificial intelligence (AI) has been incorporated into this mission and clarifies the critical Chandrayaan-3 flight and landing procedures. This mission represents India's attempt to increase its footprint in space, bring in a new era of exploration, improve our understanding of space, foster technological advancement, foster international cooperation, and raise the aspirations of upcoming generations of explorers and scientists.

Chandrayaan-4: Traveling Down the Lunar Evolution Path Building on earlier missions, Chandrayaan-4 emerges as a plausible candidate for a mission designed to return samples. If it succeeds, it might be the greatest thing since Chandrayaan-2 and Chandrayaan-3, enabling us to gather samples from the lunar surface. The effort might advance our understanding of the Moon's composition and history. A collaborative effort of ISRO and JAXA (Japan), Lunar Polar Exploration (LUPEX) seeks to study the Moon's polar regions. Its mission is to navigate through constantly shadowed environments. Determining if water might exist and whether it would be possible to establish a long-term outpost are two of LUPEX's objectives.

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