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Lunar Explorations and the Position of Chandrayaan-3: Need for Scientific Collaboration

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Abstract:

The moon has been a subject of various speculations throughout history, both scientific and sometimes superstitious in nature. This paper aims to explore the reasons for conducting lunar missions and expected outcomes of lunar exploration, and draw up a timeline containing the evolution of results obtained from missions that have been conducted till date. The paper entails an analysis of global missions and scientific expeditions including NASA's Apollo-11 and Robotic Lunar Exploration Program (RLEP), Soviet Union's Luna-Glob Projects, China's Chang'e Programmes and India's Chandrayaan missions- Chandrayaan-1 and Chandrayaan-2. A special emphasis has been provided on both the technical details of Chandrayaan-3 and the results obtained from it. The paper also describes future plans of international space research agencies, particularly the Artemis mission in progress in the United States and the Phase IV of the Chang'e mission that aims to culminate in constructing a lunar research base on the south pole of the Moon. It suggests expanding the scope for better access to resources by developing collaborative missions amongst organisations like that of China and Russia's International Lunar Research Station, ILRS as united efforts will help produce better budgeting, infrastructure and resources for all nations willing to partake in a mission to the moon.

Keywords: *Lunar, space, exploration, lunar missions, scientific expeditions, Apollo-11, Chang'e Project, Chandrayaan-3, Chandrayaan mission, rocket, lunar surface, payloads, rover, lander, south pole of moon, Artemis mission, ISRO.*

1. Introduction:

The Moon came into being from Earth, and holds a record of Earth's ancient history- a history that no longer exists, and stands erased due to continuous natural processes and weathering over the passage of time. Exploring the Moon will provide scientists with perhaps an entirely new perspective of early Earth, how the solar system or the universe formed and evolved, and the role of Earth-space interaction via asteroids and meteors in influencing Earth's history as well as future. To study the Moon would also be an attempt to create new opportunities for technological innovations, and application and utilization of new resources. David Parker,

Director of Human and Robotic Exploration for the European Space Agency, said that the moon "has lain virtually undisturbed for the last 4.5 billion years." (FP Explainers, July 2023).[1]

The lack of information creates mystery but also expands the horizon of potential that the Moon has in being a habitable ecosystem, or a provider of energy sources (like lunar ice*), or a crucial step towards analyzing the geological history of the Earth. Moreover, exploring the Moon is not a one-team task. It would require united efforts from both internal departments of a space station, and from space stations of various countries- a collective undertaking would be an attempt towards bringing humanity together.

The paper aims to describe Lunar Missions that have occurred in the past, the global scenario with regards to Moon exploration, results achieved from said explorations and future planning by international space research agencies with special emphasis on the Chandrayaan-3 mission developed by the Indian Space Research Organization (ISRO)[2].

2. Global Missions and Scientific Explorations:

The Space Race of the mid-20th century stood as a pivotal era in lunar exploration. The United States and the Soviet Union engaged in a fierce competition to conquer space, culminating in the Apollo program. In 1969, NASA's[3] Apollo 11 mission achieved what was once considered a fantastical dream - humans landing on the moon. This monumental event not only showcased human capability but also ignited a passion for space exploration that endures to this day. Following Apollo 11, the United States continued its lunar missions with Apollo 12 to 17, each contributing valuable scientific data. These missions brought back lunar samples, shedding light on the moon's composition, geology, and its relationship with Earth. In parallel, the Soviet Union

Lunar ice, when converted to water, split into hydrogen and oxygen and stored could fuel an entire rocket. This is because as highly flammable gases, they would release an enormous amount of energy upon burning- enough to propel spacecraft. achieved its own milestones. In 1959, Luna 2 became the first human-made object to reach the moon, crash-landing on its surface. Later, Luna 9 transmitted the first images from the lunar surface, while Luna 16 became the first mission to return samples from the moon.

The 21st century has witnessed a resurgence of lunar exploration. The Chinese National Space Administration's Chang'e program, named after the mythical Chinese moon goddess, has made

[1]FP Explainers, "Chandrayaan-3 launch: Why is exploring the Moon important for humanity?", Firstpost., July 2023 https://www.firstpost.com/explainers/chandrayaan-3-launch-why-is-exploring-the-moon-important-for-humanity-12854322.html
[2] The Indian Space Research Organization (ISRO). https://www.iisro.gov.in
[3] The National Aeronautics and Space Administration (NASA). https://www.nasa.gov

remarkable strides. Notably, Chang'e 4 became the first mission to land on the moon's far side*, providing unprecedented insights into this uncharted territory.

Additionally, international collaboration through programs like the Lunar Reconnaissance Orbiter (LRO) and the Indian Space Research Organization's Chandrayaan missions has continued to broaden our understanding of the moon's topography, mineralogy, and potential resources. These missions have paved the way for future endeavours, including the ambitious Artemis program, which aims to land the first woman and the next man on the moon and establish a sustainable human presence by the end of the 2020s. In support of NASA's Vision for Space Exploration that calls for undertaking lunar exploration activities to enable sustained human and robotic exploration of Mars and beyond, the Robotic Lunar Exploration Program (RLEP) has been instituted.[2] (Venkatesan Prasad Sundararajan, September 2006) The RLEP is responsible for executing a series of robotic missions to the Moon to conduct research and prepare for future human exploration.

The history of lunar exploration is a testament to human ingenuity, curiosity, and determination. From the early space race to the collaborative efforts of modern international missions, our quest to understand the moon has propelled technological advancements and expanded our cosmic horizons. The legacy of these missions will continue to shape the future of space exploration and inspire generations to come.

3. A History of Indian Missions and Scientific Expeditions:

In a historic leap for India's space program, the Indian Space Research Organization (ISRO) launched Chandrayaan-1 on October 22, 2008. This mission marked India's entry into the exclusive club of lunar explorers, joining the ranks of esteemed space agencies worldwide. Chandrayaan-1 was a multi-faceted endeavour with a comprehensive scientific agenda, aiming to conduct an exhaustive study of the moon's topography, mineralogy, and exosphere.

Equipped with an array of sophisticated scientific instruments, including spectrometers, cameras, and radar systems, Chandrayaan-1 exceeded expectations. One of its most groundbreaking. The far side of the moon is the lunar hemisphere that always faces away from Earth. Venkatesan Prasad Sundararajan, September 2006. "International Missions to the Moon: Space Exploration Goals, Programs and Economics"[4] discoveries was the detection of water molecules on the moon's surface. This revolutionized the understanding of Earth's celestial neighbour and sparked a renewed interest in lunar exploration globally. The mission also confirmed the presence of crucial minerals like calcium, aluminium, silicon, oxygen, and iron, further enhancing comprehension of the moon's composition.

[4] Venkatesan Prasad Sundararajan, September 2006. "International Missions to the Moon: Space Exploration Goals, Programs and Economics"

Despite its intended two-year mission lifespan, Chandrayaan-1 experienced an unforeseen end in August 2009 due to a communication failure. Nevertheless, it had successfully achieved a significant portion of its scientific objectives, leaving an indelible mark in the annals of lunar exploration.

Building upon the triumphs of Chandrayaan-1, ISRO launched Chandrayaan-2 on July 22, 2019, marking a significant advancement in India's space exploration endeavours. Comprising an orbiter, a lander named Vikram, and a rover named Pragyan, Chandrayaan-2 exemplified India's growing capabilities in space exploration. The orbiter was tasked with orbiting the moon and performing remote-sensing observations. Meanwhile, Vikram, the lander, was tasked with executing a soft landing on the lunar surface. Onboard Vikram was Pragyan, the rover, designed to traverse the moon's surface, conduct experiments, and transmit data back to Earth. While Vikram's hard landing faced unexpected challenges, the orbiter performed exceptionally well. It was instrumental in mapping the moon's surface, studying its exosphere, and conducting mineralogical and elemental studies.

Chandrayaan-2 not only expanded the scientific understanding of the moon but also inspired a new generation of scientists and engineers in India and around the world. Its achievements amplified India's dedication to advancing scientific knowledge and technological capabilities in space exploration.

4. Chandrayaan-3:

Chandrayaan-3 followed Chandrayaan-2 to demonstrate complete capability in both soft-landing* and roving on the lunar surface. It was composed of Lander (named *Vikram*) and Rover (named *Pragyan*) configuration. Launched on 14 July 2023 from Satish Dhawan Space Centre in Sriharikota, Andhra Pradesh, Chandrayaan-3 entered lunar orbit on 5 August. The lander exhibited a successful soft landing on the lunar south pole on 23 August at around 18.03 pm IST. This made India the first country to land on the south pole of the Moon, and the fourth country to land on the moon successfully. ISRO announced their Mission Objectives[5] (Indian Space Research Organization, Chandrayaan-3 Brochure, 2023) for the Chandrayaan-3 mission to be as follows:

Soft landing is any type of spacecraft landing that does not result in significant damage to or destruction of the vehicle or its payload. The average vertical speed should be less than or equal to 2m/s.

i) Engineering and implementing a lander to land safely and softly on the Moon surface.
ii) Observing and demonstrating the rover's driving capabilities on the Moon.
iii) Conducting and observing experiments on the materials available on the lunar surface to better understand the composition of the Moon.

[5] ISRO, Department of Space. https://www.isro.gov.in/Chandrayaan3_Details.html

Chandrayaan-3 comprised three main components: a propulsion module, lander, and rover. The propulsion module consisted of a large solar panel mounted on one side and a cylindrical mounting structure for the lander on top. It also contained a payload named Spectro-polarimetry of Habitable Planet Earth (SHAPE), which aimed to- 1. Study polarimetric measurements of the Earth from the lunar orbit, and 2. Probe into a variety of Exo-planets, upon discovery in the future, which would qualify for habitability (or for presence of life).

The lander, *Vikram,* carried the rover, and had four landing legs and four landing thrusters capable of producing 800 newtons of thrust each. It had four throttleable engines (engines where the thrust level can be changed to change the spacecraft's altitude and speed). Additionally, it contained a Laser Doppler Velocimeter, a sensor module that can sense difficult or favourable conditions on the Moon surface. The lander carried four payloads, as follows:

i) Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere (RAMBHA), fitted with a Langmuir probe, LP, which aimed to measure the near surface plasma density and its changes with time.
ii) Chandra's Surface Thermo Physical Experiment (ChaSTE) which aimed to measure the thermal properties of the lunar surface in the polar regions.
iii) Instrument for Lunar Seismic Activity (ILSA) which aimed to measure seismicity around the landing site and delineate the structure of the lunar crust and mantle.
iv) LASER Retroreflector Array (LRA) which was a passive experiment that aimed for a gross understanding of the dynamics of the Moon system.

One of the main reasons for Chandrayaan-2's landing failure was altitude increase during the camera coasting phase. This was removed by allowing the lander to control attitude and thrust during all phases of descent. The rover, *Pragyan,* was a six-wheeled vehicle weighing 26 kilograms. It was expected to take multiple measurements for further study into the chemical composition of the surface of the Moon, the presence of water ice in the soil, and the evolution of the Moon's Atmosphere.[6] (via Livemint, August 2023). The rover contained two payloads, as follows:

Polarimetry is the measurement and interpretation of the polarization of transverse waves, often electromagnetic waves.

(i) LASER Induced Breakdown Spectroscope (LIBS), which aimed to execute quantitative and qualitative analysis of the chemical and mineralogical composition of the lunar surface.

[6] Livemint, 18 August 2023.
https://www.livemint.com/news/india/chandrayaan3-live-updates-isros-lunar-mission-indian-spacecraft-landingon-moon-russia-luna-25-moon-mission-11692151720010.html

(ii) Alpha Particle X-ray Spectrometer (APXS), which aimed to determine the elemental composition i.e percentages of magnesium, aluminium, silicon, potassium, calcium, titanium and iron in the lunar soil.

The most significant detail in designing the Chandrayaan-3 spacecraft is credited by S. Somnathan, Chairman of ISRO, as the *failure-based design philosophy* in place of a success-based one, as was used in the case of Chandrayaan-2. *(Architectural Digest, August 2023)*[7]. This strategy involved meticulous consideration of numerous potential failure points and the implementation of preventative and protective measures for every worst-case scenario to ensure a successful landing. On the lunar surface, Chandrayaan-3 performed a *Hop Experiment* where *Vikram* fired its engines ascending 16 inches and translating around 16 inches laterally across the surface. The test showed capabilities that could be used in sample return missions in the future. The rover deployment ramp was retracted for the experiment but later redeployed.[6] *(ISRO, September 2023).*[8] Chandrayaan-3 was launched aboard an LVM3-M4 (Launch Vehicle Mark-3, a three-stage medium-lift launch vehicle developed by ISRO) rocket at 09:05 UTC, entering an Earth parking orbit with a perigee* of 170 km and an apogee** of 36,500 km.

5. Results of Chandrayaan-3 Mission:

After Chandrayaan-3 was placed in a trans-lunar injection orbit[9], ISRO placed the spacecraft successfully into one particular lunar orbit. The lunar orbit insertion operation was carried out by the ISRO Telemetry, Tracking, and Command Network (ISTRAC) in Bengaluru. *(The Hindu Bureau, August 2023).*[10] On 17 August, the Vikram lander separated from the propulsion module to begin the last phase of the mission. After landing, Chandrayaan-3 began surface operations that eventually led to rather remarkable discoveries.

Although Sulphur was theorized to be present on the Moon before, it was confirmed for the first time at the south pole by *Pragyan*. Towards the end of August, ISRO reported that the LIBS, Laser Induced Breakdown Spectroscope, payload on the Pragyan rover detected the presence of Sulphur in the south pole region of the lunar surface, via "first-ever in-situ measurements" [8] *(Ashok Sharma, AP News, August 2023)*[11]. It also confirmed and performed

[7] AD Staff, 24 August 2023. https://www.architecturaldigest.in/story/celebrating-chandrayaan-3-fascinating-design-insights-into-isros-historic-moon-landing

[8] Indian Space Research Organisation, 4 September 2023. https://twitter.com/isro/status/1698570774385205621 via Twitter

[9] TLI, trans-lunar injection is a propulsive manoeuvre used to set a spacecraft on a trajectory that will let it arrive at the Moon.

[10] The Hindu Bureau, 5 August 2023. https://www.thehindu.com/sci-tech/science/chandrayaan-3-enters-lunar-orbit/article67161942.ece

[11] Ashok Sharma, 30 August 2023, AP News. "India's moon rover confirms sulfur and detects several other elements near the lunar south pole." https://apnews.com/article/indias-moon-mission-finds-chemicals-a0f5b3c91fd71c2a3ae573d4048a5d05

a quantitative analysis of other elements- including calcium, Aluminium, iron, chromium, manganese, tin, silicon and oxygen.

The Chandra's Surface Thermo Physical Experiment (ChaSTE) payload was designed to investigate the thermal profile of the lunar surface. As per the data released by ISRO from ChaSTE, a high range temperature around 70 degrees Celsius was detected on the surface of the Moon. (*Poulomi Ghosh, Hindustan Times, August 2023*)[12]

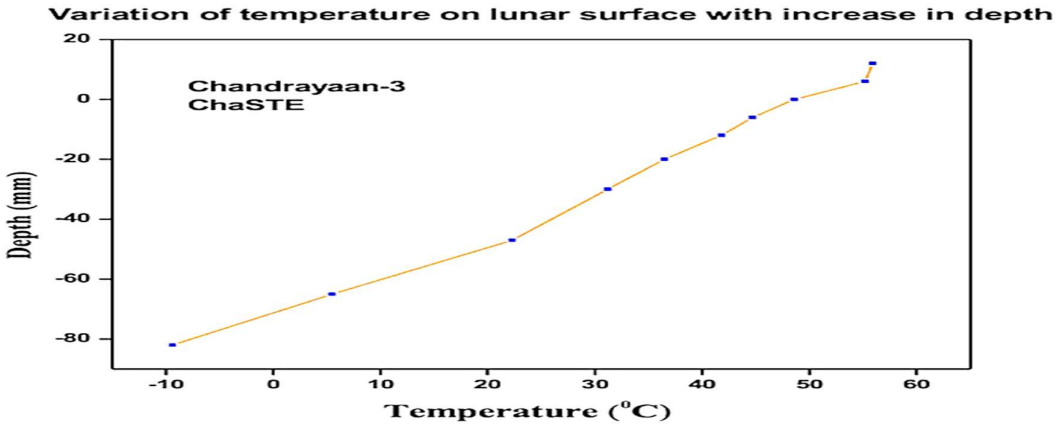

Fig. 1 - The graph of temperature variation across the lunar topsoil at a point in the solar polar region, as measured by the ChaSTE instrument[13].

The Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere, RAMBHA payload on *Vikram* reported considerably low plasma densities above the lunar surface, around 5-30 million electrons per cubic meter. This was only around the beginning of the lunar day. The ILSA payload, Instrument for Lunar Seismic Activity provided measurements of a series of vibrations of the rover movement, and a 'natural event' on 26 August. The source behind this natural event remains undisclosed, but is presumed to be a moonquake- a seismic vibration on the lunar surface. Not only has a plethora of information about the Moon been uncovered, and path paved towards future discoveries, the success of the Chandrayaan-3 mission is even expected to impact India's economy and its position in the global scenario in terms of advancement in space research and technological power. Being a successful, relatively low-cost mission, approximated at an unofficial 55 million USD, ISRO's space programmes have garnered a prestigious reputation and high credibility. The successful exploration conducted has given new hope to the youth to pursue space research in the country itself, instead of moving abroad to the West. Chandrayaan-3 has, to some extent, reinstated people's faith in India's capabilities as a technological power and pioneer in space research. With a steady

[12] **P**oulomi Ghosh, 28 August 2023, Hindustan Times. "70-degree Celsius moon surface temperature was not expected: Scientists" https://www.hindustantimes.com/india-news/70degree-celcius-moon-surface-temperature-was-not-expected-scientists-101693156089990.html
*ISRO, via X, twtr.to/yoWYS
[13] ISRO, via Twitter, now X - https://twtr.to/yoWYS

increase in the number of ISRO applications every year, the Indian economy expects a rise in employment and efficiency of work done soon.

6. Outputs Revealed in Lunar Exploration in the Global Scenario:

Lunar exploration missions conducted globally have unveiled a trove of insights about Earth's celestial companion- finding traces of evidence of ancient volcanic activity, impact cratering, and even traces of water molecules locked within lunar soil. These findings provide crucial context for comprehending the broader narrative of our solar system's formation. The European Space Agency's SMART-1 Mission tested future deep-space communication techniques for spacecraft, techniques to achieve autonomous spacecraft navigation, and miniaturized scientific instruments to examine the surface of celestial bodies in visible, infrared and X-ray light. It also studied the craters on the moon and the impacts because of which they formed. With 16 months close to the lunar orbit (*European Space Agency, SMART-1 FAQs*)[14], SMART-1 was able to provide a gallery of high-definition images that could corroborate with lunar datasets provided by other countries. Roscosmos' Luna-Glob Project for lunar exploration provided valuable insights into the chemical composition of the lunar exosphere and the magnetic field of the moon. The Japanese Aerospace Exploration Agency, JAXA was able to detect intact lunar lava tubes from analysis of observations made by SELENE, Speleological and Engineering Explorer (*Japan Space Exploration Agency, 2017*).[15] The Chinese Lunar Exploration Program launched two lunar orbiters, Chang'e 1 and Chang'e 2, which provided a 3D high-definition detailed map of the lunar surface that helped access better soft-landing spots. The Chang'e 3 and Chang'e 4 rockets showed great success in not only the soft landing but also the consequent deployment of Yutu and Yutu-2 rovers which continue to scan the lunar surface.

Furthermore, lunar exploration has catalyzed international collaboration and competition. It has served as a focal point for countries to demonstrate their scientific prowess and forge alliances in the pursuit of common goals. This has not only fostered a spirit of global cooperation but also underlined the potential for peaceful endeavours in space.

7. Future Planning and Suggestions:

As of now, China and the United States of America have fully disclosed their plans for their future lunar explorations and have stated clear objectives. The next phase of the Chinese Lunar Exploration Programme will be developing an autonomous lunar research station near the south pole of the Moon. This phase surged into active development in 2023. Chang'e 6, to be launched in 2024, will observe the composition, topography and subsurface structure of the

[14] **E**uropean Space Agency, "SMART-1 Impact Frequently Asked Questions (FAQs)"
[15]**J**apan Aerospace Exploration Agency, 18 October 2017. "Detection of intact lunar lava tubes in the data from Kaguya radar sounding" https://global.jaxa.jp/projects/sat/selene/topics.html

South Pole-Aitken Basin[16]* and return samples to the station. Chang'e 7, to be launched in 2026, will contain an additional flying probe search the lunar south pole for resources (*Jones, 2022*)[17]. Last but not the least, Chang'e 8 will aim to use a 3-D printing experiment using in-situ resource utilization, ISRU[18]**, to test technology required to construct infrastructure for a lunar science exploration base (*Chang'e-4 mission conference, 2019*)[19]. China aims to land astronauts on the moon by 2030.

As for the United States of America, the Artemis Plan entails the aims of NASA, National Aeronautics and Space Administration, to produce Human Landing Systems, HLS, that can accommodate human exploration of the Moon. Artemis-I, the first stage, will be an uncrewed flight test of the Space Launch System and the Orion spacecraft around the Moon. Artemis-II and Artemis-III will be the follow-up missions that shall culminate in human habitation on the moon.

Various other countries, including India itself, have developed plans for international lunar missions that are exceptionally detailed independent undertakings. However, the success of already executed missions has given rise to the possibility of collaborative initiatives- one of which has already been established. In 2021, China and Russia announced the construction of a lunar base through collaborative effort, and also formally invited more countries and organizations to join their International Lunar Research Station (ILRS) project as an alternative to the American Artemis Program. Such cooperation will not only produce a stronger, mutually cooperative society of space researchers but also enhance international relations that can result in the overall betterment of countries in both social and technological aspects. Clubbing international resources together can reduce scopes of error and provide access to better resources for lunar exploration. United efforts will surely go a long way in unravelling the mysteries of the moon.

8. Conclusion:

In conclusion, past explorations have provided numerous significant insights into the topology, composition, and structure of the lunar surface. Missions have been set into progress that can potentially allow human habitation on the Moon. India itself has been able to position itself as one of the pioneers of lunar research and exploration in particular after Chandrayaan-3's successful soft landing.

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[16] * *the largest, oldest, and deepest impact crater or basin discovered till date on the Moon.*

[17] [12] Andrew Jones, 19 November 2022. "China outlines pathway for lunar and deep space exploration" https://spacenews.com/china-outlines-pathway-for-lunar-and-deep-space-exploration/

[18] ** *the practice of collection, processing, storing and use of materials found or manufactured on other astronomical objects that replace materials that would otherwise be brought from Earth.*

[19] Chang'e-4 mission conference, 3 January 2019. https://www.youtube.com/watch?v=v7FiaHwv-BI

But the search for answers has not taken a pause. Scientific expeditions necessitate proper resources, infrastructure, and education. It is important to emphasize on collaboration and cooperation amongst international space agencies so as to produce an equitable distribution of said resources that can aid a cumulative effort to reach the ultimate goal- living on the moon. If organizations stand together, the fruit will not only be scientific progress, but also improved international cooperative ability, and a more harmonious coexistence.

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