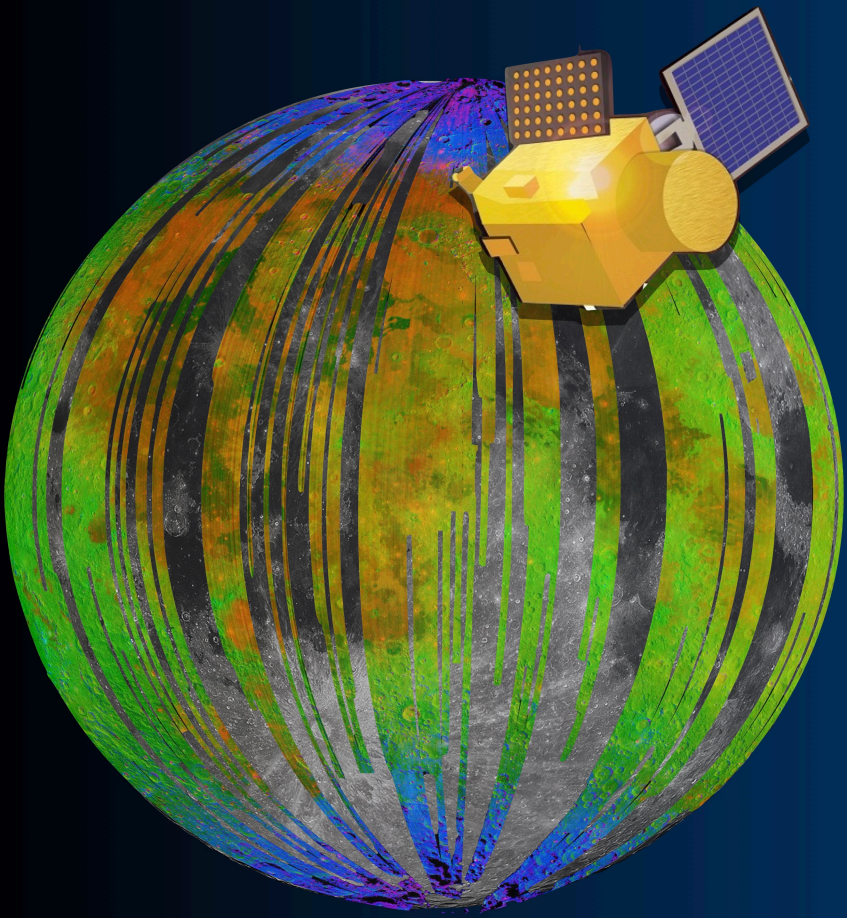
Crafty Moon-craft



Slices of creativity in lunar exploration by India's Chandrayaan missions

Jatan Mehta

Cover image: Composite graphic created by Jatan Mehta

Base images: NASA / JPL-Caltech / Brown University[1a] / Gregory Revera[1b] / ISRO / TeamIndus

Colored stripes: Illustration of the joint Indo-US discovery of water and hydroxyl across the Moon's surface by India's Chandrayaan 1 orbiter, prominently highlighted as blue and violet on this reflected infrared radiation map.

Crafty Moon-craft

Slices of creativity in lunar exploration by India's Chandrayaan missions

"Best read after having looked up at the Moon, and to it."

Jatan Mehta

Space writer, slow thinker, and poet.

jatan.space

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About

India's Chandrayaan space program is one of the few in the world dedicated to the exploration of our Moon. Every mission of the program has displayed a unique slice of creativity in its execution. This novella-sized book *Crafty Moon-craft* independently captures and archives Chandrayaan's crux by highlighting unique contributions of each of the three Chandrayaans to date.

The joint Indo-US discovery of water on the Moon by ISRO's Chandrayaan 1 satellite in 2009 catalyzed a global rush to the Moon. That India achieved such impact on its debut planetary mission inspired people worldwide, including myself. I was in school at the time, fascinated by all things space and science. Chandrayaan 1 catapulted my imagination of the international potential of space exploration. 14 years later as a space writer, I watched Chandrayaan 3 launch from the Sriharikota island and also covered its lunar landing from ISRO. My multi-year coverage of Chandrayaan 2 & 3 over on my blog & website 'jatan.space' has drawn from multiple lunar and space experts. With this book, readers worldwide can get insights into India's unique lunar program. I hope you feel as curious about the crafty Chandra-yaans as much as I did when learning the facts inside for the first time.

Book webpage: https://jatan.space/crafty-moon-craft-book



First published: November 2026

Share your thoughts about the book by posting about it or leaving a review.

Supporting open access

A personal note by Jatan

This book has been prepared with care to serve the public based on five major goals and values in mind:

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Collaboratively catalyzing a global lunar rush

Water on the Moon and Chandrayaan the first.



Launch of the Chandrayaan 1 spacecraft on a PSLV-XL rocket on October 22, 2008. Image: ISRO[1c]

In September 2009, a paper[2] published in *Science* announced the discovery of water on the Moon[3] by India's Chandrayaan 1[4] orbiter. Changing the notion of a bone-dry Moon as cemented during the Apollo era, the finding had fundamental implications for understanding the origin[5] and evolution[6] of our Earth and its intriguing cosmic companion[7]. That water was present on Luna in multiple forms also meant it could be used as a resource for future deep space exploration, offering

breathable air for astronauts, water to drink and use, and fuel when its hydrogen and oxygen is liquefied to power longer, more ambitious missions[8]. This potential, combined with the Moon's proximity making it a technological catalyst, has led to nations around the world sending[9] or planning to send[10] a flurry of robotic and even crewed missions to the Moon. Chandrayaan 1 catalyzed a global Moon rush after the decline of last century's Cold War lunar race at the dawn of the Space Age.

The discovery of lunar water came through a notable act of collaboration. Chandrayaan 1 carried 11 scientific instruments[11], six of which involved foreign partnerships across five nations. Lunar water's presence was confirmed by the Moon Mineralogy Mapper[12] (M3) instrument onboard Chandrayaan 1, provided by the US' premier space agency National Aeronautics and Space Administration (NASA). Some other Chandrayaan 1 instruments also saw signs of water but M3's detection was the unequivocal one. It could differentiate[13] between ice, liquid water, and water vapor based on how the lunar surface reflected and absorbed infrared light, which meant avoiding false positives in measurements. M3 was also an excellent mineral mapper; its data has helped scientists worldwide churn out hundreds of lunar findings[14] and counting. Noah Petro, a former Project Scientist for NASA's Lunar Reconnaissance Orbiter[15] (LRO) mission and currently a Science Lead[16] in the agency's Artemis program[17] to return humans to the Moon, praised M3[18] in 2019:

> "10 years ago today Chandrayaan-1 ended. I was so lucky to be a small part of that mission. The M3 instrument

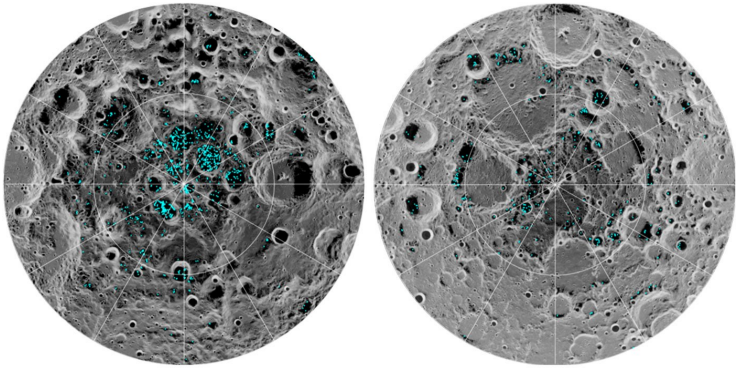
> allowed us to take a huge step forward in learning about the composition of our 8th continent!"

Unlike countries with developed space programs, India had not been one to explore worlds in our Solar System other than Earth for most of its space-faring life since the 1960s. With Chandrayaan 1's launch in 2008[19] on a PSLV-XL rocket, India forayed into planetary exploration. Confirming water's presence on the Moon was a primary mission objective for the Indian Space Research Organization (ISRO), the country's governmental space agency who designed, developed, launched, and operated Chandrayaan 1. That India achieved such an important discovery & goal on its debut planetary mission inspired people around the world, including myself. I was in school at the time, fascinated by all things space and science. Chandrayaan 1's water gem catapulted my imagination of the international prowess of space exploration. It's worth remembering that collaboration is what catalyzed Chandrayaan 1's success.

Late Srinivasa Hegde, who worked at ISRO's Satellite Center[20] in Bangalore for 36 years, was the Mission Director of Chandrayaan 1. Hegde was deeply involved in many aspects of the mission: the design of the various mission phases[21], data management, orbit determination, strategies for course corrections, orbiter operations, and so on. I asked him during a 2020 interview for Supercluster[22] the driving philosophy behind ISRO soliciting scientific instruments from other space agencies around the world for Chandrayaan 1. He noted the following:

> "We had our own science payloads on Chandrayaan 1 but we also wanted to provide the spacecraft as a platform for

> others we could collaborate with. And so ISRO put out an announcement of opportunity to scientists all over the world to pitch payloads for Chandrayaan 1. We got instruments from ESA as well as NASA, including universities associated with them. I think the timing of Chandrayaan 1 was good as NASA's next Moon mapper LRO was still a year away."



Distribution of water ice deposits inside permanently shadowed regions on the Moon's poles, shown as splotches, as detected by Chandrayaan 1's M3 instrument. Image: NASA[13]

Past missions had hinted at water's presence on the Moon. Because of its potential for exploration and future economics, space agencies globally were keen to confirm water's presence. NASA responded to ISRO's call for payloads and got to fly[23] two of its water-hunting instruments onboard Chandrayaan 1: the M3 and the Miniature Synthetic Aperture Radar[24] (Mini-SAR). The latter found indications of water ice[25] in more than 40 craters host to frigid permanently shadowed regions[26] on the Moon's poles. But just like with efforts in the previous decade[27] such as from NASA's Clementine lunar-mapping orbiter, the data wasn't conclusive by itself to rule out false positives, such

as certain rough rock textures mimicking water-ice-like signals. M3's measurements provided independent proof of water's existence, and validation for some measurements by other instruments.



Technicians handling Chandrayaan 1 pre-launch in a cleanroom. Images: ISRO[28]

Among the many more scientific results[29] that came out of Chandrayaan 1, another collaboration stands out. India, Sweden, and the European Space Agency (ESA) collaborated on the Sub-keV Atom Reflecting Analyzer[30] (SARA) instrument. By analyzing how protons—hydrogen nuclei—in the Sun's radiation wind[31] impact the Moon and get reflected, SARA helped scientists better estimate the amount and distribution of water or hydroxyl molecules[32] locked in the soil across the Moon. The discovery helped future confirmation of water's presence across the lunar globe[33], embedded in its soil and rocks. It also proved timely for ESA's ongoing BepiColombo

mission[34] to study Mercury, which carries instruments similar to Chandrayaan 1 for detecting water.

Operating and balancing the goals of 11 instruments on Chandrayaan 1 as a debut planetary mission wasn't easy. One of Hegde's tasks was to accommodate the needs of foreign instruments onboard alongside optimal craft operations. In his own words:

> "It posed challenges because they [the foreign payloads] had diverse requirements. For instance, scientists behind Mini-SAR wanted to calibrate the instrument when the spacecraft would be en-route to the Moon. They were unhappy with the fact that we couldn't accommodate that due to certain changes in our launch schedule. However, at a later stage we provided them with a geometry in lunar orbit for calibration which they said was even better than what they originally asked for."

Following up on Chandrayaan 1's findings, missions from China[35], USA[36], India[37] itself, South Korea[38], Europe[39], Japan[40], and more are trying to unravel the exact nature, state, and abundance of lunar water as the next logical step. Sustained crewed lunar exploration plans by China[41] and the US[42] also depend on it.

The Indian Government's Department of Space (DOS), under which[43] ISRO operates, stated the cost of the Chandrayaan 1 mission to be ₹386 crores[44] in 2008, which is approximately $89 million in 2026. As far as lunar and planetary missions go, that's on the lower side of expenditure. As evident by the debut mission's fundamental discoveries, welcoming foreign

instruments proved effective in increasing mission science without increasing costs. Participating nations got to fly their scientific instruments without having to build an entire mission of their own. At the same time, experience gained by ISRO in developing and/or operating some planetary instruments in collaboration with NASA and ESA helped the agency make fully indigenous, state-of-the-art instruments[45] for the Chandrayaan 2 orbiter.

For Chandrayaan 1, India also established the Indian Deep Space Network[46] to communicate with the spacecraft as well as future planetary missions. The mission established operational experience for India with spacecraft at the Moon, feeding into future planetary missions. Hegde noted here that the India-US partnership on Chandrayaan 1 also extended to NASA providing ISRO with access to its iconic Deep Space Network[47]. It was used for communicating with Chandrayaan 1 for additional bandwidth, and when the craft was outside the range of India's newly built planetary communications network. This deal with NASA for having additional communications layers for ISRO's planetary craft has persisted through India's first Mars orbiter Mangalyaan[48], the Chandrayaan 2 orbiter[49], and the Chandrayaan 3 landing[50] mission.

The world is now mounting[9] numerous[10] Moon missions[51]. As we directly explore the treacherous lunar south pole[52] and its water ice[3], we would be wise to remember the compounding effects of collaboration and sharing to make expensive, high-frequency exploration not only safer[53] and more successful[54] but also efficient[55]. Chandrayaan 1's catalyzing of a global Moon rush can remind us of the collaborative mindset the world needs more of, if only we remember its vantage point.

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*This chapter has been published as an article on my space blog to make it easy for people to access and reference it through the Web. Find it with its title "**Water on the Moon and Chandrayaan the first, collaboratively catalyzing a global lunar rush**" or directly visit the following web address:* ***jatan.space/chandrayaan-1-the-collaborative-catalyst***

Capturing a solar eclipse from Luna

How Chandrayaan 1 operators pulled off the feat despite the craft being in an ailing state.

Going to the Moon isn't only about lunar exploration. For example, China has long repurposed their Mooncraft to enable deep space exploration[56] in multiple ways. The US scientific community has been keen to conduct radio astronomy from the Moon[57]. And, in the future space agencies and companies hope for the Moon to be a literal launchpad to other worlds[8] in the Solar System. India has added two notable things to this list that leverage the Moon's vantage point: Chandrayaan 1 has viewed a solar eclipse from Luna, and the Chandrayaan 2 orbiter has been studying the Sun's flares from there. When I worked with Chandrayaan 1's Mission Director Srinivasa Hegde at the company TeamIndus, he shared with me the fascinating story of how the orbiter captured Earth during a solar eclipse—from the location of the shadowing Moon itself.

When the spacecraft imaged the total solar eclipse of July 22, 2009 from lunar orbit, it was not in a nominal state. In April 2009, only about five months post-launch, one of the two star sensors on the orbiter had failed[58]. Shortly after, exposure to extreme solar radiation combined with other factors took out the backup star sensor too[59]. Having lost both its star sensors, Chandrayaan 1 lost the ability to precisely point to a desired attitude in space. A mission failure was looming.

Instead of calling quits, ISRO engineers came up with a solution. Chandrayaan 1 mission operators used the spacecraft's Sun sensors to get knowledge of two spatial axes. They then fixed

the third axis with directional aid from communicating ground stations. With this inferred three-dimensional information in hand, operators utilized the orbiter's gyroscopes to then point the spacecraft again where needed with reasonable accuracy. The mission was back up and running.

However, this method had restrictions. For instance, it could not be used during a New Moon or Full Moon because the Earth and Sun wouldn't be at different angles for the craft. Even with angular separation, use of the Earth-Sun angle for navigation was restricted to a maximum of 25° to allow reasonable accuracy in the craft's pointing, and thus in Chandrayaan 1's operations. While limited in scope, the method proved reliable enough to work for about six months after the failure of the critical star sensors, allowing the mission's headline discovery[60] of lunar water.

It's also under such conditions that Chandrayaan 1 captured the century's longest solar eclipse from the Moon. Being far away from Earth, and at the very planetary body causing the eclipse, the spacecraft was at a convenient vantage point to image the Moon's totality shadow cast on Earth. The only problem? Capturing the shadow would require accurate spacecraft pointing, which the aforementioned method would fall short of.

Mission operators came up with yet another solution. To image Earth during the eclipse, ISRO would use Chandrayaan 1's Terrain Mapping Camera[61] (TMC), which had a Field of View of 11°. What the operators did was to *pitch*[62] the spacecraft at a slow rate to scan the Earth between +/- 10°. To account for the error in the antenna pointing mechanism, operators also made the spacecraft *roll*[62] by +/- 3°. The resulting motion and pointing

directions of the spacecraft would thus make the totality shadow fall somewhere within the view of Chandrayaan 1.

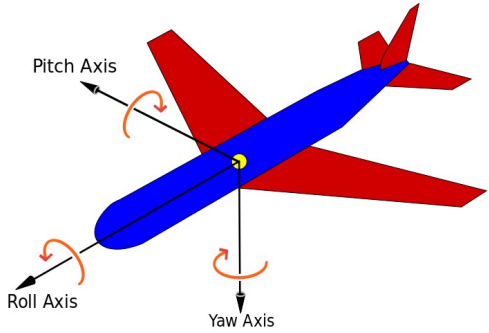
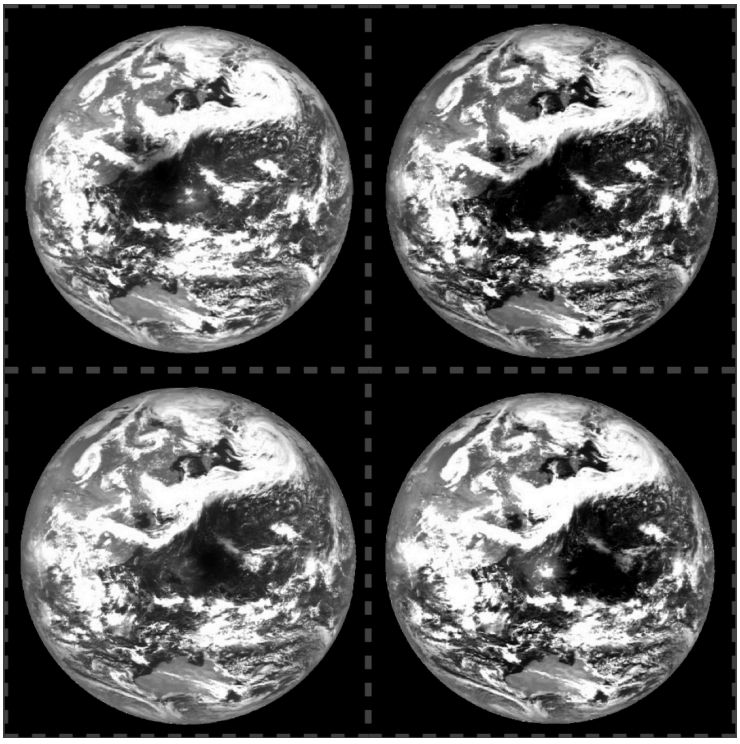


Image: Wikipedia user Auawise & Jrvz[62]

Operators were ready to image Earth on the day of the solar eclipse. But they realized there was yet another problem. If the spacecraft downlinks data to the ground station during the eclipse, executing real-time commands may not be reliable due to bandwidth limitations and time uncertainties, which could mean missing capturing the short-lived eclipse shadow. This is why mission operators instead sent precisely time-tagged commands to Chandrayaan 1 a-priori. The spacecraft then automatically executed the commands sequentially during the eclipse period.

It worked. As the spacecraft passed between the Moon and Earth in its lunar orbit on July 22, 2009, it imaged Luna's shadow cast on our planet. It was a first of its kind capture for a Moon mission, one executed while the spacecraft was in a non-nominal, ailing state. Below is a GIF of the solar eclipse shadow on Earth as captured by Chandrayaan 1.



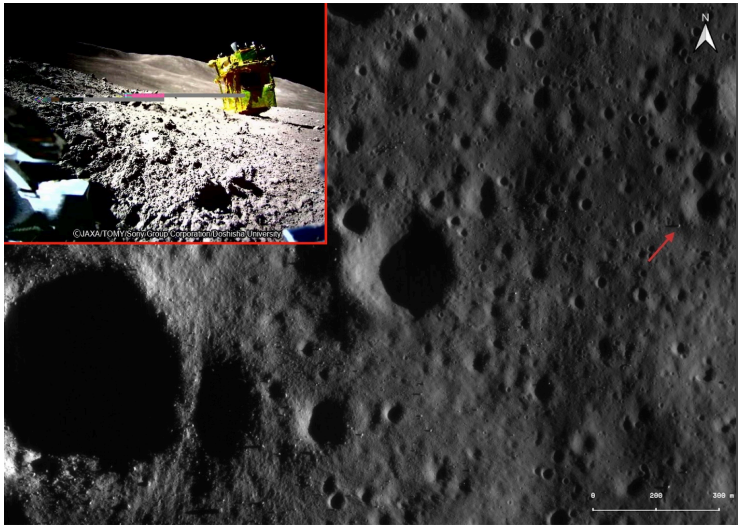
Clockwise from top left: The totality shadow cast on Earth by the Moon during the total solar eclipse of July 22, 2009, as captured by Chandrayaan 1 from lunar orbit. Images: ISRO | Gallery: Jatan Mehta

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*This chapter has been published as a leading section of an article on my space blog to make it easy for people to access and reference it through the Web. Find it with its title "**Capturing a solar eclipse from the Moon**" or directly visit the following web address: **jatan.space/indian-space-issue-22***

A fine precision landing assistant

How the Chandrayaan 2 orbiter helped Japan nail a precision Moon landing.



Japan's SLIM spacecraft on the Moon as imaged by the LEV-2 crawler bot (inset image) and India's Chandrayaan 2 orbiter (background). An arrow points to the tiny lander and its shadow. Images: JAXA / TOMY / SONY[63] / ISRO / Chandra Tungathurthi[64]

On January 19, 2024, the Japanese Aerospace Exploration Agency (JAXA) achieved a remarkable feat. Its SLIM lander[65] touched down on the Moon merely 55 meters away[66] from its target spot, making it the most precise robotic planetary landing[67] in history. A key part of how it achieved this feat is a tale of collaboration between JAXA and the Indian Space Research Organization (ISRO).

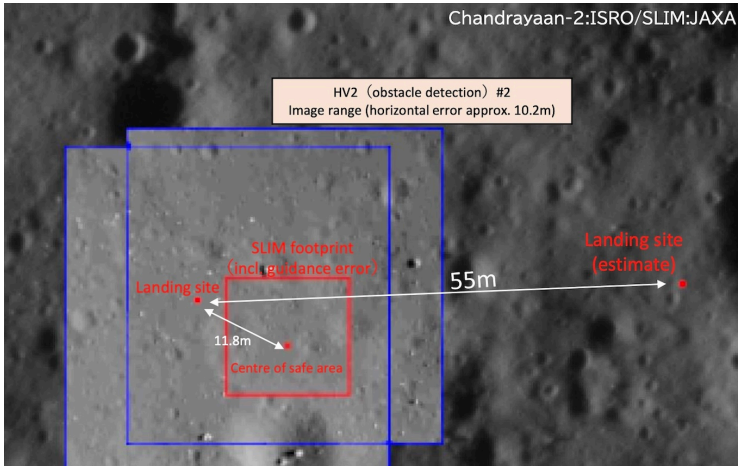
At the heart of SLIM's precision landing ability was a technology JAXA calls "vision-based navigation". During its

lunar descent, SLIM snapped images of the Moon's surface and compared them to preloaded onboard orbital maps. This process is optimized to occur in just a few seconds to let the spacecraft quickly determine where it is and where it needs to go. The reference maps come from NASA's Lunar Reconnaissance Orbiter[15] (LRO), ISRO's Chandrayaan 2 orbiter[49], and JAXA's own past SELENE[68] craft. Each orbiter's data was uniquely useful at various heights. In a post-landing media release[69], SLIM's Project Manager Shinichiro Sakai mentioned that the mission used Chandrayaan 2's imagery not just during the lander's final descent phase but also to decide the mission's target landing area pre-launch. This is because Chandrayaan 2's Orbiter High Resolution Camera (OHRC) boasts a best-case imaging resolution of about 0.25 meters/pixel, which is about twice LRO's finest and the sharpest camera ever flown in lunar orbit to date.

"JAXA sent us a request in 2021 to image SLIM's landing site, and so we planned an orbital passover of the Chandrayaan 2 orbiter to acquire OHRC images for them," said Amitabh Singh, head of ISRO's Planetary and Space Science Data Processing Division and a lead scientist on the OHRC team. Then in 2023, ISRO provided JAXA with more images of the landing site from different sun angles. This particularly helped JAXA engineers fine-tune SLIM's algorithms to instantly identify boulders and other hazards regardless of specific lighting conditions at the time of descent.

Even though most modern robotic landers, such as India's own Chandrayaan 3[50] and China's Chang'e 6[70], can find a good landing spot on their own during the final phase of their descent, the lack of a sophisticated last-mile map does affect the

landing precision. Which is why JAXA's partnership with ISRO to have SLIM use the Chandrayaan 2 orbiter's data until the very final phase is prominent.



This image shows pictures of the Moon taken by Japan's SLIM lander (inner boxes) when it was at about 50-meter altitudes. They are superimposed on the background view previously snapped by ISRO's Chandrayaan 2 orbiter. Identifying the same features across images helped the lander determine its position and a safe place prior to landing. Image: ISRO / JAXA / SLIM[71]

When SLIM was roughly 50 meters above the Moon's surface, it hovered and identified touchdown hazards[69] below it using vision-based navigation as well as Chandrayaan 2 imagery. But mysteriously one of SLIM's two main engine nozzles detached from the craft. The resulting off-center thrust made SLIM go sideways. The craft's guidance system identified this anomaly, and decided to descend using the hover-phase imagery and onboard maps while simultaneously trying to stabilize its orientation with the other working main engine and small thrusters. This partly worked. When SLIM touched the lunar surface, its vertical velocity of 1.4 meters per second was well within acceptable bounds. However, the craft's eastward lateral

motion and touchdown orientation weren't nominal, causing it to flip on the surface. SLIM nevertheless survived and operated[65] on the surface within constraints. Even when afflicted, SLIM could see and target a safe spot and land on it. It managed to avoid a crash, in part thanks to the Chandrayaan 2 orbiter maps.

Demonstrating a precision landing is not just about technological capability. It advances science missions too. "Precision landings allow you to reliably study more rock and soil types by planning an optimal touchdown point. This way you can land in, say, an impact-melt region and then drive over easily to a mare basalt," said[67] Benjamin Farcy, a postdoctoral researcher at NASA's Goddard Space Flight Center. "Without precision landings, a typical rover with a range of a kilometer might not cover both lithologies." Masaki Fujimoto, deputy director general of JAXA's Institute of Space and Astronautical Science said, "With SLIM we demonstrated that accessing specific spots of scientific interest on the Moon can now be done with small [affordable] missions too."

India and Japan are working together again on their next lunar mission called Chandrayaan 5 / LUPEX[40], which is a symmetric collaboration. The nominal six-month mission will see a Japanese heavy-lift H3 rocket launch the ISRO-developed lander which will deliver a JAXA-provided rover to the Moon's south pole. The rover will feature instruments from both Japan and India[72], with a contribution each from NASA and ESA. It will directly study the nature, abundance, and accessibility of lunar water ice[3], an important scientific goal and a prerequisite for future sustained exploration of space. To safely and precisely land LUPEX amid the Moon's unforgiving polar terrain[52], ISRO

is building the lander with input from both Chandrayaan 3's success[50] and that of SLIM.

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*This chapter has been published as an article on my space blog to make it easy for people to access and reference it through the Web. Find it with its title "**Indian Space Progress #15: An ISRO-JAXA collaboration for the Moon**" or directly visit the following web address: **jatan.space/indian-space-issue-15***

Shining light on the Sun from the Moon

Why the Chandrayaan 2 orbiter was designed to study solar activity from the lunar vantage point.

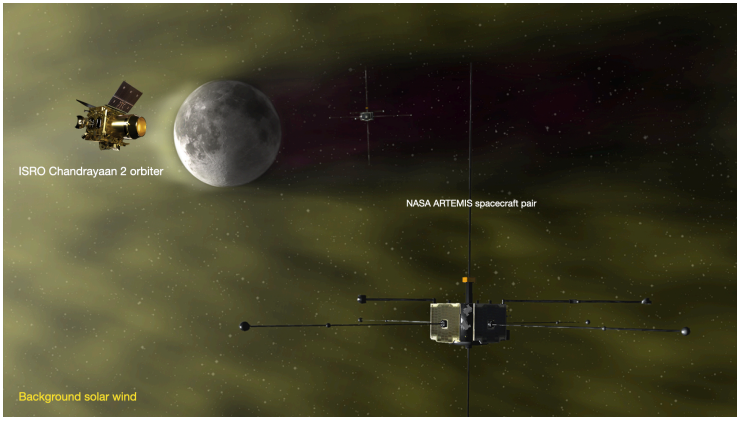


Illustration visualizing the Sun's radiation wind bombarding the Moon while various spacecraft observe its activity and effects. Background image: E. Masongsong / UCLA EPSS[73] | Derivative graphic: Jatan Mehta

ISRO's Chandrayaan 2 orbiter[49] doesn't just study the Moon's surface[74] and aid its exploration[75] but observes the Sun too. In 2024, storms on the Sun[31] caused highly energetic charged particles to gush out into the Solar System[76]. It caused beautiful, widespread auroras on Earth. And out there at the Moon, the Chandrayaan 2 orbiter was observing the influx of these storms. Our Moon lacks a global magnetic field or atmosphere. Radiation bombards its surface directly, and solar storms release more of its atoms than the usual rate. Theoretical and computational models have predicted for more than a decade that the density of the Moon's nearside exosphere must increase by at least ten times[77] during solar storms.

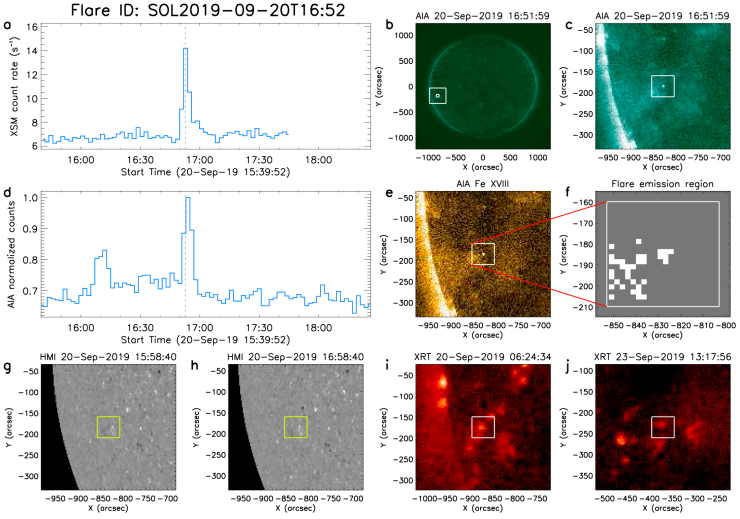
Understanding this also helps scientists better model changes in Earth's atmosphere from solar activity.

Two instruments from the Chandrayaan 2 orbiter observed[78] the storms of 2024 in particular: the CHACE-2[79] neutral gas mass spectrometer and the Solar X-ray Monitor[80] (XSM). Through a published paper[81], CHACE-2's particle detection during the heightened solar activity confirmed that the nearside lunar exosphere became at least tenfold denser. This discovery and process is part of a broader picture, in that it's also relevant to future space exploration. A lunar orbiter studying the Sun may sound like an odd thing but the Moon's vicinity, airlessness, and interconnectedness to Earth make it a grounded reference point.

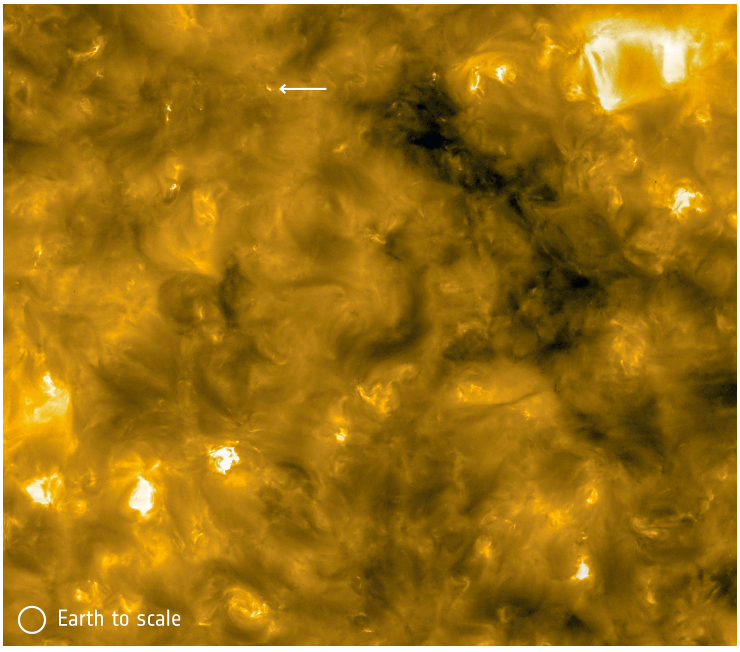
The XSM instrument measures solar flares. This, in turn, provides a reference[82] for the orbiter's Chandrayaan-2 Large Area Soft X-ray Spectrometer[83] (CLASS) instrument to map elements[84] on the lunar surface based on their varying reflectance. Scientists have published multiple results in international journals based on XSM's unique observations[85] of the Sun's surface and atmospheric activities. These include statistical measurements of micro-flares[86] and nano-flares[87] crucial to understanding our Sun's dynamic nature.

Studying micro-and-nano-flares is important because scientists think they're relevant to unlocking a fundamental mystery about our Sun: why is its extended atmosphere, the corona, much hotter than its surface? Scientists have been debating since the 1940s[88] how the Sun's atmosphere is heated to a million degrees Celsius while the surface barely crosses 6,000. Recent close-up observations of many tiny eruptions[89] across

the Sun's surface by ESA's Solar Orbiter[90] mission coupled with coronal measurements made by NASA's Parker Solar Probe[91] have helped scientists almost solve[92] the coronal heating mystery. In that context, having abundant global-scale micro-and-nano-flare observations over time from other spacecraft at different vantage points, like the Chandrayaan 2 orbiter, has helped scientists better model, contextualize, and refine our understanding of the Sun. Furthermore, XSM's high-resolution measurements of the Sun's background X-ray emissions provided the first elemental abundances[93] of magnesium, aluminum, and silicon in the Sun's corona during quiet times, refining our understanding of its core nature.



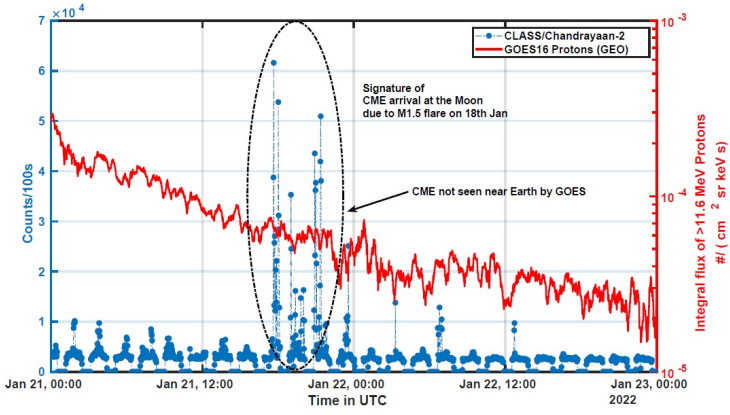
Panel (a) shows a micro-flare on the Sun detected by India's Chandrayaan 2 orbiter. Panels (b) and (c) show its locations in images captured by NASA's SDO spacecraft. Image: Santosh Vadawale, et al.[93]



A high-resolution image of the Sun from ESA's Solar Orbiter spacecraft, captured on May 30, 2020. The lower left circle indicates Earth's size for scale. The arrow points to one of the many nano-flares. Image: ESA[89]

Protecting future lunar explorers

Other than XSM, the Chandrayaan 2 orbiter's aforementioned CLASS instrument can detect[94] some solar events too. In January 2022, CLASS detected two highly energetic proton emission events[95] in the solar wind. NASA's GOES-16 satellite couldn't detect one of these two events because Earth's magnetic field shielded it from said particles. The Chandrayaan 2 orbiter being at the Moon allowed for said detection, just as other Sun-studying spacecraft outside Earth's magnetic field could.



The rate of protons recorded by India's Chandrayaan 2 lunar orbiter (dots) and NASA's GOES-16 Earth orbiter circa January 20, 2022. Image: ISRO / NASA[95]

The Chandrayaan 2 orbiter's solar studies are pertinent for astronauts exploring the Moon and deep space. During August 4–7 in 1972, the Sun released several bursts of flares[96] and associated energetic particles. This places its timeframe as being between the Apollo 16 and 17 missions to the Moon in the same year. The energetic particles slammed the Moon in a matter of hours. Had any of the astronauts been on the surface or in lunar orbit during the solar event, they could've faced damaging levels of radiation way beyond nominal rates, potentially being cancerous. As we prepare to send astronauts on much longer missions to the Moon and beyond this century, we'll need to protect our explorers from such solar storms. It's also to this end that NASA's Artemis I mission in 2022 studied solar radiation effects[97] and tested vest protection[98] inside the Orion spacecraft for future crew on lunar and deep space missions.

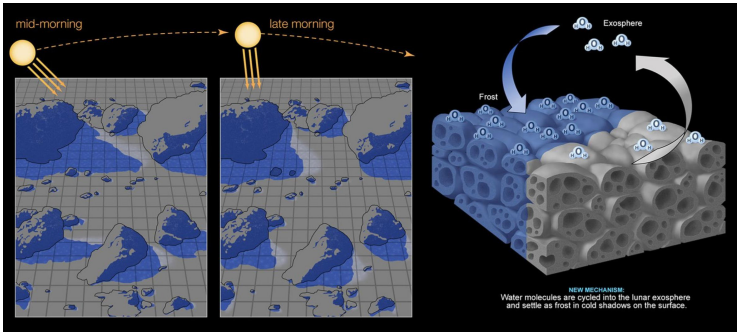
India's Chandrayaan 2 orbiter is aiding these safety efforts by not only improving our understanding of solar flares

themselves but also helping scientists better model solar effects in the Earth-Moon space and the lunar exosphere & surface, all being places host to future human explorers. Dedicated efforts from India for studying solar weather also notably include data[99] from the Aditya-L1[100] solar observatory and its ongoing[101] contributions[102] as well as specific institutional research such as from the CESSI lab in IISER Kolkata, which focuses on the fundamental physics[103] of stellar dynamics and modeling of solar weather.

Lunar water and exosphere

With the above context, let's come back to the discovery we started with originally about the Sun's wind affecting the lunar ionosphere. The notable fact is it affects water on the Moon[3] too, whose presence and nature is central to sustaining future exploration.

The Sun's wind of charged particles is one of the key sources of lunar water[104], and so understanding how the solar wind shapes the lunar exosphere simultaneously helps us understand related fundamental processes like how water is altered and moves across the Moon[105], and how it's lost. Lunar missions wanting to map and analyze surface water, like China's upcoming Chang'e 7[35] craft or the joint ISRO-JAXA Chandrayaan 5/LUPEX[40], will be best served when accounting for all of this contextual knowledge. The overall work also enables planetary scientists to make better water cycle models on other airless bodies across the Solar System like Mercury, moons of gas giants, Ceres, and so on, punching yet again well above its weight.



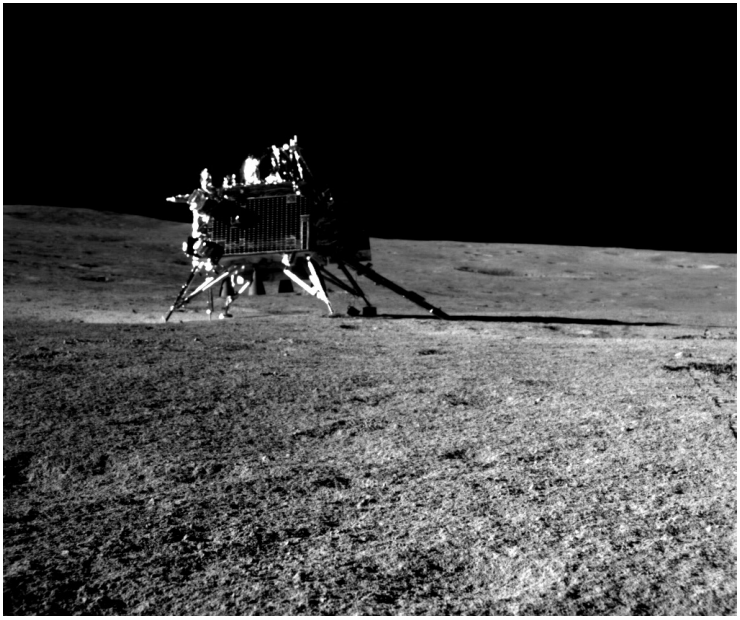
Shadows on the Moon due to terrain can enable water ice to survive on the sunlit lunar surface. Instead of being trapped within lunar soil and rocks, where water is largely immobile, a study suggested that water molecules remain as frost on the surface in cold shadows and move to other cold locations via the Moon's thin exosphere. Image: NASA / JPL-Caltech[105]

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*This chapter has been published as an article on my space blog to make it easy for people to access and reference it through the Web. Find it with its title "**Shining light on solar activity and the Moon's exosphere**" or directly visit the following web address: **jatan.space/moon-monday-issue-247***

A triumphant touchdown on the Moon, mode autonomous

The story of Chandrayaan 3's rigorous landing approach reminds us of the testing regime key to future global success in space.



The Chandrayaan 3 lander Vikram on the Moon, imaged by the mission's rover Pragyan on August 30, 2023. Image: ISRO[106]

On August 23, 2023 at 12:33 UTC, India's robotic Chandrayaan 3[107] robotic lander completed the 19 minutes of its nerve-wracking autonomous descent to the Moon. In one piece and upright, it now lay near the lunar south pole at the coordinates 69.37°S, 32.32°E[108]. The triumphant touchdown made India only the fourth nation to achieve the feat of a soft lunar landing, following the former Soviet Union, the US, and China. Success wasn't a given, especially when four out five previous lunar

landing attempts had failed: namely the Israel-based SpaceIL's Beresheet[109] craft, India's own Chandrayaan 2[110] lander, private Japanese firm ispace's Hakuto-R[111], and Russia's Luna 25[112].

Launched[113] by ISRO four years after Chandrayaan 2's crash on the Moon, Chandrayaan 3 saw the agency pursue and clinch its goal with a completely different approach. "Instead of a success-based design, ISRO has this time opted for a failure-based design," said ISRO's then-Chief S. Somanath in a press briefing[114]. Chandrayaan 3 focused on all that can fail, and how those failures can be prevented. "We looked at sensor failure, engine failure, algorithm failure, calculation failure," added Somanath. But when the mission's LVM3 rocket, spacecraft mass, and the mission's budget as approved by the Indian government all remained roughly the same as Chandrayaan 2, how can redundancies against failures be built in?



Left: Liftoff of the Moonbound Chandrayaan 3 spacecraft by an LVM3 rocket from India's Sriharikota spaceport; **Right:** The rocket path captured from the Launch View Gallery[115] where spectators arrive in thousands. Look at that beautiful rocket trail shadow! Images: ISRO[106] / Jatan Mehta

This is where the Chandrayaan 2 orbiter[49] comes in, which has been operating nominally in lunar orbit since 2019 and mapping the Moon[74] with its many instruments[45]. The orbiter had ended up with ample fuel margin after carrying the Chandrayaan 2 lander from Earth orbit to lunar orbit in 2019. Because of its good performance, ISRO figured it could lend some of the Chandrayaan 3 orbiter's[116] mass to the lander instead, which includes fuel reserves.

The 1752-kilogram Chandrayaan 3 lander, named *Vikram* after the originator of the Indian space program Vikram Sarabhai, was 280 kilograms heavier than its predecessor. This provided greater redundancy[117], such as more fuel to better stay on its intended trajectory onto the lunar surface, strengthened legs to absorb the mechanical shocks of touchdown, extended solar panels to ensure power generation in more orientations post-landing, a new velocity sensor for enhanced navigation measurements during descent, and software improvements to accommodate sensor failures. "Getting the reconfigured lander as a robust system on paper itself was crucial because you can't really redo hardware in advanced development phases. This is where Chandrayaan 2's flight was invaluable. Its many in-house developed systems that did work allowed us to arrive at a Chandrayaan 3 configuration that wasn't overdone," said Kalpana Kalahasti, the mission's Associate Project Director, during an interview for *Nature*[118].

Kalahasti and Project Director Palanivel Veeramuthuvel led the mission through ISRO's Bangalore-based U R Rao Satellite Center (URSC), which integrated the Chandrayaan 3 spacecraft by coordinating with various ISRO centers and suppliers across the nation. Kalahasti and Veeramuthuvel said they spent the

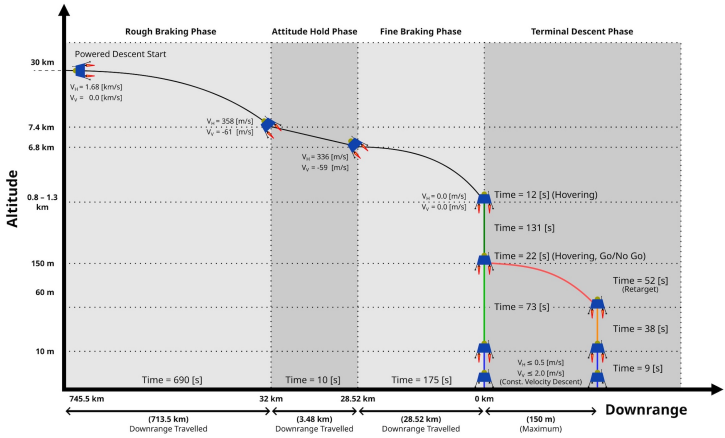
bulk of Chandrayaan 3's development time coming up with and overseeing comprehensive ground tests[117] to increase the likelihood of a safe landing. These efforts spanned testing landing sensors on a helicopter to mimic different descent phases, examining the performance of engines which need to dynamically throttle, and assessing the navigation system's ability to avoid hazards before touchdown using crane-based setups on Moon-like terrain. ISRO also conducted lander leg drop tests on lunar simulant beds to ensure it can handle varied slopes and a range of velocities during the crucial moment of touchdown. The agency developed a lunar soil simulant called LSS-ISAC-1[119] by sourcing naturally occurring, Moon-like anorthositic rock fragments from the Sittampundi Anorthosite Complex[120] in southern India. This aided the simulant's fidelity[121], and therefore built confidence in the hardware test results translating to success when at the real Moon.

ISRO then topped off the efforts with another measure. "You can only go so far with hardware tests. You can't subject hardware to many failure scenarios, and so we formed a dedicated simulation group to characterize our lander's ability to recover from off-nominal trajectories," added Kalahasti. This group[122] also simulated each redundant path the lander could've taken during autonomous descent to be confident about the desired outcome.

Lunar descent, mode autonomous

Chandrayaan 3's entire lunar descent had to be fully autonomous. During this crucial stage of the mission, signals take about three seconds to go from the lander to Earth and back again—a delay too long for earthbound ISRO engineers to

reliably guide the landing. So Vikram's task was to reduce its high orbital velocity to zero, such that it stays as close to its intended trajectory as possible all the way until a soft touchdown. To do so, it needed to orchestrate the firing of its engines based on continuous measurements of distance, velocity, and orientation. Chandrayaan 3's guidance, navigation, and control abilities were thus improved. "There were improvements to 21 subsystems for Chandrayaan 3. These changes have been reinforced by numerous helicopter- and crane-based ground tests," said Nilesh Desai[123], the then-director of ISRO's Space Applications Center (SAC) in Ahmedabad, for an article for Scientific American[124].



The descent and landing profile of Chandrayaan 3. Graphic: Ohsin / ISRO[125]

Vikram's roughly 19-minute-long lunar descent comprised four major phases. The first, the "rough braking" phase, began[126] when the spacecraft was 30 kilometers above the Moon in its orbit and about 750 kilometers downrange from its landing site. By firing all of its four 800-newton main engines for about 12 minutes until it was at a 7-kilometer altitude, Chandrayaan 3

reduced its high horizontal velocity of about 1.7 kilometers/second by some 80 percent. Next up came a brief but crucial 10-second “attitude hold” phase, wherein the lander stabilized itself using its eight smaller thrusters to gain a steady view of the looming lunar surface for its various landing sensors[127]. Here, Chandrayaan 3 could throttle its engines and correct deviations from its intended trajectory more quickly[117] than Chandrayaan 2.

For height measurements, Chandrayaan 3 relied on two altimeters, one using lasers and the other using microwaves. While laser altimeters are commonly employed by several lunar landers, they can be prone to failures or report anomalous heights at times if, say, a lander passes over a mountainous terrain or a large crater. Dysfunctional altimeters have led to crashed landings for ispace Japan’s first[111] and second[128] Mooncraft as well as hard landings for US-based Intuitive Machine’s IM-1[129] and IM-2[130] missions, all in this decade itself. Chandrayaan 3 would benefit from a redundancy here. Unlike laser rangefinders, “the microwave altimeter’s wider footprint allowed Chandrayaan 3 to better tolerate abrupt changes in altitude,” explained Priyanka Mehrotra[131] of SAC, who was the lead system designer of Chandrayaan 3’s Ka-Band microwave altimeter.

Chandrayaan 3’s lander also used a new instrument called a Laser Doppler Velocimeter (LDV) to navigate more precisely in the first place. “While there are other ways for a lunar lander to measure its velocity, an LDV provides a direct measurement with respect to the ground, which allows a lander to greatly reduce accumulation of navigation errors,” said William Coogan[132], lunar lander chief engineer at Firefly Aerospace, a

US-based company which landed the Blue Ghost spacecraft on the Moon[133] for NASA's CLPS program[134] later in 2025. However, in a post-landing interview with Republic World, Somanath said[135] that Chandrayaan 3's descent and landing went so nominally that the LDV didn't end up being necessary. The development nevertheless enables ISRO to use the advanced sensor on upcoming missions like Chandrayaan 4 sample return[136] and Chandrayaan 5 / LUPEX[40], which have greater precision requirements.

After the attitude hold phase, Chandrayaan 3 entered a three-minute "fine braking" phase in which it used only two of its four main engines to descend up to roughly 850 meters above the Moon's surface. It then briefly hovered there, so as to capture pictures of the surface and compare them to preloaded onboard satellite images to determine whether it was above its desired landing region. The preloaded maps were primarily sourced from the Chandrayaan 2 orbiter and NASA's Lunar Reconnaissance Orbiter[15] (LRO). High-resolution images from them were also used to select[137] Chandrayaan 3's landing site. "The target landing zone spans 4 by 2.5 kilometers. ISRO scientists and engineers divided it into 3900 equal-sized subsections, meticulously assessed the safety level of each for a landing, and loaded it into the lander as reference information," noted Desai.

After hovering over the surface and comparing snapped images to preloaded maps, the Vikram lander determined that it was indeed above the intended landing zone. Its onboard computer then identified the safest feasible subsection area and accordingly proceeded toward touchdown. Had Vikram found itself elsewhere, it would've still proceeded with an

autonomous landing but based on self-identified hazard levels from captured imagery instead of a predetermined subsection.

Triumphant touchdown

In the final “terminal descent” phase, Chandrayaan 3 lowered itself to about 150 meters above the surface and then hovered again for about half a minute to assess the area below for landing hazards. At this point, since the surface right below the lander didn’t look safe, the lander sought a safer adjacent area and deviated to touchdown there. “The processing system for hazard avoidance was sped up for Chandrayaan 3 to make the lander’s decision-making during the critical final phases significantly faster than Chandrayaan 2,” said Rinku Agrawal[138] of SAC, who led the team that developed the processing unit of the hazard detection and avoidance system.

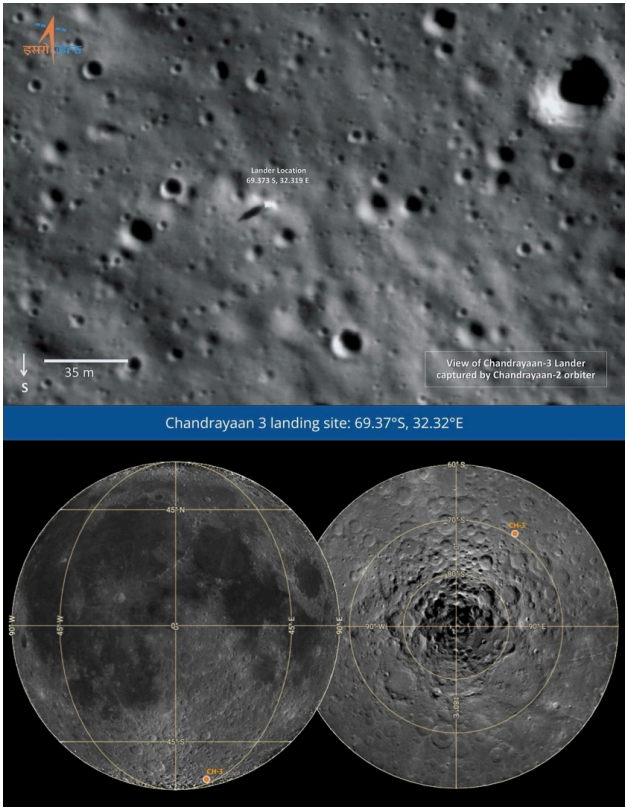
Finally, Chandrayaan 3 made contact with the Moon’s surface. Sensors on the lander’s legs detected the same and triggered the shutdown of its main engines. ISRO designed the legs to absorb most of the mechanical shock from the touchdown. The agency’s leg design tests on lunar simulant test beds on Earth ensured that the lander could tolerate a high vertical velocity of three meters per second—and even a horizontal velocity of one meter per second if it were to touch down askew. Vikram’s touchdown was smooth, hitting the surface with a vertical velocity of 0.983 meters/second, notably less than the nominally expected upper bound of 2 meters/second. The final location of 69.37°S, 32.32°E placed Chandrayaan 3 just ~350 meters away[108] from its targeted ideal spot.



Mission control graph at ISRO's ISTRAC center showing specific parameters of Chandrayaan 3's descent and landing. Image: ISRO[139]

Chandrayaan 3's landing was the most pole-ward at the time. The near-polar lunar surface and environment had never been measured in-situ before Chandrayaan 3 arrived. Chandrayaan 3 was intentionally landed a day after local dawn to maximize the solar-powered lander and rover's surface operations lifetime to most of the lunar daylight period of 14 Earth days. ISRO powered on[140] the lander's three active instruments on August 24, each of which returned valuable data for 11 days since. From August 25, the rover began exploring[141] the geologically rich landing region[142] and traversed 100 meters on the lunar surface over 10 Earth days. As usual, r/ISRO subreddit admin u/Ohsin had compiled a detailed rundown of post-landing events[143], something which ISRO did not adequately, contextually provide or even list later on in one place. Three

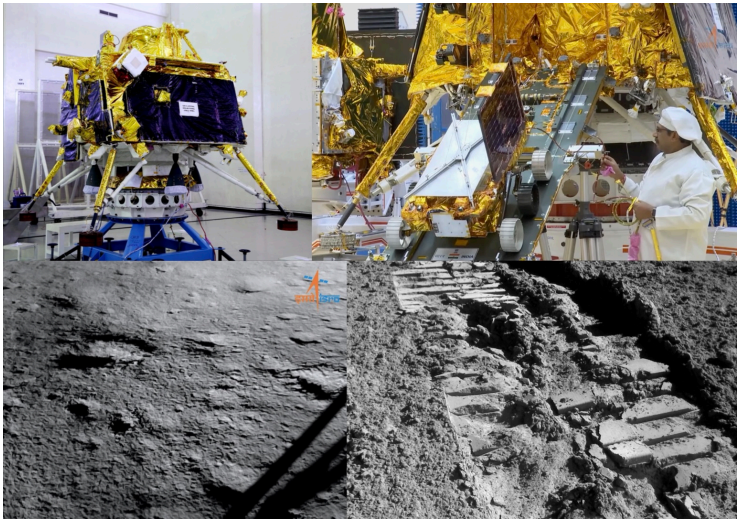
years after Chandrayaan 3's lunar surface operations, science from the mission[144] has grounded our understanding of a distinct region on the Moon just as we prepare to send a wave of lunar missions[10].



Top: ISRO's Chandrayaan 3 lander on the Moon as imaged by the Chandrayaan 2 orbiter, which is the world's sharpest lunar orbital imager; **Bottom:** Chandrayaan 3's landing region marked as a dot on a map. Click to explore the region[108]. Images: ISRO[106] / LROC Quickmap | Graphic: Jatan Mehta

Meticulous Moonshot

Chandrayaan 3 should be remembered for how the team meticulously emerged from failure. Moon landings remain hard even on retries, evident by the failed soft landing of Intuitive Machines' second lunar lander IM-2[130] and the crash of ispace Japan's second Hakuto-R craft[128], both flying after Chandrayaan 3 and within two years of their respective first missions. At a critical time, Chandrayaan 3 kept the momentum for the Moon[7] and its south pole[107] going. "India giving the hard problem of a lunar landing a second try soon after its first attempt is an appreciated investment the whole world will benefit from," said Jessy Kate Schingler[145], a space policy researcher and a senior advisor at the Open Lunar Foundation (a Moon Monday[146] sponsor).



Top: The Chandrayaan 3 lander and rover being prepared for launch; **Bottom:** Closeup images of the lunar surface captured by the lander and rover respectively. Images: ISRO[106]

Chandrayaan 3's tedious developmental efforts evidently paid off. However, conducting so many tests and integrating their

results while also working towards the flight model was a giant, iterative task. Swiftly coordinating the dozen ISRO centers[147] involved countrywide wasn't easy. "It was as if we were building five to six different satellites together," remarked Kalahasti. To take on the responsibility, Kalahasti leaned on her past experiences in project management and systems engineering, which notably included leading roles in ISRO's Earth observation satellites such as the Indo-French SARAL[148] craft. "The goal was to have a well documented, well understood system. There was no compromise in demonstrating the system's performance down to its specifics," said Kalahasti, who represents not just herself but Mehrotra, Agrawal, the over 100 such women who worked on the mission, and the nation-wide Chandrayaan 3 team[147]. India now celebrates August 23 as National Space Day.

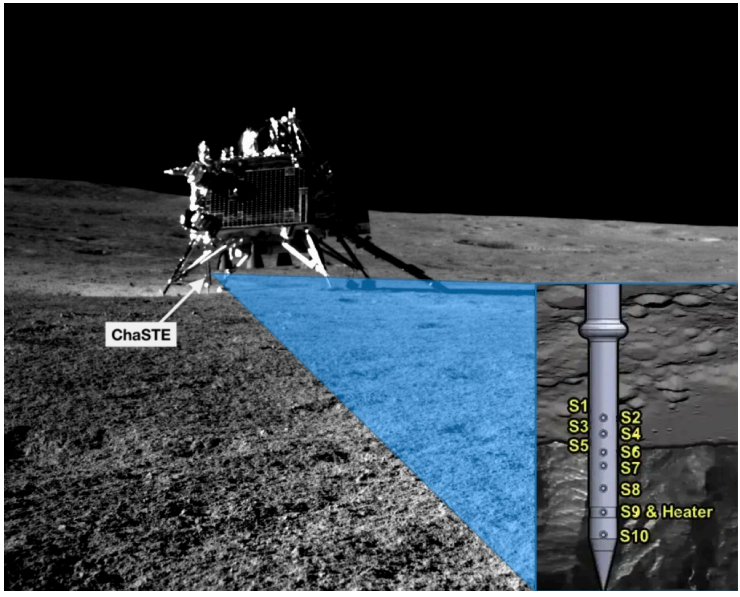
The world is now mounting[9] numerous[10] Moon missions[51] to directly explore the treacherous lunar south pole[52] and its water ice[3]. In this new frontier, Chandrayaan 3's rigorous testing approach must remain a reminder of not leaving success to chance as much as possible. There is another important reason to remember Chandrayaan 3. The country is facing an orbital launch crisis[149] this decade and next while its national needs and ambitions have scaled and spanned across the spectrum. And so the time is here again to reinforce, scale, and apply Chandrayaan 3's diligence to the most fundamental technology driving space activities.

This chapter is a synthesized and edited composition of my coverage of Chandrayaan 3 across Moon Monday[146], Scientific

*American[124], Nature[118], and Indian Space Progress[150], done so to provide a complete picture of the most critical aspect of the mission: the nail-biting descent and landing. The chapter has been published as an article on my space blog to make it easy for people to access and reference it through the Web. Find it with its title "**Chandrayaan 3's rigorous Moon landing approach reminds us of the testing regime key to future global success in space**" or directly visit the following web address:* ***jatan.space/chandrayaan-3-makes-historic-touchdown***

Literal insights into the lunar surface

Results from Chandrayaan 3 thermal experiment benefit future missions eyeing lunar water.

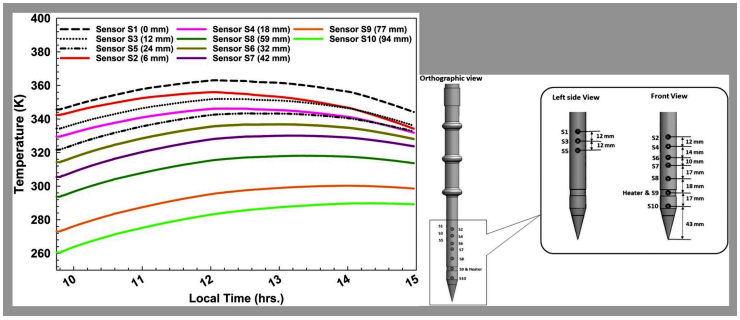


The Chandrayaan 3 lander on the Moon with its ChaSTE thermal probe deployed. The inset image illustrates the probe being inserted into the lunar surface, touting various temperature sensors and a heater. Image: ISRO[106]

The Chandrayaan 3 Moon lander carried a payload called Chandra's Surface Thermo-Physical Experiment[151] (ChaSTE), developed jointly by two ISRO-affiliated institutions SPL[152] and PRL[153]. Shortly after landing, Chandrayaan 3 deployed and inserted the ChaSTE thermal probe almost 10 centimeters into the lunar soil. The probe touted 10 temperature sensors across its length, and took pristine measurements for each sensor-point from lunar morning to twilight. A study published in *Nature*[154] in 2025 showed how the measurements helped

scientists learn exactly how the Sun's heat propagates downward from the Moon's surface, which has key implications for the world's planning of future polar missions[10] scouting for water ice[3].

ChaSTE's measurements from Chandrayaan 3's near-polar landing site of 69°S[50] are unique because earlier heat flow experiments on Apollo missions[155] and most recently on Firefly's Blue Ghost[156] lander were in near-equatorial locations, thus tailoring to different objectives not related to understanding water ice deposits on the Moon's poles. "ChaSTE is the first ever in-situ thermal profiling of the Moon's near subsurface," said planetary scientist and one of the experiment leads K. Durga Prasad[157] for an article I wrote for Scientific American[124]. ChaSTE sensors noticed a large temperature difference of 50–80°C between the two ends of the probe, showing that the Moon's near-polar soil-surface is a poor conductor of heat.



Left: Temperature profiles measured by the ten ChaSTE sensors at different depths; **Right:** Structural diagram of the ChaSTE probe with mounting positions of the sensors and heater. Image: K. Durga Prasad, et al.[154]

The thermal probe's tip also carried a heater just above it. It warmed up the subsurface soil, measurements of which let

scientists determine its thermal conductivity[158], and from that infer its density and physical properties. Future missions operating at or near the Moon's poles need to account for these characteristics. Even though the ChaSTE experiment did not directly study water ice, its results have further relevant implications for future missions looking for said watery deposits. The aforementioned ChaSTE study combined multiple measurements and extensive modeling[159] of Chandrayaan 3's landed geometry, local topography, and actual observational conditions to derive high-resolution surface and subsurface temperatures across the landed region. This result was more accurate than temperatures inferred coarsely from orbit using the Diviner radiometer[160] on NASA's Lunar Reconnaissance Orbiter[15]. It allowed for a conclusion in the paper which proved relevant to future water-ice hunting missions on or near the Moon's poles:

> "ChaSTE observations have shown that at high-latitudes, sunward slopes are considerably warmer and poleward slopes just about a meter apart could be much cooler, providing an environment conducive for the presence of water-ice within the shallow sub-surface."
> […]
> "A relationship between the local slope and expected surface peak temperature has been derived. The interesting outcome is that the high latitude sites with local slope greater than 14° in poleward direction might offer similar environment as polar sites for accumulating water ice at shallow depths."

The ChaSTE experiment thus suggested that the local terrain and slopes play an outsized role in the ability of near-polar and

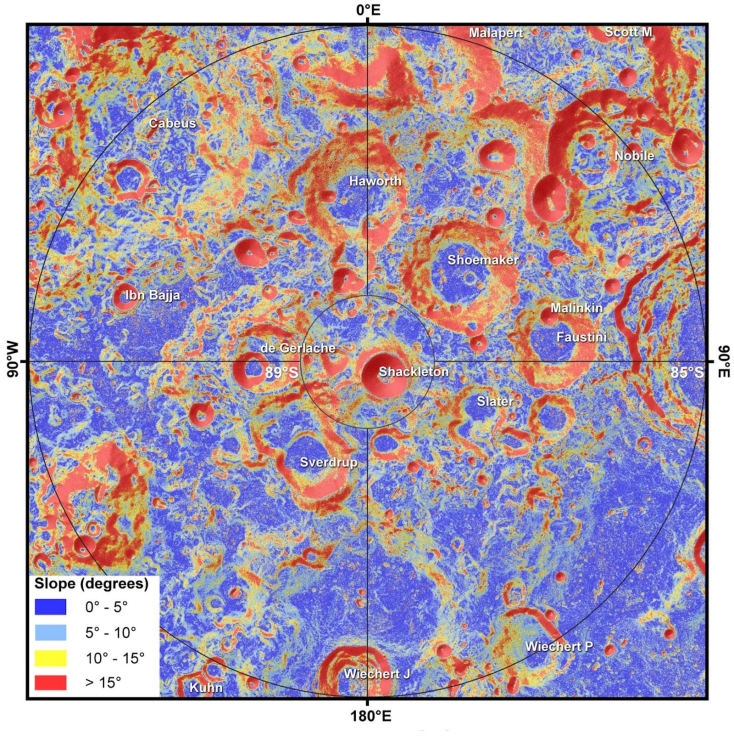
polar areas to feed[161] and accumulate[162] water ice deposits into their subsurfaces. “Temperatures dictate the presence, stability, and mobility of water on the Moon,” said Durga. The paper elaborates:

> “Modeling studies showed that surface temperatures ranging from 110 K to 114 K [-163°C to -159°C] are suitable conditions for cold-trapping of water ice, particularly at polar regions. It is also suggested that water-ice can migrate to the subsurface due to strong thermal pumping, if the diurnal [daily] maximum temperature (Tmax) is above 120 K [-153°C] and the mean temperature (Tmin + (Tmax-Tmin/π)) is below 105 K. [-168°C] Also, the presence of a dry regolith layer can reduce sublimation rates, potentially burying water ice deposits (due to any transport mechanisms) under a few centimeters thick layer. Such buried water-ice can remain stay put as long as the temperatures are maintained below cold-trapping limits, especially during lunar nights.”

Considering that local surface temperatures at the Chandrayaan 3 landing site hovered around -168°C by nighttime, it’s possible that several sizable poleward slopes in the region are host to subsurface water ice. The findings thus lent mission planners more & broader areas to prospect for water ice instead of being limited to the treacherously rocky regions[52] at 86-90°S. From the paper again:

> “High-latitude regions with larger poleward slopes can also be potential sites for water-ice prospecting for future exploration and in-situ resource utilization. Such sites would be technically less challenging for exploration in

comparison to extreme polar sites, but scientifically equally interesting for enhancing our understanding about the water ice quantification, distribution and migration."



The rather scary slope map of the Moon's south pole (85–90°S). Image: CLSE / LPI[163]

Now, exploring high-latitude lunar regions between 70–85°S is still more challenging in itself compared to the relatively benign near-equatorial and mid-latitude regions, especially in terms of temperature ranges, line of sights to the Sun and Earth, terrain, and slopes. But the high lunar latitudes are still not as extreme as 86–90°S[163]. The Moon's peak polar areas demand 100-meter precision landings[67] like Japan's SLIM spacecraft demonstrated,

and require mission profiles optimized for local summer windows in order to survive and conduct long duration missions. As such, ChaSTE's findings suggest that future missions with relatively lower budgets and moderate risk appetites could still explore water ice in less extreme near-polar areas, or even peak polar sites for a shorter duration.

Towards the end of Chandrayaan 3's surface mission, ISRO pulled a trick up its sleeve and made the lander hop[164] about ~50 centimeters away; after ensuring that the deployed payloads and rover ramp were all stowed. During the hop, the briefly lit but powerful engine plumes blew away the fluffy top layer of lunar soil beneath. Chandrayaan 3 then deployed its instruments again, providing ChaSTE a chance to study the older, more pristine lower surface strata. Scientists published findings[165] that this block was about twice as dense and about five times more cohesive than the topmost strata encountered pre-hop. ISRO described the result[166] as the difference between an astronaut walking on dry flour versus damp, stiff clay. ChaSTE showed that even within seven centimeters of depth, the thermophysical nature of the Moon's surface changes considerably. These cake-like layers need to be accounted for in the planning of long duration crewed and robotic missions.

The post-hop ChaSTE measurements also coincided with the time of lunar twilight, which takes many hours on the Moon compared to minutes on Earth. During this time, the probe measured sharp drops[165] in temperatures due to increasing local shadows. This told engineers that the local terrain and object shadows affect the ambiance for hardware operations more than the broader region's environment does. And it told scientists that both local shadows and the distinct nature of

inner lunar surface layers contribute to water's presence, movement[105], and storage on the Moon. ChaSTE's unique set of findings are thus relevant for water scouting, drilling, and even oxygen extraction[167] activities planned by future near-polar and polar missions. The probe's data is publicly available[168] on ISRO's ISSDC portal for planetary missions.

India's next Moon mission Chandrayaan 4[136] aims to bring polar lunar samples. And the follow-on joint Indo-Japanese Chandrayaan 5/LUPEX[40] rover mission aims to complement it by directly studying the nature, accessibility, and abundance of polar water ice on-site. ChaSTE's work and science results from Chandrayaan 3[144] at large feed into both missions as India prepares to take another giant leap for its Chandrayaan program[37].

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*This chapter has been published as an article on my space blog to make it easy for people to access and reference it through the Web. Find it with its title "**Results from India's Chandrayaan 3 thermal probe experiment benefit future Moon missions eyeing water**" or directly visit the following web address: **jatan.space/moon-monday-issue-297***

Crafty Moon-craft: A poetic ode

The craft which
catalyzed a global Moonrush,
carrying five nations
other than its own

The craft which
captured Lune's shadow on Earth
with an ailing raft
in a show of mastercraft

The craft which
shone light on the Sun
from a crafty vantage point

The craft which
helped another nail its landing
with precision and collaboration

The craft which
emerged from failure
through a new descent
of craftiness and rigor

The craft which
widened watery horizons
for future Mooncraft

Call them all
Chandra-yaan,
the literal Moon-craft.

Resource: Deep dive into India's Chandrayaan Moon missions like never before

The successes of India's Chandrayaan program has gotten it media, creator, and public attention worldwide. However, it has often lacked global context and has missed covering the program's specific scientific, technological, and geopolitical outcomes. Without adequate worldwide context and clarity of outcomes, no space mission can be understood well. Which is why I've been writing articles and explainers on Chandrayaan Moon missions for years now with these anchor points in mind. Gladly, my work has been globally quoted and cited[169] in books, published research, on Nature's media arm, by ISRO, and so on. If what you read on Crafty Moon-craft piqued your interest and imagination, I welcome you to check out my special webpage on Chandrayaan missions at '**jatan.space/chandrayaan**'[37].

It's a master list of organized, linked articles covering ISRO's Chandrayaan lunar program, mission by mission. Have fun diving into the depths of how the Chandrayaans have contributed to lunar exploration, science and policy, get excited about missions in store for the future, and also reflect on parts where the program has lagged or been unsuccessful. As far as I know, no such centralized resource exists the world over. And it's all free to read, with zero ads. If you value this work done over years to improve public understanding of Chandrayaan missions worldwide, kindly support my independent writing through the webpage 'jatan.space/support'. 🌙

Supporters

All of my work on my website & blog '**jatan.space**', including my flagship Moon Monday[146] newsletter, is absolutely free to access by everyone. And I never display ads. *jatan.space* has gladly become a globally read community resource, having been quoted on Nature[170], cited in books[169] and by ISRO[171], featured on the lunar community sites like Lunar-L[172] and NextGen[173], and recommended by Universe Today[174] and Ars Technica[175] among others. My lunar poetry[176] has been featured on Nature's newsletter[177]. My space writing has been purely community-supported by the kind organizational and individual donors listed on my website at 'jatan.space/support'. A warm thank you to all, especially to the top supporters at the time of publishing as listed below. <3

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I did not use AI to write a single word of this book, and cited everything. If you too value my work and time poured into making my blog & books accessible worldwide, kindly sponsor my writing by visiting '**jatan.space/support**'. Thank you for considering supporting independent writing & journalism, which the world needs more of.

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Your space: What about Chandrayaan missions stands out to you?

Write some words, maybe some poetry, or even illustrate. This space is all yours. Feel free to let me know your thoughts through my contact at 'jatan.space/connect'.

About the Author



Jatan Mehta is a globally published and cited space writer & journalist, poet, and invited speaker. He authors Moon Monday, the world's only blog & newsletter dedicated to the exploration of our Moon by countries worldwide. Explore Jatan's works and its citations by visiting his website & blog '**jatan.space**'. When not writing about space, Jatan might be found reading on his beloved ereaders in parks, taking walks, having chai with friends, playing badminton, writing on his personal blog 'journal.jatan.space', or participating in literary communities.

Jatan has previously published a poetry collection called *Seven uni-verses*, which you can read for free at 'jatan.space/seven-uni-verses-poetry'. To follow Jatan's articles and future books, subscribe for free by visiting 'jatan.space/subscribe'.

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