Chandrayaan-3: Advancements in lunar exploration science

On 23 August 2023, India's Chandrayaan-3 mission achieved a historic lunar landing, marking India as the fourth nation to master lunar landings. India, now the fourth nation to accomplish this remarkable feat, following the Soviet Union, the United States and China, in mastering the art of lunar landings. Most importantly, India is the first country to make a safe and successful landing on the lunar south pole.

Careful site selection

The selection of Chandrayaan-3's landing site exemplifies the mission's scientific rigour. Drawing on insights from previous lunar missions, the team considered topographical, slope, illumination and safety factors. These parameters informed the pinpointing of the final landing site, ensuring a scientifically rich location for exploration.

The Lander-Rover duo: a synergy of science

At the core of Chandrayaan-3's scientific endeavours is the collaborative partnership between the Vikram lander and the Pragyan rover. Equipped with advanced instruments, their mission is to conduct scientific experiments on the lunar south pole. These instruments enable on-site scientific inquiries to explore the lunar surface, study moonquakes and analyse the near-surface plasma environment.

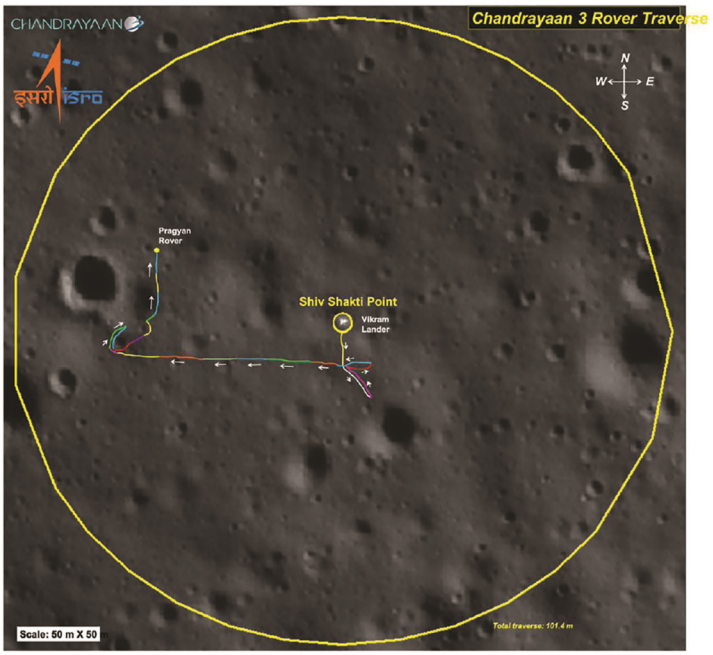
Scientific objectives of Chandrayaan-3

The Chandrayaan-3 mission addresses critical aspects of lunar research. The elemental composition of lunar regolith holds vital clues about the moon's origin and history. Instruments like the Alpha Particle X-ray Spectrometer (APXS) and Laser-Induced Breakdown Spectroscopy (LIBS) aboard the rover played a pivotal role in decoding this elemental blueprint.

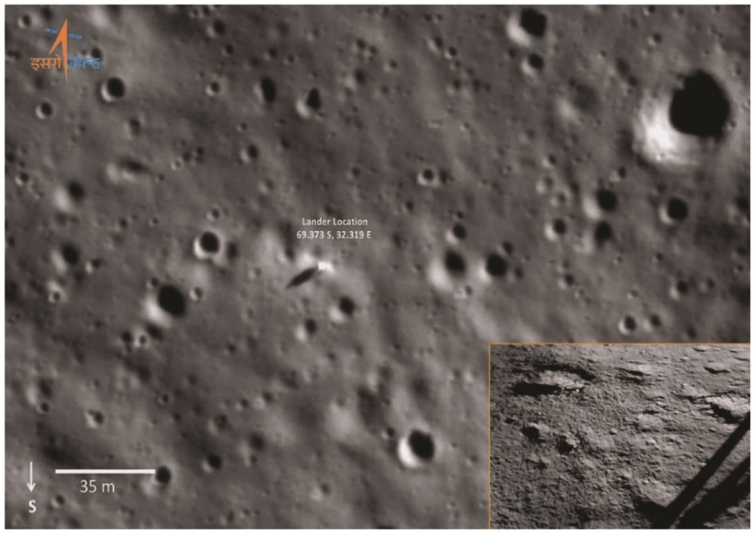
Understanding the thermal properties of lunar regolith is equally important to decipher the moon's thermal history and its interaction with solar radiation. The ChASTE instrument onboard the lander played a crucial role in examining heat absorption and retention, information essential for future lunar exploration and potential human missions.

The lunar surface is immersed in a complex plasma environment, influenced by solar wind plasma and solar radiation. The Langmuir Probe, known as RAMBHA-LP on Chandrayaan-3's lander, provided valuable insights into lunar dynamics by measuring near-surface plasma density and properties.

Studying moonquakes through the ILSA instrument, deployed on the lunar surface, unveils the moon's interior structure and geological history. These scientific pursuits



The path traversed by Pragyan on the lunar surface.



Chandrayaan-3 lander on the Moon, imaged by OHRC onboard Chandrayaan-2 orbiter, which is the world's sharpest lunar orbital imager. The bottom right inset image shows the lunar surface near one of Chandrayaan-3's legs (and its shadow) as imaged by an onboard camera right after touchdown.

not only deepen our understanding of lunar science but also provide practical knowledge for future lunar expeditions.

Chandrayaan-3's celestial journey

The journey of Chandrayaan-3 commenced on 14 July 2023, with a momentous launch from the Satish Dhawan Space Centre atop the LVM3-M4 launch vehicle. The spacecraft was initially placed in an Earth-bound orbit, specifically at 169 km × 36,490 km with a 21.3-degree inclination. A series of meticulously planned manoeuvres elevated its orbit, starting on 15 July 2023, when it reached a 41,762 km × 173 km orbit. Subsequent manoeuvres on 17 July brought it to a 41,603 km × 226 km orbit. Additional manoeuvres on 22 and 25 July set the stage for its forthcoming lunar voyage.

On 1 August 2023, Chandrayaan-3 achieved escape velocity during the Trans Lunar Injection, liberating itself from Earth's gravitational pull. After four days of coasting through the celestial expanse, it succumbed to the gravitational embrace of the moon on 5 August 2023, settling into an orbit at 164 km × 18,074 km. Further manoeuvres meticulously refined its lunar orbit, culminating in a descent to a 170 km × 4,313 km orbit around the moon on 6 August. Subsequent lunar-bound manoeuvres on 9, 14 and 16 August adjusted its orbits to 174 km × 1,437 km, 151 km × 179 km, and 153 km × 163 km respectively. A significant milestone awaited on 17 August 2023, when the Lander Module (LM) detached from the Propulsion Module (PM). A precisely choreographed series of deboost operations led the LM to a precise orbit of 25 km × 134 km. The LM assumed its position, awaiting the lunar dawn at the designated landing site.

The pivotal moment arrived on 23 August 2023, at 17:47 hours, when the powered descent initiated. The Autonomous Landing Sequencer (ALS) orchestrated the descent at the peri-selene point, gradually reducing the LM's velocity. A sequence of braking phases, both rough and fine, managed the velocity components, culminating in a hovering phase where the LM hovered approximately 800 meters above the lunar surface. Subsequent manoeuvres guided the LM in its descent, with careful oversight by the hazard detection system. The Lander retargeted close to the lunar surface, and the LM descended. As it approached the final phase, the LM's vertical velocity slowed to approximately 0.8 m/s, gently touching the lunar surface. The final landing coordinates of 69.37°S, 32.32°E placed Chandrayaan-3 just ~350 meters away from the targeted spot, well within the target landing zone measuring 4 by 2.4 kilometers.

Scientific payload operations and preliminary discoveries

Chandrayaan-3's Lander Module, consisting of the lander and rover, carried six scientific instruments. The rover's exploration began shortly after landing, powered by solar energy. Instruments activated on 24 August revealed preliminary findings, including temperature measurements, ground vibrations and plasma density data, offering intriguing insights into lunar science. Preliminary findings include temperature measurements by ChASTE, revealing the rapid decline in temperature from 50°C to below freezing with only eight centimeters of insulating lunar regolith. ILSA recorded ground vibrations caused by rover movements, the rover's rollout, ChASTE drilling, and more. Initial measurements from RAMBHA-LP indicated that the plasma enveloping the lunar surface is relatively sparse, characterized by a number density ranging from approximately 5 to 30 million electrons per cubic meter. The rover's payload conducted *in situ* investigations, detecting elements in the vicinity of the landing site.

The propulsion module continues to orbit the moon, hosting an instrument called SHAPE, dedicated to spectro-polarimetric studies of the Earth from lunar orbit. Data analysis and interpretation are currently underway at various ISRO/DOS centres and labs.

Inspiration to the space community

The Chandrayaan-3 mission not only advances lunar science but also ignites scientific curiosity and exploration across India. The mission's legacy includes the declaration of 23 August as National Space Day and the christening of landing sites to honour the nation's spirit and determination.

As an invaluable addition to the mission, ISRO executed a manoeuvre on 2 September, around 21:21 UT, in which the Vikram lander executed a controlled hop, lifting approximately 0.4 meters before safely landing again 30–40 centimeters away. At present, both the lander and rover are in sleep, slated for reawakening on 22 September 2023.

Chandrayaan-3 represents a scientific odyssey that promises to deepen our understanding of the moon. Through meticulous planning, state-of-the-art instruments and groundbreaking discoveries, this mission exemplifies India's commitment to lunar exploration and its contribution to the global scientific community. Beyond its scientific achievements, Chandrayaan-3 inspires future generations to embrace STEM disciplines and contribute to the advancement of human knowledge.