SPACE SCIENCE AND ASTRONOMY

Chandrayaan-3 and Aditya-L1: A Review of Early Scientific Findings

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Abstract

India's Chandrayaan-3 and Aditya-L1 missions, launched by the Indian Space Research Organisation (ISRO) in 2023, mark major milestones in Indian planetary and solar science. Chandrayaan-3 achieved a soft landing in the lunar south polar region on 23 August 2023 and, through its Vikram lander and Pragyan rover, returned in-situ data on surface and subsurface temperatures, regolith thermal properties, elemental composition, the near-surface plasma environment and seismic activity. Aditya-L1, India's first dedicated solar observatory, was placed in a halo orbit around the Sun–Earth L1 Lagrange point on 6 January 2024; its seven payloads observe the solar corona, chromosphere and photosphere and measure the solar wind and interplanetary magnetic field in situ. This review synthesises the early scientific findings of both missions using peer-reviewed and open-access publications, ISRO releases and recent literature, and presents diagrams of the missions' thermal environment, orbital configuration and payload distribution, together with a comparative table. It also outlines the scientific value of both missions and their implications for future lunar and solar exploration.

Keywords: Chandrayaan-3; Aditya-L1; ISRO; lunar south pole; solar corona; in-situ observations

1 Introduction

The Indian Space Research Organisation (ISRO) reached two major milestones within a few weeks in 2023. On 23 August 2023, Chandrayaan-3 became the first spacecraft to soft-land near the Moon's south pole [1], a region where scientists believe water ice may be preserved in permanently shadowed craters. Ten days later, on 2 September, ISRO launched Aditya-L1, India's first mission dedicated to the study of the Sun [2]. The spacecraft was placed in orbit around the Sun–Earth L1 Lagrange point, from which it can observe the Sun continuously without the Earth blocking the view.

Together, these missions illustrate the progress of India's space programme in both planetary science (the study of the Moon and planets) and solar physics (the study of the Sun). Both missions have made science data available to the research community [3,4], and many studies based on these data have since been published (see Sections 2 and 3). This review compiles the principal early findings of both missions using only openly accessible sources: ISRO announcements, government press releases and open-access research papers.

2 Chandrayaan-3: mission overview

Chandrayaan-3 was launched on 14 July 2023 and landed on 23 August 2023 near the Moon's south pole (69.37°S, 32.32°E) [1,5,6]. The landing site was named Shiv Shakti Point and was later approved

by the International Astronomical Union (IAU) as Statio Shiv Shakti [5]. The mission comprised three modules: a propulsion module, which carried the lander to lunar orbit; the Vikram lander; and the Pragyan rover, a small six-wheeled robotic vehicle that explored the surface (Figure 1).

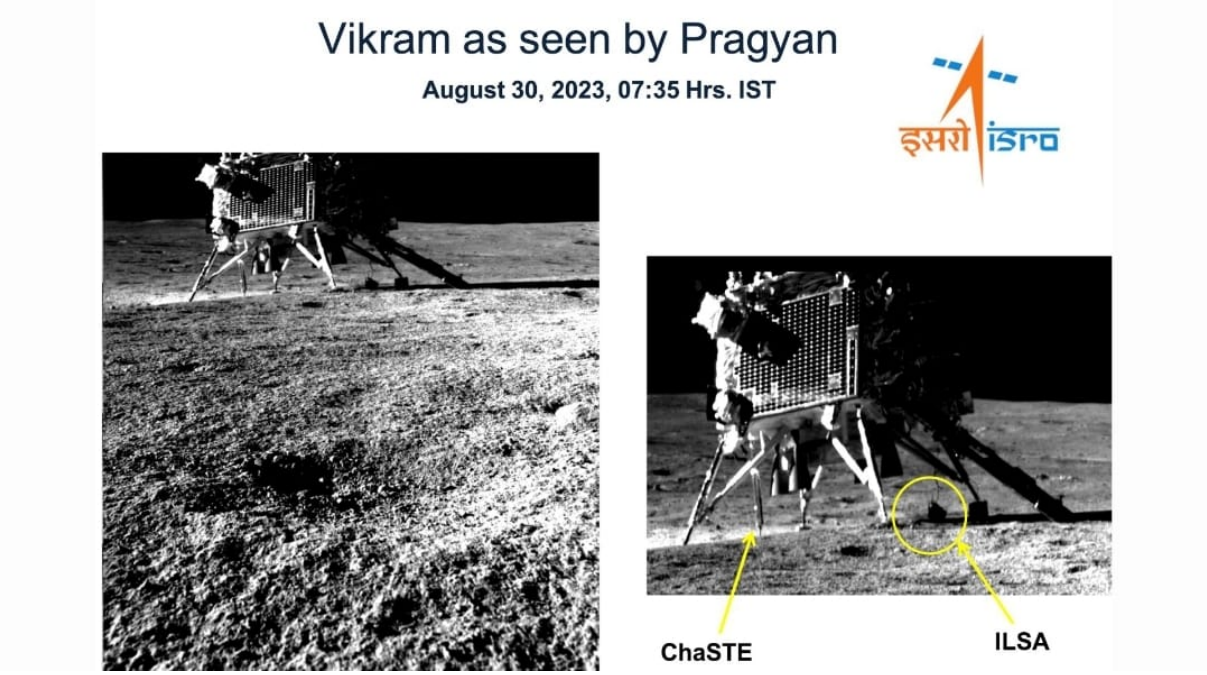


Figure 1. Vikram lander as imaged by the Pragyan rover on 30 August 2023 (image credit: ISRO).

2.1 Instruments carried

- The lander and rover together carried six payloads: five active science instruments and one passive laser retroreflector [1,3].
- **ChaSTE** (Chandra's Surface Thermophysical Experiment) measured the temperature of the lunar regolith at the surface and to a depth of about 10 cm, and its thermal conductivity.
- **RAMBHA-LP** (Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere – Langmuir Probe) measured the density of the plasma close to the lunar surface.
- **ILSA** (Instrument for Lunar Seismic Activity) recorded ground vibrations and seismic events at the landing site.
- **LIBS** (Laser-Induced Breakdown Spectroscope) , mounted on the rover, determined the elemental composition of the soil and rocks by analysing the light emitted by a laser-produced plasma [7].
- **APXS** (Alpha Particle X-ray Spectrometer) , mounted on the rover, determined the elemental composition of the lunar soil [8].
- **LRA** (Laser Retroreflector Array) is a passive reflector on the lander, supplied by NASA, that allows precise laser ranging from lunar orbit.

The propulsion module additionally carried the SHAPE (Spectro-polarimetry of HAbitable Planet Earth) experiment, which observed Earth from lunar orbit, bringing the mission total to seven payloads [1]. The lander and rover operated for about ten Earth days [6], a little less than one lunar day (roughly 14 Earth days), and were then placed in sleep mode before the lunar night, whose extreme cold they were not designed to survive; they have not resumed operation since.

2.2 Key findings

ChaSTE made the first in-situ temperature measurements at a high southern latitude of the Moon, showing that the surface temperature varies drastically between lunar day and night. The peak surface temperature at the landing site was 355 K (about 82°C), noticeably higher than the roughly 330 K predicted from earlier observations, because the probe was deployed on a sunward-facing slope of about 6°; a flat spot about one metre away peaked at a lower value of about 332 K. The associated thermal model, constrained by the ChaSTE data, gives a night-time minimum of about 105 K (about −168°C), a day–night swing of roughly 250 K [6,9]. Figure 2 illustrates this cycle. Such large variations occur because the Moon has virtually no atmosphere to retain or redistribute heat.

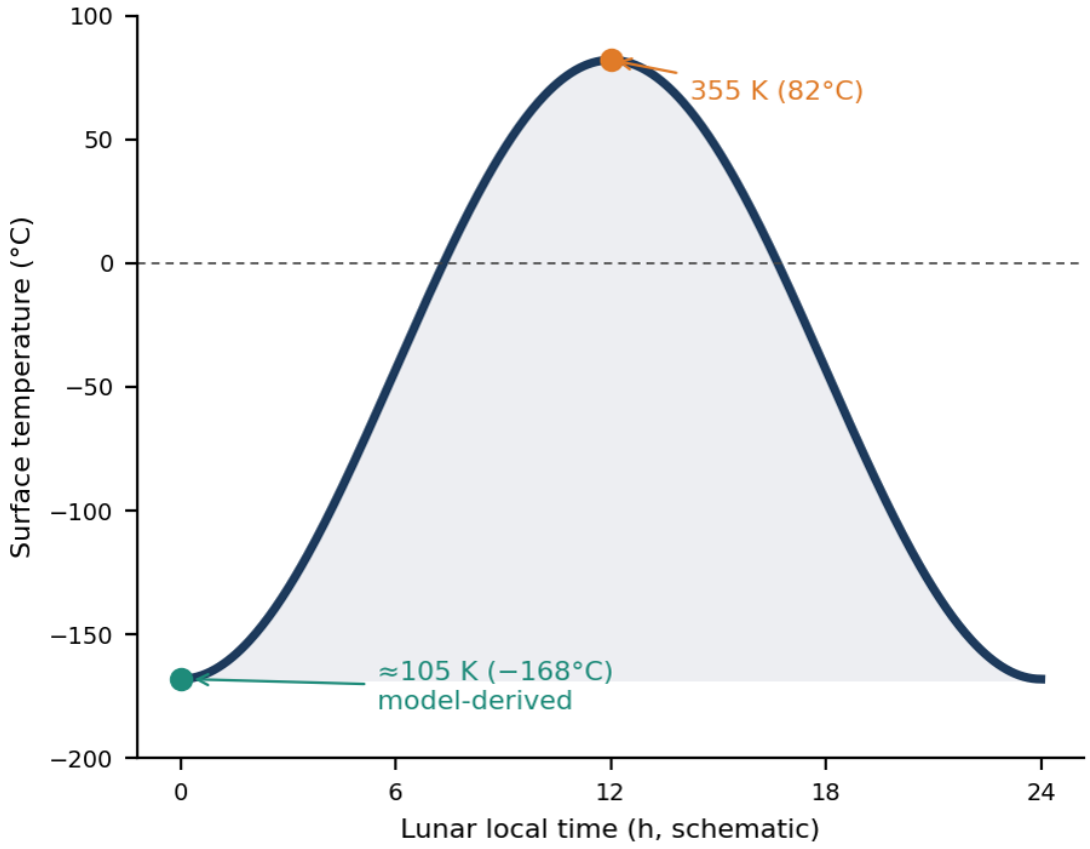


Figure 2. Schematic of the diurnal surface temperature variation at the landing site: measured peak of 355 K (82 °C) and model-derived night-time minimum of about 105 K (−168 °C).

ChaSTE also made the first in-situ measurement of the thermal conductivity of the lunar regolith at southern high latitude. Two active-heating experiments at a depth of 80 mm gave values of about 0.0115 and 0.0124 W m^{-1} K^{-1}, showing that the regolith is a very poor conductor of heat [10]. Later in the mission, the Vikram lander performed a short “hop” using its remaining propellant. ChaSTE observations at the post-hop location during lunar twilight revealed a layered regolith structure in the upper 6.5 cm, including a highly porous, cohesive layer a few centimetres thick that acts as a thermal blanket, together with evidence of surface erosion at that location [11].

In September 2024, scientists from the Physical Research Laboratory (PRL) and ISRO reported, using images from the Pragyan rover together with Chandrayaan-2 orbiter data, that the landing site lies within a heavily degraded, buried impact crater about 160 km in diameter and up to about 4.4 km

deep. This crater is likely to be older than the South Pole–Aitken (SPA) basin, one of the oldest and largest impact basins on the Moon [12]. The landing site seen from lunar orbit is shown in Figure 3.

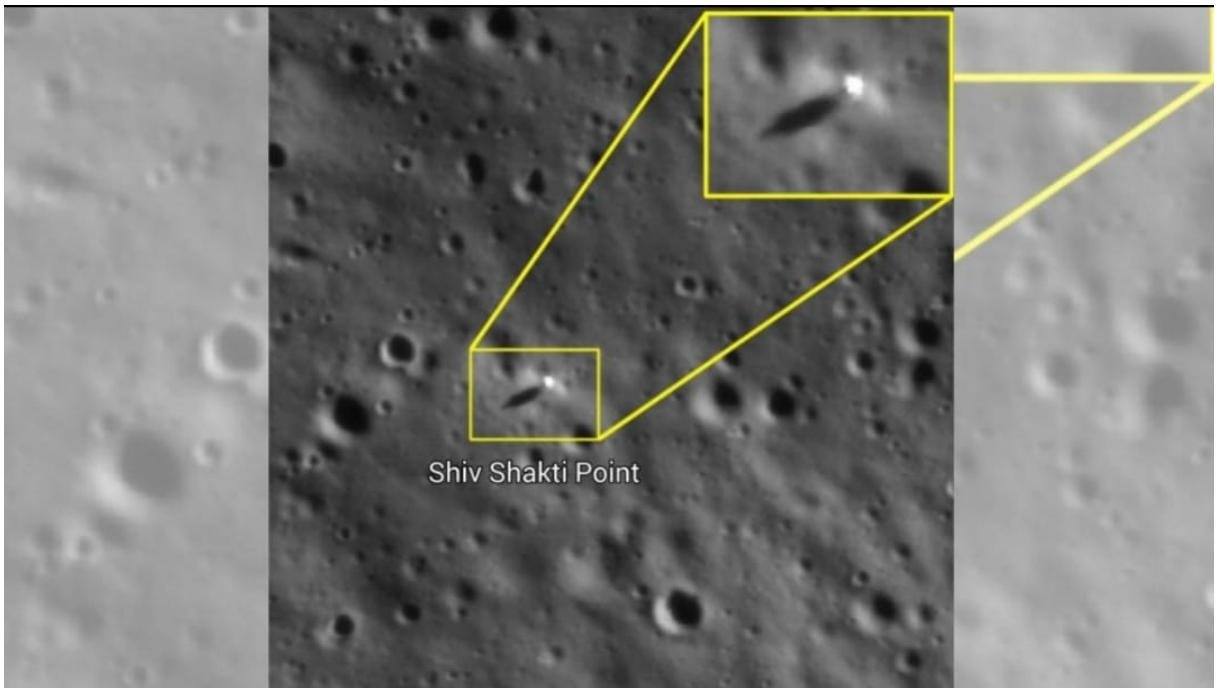


Figure 3. Shiv Shakti Point, the Chandrayaan-3 landing site, seen from lunar orbit (image credit: ISRO).

In 2025, a geological map of the landing area, made from high-resolution remote-sensing data, estimated the age of its mapped units, including the smooth plains that host the landing site, at about 3.7 billion years using crater size–frequency distributions [13]. In March 2025, ChaSTE data and thermal modelling indicated that poleward-facing slopes steeper than about 14° at high southern latitudes may remain cold enough for water ice to accumulate at shallow depths of a few tens of centimetres, even outside the permanently shadowed craters. This is a model-based inference: ice itself was not detected, but the result suggests that there may be more places to prospect for water ice than previously assumed [9]. In addition, LIBS and APXS measurements of the soil at the landing site have provided new data on the elemental composition of the lunar south polar region [7,8].

3 Aditya-L1: mission overview

Aditya-L1 was launched on 2 September 2023. After a journey of about 126 days, it was inserted into a halo orbit around the first Sun–Earth Lagrange point (L1) on 6 January 2024 [2]. L1 lies roughly 1.5 million km from the Earth towards the Sun. There, the combined gravitational attraction of the Sun and the Earth provides the force needed to keep a spacecraft orbiting the Sun in step with the Earth, so that it can remain near L1 using very little fuel while providing a near-continuous view of the Sun. The spacecraft and its launch are shown in Figure 4.

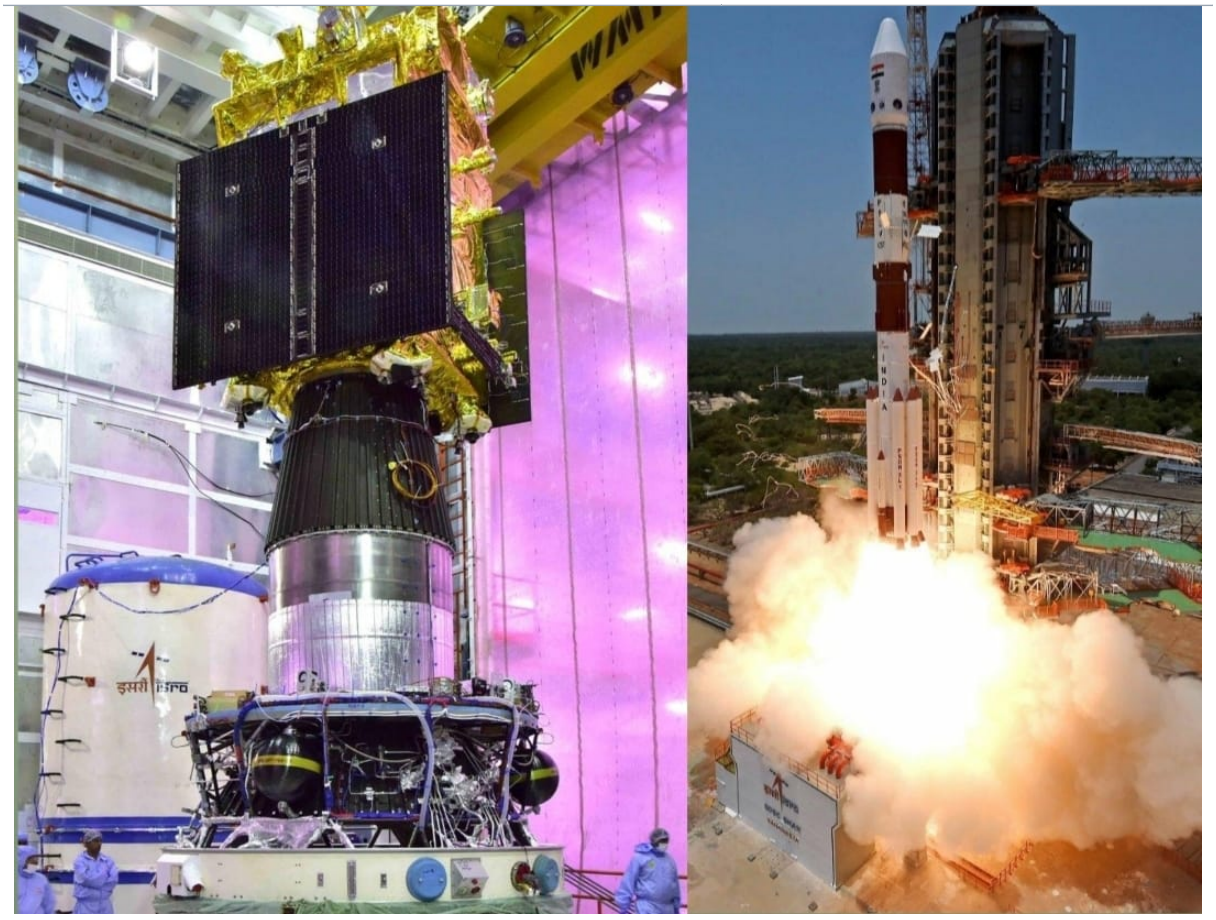


Figure 4. Aditya-L1 spacecraft (left) and its PSLV-C57 launch (right) (image credit: ISRO).

Aditya-L1 carries seven scientific payloads. Four are remote-sensing instruments that observe the Sun from a distance (VELC, SUIT, SoLEXS and HEL1OS), and three are in-situ instruments that measure the solar wind and magnetic field around the spacecraft itself (ASPEX, PAPA and MAG) [2]. The halo orbit is shown schematically in Figure 5.

3.1 Instruments carried

- **VELC** (Visible Emission Line Coronagraph) images the Sun's corona, its outer atmosphere, and records its spectra by blocking out the bright solar disc [14].
- **SUIT** (Solar Ultraviolet Imaging Telescope) images the photosphere and chromosphere in the ultraviolet (200–400 nm) through 11 filters [15].
- **SoLEXS** (Solar Low Energy X-ray Spectrometer) measures the soft X-ray emission of the Sun to study solar flares.
- **HEL1OS** (High Energy L1 Orbiting X-ray Spectrometer) measures the hard X-ray emission of solar flares.
- **ASPEX** (Aditya Solar wind Particle EXperiment) measures solar-wind ions (SWIS) and supra-thermal and energetic particles (STEPS) [16].
- **PAPA** (Plasma Analyser Package for Aditya) analyses the low-energy electrons and ions of the solar wind.
- **MAG** (Magnetometer) is a fluxgate magnetometer that measures the strength and direction of the interplanetary magnetic field at the spacecraft [17].



Figure 5. Schematic (not to scale) of the Aditya-L1 halo orbit around the Sun–Earth L1 point.

ISRO released the first set of science-ready Aditya-L1 data to the global scientific community on 6 January 2025, the first anniversary of the spacecraft's arrival at L1, through the Indian Space Science Data Centre (ISSDC) [4]. A second set followed on 14 February 2025 [18].

3.2 Key findings

On 22 February 2024, SUIT observed an X6.3-class solar flare (X is the most intense category of solar flares) and imaged a flare "kernel", a compact bright region in the lower solar atmosphere (the photosphere and chromosphere), in the ultraviolet. The flare brightened in several SUIT filters at the same time as the hard X-ray peak and the peak plasma temperature derived from SoLEXS, linking the response of the lower atmosphere to the heating of the flaring plasma above it [15,19].

A team led by Professor R. Ramesh of the Indian Institute of Astrophysics used VELC observations of a coronal mass ejection on 5 August 2024 to address one of the oldest unsolved problems in solar physics: why the corona is millions of degrees hotter than the Sun's visible surface, although it lies farther from the Sun's core. For the CME analysed in the study, magnetic reconnection was estimated to contribute approximately 93% of the energy, while waves contributed about 7% [20]. Separately, the MAG instrument recorded the interplanetary magnetic field during three solar transient events in March, May and October 2024. The power spectra of the field fluctuations followed a Kolmogorov-type power law with a slope close to −5/3, the same form of spectrum seen in ordinary fluid turbulence, such as swirling air or water. The turbulence was anisotropic (direction-dependent) during quiet solar-wind conditions but quasi-isotropic during the events [17].

The SWIS sensor of the ASPEX instrument observed the interplanetary coronal mass ejection (ICME) of August 2024, associated with a CME seen on 7 August 2024, recording sharp changes in bulk speed, thermal speed and number density that agreed with independent measurements from the Wind and DSCOVR spacecraft. Because SWIS uses two orthogonally mounted analysers, it can detect directional features of the solar wind that a spin-averaged instrument may miss [16]. VELC has also

measured how the Fe XIV 5303 Å coronal emission line (emitted by highly ionised iron) broadens during coronal mass ejections, which are huge eruptions of solar plasma into space; a line-width increase of about 15% was reported for a CME on 16 July 2024 [21], and later work has examined the power spectra of the line widths before and after a CME [22].

4 Comparative discussion

Although Chandrayaan-3 investigated the Moon's surface and Aditya-L1 observes the Sun from the Sun–Earth L1 point, each mission gave India new capabilities in its field: Chandrayaan-3 provided India's first measurements made directly on the lunar surface, and Aditya-L1 provides India's first dedicated space-based solar observations from the Sun–Earth L1 point. Figure 6 compares the number of payloads carried by each mission, grouped by location (lander, rover and propulsion module) for Chandrayaan-3 and by type (remote-sensing and in-situ) for Aditya-L1.

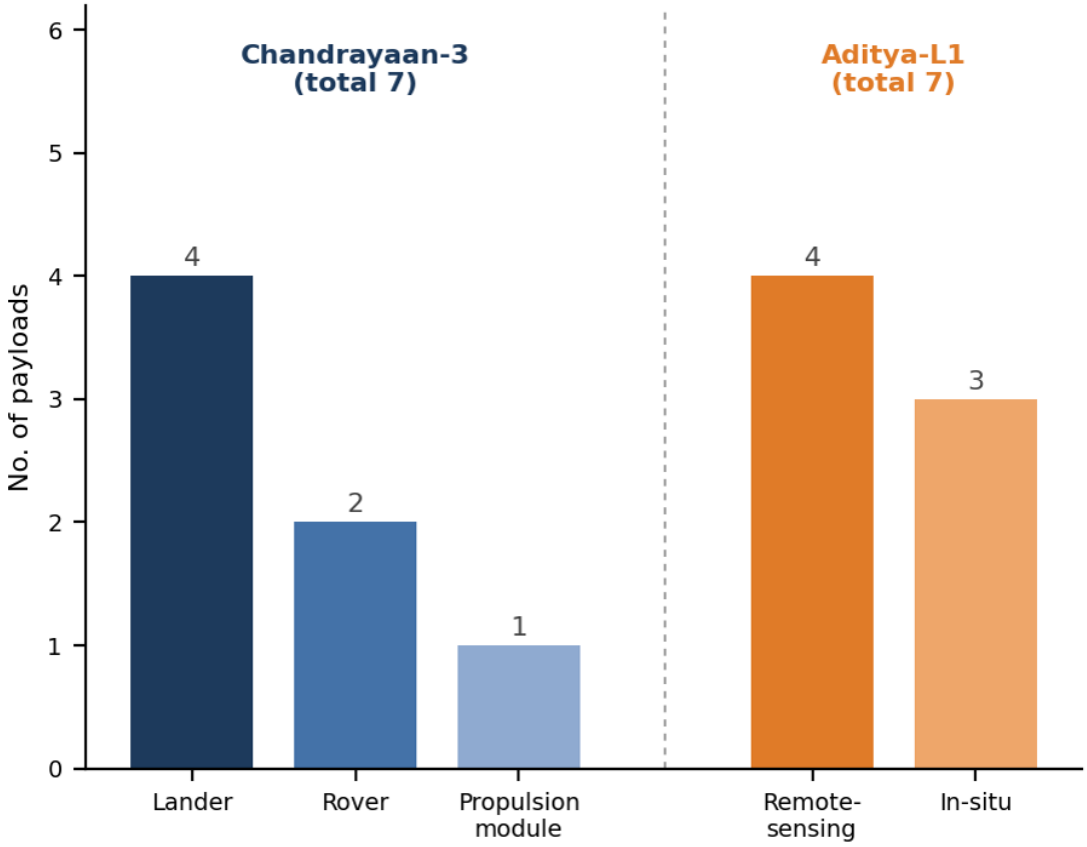


Figure 6. Distribution of scientific payloads: Chandrayaan-3 (lander 4, rover 2, propulsion module 1) and Aditya-L1 (remote-sensing 4, in-situ 3).

Chandrayaan-3's results are directly useful for planning future landing sites and for assessing resources, such as water ice, that may be accessible on the Moon. Aditya-L1's data are useful for monitoring and predicting "space weather": solar storms that can affect satellites, power grids and astronauts. Science data from both missions are openly available to researchers worldwide, not only in India [3,4,18]. Table 1 summarises the main parameters of both missions.

Table 1. Comparison of mission parameters.

Parameter	Chandrayaan-3	Aditya-L1
Launch	14 Jul 2023	2 Sep 2023
Landing / L1 insertion	23 Aug 2023	6 Jan 2024
Payloads	7	7
Focus	Regolith thermal, composition, seismic, plasma	Corona, flares, solar wind, magnetic field
Data release	23 Aug 2024 (PDS4)	6 Jan and 14 Feb 2025

Figure 7 places the main milestones of the two missions on a single timeline, from the launches in 2023 to the data releases and published results of 2024 and 2025 [1–5,9,12,15,18].

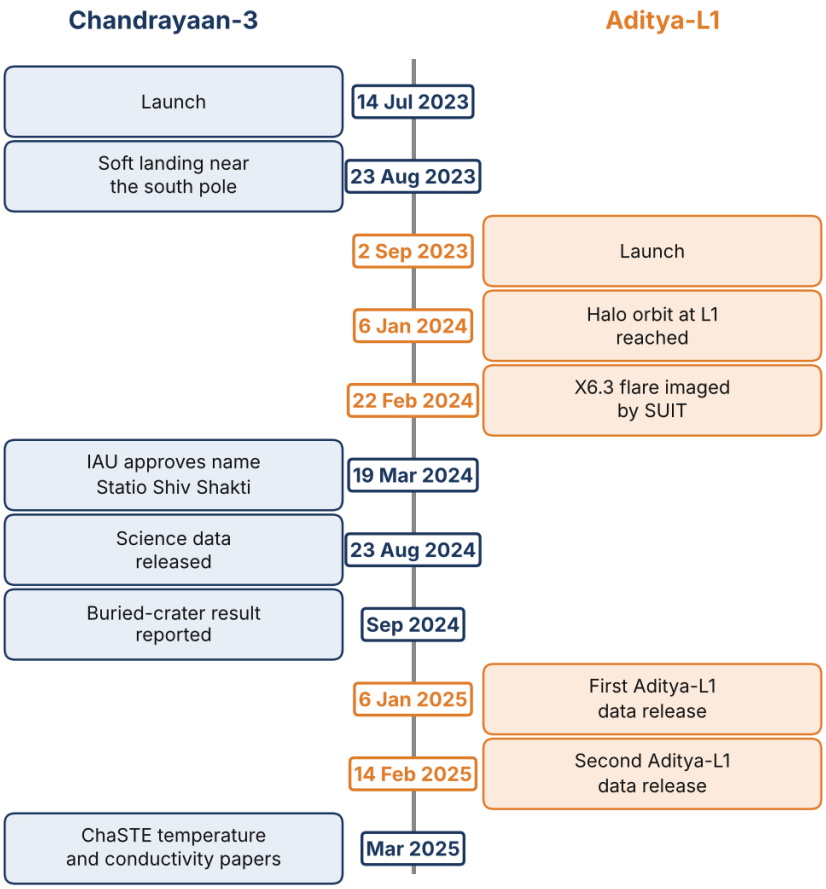


Figure 7. Timeline of key milestones of Chandrayaan-3 (left) and Aditya-L1 (right), 2023–2025; events are equally spaced and the axis is not to scale.

Table 2 brings together the main quantitative results discussed in Sections 2 and 3, with the reference for each value.

Table 2. Key quantitative results of the two missions.

Result	Value	Ref.
Chandrayaan-3		

Result	Value	Ref.
Peak surface temperature at the landing site (ChaSTE)	355 K (82 °C)	[6,9]
Model-derived night-time minimum temperature	≈105 K (−168 °C)	[9]
Regolith thermal conductivity at 80 mm depth	0.0115 and 0.0124 W m^{-1} K^{-1}	[10]
Buried crater beneath the landing area	≈160 km wide, ≈4.4 km deep	[12]
Age of the mapped geological units	≈3.7 billion years	[13]
Aditya-L1		
Flare imaged by SUIT on 22 February 2024	X6.3 class	[15]
Increase in 5303 Å line width (CME of 16 July 2024)	≈15%	[21]
Estimated energy share, CME of 5 August 2024	≈93% reconnection, ≈7% waves	[20]
Spectral slope of magnetic-field fluctuations (MAG)	≈ −5/3	[17]

5 Why these missions matter

For a student of physics, these missions are useful illustrations of how fundamental principles, such as heat transfer, spectroscopy, magnetism and orbital mechanics, are applied in real space engineering projects. Chandrayaan-3 is a practical demonstration of thermal physics and regolith thermophysics in an extreme, airless environment. Aditya-L1 is a working example of plasma physics and electromagnetism, studied from a vantage point outside the Earth's atmosphere and magnetosphere. Both missions also show the value of open data: because ISRO has made its science data publicly available, researchers outside ISRO can carry out independent analyses, as reflected in the growing number of publications based on these data.

5.1 Heat transport in the regolith

Heat moves through the lunar regolith mainly by conduction, which Fourier's law describes: the heat flux is proportional to the thermal conductivity and to the temperature gradient. In a material of very low conductivity, such as the regolith [10], absorbed sunlight cannot spread downwards quickly, so the top few centimetres warm and cool rapidly while the layers beneath respond slowly. This contrast explains why the surface temperature depends so strongly on the angle of the Sun, and why a slope of only a few degrees can shift the peak temperature noticeably [9].

5.2 Halo orbits at L1

The L1 point is an equilibrium position where the combined pull of the Sun and the Earth gives a spacecraft the same orbital period as the Earth [2]. The equilibrium is unstable, so a spacecraft left alone slowly drifts away and needs small, occasional manoeuvres to stay near the point. A halo orbit around L1 keeps the spacecraft off the direct Sun–Earth line, which reduces interference from the Sun when signals are sent to Earth. From this position the Earth and the Moon never block the Sun, so Aditya-L1 can observe it without interruption [2].

5.3 Why the Sun is observed from space

The Earth's atmosphere absorbs most ultraviolet and X-ray radiation, so instruments such as SUIT, SoLEXS and HEL1OS can only work from space [2]. The corona is also much fainter than the solar disc, so VELC, like other coronagraphs, uses an occulter to block the disc and make the corona visible

[14]. Emission lines such as Fe XIV 5303 Å come from highly ionised iron and therefore trace plasma at temperatures of about a million kelvin or more, which makes them useful for studying how the corona is heated [21].

6 Future prospects

Chandrayaan-3's results are expected to inform the choice of landing sites for future missions, including ISRO's planned Chandrayaan-4, which aims to bring lunar samples back to Earth, and the plans of other countries to explore the south polar region for water ice. For Aditya-L1, continued operation will build up a long record of solar activity across the current solar cycle (the Sun's roughly 11-year cycle of activity), which will help with space-weather forecasting and can be compared with data from earlier solar missions such as SOHO and the Solar Dynamics Observatory. Continuous observations that connect the corona with in-situ measurements in the heliosphere are important for linking coronal and heliospheric dynamics [23].

7 Limitations of this review

This review is based only on openly accessible sources, such as ISRO announcements, government press releases and open-access papers (including preprints on arXiv). Some findings, especially very recent ones, may not yet have completed peer review and should therefore be treated as early results rather than final conclusions. Chandrayaan-3 completed its surface operations in September 2023, but analysis of its data is continuing, and Aditya-L1 remains in operation; many more results are therefore expected in the coming years as scientists continue to study the data.

8 Conclusion

Chandrayaan-3 and Aditya-L1 have already produced a substantial early scientific return. More than three years after landing, Chandrayaan-3 has provided the first in-situ temperature and thermal-conductivity measurements at a high southern lunar latitude, including a peak surface temperature of 355 K (about 82°C) at the landing site and a model-derived night-time minimum of about 105 K (about −168°C). It has also shown that the mapped geological units of the landing area are about 3.7 billion years old and, through thermal modelling, that poleward-facing slopes steeper than about 14° could provide conditions favourable for shallow water ice outside permanently shadowed craters (ice itself was not detected), and it has revealed that the landing site lies within a buried crater about 160 km wide, adding to what is known about the Moon's early history. Aditya-L1, meanwhile, has imaged a flare kernel in ultraviolet light during an X6.3-class flare, recorded Kolmogorov-type turbulence in the interplanetary magnetic field during solar transient events, and contributed new observations towards understanding why the solar corona is far hotter than the Sun's surface. Together, these missions show how sustained in-situ and remote-sensing observations can answer long-standing questions in planetary and solar physics. Because both missions share their data openly, researchers around the world are likely to keep publishing new findings from them for years to come.

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