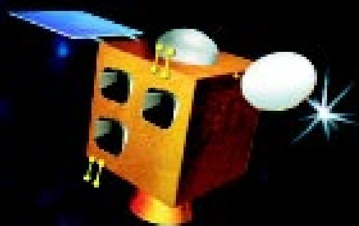
CHANDRAYAAN-1

INDIA'S FIRST SCIENTIFIC MISSION TO MOON



by

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1. Introduction to Chandrayaan-1

Chandrayaan-1, India's first scientific mission to Moon is slated for launch during 2007. The primary objectives of the mission are to expand the scientific knowledge about the origin and evolution of moon, upgrade India's technological capabilities and provide challenging opportunities to the young scientists working in planetary sciences.

Pursuit of space science is one of the important objectives of the Indian Space Programme. The Thumba Equatorial Rocket Launching Station (TERLS) was established near Thiruvananthapuram in 1963 for studying the ionospheric electrojet and related phenomenon, which paved the way for space research activities in the country. Also, the first Indian satellite, Aryabhata, launched in 1975, carried scientific experiments to investigate X-ray astronomy, Solar neutrons and supra thermal electron density. Since then, several instruments for scientific research have been flown on board high altitude balloons, sounding rockets and satellites. Several ground based facilities have also been set up for conducting research by scientists from universities and research institutions in astrophysical, solar and atmospheric research programmes.

India has vast experience in developing and launching operational spacecraft systems for survey and management of natural resources, meteorological services and satellite communication. The technologies developed and available now at ISRO can be fully exploited for embarking on planetary missions with well thought out scientific objectives. The Polar Satellite Launch Vehicle (PSLV) is capable of undertaking missions to moon and other terrestrial planets.

The idea of undertaking a scientific mission to Moon was mooted by the Indian Academy of Sciences. It was further discussed by the Astronautical Society of India. Based on recommendations of the scientific community and as a first major initiative, a National Lunar Mission Task Force was constituted by ISRO with leading scientists and technologists from all over the country for considering and making an assessment of the possible configuration and feasibility of taking up an Indian Moon Mission. The task team conducted a feasibility study and recommended the Indian lunar mission detailing scientific objectives, instruments to be flown, launch and spacecraft technologies that are available and those to be developed, setting up of a Deep Space Network (DSN) station for communication between lunar craft and earth and budgetary aspects.

The Study Report of the Task Team was reviewed in April 2003 by a peer group of about 100 eminent scientists from various relevant fields of planetary & space physics, earth sciences, geology, physics, astronomy and cosmology. After detailed discussions, the participants unanimously recommended that India should undertake the Moon Mission.

The recommendations are summarized as follows:

- The Indian Moon Mission assumes significance in the context of the international scientific community considering several exciting missions in planetary exploration, in the new millennium.
- ISRO has the necessary expertise to develop and launch the Moon Mission with imaginative features and it would be different from the past missions. Hence ISRO should go ahead with the project approval and implementation.
- Apart from technological and scientific gains, it would provide the needed thrust to basic science and engineering research in the country. The project would help return of young talents to the arena of fundamental research.
- The Academia, in particular, the university scientists would find participation in such a project intellectually rewarding. In this context, the scientific objectives would need further refinement to include other innovative ideas from a broader scientific community through Announcement of Opportunity, etc.

Subsequently, Government of India has approved ISRO's proposal for the first Indian Moon Mission, called Chandrayaan-1.

2. Scientific Objectives

Chandrayaan-1 is aimed at chemical, mineralogical and photo-geologic mapping of the moon in visible, near infrared, low energy and high energy X-rays with high spatial resolution. Specifically, the objectives will be to carry out high-resolution three-dimensional mapping of topographic features along with the simultaneous mapping of distribution of minerals such as Si, Al, Mg, Ca, Ilmenites ($FeTiO_3$, which may retain ^3He) and elemental chemical species including radioactive nuclides. This mapping could unravel the mysteries about the origin and evolution of the planetary system in general and moon-earth system in particular. The instruments that will be used for the mapping are:

- Terrain Mapping stereo Camera (TMC)
- Hyper Spectral Imager (HySI)
- Lunar Laser Ranging Instrument (LLRI)
- Collimated Low Energy X-ray spectrometer (LEX)
- Solar X-ray Monitor (SXM)
- High Energy X-ray/γ-ray spectrometer (HEX)

In addition to the above Indian payloads, a provision of 10 kg is made for international/national proposals on new ideas and experiments.

3. About Moon

Looming at about 384,400 km from the Earth, the Moon is the brightest object in the night sky and only second in brightness to that of the Sun. It has a diameter of 3,476 km and a mass of 7.35×10^{22} kg with a mean density of only 3.35 g/cc as compared to 5.52 g/cc of that of Earth. It has no atmosphere and degassing from the surface produces only trace gases. The gravitational force on the Moon is only 1/6th of that of Earth, and is not able to retain its atmosphere. The Moon does not have a substantial core of molten iron like Earth and hence has no magnetic field. The Moon undergoes extremes in temperature — it is scorching heat at 110° C during the day and freezing cold at –180° C during night.

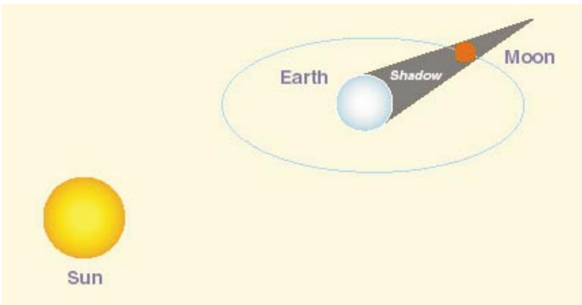
Basic parameters of the Earth and the Moon

Parameters	**Moon**	**Earth**	**Ratio**
Mass (10^{24} kg)	0.07349	5.9736	0.0123
Volume (10^{10} km^3)	2.1958	108.321	0.0203
Equatorial radius (km)	1738.1	6378.1	0.2725
Polar radius (km)	1736.0	6356.8	0.2731
Volumetric mean radius (km)	1737.1	6371.0	0.2727
Ellipticity	0.0012	0.00335	0.36
Mean density (kg/m^3)	3350	5515	0. 607
Surface gravity (m/s^2)	1.62	9.78	0.166
Escape velocity (km/s)	2.38	11.2	0.213
Obliquity (deg)	6.7	23.4	0.286
Rotational period	27.32 days	23 hr 56 min 4.09s	1.138
Revolution period	27.32 days	365.26 days	0.0748
Eccentricity	0.055	0.017	3.235

An eclipse occurs at those times when the Moon moves into a position of direct alignment with the Sun and the Earth. A solar eclipse can occur only at New Moon when the Moon passes

The geometry of Solar Eclipses: Total solar eclipse occurs when umbra of Moon's shadow touches a region on the surface of the Earth, Partial solar eclipse occurs when penumbra of the Moon's shadow passes over a region on the Earth's surface, Annular solar eclipse occurs when a region on the Earth's surface is in line with the umbra, but the distances are such that the tip of the umbra does not reach the Earth's surface. ('Eclipse' by Bryan Brewer.)

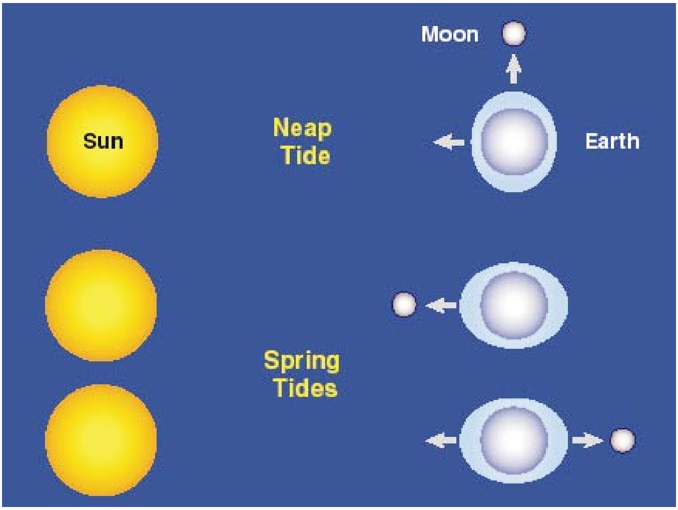
between Earth and Sun. If the Moon's shadow happens to fall upon Earth's surface at that time, we see some portion of the Sun's disk covered or 'eclipsed' by the Moon. Whereas lunar eclipse occurs when the Sun and the Moon are on opposite sides of the Earth and the full Moon passes through the shadow of the Earth. The solar and lunar eclipses are truly spectacular celestial phenomenon.



A total lunar eclipse with the Moon lying in the umbra of the Earth's shadow (http://csep10.phys.utk.edu)

The low and high tides due to the gravitational effects of Sun and the Moon are well known phenomena affecting day-to-day life. An interesting fact is that the Moon's rotation period around its axis and revolution period around the Earth takes the same time of about 27 days and hence the same side of Moon is permanently facing the Earth. The time taken from one new Moon to another new Moon (synodic period) is about 29 days.

So far there has been no indication of life existing on Moon.



Tides are periodic rise and fall of large bodies of water, caused by the gravitational interaction between Sun, Moon and Earth. Large tides are experienced in Earth's oceans when Sun and Moon are lined up with the Earth at new or full phases of the Moon. These are called spring tides. Conversely when the Moon is located at right angles to the Sun-Earth line, the Sun and Moon interfere with each other in producing tidal bulges and tides are generally weaker- these are called neap tides. (http://csep10.phys.utk.edu)

The Moon's surface is generally dry, dusty and rocky. The rocky crust is about 60 km thick on the near side that faces the Earth and about 107 km on the far side. Moon's terrain is divided into two sharply contrasting areas – the rugged and very ancient mountainous '*Highlands*' regions and smooth younger lowland '*Maria*' regions. While Earth's mountain ranges are formed by movements and coming closer of crust sections pushing against each other (known as plate tectonics), the lunar highlands did not result from an active uplifting process due to crustal dynamics. But its surface has been periodically bombarded with different sizes of meteorites and asteroids. During the initial period of lunar evolution, such giant meteor impacts resulted in the creation of flatlands or lunar basins. The regions not affected by these giant impacts are the lunar highlands.

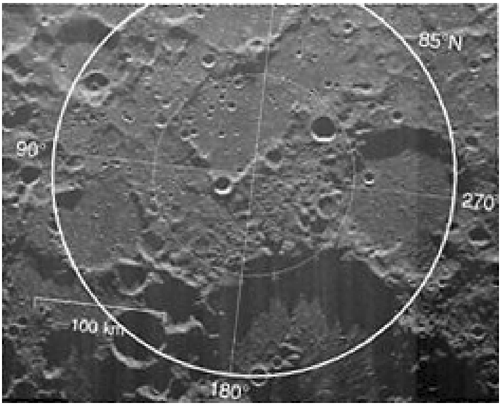
NEAR SIDE FAR SIDE

The near face of the Moon, face turned towards the Earth, shows a number of Mare (dark), whereas largely highland terrain (bright) are seen on the far side, side of the Moon unseen from the Earth. (Astronomy: Journey to the Cosmic Frontier by John D Fix.)

Ancient observers thought that the round and dark areas on the face of the Moon are seas, which they called Maria (Latin word for seas). Maria are not seas at all but relatively flat areas produced by massive flow of lava from earlier period of lunar volcanism.

Maria comprises 16 percent of the Moon's surface and has huge impact basins. They are concentrated in the near side of the Moon. Associated with the Lunar Maria are gravity anomalies called 'mascons' (mass concentrations). A spacecraft would accelerate as it nears the Maria region and decelerate as it move away due to such gravitational anomalies.

The Moon is covered with a gently rolling layer of powdery soil and rock fragments called the 'regolith', which is made of debris created by the meteor impacts forming the craters. Such craters are the remains of collisions between an asteroid, comet or meteorite and the Moon. The size, mass, speed and angle of the falling object determine the size, shape and complexity of resulting craters. Surface of the Moon is scarred with millions of impact craters and the record has been retained on Moon's surface.



North Polar Region (Courtesy: NASA)

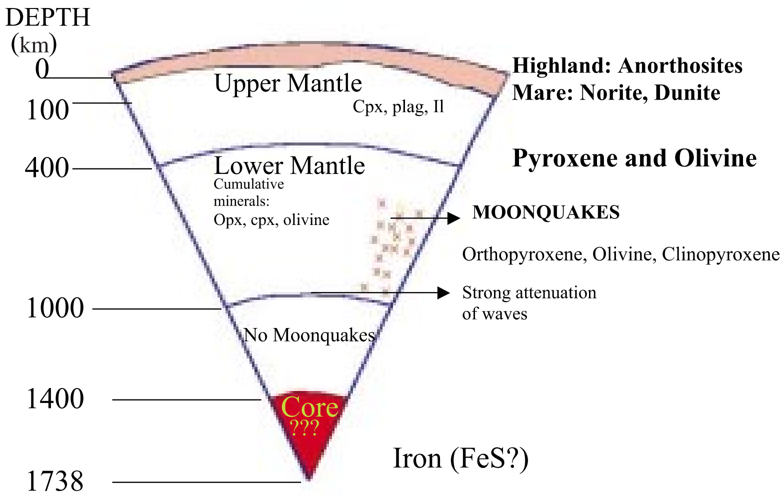
One striking difference between the lunar surface material and that of Earth concerns the most common kinds of rocks. On the Earth the most common rocks are sedimentary because of atmospheric and water erosion of the surface. On the Moon there is no atmosphere and little or no water, and the most common kind of rock is igneous ('fire-formed-rocks'). According to studies, the lunar surface material has the following geological characteristics:

- The Maria are mostly composed of dark 'basalts' which are formed from rapid cooling of molten rocks from massive lava flows.
- The Highlands rocks are largely 'Anorthosite', which is a kind of igneous rock that forms when lava cools more slowly than in the case of basalts.
- 'Breccias' are fragments of different rocks compacted and welded together by meteoric impacts and are found in Maria and Highlands.
- The Moon has either a very small core rich in iron ore or no core at all.

Analysis of lunar rock samples indicate that

- The rocks are rich in Calcium (Ca), Aluminium (Al) and Titanium (Ti)
- There is high abundance of Silicon (Si) and Oxygen (O)
- There is a relative abundance of ^3He on the Moon, compared with Earth. This may be due to the fact that over the four billion year history of the Moon, several hundred million tons of solar ^3He have impacted directly onto the surface of the Moon and got trapped in minerals such as Ilmenite (a compound of iron and titanium; $FeTiO_3$).

Internal Structure of Moon



The figure shows current understanding of the layered interior structure of Moon. The inferred lithosphere of Moon extends up to 1000 km. Orthopyroxene (opx), Olivine are Fe-Mg rich silicate mineral, Clinopyroxene (cpx) - Ca rich silicate mineral with Fe and Mg, Plagioclase (plag)-a type of feldspar (Al rich mineral). Quakes inside Moon occur in the band around 800-1000 km in depth, a level that is interpreted as the base of lunar lithosphere. (Courtesy: American Scientist)

The abundance of radioactive elements in rock samples can be used to determine the age of the rocks in a process called 'Radioactive dating'. Using such techniques on lunar samples brought back by the Apollo missions, it has been found that the oldest material from the surface of the Moon is almost as old as we believe the Solar system to be that is 5 billion years. Thus the material brought back from the Moon by Apollo missions provides a window on the very early history of our Solar system that would be difficult to find on the Earth, which is geologically active and has consequently obliterated its early geological features.

Seismic S waves apparently do not traverse the region below the zone of Moonquakes, suggesting that this material has very low shear strength, possibly containing some liquid.

4. Origin of Moon

The origin of the Moon is still not clearly understood and there have been speculations about its origin — how it was formed and how it acquired its present orbit around the Earth. Studies using the chemical, mineralogical, isotopic and chronological data led to postulation of five major theories on the origin of the Moon:

Picture of giant impact that threw the material for the Moon into Earth's orbit. (Courtesy: Scientific American)

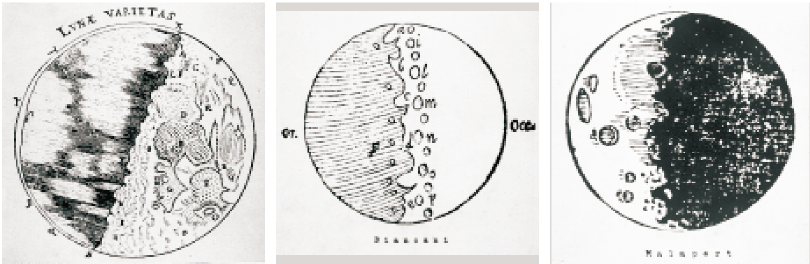
- The Fission Theory: At some time in the distant past, the Moon had separated from the Earth. Perhaps the Earth was not as round then as it is today and that imbalance caused it to split in two.
- The Capture Theory: The Moon was formed somewhere in the solar system and was later captured by the gravitational field of the Earth.
- The Co-accretion Theory: The Earth and Moon may have been formed at the same time from solar nebula by co-accretion.

- The Colliding Planetesimal Theory: Moon condensed from the debris of the interaction of Earth-orbiting and Sun-orbiting planetesimals (very large chunks of rocks like asteroids) early in the history of the solar system.
- The Giant Impact Theory: A planetesimal of Mars size had impact with the Earth, early in its history, ejecting large volume of matter from the evolving Earth, which aggregated and formed the Moon.

5. Early Interest

Through the ages Moon has been the heavenly body, which sparked the imagination of mankind more than the planets in our solar system. In the distant past our ancestors looked up to the sky with awe and wonder. At the beginning of recorded history, the passage of time was decided by observing the positions and phases of the Moon. The idea that the Moon was not perfectly smooth can be traced back to 450 B.C. At approximately the same time the Greek astronomer, Hipparchus, using observations and mathematical formulae measured the distance to the Moon as well as the Sun with surprising accuracies. In the Vedic period (1500-500 B.C.), Indian astronomers had determined the orbit of the Moon precisely and based on the phases of the Moon, developed the lunar calendar which is used even now. The Indian astronomer Aryabhata (~500 A.D), after whom the first Indian satellite was named, was one of the early scholars who determined the Moon's size and distance accurately.

The end of fifteenth century was apparently the period when serious study of the Moon began. Around 1603, the first lunar drawing based on naked eye observation was compiled.

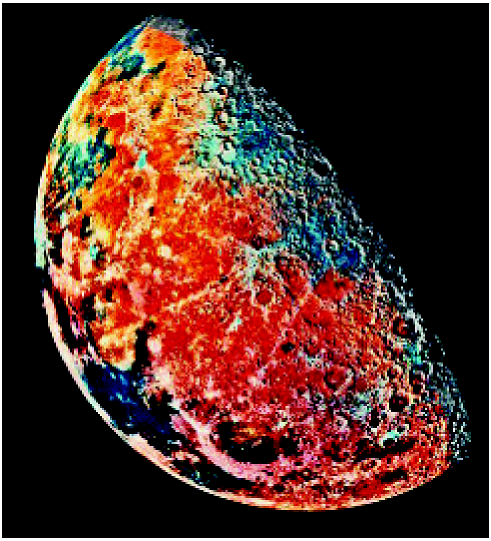


Sketches of the Moon by Scheiner (1614), Biancani (1620) and Malapert (1619)
Scheiner: Disquisitiones Mathematicae (Ingolstadt, 1614).
Biancani: Spaera Mundi (Bologna, 1620).
Malapert: Oratio (Douai, 1619). (Courtesy: Albert Van Helden)

Later the telescope was used to explain the Moon's spots. At the beginning of seventeenth century, a closer look at the Moon by Galileo using his telescope, showed that its surface is uneven demarcating the dark areas (lowlands) and bright ones (highlands). Selenography, the study of the physical features of the Moon systematically began in 1799 when observations and measurements were made on lunar features. In 1840 a five-inch reflector telescope was used to produce a picture of the Moon. By 1890 lunar photography became a recognized branch of astronomical research. The twentieth century brought more advances to the study of the Moon. In 1946 scientists turned a radar dish to the Moon and for the first time received a return signal.

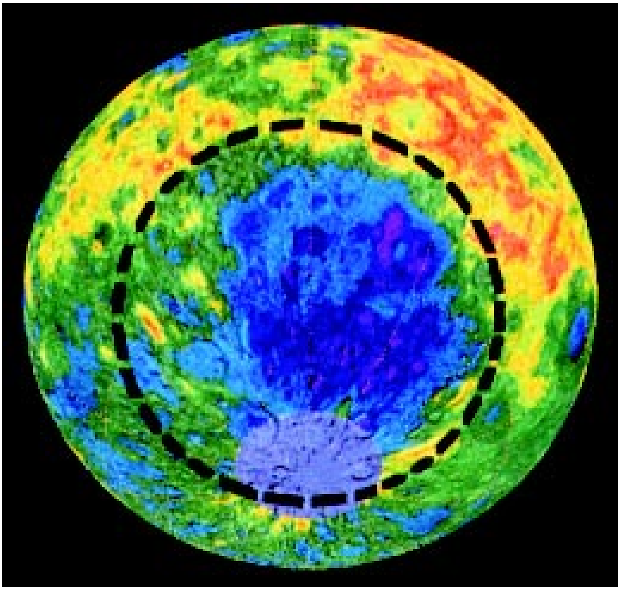
6. Recent Lunar Explorations

The ushering in of the space era with the launch of the first artificial satellite, Sputnik in 1957, opened up the prospects of realizing the man's long cherished dream to reach Moon. The space programme was undertaken for lunar exploration as early as 1959. Since then, more than 50 lunar exploratory missions have been conducted. Erstwhile Soviet Union's LUNA spacecraft missions were followed by United States RANGER and SURVEYOR missions, going through the Lunar Orbiters culminating into the APOLLO Moon landing missions. Trips to the Moon moved out of science fiction into reality on July 20, 1969, when Neil Armstrong became the first man to set his foot on the lunar surface (Sea of Tranquillity). Over a dozen astronauts have since explored the surface of the Moon and brought back about 400 kg of lunar material. The instruments left behind on the Moon by APOLLO astronauts provided new information on the Moonquakes, heat flow, meteorite impacts, etc.



This false colour image of Moon has been created by combining 53 images taken from three different filters on Galileo during the 1992 flyby. Pink represents highlands, blue to orange denote volcanic flows. (Courtesy: NASA)

Interest in lunar science was renewed when the imaging system on board NASA's "Galileo" spacecraft sent pictures of some of the previously unexplored regions of the Moon during 1990. Galileo identified a large impact basin, about 2500 km in diameter


Southern topography view of the South Pole-Aitken Basin, on the Lunar far side, currently the largest known impact basin in the solar system. It was excavated by a large impact. (Courtesy: Science)

and 10 to 12 km deep in the South Pole Aitken Region (SPAR) on the far side of the Moon, which could not be recognized by the earlier missions. Thus a long gap of about 20 years since the Apollo mission was broken by the Galileo mission and others to follow mainly due to unprecedented growth of advanced technology in the area of remote sensing, imaging devices and digital electronics.

With the development of new technology, a new era of lunar exploration by many countries have now begun and lunar exploration is continuing, using the advanced instruments and computer technologies. The Japanese mission, HITEN (formerly called MUSES-A) was successfully launched in 1990, to perform a sophisticated Earth-Moon circumnavigation and was finally directed to impact on lunar far side. Between February and May 1994, the joint European-American CLEMENTINE mission, equipped with a laser image detection and ranging system (LIDAR) and high resolution cameras (HIRES) photographed nearly the whole lunar surface in ultra violet, visible, near IR and long wave IR bands from a lunar orbit of about 425 km. It provided the first global data sets for lunar gravity, topography and multi spectral imaging with about 200 m resolution. LUNAR PROSPECTOR launched in January 1998 carried remote sensing instruments such as gamma-ray spectrometer, neutron spectrometer, alpha particle spectrometer, etc. This mission was designed to provide answers to longstanding questions about the Moon, its resources, structure and origin and provided valuable scientific data on the distribution of Thorium, Potassium, other radioactive and stable elements eg., Fe, Ti, etc.

A common objective of both Clementine and Lunar Prospector was to search for lunar water/ice deposits. Radar reflectivity experiments performed by Clementine hinted at the possibility of existence of large amounts of water frozen on the permanently shadowed polar regions of the Moon. Lunar Prospector's neutron spectrometer detected bursts of slow neutrons over the Moon's poles, suggesting presence of hydrogen atoms and hence possible presence of water/ice. However, these experiments could not decisively confirm the presence of water/ice on Moon, which still remains a mystery.

7. Renewal of Interest

Telescopes have been trained on the Moon since Galileo's days and dozens of spacecraft have flown by, orbited around and landed on the Moon. A few astronauts have brought back rock and soil samples from Moon. Much has been learnt about the astronomical, physical, chemical, isotopic, geological and chronological aspects of the Moon. Despite a wealth of data, critical and fundamental questions still remain about the Moon's origin and formation and its chemical composition. Particularly question related to existence of water/ice and life is still unresolved. Hence even after three decades of Apollo, our knowledge about the Moon is still incomplete.

The advancements in sensor, detector and miniaturization technologies have now prompted renewed scientific interest on lunar exploration.

Apart from the scientific interest, the Moon could have economic benefits to mankind. This includes exploitation of the resource potential of the Moon including habitation of the Moon to reap the benefits on a continuous basis. The Moon has abundant resources of oxygen, hydrogen and other solar wind gases trapped in its regolith. Understanding the availability of such resources from the perspective of mineralogy, lithology and regional geology is a prerequisite for efficient human presence on the Moon. Early studies of the lunar regolith showed that there is a relative abundance of Helium-3 (^3He) isotope on the Moon compared to that of Earth. ^3He can be used as a fusion element and is thus considered as one of the important fuels for power generation in the future. Since ^3He has high diffusivity, it normally gets lost from lunar grains. However, the mineral Ilmenite ($FeTiO_3$) is abundant on the Moon and has high retentivity for ^3He. The distribution of ^3He associated with Fe and Ti can be determined by geochemical mapping since it would have the same distribution as (Fe + Ti). Over the four billion-year history of the Moon, several hundred million tonnes of ^3He have impacted the surface of the Moon from the solar wind. The analyses of Apollo and Luna samples showed that over 1 million tonnes of ^3He still remain embedded in the surface of the Moon. Even a small fraction of this could provide the world's electricity for centuries to come. A large number of studies are being carried out to determine the technical feasibility of having a human outpost on the Moon.

The twenty-first century will mark a significant milestone in the history of human development: the colonisation of the Moon! The Moon being the nearest neighbour of Earth and with 1/6 th of the Earth's gravity offers a unique outpost for planetary exploration. The conditions may be adapted to generate lunar self-sustaining bases for such endeavours. Moon's far side would provide an excellent site for establishing an astronomical observatory because of the absence of atmosphere and the absence of Earth's reflected radiation on the far side of Moon.

8. Forthcoming Lunar Explorations

A number of missions to the Moon are planned during current decade by Japan and European Space Agency (ESA) and some missions are being discussed by United States (NASA) and other countries. These include orbiter, lander and sample return missions. Important missions currently launched and planned in the next one or two years are SMART-1 (ESA), Lunar A (Japan), SELENE (Japan). The mission configurations and their scientific objectives are briefly described below.

- The primary objective of SMART-1 (Small Mission for Advance Research and Technology) launched by Ariane-5 rocket during September 2003 is to test solar-electric propulsion with several technology goals. The scientific payload of SMART-1 includes a high-resolution camera, a near infrared spectrometer and a compact X-ray spectrometer with a new type of swept charge detector and micro collimator.

- The Lunar A mission of Japan expected for launch in 2005 is primarily meant for studying Moon's seismic and heat flow phenomena. The objective of the mission is to determine whether the Moon has a core and if so, its size and physical properties using two penetrators.
- SELENE (Selenological and Engineering Explorer) is a Japanese mission to be launched during 2005. The mission will consist of a main orbiting satellite at about 100 km altitude in polar circular orbit and two sub-satellites in elliptical orbit with apolune at 2400 and 800 km. The scientific objectives include mapping of lunar topography, surface composition, magnetic field and study of lunar and solar terrestrial environment.

9. Indian Mission

The Indian Space Programme has the primary goal of promoting and establishing a vibrant space science, application and technology programme to assist in all-round development of the nation.

Keeping in mind the goal, the capabilities that India has acquired can be fruitfully exploited to undertake outer space explorations and contribute to answering some of the fundamental questions regarding the origin and evolution of Moon, which still remain unanswered.

The photo geological, mineralogical and chemical mapping through Chandrayaan-1 mission will enable to identify different geological units, which will test the early evolutionary history of the Moon. The chemical mapping will enable to determine the heterogeneous nature and depth stratigraphy of the Moon's crust and thereby test certain aspects of magma ocean hypothesis and may allow to determine the compositions of impactors, which are also relevant to the formation of the Earth.

Apart from technological and scientific gains, Chandrayaan-1 will provide thrust to basic science and engineering research in the country. The mission will be an important catalyst for the youngsters to pursue fundamental research. The academia, in particular the university scientists, would find Chandrayaan-1, highly rewarding.

10. Scientific Instruments for Chandrayaan-1

Terrain Mapping Camera (TMC): This Camera will generate high-resolution 3-D cartographic map of the Moon using stereoscopic cameras. The broad specifications of TMC are given below:

Ground resolution	5 m
Swath	40 km
Spectral Band	Panchromatic

Hyper Spectral Imager (HySI): This instrument uses a wedge filter and an area array detector to obtain the full spectrum information of the target by acquiring image data for mineralogical mapping. The broad specification of HySI are given below:

Ground resolution	80 m
Swath	40 km
Spectral range	400-900 nm
No of spectral bands	32
Spectral resolution	15 nm

Lunar Laser Ranging Instrument (LLRI): This instrument is used for providing ranging data for determining the accurate altitude of the spacecraft above the lunar surface. The broad specification of LLRI are given below:

Pulse repetition rate	1 Hz
Telescope	15 cm dia, reflective
Pulse-width	10 ns
Vertical resolution	10 m

X-ray Fluorescence Spectrometers: This instrument consists of three parts: (a) Low Energy X-ray detector (LEX) to map the abundance of light elements like Mg, Al, Si, Ca, Ti and Fe (b) High Energy X-ray/γ-ray detector (HEX) to map the distribution of high atomic number elements over the lunar surface such as U, Th, etc. and (c) Solar X-ray Monitor (SXM) to continuously measure the flux of solar X-rays. The characteristics of X-ray payloads are given below:

	LEX	**HEX**	**SXM**
Energy range	0.5 – 10 keV	10 – 200 keV	2 – 10 keV
Energy resolution (FWHM)	8% at 1.5 keV 4% at 6 keV	5% at 60 keV	5% at 6 keV
Field of View (FOV)	5^0 x 5^0	10^0 x 10^0	90^0
Spatial resolution	9 km	18 km	—

11. Launch Vehicle and Spacecraft

Polar Satellite Launch Vehicle (PSLV) of ISRO, which has already flown seven times successfully and placed Indian remote sensing satellites in polar orbit and also a meteorological satellite, KALPANA-1, into Geosynchronous transfer orbit, will be used for Chandrayaan-1 mission.

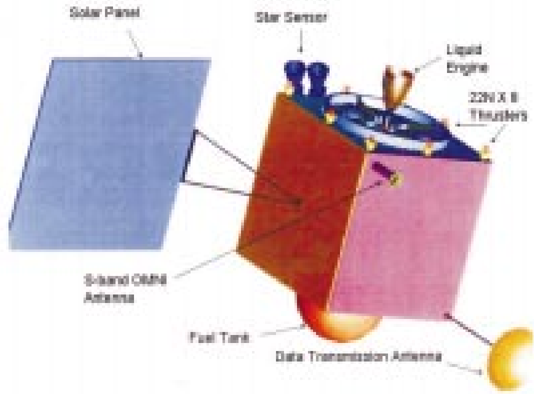
In the Chandrayaan-1 mission, the spacecraft will be placed in a polar orbit at an altitude of about 100 km above the Moon's surface. The spacecraft, initially weighing 1050 kg, will be launched by PSLV into an Elliptical Parking Orbit (EPO) of 240 km perigee and 36,000 km apogee which is very similar to the Geosynchronous Transfer Orbit (GTO) into which Kalpana-1 was placed. The spacecraft will then use its own Liquid Apogee Motor (LAM) to take it to a Trans Lunar Injection (TLI) orbit and finally for Lunar Orbit Insertion (LOI). In its final orbit of 100 km above the Moon, the spacecraft will weigh 525 kg (including liquid fuel and micro thrusters required for a life period of 2 years). It will take about 5 ½ days for the spacecraft to attain the lunar orbit.

Nominal PSLV Mission to Moon

• Mission Strategy	EPO- TLI- LOI
• EPO~GTO	240X36000 km
• Inclination	18°
• Argument of perigee	179°
• EPO/GTO mass	1050 kg
• LAM First Burn	239 kg
• TLI Mass	811 kg
• LAM Subsequent Burns	287 kg
• LAM Total Loading	526 kg
• Mass in 100 X 100 km Lunar Orbit	523 kg
• Propellant for 2-year Orbit Maintenance	83 kg
• Dry mass of Lunar Spacecraft	440 kg

PSLV

The spacecraft for Chandrayaan-1 has the shape of a cuboid measuring 1.5 m. It will have canted solar array generating 630 W of power backed up by Lithium Ion battery.It will be 3-axis stabilised and use fibre optic gyro for accurate attitude control. It will have gimballed steerable high gain antenna system for transmitting the scientific data. The Telemetry, Tracking and Command (TTC) would be in S-band frequency while the scientific payload data transmission will be in X-band.



Artist's impression of the Chandrayaan-1 Spacecraft

12. Ground Facilities

To provide continuous radio link with the Chandrayaan-1 spacecraft, a Deep Space Network (DSN) station will be set up near Bangalore. This station will track the spacecraft which will be about 4,00,000 km away, communicate with it and send commands as well as receive the scientific data from its instruments. The DSN station will have a fully steerable, dual feed 34 m-diameter antenna. Once established, DSN will not only support the Chandrayaan-1 mission but also form an important asset to serve future planetary missions. The Mission Control Centre (MCC) situated at Bangalore will carry out all spacecraft operations, raw data reception and archival. A National Science Data Centre (NSDC) will act as a repository of scientific data from experiments conducted on-board Chandrayaan-1. The data will be processed and archived in user-friendly format for distribution to interested scientists.

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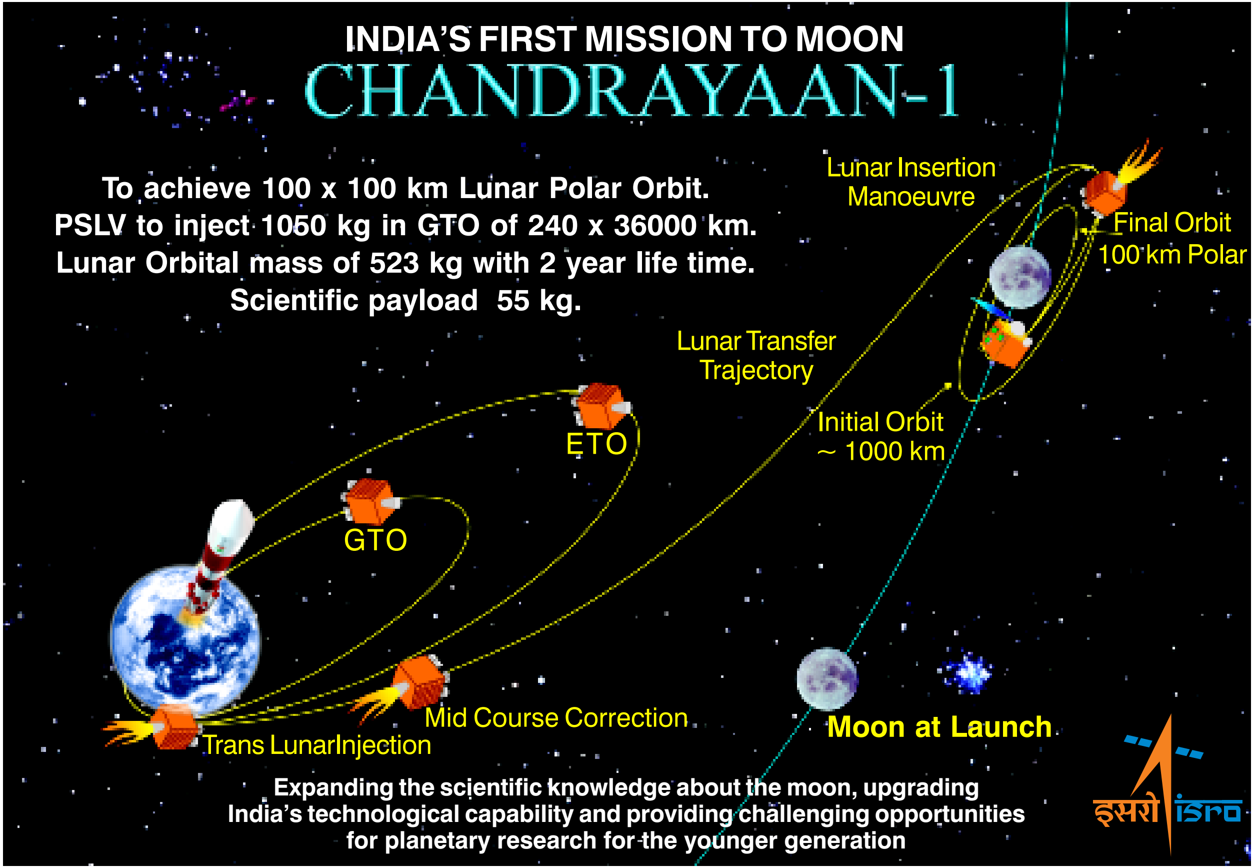
CHRONOLOGY OF LUNAR EXPLORATION

No	Launch date	Mission	Country	Accomplishment
1.	2 Jan 1959	Luna 1	USSR	First lunar flyby, magnetic field
2.	3 Mar 1959	Pioneer 4	USA	Lunar flyby by 60,000 km, radiation
3.	12 Sept 1959	Luna 2	USSR	First hard landing, magnetic field
4.	4 Oct 1959	Luna 3	USSR	First photos of lunar farside
5.	23 Aug 1961	Ranger 1	USA	Attempted test flight
6.	18 Nov 1961	Ranger 2	USA	Attempted test flight
7.	26 Jan 1962	Ranger 3	USA	Missed the Moon by 36,793 km
8.	23 Apr 1962	Ranger 4	USA	Crashed on the lunar farside
9.	18 Oct 1962	Ranger 5	USA	Missed the Moon by 724 km
10.	2 Apr 1963	Luna 4	USSR	Missed the Moon by 8,500 km
11.	30 Jan 1964	Ranger 6	USA	Hard landing, television failed
12.	29 July 1964	Ranger 7	USA	Hard landing, First close-up TV
13.	17 Feb 1965	Ranger 8	USA	Hard landing, close-up TV
14.	21 Mar 1965	Ranger 9	USA	Hard landing, close-up TV
15.	9 May 1965	Luna 5	USSR	Crashed on the Moon
16.	8 June 1965	Luna 6	USSR	Missed the Moon by 1,60,000 km
17.	18 July 1965	Zond 3	USSR	Photographed lunar farside
18.	4 Oct 1965	Luna 7	USSR	Crashed on the Moon
19.	3 Dec 1965	Luna 8	USSR	Crashed on the Moon
20.	31 Jan 1966	Luna 9	USSR	First soft landing and TV panorama
21.	31 Mar 1966	Luna 10	USSR	First lunar satellite, gamma-spectra, magnetic and gravity measurements
22.	30 May 1966	Surveyor 1	USA	Lander, on-surface TV, soil mechanics
23.	10 Aug 1966	Lunar Orb1	USA	TV imaging, radiation, micrometeorites

24.	24 Aug 1966	Luna 11	USSR	Orbiter, gamma-and X-ray measurements, gravity, micrometeorites
25.	22 Oct 1966	Luna 12	USSR	Orbiter, TV imaging
26.	6 Nov 1966	Lunar Orb 2	USA	TV imaging, radiation, micrometeorites
27.	21 Dec 1966	Luna 13	USSR	Lander, on-surface TV, soil mechanics
28.	5 Feb 1967	Lunar Orb 3	USA	TV imaging, radiation, micrometeorites
29.	17 Apr 1967	Surveyor 3	USA	Lander, on-surface TV, soil mechanics
30.	4 May 1967	Lunar Orb 4	USA	TV imaging, radiation, micrometeorites
31.	19 July 1967	Explorer 35	USA	Orbiter, Plasma, fields and particles
32.	1 Aug 1967	Lunar Orb 5	USA	TV imaging, radiation, micrometeorites
33.	8 Sept 1967	Surveyor 5	USA	Lander, on-surface TV, First chemistry
34.	7 Nov 1967	Surveyor 6	USA	Lander, on-surface TV, chemistry
35.	7 Jan 1968	Surveyor 7	USA	Lander, on-surface TV, chemistry
36.	7 Apr 1968	Luna 14	USSR	Orbiter, gamma-spectra., magnetic measurements
37.	14 Sept 1968	Zond 5	USSR	First lunar flyby and Earth return
38.	10 Nov 1968	Zond 6	USSR	Lunar flyby and Earth return
39.	21 Dec 1968	Apollo 8	USA	First humans to orbit the Moon
40.	18 May 1969	Apollo 10	USA	First docking in lunar orbit
41.	13 July 1969	Luna 15	USSR	Failed robotic sampler
42.	16 July 1969	Apollo 11	USA	First humans on the Moon (20 July)
43.	6 Aug 1969	Zond 7	USSR	Lunar flyby and Earth return
44.	14 Nov 1969	Apollo 12	USA	Human landing, Oceanus Procellarum
45.	11 Apr 1970	Apollo 13	USA	Aborted lunar landing
46.	12 Sept 1970	Luna 16	USSR	First robotic sample return, Mare Feccunditatis

47.	20 Oct 1970	Zond 8	USSR	Lunar flyby and Earth return
48.	10 Nov 1970	Luna 17	USSR	First robotic rover Lunokhod 1, Mare Imbrium
49.	31 Jan 1971	Apollo 14	USA	Human landing, Fra Mauro
50.	26 July 1971	Apollo 15	USA	Human landing, Hadley-Apennine
51.	2 Sept 1971	Luna 18	USSR	Failed robotic sampler
52.	28 Sept 1971	Luna 19	USSR	Orbiter, lunar gravity, TV, micrometeorites
53.	14 Feb 1972	Luna 20	USSR	Robotic sample return, Apollonius
54.	16 Apr 1972	Apollo 16	USA	Human landing, Descartes
55.	7 Dec 1972	Apollo 17	USA	Human landing, FIRST geologist on the Moon, Taurus-Littrow
56.	8 Jan 1973	Luna 21	USSR	Robotic rover Lunokhod 2, Le Monier
57.	10 Jun 1973	Explorer 49	USA	Non-lunar radio astronomy from lunar orbit
58.	29 May 1974	Luna 22	USSR	Orbiter, lunar gravity, TV, micrometeorites
59.	28 Oct 1974	Luna 23	USSR	Failed robotic sampler
60.	9 Aug 1976	Luna 24	USSR	Robotic sampler return, Mare Crisium
61.	24 Jan 1990	Hiten	Japan	Flyby and orbiter, technological experiments
62.	25 Jan 1994	Clementine	USA	Orbiter, imaging lunar surface in UV, VIS, IR, laser altimetry
63.	6 Jan 1998	Lunar Prospector	USA	Gamma-neutron-alpha spectrometry, magnetometry, gravity
64.	Sept 2003	SMART-1	ESA	Solar electric propulsion, near IR and X-ray Spectrometer
65.	2005	Lunar-A	Japan	Seismic heat flow phenomena
66.	2005	Selene	Japan	Mapping of lunar topography, surface composition & magnetic field

Chandrayaan-1, the first Indian mission to Moon, would play a major role in reinvigorating research in fundamental science, help in upgrading technological capabilities for future space systems, become a meaningful contender in the international space arena for exploration and commercial exploitation of resources in the immediate neighborhood of our planet. Above all, the mission would help the young talented scientists and engineers of the country to take up the challenging high level of intellectual activities in basic sciences. Chandrayaan-1 mission would pass on the baton to sophisticated future lunar and planetary missions with possible landing and sample return capability.


INDIA'S FIRST MISSION TO MOON
CHANDRAYAAN-1
To achieve 100 x 100 km Lunar Polar Orbit.
PSLV to inject 1050 kg in GTO of 240 x 36000 km.
Lunar Orbital mass of 523 kg with 2 year life time.
Scientific payload 55 kg.
Lunar Insertion Manoeuvre
Final Orbit 100 km Polar
Lunar Transfer Trajectory
Initial Orbit ~ 1000 km
ETO
GTO
Mid Course Correction
Trans LunarInjection
Moon at Launch
Expanding the scientific knowledge about the moon, upgrading India's technological capability and providing challenging opportunities for planetary research for the younger generation
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Chandrayaan-1: Summary

♦ Scientific Objectives:	♦ Simultaneous chemical, mineralogical and photogeologic mapping of the whole moon in visible, near infrared, low and high energy X-rays with high spatial resolution
♦ Scientific Payloads:	♦ Terrain Mapping Camera-TMC ♦ Hyper Spectral Imager-HySI ♦ Lunar Laser ranging Instrument-LLRI ♦ Low Energy X-ray Spectrometer-LEX ♦ Solar X-ray Monitor- SXM ♦ High Energy X-ray /γ-ray Spectrometer-HEX
♦ Payload Weight:	♦ 55kg (Including 10kg Announcement of Opportunity payload)
♦ Launcher:	♦ Polar Satellite Launch Vehicle-PSLV
♦ Mission Strategy:	♦ Elliptic Parking Orbit – Trans Lunar Injection – Lunar Orbit Insertion
♦ Lunar Orbit:	♦ 100 X 100 km Circular Polar
♦ Operational Life Time:	♦ Two Years
♦ Spacecraft:	♦ Cuboid shape, 1.5 m side, 3-axis stabilized
♦ Spacecraft Mass:	♦ Dry mass-440kg, Initial Lunar Orbit Mass with propellant-524kg
♦ Communication System:	♦ S-Band uplink for telecommand, S-Band downlink for telemetry, X-Band for Payload data reception
♦ Deep Space Network (DSN) Station:	♦ Location: Bangalore, Fully steerable dual feed 34m-dia antenna
♦ Mission Control Centre	♦ Location: Bangalore-responsible for all spacecraft operations, running of ground infrastructure
♦ National Science Data Centre (NSDC):	♦ Act as repository of scientific data from experiments conducted on-board Chandrayaan-1

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