



CHANDRAYAAN-1

INDIA'S FIRST MISSION TO MOON

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CHANDRAYAAN-1



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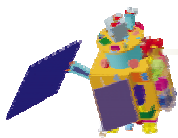
Foreword

The quest for knowledge had always been the main driving force for any exploration in general and space exploration in particular. The mankind has always been inquisitive about the origin of our planet Earth, the solar system celestial bodies and also the Universe itself. With the advent of technology, the space exploration studying the characteristic behaviour of planetary system got an impetus and the exploration of our nearest neighbour Moon had been the natural sequence in it.

With four billion years of solar system history preserved in it, the Moon, the nearest neighbour of the Earth, had always evoked intense curiosity. Since the initiation of lunar exploration as early as 1959, more than 100 exploratory missions have been carried out and a wealth of lunar data has been accumulated. However, many critical and fundamental questions about Moon's origin, its formation and interior structure, chemical/mineralogical composition are still open.

After the initial euphoria in the sixties and seventies there had been a lull in the lunar exploration. In the recent times, there had been a rejuvenation due to the possibility of certain distinct advantages the moon could provide, as a platform for future Deep Space missions and also the emerging possibility of certain exploitation for the benefit of mankind, in addition to the scientific objectives.

India as one among the very few space faring nations has chalked out its own roadmap for exploring the moon and other bodies in the solar system. Chandrayaan-1 is the first instrumented Indian mission to the Moon and also, the first ISRO venture to leave Earth's gravity. The mission is aimed at high-resolution remote sensing of lunar surface in visible, near infrared



(NIR), low and high energy X-ray regions, to prepare a three-dimensional atlas of both near and far side of the moon and conduct chemical and mineralogical mapping of the entire lunar surface by using the eleven 'state-of-the-art' instruments. In addition, Chandrayaan-1 will release a Moon Impact Probe, which would explore the moon from close quarters as it descends, till impact.

International co-operation has been the hallmark of Indian Space Programme since its inception. ISRO has taken up various space science projects/studies as collaborative effort with the international counterparts at the agency level as well as at various space forums. Chandrayaan-1 mission is one of the most exceptional examples of international collaboration towards exploring the Moon. In addition to the five indigenous instruments, there are six scientific payloads from NASA, ESA and Bulgaria onboard Chandrayaan-1.

This booklet (third edition) elucidates in a systematic and coherent way the basic information about the Moon, relevance of Chandrayaan-1 mission in the context of other lunar missions and overall relevant information on technical and scientific features of ISRO's first mission to the Moon. The authors have done a commendable job in bringing out this booklet in simple language, which I am sure, would provide useful insight to not only scientists and students but, also to common man.

Bangalore
October 2008

G. Madhavan Nair
Chairman, ISRO

Chandrayaan-1

India's First Mission to Moon

1. INTRODUCTION

“MOON”, our closest celestial neighbour, has aroused curiosity much more than any other object in the sky. Moon has been worshipped as deity in different mythologies, called as Chandra / Soma in Indian, Luna in Roman, Selene in Greek and Chang'e in Chinese civilization. One of the oldest Indian scriptures 'Àgveda' which originated in Indus valley civilization states.

त्वं सोम प्र विवित्तो मनीषा ।
त्वं रजिष्ठ मनु नेषि पन्थाम ॥

*O Moon! We should be able to know you through our intellect,
You enlighten us through the right path.*

Àgveda Part – I/91/1
(About 2000 years B.C)

The Moon with the early history of the solar system etched on it, challenges mankind from time immemorial to discover its secrets and admire its marvels. Understanding the Moon provides a pathway to unravel the early evolution of the solar system and that of planet Earth.

2. ABOUT THE MOON

The Moon is the brightest object in the night sky, fifth largest satellite of the solar system and only second in brightness to that of the Sun. The Moon orbits the earth at a distance of about 384,400 km, has a diameter of 3,476 km and a mass of 7.35×10^{22} kg with a mean density of only



3.35 gcm⁻³ as compared to 5.52 gcm⁻³ of that of the Earth. It has no atmosphere and outgassing from the surface is negligible. The gravitational force on the Moon is only one sixth of that of the Earth, and not capable of retaining an atmosphere. The absence of any atmosphere causes the Moon to undergo extremes in temperature. The side of the Moon receiving sunlight becomes scorching hot reaching 130 °C. the night side of the Moon reaches freezing cold temperature of -180 °C. The Moon does not have a substantial core of molten iron like Earth and hence, has no intrinsic magnetic field; but it has weak, scattered, localized magnetic anomalies.

An interesting fact is that the Moon always has the same side facing the Earth. This is because Earth's gravity has slowed the Moon's rotation in such a way that the rotation time just matches the time it takes to go around the Earth. The Moon's rotation period around its axis and revolution period around the Earth are same and is about 27 $\frac{1}{2}$ days. Therefore the Moon's day is equal to its year. The time taken from one new Moon to another new Moon (synodic period) is about 29 $\frac{1}{2}$ days.



Near Side



Far Side

The near side 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.)

Another feature of interest is the fact that the Moon's axis of rotation is inclined at 1.5° to its orbital plane around the Sun. Consequently, the Sun always appears low and close to the horizon at the lunar poles and most craters in the polar regions are in permanent shadow, never receiving sunlight.

2.1. SURFACE

The Moon's surface consists of dry, dusty and rocky material. The rocky crust is about 60 km thick on the near side that faces the Earth and about 150 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. Moon's surface is periodically bombarded with different sizes of meteorites and asteroids. During the initial period of lunar evolution, such giant meteorite impacts resulted in the creation of lunar impact basins.

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, but, relatively low-lying flat areas, produced by massive flow of lava from early era of lunar volcanism, going back to more than 3 billion years. The 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 moves 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 impacts of meteorite of all sizes. The large 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 they record the past impact history of the Moon.

One striking difference between the lunar surface material and that of the Earth concerns the most common kinds of rocks. On the Earth the most common rocks are sedimentary because of erosion of the surface by water and deposition under the sea. On the Moon there is no atmosphere and no water, and the most common kind of rock is igneous ('melt-rocks') in nature.

According to studies, the lunar surface material has the following geological characteristics:

- The Maria contains mostly Fe, Mg, Ti, silicates which form high density minerals, which sink at the bottom of the Lava. These are dark because of the presence of Iron (Fe), which has poor reflectivity;
- The Highlands rocks are largely 'Anorthosite', which is a kind of igneous rock composed of Ca, Al-rich silicates. Since Ca Al Silicates are light in density, they float on the lava and solidify by slow cooling;
- 'Breccias' are fragments of different rocks compacted and welded together by meteorite impacts and are found both in Maria and Highlands.

Analysis of lunar rock samples brought by Apollo missions indicate that

- The rocks have high Calcium (Ca), Aluminium (Al) or Titanium (Ti);
- There is high abundance of Silicon (Si);
- The abundance of Helium on the Moon is much higher compared to that on Earth. This may be due to the fact that over the history of

the Moon, billions of tons of solar Helium have impacted directly onto the surface of the Moon and got trapped in minerals, such as Ilmenite (a mineral of Iron and Titanium; FeTiO_3) that did not diffuse out during the hot cycle of lunar day. Thus abundance of both Helium-3 and Helium-4 should be much higher in lunar Ilmenite than in terrestrial or other extra-terrestrial samples.

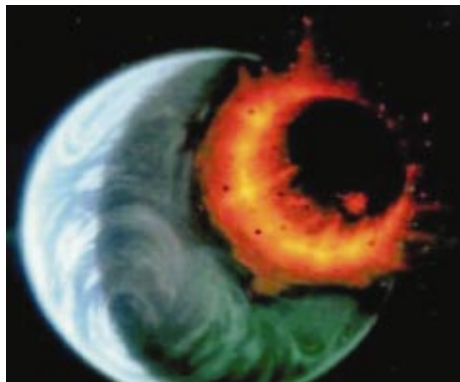
2.2 ORIGIN

The origin of the Moon is still not clearly understood and there are 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 four major theories on the origin of the Moon.

1. **Simultaneous Formation:** Earth and the Moon were formed from the solar nebula near each other. This theory is able to explain why the Earth and the Moon rocks are isotopically so similar, but cannot explain why the Moon is depleted in Iron (Fe).
2. **Capture:** Moon formed somewhere else in the Solar System where the iron content was lower. After it formed, it drifted close to the Earth and was captured by the Earth's gravitational field. This theory cannot explain why the Earth and the Moon rocks are isotopically similar but explains the high angular momentum of the Earth-Moon system.
3. **Fission:** According to this hypothesis, the Moon broke off from the hot molten Earth while the Earth was spinning very rapidly. This hypothesis can explain why the Earth and the Moon rocks are similar, chemically and isotopically, and the low iron content of the Moon, but is not able to explain the high angular momentum of the Earth-Moon system.



4. **Giant impact:** This hypothesis suggests that a body about 1-3 times the size of Mars impacted on the Earth during the last stages of the Earth's formation, after the Earth's iron core has already formed. When the impact occurred, it ejected a large part of the Earth into space and the ejecta then began orbiting the Earth. The material blasted off the Earth coalesced into the Moon. This hypothesis is able to explain (a) the missing Moon iron as most of the material blasted into space would have been depleted in iron, (b) Moon rocks and Earth rocks are isotopically similar and (c) why the Moon's orbit as well as the Earth's orbit are tilted. The giant impact hypothesis however have some difficulties since numerical models predict that a large fraction of the Moon would come from the impactor, leading to the same dilemma as the Capture theory.

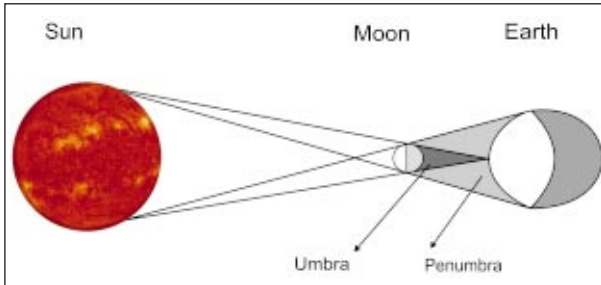


*Picture of giant impact that threw the material from the Earth in Earth's orbit
(Courtesy: Scientific American)*

2.3. ECLIPSES

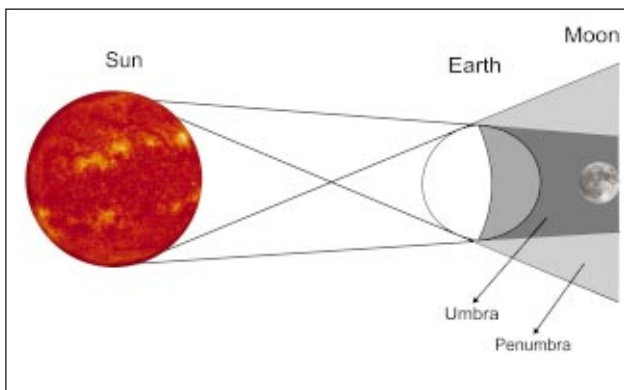
Eclipses occur when the Sun, the Earth and the Moon fall in a straight line and occur only when the new / full moon is near one of its nodes. The nodes are the two points where the orbit of the Moon intersects the plane of the Earth's orbit, the ecliptic.

Solar eclipse takes place on a New Moon day when the Moon passes between the Earth and the Sun. The Moon's shadow fall on the Earth's surface and cover or eclipse some portion of the solar disc.



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)

Lunar eclipses occur at Full Moon when the Sun and the Moon are on opposite sides of the Earth and the full Moon passes into the Earth's shadow cone, in opposition to the Sun.



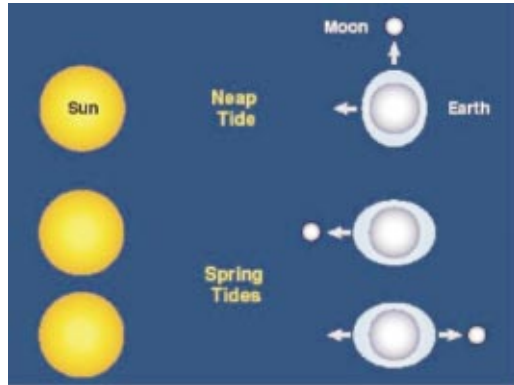
A total lunar eclipse with the Moon lying in the umbra of the Earth's shadow



2.4. TIDES

Tide is the periodic rise and fall of ocean water caused by gravitational forces of the Moon and the Sun. The tidal cycles contain two high tides and two low tides each day.

The gravitational force of the moon pulls the surface of the ocean and it swells outward. The tides are affected by both the Sun and the Moon. The effect of the Sun is less than half of that of the Moon, but when these two bodies are in alignment, the combined pull in the same direction cause large high tides called spring tides.



Tides (<http://csep10.phys.utk.edu>)

On the other hand when the Sun and the Moon are at right angles to each other, with the Moon pulling in one direction and the Sun pulling in another, there is a canceling affect leading to weaker tidal bulges, called neap tides.

2.5. LUNAR MAGNETIC FIELD

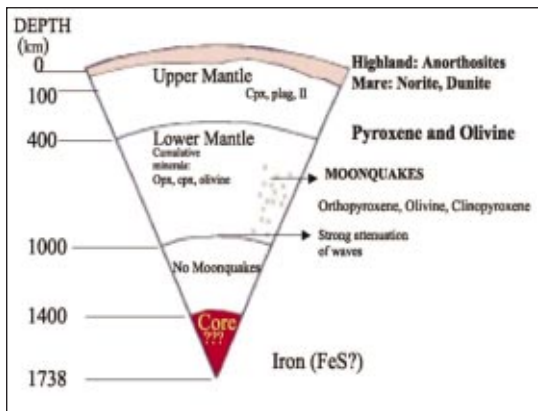
The Moon has no global magnetic field, but magnetization of lunar rocks suggests that it may have had a larger one, earlier in its history. The moon does not have a dipolar magnetic field and presently have variable crustal magnetized zones. It is possible that the transient magnetic fields may have been generated during large impact events. It has been noted that the largest crustal magnetizations appear to be located near the antipodes of the giant impact basins.

2.6. LUNAR GRAVITY

The moon has 1/6th gravity of that of the Earth. The lunar gravity field varies across its surface. These variations are caused by the mascons, which are large mass concentrations, buried underneath the moon's basins. The mascons are due to the presence of dense mare basaltic rocks that fill some of the impact basins. As a result, the major anomalies of the Moon's gravitational field are associated with some of the giant impact basins.

2.7. LUNAR INTERIOR

The present picture of the Moon's interior is that it has a crust about



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)- Al rich mineral (a type of feldspar). Quakes inside the 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)

65 km thick, a mantle about 1000 km thick, and a core if present would be about 300 km in radius. A limited amount of seismic data suggests that the outer core may be molten. Although, there is a small amount of geological activity on the Moon, it is largely inactive.

The age of the rocks can be determined using 'radio-isotope dating' methods.

From the determination of ages of lunar samples brought back by the Apollo missions, it has been found that the oldest material from the



surface of the Moon is 4.5 billion years old, almost as old as the Solar system. Thus the material brought back from the Moon by Apollo and Luna missions provide a window on the very early history of our Solar system that would be difficult to find on the Earth, since the Earth is geologically active and the early geological records have been consequently, obliterated.

3. EARLY INTEREST

The Moon has been the center of attention for mankind, more than any other heavenly body in the sky. Our ancestors recorded the passage of time 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 scientific study of the Moon began. Around 1603, the first lunar drawing based on naked eye observation was compiled.

At the beginning of seventeenth century, a closer look at the Moon by Galileo using his newly invented telescope showed that its surface is uneven, having dark lowland areas and bright 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 reflected signal.

4. LUNAR MISSIONS:

Phase-1: 1959-1980

The ushering in of the space era with the launch of the first artificial satellite, Sputnik-1 in 1957, opened up the prospects of realising the



View of the lunar farside showing the crater Tsiolkovsky, as photographed by the crew of the Apollo 13 mission during lunar pass. (Courtesy: NASA)

man's long cherished dream of reaching the Moon. The programme for lunar exploration was initiated as early as 1959. So far more than 100 lunar exploratory missions (unmanned as well as manned) have been conducted and a dozen men have landed on the Moon. A chronological list of the Lunar Missions is provided later in Section 16 – Chronology of Lunar Exploration.

The first man-made object to reach the Moon was the unmanned Soviet probe, Luna-2 in September 1959. It impacted the lunar surface east of Mare Serenitatis. The mission confirmed that the Moon had no appreciable magnetic field, and found no evidence of radiation belts around the Moon. The Soviet Luna-9 spacecraft was the first spacecraft to achieve a lunar soft landing in February 1966 and to transmit photographic data to Earth. These photographs provided a panoramic view of the nearby lunar surface. Luna-16 was the first robotic probe to land on the Moon and bring back a



Photograph of the Moon's far side showing representative examples of small lunar craters. The largest of the craters seen here, in the left-central part of the photograph, is about 15 kilometers across and has a flat floor. North is to the right in this photograph. (Courtesy: NASA, Apollo 16)

core to the Earth. The first robot lunar rover to land on the Moon was the Soviet Lunokhod-1 in November 1970. The three Luna series of spacecrafts, Luna-16, 20 and 24, retrieved lunar samples.

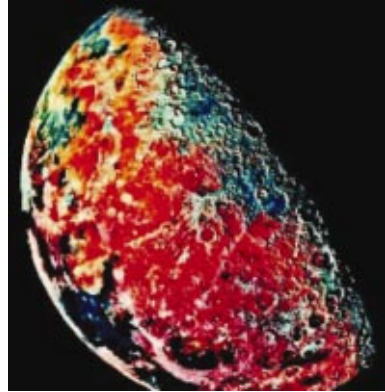
While the Soviet Union was carrying out the Luna series of missions, United States embarked on Ranger and Surveyor missions and the Lunar Orbiters, culminating in the Apollo Moon landing missions. Trips to the Moon moved out of science fiction into reality on July 20, 1969, when Neil Armstrong became the first man to set his foot on the lunar surface (Sea of Tranquility). Astronauts have since explored the surface of the Moon and lunar soil and rock samples weighing about 400 kg have been brought back to Earth by three Luna missions (Luna 16, 20, and 24) and the six Apollo missions 11 through 17, except Apollo 13. The instruments left behind on the Moon by Apollo astronauts provided new information on the Moonquakes, heat flow, meteorite impacts, etc.

Phase-2: 1990 to 2003

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 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.

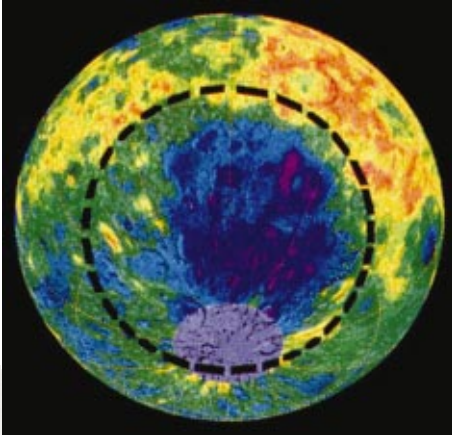
A new era of lunar exploration by many countries has begun using advanced instruments. The Japanese mission, **Hiten** (formerly called MUSES-A) was successfully launched in 1990, to perform a sophisticated Earth-Moon



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

circumnavigation and was finally directed to impact on lunar far side. After a long gap of about 20 years since the Apollo missions in 1970s, the joint European-American **Clementine** mission, equipped with laser image detection and ranging system (LIDAR) and high resolution cameras (HIRES) was launched in 1994. Clementine 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.

The next NASA mission **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 and other radioactive as well as stable elements like Fe, Ti, etc.



View of the South Pole-Aitken Basin, on the Lunar far side- revealed by Clementine laser altimetry (Courtesy: Science)

A common objective of both Clementine and Lunar Prospector missions was to search for lunar water/ice deposits. Radar reflectivity experiments performed by Clementine hinted at the possibility of large amounts of water frozen on the permanently shadowed south polar region of the Moon. Lunar Prospector's neutron spectrometer determined slow

and fast neutron fluxes over the Moon's poles, suggesting the presence of hydrogen and hence possible presence of water/ice. However, these experiments could not decisively confirm the presence of water/ice on the Moon.

SMART-1 (Small Mission for Advance Research and Technology), a lunar orbiter mission was launched by ESA in 2003 with a primary objective of flight-testing solar electric propulsion. SMART-1 had about 7 payloads, the main scientific ones were: a high-resolution camera, a near infrared spectrometer and a low energy compact X-ray spectrometer with a new type of swept charge detector and micro collimator.

5. RENEWAL OF INTEREST

Telescopes have been trained on the Moon since Galileo's days and a number of spacecrafts have flown by, orbited around and landed on the Moon, 12 Apollo astronauts walked on the Moon, collected 382 kg of

lunar rock and soil samples for return to the Earth. Much has been learnt about the astronomical, physical, chemical, isotopic, geological and chronological aspects of the Moon. Despite a wealth of data from lunar exploration to date, critical and fundamental questions still remain about the Moon's origin and formation and its chemical composition. Particularly, a question related to existence of water-ice 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 in lunar exploration.

Apart from the scientific interest, the Moon could offer 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, such as, Helium 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. The relatively high abundance of Helium-3 (^3He) isotope on the Moon 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-silicate grains. However, the mineral Ilmenite (FeTiO_3) that is abundant on the Moon has a 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 that of (Fe + Ti). Over the four billion-year history of the Moon, several hundred million tonnes of ^3He have impacted the surface of the Moon in the form of solar wind. The analyses of Apollo and Luna



samples showed that over 1 million tonnes of ^3He still could remain embedded in the surface of the Moon. Use of a small fraction of this, as fusion fuel would provide for the world's electricity requirements 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 an eagerly waited significant milestone in the history of human development: the colonisation of the Moon! The Moon being the nearest neighbour of the Earth, with lower 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 astronomical observatories, because of the absence of atmosphere and the absence of the Earth's reflected radiation on the far side of the Moon.

5.1. RECENT MISSIONS

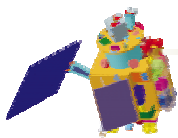
This millennium has seen a resurgence of Planetary Exploration Programme (Moon and beyond), with a large number of space missions announced by USA, Europe, Japan, China and Russia. Apart from understanding the evolution of the solar system objects, a major driving force for this resurgence is to use the Moon as a gateway for exploration of the solar system and beyond. This will require exploration and utilization of available resources on the Moon in an unprecedented scale to ensure that a lunar-base can be established in the foreseeable future. Another important element is the search for any evidence of extinct or extant life form in extra-terrestrial environment, similar to such possibilities on Mars or in the icy satellites of the major planets in the outer solar system.

SELENE (Selenological and Engineering Explorer) is a Japanese mission launched on 14 September 2007. The mission consists 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 km and perilune at 800 km. The scientific objectives include investigation of lunar elemental and mineralogical composition, surface and subsurface structure, the remnant magnetic field and the gravity field.

China has launched a probe called **Chang'e** on 24 October 2007 for orbiting the Moon at about 200 km polar circular orbit and map its surface, measure content and density of lunar soil and explore its environment. The mission carried stereo camera, spectrometer, imager, laser altimeter, microwave radiometer, gamma and X-ray spectrometer for this purpose.

5.2. FUTURE MISSIONS

Lunar Reconnaissance Orbiter (LRO) mission of NASA has the overall objective of obtaining data on lunar resources and other parameters that will facilitate returning man safely to Moon, where, testing and preparation for an eventual manned mission to Mars will be undertaken. The mission would carry multi-channel solar reflectance spectrometer, cosmic ray telescope system, UV measuring instrument, neutron detector, laser altimeter and panchromatic camera. The LRO would be launched together with the **Lunar Crater Observation and Sensing Satellite (LCROSS)**, using the same launch vehicle. The major objective of the LCROSS is to confirm the presence or absence of water/ice in lunar poles. The mission would directly excavate a crater (approximately 20m in diameter) in the permanently shadowed regions of the Moon. This impact will release



materials from the lunar surface that will be analysed for the presence of water (ice and vapour), hydrocarbons and hydrated materials.

6. INDIAN MISSION TO MOON: CHANDRAYAAN-1

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

Right from its inception, pursuit of space research 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 phenomena, which opened up a new chapter in 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 as part of astrophysical, solar and atmospheric research programmes.

India has a vast experience in developing and launching operational spacecraft systems for survey and management of natural resources, meteorological services and satellite communication. Technologies developed for those spacecraft systems, which are readily 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) and Geosynchronous Satellite Launch Vehicle (GSLV) of ISRO are capable of undertaking missions to the Moon and other nearby planets.

The technical capabilities acquired by India and the enthusiasm of modern Indian scientists in exploring the Moon, prompted ISRO to undertake - Chandrayaan-1, India's first mission to the Moon. The primary objectives of the mission are to expand knowledge about the origin and evolution of the Moon, further upgrade India's technological capabilities and provide challenging opportunities to the young scientists working in planetary sciences.

The idea of an Indian mission to the Moon was initially mooted in a meeting of the Indian Academy of Sciences in 1999 that was followed up by discussions in the Astronautical Society of India in 2000. Based on the recommendations made by the learned members of these forums, a National Lunar Mission Task Force was constituted by the Indian Space Research Organisation (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 Mission to the Moon.

A peer group of more than hundred eminent Indian scientists representing various fields of planetary and space sciences, earth sciences, physics, chemistry, astronomy, astrophysics, engineering and communication sciences deliberated on the Study Report of the Task Team in 2003 and unanimously recommended that India should undertake the Mission to the Moon, particularly, in view of the renewed international interest with



several exciting lunar missions planned for the new millennium. In addition, such a mission will provide the needed thrust to basic science and engineering research in the country, including new challenges to ISRO to go beyond the geostationary orbit.

The Chandrayaan-1 mission will be an important catalyst for the youngsters to pursue fundamental research. The academia, in particular, the university scientists would find participation in such a project like Chandrayaan-1 intellectually rewarding.

Government of India approved ISRO's proposal for the first Indian Moon Mission, called Chandrayaan-1, in November 2003.

7. OBJECTIVES

7.a *Scientific Objectives*

The Chandrayaan-1 mission is aimed at high-resolution remote sensing of the Moon in visible, near Infrared, low energy X-ray and high-energy X-ray regions. Specifically, the objectives are

- To prepare a three-dimensional atlas (with a high spatial and altitude resolution of 5-10 m) of both near and far side of the Moon.
- To conduct chemical and mineralogical mapping of the entire lunar surface for distribution of mineral and chemical elements such as Magnesium, Aluminum, Silicon, Calcium, Iron and Titanium as well as high atomic number elements such as Radon, Uranium and Thorium with high spatial resolution.

The simultaneous photo-geological, mineralogical and chemical mapping through Chandrayaan-1 mission will enable identification of different geological units to infer the early evolutionary history of the Moon. The

chemical mapping will enable to determine the stratigraphy and nature of the Moon's crust and thereby test certain aspects of magma ocean hypothesis. This may allow to determine the compositions of impactors that bombarded the Moon during its early evolution, which is also relevant to the formation of the Earth.

7.b Mission Objectives

- To realise the mission goal of harnessing the science payloads, lunar craft and the launch vehicle with suitable ground support systems including Deep Space Network station.
- To realise the integration and testing, launching and achieving lunar polar orbit of about 100 km, in-orbit operation of experiments, communication/ telecommand, telemetry data reception, quick look data and archival for scientific investigation by identified group of scientists.

8. SCIENTIFIC PAYLOADS

Chandrayaan-1 is a well-planned mission to be launched on 22 October 2008, with a significant international participation and with ten scientific payloads and an impact probe.

Chandrayaan-1 has indigenously developed four core payload/experiments: TMC, HySI, LLRI and HEX and a Moon Impact Probe (MIP) to impact on a predetermined location on the lunar surface.

- Terrain Mapping stereo Camera (TMC) in the panchromatic band, having 5 m spatial resolution and 20 km swath
- Hyper Spectral Imaging camera (HySI) operating in 0.4-0.95 μm band with a spectral resolution of 15 nm and spatial resolution of 80 m with a swath of 20 km



- Lunar Laser Ranging Instrument (LLRI) with height resolution of less than 5 m
- High Energy X-ray spectrometer (HEX) using Cadmium-Zinc-Telluride (CdZnTe) detector in the 30-270 keV energy region with spatial resolution of 33 km
- Moon Impact Probe (MIP) as piggyback payload on the main orbiter of the Chandrayaan-1 spacecraft, which will impact on the surface of the Moon

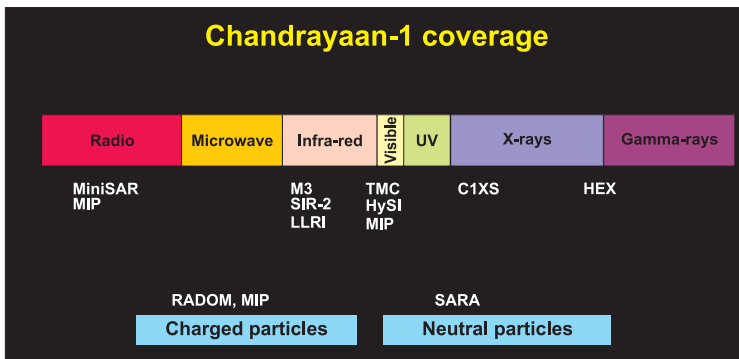
Apart from the above indigenous payloads/experiments, ISRO solicited proposals through an Announcement of Opportunity (AO) from International and Indian Scientific Community for participating in the mission by providing suitable scientific payloads, complementing the overall Chandrayaan-1 scientific objectives. Out of the proposals received, six experiments were selected for inclusion in Chandrayaan-1 mission; two of the AO payloads, C1XS and SARA are developed by ESA jointly with ISRO.

- Chandrayaan-1 X-ray Spectrometer (C1XS) through ESA - collaboration between Rutherford Appleton Laboratory, UK and ISRO Satellite Centre, ISRO. Part of this payload is redesigned by ISRO to suit Chandrayaan-1 scientific objectives.
- Near Infra Red spectrometer (SIR-2) from Max Plank Institute, Lindau, Germany through ESA.
- Sub keV Atom Reflecting Analyser (SARA) through ESA, collaboration between Swedish Institute of Space Physics, Sweden and Space Physics Laboratory, Vikram Sarabhai Space Centre, ISRO. The Data Processing Unit of this payload/ experiment is designed and developed by ISRO, while Swedish Institute of Space Physics has developed the payload sensor.

- Radiation Dose Monitor Experiment (RADOM) from Bulgarian Academy of Sciences.
- Miniature Synthetic Aperture Radar (Mini-SAR) from Applied Physics Laboratory, Johns Hopkins University and Naval Air Warfare Centre, USA through NASA.
- Moon Mineralogy Mapper (M3) from Brown University and Jet Propulsion Laboratory, USA through NASA.

Provided below is the summary of the prime objectives of the eleven payloads carried onboard Chandrayaan-1 mission

Prime Objectives	Payload
Chemical Mapping	C1XS, HEX
Mineralogical Mapping	HySI, SIR-2, M3
Topography Mapping	LLRI, TMC
Radiation Environment	RADOM, HEX, C1XS
Magnetic Field Mapping	SARA
Volatile Transport	HEX
Lunar Atmospheric constituent	MIP



Summary of Chandrayaan-1 Prime Science Objectives and Wavelength Range Coverage



8.1. DETAILS OF INDIAN PAYLOADS

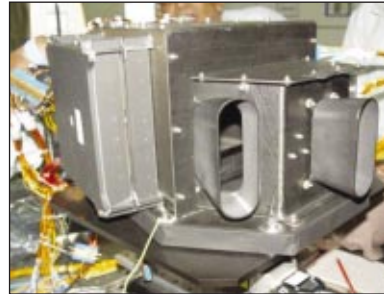
i. Terrain Mapping Camera (TMC)

Scientific Objective

The aim of TMC is to map topography of both near and far side of the Moon and prepare a 3-dimensional atlas with high spatial and elevation resolution of 5 m. Such high resolution mapping of complete lunar surface will help to understand the evolution processes and allow detailed study of regions of scientific interests. The digital elevation model available from TMC would improve upon the existing knowledge of Lunar Topography.

Payload Configuration Details

The TMC will image in the panchromatic spectral region of 0.5 to 0.85 μm , with a spatial/ ground resolution of 5 m and swath coverage of 20 km. The camera is configured for imaging in the pushbroom mode, with three linear 4k element detectors in the image plane for fore, nadir and aft views, along the ground track of the satellite. The fore and aft view angles are $\pm 25^\circ$ respectively w.r.t. Nadir. TMC will measure the solar radiation reflected / scattered from the Moon's surface. The dynamic range of the reflected signal is quite large, represented by the two extreme targets – fresh crust rocks and mature mare soil.



TMC

TMC uses Linear Active Pixel Sensor (APS) detector with in-built digitizer. Single refractive optics will cover the total field of view for the three detectors. The output of the detector will be in digitized form. The optics

is designed as a single unit catering to the wide field of view (FOV) requirement in the direction along the ground track. The incident beams from the fore (+25°) and aft (-25°) directions are directed on to the focusing optics, using mirrors. Modular camera electronics for each detector is custom designed for the system requirements using FPGA. The expected data rate is of the order of 50 Mbps. The dimension of TMC payload is 370 mm x 220 mm x 414 mm and mass is 6.3 kg.

ii. Hyper Spectral Imager (HySI)

Scientific Objective

The main aim is to obtain spectroscopic data for mineralogical mapping of the lunar surface. The data from this instrument will help in improving the available information on mineral composition of the surface of Moon. Also, the study of data in deep crater regions/central peaks, which represents lower crust or upper mantle material, will help in understanding the mineralogical composition of Moon's interior.

Payload Configuration Details

The uniqueness of the HySI is in its capability of mapping the lunar surface in 64 contiguous bands in the VNIR, the spectral range of 0.4-0.95 μm region with a spectral resolution of better than 15 nm and spatial resolution of 80 m, with swath coverage of 20 km. HySI will collect the Sun's reflected light from the Moon's surface through a tele-centric refractive optics and focus on to an APS area detector for this purpose.

The dispersion is achieved by using a wedge filter so as to reduce the



HySI



weight and compactness of the system compared to using a prism / grating. The wedge filter is an interference filter with varying thickness along one dimension so that the transmitted spectral range varies in that direction. The wedge filter will be placed in close proximity to an area detector. Thus, different pixels in a row of the detector will be receiving irradiance from the same spectral region but different spatial regions in the across track direction. In the column direction of the detector, different rows will receive irradiance of different spectral as well as spatial regions in the along track direction. The full spectrum of a target is obtained by acquiring image data in push broom mode, as the satellite moves along the column direction of the detector. An Active Pixel Sensor (APS) area array detector with built-in digitizer would map the spectral bands. The payload mass is 2.5 kg and its size is 275 mm x 255 mm x 205 mm.

iii. Lunar Laser Ranging Instrument (LLRI)

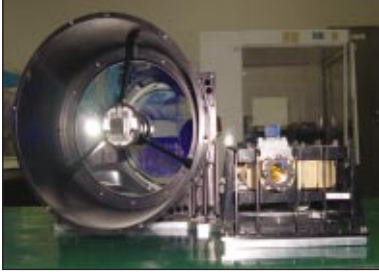
The elevation map of the Moon prepared using the laser ranging instrument carried onboard Chandrayaan-1 spacecraft will help in studying the morphology of large basins and other lunar features, study stress, strain and flexural properties of the lithosphere and when coupled with gravity studies, would be able to find the density distribution of the crust.

Scientific Objective

To provide ranging data for determining the height difference between the spacecraft and the lunar surface.

Payload Configuration Details

LLRI works on the time-Of-Flight (TOF) principle. In this method, a coherent pulse of light from a high power laser is directed towards the target whose range is to be measured. A fraction of the light is scattered back in the direction of the laser source where an optical receiver collects it and focuses it on to a photoelectric detector. By accurately measuring



LLRI

the roundtrip travel time of the laser pulse, highly accurate range/spot elevation measurements can be made.

LLRI consists of a 10 mJ Nd:YAG laser with 1064nm wave source operating at 10 Hz pulse repetition mode. The reflected laser pulse from the lunar surface is collected by a 200 mm Ritchey-Chrétien Optical receiver and focused on to a Silicon Avalanche Photodetector. The output of the detector is amplified and threshold detected for generating range information to an accuracy <5m. Four constant fraction discriminators provide the slope information in addition to range information. The different modes of operation of LLRI and the range computations from the detector output are controlled and computed by a FPGA based electronics. The processed outputs of LLRI will be used for generating high accuracy lunar topography. The payload mass is 11.37 kg with base plate.

iv. High Energy X-ray Spectrometer (HEX)

The High-Energy X-ray spectrometer covers the hard X-ray region from 30 keV to 270 keV. This is the first experiment to carry out spectral studies of planetary surface at hard X-ray energies using good energy resolution detectors.

The High Energy X-ray (HEX) experiment is designed primarily to study the emission of low energy (30-270 keV) natural gamma-rays from the lunar surface due to ^{238}U and ^{232}Th and their decay chain nuclides.

Scientific Objectives

The scientific goal of the HEX instrument is as follows



- To identify excess ^{210}Pb in lunar polar regions deposited there as a result of transport of gaseous ^{222}Rn , a decay product of ^{238}U from other regions of the Moon. This will enable us to understand transport of other volatiles such as water to the polar regions.
- To detect other radioactive emissions, to characterise various lunar terrains for their chemical and radioactive composition on the basis of specific/integrated signal in the 30-270 keV region.
- To explore the possibility of identifying polar regions covered by thick water-ice deposit from a study of the continuum background.

Payload Configuration Details

The geometric detector area of 144 cm^2 is realized by nine Cadmium Zinc Telluride (CZT) arrays, each $4\text{ cm} \times 4\text{ cm}$ (5 mm thick), composed of 256 (16x16) pixels (size: $2.5\text{ mm} \times 2.5\text{ mm}$). Each CZT array is readout using two closely mounted Application Specific Integrated Circuits (ASICs), which provides self-triggering capability. The detector will be biased at the cathode with -550 V and the electronic charge signals are collected at the anode. A Cesium Iodide (CsI (TI)) scintillator crystal coupled to photomultiplier tubes (PMT), will be used as the anticoincidence system (ACS). The ACS is used to reduce the detector background.



HEX

A specially designed collimator provides a field of view (FOV) of $33\text{ km} \times 33\text{ km}$ at the lunar surface from a 100 km orbit. The spatial resolution of HEX is 33 km and the mass is 14.4 kg.

v. Moon Impact Probe (MIP)

The impact probe of 35 kg mass will be attached at the top deck of the main orbiter and will be released during the final 100 km x 100 km orbit at a predetermined time to impact at a pre-selected location. During the descent phase, it is spin-stabilized. The total flying time from release to impact on Moon is around 25 minutes.

The primary objective is to demonstrate the technologies required for landing the probe at a desired location on the Moon and to qualify some of the technologies related to future soft landing missions.

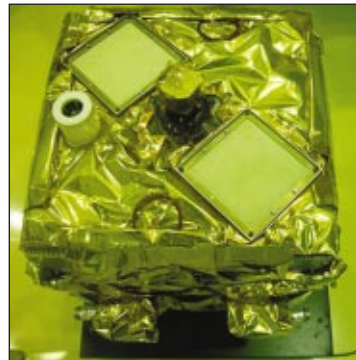
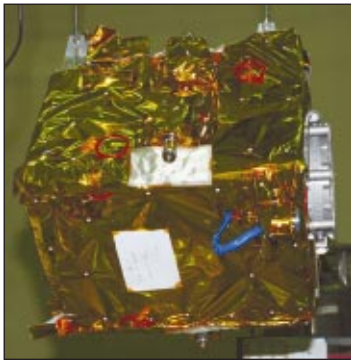
Main Objectives

- Design, development and demonstration of technologies required for impacting a probe at the desired location on the Moon.
- Qualify technologies required for future soft landing missions.
- Scientific exploration of the Moon from close range.

Payload Configuration Details

There will be three instruments on the Moon Impact Probe

- Radar Altimeter – for measurement of altitude of the Moon Impact



MIP



Probe and for qualifying technologies for future landing missions. The operating frequency band is $4.3 \text{ GHz} \pm 100 \text{ MHz}$.

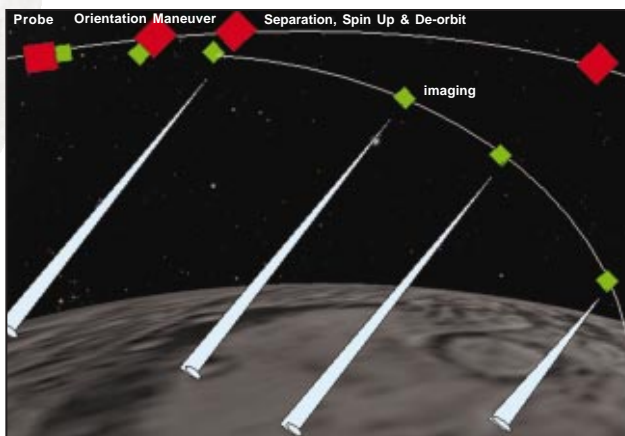
- Video Imaging System – for acquiring images of the surface of the Moon during the descent at a close range. The video imaging system consists of analog CCD camera.
- Mass Spectrometer – for measuring the constituents of tenuous lunar atmosphere during descent. This instrument will be based on a state-of-the-art, commercially available Quadrupole mass spectrometer with a mass resolution of 0.5 amu and sensitivities to partial pressure of the order of 10^{-14} torr.

The dimension of the impact probe is 375 mm x 375 mm x 470 mm

MIP System configuration

The Moon Impact Probe (MIP) essentially consists of honeycomb structure, which houses all the subsystems and instruments. In addition to the instruments, the separation system, the de-boost spin and de-spin motors, it comprises of the avionics system and thermal control system. The avionics system supports the payloads and provides

communication link between MIP and the main orbiter, from separation to impact and provides a database useful for future soft landing.



Impact Probe Mission Profile

The mission envisages collecting all the instrument data during descent and transmits to main orbiter, which in turn will transmit them to the ground station during visible phases.

8.2. DETAILS OF ANNOUNCEMENT OF OPPORTUNITY PAYLOADS

i. Chandrayaan-1 X-ray Spectrometer (C1XS)

Scientific Objective

The primary goal of the C1XS instrument is to carry out high quality X-ray spectroscopic mapping of the Moon, in order to constrain solutions to key questions on the origin and evolution of the Moon. C1XS will use X-ray fluorescence spectrometry (1.0-10 keV) to measure the elemental abundance, and map the distribution, of the three main rock forming elements: Mg, Al and Si. During periods of enhanced solar activity (solar flares) events, it may be possible to determine the abundance of minor elements such as Ca, Ti and Fe on the surface of the Moon.

Background

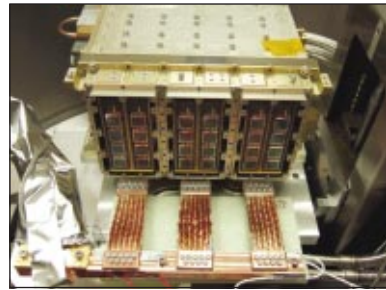
When a primary X-ray beam strikes a sample, the X-rays can either be absorbed or scattered by the atom. Upon absorption the X-ray, transfers all its energy to an innermost electron. If the primary X-ray has sufficient energy, electrons are ejected from the inner shells creating vacancies, causing an unstable condition for the atom. As the atom returns to its stable condition, electrons from the outer shells are transferred to the inner shells and in the process they radiate an X-ray photon at a characteristic energy. Each element has a unique set of energy levels, and produces X-rays at a unique set of energies, allowing it to be identified by measurement and thereby to derive the elemental composition of a sample. The process of emission of characteristic X-rays is called 'X-ray Fluorescence' or XRF and is widely used to measure the elemental composition of materials.



Solar X-rays excite fluorescent emission from the lunar surface. It is possible to map the absolute elemental abundances of the main rock-forming elements on the Moon by simultaneous measurement of this emission, and by monitoring of the incident Solar X-ray flux. In addition, during bright flares, localized concentration levels of key minor elements can also be detected.

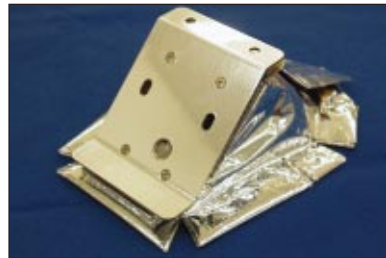
Payload Configuration Details

The instrument utilises technologically innovative Swept Charge Device (SCD) X-ray sensors, which are mounted behind low profile gold/copper collimators and aluminium/polycarbonate thin film filters. The system has the virtue of providing superior X-ray detection, spectroscopic and spatial measurement capabilities, while also operating at near room temperature. A deployable proton shield protects the SCDs during passages through the Earth's radiation belts, and from major particle events in the lunar orbit. In order to record the incident solar X-ray flux at the Moon, which is needed to derive absolute lunar elemental surface abundances, C1XS also includes an X-ray Solar Monitor.



C1XS

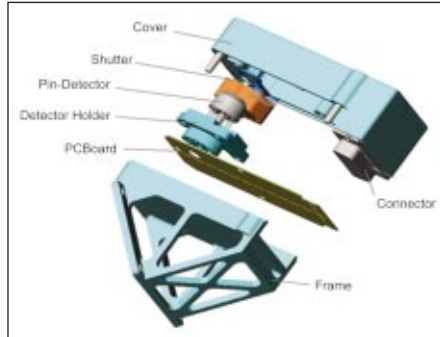
The X-ray Solar Monitor (XSM) is provided through collaboration between Rutherford Appleton Laboratory (RAL) and University of Helsinki. With its wide field-of-view of ± 52 degrees, XSM provides observation of the solar X-ray



XSM

spectrum from 1-20 keV with good energy resolution ($< 250 \text{ keV}@5.9 \text{ keV}$) and fast spectral sampling at 16 s intervals.

Throughout the normal solar conditions, C1XS will be able to detect abundance of Mg, Al and Si in the lunar surface. During solar flare events, it may additionally be possible to detect other elements such as Ca, Ti and Fe. The onboard solar monitor acting in real time will greatly enhance the capability of C1XS to determine absolute elemental abundances as well as their ratios. The total mass of C1XS and XSM is 5.2 kg.



XSM Sensor Unit Parts

C1XS will be able to map the highland, mare regions, impact basins and large craters on the Moon. The observation may be able to shed some light on the existence and scale of pre-mare volcanism, help to refine estimates of the bulk composition of the Moon and improve the evolutionary models.

Heritage: The primary C1XS instrument is based on the D-CIXS instrument on the ESA SMART-1 mission, which is redesigned to suit Chandrayaan-1 scientific objectives.

ii. Sub keV Atom Reflecting Analyser (SARA)

Scientific Objectives

SARA will image the Moon surface using low energy neutral atoms as diagnostics in the energy range 10 eV - 3.2 keV to address the following scientific objectives:

- Imaging the Moon's surface composition including the permanently



shadowed areas and volatile rich areas

- Imaging the solar wind-surface interaction
- Imaging the lunar surface magnetic anomalies
- Studies of space weathering

Background

The Moon does not possess a magnetosphere and atmosphere. Therefore, the solar wind ions directly impinge on the lunar surface, resulting in sputtering and backscattering. The kick-off and neutralized solar wind particles leave the surface mostly as neutral atoms. The notable part of the atoms has energy exceeding the escape energy and thus, such atoms propagate along ballistic trajectories. The SARA instrument is designed to detect such atoms with sufficient angular and mass resolution to address the above scientific objectives. SARA is the first-ever energetic neutral atom imaging mass spectrometer.

Payload Configuration Details

The SARA instrument consists of neutral atom sensor CENA (Chandrayaan-1 Energetic Neutrals Analyzer), solar wind monitor SWIM and DPU (Data Processing Unit). CENA and SWIM interface with DPU, which in turn interfaces with the spacecraft. The masses of CENA, SWIM and DPU are

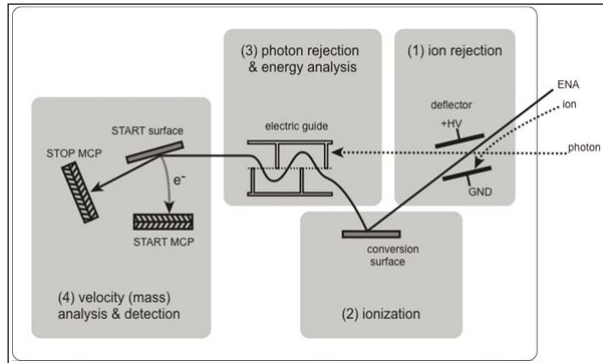


SARA

2 kg, 0.5 kg and 2 kg respectively, totaling the SARA mass as 4.5 kg.

The functional blocks of CENA are shown below: Low-energy neutral atoms enter through an electrostatic charged particle deflector (1), which sweeps away ambient charged particles by a static electric field. The

incoming low energy neutral atoms are converted to positive ions on an ionization surface (2), and then passed through an electrostatic



CENA main components

analyzer of a specific (“wave”) shape that provides energy analysis and effectively blocks photons (3). Particles finally enter the detection section (4) where they are reflected at grazing incidence from a start surface towards one of several stop micro channel plate (MCP) detectors. Secondary electrons generated at the start surface and the stop pulses from the stop MCP detectors preserve the direction and the velocity of the incident particle.

SWIM is an ion mass analyzer, optimized to provide monitoring of the precipitating ions. Ions first enter the deflector, which provides selection on the azimuth angle, following a cylindrical electrostatic analyzer. Exiting the analyzer the ions are post-accelerated up to 1 keV and enter the time-of-flight cell, where their velocity is determined by the same principle (surface reflection), as in the CENA instrument.

iii. Near-IR Spectrometer (SIR-2)

Scientific Objectives

SIR-2 will address the surface-related aspects of lunar science in the following broad categories:

- Analyse the lunar surface in various geological/mineralogical and topographical units;



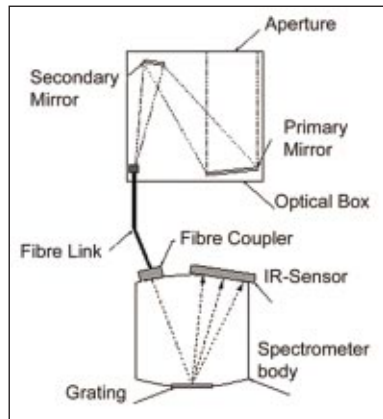
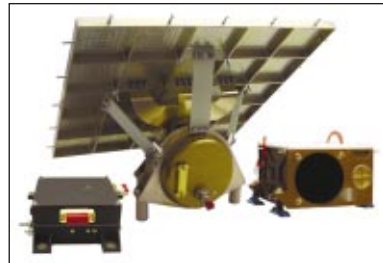
- Study the vertical variation in composition of crust;
- Investigate the process of basin, maria and crater formation on the Moon;
- Explore “Space Weathering” processes of the lunar surface;
- Survey mineral lunar resources for future landing sites and exploration.

Background

The determination of the chemical composition of a planet's crust and mantle is one of the important goals of planetary research. Diagnostic absorption bands of various minerals and ices, which are expected to be found on the surfaces of planetary bodies, are located in the near-IR range, thus making near-infrared measurements of rocks, particularly, suitable for identifying minerals.

Payload Configuration Details

SIR-2 is a grating NIR point spectrometer working in the 0.93-2.4 microns wavelength range with 6 nm spectral resolution. It collects the Sun's light reflected by the Moon with the help of a main and a secondary mirror.



This light is fed through an optical fiber to the instrument's sensor head, where it is reflected off a dispersion grating. The dispersed light reaches a detector, which consists of a row of photosensitive pixels that measure

the intensity as a function of wavelength and produces an electronic signal, which is read out and processed by the experiment's electronics.

The mass of the instrument is 3.3 kg and the instrument unit dimension is 260 mm x 171 mm x 143 mm.

iv. Radiation Dose Monitor Experiment (RADOM)

Scientific Objectives

RADOM will qualitatively and quantitatively characterize the radiation environment in near lunar space, in terms of particle flux, dose rate and deposited energy spectrum. The specific objectives are

- Measure the particle flux, deposited energy spectrum, accumulated radiation dose rates in Lunar orbit;
- Provide an estimate of the radiation dose around the Moon at different altitudes and latitudes;
- Study the radiation hazards during the Moon exploration. Data obtained will be used for the evaluation of the radiation environment and the radiation shielding requirements of future manned Moon missions.

Background

The dominant radiation components outside the earth's magnetosphere are the Galactic Cosmic Rays (GCR), modulated by the magnetic fields associated with the low energy charged particles (the solar wind), which are continuously emitted from the Sun and the Solar energetic Particle Events (SPE) emitted during solar flares, sudden sporadic eruptions of the chromosphere of the Sun.

Radiation exposure of crewmembers on future manned space flight had been recognised as an important factor for the planning and designing of such missions. Indeed, the effects of ionising radiation on crew health,



performance and life expectancy are a limitation to the duration of man's sojourn in space. Predicting the effects of radiation on humans during a long-duration space mission requires i) accurate knowledge and modelling of the space radiation environment, ii) calculation of primary and secondary particle transport through shielding materials and through the human body, and iii) assessment of the biological effects of the dose. The general purpose of RADOM is to study the radiation hazards during the Moon exploration. Data obtained will be used for the evaluation of radiation environment and radiation shielding requirements for future manned lunar missions.

Payload Configuration Details

RADOM is a miniature spectrometer-dosimeter containing one semiconductor detector of 0.3 mm thickness, one charge-sensitive preamplifier and two micro controllers. The detector weighs 139.8 mg. Pulse analysis technique is used for obtaining the deposited energy spectrum, which is further converted to the deposited dose and flux in the silicon detector. The exposure time for one spectrum is fixed at 30 s. The RADOM spectrometer will measure the spectrum of the deposited energy from primary and secondary particles in 256 channels. RADOM mass is 160 g.



RADOM

v. Miniature Synthetic Aperture Radar (Mini-SAR)

Scientific Objective

To detect water ice in the permanently shadowed regions on the Lunar poles, upto a depth of a few meters.

Background

Although returned lunar samples show the Moon to be extremely dry, recent research suggest that water-ice may exist in the polar regions. Because its axis of rotation is perpendicular to the ecliptic plane, the poles of the Moon contain areas that never receive light and are permanently dark. This results in the creation of “cold traps”, zones that, because they are never illuminated by the sun, may be as cold as 50–70° K. Cometary debris and meteorites containing water-bearing minerals constantly bombard the Moon. Most of this water is lost to space, but, if a water molecule finds its way into a cold trap, it remains there forever – no physical process is known that can remove it. Over geological time, significant quantities of water could accumulate.

In 1994, the Clementine polar-orbiting spacecraft used its radio transmitter to “illuminate” these dark, cold trap areas; echoes were recorded by the radio antennas of the Earth-based Deep Space Network. Analysis of one series of data indicated that at least some of the dark regions near the South Pole had reflections that mimicked the radio-scattering behavior of ice. Subsequently, the orbiting Lunar Prospector spacecraft found large quantities of hydrogen in the polar regions, corresponding closely with large areas of permanent shadow, consistent with the presence of water ice. The controversy over lunar polar ice continues to this day.

An onboard SAR at suitable incidence would allow viewing of all permanently shadowed areas on the Moon, regardless of whether sunlight is available or the angle is not satisfactory. The radar would observe these areas at incidence angle near 45 degrees, recording echoes in both orthogonal senses of received polarization, allowing ice to be optimally distinguished from dry lunar surface.

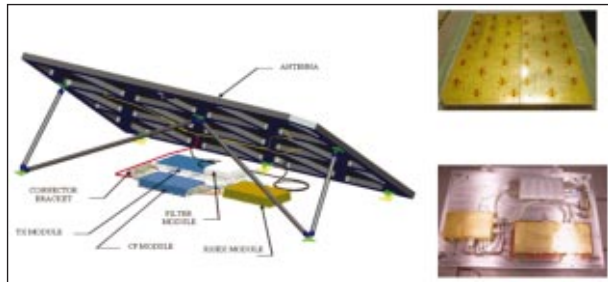


The Mini-SAR radar system can operate as an altimeter/scatterometer, radiometer, and as a synthetic aperture radar imager.

Payload Configuration Details

The Mini-SAR system will transmit Right Circular Polarization (RCP) and receive, both Left Circular polarization (LCP) and RCP. In scatterometer

mode, the system will measure the RCP and LCP response in the altimetry footprint, along the nadir ground



Mini-SAR

track. In radiometer mode, the system will measure the surface RF emissivity, allowing determination of the near normal incidence Fresnel reflectivity. Meter-scale surface roughness and circular polarization ratio (CPR) will also be determined for this footprint. This allows the characterization of the radar and physical properties of the lunar surface (e.g., dielectric constant, porosity) for a network of points. When directed off nadir, the radar system will image a swath parallel to the orbital track by delay/Doppler methods (SAR mode) in both RCP and LCP.

The synthetic aperture radar system works at a frequency 2.38 GHz, with a resolution of 75 m per pixel from 100km orbit and its mass is 8.77 kg.

vi. Moon Mineralogy Mapper (M3)

M3 with high-resolution compositional maps will improve the understanding of the early evolution of a differentiated planetary body and provide a high-resolution assessment of lunar resources.

Scientific Objectives

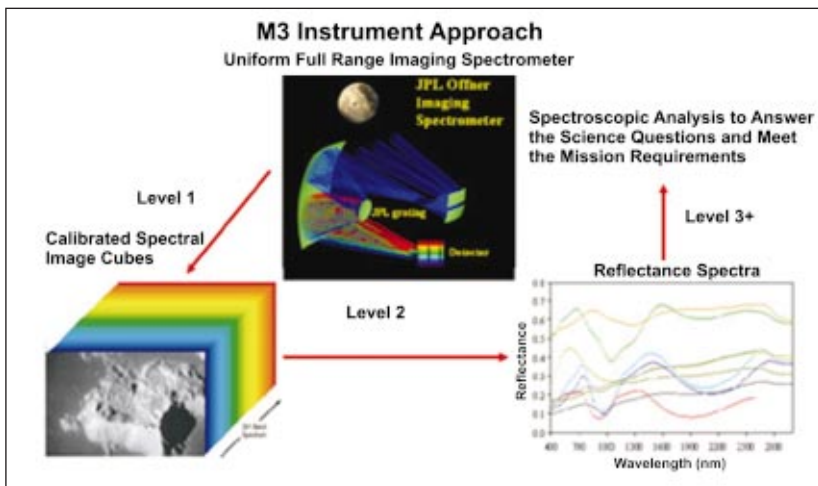
The primary Science goal of M3 is to characterize and map lunar surface mineralogy in the context of lunar geologic evolution. This translates into several sub-topics relating to understanding the highland crust, basaltic volcanism, impact craters, and potential volatiles.

The primary *exploration* goal is to assess and map lunar mineral resources at high spatial resolution to support planning for future, targeted missions. These M3 goals translate directly into the following requirements:

- Accurate measurement of diagnostic absorption features of rocks and minerals;
- High spectral resolution for deconvolution into mineral components;
- High spatial resolution for assessment geologic context and active processes;

M3 Measurements

M3 measurements are obtained for 640 cross track spatial elements



M3 Optical Configuration

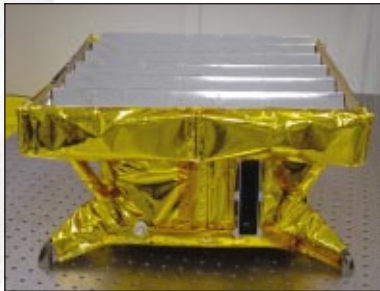


and 261 spectral elements. This translates to 70 m/pixel spatial resolution and 10 nm spectral resolution (continuous) from a nominal 100 km polar orbit for Chandrayaan-1. The M3 FOV is 40 km in order to allow contiguous orbit-to-orbit measurements at the equator that will minimize lighting condition variations.

Payload Configuration Details

The M3 scientific instrument is a high throughput pushbroom imaging spectrometer, operating in 0.7 to 3.0 μm range. It measures solar reflected energy, using a two-dimensional HgCdTe detector array.

Sampling	:	10 nanometers
Spatial resolution	:	70 m/pixel [from 100 km orbit]
Field of View	:	40 km [from 100 km orbit]
Mass	:	8.2 kg



M3

The spectral range 0.7 to 2.6 μm captures the absorption bands for the most important lunar minerals. In addition, the spectral range 2.5 to 3.0 μm is critical for detection of possible volatiles near the lunar poles. The presence of small amounts of OH or H₂O can be unambiguously identified from

fundamental absorptions that occur near 3000 nm.

9. SPACECRAFT

Spacecraft for this lunar mission is a cuboid of approximately 1.5 m side, weighing about 675 kg at lunar orbit. It is a 3-axis stabilized spacecraft. A single canted solar array will provide the required power during all phases



View of Chandrayaan-1 Spacecraft

of the mission. The panel generates about 750 W of average power and will be supported by a Lithium ion (Li-Ion) battery during eclipse operations. The Chandrayaan-1 deployable solar array consisting of a single panel and yoke is stowed on the deck of the spacecraft. After deployment, the solar panel plane is canted by 30° to the spacecraft pitch axis.

The spacecraft uses an X-band, 0.7 m diameter parabolic dish antenna for payload data transmission.

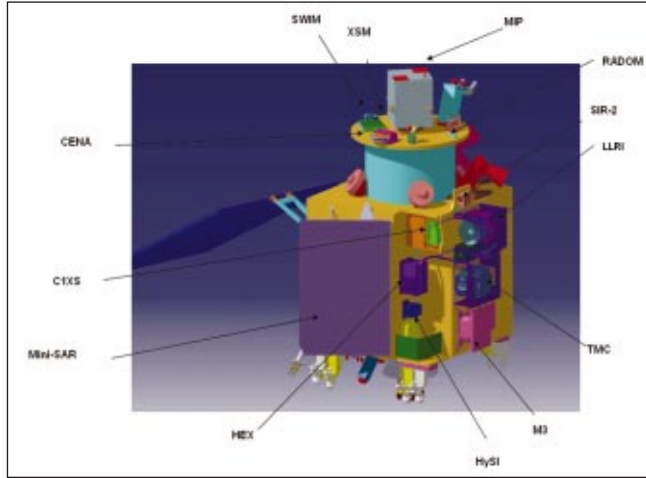
The antenna is required to track the earth station, when the spacecraft is in lunar orbit.

The spacecraft uses a bipropellant integrated propulsion system to carry it to lunar orbit as well as to provide orbit and attitude maintenance, while at the Moon. The propulsion system will carry required propellant for a mission life of 2 years, with adequate margin. The Telemetry, Tracking & Command (TTC) communication will be in the S-band and the scientific payload data transmission will be in X-band.

The spacecraft has three Solid State Recorders (SSRs) on board to record data from various payloads. SSR-1 (TMC/HySI/Mini-SAR) will store science payload data and has capability of storing 32Gb data; SSR-2



will store science payload data (HEX, C 1 X S , R A D O M , L L R I , S I R - 2 , S A R A and M I P) along w i t h spacecraft attitude information



Artist's impression of Chandrayaan-1 Spacecraft

(gyro and star sensor), satellite house keeping data and other auxiliary data. SSR-2 is designed to collect and store data for 7 non-visible orbits w.r.t. IDSN Bangalore. The storing capacity of SSR-2 is 8Gb. M3 payload has an independent SSR with 10Gb capacity.

10. LAUNCH VEHICLE

The Indian Space Research Organisation (ISRO) built its first Polar Satellite Launch Vehicle (PSLV) in the early 90s. The 45 m tall PSLV with a lift-off mass of 295 tonne, had its maiden success on October 15, 1994, when it launched India's IRS-P2 remote sensing satellite into a Polar Sun Synchronous Orbit (SSO) of 820 km altitude. Since its first successful launch in 1994, PSLV has launched nine Indian Remote Sensing satellites as well as two micro satellites HAMSAT and IMS-1 built by ISRO, a recoverable space capsule SRE-1, and fourteen small satellites for foreign customers into polar Sun Synchronous Orbits. Besides, it has launched one Indian meteorological satellite Kalpana-1 into Geosynchronous Transfer Orbit (GTO). PSLV has emerged as ISRO's workhorse launch vehicle and proved its reliability and versatility by scoring continuous

successes in launching multiple payloads to both SSO as well as GTO.

Considering the maturity of Polar Satellite Launch Vehicle (PSLV) demonstrated through various performances, PSLV is chosen for the first lunar mission. The upgraded version of PSLV viz., PSLV-XL (PSLV-C11) will be used to inject the 1380 kg mass spacecraft into a 257 x 22,858 km orbit.

PSLV has four stages, using solid and liquid propulsion systems alternately. Six strap-on motors augment the first stage thrust. PSLV-XL is the upgraded version of PSLV. In PSLV-XL, the six strap-on motors carry 4 tonne more propellant compared to PSLV; There is also an increase in the length of each strap-on.

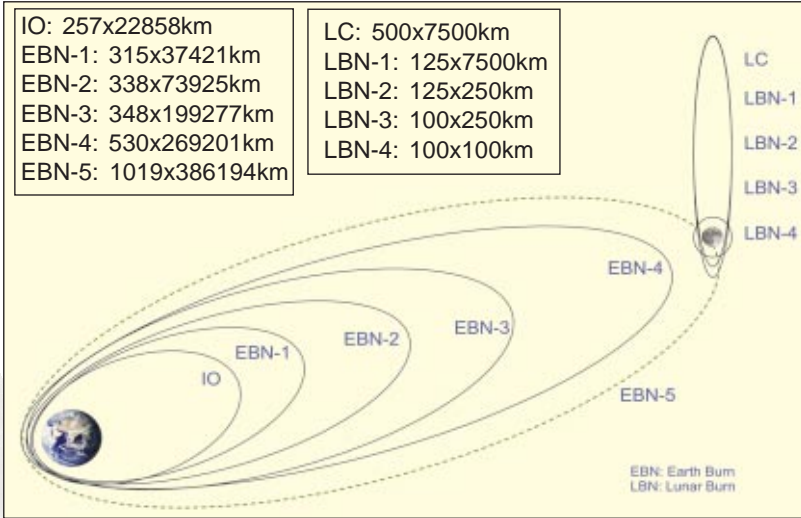


PSLV-C11

11. MISSION PROFILE

Chandrayaan-1 spacecraft would be launched from the Satish Dhawan Space Centre, SHAR, Sriharikota by PSLV-XL (PSLV-C11) in an highly elliptical initial orbit (IO) with perigee (nearest point to the Earth) of about 257 km and an apogee (farthest point from the Earth) of about 22,858 km.

After a few revolutions in the initial orbit, the spacecraft's Liquid Apogee



Chandrayaan-1 Mission profile

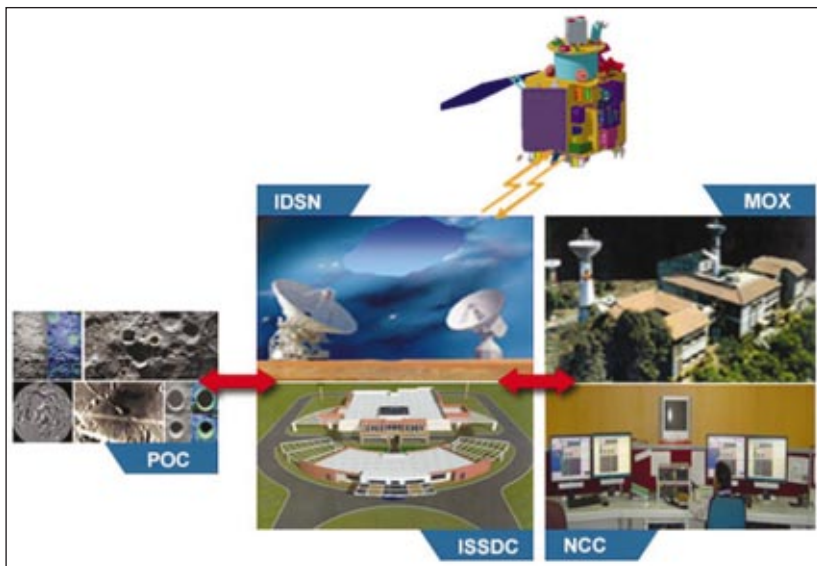
Motor (LAM) firing would be done, when the spacecraft is near perigee, to raise the apogees to 37,421 km and 73,925 km respectively.

Subsequently, the LAM is fired to take the Chandrayaan-1 spacecraft to extremely high elliptical orbit with apogees 199,277 km and 269,201 km. Later the spacecraft would be raised to an orbit with 1,019 km perigee and 386,194 km apogee.

Once the Chandrayaan-1 spacecraft reaches the vicinity of the Moon, the spacecraft is slowed down sufficiently so as to enable the gravity of the moon capture it into an elliptical orbit (LC). After a careful and detailed observation the height of the spacecraft's orbit will be finally lowered to its intended 100 km circular polar orbit. Following this, the Moon Impact Probe (MIP) would be ejected from Chandrayaan-1 to impact on the lunar surface. Afterwards, all the scientific instruments/payloads are commissioned sequentially and Chandrayaan-1 spacecraft explores the Moon with its array of instruments for two years.

12. GROUND SEGMENT FOR CHANDRAYAAN-1 MISSION

The Ground Segment for Chandrayaan-1 comprises of three major elements : the Ground Station Network including the Indian Deep Space Network (IDSN), Mission Operations Complex (MOX) and Indian Space Science Data Centre (ISSDC). This trio of ground facility ensures the success of the mission by providing to and fro conduit of communication, securing good health of the spacecraft, maintaining the orbit and attitude to the requirements of the mission and conducting payload operations. The ground segment is also responsible for making the science data available for the Payload Scientists along with auxiliary information, in addition to archiving of payload and spacecraft data. Payload Operation Centres (POCs) also form a part of the Ground Segment. The figure refers to the overall Ground Segment concept for Chandrayaan-1 Mission.



Elements of Ground Segment



12.1. Indian Deep Space Network (IDSN)

The Indian Deep Space Network consists of a 18-m and a 32-m antennae that are established at the IDSN campus, Byalalu, Bangalore. The Network is augmented with a couple of stations in the western hemisphere in addition to the 64-m antenna in Bearslake, Russia to improve the visibility duration and to provide support from the antipodal point.

The existing ISTRAC S-Band Network stations will be used to support the mission during Launch and Early Orbit Phase (LEOP) that includes Earth Transfer Orbit (ETO) up to a range of about 1,00,000 km. Although the 18-m antenna is tailored for Chandrayaan-1 mission, the 32-m antenna can also support other planetary missions. The established IDSN is a state-of-the-art system, with its base band system adhering to CCSDS (Consultative Committee for Space Data Systems) Standards, thus facilitating cross-support among other TTC agencies. The supporting network stations will ensure the adequacy of the link margin for telemetry/dwell, tracking, tele command and payload data reception. The IDSN station has the responsibility of receiving the spacecraft health data as well as the payload data in real time. Later, conditioning of the data takes place, before onward transmission of the same to Mission Operations Complex at Bangalore. The tracking data comprising Range, Doppler and Angle data will be transferred to the control center for the purpose of orbit determination. The payload data will be transmitted to the Indian Space Science Data Center (ISSDC) as and when received by the payload data acquisition system, located at the station.

12.2. 18-m Antenna

The 18-m dish antenna is configured for Chandrayaan-1 mission operations and payload data collection. The antenna is established at the IDSN Campus, Byalalu, situated at the outskirts of Bangalore with built in support facilities. A fibre optic / satellite link will provide the necessary

communication link between the IDSN Station and Mission Operations Complex (MOX) / Indian Space Science Data Centre (ISSDC). This antenna is capable of S-Band uplink (2 kW) and both X-Band and S-Band



18-m Antenna

downlink. This system has provision to receive two downlink carriers in S-Band and one carrier in X-Band (RCP and LCP) simultaneously, whereas, the uplink is either RCP or LCP. The system will have a G/T of 30/39.5 dB/K (45° elevation, clear sky) for S/X-Band. The base-band system will adhere to the CCSDS Standards. The station can be remotely operated from ISTRAC Network Control Centre (NCC). The figure depicts the 18-m antenna.

12.3. 32-m Antenna

The wheel and track 32-m antenna is a state-of-the-art system that will support the Chandrayaan-1 mission operations and beyond. This is co-located with 18-m antenna in the IDSN site at Byalalu. A fibre optics / satellite link will provide the necessary connectivity between the IDSN site and Spacecraft Control Centre / Network Control Centre. This



32-m Antenna



antenna is designed to provide uplink in both S-Band (20/2 kW) and X-Band (2.5 kW), either through RCP or LCP. The reception capability will be in both S-Band and X-Band (simultaneous RCP & LCP). It can receive two carriers in S-Band and one carrier in X-Band, simultaneously. The system will have a G/T of 37.5/51 dB/K (45° elevation, clear sky) for S/X-Band. The base-band will adhere to CCSDS Standards facilitating cross-support among the space agencies. The station is also equipped for remote control from the ISTRAC Network Control Centre (NCC).

12.4. Existing S-Band ISTRAC Network

Indian lower earth orbit satellites are controlled by the ISRO Telemetry Tracking and Command (ISTRAC) Network stations. The Elevation over Azimuth 10/11/12-m dish antennae at the existing ISTRAC network stations (Bangalore, Lucknow, Mauritius, Bearslake, Biak, Brunei, Trivandrum and Port Blair) will be augmented to serve the Chandrayaan-1 mission during Earth Transfer Orbits and Lunar Transfer Trajectory up to a range of about 1,00,000 km. All these antennae are configured for two-carrier reception (RCP&LCP) and uplink, in either RCP or LCP in S-Band. The G/T of the stations is 21/23 dB/K.

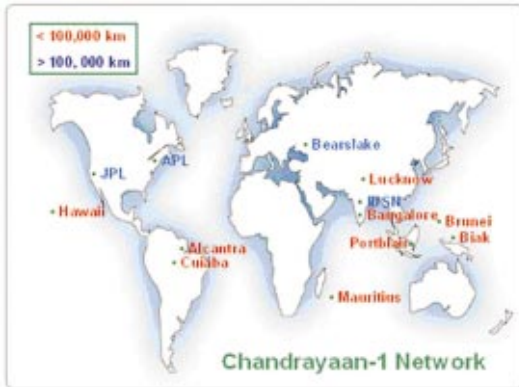
The base-band will adhere to CCSDS Standards, facilitating cross-support among the TTC agencies. The stations are being



equipped for remote control from the ISTRAC Network Control Centre (INCC). These stations are linked to MOX by dedicated communication links.

12.5. External Network Stations

External network stations APL, JPL (Goldstone, Canberra, Madrid), Hawaii, Brazil (Alcantara, Cuiaba) are requisitioned in for the purpose of extended visibility of Launch and Early Orbit Phase (LEOP) operations, as well as to gain the near continuous visibility during the normal phase operations. All the external stations will ensure the required compatibility to communicate with the spacecraft.



12.6. ISTRAC Network Control Centre (NCC)

NCC enables remote monitoring and control of all ISTRAC Ground Stations including IDSN and it is located in Peenya, Bangalore Campus. NCC also facilitates Data Service from all stations through Standard Station Computers, SLE Gateway or any other agency specific data interface through external station computers. The payload data acquisition system at IDSN also interfaces with NCC for obtaining the payload operations schedule. The multi-mission schedule system of ISTRAC provides the required schedules to NCC for day-to-day operations.

12.7. Mission Operations Complex (MOX)

The nerve centre for this Moon Mission will be the Mission Operations Complex, situated within the ISTRAC campus, Bangalore. The MOX will be responsible for all spacecraft operations during various phases of the mission viz. pre-launch, launch and early orbit phase, normal phase and



terminal phase, as well as for the health monitoring of the spacecraft and payloads. MOX is authorised for up linking of commands for change of onboard configuration, payload operations and conduction of maneuvers as required. MOX facility has a number of elements that function in unison to support round-the-clock spacecraft operations. The Mission Operations Complex and the ISSDC facilities are linked through a secure network for data transfers.

12.8. Spacecraft Operations

Mission activities will be conducted from the Mission Operations Complex. The health keeping data / dwell received will be monitored in real-time to ensure good functioning of the onboard systems. Telecommands for changes of spacecraft configurations and payload operations will be uplinked after verification and due authorisation. The centre will also be equipped to handle special operations and contingency recovery. Periodic orbit maneuvers will be planned and conducted to maintain the altitude / eccentricity that satisfies the payload data overlap requirements and safe altitude of the spacecraft. Periodical reports on the performance of spacecraft and payload services are generated and passed on to designers and users. The centre maintains an archive of all satellite operations, health, special operations, attitude/orbit maneuvers, anomalies and recoveries.

12.9. Indian Space Science Data Centre (ISSDC)

Indian Space Science Data Center (ISSDC) is a new facility being established by ISRO, as the primary data center for the payload data archives of Indian Space Science Missions. This data center, located at the Indian Deep Space Network (IDSN) campus in Bangalore, is responsible for the ingestion, archive, and dissemination of the payload data and related ancillary data for Space Science missions. The principal investigators of the science payloads as well as scientists from other

institutions and general public will use this facility. The facility will be supporting Chandrayaan-1, ASTROSAT and Megha-tropiques and any other future space science missions.

Payload data from the satellites will be received at the data reception stations and subsequently transferred to ISSDC for further processing.

The raw payload data received through the data reception stations is further processed to generate Level-0 and Level-1 data products that are stored in the ISSDC archives for subsequent dissemination. Automation in the entire chain of data processing is planned. Raw payload data / Level-0 data/ Level-1 data for each science payload is transferred to the respective Payload Operations Centers (POC) for further processing, analysis and generation of higher level data products. The higher level data products generated by the POC's are subsequently transferred to ISSDC archives for storage and dissemination. The data archives for Level-0 and higher products are organized following the Planetary Data System (PDS) standards.

The dissemination of data from ISSDC to the payload operations centers / principal investigators, scientists and general public is supported through private WAN connections and Internet.

Software packages developed by software development teams in the different centers of ISRO, by the principal investigator's teams / payload development teams are to be deployed at ISSDC to support these functions.

ISSDC data archival and distribution functions follow the data policy guidelines of ISRO. The data transfer system at ISSDC, with suitable security systems, provides for distribution of science data (as per data policy). After a pre-specified proprietary period, ISSDC would make the



data available to public users who can access the archives through the Internet.

ISSDC supports six primary services; viz Access Services, Interchange Services, Archive Services, Support Services, Operations Services and Maintenance Services.

ISSDC interfaces with Mission Operations Complex, Data reception centers, Payload designers, Payload operations centers, Principal investigators, Mission software developers and Science data users to execute its functions.

The primary facilities for ISSDC have been established at the IDSN site, Byalalu at Bangalore.

12.10. Payload Operations Centre (POC)

Payload Operation Centres focus on the higher levels of science data processing, planning of payload operations, performance assessment of the payload and payload calibration. POC is authorized to interact with MOX in conducting the payload operations. These centers are co-located with the institutions/laboratories of the Instrument designers, Principal Investigators and will be processing and analysing data from a specific payload. POCs will pull relevant payload (level 0 and level 1) and ancillary data sets from the ISSDC dissemination server and process the data to generate higher level products. These products will be archived in ISSDC after qualification.

Payload Operations Centers are planned at SAC, Ahmedabad (TMC, HySI), ISAC, Bangalore (C1XS, HEX, LLRI), SPL,VSSC, Trivandrum (SARA, MIP), APL, Maryland, USA (MiniSAR), Brown University, JPL, USA (M3), Max Planck Institute, Germany (SIR-2), RAL,UK (C1XS), Swedish institute of Space Physics,Kiruna, Sweden (SARA)

13. FUTURE BEYOND CHANDRAYAAN-1

The Chandrayaan-1 mission is now ready for launch and will provide excellent opportunity to orient ISRO's technological resources towards realizing a viable long-term programme of Planetary exploration. Realization of this mission will lead to several developments of satellite technology, design, development and fabrication of a variety of experiment / payloads, set up communication, navigation and control systems for going beyond the geostationary orbit, capture of a spacecraft in an orbit around another solar system object, maintenance, observation, acquisition and transfer of data from lunar orbit to ground station and finally establishment of a Indian Space Science Data Center. Above all, the mission will help the young talented scientists and engineers of the country to take up the challenging high level of intellectual activities in basic sciences.

Planetary Exploration seeks to answer the questions that are fundamental to the understanding of our existence on the Earth, origin and evolution of the solar system, planetary environment and present state of its evolution. These questions have stimulated human thought and scientific investigation throughout history and continue to be among the most basic and pressing scientific questions today.

The primary focus of the future planetary exploration plan of ISRO would be governed by science aspects with the basic theme of *"Understanding the Origin and Evolution of Solar System Objects"*.

Based on science objective, accumulated experience, available resources and technology maturity, plan has been sketched out for undertaking more challenging planetary exploration programme for conducting new and innovative experiments / observations in the future.

A brief outline of the three specific missions and planetary targets for the time span of 2020 are given below.



Second Lunar mission has been envisaged as a lunar orbiter with a lander. The robotic spacecraft would land on and rove over the Moon, take measurements to characterize the lunar surface and space environment in support of science objectives. The payload/instruments would be for imaging, study of mineralogy, chemistry, alpha / neutron spectrometry. In-situ analysis of lunar samples may be carried using alpha/neutron/X-ray Florescence spectroscopy.

Mars is an important research target and a stepping-stone to the vast planetary world beyond. The scientific goals for the mission to the Red Planet-Mars is primarily to understand the Martian atmospheric processes and weather/dust storms; Martian ionosphere, effect of solar wind, surface magnetic fields, search for paleo-water and surface resources.

Getting to Mars is a tremendous challenge and ISRO will develop new technology solutions to reach beyond Moon – to the Red Planet, to place a spacecraft in low altitude orbit around Mars, develop sensitive instruments to monitor radiation, electric and magnetic fields (tens of nano tesla) and energetic particles in Martian space and a capable space communication for future lunar and Mars missions. The technology goal also includes advanced command, communication, navigation and control.

Scientists are curious to learn how the Sun's family of planets and minor bodies originated. Remote sensing of the asteroids and comets will help to understand the evolution of asteroids and comets, early solar system processes, meteorite-asteroid connection, physical and chemical properties of Asteroid and cometary material.

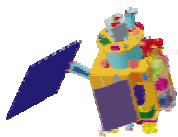
Asteroid Vesta may be considered as the primary target option. The payloads would include all standard remote-sensing instruments for

imaging, mineralogy and chemistry of surface as well as sub-surface. Studies of energetic particles, radiation and fields in interplanetary space need to be an integral part of this long duration mission.

Science enables and is enabled by exploration. ISRO with its access to space will help in research of the scientific questions, which have still not been answered. Chandrayaan-1 mission will pass on the baton to sophisticated future lunar and planetary missions, with possible landing and sample return capability and through rendezvous with comet/asteroid systems to conduct new and innovative experiments /observations.

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15. LIST OF INSTITUTIONS PARTICIPATING IN CHANDRAYAAN-1 MISSION

ISRO Centers

1.	ISRO Headquarters, Bangalore
2.	ISRO Satellite Centre (ISAC), Bangalore
3.	ISRO Inertial Systems Unit (IISU), Thiruvananthapuram
4.	ISRO Telemetry, Tracking and Command Network (ISTRAC), Bangalore
5.	Laboratory for Electro-Optics Systems (LEOS), Bangalore
6.	Liquid Propulsion Systems Center (LPSC) Bangalore & Mahendragiri
7.	National Remote Sensing Centre (NRSC), Hyderabad
8.	Physical Research Laboratory (PRL), Ahmedabad
9.	Space Physics Laboratory (SPL), VSSC, Thiruvananthapuram
10.	Satish Dhawan Space Centre (SDSC), SHAR, Sriharikota
11.	Space Applications Centre (SAC), Ahmedabad
12.	Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram

<i>International Lead Institutes participating in the Mission</i>	
13.	Applied Physics Lab, Johns Hopkins University, MD, USA
14.	Brown University, USA
15.	Centre d'Etude Spatiale des Rayonnements, Toulouse, France
16.	European Space Agency (ESA)
17.	Institute for Radiological Protection and Nuclear Safety, France
18.	Institute of Space and Astronautical Science, (ISAS/JAXA), Japan
19.	Jet Propulsion Laboratory, USA
20.	Max Planck Institute for Solar System Science, Lindau, Germany
21.	National Aeronautics and Space Administration (NASA)
22.	Naval Air Warfare Centre, Chinalake, CA, USA
23.	Nuclear Physics Institute, Czech Academy of Sciences, Czechoslovakia
24.	Rutherford Appleton Laboratory, UK
25.	Solar-Terrestrial Influences Laboratory, Bulgarian Academy of Sciences, Sofia, Bulgaria
26.	Swedish Institute of Space Physics, Kiruna, Sweden
27.	University of Bern, Switzerland
28.	University of Helsinki, Finland



16. CHRONOLOGY OF LUNAR EXPLORATIONS

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 Sep 1959	Luna 2	USSR	FIRST hard landing, magnetic field
4	20 Apr 1960	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 Jul 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 Jun 1965	Luna 6	USSR	Missed the Moon by 1,60,000 km
17	18 Jul 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 Orb 1	USA	TV imaging, radiation, micrometeoroids
24	24 Aug 1966	Luna 11	USSR	Orbiter, gamma-and X-ray measurements, gravity, micrometeoroids
25	22 Oct 1966	Luna 12	USSR	Orbiter, TV imaging
26	6 Nov 1966	Lunar Orb 2	USA	TV imaging, radiation, micrometeoroids
27	21 Dec 1966	Luna 13	USSR	Lander, on-surface TV, soil mechanics
28	5 Feb 1967	Lunar Orb 3	USA	TV imaging, radiation, micrometeoroids
29	17 Apr 1967	Surveyor 3	USA	Lander, on-surface TV, soil mechanics
30	4 May 1967	Lunar Orb 4	USA	TV imaging, radiation, micrometeoroids
31	19 Jul 1967	Explorer 35	USA	Orbiter, Plasma, fields and particles
32	1 Aug 1967	Lunar Orb 5	USA	TV imaging, radiation, micrometeoroids
33	8 Sep 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 Sep 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 Jul 1969	Luna 15	USSR	Failed robotic sampler
42	16 Jul 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 Sep 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 Jul 1971	Apollo 15	USA	Human landing, Hadley-Apennine
51	2 Sep 1971	Luna 18	USSR	Failed robotic sampler
52	28 Sep 1971	Luna 19	USSR	Orbiter, lunar gravity, TV, micrometeoroids
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, micrometeoroids
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	27 Sep 2003	SMART-1	ESA	Solar electric propulsion, near IR and X-ray Spectrometer
65	14 Sep 2007	Kaguya (Selene)	Japan	Mapping of lunar topography, surface composition & magnetic field
66	24 Oct 2007	Chang'e	China	Explore lunar surface environment, topography, and geological structures
67	2008	Chandrayaan-1	India	High resolution Chemical, mineralogical and photo-geological mapping of lunar surface in visible, near IR, low and high energy X-rays
68	2009	LRO	USA	Obtain data to facilitate returning men safely to the moon



17. CHANDRAYAAN-1 SUMMARY

<p>Scientific Objective</p>	<p>Simultaneous chemical, mineralogical and photogeologic mapping of the whole Moon in the visible, near infrared, low and high energy X-rays with high spatial resolution.</p>
<p>Scientific Payloads</p>	<ul style="list-style-type: none">• Terrain Mapping Camera - TMC• Hyper Spectral Imager - HySI• Lunar Laser Ranging Instrument - LLRI• High Energy X-ray Spectrometer -HEX• Moon Impact probe (MIP)• Chandrayaan-1 X-ray Spectrometer (C1XS), Solar X-ray Monitor (XSM)• Sub keV Atom Reflecting Analyser (SARA)• Near Infrared Spectrometer (SIR-2)• Radiation Dose Monitor (RADOM)• Miniature Synthetic Aperture Radar (Mini-SAR)• Moon Mineralogy Mapper (M3)

Payload Mass	105 kg (Including ISRO & Announcement of Opportunity payloads)
Launch Vehicle	Polar Satellite Launch Vehicle - PSLV-XL (PSLV-C11)
Mission Strategy	Initial Orbit (IO)- Highly Elliptic Orbit– Lunar Capture
Lunar Orbit	100 km Circular Polar Orbit
Operational Life Time	Two Years
Spacecraft	Cuboid shape, 1.5 m side, 3-axis stabilized
Spacecraft Mass	Dry mass - 560 kg, Initial Lunar Orbit Mass with propellant – 675 kg
Communication System	S-Band uplink for telecommand, S-Band downlink for telemetry, X-Band for Payload data reception
Indian Deep Space Network (IDSN) Station	Location: Byalalu, Bangalore, Fully steerable dual feed 18 m and 32 m -dia antenna
Mission Operations Complex (MOX)	Location: Bangalore-responsible for all spacecraft operations, running of ground infrastructure
Indian Space Science Data Centre (ISSDC)	Act as a repository of scientific data obtained from payloads onboard Chandrayaan-1



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