LEAD PAPER

CHANDRAYAAN-1: THE FIRST INDIAN MISSION TO THE MOON

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Abstract

There are numerous reasons for continuing the study of the Moon. Although the Moon is better characterized and more studied than any other planetary body in the solar system, hypothesis of it's origin is still controversial. Earlier missions were limited in characterizing the moon in the sense that the data were only from samples on representative locations of moon or the observations are not detailed enough to make in depth study. With the advancement in technology and miniaturization, it is now possible to observe moon as close as possible with better resolutions both in spatial and spectral that would provide better insight in the origin and early evolution of the moon based on chemical and mineralogical criteria. Chandrayaan-1 is one such mission.

The primary objectives of the Chandrayaan-1 mission are simultaneous chemical, mineralogical and topographic mapping of the lunar surface. These data should enable us to understand compositional variation of major elements. The major element distribution will be determined using an X-ray fluorescence spectrometer (LEX), sensitive in the energy range of 1-10 keV where Mg, Al, Si, Ca and Fe give their $K\alpha$ *lines. A solar X-ray monitor (SXM) to measure the energy spectrum of solar X-rays, which are responsible for the fluorescent X-rays, is included. Radioactive elements like Th will be measured by its 238.6 KeV line using a low energy gamma ray spectrometer (HEX) operating in 20-250 keV regions. The mineral composition will be determined by a Hyperspectral imaging spectrometer (HySI) sensitive in 400-930 nm range. The wavelength range is further extended to 3000 nm where some spectral features of the abundant lunar minerals and water occur, by using a near infra-red spectrometer (SIR-2) and Moon Mineralogy Mapper (M3). A terrain mapping camera (TMC) in the panchromatic band will provide three dimensional map of the lunar surface with a spatial resolution of about 5 m. Aided by a laser altimeter (LLRI) to determine the altitude of the lunar craft, to correct for spatial coverage by various instruments, TMC should enable us to prepare an elevation map with an accuracy of about 10m.*

Five instruments under international cooperation have been accommodated that will complement and supplement the scientific objectives of Chandrayaan-1. These are: a Miniature Imaging Radar Instrument (mini-SAR), Sub keV Atom Reflecting Analyser (SARA), The Moon Mineralogy Mapper (M^3*), Infra Red Spectrometer (SIR-2) and a Radiation Dose Monitor (RADOM). Apart from these scientific payloads, a Moon Impact Probe (MIP) which will be released to impact on the Moon during the Mission is also accommodated as a technology fore runner for future Lunar Landing mission.*

Chandrayaan-1 will be launched from SHAR using PSLV-XL a variant of flight proven PSLV. The mission will have two years nominal mission life in 100km lunar polar orbit. ISRO is setting up an Indian Deep Space Network (IDSN) near Bangalore consisting two ground terminals of 18m and 32m diameter. Indian Space Science Data Centre will be suitably located to act as science data repository.

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Background

India recognized the potential of space science and technology for the socio-economic development of the society soon after the launch of Sputnik by the erstwhile USSR in 1957 and embarked upon development of an ambitious space program. Over the last three decades, India has achieved significant progress in design, development and operation of space systems, as well as in using the systems for vital services like telecommunication, television broadcasting, meteorology, disaster warning and natural resources survey and management. The Indian space program has become largely self-reliant with capability to design, build and launch its own satellites using indigenously designed and developed launch vehicles, for providing space services to the country.

The state of maturity of spacecraft development at ISRO is amply demonstrated with launch and maintenance of a series of remote sensing satellites in low earth polar orbit and communication satellites in geostationary orbit. Launch vehicle PSLV has been operationalized through successful demonstration of a series of flights to place spacecraft in low earth polar orbit. The GSLV had its three successful flights to place GSAT-1, GSAT-2 and GSAT-3 communication satellites in geostationary orbit. The capability of PSLV to place a satellite in geostationary orbit has been demonstrated in 2002 when meteorological satellite, KALPANA-1 was launched. Also X-ray astronomy experiments have been successfully carried out in low earth orbiting spacecraft and the X-ray payload has provided valuable scientific data for over 5years. With these developments, ISRO is in a position to embark on newer missions. Lunar and interplanetary explorations provide such an opportunity.

In the new millenium international community has considered several exciting missions in space science and exploration. These have the prospect of expanding horizons of our knowledge effectively and will provide benefits to the human society at large. In the Indian context, one of the initiatives, which attracted debates and excited the imagination of a large number of people, was the possibility of a lunar mission involving an instrumented spacecraft, through an Indian launcher. Groups of national scientists and technologists debated this in various fora under the aegis of Indian academy of sciences as well as Astronautical Society of India (ASI). Based on these interactions it was felt appropriate that ISRO examine and plan for a mission to the moon in greater depth. Chandrayaan-1 is outcome of in depth study by a National task team constituted by Chairman ISRO.

Mission Objectives

The overall objective of the mission is summarized as

- High resolution imaging and chemical and mineralogical mapping of lunar surface to define the process leading to the formation and chemical evolution of the moon.
- Systematic topographic mapping of the whole surface of the moon.
- To establish capability of planetary data analysis and also data archival and dissemination.
- To create expertise in development of detectors and sensor technology for planetary remote sensing for future planetary exploration programme.
- Develop new miniaturized spacecraft technologies that would cater to future missions.
- Develop expertise of planning and execution of mission for sending spacecraft from low earth orbit to orbit around the planet that would be needed for future planetary exploration missions.

To enhance India's image in the international scene by being part of a select group having capability to observe planets directly.

Scientific Payloads

Chandrayaan-1 Carries the following science instruments from ISRO to achieve its science objectives:

- Terrain mapping stereo camera (TMC) in the panchromatic band, having 5m spatial resolution and 20km swath.
- A hyperspectral wedge filter camera (HySI) operating in 400-900nm band with a spectral resolution of 15nm and spatial resolution of 80m with a swath of 20km.
- A laser ranging instrument (LLRI) with height resolution of about 10m.
- A collimated low energy (1-10keV) X-ray spectrometer (LEX) using a swept charge X-ray detector for measuring the fluorescent X-rays emanating from the lunar surface having a foot print of approximately 20km.
- A high energy X-ray (10-250keV) mapping (HEX) employing CdZnTe solid state detector with CSI anti-

coincidence system having a foot print of approximately 40km to identify degassing faults or zones on the moon by mapping ^{222}Rn and its radioactive daughter ^{210}Pb. This will enable us to understand the transport of volatiles on the moon.

- Chandrayaan-1 carries a Moon Impact Probe (MIP) which will be released to land on the Moon during the Mission. MIP in turn carries three instruments, a mass spectrometer, a C- band altimeter and a video camera.

Apart from the five payloads (TMC, HySI, LLRI, LEX and HEX) and MIP discussed above, five more instruments under international collaboration have been accommodated in Chandrayaan-1. They are,

- Miniature Imaging Radar Instrument (Mini-SAR) from Applied Physics Laboratory USA supported by NASA.
- Sub KeV Atom Reflecting Analyser (SARA) from IRF, Sweden, JAXA, Japan and SPL, VSSC, supported by ESA.
- Moon Mineralogy Mapper (M^3) from Jet Propulsion Laboratory and Brown University, USA, supported by NASA.
- Infra Red Spectrometer-(SIR-2) from Max Plank Institute , Germany, supported by ESA.
- Radiation Dose Monitor (RADOM) Bulgarian Academy of Science, Bulgaria.

Table-1 provides the summary of Chandrayaan-1 Payloads, their configuration and objectives.

The Spacecraft and Launch Vehicle

Spacecraft for lunar mission is judicious mix of heritage from Indian Remote Sensing (IRS) missions and

Table-1 : Chandrayaan-1 payloads and their configurations

Payload	Sensor Configuration	Wavelength/Energy Range	Spatial Resolution	Objective
Hyperspectral imager (HySI)	Wedge filter pixelated imager	0.4 - .95 μm with 15nm resolution	80 m	Mineral mapping
Infra-red spectrometer (SIR-2)	Grating spectrometer	0.90 - 2.6μm	100 m	Mineral mapping
Moon Mineral Mapper (M^3)	Grating spectrometer and HgCdTe detector	0.4 to 3.0 μm with 10nm resolution	30 m	Mineral mapping and resource identification
Terrain Mapping Camera (TMC)	Three stereo cameras (pixelated detectors)	Panchromatic	5 m	Topographic mapping
Laser Ranging (LLRI)	Pulsed Nd-Yag laser with optical system	1064nm	10 m (Height)	Topography
X-ray Fluorescence Spectrometer (LEX)	Swept charged CCD	1-10 kev	20 Km	Chemical mapping (Mg-Fe)
Solar X-ray Monitor (XSM)	Si pin diode	2-10 kev	--	Solar X-ray spectrum
High energy X-ray Spectrometer (HEX)	CdZnTe detector	20-250kev	40 Km	Th, ^{210}Pb
Synthetic Aperture Radar (mini SAR)	Radar, Scatterometer and altimeter	2.4 GHz	100 m	Soil Topography, altimetery, detection of polar ice
Sub KeV Neural atom analyzer (SARA)	Mass spectrometer and solar wind monitor	10ev-2kev	100 m	Atmospheric neutrals (H-Fe) composition, Magnetic anomalies
Radiation Dose Monitor (RADOM)	Si semiconductor	>8kev	--	Radiation dose

KALPANA-1(Meteorological Spacecraft) mission with required mission specific modifications.

For a mission like PSLV-C4/KALPANA-1 there is no need to have a separate upper stage since the spacecraft liquid apogee motor can carry the spacecraft from Elliptical Parking Orbit (EPO) to lunar orbit. Liquid apogee motor (LAM) has been used in INSAT series of satellites and has a good heritage. Thus from the point of view of propulsion system the spacecraft can be considered to have its heritage from KALPANA1. However once the spacecraft reaches the lunar orbit it functions more like any other IRS mission, majority of the onboard systems derive heritage from IRS missions. A judicious choice has been made to keep the mission as reliable as possible and at the same time develop new technologies in the form of miniaturization which will be required for future missions. However, some changes specific to lunar mission is also required. These include extending the thrust cylinder and having an upper payload deck to accommodate MIP and few other payloads. Additionally Chandrayaan-1 will have a canted solar array since the orbit around the moon is inertially fixed resulting in large variation in solar incidence angle. There is a need to have a gimbaled high gain antenna system for downloading the payload data to the Indian Deep Space Network (IDSN). Thus the spacecraft will be cuboids in shape of approximately 1.50m side, weighing about 590kg at lunar orbitThis would be a 3-axis stabilized spacecraft generating about 750W of peak power using canted single sided solar array and will be supported by Li-Ion batteries for eclipse operations. The spacecraft would adopt bipropellant system to carry it from EPO through lunar orbit, including orbit and attitude maintenance in lunar orbit. The propulsion system would carry required propellant for a mission life of 2 years, with adequate margin. The TTC communication would be in the S-band and the scientific payload data transmission would be in X-band. Fig.1 provides the spacecraft Configuration with payloads Fig.2 gives the configuration of the polar satellite launch vehicle with its capability.

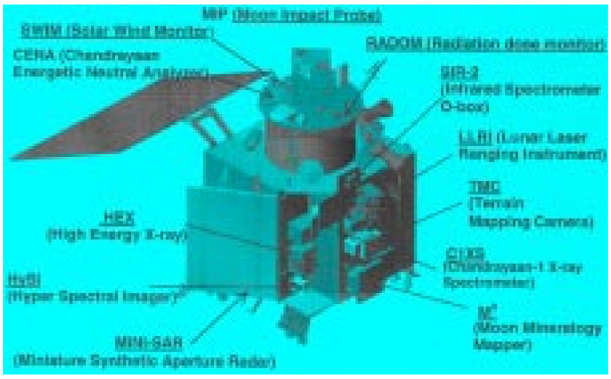

Fig.1 Chandrayaan-1 spacecraft configuration with payloads

Fig.2 PSLV-XL and its payload capability

The Mission Sequence

Chandrayaan-1 will be launched by PSLV-XL, a variant of flight proven PSLV, from Satish Dawan Space Centre, SDSC- SHAR. The spacecraft will be injected into 240Km X 24,000Km orbit. After separation from the launcher solar panel is deployed. The spacecraft is raised to moon rendezvous orbit by three consecutive in-plane perigee maneuvers to achieve the required 3, 86,000Km apogee. After the third perigee burn, a quick estimate of the achieved lunar transfer trajectory (LTT) is made and a mid-course correction is imparted at the earliest opportunity. The spacecraft coasts for about 5 days in this trajectory prior to the lunar encounter. During the coasting phase the spacecraft would stay mostly in the sun-pointed mode and at the same time ensuring good communication link to ground. The major maneuver of the mission, called lunar orbit insertion (LOI) leading to lunar capture, is carried out at the peri-selene (nearest point in lunar orbit) part of the trajectory. The maneuver ensures successful lunar capture in a polar, near circular 1000Km-altitude orbit around the moon. After successful capture and health checks, the altitude is lowered through a series of in-plane corrections to 200Km near circular orbit. After studying the orbit perturbations for a week or two, the target altitude of 100km circular, polar orbit is achieved. Fig.3 depicts Chandrayaan-1 Mission Sequence.

The terrain mapping camera (TMC) generates data at 25 mbps for each of the three imaging strips and the hyper spectral scanner data readout rate is 3.1 mbps, totaling data rate of 78.1 mbps. Loss-less compression reduces the data volume by half. A solid state recorder is used to store data

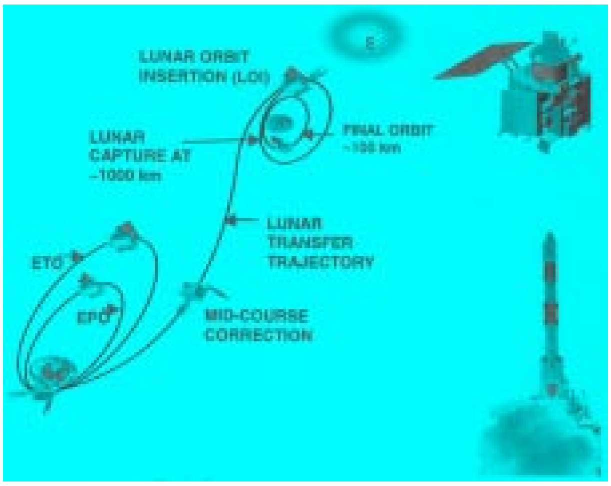

Fig.3 Chandrayaan-1 Mission Sequence

while imaging and interfaces with the down link system. The stored data is later played back and down linked in X-band through 20MHz bandwidth by a steer able antenna pointing at DSN.

Since the solar angle and hence illumination changes with time as the moon moves in its orbit, the imaging can be done only for limited period of time. One year is thus divided into two prime imaging seasons of 60 days each separated by a gap of 120 days. During the prime imaging season ±60° latitude is covered. During the four months interim period between the two prime imaging seasons, 60° to 90° of North/South polar regions will be covered. Due to poor solar illumination in this region, the spatial resolution will be degraded to get a reasonable signal to noise ratio. During the two-year period of mission life, the entire moon will be imaged with a possibility of repetitive coverage of selected regions. MiniSAR polar imaging is planned during non-imaging seasons.

The X-ray payloads, LLRI, SARA, and RADOM are kept 'ON' continuously and separate solid state recorder (SSR-2) is provided for recording data from these instruments. SSR-2 is sized to record the data for about 7 orbits covering the entire ground trace of the moon before played back. The other SSR namely SSR-1 will record data from optical imaging instruments or MiniSAR for subsequent transmission to ground.

Development Plan

Development of some new technologies have been identified to realize Chandrayaan-1 mission. These include Lithium-ion batteries, gimbaled antenna system, miniaturization of systems namely, communication system, data handling system, Solid state Recorders, Gyros, star sensors and bus management unit (BMU -that integrates satellite electronics functions). Though expertise in the country in realizing satellite-borne imaging cameras, laser ranging instrument and X-ray payloads with appropriate collimation exists, the detector systems which require large area arrays and miniaturized electronics, need new developments.

The developmental plan assumes building only one flight model spacecraft, as sufficient maturity exists in launch vehicle and spacecraft. As payloads for the mission are new, one engineering model besides the flight model is made for evaluating their electrical performance and laboratory calibrations and putting them through qualification program. Some of the spacecraft subsystems that are being developed newly for this mission also have engineering models for performance evaluation and qualification program. This enables to keep the cost optimum and realization time minimum.

The lunar mission is planed to be realized with a blend of flight proven elements that are already realized under ongoing INSAT/ IRS missions and certain new elements that are to be developed specific to this mission. The launcher for this mission is a variant of PSLV that had recorded several successful flights. Thus the new elements are development of scientific payloads, establishment of Indian Deep Space Network (IDSN) and Indian Space Science Data Center (ISSDC). The developmental efforts for the payloads have been completed and the IDSN installation is in progress. The launch of the mission is planned for early 2008.

Indian Deep Space Network (IDSN)

Establishment of IDSN is a vital element not only for Chandrayaan-1 but also to cater to future planetary missions. The existing ISTRAC/TTC and external S-band network can support slant range up to 1, 00,000Km during journey towards moon orbit. Beyond this range during the mission profile and at lunar distance of approximately 4,00,000Km, IDSN is necessary both for TTC and payload data reception. Two ground terminals one with 18m antenna and another with 32 m antenna are being established near Bangalore as a part of IDSN. Though 18m terminal is suffice for Chandrayaan-1, 32m antenna would cater to the futuristic needs also. ECIL, Hyderabad has the prime responsibility of realizing 32m antenna with the technical contributions from ISTRAC, ISAC, BARC and others. Fig.4 depicts IDSN antenna as being installed.

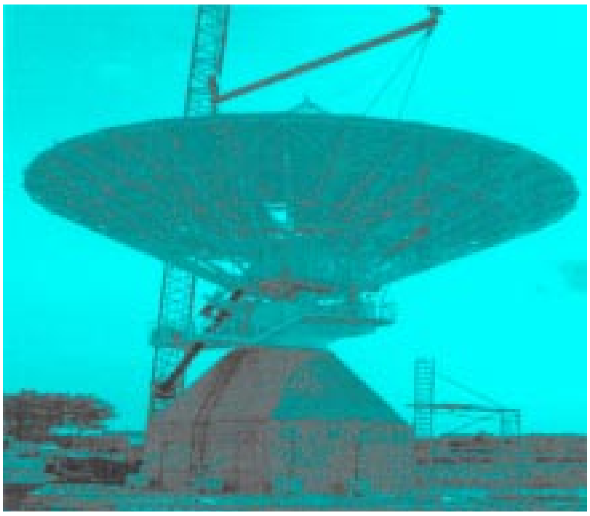

Fig.4 Bangalore IDSN (installation under progress)

Bangalore IDSN has 180° longitudinal shift with respect to Goldstone, California, USA and is centrally located with respect to the other two DSNs, viz., Villa Franca, Spain and Perth, Australia. Establishing IDSN at Bangalore has the potential of commercial benefit since it may be useful to international space agencies for their planetary missions.

Indian Space Science Data Centre (ISSDC)

The IDSN in Bangalore will receive the payload data. The data in its raw form along with auxiliary data will be sent to Indian Space Science Data Centre (ISSDC) that is being set up in Bangalore. ISSDC would process the raw data and convert it into user-friendly form. The data centre will also archive all the payload data and will be the focal point for foreign payload teams.

As a standard, two processing levels are identified for all payloads of Chandrayaan-1 for archival at ISSDC viz.,

- Level ‘0’- is the Raw instrument data along with ancillary information like orbit, attitude etc and
- Level ‘1’- processing involves radiometric and geometric calibration of instrument data. All other higher levels are instrument specific.

The basic products identified for scientific study are

- Raw payload data along with the ancillary information (level ‘0’), which includes data qualification, byte alignment, data decompression (only for TMC) and time tagging
- Radiometrically calibrated/corrected and geometrically mapped (level ‘1’) products. The processing includes detector response normalization, framing, line/pixel loss correction and tagging the selenographic coordinate to each pixel.
- Digital elevation model from TMC (level ‘2’).

Level ‘1’ and Level ‘2’ products are archived in PDS (Planetary Data System) standards at ISSDC and supplied to Principal Investigators and to the other users on request.

The envisaged higher level products for which tools/utilities are planned to be developed are:

- Global map of moon (in terms of geometrically corrected nadir image from TMC as well as color composite from HySI), with layers of information from other payload data.
- Visualization/coded layers of digital elevation.
- Fused products (TMC + HySI) to generate high resolution multi-spectral layers (for specific bands of HySI) and fused products of HySI and SIR-2 for two bands, which has correlation.
- Detailed Lunar Atlases on predefined indexing.

Science Products

Chemical Mapping

The prime aim of this mission is to develop a more reliable chemical stratigraphy of the Moon. This will be accomplished by X-ray imaging of the central hills within large craters and some regions of the South Pole Aitken basin. The magnesium number (Mg/Mg+Fe) and known stratigraphic depth of some selected regions, if correlated, will enable us to develop some criteria for chemical stratigraphy of lunar formations. The high energy X-ray spectrometer (HEX) will measure the 238.6 kev line of Th and determine its distribution. Th, U and K in lunar samples are correlated and therefore it is sufficient to measure any one of them.

Imaging of Poles and Detection of Water Ice

Solar illumination or even Earth shine does not reach the poles and they are under permanent shadow. However, stellar light, though very faint can reach the poles. Repeated passes on the poles should allow large integration times for imaging and enable us to image the polar regions.

An imaging strategy has therefore been developed to image the polar regions.

A search for the presence of Water-ice will be made in multiple ways by Chandrayaan-1. Water (ice) has some characteristic absorption bands at 0.81, 0.9, 1.04, 1.25, 1.65, 2.0 and 2.6 μm which can be detected by some of the imaging instruments included in the Chandrayaan-1 payloads e.g. by HySI, SIR-2 and M^3. In addition the signals observed by the X-ray payloads i.e. LEX and HEX, and MiniSAR and SARA can also be useful in identifying presence of water ice on permanently shadowed regions and search for volatiles on the lunar poles. The photon flux in 50-150 keV range which is mainly due to radioactive elements and cosmic ray interactions from the Moon varies for different terrain types, being maximum for KREEP and decreasing for basalts and highlands. Minimum flux is expected for water-ice. Therefore HEX and LEX signals can be useful in identifying the presence of water.

Some of the instruments are sensitive to water/ice lying on the surface of the Moon whereas HEX and MiniSAR can possibly detect it even if it is covered by a thin (<1m) regolith.

Conclusion

The scientific objectives of higher resolution topographic mapping of the Moon and imaging in X-rays identified for the present mission are unique experiments in many ways and would provide insight into the chemical composition of the moon and frequency of small impactors. A comprehensive image and topography of the moon will be generated using data from Chandrayaan-1 instruments. Such a topography database would be valuable for onward research, by both Indian and the international science committee. It will also enable to understand the lunar surface features for a more systematic planning of future missions.

The Indian mission to the moon should be seen beyond the scientific results it produces. Studies have shown that the moon could serve as a source of economic benefit to mankind and could be of strategic importance. The moon can be both, a beacon and a focus for the next generation of space exploration which will accrue new and important benefits, to the people of all nations and the earth.

Just a few decades back, man never imagined that he would set foot on the moon. Decades from know, human colonies on the moon could become a reality. India should also be in the forefront of this challenging and exciting endeavor. Chandrayaan-1 is the first calculated and well planned initiative by ISRO in this direction.