CHANDRAYAAN-1: INDIA'S FIRST PLANETARY SCIENCE MISSION TO THE MOON. J. N. Goswami[1] (goswami@prl.res.in) and M. Annadurai[2] (madurai@isac.gov.in), [1]Physical Research Laboratory, Ahmedabad-380009, India; [2]ISRO Satellite Center, Bangalore 560017, India.

Introduction: The current decade has seen a revival in the field of planetary exploration, and in particular in lunar exploration, with several new initiatives by various space agencies including the Indian Space Research Organization (ISRO). The first Indian planetary exploration mission, Chandrayaan-1, was launched from The Shriharikota Space Center on 22 October, 2008. This mission is international in character with participation of NASA, ESA and and BAS (Bulgaraian Academy of Sciences) through announcement of opportunity (AO) payloads. A brief summary of the science objectives, various payloads, the mission details and observational plans are presented here.

Science Objectives and Payloads: The primary science objective of the Chandrayaan-1 remote sensing mission is to further our understanding of the origin and evolution of the Moon based on simultaneous mineralogical, chemical and photo-geological mapping of the lunar surface at resolutions better than previous and contemporary lunar missions. A suite of baseline payloads, identified to meet this scientific objective, includes a Terrain Mapping Camera (TMC), a Hyper-Spectral Imager (HySI), a Low Energy X-ray Spectrometer, a High Energy X-γ ray Spectrometer (HEX) and a Lunar Laser Ranging Instrument (LLRI). A Moon Impact Probe carrying a mass spectrometer, a video camera and a radar altimeter was also included. TMC, HySI, HEX, LLRI and the MIP were designed and developed at various ISRO centers.

ISRO also selected several AO payloads that complement and supplement the basic objectives of the mission. These are: a miniature imaging radar instrument (Mini-SAR), two infrared spectrometers (Smart Infrared spectrometer: SIR-2 and Moon Mineralogy Mapper: M3) and a radiation dose monitor (RADOM). Two other AO payloads, the Chandrayaan-1 X-ray Spectrometer (C1XS) and the Sub-keV Atom Reflecting Analyzer (SARA) have strong Indian collaboration.

Three payloads (HySI, SIR-2 and MMM), will study solar reflected energy from the lunar surface covering the 0.4 to 3 micron and will provide high resolution mineralogical map of the entire lunar surface. HySI operates in the 400-950 nm range employing a wedge filter and will have spectral resolution of ~15nm and a spatial (pixel) resolution of 80m. SIR-2, a compact, monolithic grating, NIR point spectrometer covers the wavelength region 0.9 to 2.4 micron with a spectral resolution of 6 nm and spatial (pixel) resolution of ~80m. The Moon Mineralogy Mapper (M3) is a high throughput push broom imaging spectrometer operating in 0.7 to 3.0 micron range with high spatial (70m per pixel) and spectral (10 nm) resolution.

C1XS, a collimated low energy X-ray spectrometer, uses a swept-charge X-ray detector (SCD) and has a field of view of ~25 km. It will provide chemical map of the lunar surface for the elements, Mg, Al and Si and also for Ca, Ti and Fe during major solar flares. An X-ray solar monitor (XSM) will provide data on solar X-ray flux. The high-energy X-γ ray (30-270keV) spectrometer (HEX) will employ CdZnTe solid-state detectors and has a collimator providing an effective spatial resolution of ~40 km at energies <120 keV. It employs a CsI anticoincidence system for reducing background and is primarily intended for the study of volatile transport on Moon using the 46.5 keV γ ray line from ^{210}Pb (a decay product of volatile ^{222}Rn) as tracer. HEX will make the first attempt to detect low energy (<300 keV) γ rays from a planetary surface.

The terrain mapping camera (TMC) in the 500-850 nm band hosts three linear array detectors for nadir, fore and aft viewing and will have a swath of 20 km. TMC will provide 3D image of the lunar surface with a ground resolution of 5m with base to height ratio of one. The Lunar Laser Ranging Instrument (LLRI) employs a Nd-Yag laser with energy 10mJ and have a 20 cm optics receiver. It will be operating at 10Hz (5ns pulse) and will provide a vertical resolution better than 5m. Data from LLRI and TMC will be used to generate topographic map of the Moon, including the polar region, and quantitative lunar gravity model.

The SARA payload consists of the Chandrayaan-1 Low Energy Neutral Atom (CENA), and Solar Wind Monitor (SWIM). CENA detects solar wind sputtered low energy (10eV-2 keV) neutral atoms from the lunar surface and can broadly resolve H, O, Na-Mg, K-Ca groups and Fe atoms. SWIM is an ion mass analyzer for determining energy and mass of the incident solar wind ions. The data obtained by SARA will also identify small scale lunar surface magnetic anomalies.

The multi function mini-SAR consisting of SAR, altimeter, scatterometer and radiometer operating at 2.5 GHz will explore the permanently shadowed areas near lunar poles to look for signature of water ice mixed within the top meter of lunar regolith. It will transmit Right Circular Polarization (RCP) and receive both Left Circular Polarization (LCP) and RCP to infer possible presence of water ice. The SAR system has a nominal pixel resolution of 150 meter and 8 km swath.

Radom uses a semiconductor detector and measure the deposited energy from primary and secondary particles of solar and galactic in origin using a 256 channel pulse analyzer. The deposited energy spectrum can then be converted to deposited dose and flux of charged particles incident on the silicon detector.

The Moon Impact Probe (MIP) will be released at the beginning of the mission, after the spacecraft reach the designated 100km lunar polar orbit, to go over the Malpert Mountain and impact in the south polar region. Apart from collecting video images, the onboard mass spectrometer will try to detect possible presence of trace gases in the lunar exosphere.

The Spacecraft: The Chandrayaan-1 spacecraft design is adopted from flight proven Indian Remote Sensing (IRS) satellite bus. Apart from the solar array, TTC and data transmission, that are specific to the lunar mission, other aspects of system design have flight heritage. Some changes specific to the mission such as extending the thrust cylinder and having an upper payload deck to accommodate MIP and other payloads have been implemented. Chandrayaan-1 will have a canted solar array and a gimbaled high gain antenna system will be employed for downloading the payload data to the Indian Deep Space Network (IDSN) established near Bangalore. The spacecraft is cuboids in shape of approximately 1.5m side, with a liftoff mass of ~1300 kg. It is a three-axis stabilized spacecraft generating about 750W of peak power using the solar array and will be supported by a Li-Ion battery for eclipse operations. The spacecraft would adopt bipropellant system to carry it from ETO through LTO and to place it in designated 100 km lunar polar orbit, including orbit and attitude maintenance in lunar orbit. The TTC communication would be in the S-band. The scientific payload data will be stored in two solid state recorders (SSR#1 & SSR #2) and subsequently played back and down-linked in X-band through 20MHz bandwidth by a steerable antenna pointing at IDSN. Fig 1 provides the spacecraft Configuration with payloads.

Lunar Observation Plans: The imaging instruments will cover regions within $\pm$60° latitude during two prime imaging seasons, each of 60 days, in a given year. During intervening non-prime imaging seasons, 60° to 90° of North/South polar regions will be covered to complete coverage of the entire moon during the two-year mission. MiniSAR polar imaging is planned during non-imaging seasons. Data from these instrument will be stored in SSR#1 for subsequent transmission to ground. RADOM, LLRI, SARA and the X-ray payloads will be kept 'ON' continuously and SSR#2 will record data from these instruments. Two ground terminals (18m and 32m antenna), at the IDSN will receive the payload data from Chandrayaan-1. The raw data along with auxiliary data will be stored at the Indian Space Science Data Centre (ISSDC), also set up in the ISDN site, for processing and archiving in PDF format.

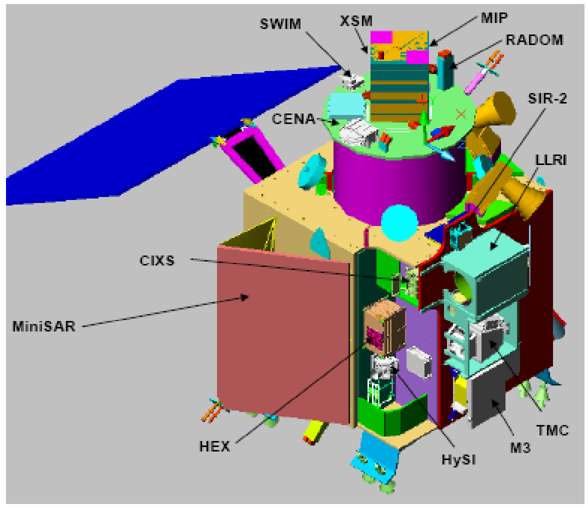

Fig. 1 The Chandrayaan-1 Spacecraft

Mission Sequence: The Chandrayaan-1 spacecraft was launched on 22nd October, 2008, by PSLV-XL, a variant of the indigenous Polar Satellite Launch Vehicle (PSLV) and was injected into 255km×22,860km orbit. After separation from the launcher, the solar panel is deployed and the spacecraft is raised to moon rendezvous orbit by five consecutive in-plane perigee maneuvers to achieve the required 3,86,000km apogee to place it in a lunar transfer trajectory. The major maneuver, lunar orbit insertion leading to lunar capture, was carried out successfully on 8 November and the spacecraft was placed in an elliptical (504 km×7502 km) polar orbit. After checks of various spacecraft sub-systems, three orbit manoeuvres were conducted to place the spacecraft at the operational 100 km circular polar orbit on 12 November.

Instruemnt Commissioning: RADOM was switched on soon after launch and the TMC was commissioned while the spacecraft was in ETO and it captured images of the Earth and the Moon. The MIP was released on 14th November and it crossed the Malapert mountain and impacted close to 88°S latitude. All the other instruments were successfully commissioned between 15 November and early January. Anticipated thermal excursions experienced by the spacecraft when the solar phase angle is less than 10 degrees led to a restricted payload operation schedule during such a period during the commissioning phase. Results obtained by different payloads during the commissioning phase are described in several companion abstracts.