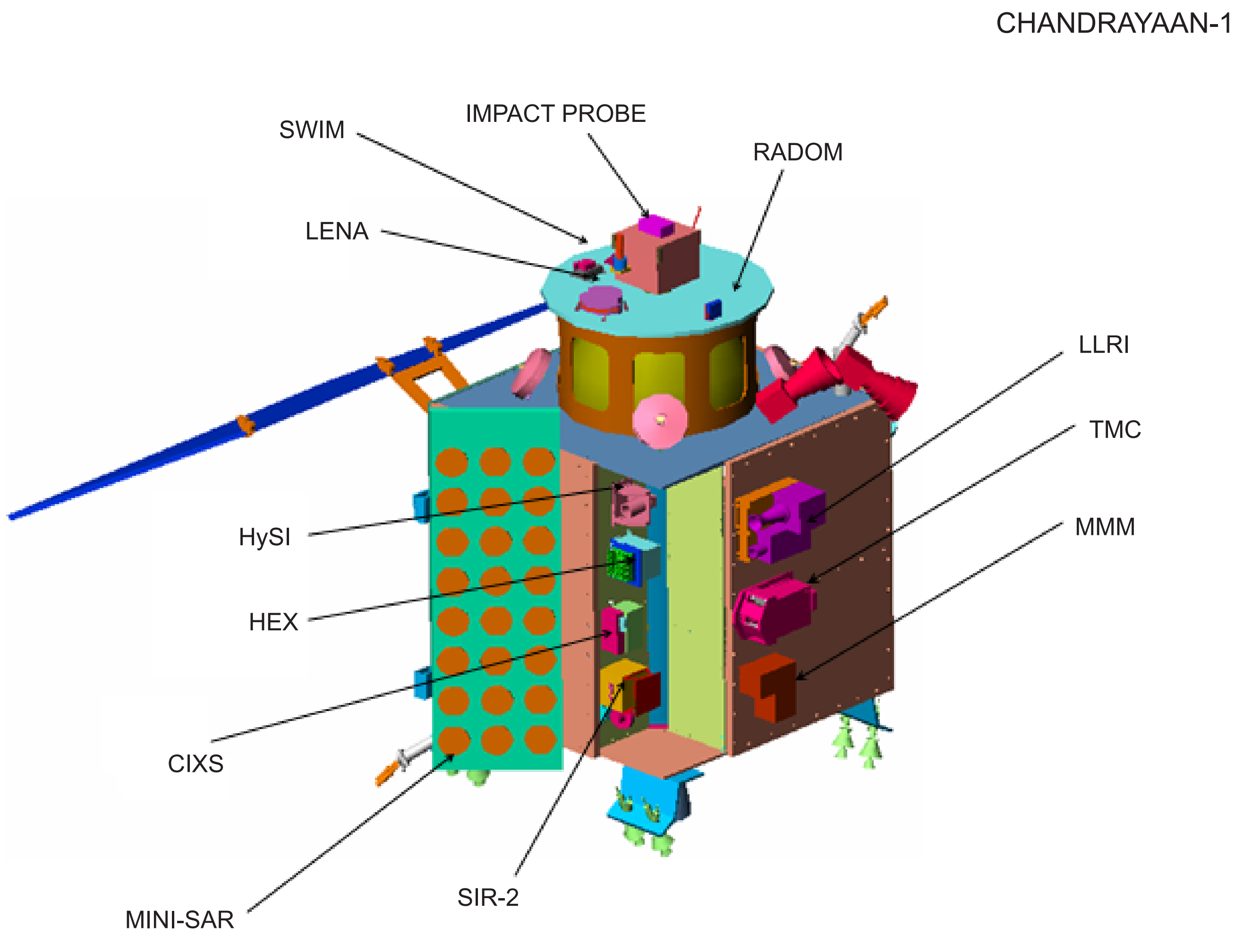

Chandrayaan-1 sketch, with its full ensemble of payloads and impact probe (Courtesy M Annadurai, ISRO, Bangalore).

Chandrayaan-1: Science goals

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The primary objectives of the Chandrayaan-1 mission are simultaneous chemical, mineralogical and topographic mapping of the lunar surface at high spatial resolution. These data should enable us to understand compositional variation of major elements, which in turn, should lead to a better understanding of the stratigraphic relationships between various litho units occurring on the lunar surface. 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 Kα 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 the 20–250 keV region. The mineral composition will be determined by a hyper-spectral imaging spectrometer (HySI) sensitive in the 400–920 nm range. The wavelength range is further extended to 2600 nm where some spectral features of the abundant lunar minerals and water occur, by using a near-infrared spectrometer (SIR-2), similar to that used on the Smart-1 mission, in collaboration with ESA. A terrain mapping camera (TMC) in the panchromatic band will provide a 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 10 m.

Four additional instruments under international collaboration are being considered. These are: a Miniature Imaging Radar Instrument (mini-SAR), Sub Atomic Reflecting Analyser (SARA), the Moon Mineral Mapper (M3) and a Radiation Monitor (RADOM). Apart from these scientific payloads, certain technology experiments have been proposed, which may include an impactor which will be released to land on the Moon during the mission.

Salient features of the mission are described here. The ensemble of instruments onboard Chandrayaan-1 should enable us to accomplish the science goals defined for this mission.

1. Introduction

A large amount of data on the Moon covering chemical, geophysical and geochronological aspects are now available as a result of the pioneering observations made by Apollo, Luna, Clementine and Lunar Prospector missions and the laboratory analysis of lunar samples. These data, relevant to the origin of the Moon, have been discussed in Hartmann *et al* (1986) and Canup and Righter (2000). Some of the crucial data and the need for further lunar exploration have been summarized by Bhandari (2002, 2004). The observations made by Apollo missions, although limited to the equatorial regions of the near side of the Moon, and the documented rock and dust samples from nine locations, available for laboratory studies, have given important clues to the origin of the Moon

Keywords. Chandrayaan-1; surface composition; mineralogy; imaging payloads; radon; radioactivity.

J. Earth Syst. Sci. **114**, No. 6, December 2005, pp. 701–709

and its early evolutionary stages. However, they are inadequate for accurate modeling of the chemical and physical evolution of the Moon. The details of these processes, their time scales and the extent to which the Moon was subjected to them have not been fully understood. It is therefore desirable to undertake further studies and carry out a sustained exploration of the Moon using orbiter, landers and sample return missions. This paper gives an overview of the Chandrayaan-1 mission, its scientific objectives and briefly describes the various payloads. The launch and imaging strategies are discussed in accompanying papers by Adimurthy *et al* (2005) and Ananth Krishna *et al* (2005) and detailed description of some payloads can be found in Kiran Kumar and Roy Chowdhury (2005a, b); Goswami *et al* (2005) and Kamalakar *et al* (2005).

2. Chandrayaan-1 mission profile

Chandrayaan-1 is a remote sensing mission proposed to be launched from the Satish Dhawan Launch Station at Sriharikota in 2007 by the Indian Space Research Organization using the Polar Satellite Launch Vehicle. It will be injected into $240 \times 36{,}000$ km Elliptic Transfer Orbit (ETO) around the Earth and will be inserted in a circumlunar orbit (LOI) via Lunar Transfer Trajectory (LTT). The launch profile is discussed in detail in an accompanying paper (Adimurthy *et al* 2005). It will enter the lunar orbit at about 1000 km altitude and brought down to 100 km polar circular orbit in one or two stages. The lunar craft is designed to orbit the moon for a period of two years during which it will carry out chemical, mineralogical and topographic study of the lunar surface.

There are several questions which are critical for understanding the formation and early evolutionary history of the Moon, and the Chandrayaan-1 mission objectives have been formulated keeping this in mind.

3. Chandrayaan-1: Mission objectives

The main objective of the mission is simultaneous chemical, mineral and topographic mapping with the specific goal of understanding the early evolution of the Moon. Chemical stratigraphy can provide better estimation of the average lunar composition and processes responsible for chemical differentiation of the Moon. Transport of volatiles, specifically water, and their deposition in the colder regions of the Moon and degassing of the Moon can be understood by using radon and its daughter nuclide ^{210}Pb as tracers.

3.1 *Formation of the Moon*

Hartmann and Davis (1975) and Cameron and Ward (1976) proposed that the Moon was formed from accumulation of the material ejected from the Earth as a result of the impact of a large ($0.1\,M_E$) differentiated interplanetary body (named Thiea) on the Earth during the terminal stage of its formation. This model, known as the Giant Impact Hypothesis has been simulated by Canup and Asphaug (2001) and Canup (2004) and they have shown that the debris ejected from the Earth after the impact can quickly accumulate in a moon-size body. However several questions remain to be understood. Firstly, where did the Thiea came from? The similarity of the oxygen isotopic composition of the Earth and the Moon and the distinct difference from the other known meteorite types (except Enstatites) indicate that Thiea must have initially formed from the same cloud of dust and gas as the Earth and hence, probably, in the vicinity of the Earth. Belbruno and Gott (2005) have argued that Thiea formed at the Lagrangian point L4 or L5 of the Earth. The question is that if both L4 and L5 are equally stable, bodies must be formed at both the Lagrangian points and if one has impacted on the Earth by some perturbation, what happened to the other. Will the other possibly sweep the ejected material and form the core of the infant Moon? Secondly, in a system where the planets form by accretion of a large number of planetesimals, several bodies can be captured in planetocentric orbits since there are stable orbits (Keplerian, horseshoe and corotating orbits) around any body. In fact several asteroids have been observed in transient geocentric orbits in recent times. For example, Asteroid 2002 AA_{29}, having a diameter of 0.1 km (Conners *et al* 2002), Asteroid 3753 Cruithne and Asteroid 2003 YN17 have been or are moving in temporary orbits as quasi moons. The role of these geocentric objects, which we term here as 'moonlets', in the formation of the Moon and subsequent modification of the lunar surface, e.g., in formation of mares, is not clear. This has been briefly discussed in an accompanying paper (Shiv Kumar and Bhandari 2005).

3.2 *Early lunar evolution*

The other important questions refer to the extent of the magma ocean and its cooling rate. The hemispheric asymmetry between the Earth-facing side and the far side of the Moon indicates a different crustal thickness in the two hemispheres. The elemental maps available for the Moon, based mainly on Clementine and Lunar Prospector data do not show if the magma ocean extended throughout the

Moon or if there were several small pockets distributed over the lunar surface. The depth to which the Moon melted has also not been determined and the seismic data available at present are not sufficient to resolve the internal structure of the Moon. These questions can be better understood if the chemical stratigraphy is determined. The remote sensing instruments can only analyse the surface materials, but it is known that the deeper material of the Moon is exposed in certain locations such as the central hills within large craters and some areas of the South Pole–Aitken (SPA) region. Pieters *et al* (1997) based on the Clementine data, have determined that some regions of the SPA, such as crater Bose (diameter 100 km) and Bhabha (80 km) and the Olivine Hill might represent lower crust or upper mantle material. Chemical analysis of the central hills which are small in areal extent, require instruments having high spatial resolution.

3.3 *Water at lunar poles*

Water (ice or H_2O in any form) is an important resource on the Moon, not only for establishing human bases but also for understanding how volatiles behave and are transported on the Moon. Water can be expected to be found on the Moon because

- the material of which the Moon is formed must have contained some water;
- water may have been deposited on the Moon by the impacting asteroids and comets over the ages;
- the solar wind hydrogen reduces lunar silicate and may form water by chemical reactions.

In spite of these possibilities, the Apollo and Luna samples, representing nine locations on the front side of the Moon did not contain any water or even the water of crystallization. Clementine and Lunar Prospector, however, indicated large amounts of water on both the lunar poles.

There are two observations made by the Lunar Prospector which indicate that water or hydrogen bearing compounds might be present at both the north and south poles of the Moon. The most compelling evidence is that the neutron spectrometer indicates a significant decrease in epithermal to fast neutron ratio at the poles (Feldman *et al* 2000). Fast neutrons are produced in the Moon by cosmic ray interactions with elements present within the upper meter of the lunar surface such as Fe, O, Al, etc. and are thermalised by the hydrogen, if present there. The epithermal to fast neutron ratio should therefore decrease in the presence of hydrogen-bearing compounds. The Lunar Prospector data indicate that about 1 billion tons of water is present at and near the north pole and 2 billion tons around the south pole, spread over a vast region. The data best match the model where water is mixed with the regolith soil or is overlain by about 40 cm of soil. The data are insensitive to any water which may be buried at depths deeper than a couple of meters. Crider and Vondrak (2000) have proposed that implanted hydrogen from the solar wind incident on the Moon is adequate to give the requisite signal observed by the neutron spectrometer. They calculate that an exposure of 7 m.y to solar wind is sufficient to deposit enough hydrogen which will match the data.

Another evidence for presence of water is given by bistatic radar experiment carried out on Clementine. Based on the polarization of the reflected to the incident signal, Nozette *et al* (1996) were able to show the possibility of water at the lunar south pole. A supporting evidence came from the observation made during the passage of the Lunar Prospector near the south pole, where it detected a positive signal for the presence of water. This evidence has been refuted by observations from the Earth using the Arecibo telescope where no evidence of water at the south pole was found (Bernard 2000). The signal is distinctly different from the observations of the poles of Mercury where the presence of water has been confirmed by using the same technique. In view of these conflicting observations it has not been possible to make any conclusions about presence of water on the lunar poles.

Arnold (1979) has discussed the possibility of ice deposits in the lunar polar regions. Because of severe temperature differences between lunar day and night times of nearly 300°C and severe temperature differences between lunar polar regions which are under a continuous shadow and the other areas of the Moon, water together with other volatiles degassing from the Moon or deposited on the surface are transported from hotter regions to the colder regions, ultimately ending up at the lunar poles. The water molecule, released from the lunar surface undergoes ballistic trajectory, depending on its thermal energy and hops from place to place till it finds a permanent cold trap.

4. Chandrayaan-1 payloads

Chandrayaan-1 payloads have been designed keeping these objectives in mind. There are two sets of payloads: the base line payloads originally proposed by the Moon Mission Task Force, and the payloads proposed by the international community in response to an announcement of opportunity issued by ISRO, which are currently under

Table 1. *Proposed payloads for Chandrayaan-1 and their configurations.*

Payload	Sensor configuration	Wavelength/ energy range	Spatial resolution	Objective
Hyper-spectral imager (HySI)	Wedge filter pixelated imager	0.4–0.92 μm with 15 nm resolution using 64 channels	80 m	Mineral mapping
Infrared spectrometer (SIR-2)	Grating spectrometer	0.93–2.4 μm	100 m	Mineral mapping
Moon mineral mapper (M3)	Grating spectrometer and HgCdTe detector	0.7 to 3.0 μm with 10 nm resolution	30 m	Mineral mapping and resource identification
Terrain mapping camera (TMC)	Three stereo cameras with pixelated detectors	Panchromatic	10 m 5 m elevation	Topographic mapping
Laser ranging (LLRI)	Pulsed Nd-Yag laser with optical system	1064 nm	Elevation 10 m	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	20–250 keV	20 km	Th, ^{210}Pb
Synthetic aperture radar (miniSAR)	Radar, scatterometer and altimeter	2.4 GHz	100 m	Soil properties, topography, altimetery
Neutral atom analyzer (SARA)	Mass spectrometer and solar wind monitor	10 eV–keV	100 m	Atmospheric neutrals (H-Fe) composition, Magnetic anomalies
Radiation dose monitor (RADOM)	Si semiconductor	$>$ 8 keV	–	Radiation dose

consideration. The base line payloads include two imaging payloads, i.e., a Terrain Mapping Camera (TMC) and a Hyper-spectral imager (HySI), two X-ray payloads (LEX/DCIXS and HEX) and a laser altimeter (LLRI). The payloads which are under consideration as a part of international collaboration, are an infra-red camera similar to the one used on Smart-1 (SIR-2), a Miniature Imaging Radar (mini SAR), Sub-keV Atomic Reflection Analyzer (SARA), and a Radiation Monitor (RADOM). Table 1 gives the sensitivity range and objectives of various payloads, briefly described below.

4.1 *Terrain Mapping Camera (TMC)*

TMC consists of three cameras for fore, nadir and aft viewing in order to obtain a stereoscopic view of the lunar surface. It will image the lunar surface in push broom mode in panchromatic spectral region between 0.5 and 0.85 μm. The fore and aft view angle is $\pm 25°$ with respect to nadir. It is expected to provide a spatial resolution of 5 m and a swath coverage of 20 km from a nominal altitude of 100 km. The illumination conditions on the Moon vary significantly, therefore there is a provision of adjustable gain and integration times to improve the signal to noise. The details are discussed by Kiran Kumar and Roy Chowdhury (2005a). It requires solar illumination for optimum performance and the observation period of two years therefore, is divided into several imaging seasons, depending on the solar aspect angle (Ananth Krishna *et al* 2005).

4.2 *Hyper-Spectral Imager (HySI)*

The Hyper-spectral imager is designed to map the major minerals present on the Moon (such as olivines, pyroxenes, feldspars, water-ice) with high spatial resolution and determine their composition. It employs a wedge filter sensitive in the range of 0.4 to 0.92 μm having 64 continuous bands with a spectral resolution of about 15 nm. It will have a spatial resolution of 80 m with a swath of 20 km. The wedge filter is an interference filter varying in thickness along one dimension. The signal is received by an area array detector such that different pixels in a row of the 256×512 APS detector will receive irradiance from the same spectral region but different spatial regions in the across track direction and different columns will receive irradiance from different spectral as well as spatial regions in the along track direction. The imager works in a push broom mode. This instrument also depends on the solar illumination and, therefore an imaging strategy depending on the solar aspect angle, has been developed (Kiran Kumar and Roy Chowdhury 2005b; Ananth Krishna *et al* 2005).

4.3 *Lunar Laser Ranging Instrument (LLRI)*

A laser altimeter for topographic mapping has been included in Chandrayaan-1 payloads. Together with TMC, it should be able to provide a digital elevation map of the Moon with 5 m spatial resolution. The LLRI observations are not dependent on solar illumination and, therefore the shadowed areas of the Moon can also be mapped. The altimetry information will be used to correct the data obtained by other instruments for viewing geometry. The LLRI employs a transmitting and a receiving optics for the 1064 nm Nd-Yag laser beam to measure the roundtrip travel time which is converted into altitude information. The instrument has been described in detail elsewhere (Kamalakar *et al* 2005).

4.4 *X-ray fluorescence spectrometer (LEX)*

An X-ray spectrometer, sensitive in the 1 to 10 keV region will determine the major element composition of the lunar surface material, by determining the flux of the characteristic Kα X-rays of various elements like Mg, Al, Si, Ca and Fe. Since fluorescent X-rays are excited by the solar flare X-ray flux, a solar X-ray monitor (SXM), consisting of two Si pin diodes, orthogonally placed, each covering a field of view of 90° will monitor the Sun all the time. The frequency and energy spectrum of the solar flares depend on the phase of the solar cycle. Distribution of Mg, Al and Si and, possibly Ca, Ti and Fe during energetic X-ray flares, can be measured using this technique. A spectrometer similar to the one onboard Smart-1 mission (DCIXS, Foing *et al* 2004; Grande *et al* 2003) having an active area of 50 cm^2 should be quite suitable for this purpose. The spectrometer uses a swept charge device for optimizing the signal to background ratio. With a 5° collimator, it is expected to have a spatial resolution of 20 km. Since the operation of the X-ray spectrometer depends on solar illumination, an imaging strategy has been developed, although it will provide useful data only during flare time.

4.5 *High Energy X-ray spectrometer (HEX)*

The high energy X-rays and gamma rays above about 20 keV are produced as a consequence of cosmic ray interactions in the lunar surface material and inherent radioactivity (e.g., K, and U and Th decay nuclides) present in the Moon. The nuclear interactions of primary and secondary cosmic rays with lunar material are confined to the upper meter or two of the lunar surface and produce gamma rays by de-excitation, spallation, decay of induced radionuclides and by neutron capture reactions, etc. Thus their flux has the signature of the lunar composition. An X-ray spectrometer, sensitive in the 20–250 keV region has therefore been included in the Chandrayaan-1 payloads. In this region, there are a number of gamma ray lines due to U and Th decay series nuclides like ^{210}Pb (46.5 keV), ^{228}Th (238.6 keV) and also due to neutron capture in rare earth elements like Gd and Sm which have high neutron capture cross section. However, because of the high Compton background, the signal to background ratio is poor. The background is also produced by the space craft and detector material which makes it difficult to determine the peak strengths with good precision. However, the flux of scattered gamma rays in this energy region is itself characteristic of the lunar terrain, being high in KREEP, gradually decreasing in basalt, highland and water bodies and can possibly be used to map the various lunar terrains.

The flux of gamma rays from radionuclides produced in decay of radon, e.g., ^{210}Pb, depends, not only on the *in situ* production in lunar surface but also on degassing of radon from the lunar interior (Bhandari *et al* 2004a). Once in the lunar atmosphere, radon decays to ^{210}Pb while it gets deposited in lunar cold traps (e.g., poles or cool night side). According to the model of Heymann and Yaniv (1971) radon is expected to pile up and show a peak at the morning and evening terminators and for this reason, radon (^{210}Pb) can be used as a tracer for transport of volatiles on the lunar surface. Brodzinski and Langford (1975) have summarized the observations on ^{210}Po and radon made at the Apollo landing sites. Considering plausible diffusivity coefficients of radon in the lunar regolith, the signal due to ^{210}Pb, deposited on the lunar surface as a thin paint, must be measurable.

There are many suitable solid state detectors (e.g., CdZnTe) and scintillators (e.g., BGO, CsI) available for the measurement of low energy gamma rays. The measurement of excess ^{210}Pb due to diffusion of ^{222}Rn from the lunar interior (Bhandari *et al* 2004a), over the amount produced *in situ* in the lunar surface due to U, requires high spatial resolution and therefore a 10° field of view collimator is proposed for a large area gamma ray detector, which will have a spatial resolution of 20 km from a nominal altitude of 100 km.

4.6 *Infrared spectrometer (SIR-2)*

The infrared spectrometer, proposed by U Mall and H U Keller of Max Planck Institute, Germany, is a grating spectrometer covering the wavelength range of 0.93 to 2.4 μm, having a spectral resolution of 6 nm and an angular resolution of 1.11 milirad. It is similar to the Smart-1 infrared spectrometer, described by Keller *et al* (2003). The spectrometer collects the reflected sunlight, which with the help of suitable optics is dispersed by grating and analysed by photosensitive pixels. Apart from lunar mineral mapping, which is accomplished by pointing the spectrometer facing nadir, it is capable of active tracking of particular features of interest for some duration.

4.7 *Moon mineral mapper (M3)*

The Hyper-spectral Imager (HySI) and the SIR-2, described above, cover a spectral range from 400 nm to 2400 nm and provide lunar reflectance spectra which can be used for mineral mapping of the Moon. However, there is critical information beyond 2400 nm which may be useful in identifying hitherto unidentified minerals or potential polar resources, such as volatiles and organic compounds, if they are deposited on the lunar poles, and therefore a moon mineral mapper (M3), proposed by the American group of Carle Pieters, has been included in the Chandrayaan payloads. M3 operates between 700 and 3000 nm with 10 nm resolution. It has a swath of 20 km with a spatial resolution of 30 m. The reflected solar light enters the M3 instrument, having 12° field of view, through an f/2.7 three mirror telescope. The focused light from the telescope passes through a slit into the high efficiency offner spectrometer. The spectrometer also uses an electron beam written convex dual blaze grating to achieve uniformity of design. At the focus of the spectrometer is located a 640 spatial by 231 spectral HgCdTe detector array sensitive from 700 to 3000 nm. A cryocooler is used for cooling the detector array. The long wavelength part (2600–3000 nm) is specially designed to investigate potential polar resources. It will have some overlap with HySI as well as SIR-2 and thus the three instruments together will make a comprehensive set of payloads for mineral mapping of the lunar surface.

4.8 *Miniature Synthetic Aperture Radar (MiniSAR)*

The miniSAR, proposed by the Applied Physics Laboratory, USA, is a multifunction instrument working as a synthetic aperture radar imager, an altimeter, scatterometer or radiometer. The radar operates at 2.5 GHz with a maximum peak RF power of 20 W. The primary antenna transmits a right circular polarized (CP) signal, while receiving the dual polarized, i.e., right as well as left circularly polarized signal. The radar observes the lunar surface at 45° incidence angle, recording echoes in both the orthogonal directions and creates an image. It has a resolution of 100 meters per pixel but in spotlight or low altitude mode, it has a resolution of 10 m/pixel. In the scatterometer/altimeter mode, the system will be nadir pointing and functions as a backscatter imaging radar with 300 m/pixel resolution. The radiometer, measuring the RF surface emissivity, is capable of measuring lunar surface temperatures in the range of 100–400 K, with a precision of 1 K, with a spatial resolution of 1 km. The meter scale surface roughness will be determined in the footprint. The circularly polarized ratio (CPR) will allow characterization of the physical properties of the lunar surface like dielectric constant and porosity.

4.9 *Sub Atomic Reflection Analyser (SARA)*

The SARA will image the surface using low energy neutral atoms (up to iron) in the energy range of 10 eV to 2 keV. It consists of a low energy neutral atom sensor and a solar wind monitor. The neutral atoms, after sweeping away the ambient charged particles by an electrostatic deflector, are converted to positive ions on an ionisation surface and then enter the sensor. The particle velocity is measured by time of flight measurement and the energy and mass are deduced by electrostatic analyzer. The mass resolution is such that H, O, Na–Mg, K–Ca and Fe group elements can be distinguished. Since the Moon does not have a magnetosphere or atmosphere, neutral atom density in the Moon's environment is extremely small, produced mainly by sputtering due to solar wind ions. The contribution due to micrometeorite vaporization and solar photon simulated desorption is estimated to be small in this low energy region of interest. LENA imaging of the neutral atoms will thus provide maps of the sputtered elements which can be converted into surface composition maps, making suitable corrections for the sputtering yield and the solar wind flux, which depends on the cosine of the solar zenith angle.

The Moon does not have a magnetosphere but small magnetic anomalies, strong enough to shield them to solar wind have been observed. In these regions, the neutral atom density will be small as sputtering due to solar wind would be absent. Thus LENA can detect magnetic anolmalies. For these measurements it is desirable to monitor the solar wind flux, which will be done by the SARA ion mass analyzer. The instrument and its operation is described in detail in the accompanying paper by Bhardwaj *et al* (2005).

4.10 *Radiation Dose Monitor (RADOM)*

An instrument for measuring the radiation dose (RADOM), proposed by T Dachev of the Bulgarian Academy of Sciences has been included in the Chandrayaan-1 payloads. RADOM consists of a semiconductor detector which measures the incident particle flux (ions, electrons and gamma rays) due to solar and galactic cosmic rays, accumulated absorbed dose rate and the deposited energy spectrum. The Si detector with an area of $2\,cm^2$ has a charge sensitive preamplifier and a multichannel analyzer. Its threshold level is 8 keV. It will make the measurement in the lunar environment as a function of altitude as the spacecraft descends from the lunar capture orbit to its final altitude of 100 km.

5. Prime targets for detailed study

The various instruments described above are expected to cover the whole lunar surface and Chandrayaan-1 has been designed to provide a global chemical, mineralogical and topographic map of the lunar surface. However, there are some areas on the Moon which are of special interest to Chandrayaan-1 in the context of its objectives defined above. Also, because of data transmission limitations of the lunar craft imposed by its visibility from the Indian Deep Space Network and capacity of the solid state recorder onboard, it is difficult to cover the whole Moon by high resolution hyper-spectral images in a limited time. It may, therefore, be useful to concentrate on some scientifically important features for a high resolution study by appropriate instruments during the initial phase of the mission. Therefore, based on the observations made earlier by Surveyor, Apollo, Luna, Clementine, Lunar Prospector and other missions, as well as by Earth based telescopes, we have selected some prime sites, for detailed observations by Chandrayaan-1 (Bhandari *et al* 2004b). These include several mares, e.g., Mare Fecunditatis, Imbrium, Orientale, Oceanus Procellarum and South Pole–Aitken basin (SPA). The edges of Mare Fecunditatis (7.8°S, 308.7°) has several dark haloed craters which, based on Apollo 15 and 16 and Surveyor 5 and 7 observations, are known to have enhanced alpha particle fluxes with anomalous $^{222}Rn/^{210}Po$ and may be of special interest for study at a high spatial resolution by HEX.

Lunar Transient Phenomena (LTP) have been observed at many sites on the Moon but their causes are not known. Some of them are associated with swirls which may be caused by magnetic anomalies, degassing events or cometary impacts. Measurements of radioactivity (^{210}Pb-^{222}Rn) may be helpful in assessing the importance of degassing at these sites. Pre-Nectarian Ingenii basin (33.7°N 163.5°), located on the Moon's southern far-side and Fecunditatis on the near-side have younger basalts, swirls and have a relatively thin filling. Crater Reinier γ (7.5°N 59°) on the near-side has a bright swirl which, with a distinctive figure of "8" shape, may have been formed either due to magnetic anomaly or by leakage of gases from the Moon's interior and may be of particular interest from the point of view of measurements of radon and ^{210}Pb. Bright swirls have also been found in Mare Marginis (13.3°N, 86.1°E), in Mare Ingeneii on the far-side and close to the far-side craters Fleming and Gerasimovich (22.9°S 122.6°), usually ascribed to magnetic anomalies (MAGCONS). These may be good sites to study by LEX, HEX and SARA spectrometers as well as HySI for chemical, radioactive and mineral composition and magnetic anomalies.

SPA basin has some special features like the Olivine Hill, Craters Bose and Bhabha and some formations on Highlands have been noted to have either special chemistry, characteristic of the deep interior of the Moon or may have evidence of the release of radon (and other gases, e.g., CO_2) from the interior. Similarly, central hills of complex craters contain material from great depths (up to about 30 km). Their mineralogy, chemical composition and structural disposition should enable us to understand compositional variation with depth in the crust. Young-rayed craters have fresh, deep material exposed and may also offer an opportunity of determining the chemical composition of the lunar interior. Among the various craters of interest are Aristarchus (23.7°N, 47.4°, diameter $\sim$ 40 km), Giordano Bruno (43.4°S, 11.1°, 22 km), Tycho (43.4°S, 11.1°, 102 km), Copernicus (9.7°N, 20°W, 93 km), Alphonsus (13.7°S, 3.2°W, 108 km), on the near-side and on the far-side, 185 km diameter crater Tsiolkovsky (21.2°231.1°). Tsiolkovsky has a smooth floor and is the preferred site for a low frequency radio telescope. Davy catena (11°S, 7°W), and Marius Hills are also selected as candidates for high resolution study. Aristarchus is reported to have olivine, which could have resulted either by puncturing of shallow plutons or may have a pyroclastic or deep-seated origin. On 29th October, 1963, James Greenacre at the Lowell Observatory in Arizona, reported transient red spots in this crater, possibly due to release of gases from the lunar interior. Craters Mendel (48.8°S, 109.4°E, 138 km) and Schiller (51.9°S, 39°, 180 km) on the near-side and Hertzsprung (26°N, 129.2°, 591 km), Coulomb (54.7°N, 114.6°, 89 km) and Freundlich (25°189°, 85 km) on the far-side have MASCONS, although they are not filled with lava and therefore it may be useful to study them chemically by X-ray fluorescence spectrometer and for mineral composition using the Hyper-spectral imager and Moon Mineral Mapper. MASCONS (mass concentrations) have been found in large basins with and without lava filling. A comparison of the mineralogical and elemental nature of basins will enable us to understand the internal structure of the crust. Davy Catena system (11°S, 7°W) is a linear chain of kilometer size craters in the Crater Davy, suspected to have been formed from the impact of cometary nuclei which may have been fragmented due to the gravitational effect of the Earth. The site will be useful for identifying cometary material which may be lying in the ejecta of these craters. Crater Marius, is suspected to be a series of volcanic hills in NW Ocenaus Procellarum and may be of special interest.

The area surrounding the north and south poles may be of interest because of the possibility of water-ice present there. Clementine and Lunar Prospector found some evidence of ice in the Crater Shackleton (89.6°S, 110°E) near the south pole which needs confirmation. Crater Peary (88.6°N, 33°E) near the north pole and Malapert mountain near the south pole have solar illumination for most of the time and are candidates for a more detailed study with the TMC by Chandrayaan-1 since it will pass over the poles during every orbit and will observe the Moon for 2 years.

There has been some discussion that Crater Bruno (35.9°N, 257.2°E, 22 km) may have formed in historical times. Its study will be useful in determining mineralogical and chemical composition, least affected by space weathering. It may be noted that mafic and ultramafic rocks and minerals like olivine which are characterized by high magnesium number are representative of deep seated material.

5.1 *Imaging of poles and detection of water-ice*

Solar illumination or even Earth shine does not reach the poles and they are under a permanent shadow (Arnold 1979). 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 (Ananth Krishna *et al* 2005).

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 M3. 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 the presence of water-ice on permanently shadowed regions and in the search for volatiles on the lunar poles. The photon flux in the 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 (< 1 m) regolith. None of the instruments can detect water lying at great depths even if the quantity of such deposits is large.

5.2 *Chemical stratigraphy*

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 discussed above, and some regions of the South Pole–Aitken basin, since deep seated material has been documented there (Pieters *et al* 2001). 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.

Acknowledgements

I thank members of the Moon Mission Task Force, Science Advisory Board of the Indian Space Research Organization, Principal Investigators of various payloads of Chandrayaan-1, numerous colleagues in ISRO and Physical Research Laboratory who contributed to the formulation of scientific goals, selection of payloads, and the designing of the instruments described in this paper.

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