SCIENTIFIC OBJECTIVES OF THE JAPANESE MOON-ORBITING SATELLITE

S.Sasaki*, Y.Iijima and H.Mizutani
The Institute of Space and Astronautical Science (ISAS)
3-1-1, Yoshinodai, Sagamihara, Kanagawa 229, Japan

Y.Takizawa
National Space Development Agency of Japan (NASDA)
2-1-1, Sengen, Tsukuba-City, Ibaraki 305, Japan

Abstract

A moon-orbiting observatory mission is now under investigation in Japan for lunar science, study of lunar and solar-terrestrial environment, and technology development for future lunar exploration. The mission will consist of a main orbiting satellite at about 100 km altitude near the polar circular orbit, a relay satellite, and a lander. The scientific objectives of the mission are ; 1) study of the origin and evolution of the moon, 2) in-situ measurement of the lunar environment, and 3) observation of the solar-terrestrial plasma environment from the lunar orbit. The orbiter will carry instruments for scientific investigation, including mapping of lunar topography and surface composition, measurements of gravity and magnetic field, and observation of lunar and solar-terrestrial environment. The total mass of scientific payload on the orbiter is about 300 kg. The launch by H-II rocket is currently planned for 2003 and the lifetime of the orbiter is typically 1 year. If extra fuel is available, the mission will be extended in a lower altitude orbit at 70-40km. The remote sensing for one year will provide a global map of the surface composition, surface topography, and magnetic and gravity field, and will greatly contribute to understand the origin and evolution of the moon.

1. Introduction

The moon has been observed and explored extensively as the most familiar planetary body in the solar system. Since 1950's, the lunar surface has been explored by the unmanned and manned mission. The Apollo program from 1969 to 1972 was undoubtedly epoch-making in the advancement of lunar science. After the Apollo, moon mission had not been realized for more than 15 years. Recently, the moon was explored by the Galileo mission on its way to the Jupiter and by the Clementine mission. Although the previous missions have provided a lot of return in the field of lunar science, still, the most basic question in the lunar science concerning the origin and early evolution of the moon is left open.

* Associate Professor, Research Division for Space Applications.

The study of the moon is particularly important in the planetary science because its birth and development are closely related to the evolution of the other solid bodies in the solar system. The moon is not so primitive as the meteorite or comet, but is relatively simple as compared with the earth covered with the atmosphere. The geological processes can be easily identified and be applied to the other planetary bodies. Since the moon is considered to be created and evolved near the earth, the study is also important to picture the evolution of our earth itself.

After 25 years since the Apollo program, there is an international tendency to challenge the study of the origin and evolution of the moon, using advanced observation technologies. Many scientists believe time is ripe for starting the new challenge now that the fruits reaped during the Apollo era are well digested. The mission of the Japanese moon explorer Lunar-A[1] and American lunar orbiter Lunar Prospector are just ahead planned in 1997. In Europe, although the lunar polar orbiter mission concept, MORO[2], has not been accepted, another exploration mission concept[3] for early 2000's is now under investigation.

In Japan, researchers in the field of planetary science are now interested in the next exploration program after Lunar-A to proceed further step for the lunar science. A proposal for next lunar mission consisting of a polar orbiter, a lander and a relay satellite has been generated to perform remote-sensing observations of the lunar surface and measurements of gravity and magnetic field of the moon[4]. The mission concept is summarized in Table 1. The proposed instruments for the orbiter are ; an X-ray spectrometer, a γ -ray spectrometer, a VIS-near IR imager and spectral profiler, a high-resolution stereo camera, a laser altimeter, and a radar sounder for remote-sensing observations inside the lunar surface, a radio source for differential VLBI observation from the ground, a magnetometer, dust analyzers, a plasma measurement assembly, imaging instruments for the earth magnetosphere, and a charged particle spectrometer. The major purpose of the lander is verification of autonomous landing technologies but it will carry another radio source for the differential VLBI observation. The relay satellite will be used to make the range and range rate measurement of the orbiter while the orbiter is in the far side. The radio science to detect the tenuous lunar ionosphere is also proposed to conduct intermittently during egress and ingress.

Table 1 Mission summary.

Launch	H-II launch in 2003	
Orbit	Hohmann Transfer into Lunar Polar Orbit 100 km Altitude, Inclination 95°	
System	Orbiter, Lander and Relay Satellite	
Attitude	3-axis Control	
Mission Period	1year typical	
Orbiter Data Downlink Rate	10 - 15 Mbps	
Orbiter Data Recorder	10 GByte	
Weight	at Lunar Transfer Trajectory Injection	2800 kg
	Lunar Orbiter	1500 kg
	Science payload	305 kg
	Lander	410 kg

2. Mission Scenario

The mission profile is illustrated in Fig.1. The spacecraft will be launched by the NASDA H-II rocket and directly injected into the lunar transfer trajectory. It takes about five days to reach the lunar orbit. A mid-course maneuver is required twice on its way to the moon. The spacecraft is captured by the moon into an elliptical orbit with apogee at 15000 km and perigee at 100 km. The spacecraft will finally reach a circular 95 degrees-inclination orbit at about 100 km altitude after 4 orbit-transfer maneuvers. During the orbit transition, the relay satellite is released on an elliptical orbit with apogee at 4300 km. Upon arriving at the final circular orbit, the lander is separated for soft landing testing at the early opportunity. After the landing operation, the orbiter extends the antennas for radar sounder experiment and the mast for the magnetometer, and starts the scientific mission operation.

The concept of the orbiter configuration is shown in

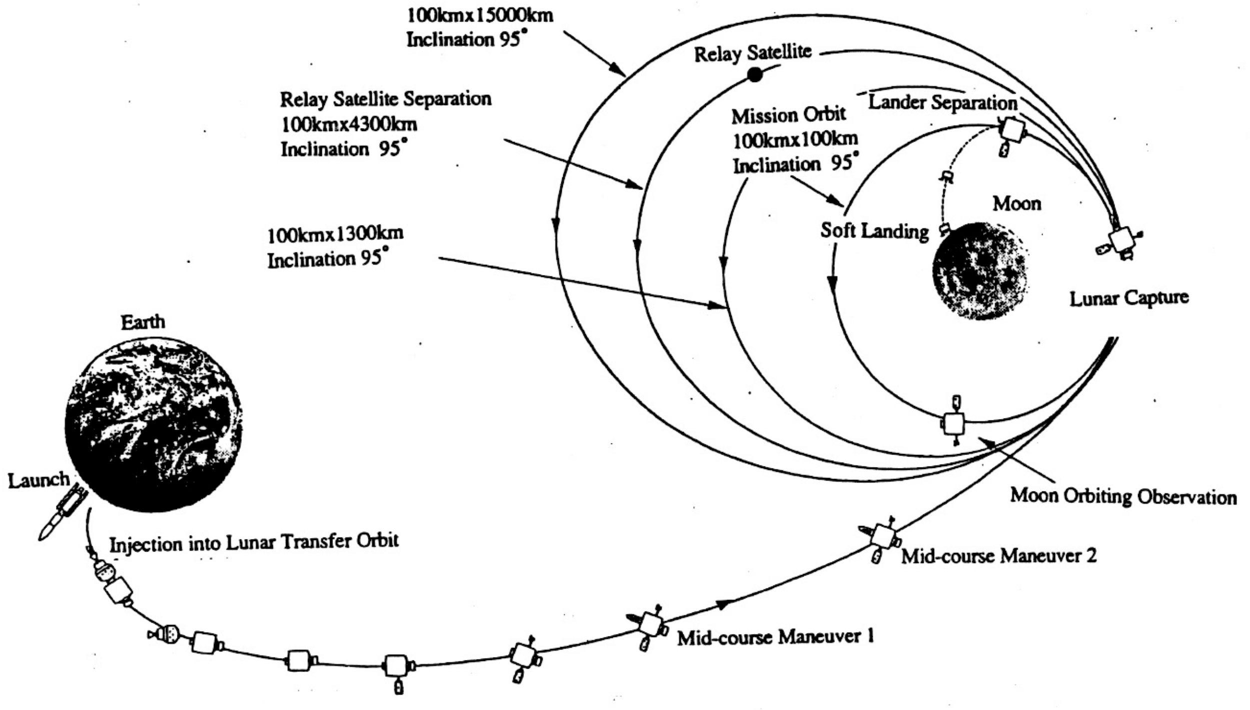

Fig.1 Mission profile of the Japanese moon-orbinting satellite.

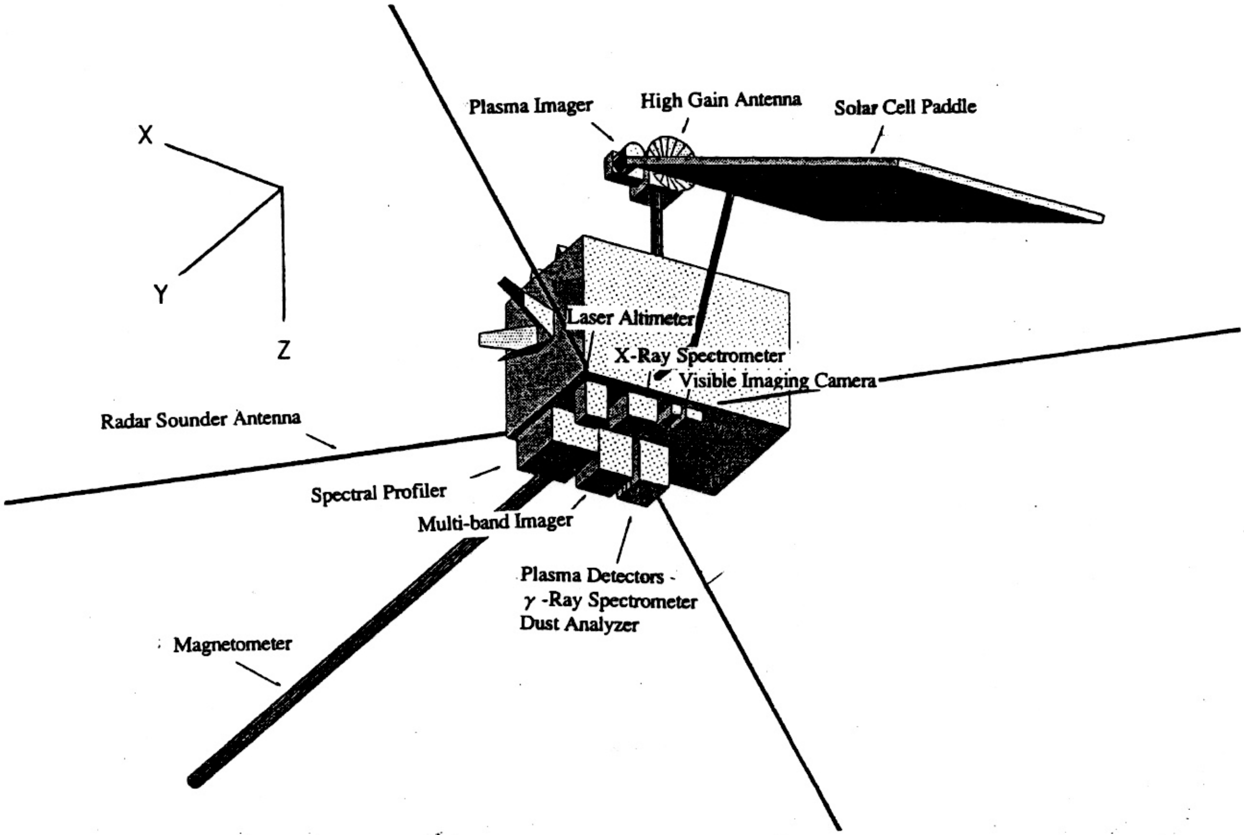

Fig.2 Concept of the orbiter configuration.

Fig.2. The orbiter moves towards +x direction in the figure. Most of the sensors for the remote-sensing instruments are installed on the z-plane which is controlled to direct the lunar surface by a three-axis attitude control system. Two pairs of the antenna for radar sounding are configured to cross perpendicularly to each other. The mast for the magnetometer is deployed either in +y or +x direction. The plasma imager to observe the earth ionosphere is installed on a movable platform of the high-gain antenna to direct the earth. The solar array panel deployed in the -y direction will rotate along the y axis to track the sun.

The orbital period is about 2 hours. Since the distance of the adjacent orbit is about 35 km on the equator, the orbiter returns the initial orbit every month if the orbital perturbation is negligible. By adjusting the orbital latitude every month, global mapping with a high-latitude resolution less than 35 km on the equator is possible. The capability for data recording and data downlink is expected to be 10 GB and 10-15 Mbps, respectively.

After the observation at the altitude of 100 km for 1 year, the altitude of the orbiter will be lowered to 70-40 km, to measure the lunar magnetic and gravity field more precisely and to observe the scientifically-valuable areas with a higher spatial resolution.

The lander carries a radio source for differential VLBI experiment. Although the capability of the telemetry and commanding of the lander is terminated during the first lunar night, the radio source will survive for at least 1 year by getting the electric power from the lander. The relay satellite consisting of two S-band transponders will be designed to survive at least 2 months to provide the tracking data from the orbiter in the far side.

3. Scientific Research Subjects

The major scientific objective of the mission is study of the origin and evolution of the moon. To fulfill the objective, global mapping of elemental abundances and mineralogical composition, surface geographical mapping including subsurface radar sounding, and gravity and magnetic field measurements have been proposed. The integrated research scenario towards the objective is illustrated in Fig.3. For the in-situ measurement of the lunar environment, the measurements of the high energy particles, the electromagnetic environment, solar wind plasma, lunar ionosphere, and the cosmic dusts are proposed. For the observation of the solar-terrestrial plasma environment from the lunar orbit, observations of earth plasma environment and planetary radiation are considered. The model instruments currently proposed for the mission are summarized in Table 2. The performance in the table will be modified by further investigation in the feasibility study.

3.1 Global Mapping of Elemental Abundances and Mineralogical Composition

Global mapping of the lunar elemental abundances and mineralogical composition will enable us to estimate the entire lunar composition, which will give constraints on the origin and evolution of the moon. The elemental abundances are measured by the x-ray and γ -ray spectrometers. The x-ray spectrometer up to 10 keV with a large aperture totally 500 cm^2 will be capable to measure the major elements such as Mg, Al and Si at a 12 km resolution. The γ -ray spectrometer up to 10 MeV using a high-purity germanium crystal of 200 cm^3 size will measure the natural radio-nucleides, such as U, Th, and K, and major chemical constituents of some 10 kinds at a 120 km resolution. Stirling cooler will be required for the measurement. Since the solar activity is relatively high in early 2000's, induction of x-ray and γ -ray from the lunar surface by the solar radiation are expected to be stronger than usual. As a consequence, the measurement with a higher S/N ratio could be possible in that time frame. Alpha particle spectrometer will be used to detect alpha particles from the radon gas and polonium. The observation of gas ejection will contribute to understand the lunar tectonic activity.

The mineralogical characterization is performed by a multi-band imager with 10 spectral bands ranging from 0.35 to 1.0 μ m at a high spatial resolution typically 20 m. The spatial resolution is roughly 10 times higher than that of the Clementine. The identification of mineralogical composition, such as pyroxene, olivine, and anorthite, is performed by the spectral profiler with a continuous spectrophotometry from 0.5 to 1.9 μ m at a 500 m resolution. Active cooling by Stirling cooler is currently considered for the IR sensor. The comprehensive data from the multi-band imager and the spectral profiler are combined to map the mineralogical composition. The data inversion from the multi spectral data to the mineralogical composition requires a data base for inversion which will be generated by laboratory simulation experiments in the mission preparation phase. Besides the surface mapping function, the spectral profiler is expected to identify the mineralogical composition of the deep crust material which possibly appear at the lunar surface, such as inside the large-scale impact craters.

3.2 Global Mapping of Lunar Surface

The surface topographic data are obtained by the high resolution stereo camera and laser altimeter. The stereo camera has a field view of 17 km with a spatial resolution of 5-10 m to provide images in three dimensions. The laser altimeter measures the altitude every 300 m with a vertical resolution of 5 m and a spot size of 30 m diameter. These data are used to produce global topographical maps with a higher accuracy than before. Combining to-

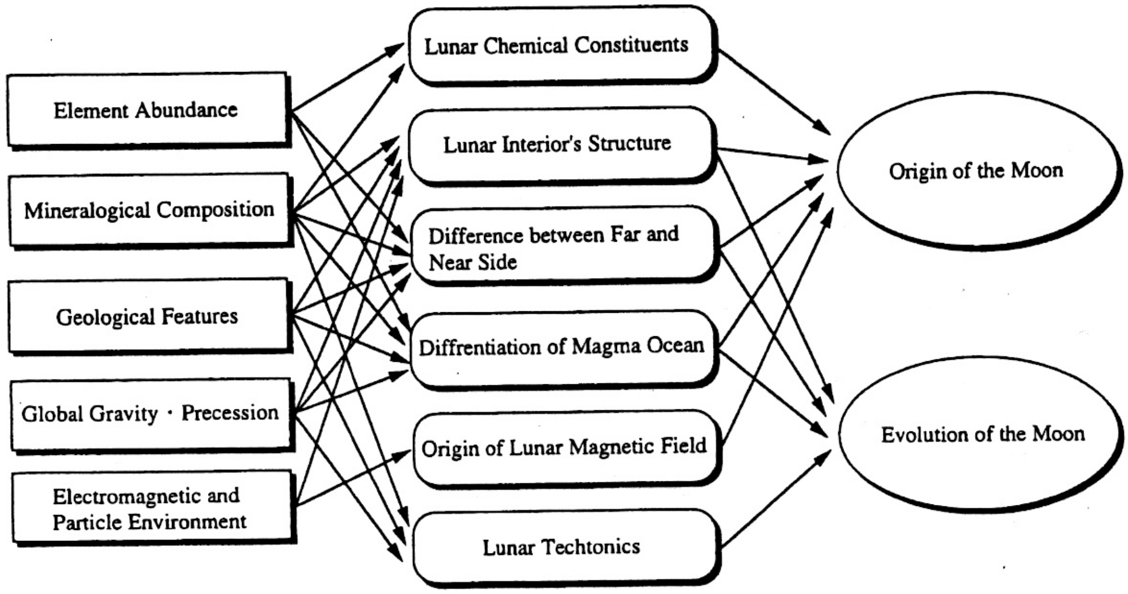

Fig.3 Research scenario for origin and evolution of the moon.

Table 2 Model mission instruments.

Instrument	Characteristics
X-ray Spectrometer	GSPC type, Mg, Al, Si, etc Detection 12 km × 12 km Resolution
γ -ray and Alpha Particle Spectrometer	γ -ray Spectrometer High Purity Germanium, Stirling Cooler, 120 km Resolution Alpha Particle Spectrometer Large Detection Area for Rn Gas and Po
Multi-band Imager	UV-VIS-NIR Mapping Spectrometer, 0.3 ~ 1.0 μm Bandwidth, 10 filters, 20 m Resolution, 17.5 km FOV
Spectral Profiler	VIS-NIR Spectrometer, 0.5 ~ 1.9 μm Bandwidth, 5 nm Sampling, Stirling Cooler, 500 m Resolution
Topographical Camera	High Resolution Stereo Camera, 5 ~ 10 m Resolution, 17 km FOV
Radar Sounder	5 MHz Radar, 4 - 15 m Antennas, 5 km Vertical Range, 100 m Vertical Resolution, High Performance Wave Receivers
Differential VLBI Radio-Source	Orbiter and Lander, X and S Transmitters, Ground VLBI Stations
Laser Altimeter	Nd: YAG, 2 Sets, 0.3 mrad Beam, 5 m Vertical Resolution, 300 m Sampling
Magnetometer	3-Axis Fluxgate Type, 0.5 nT Accuracy, 12 m Mast
Dust Analyzer	Impact Plasma Detection, Combined with Mass Analyzer
Plasma Imager	EUV ~ Visible Imager for Terrestrial Plasma Observation
Charged Particle Spectrometer	High-energy Isotope Detector (~ 300 MeV/n), Low-energy Isotope Detector (~ 30 MeV/n)
Plasma Measurement Assembly	Ion Energy / Mass Analyzer (~ 30 keV/q), Electron Energy Analyzer (~ 30 keV/q)
Relay Satellite	Two Transponders, 4300 km Apogee, 100 km Perigee

pographic data with the spectral data from the multi-band imager and spectral profiler, the mineralogical composition will be identified for the different geologic units which would make it possible to presume the origin of the geologic structure. The structure below the surface regolith, such as dislocation, volcano and lava flow, can be mapped by the radar sounder using a 5 MHz transmitter. The sounder experiment will reveal the inside structure up to 5 km below the surface with a vertical resolution of 100 m. The survey of the high land will provide important information on the hypothesis of "magma ocean". The observation of lunar surface will enable to understand the history of impact cratering, volcanism and tectonism. The topographic information is required also for construction of the scientific facilities on the moon such as astronomical observatory in the future.

3.3 Gravity Field Measurement

The radio sources on the orbiter and lander are used to conduct differential VLBI observation from ground stations. Several frequencies in the S and X bands are radiated from the sources. The observation enables to determine the location of the radio sources with a high accuracy. This will provide accurate measurements of the lunar gravity field, the libration and the moment of inertia of the moon, typically 10 times better than before. With information of size of the core if any to be obtained by the Lunar-A mission in 1977, the composition of the core can be determined with a high accuracy. This will greatly contribute to the study of the origin and evolution of the moon. On the other hand, the Doppler tracking of the orbiter via the relay satellite when the orbiter is in the far side is used to determine the gravity field of the far side. The gravity anomalies typically less than 100 km will be determined for geodesy. The global modeling will provide detailed information on the global crustal asymmetry as well as the internal lunar structure.

3.4 Magnetic Field Measurement

The magnetometer will provide data on the lunar surface magnetic field and the lunar induced magnetic dipole. In order to estimate the lunar magnetic field separating from the fields in the solar wind, the solar wind plasma is simultaneously measured by the solar wind detectors. The electron energy analyzer of the solar wind detectors which is capable of detecting the reflected electrons by the lunar magnetic field will show the distribution of magnetic field strength. The data on the lunar magnetic field will provide an understanding of the origin of lunar paleomagnetism and paleomagnetism induced by impacts. The measurement of the electromagnetic response to the change of the solar wind field will allow to estimate the internal conductivity and temperature profile, which gives constraints on the size and composition of the lunar core.

3.5 Lunar Environment

The study of the lunar environment, such as high energy particles, electromagnetic field, plasma and cosmic dust, is required for the future manned and unmanned utilization of the moon. It also includes a valuable scientific aspect in each field. The observation of the energetic particles including heavy cosmic particles will contribute to study the composition of solar and interstellar matter and their evolution. The dust detector with a capability of mass analyzer will allow identification of the origin of the dust. It may detect the dust originated from the lunar surface. The solar wind plasma detectors including ion mass/energy analyzer plus electron energy analyzer and electromagnetic wave receivers will be used to study not only the solar wind itself and the geomagnetic tail, but also the interaction of the solar wind with the moon. The radio science using coherent x and s band carriers from the orbiter will be able to detect the tenuous lunar ionosphere.

3.6 Observation from the Moon

Two research subjects are proposed as a solar-terrestrial observation from the lunar orbit. One is the imaging observation of the earth using the wavelength ranging from extreme ultraviolet to visible radiation, which is expected to clarify the macroscopic dynamics of the terrestrial plasma environment and aurora activities. Another is the observation of planetary radiation from Jupiter and Saturn under the extremely low noise environment in which the dominant radiation from the sun and earth is shielded by the moon itself

4. Summary

The moon-orbiting observatory mission for lunar science, study of lunar and solar-terrestrial environment, and technology development for future lunar exploration has been extensively investigated in Japan by space scientists and engineers. The mission includes a polar orbiter of 100 km altitude, a relay satellite and a lander. The study has represented a significant contribution to lunar science concerning the origin and evolution of the moon. The technical feasibility of the mission scenario has been demonstrated in the study. Start of the Phase-A study has been accepted for further investigation as a national space program to be performed jointly by ISAS and NASDA.

References

1. H.Mizutani, S.Nakajima, J.Kawaguchi, H.Saito, A.Fujiwara, and M.Hinada, Japanese Lunar Exploration, LUNAR-A, 30th COSPAR Scientific Assembly, Hamburg, Germany, July, 1994.
2. A.Chicarro, G.Racca, and M.Coradini, A European Moon-Orbiting Observatory for Global Lunar Characterisation, ESA Journal, Vol.8, 1994.
3. D.Kassing and M.Novara, The LEDA Mission : Breaking New Ground to Prepare a Return to Lunar Surface Exploration, International Moon Workshop, Berlin, Germany, Jan., 1996.
4. ISAS Moon Orbiter Working Group, Proposal for moon-orbiting observatory mission (in Japanese) , March, 1996.