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SCIENTIFIC OBJECTIVES OF SELENE MISSION

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Abstract

A Moon-orbiting mission (SELENE ; Selenological and Engineering Explorer) is prepared in Japan for lunar science and technology development for future lunar exploration. The mission consists of a main orbiting satellite at about 100 km altitude near the polar circular orbit and a relay satellite on an elliptical orbit with an apolune at 2,400 km at the orbit injection. 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. SELENE will carry instruments for scientific investigation including mapping of lunar topography and surface composition, measurement of the gravity and magnetic fields, and observation of lunar and solar-terrestrial environments. The total mass of scientific payload is about 300 kg. The launch by H-IIA rocket is currently planned for 2003. The mission period will be 1 year for remote sensing observation and additional 2 months for VLBI observation.

1. Introduction

The Moon has been explored repeatedly more than any other planetary body. Especially the Apollo program from 1969 to 1972 brought about a significant progress in lunar science. However, the most basic question concerning the origin and evolution of the Moon still remains a mystery. The study of the Moon is particularly important because it is closely related to the origin and evolution of our earth. There is an international movement to challenge the study of the origin and evolution of the Moon. The Lunar Prospector[1] for characterization of surface composition, measurement of magnetic and gravity fields, and study of lunar outgassing events just started in January 1998. The Japanese Moon explorer Lunar-A[2], a penetrator mission, is almost ready for launch in 1999. Studies for new lunar mission are now under way in Europe and Russia.

In Japan, another lunar mission, SELENE, is prepared for launch in 2003, which will be the largest lunar mission after the Apollo program. The mission is planned primarily for planetary science to study the origin and evolution of the Moon. The spacecraft consists of a main orbiter on a circular orbit at the altitude of 100 km and a relay satellite on an elliptical orbit with the initial apolune at 2,400 km. The main orbiter conducts global mapping of element abundances and mineralogical composition, surface geographical mapping including subsurface radar sounding, and magnetic field measurement.

The concept of SELENE observatory mission is illustrated in Fig.1. The element abundances are measured by x-ray and γ -ray spectrometers. Alpha particle spectrometer is used to detect the radiation from the radon gas and polonium. The mineralogical characterization is performed by a multiband-spectrum imager at a high spatial resolution. The mineralogical composition can be identified by a spectral profiler, a continuous spectral analyzer in visible and near infrared bands. The surface topographic data are obtained by high resolution stereo cameras and a laser

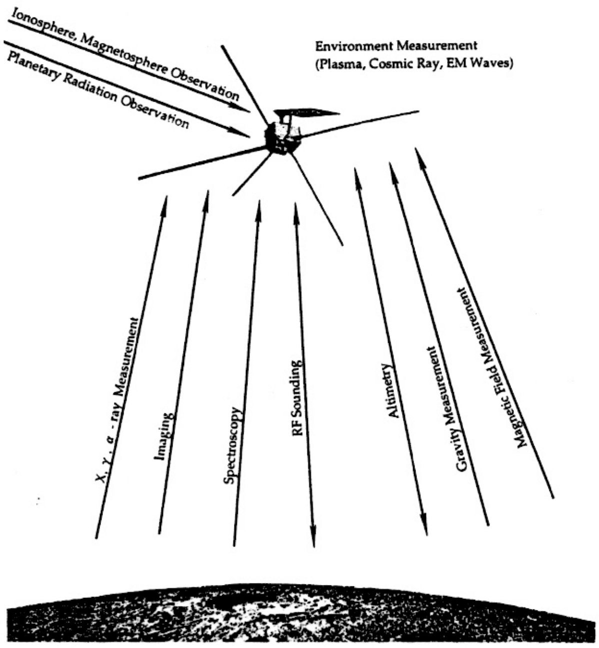

Fig.1 Concept of SELENE observatory mission.

altimeter. The subsurface structure is probed by an rf radar sounder experiment. Doppler tracking of the orbiter via the relay satellite when the orbiter is in the far side is planned for the study of gravimetry and geodesy. A magnetometer and electron detectors will provide data on the lunar surface magnetic field. After completion of the remote-sensing observation mission, the propulsion module of the orbiter is separated and used as a lander. Radio sources on the relay satellite and the lander on the lunar surface are used to conduct differential VLBI observations from ground stations. Although the methodology of SELENE observation is conventional except for the gravimetry research, state of art technologies are fully utilized for the instruments to maximize the scientific return.

Measurement of the lunar environment and observation of the solar-terrestrial environment are also planned in the mission. The study of the lunar environment includes the measurement of high energy particles, electromagnetic field, and plasma. For the solar-terrestrial observation, the orbiter carries imaging instruments to observe the dynamic structure of the earth plasma environment. High-sensitivity wave receivers are also onboard for detection of the planetary radiation from the Jupiter and Saturn.

2. Mission Scenario

The SELENE mission is summarized in Table 1. The mission profile is shown in Fig.2. The spacecraft will be launched by the H-IIA 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 apolune at 15,000 km and perilune at 100 km. The apolune is lowered by 6 orbit transfer maneuvers and finally the orbiter reaches the mission orbit at about 100 km altitude. During the orbit transition, the relay satellite is released on an elliptical orbit with an apolune at 2,400 km. Upon arriving at the mission orbit, the orbiter extends the antennas for the radar sounder experiment and the mast for the magnetometer. Remote-sensing observation of the lunar surface and observation of the lunar and solar-terrestrial environments will be performed for about one year. If the fuel to control the orbit is available to extend the observatory mission, the orbiter will be lowered and maintained at 40-70 km altitude for another two months to measure the lunar magnetic and gravity fields more precisely.

The configuration of the orbiter is shown in Fig. 3. The orbiter moves towards +x or -x direction in the figure. Most of the sensors for the remote-sensing observation are installed on the z-plane which is controlled to face the lunar surface all the time by a three-axis attitude control

Table 1 SELENE mission summary.

Launch	H-IIA Launch in 2003
Orbit	Hohmann Transfer into Lunar Polar Orbit 100km Altitude, Inclination 95°
Configuration	Orbiter(including Landing Module) and Relay Satellite
Size	2mx2mx4m(Orbiter), 1m ϕ x1m(Relay Satellite)
Power	3.5kW(Orbiter)
Attitude Control	3-axis Control(Orbiter), Spin Stabilized(Relay Satellite)
Mission Period	1 year for remote sensing observation plus 2 months for dedicated VLBI experiment(nominal)
Orbiter Data Downlink Rate	10 Mbps
Orbiter Data Recorder	10 GBytes
Weight	Launch 2,900kg Lunar Orbiter (Initial Phase) 2,100kg Science Payload 275kg Relay Satellite 40kg (Landing Module 360kg)

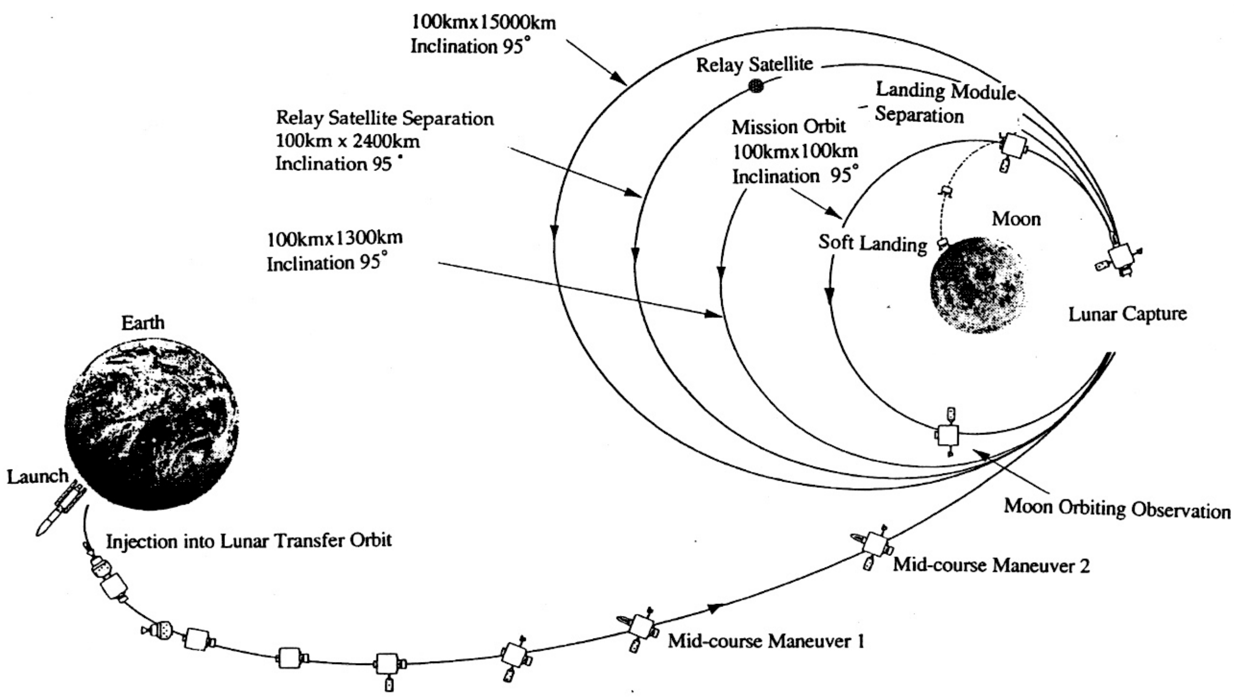

Fig.2 SELENE mission profile.

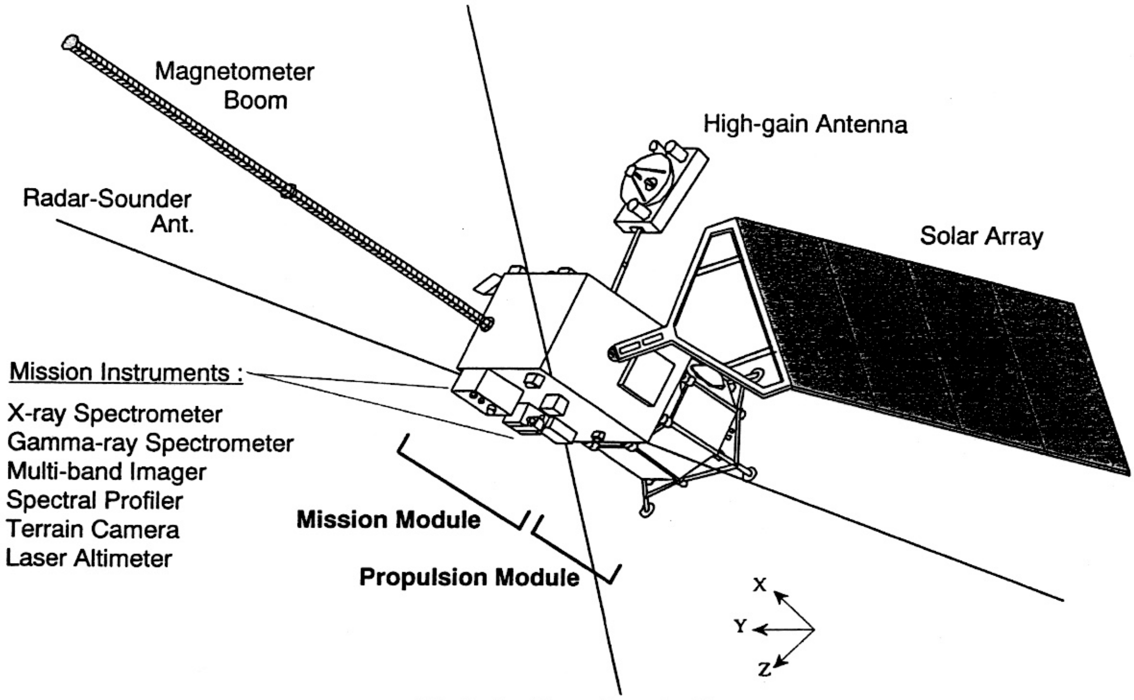

Fig.3 Configuration of orbiter.

system. Two pairs of 15 m antenna for radar sounding are configured to cross perpendicularly to each other. The mast for the magnetometer is deployed by 12 m in +x direction. The plasma imager to observe the earth ionosphere is installed on the movable platform of the high-gain antenna to direct to the earth. The solar array panel deployed in the -y direction rotates along the y-axis to track the sun.

The orbital period is about 2 hours. 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, global mapping with a high-latitude resolution less than 35 km on the equator is possible. Totally four maneuvers to keep the altitude are planned during one year. The capability for data recording and data downlink are expected to be 10 GBytes and 10 Mbps, respectively.

After the remote-sensing observatory mission for one year or possibly more months, the propulsion module is separated from the orbiter for soft landing testing. Since the attitude control system is separated together with the propulsion module, the observatory mission is terminated at the separation. The landing module carries radio sources for differential VLBI experiment in combination with the radio sources on the relay satellite. Although the capability of the telemetry and commanding for the landing module is terminated during the first lunar night, the radio

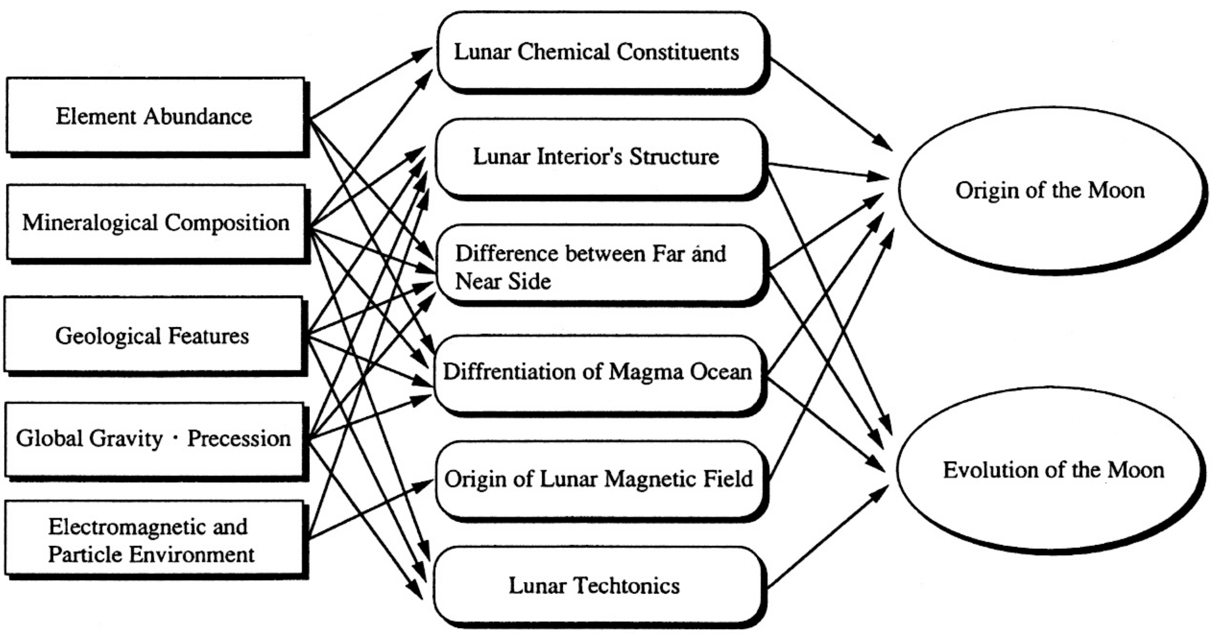

Fig.4 Research scenario for origin and evolution of the Moon.

Table 2 SELENE scientific instruments.

Measurement Item	Instrument	Characteristics
Element Abundance	X-ray Spectrometer	CCD (Charged Coupled Device), Global mapping of Al, Si, Mg, Fe distribution Spatial resolution 20km
	Gamma-ray Spectrometer	High pure Ge crystal, Global mapping of U, Th, K distribution Spatial resolution 160km
Mineral Composition	Multi-band Imager	UV-VIS IR imager, 9 bands in spectrum range from 0.4 to1.6 μm, Spectrum band width 20~30nm, Spatial resolution 500m
	Spectral Profiler	Continuous spectrum profile ranging from 0.5 to 2.6 μm、Spectrum Sampling 6~8nm Spatial resolution 500m
Topography Geological structure	Terrain Camera	High resolution stereo camera, Spatial Resolution 10m
	Lunar Radar Sounder	Mapping of subsurface structure using active sounding, Frequency 5MHz, 5km depth with 100m resolution, Observation of planetary radiation (10k~30MHz)
	Laser Altimeter	Nd:YAG laser altimeter (1064nm), Height resolution 5m, Spatial resolution 800m (pulse rate 2Hz)
Gravity Field	Differential VLBI Radio Source	Differential VLBI observation from ground (3 stations or more), Accuracy 1m for relay satellite and 10cm for propulsion module after landing
	Relay Satellite	Far-side gravimetry using 4 way range rate measurement from ground station via relay satellite, Perilune 110km and Apolune 2400km at orbit injection
Magnetic Field	Lunar Magnetometer	3- axis flux gate magnetometer, Accuracy 0.5nT
Lunar Environment	Charged Prticle Spectrometer	Measurement of high energy particles. Low energy range 1~30MeV, High energy range 8 ~300MeV, Alpha particle detector 4~6.5MeV
	Plasma Analyzer	Plasma energy and compositon measurement, 10eV/q~30keV/q
	Radio Science	Detection of tenuous lunar ionosphere using S and X band carriers
Earth Ionosphere	Plasma Imager	Observation of plasmasphere from XUV to visible range

sources can survive for about two months using dedicated batteries.

The relay satellite consisting of S and X-band transponders will relay the Doppler signal between the ground and the orbiter in the far side. It will be designed to survive at least 14 months after injection to the lunar orbit.

3. Scientific Subjects

The global characterization of the lunar surface and investigations of the interior in this mission are categorized into 5 fields of observation ; element abundance, mineralogical composition, geological features, global gravity, and magnetic field. The integrated research scenario towards the origin and evolution of the Moon is illustrated in Fig4. Totally 14 scientific instruments including those for the observation of solar-terrestrial and lunar environments will be developed which are listed in Table 2.

3.1 Global Mapping of Element Abundances

Global mapping of the lunar element abundances and mineralogical composition will make it possible to estimate the entire lunar chemical composition, which gives constraints to the origin of the Moon. The element abundances are measured by the x-ray and γ -ray spectrometers. The x-ray spectrometer up to 10 keV with a large aperture CCD totally 100 cm^2 will be capable of measuring the major elements such as Mg, Al and Si. The γ -ray spectrometer up to 10 MeV using a high-purity germanium crystal of 250 cm^3 will measure the natural radioactive elements, such as U, Th, and K, and major chemical constituents of some 10 kinds. A Stirling refrigerator will be used to achieve the operational temperature about 80° K for the crystal. Since the solar activity is relatively high in early 2000's, a high S/N ratio is expected in the measurement of the x-ray and γ -ray from the lunar surface in that time frame. The ground trace for the x-ray and γ -ray observation along the orbit is illustrated in Fig.5. One-year observation provides complete global mapping except for the polar region for the x-ray observation. Alpha particle spectrometer with a wide detection area typically 500 cm^2 with anti-coincidence will be used to detect alpha particles from the radon gas and polonium. The observation of the gas ejection will contribute to understanding the lunar tectonic activity.

3.2 Global Mapping of Mineralogical Composition

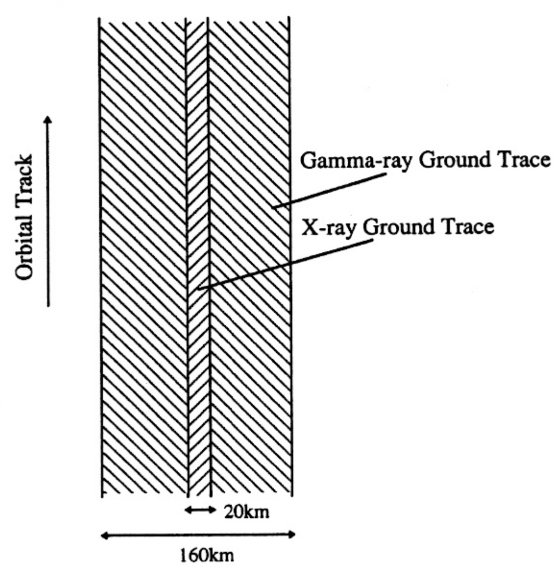

Fig.5 Ground trace of x-ray and γ -ray observation.

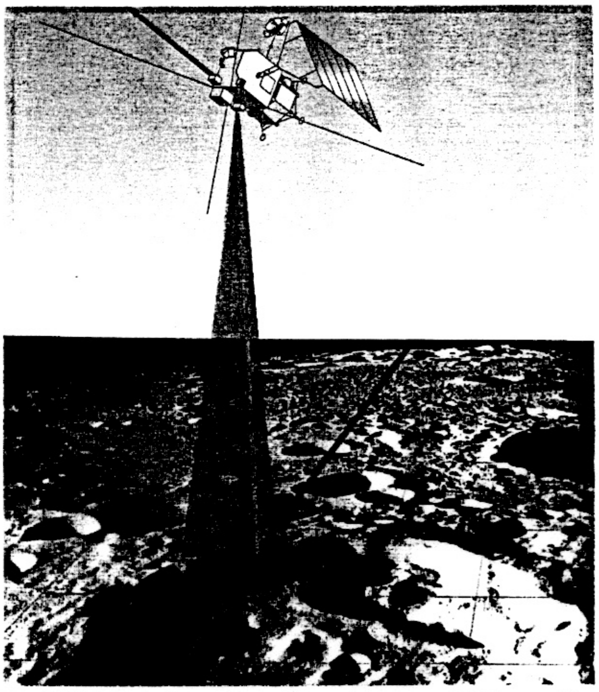

Fig.6 Field of view of multiband imager (11 km x 11 km) and spectral profiler (500 m width) .

The mineralogical characterization is performed by a multiband imager with 9 spectral bands ranging from 0.4 to 1.6 μ m at a high spatial resolution typically 20 m. The spatial resolution is nearly 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 2.6 μ m at a 500 m spatial resolution. Electric cooler is used for the IR sensor. The geometric relation of the field of view of the two instruments along the ground track is shown in Fig.6. The comprehensive data from the multiband imager and the spectral profiler are combined to map the mineralogical composition. The data inversion from the multispectral data to the mineralogical composition requires a data base 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 appears at the lunar surface, such as the inside of the large-scale impact craters.

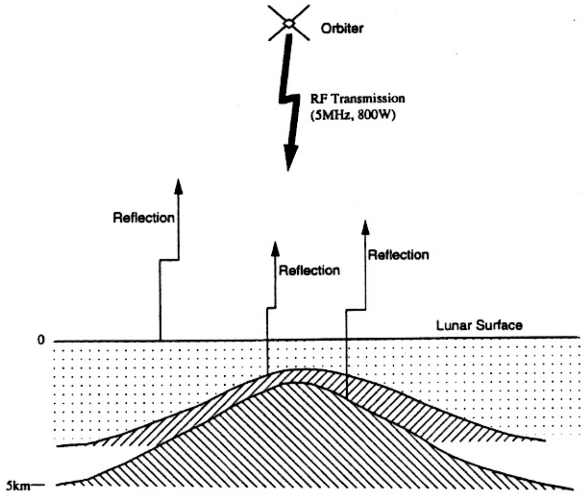

Fig.7 Concept of the subsurface sounding.

3.3 Global Mapping of Lunar Surface

The surface topographic data are obtained by the high resolution stereo cameras and the laser altimeter. The stereo camera has a field view of 35 km with a spatial resolution of 10 m to provide images in three dimensions. The angle between the lines of sight for the two cameras is 32 degrees. The laser altimeter measures the altitude every 800 m along the orbit 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 topographic data with the spectral data from the multiband imager and spectral profiler, the mineralogical composition will be identified for individual geologic units which would make it possible to identify the origin of the geologic structure. The structure below the surface regolith, such as dislocation, volcano and lava flow, can be probed by the radar sounder using a 5 MHz transmitter. The concept of the subsurface sounding is shown in Fig.7. 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 enables us to understand the history of impact cratering, volcanism and tectonism. The topographic data can be used to investigate construction of the scientific facilities on the Moon such as the astronomical observatories in the future.

3.4 Gravity Field Measurement

The radio sources on the relay satellite and propulsion module landed on the lunar surface are used to conduct differential VLBI observation from the ground. Waves at 4 frequencies in the S and X bands are radiated from each system. At least three stations are used for the observation. The VLBI observation enables us to determine the location of the radio source with a high accuracy, 1m for the relay satellite and even 0.1 m for the propulsion module. This will provide accurate information of the low-order 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 preceding mission Lunar-A, the composition of the core can be determined. This will give a definite constraint to the origin and evolution of the Moon. On the other hand, the Doppler measurement of the orbiter via the relay sat-

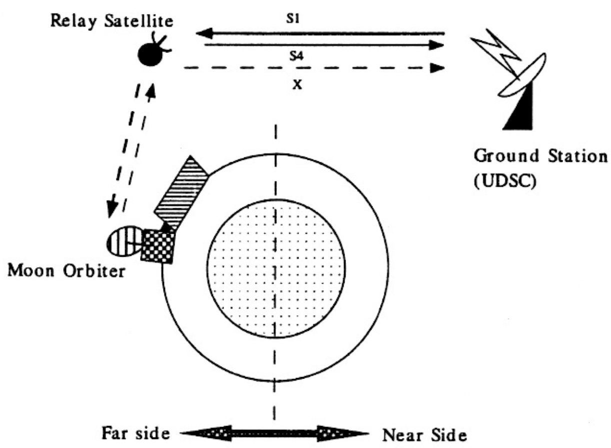

Fig.8 Configuration of 4-way Doppler measurement.

ellite when the orbiter is in the far side is used to determine the local gravity field of the far side. The configuration of this experiment is shown in Fig.8. The relay satellite is tracked by the 64 m dish at Usuda station and the accuracy is expected to be 1 mm/sec for 10 sec integration. The gravity anomalies typically less than 100 km will be determined for geodesy. The global gravity modeling will provide detailed information on the global crustal asymmetry as well as the internal lunar structure.

3.5 Magnetic Field Measurement

The magnetometer of 0.5 nT accuracy will provide global data on the lunar surface magnetic field and the lunar induced magnetic dipole. In order to estimate the lunar magnetic field separating from the magnetic field of the solar wind, the solar wind plasma is simultaneously measured by the plasma analyzer. The electron energy analyzer of the plasma analyzer which is capable of detecting the electrons reflected by the lunar magnetic field will show the distribution of the surface magnetic field. The data of 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 magnetic field will allow us to estimate the internal conductivity and temperature profile, which give constraints to the size and composition of the lunar core.

3.6 Lunar Environment

The study of the lunar environment, such as the high energy particles, electromagnetic field and plasma, 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 plasma analyzer including ion mass/energy analyzer plus electron energy analyzer and electromagnetic wave receivers will be used to study not only the solar wind 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 make it possible to detect the tenuous lunar ionosphere which has not been confirmed yet.

3.7 Observation from the Moon

SELENE plans to observe the solar-terrestrial environment from the lunar orbit. The earth ionosphere is observed by an imaging instrument in the wavelength ranging from extreme ultraviolet to visible radiation, which will clarify the global dynamics of the terrestrial plasma environment and auroral activities. For imaging of the OI emission at 130.4 nm free from the background of Lyman-α, an active filter using a hydrogen absorption cell will be used. The planetary radiations up to 30 MHz from Jupiter and Saturn are observed under the extremely low noise environment in which the dominant radiations from the sun and earth are shielded by the Moon itself. For the observation of the planetary radiation, the four 15 m antennas are shared with the radar sounder experiment.

4. Summary

The scientific background and objectives of the Moon-orbiting observatory mission SELENE are described. SELENE will carry 14 scientific instruments on the orbiter and the relay satellite. The mission aims at mapping lunar topography and surface composition, and measuring the gravity and magnetic fields. The phase-A feasibility study conducted by the SELENE project team for two years demonstrated that the mission will greatly contribute to lunar science concerning the origin and evolution of the Moon. Phase-B study started in April 1998 with the launch target in 2003 as a national space program to be conducted jointly by ISAS and NASDA.

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