IAF-99-Q.4.04
SCIENTIFIC RESEARCH IN SELENE MISSION

S.Sasaki, Y.Iijima, K.Tanaka, M.Kato, M.Hashimoto, H.Mizutani, and K.Tsuruda
The Institute of Space and Astronautical Science(ISAS)
3-1-1, Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan

Y.Takizawa
National Space Development Agency of Japan(NASDA)
2-1-1, Sengen, Tsukuba, Ibaraki 305-8505, Japan

Abstract

A Moon-orbiting and landing mission SELENE (Selenological and Engineering Explorer) is planned 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. SELENE will make global mapping of the lunar surface for one year, then conduct a softlanding experiment and VLBI observation for two months. 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 payloads is about 270 kg. The launch by H-IIA rocket is planned in summer of 2003.

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] has conducted scientific mission in 1998 and 1999 for characterization of surface composition and measurement of magnetic and gravity fields. The Japanese Moon explorer Lunar-A, a penetrator mission, is now planned in early 21 century. Studies for new lunar mission are under way in Europe and Russia.

In Japan, another lunar mission, SELENE, is in preparation for launch in 2003, which will be the largest lunar mission after the Apollo program. The primary objective of the mission is to study the origin and evolution of the Moon by global mapping from the 100 km polar orbit. The concept of SELENE observatory mission is illustrated in Fig.1. The element abundances are measured by x-ray and gamma-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 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 study of gravimetry and geodesy. A magnetometer and electron detectors will provide data on the lunar surface magnetic field. After completion of the re-

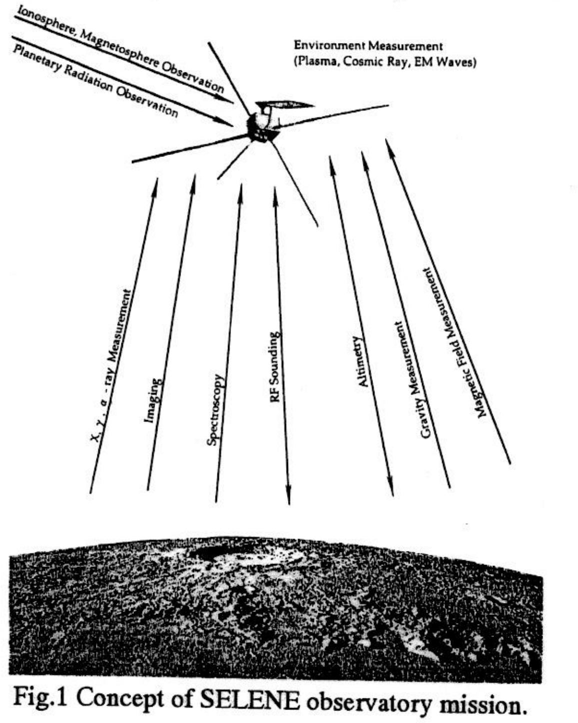

Fig.1 Concept of SELENE observatory mission.

Table 1 SELENE mission summary.

Launch	H-IIA Launch in 2003 from Tanegashima
Orbit	Direct injection into lunar transfer trajectory 100 km circular, Inclination 95° (Main orbiter) 100 km x 2400 km elliptical at injection (Relay satellite)
System	Main orbiter (2 x 2 x 4m) and relay satellite (1mø x 0.65m) Propulsion module of main orbiter is used as a landing module.
Mission Period	1 year for global mapping plus 2 months for VLBI observation
Attitude Control System	3-axis control, 2 star sensors+ 2 IMU, 4 reaction wheels 20Nms, Pointing ±0.1°(3 σ), Determination ±0.025°(3 σ), Stability ±0.003°/s (3 σ)
Thruster System	1700N x 1, 40N x 8 (N_2H_4, NTO), 1N x 8 (N_2H_4)
Power System	GaAs solar array paddle 3.5kW, Battery Ni-H2, 50AH x 2, 50V
Communication System	S and X bands, High gain antenna (S,X), 4 omni antenna (S), 10 Mbps (X downlink), 32 kbps (S downlink), 1kbps (uplink)
Orbiter Data Recorder	10 GBytes
Relay Satellite	Spin stabilization (>10rpm), High efficiency Si Solar Cell 70 W, NiMH 13AH
Propulsion Module	NiMH 16AH, 28 V, Attitude control system, Radio altimeter, velocity meter, Thruster system, 4 landing gears
Weight	Launch 2885kg Lunar Orbiter (Initial Phase) 2000kg Science Payload 270kg Relay Satellite 40kg (Landing Module 420kg)

mote-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 the differential VLBI observation from ground stations. Although the methodology of SELENE observation is conventional except for the gravimetry and spectroscopic 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 and the aurora. 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 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. Since the solar paddle is deployed in the -y axis, the orbiter has to make yaw-maneuver and change the direction of the motion when the beta angle is 0° and 180°. 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 system. The control capability is ±0.1°(3 σ). Two pairs of 15 m antenna for radar sounding are configured to cross perpendicularly to each other. The mast for the magnetometer is deployed 12 m in +x direction To avoid the magnetic interferences from the main body. The plasma imager to observe the earth ionosphere is installed on a movable platform on the +x plane to track the earth. The solar array paddle in the -y direction rotates along the y-axis to

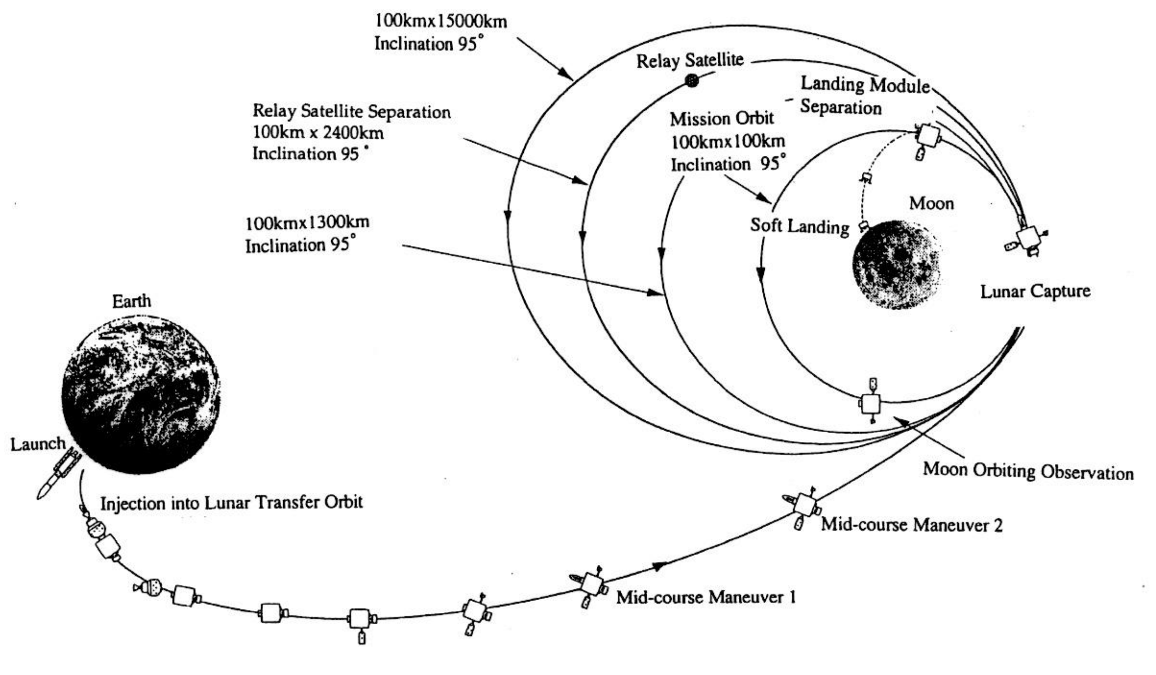

Fig.2 SELENE mission profile.

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 capabilities for data recording and data downlink are 10 GBytes and 10 Mbps, respectively.

After the remote-sensing observatory mission for one year or possibly two more months, the propulsion module is separated from the orbiter for soft landing experiment. 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 function of the landing module is terminated several hours after landing, the radio sources thermally isolated from the lander can survive for another two months using dedicated batteries.

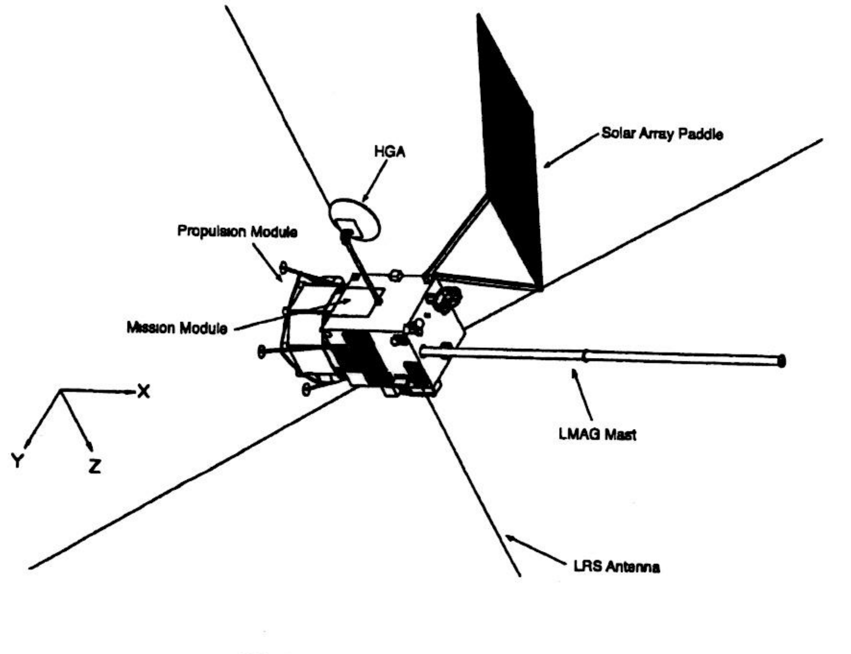

Fig.3 Configuration of orbiter.

Table 2 SELENE scientific instruments.

Measurement Item	Instrument	Characteristics
Element Abundance	X-ray Spectrometer	CCD 100cm², Energy range 0.7-8 keV, Resolution 90 eV, 5μm Be film, Solar x-ray monitor, Calibrator with sample, Global mapping of Al, Si, Mg, Fe distribution, Spatial resolution 20km
	Gamma-ray Spectrometer	High pure Ge crystal 250cm³, Energy range 0.1-10MeV, Resolution 2-3 keV, Stirling refrigerator 80° K, Global mapping of U, Th, K, O, Al, Ca, Fe, Mg, etc., Spatial resolution 160km
Mineral Composition	Multi-band Imager	UV-VIS IR imager, Si-CCD and InGaAs, 9 bands in 0.4-1.6 μm(Si: 415,750,900,950,1000; InGaAs: 1000,1050,1250,1550nm), Band width 20~50nm, Spatial resolution 20-60m
	Spectral Profiler	Spectrometer, Si pin photo-diode and InGaAs, Band 0.5 to 2.6 μm、Spectrum Sampling 6~8nm, Spatial resolution 500m, Calibration by halogen lamp, Observation of standard lunar site
Topography, Geological Structure	Terrain Camera	High resolution stereo camera(±15°), Si-CCD, Spatial resolution 10m
	Lunar Radar Sounder	Mapping of subsurface structure, Frequency 5MHz(4-6MHz swept in 200 μs every 50ms), four-15 m antennas, 5km depth with 100m resolution, Observation of natural waves (10k~30MHz)
	Laser Altimeter	Nd:YAG laser altimeter (1064nm, 100mJ, 15ns), Si-APD, Beam divergence 3 mrad(30m spot), 40° reflection mirror, Height resolution 5m, Spatial resolution 800m (pulse rate 2Hz)
Gravity Field	Differential VLBI Radio Source	Radio sources(3 S-bands, 1 X-band), Several tens of mW, Differential VLBI observation from ground (3 stations or more), Accuracy 1m for relay satellite and 10cm for landing module
	Relay Satellite	Far-side gravimetry using 4 way Doppler measurement , S uplink, S spacelink, X downlink, Perilune 100km and Apolune 2400km at orbit injection, Doppler accuracy 1mm/s(10sec)
Magnetic Field	Lunar Magnetometer	3- axis flux gate magnetometer, Accuracy 0.5nT, 32 Hz sampling, Mast 12m, Alignment monitor
Lunar Environment	Charged Particle Spectrometer	Measurement of high energy particles, Si-detectors, Wide energy range 1.8~28(p), 4~113 MeV(Fe), High energy range 50~430MeV(Fe), Alpha particle detector 4~6.5MeV, 400cm²
	Plasma Analyzer	Plasma energy and composition measurement, 5eV/q~28keV/q(ion), 5eV~17keV(e)
	Radio Science	Detection of tenuous lunar ionosphere using S and X band coherent carriers
Earth Ionosphere	Plasma Imager	Observation of plasmasphere and aurora: XUV(304Å) and visible(5 bands)

☐ : Science of the Moon (Origin and Evolution) ☐ : Science of the Moon ■ : Science from the Moon

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 initial elliptical orbit.

3. Scientific Research

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. Totally 14 scientific instruments including those for the observation of lunar and solar-terrestrial environments are under development. The major characteristics of the instruments 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 gamma-ray spectrometers. The x-ray spectrometer up to 10 keV with a large aperture CCD totally 100 cm² will be capable of measuring the major elements such as Mg, Al and Si. The gamma-ray spectrometer up to 10 MeV using a high-purity germanium crystal of 250 cm³ will measure the natural radioactive elements, such as U, Th, and K, and major chemical constituents of some 10 kinds. A Stirling refrigerator is used to achieve the operational temperature about 80° K for the crystal. The high-energy resolution(2~3keV) enables us to identify the hydrogen of the water ice which is expected to exist in the polar region. 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 gamma-ray from the lunar surface in that time frame. The ground trace for the x-ray and gamma-ray observation along the orbit is illustrated in Fig.4. One-year observation provides complete global mapping except for the polar region for the x-ray observation. Alpha particle spectrometer with a

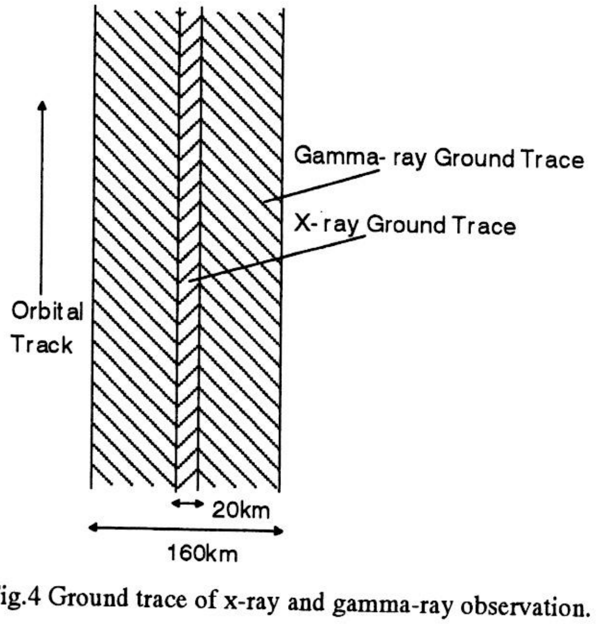

Fig.4 Ground trace of x-ray and gamma-ray observation.

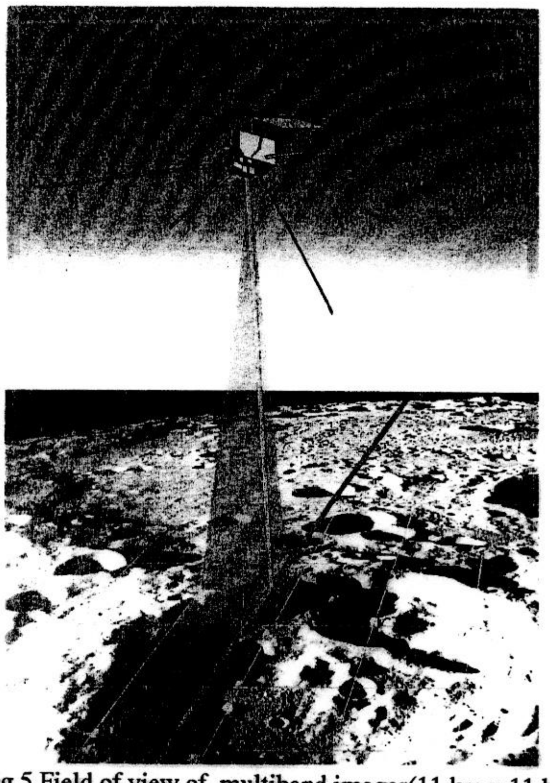

Fig.5 Field of view of multiband imager(11 km x 11 km) and spectral profiler(500 m width).

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

The mineralogical characterization is performed by a multiband imager with 9 spectral bands ranging from 0.4 to 1.6 μm at a high spatial resolution typically 20 m. The bandwidth is 20~50 nm. 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. The spectrum is sampled every 6~8 nm. 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.5. The comprehensive data from the multiband imager and the spectral profiler are combined to map the mineralogical composition globally. 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 is possibly exposed at the lunar surface, such as the inside of the large-scale impact craters.

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 30 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.6. 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 observa-

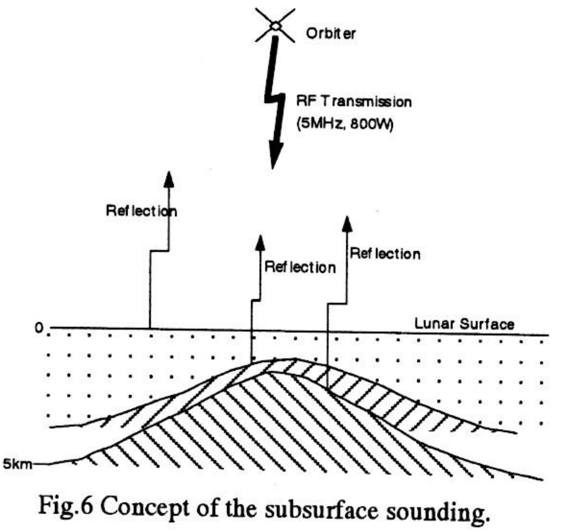

Fig.6 Concept of the subsurface sounding.

tion. 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 landing 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 Lunar-A mission, the composition of the core can be determined accurately. 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 satellite 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.7. 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 which is capable of detecting the solar wind 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.

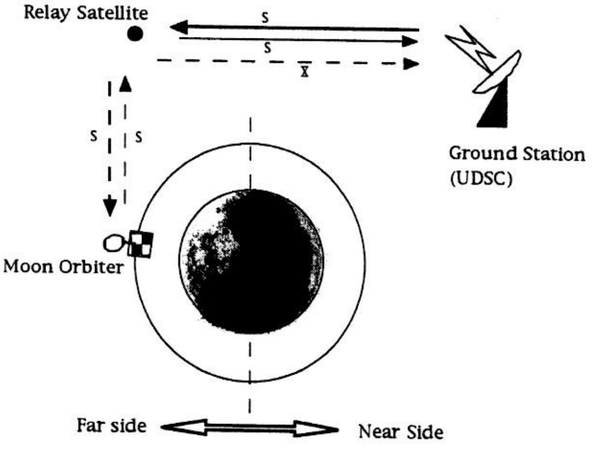

Fig.7 Configuration of 4-way Doppler measurement.

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 studying the composition of solar and interstellar matter and their evolution. The plasma analyzer containing 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 was reportedly detected by Luna19 but 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 in extreme ultraviolet(304Å) and visible radiations(4278, 5577, 5893, 6300, and longer than 7300Å), which will clarify the global dynamics of the terrestrial plasma environment and auroral activities. 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 15 m dipole antennas are shared with the radar sounder experiment.

4. Summary

The scientific background and objectives of the Moon-orbiting and landing mission SELENE are described. SELENE will carry 14 scientific instruments on the orbiter, the relay satellite, and the landing module. The mission aims at mapping lunar topography and surface composition, and measuring the gravity and magnetic fields. The phase-B study has been conducted to make preliminary design of the instruments since April 1998. Critical elements and components of the instruments have been developed and tested. The design of the flight models will start next year targeting the launch in 2003.

References

1. Binder A.B., Lunar Prospector: Overview, Science, 281, 1475-1476, Sept. 1998.