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SCIENTIFIC RESEARCH IN THE SELENE MISSION

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Abstract The Moon-orbiting SELENE (Selenological and Engineering Explorer) mission is panned early in 2006 for lunar science and technology development. The spacecraft will consist of a main orbiting satellite at about 100 km altitude in the polar orbit and two sub-satellites in the higher elliptical orbits. The scientific objectives 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. SELENE will carry the 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 plasma environment. The total mass of scientific payload is about 300 kg. The nominal mission period will be 1 year.

1. Introduction

The primary objective of the SELENE mission is to study the origin and evolution of the Moon by global mapping from the polar orbit at 100 km altitude. 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. Radio sources on the two subsatellites are used to conduct the differential VLBI (Very Long Baseline Interferometry) observation from ground stations.

In addition to the study of the origin and evolution of the Moon, measurement of the lunar environment and observation of the solar-terrestrial plasma 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 plasma observation, the orbiter carries imaging instruments to observe the dynamic structure of the earth plasma environment and the aurora. High-sensitivity wave receivers are used to detect the planetary radiation from the Jupiter and Saturn. For publicity and educational purposes, high-resolution TV cameras are onboard to observe the Earth from the Moon orbit.

2. SELENE System

The configuration of the orbiter in the lunar orbit is shown in Fig. 1. The orbiter moves towards +x or -x direction. Since the solar paddle is deployed in the -y axis, the

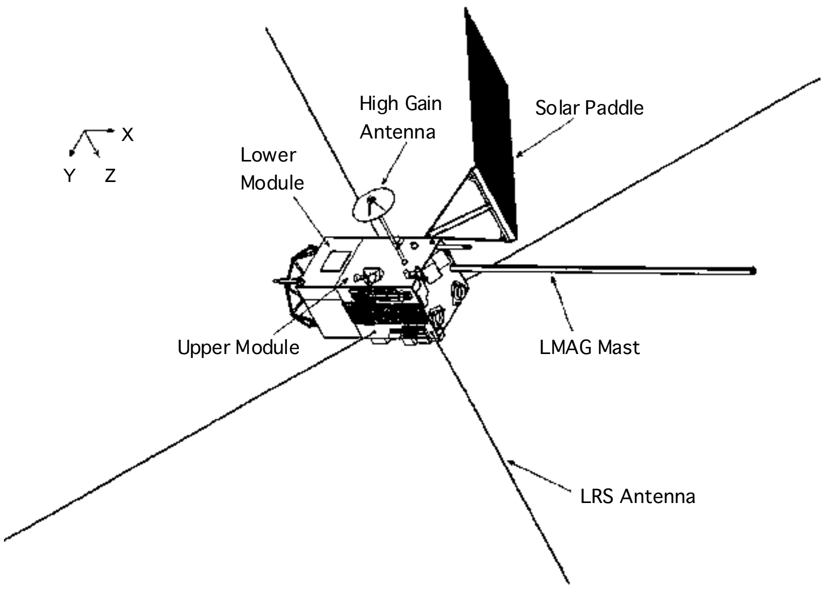

Fig.1 Configuration of the orbiter.

orbiter has to make yaw-maneuver and change the attitude to keep the –y direction towards the Sun when the beta angle is 0ß and 180ß. 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 accuracy is 0.1ß(3σ). 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 solar array paddle rotates along the y-axis to track the sun to generate 3.5 kW power. The capabilities for mission data recording and downlink are 10 GBytes and 10 Mbps, respectively.

The phase-A study of SELENE started in 1996. The preliminary design of spacecraft was completed in March 2001. Environmental tests using a Mechanical Test Model (MTM) and a Thermal Test

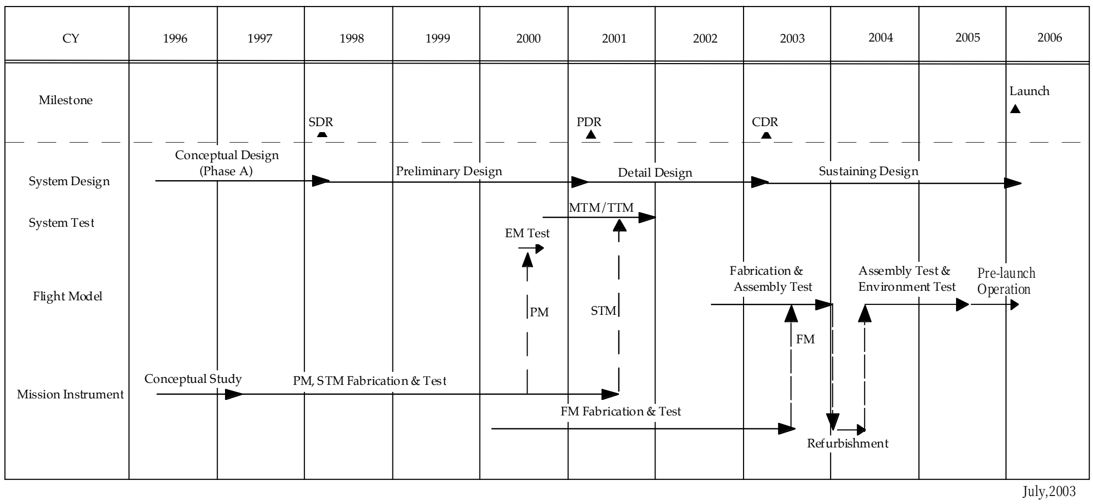

Fig.2 Development schedule of spacecraft.

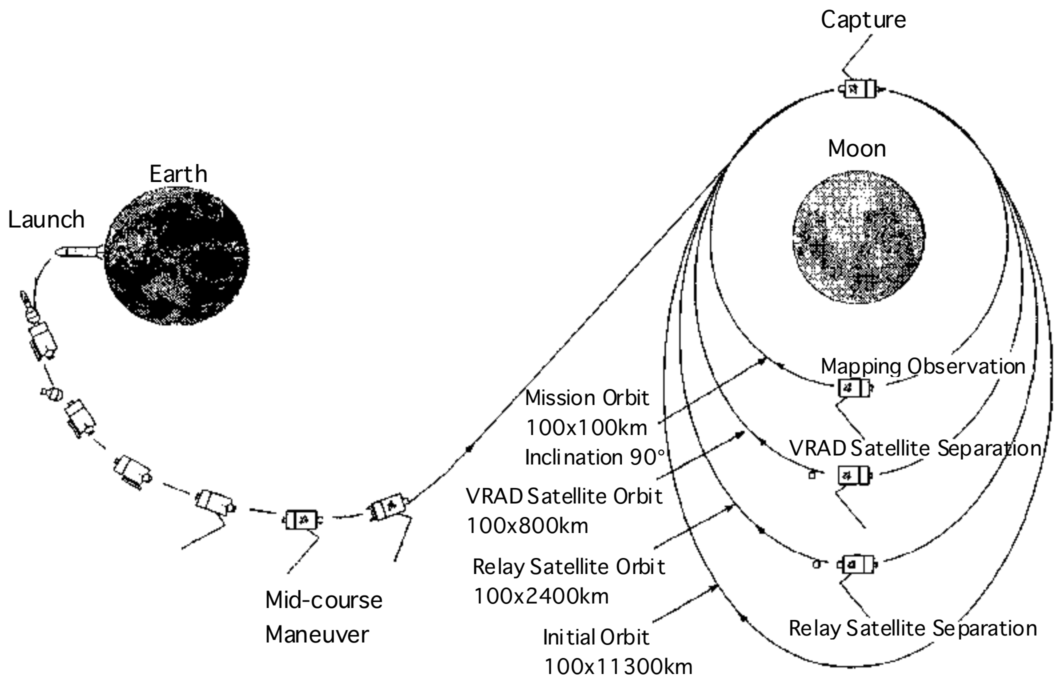

Fig.3 Mission Profile.

Model(TTM) were conducted in 2002. The fabrication and tests of the flight models are now under way and the systems test is planned in 2004. The overall development schedule is shown in Fig.2.

3. Mission Scenario

The mission profile is shown in Fig.3. 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. The mid-course maneuver is planned twice on its way to the Moon. The spacecraft is captured by the Moon into an elliptical polar orbit with apolune at 11,300 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 and the VRAD satellite are released in the elliptical orbit with an apolune at 2,400 km and 800 km, respectively. Upon arriving at the mission orbit, the main orbiter extends 4 antennas for the radar sounder experiment and a mast for the magnetometer. Remote-sensing observation of the lunar surface and observation of the lunar and solar-terrestrial plasma environment will be performed for about one year. The altitude of the main orbiter will be kept at 100–30 km by orbit maintenance operation. If the fuel to keep and control the orbit is available, the observation mission will be extended. One option is to lower the orbiter to 40-70 km altitude for precise measurement of the lunar magnetic and gravity fields. The two subsatellites have no fuel to keep their orbits, but will survive more than one year. Especially the VRAD satellite is expected to survive much longer.

The orbital period is about 2 hours. The distance of the adjacent orbit is about 35 km at the equator. The orbiter returns the initial orbit every month. By adjusting the orbital latitude, global mapping with a high-latitude resolution less than 35 km at the equator is possible. Totally four maneuvers to keep the altitude are planned during one year.

Figure 4 shows commanding and telemetry system for SELENE. Commands are up-linked to the three satellites through the NASDA ground stations. S-band telemetry data of the main orbiter are down-linked to the NASDA ground stations. X-band mission data (10 Mbps)

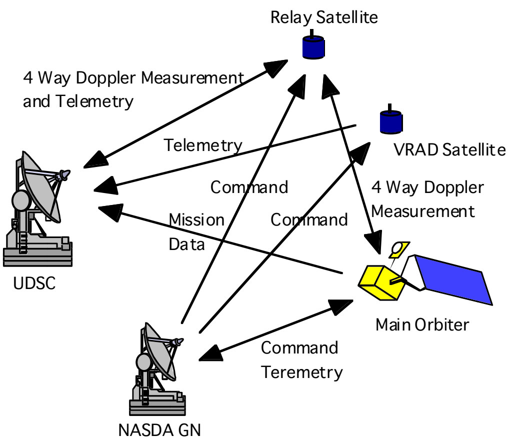

Fig.4 Commanding and telemetry system.

are down-linked to the ISAS Usuda Deep Space Center (UDSC). Telemetries from the subsatellites are also down-linked to UDSC. In the initial phase before injection to the mission orbit, JPL/DSN stations will be used to support the critical operation for the orbit maneuvering.

4. 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 15 mission instruments including those for observation of the lunar and solar-terrestrial environments have been developed. The major characteristics of the instruments are listed in Table 1. The configuration of the sensors is illustrated in Fig.5.

4.1 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 spectrometer[1] and gamma-ray spectrometer[2]. The x-ray fluorescent 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 with a spatial resolution of 20 km. The gamma-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. The spatial resolution is 160 km. A Stirling refrigerator

Table 1 SELENE Scientific Instruments

Observation	Instrument	Characteristics
Element Abundance	X-ray Spectrometer	CCD 100 cm^2, Energy range 0 7~8 keV, Resolution 90eV, 5 m-Be film, Solar x-ray monitor, Calibrator with sample, Global mapping of Al, Si, Mg, Fe, Spatial resolution 20 km
	Gamma-ray Spectrometer	High purity Ge crystal 250 cm^3, Energy range 0.1~10 MeV, Resolution 2-3 keV, Stirling refrigerator 80 K, Global mapping of U, Th, K, O, Al, Ca, Fe, Mg, etc., Spatial resolution 130~150 km
Mineral Composition	Multi-band Imager	UV-VIS IR imager, Si-CCD and InGaAs, 9 bands in 0.4-1.6 m (Si: 415, 750, 900, 950, 1000; InGaAs: 1000, 1050, 1250, 1550 nm), Band width 20~50 nm, Spatial resolution 20-60 m
	Spectral Profiler	Spectrometer, Si pin photo-diode and InGaAs, Band 0.5 to 2.6 m、Spectrum Sampling 6-8 nm, Spatial resolution 500 m, Calibration by halogen lamp, Observation of standard lunar site
Topography, Geological Structure	Terrain Camera	High resolution stereo camera (±15), Si-CCD, Spatial resolution 10 m
	Lunar Radar Sounder	Mapping of subsurface structure, Frequency 5 MHz (4~6 MHz swept in 200 s every 50 ms), four 15 m antennas, 5 km depth with 100 m resolution, Observation of natural waves (10 kHz~30 MHz)
	Laser Altimeter	Nd:YAG laser altimeter (1064 m, 100 mJ, 15 ns), Si APD, Beam divergence 3 mrad (30 m spot) Height resolution 5 m, Spatial resolution 1600 m (pulse rate 1 Hz)
Gravity Field	Differential VLBI Radio Source	Radio sources on Relay Satellite and VRAD Satellite (3 S-bands, 1 X-band), Several tens of mW, Differential VLBI observation from ground (3 stations or more)
	Relay Satellite	Far-side gravimetry using 4 way Doppler measurement, S uplink, S space link, X downlink, Perilune 100 km and Apolune 2400 km at orbit injection, Doppler accuracy 1 mm/s (10 sec)
Magnetic Field	Lunar Magnetometer	3-axis fluxgate magnetometer, Accuracy 0.5 nT, 32 Hz sampling, Mast 12 m, Alignment monitor
Lunar Environment	Charged Particle Spectrometer	Measurement of high energy particles, Si-detectors, Wide energy range 18-28 (p), 4~113 MeV (Fe), High energy range 6-430 MeV (Fe), Alpha particle detector 4~6.5 MeV, 400 cm^2
	Plasma Analyzer	Plasma energy and composition measurement, 5 eV/q-28 keV/q (ion), 5 eV~17 keV (electron)
	Radio Science	Detection of tenuous lunar ionosphere using S and X band coherent carriers
Earth Ionosphere	Plasma Imager	Observation of plasmasphere and aurora, XUV (834) and visible (5 bands)
Earth	High Density TV	Observation of the earth in a super high resolution, for publicity and educational purposes

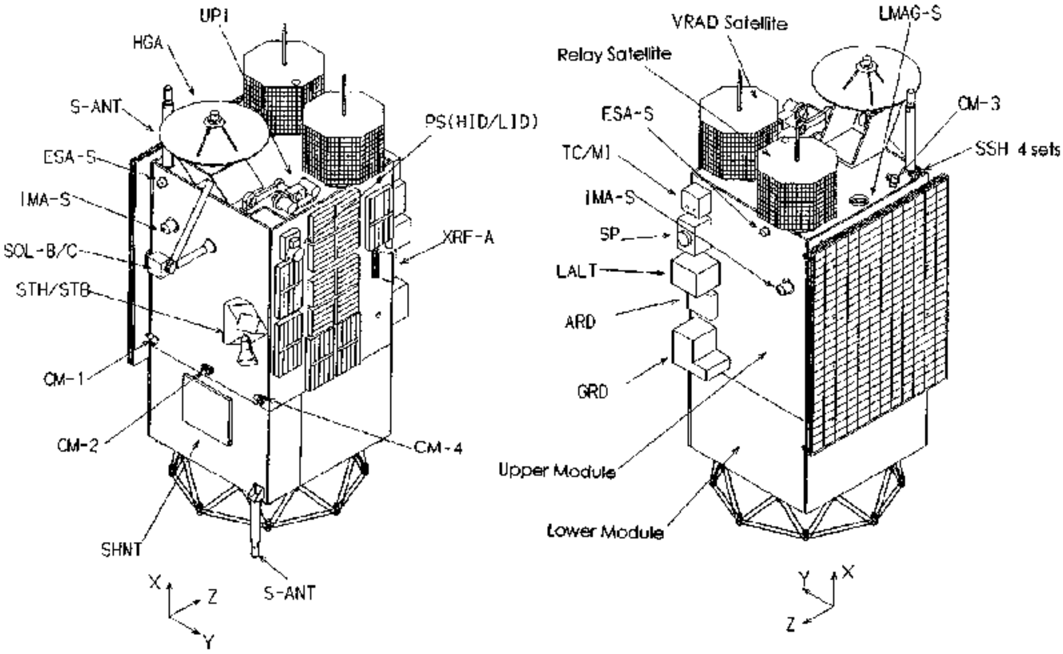

Fig.5 Configuration of instruments. UPI: Plasma Imager, HGA: High Gain Antenna, S-ANT: S-band Antenna, ESA-S: Plasma Analyzer (Electron), IMA-S: Plasma Analyzer (Ion), SOL-B/C: X-ray Spectrometer (Solar X-ray Monitor and Calibrator), ST: Star Sensor, CM: Monitor Camera, SHNT: Shunt Dissipator, XRF-A: X-ray Spectrometer, PS: Charged Particle Spectrometer, LMAG-S: Lunar Magnetometer, VSTAR: VRAD Satellite, RSTAR: Relay Satellite, TC/MI: Terrain Camera/Multi-band Imager, SP: Spectral Profiler, LALT: Laser Altimeter, ARD: Alpha Particle Detector, GRD: Gamma-ray Spectrometer, SSH: Sun Sensor.

is used to achieve the operational temperature about 80ß K for the crystal. The high-energy resolution (~3 keV) enables us to identify the hydrogen of the water ice which is expected to exist in the polar region. One-year observation provides complete global mapping. Alpha particle spectrometer with a wide detection area of 400 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.

4.2 Global Mapping of Mineralogical Composition

The mineralogical characterization is performed by a multiband imager[3] with 9 spectral bands ranging from 0.4 to 1.6 m 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[4] with a continuous spectrophotometry from 0.5 to 2.6 m. The spatial resolution is 500 m. The spectrum is sampled every 6~8 nm. An electric cooler is used for the IR sensor. 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. The data of the spectral profiler are also used 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.

4.3 Global Mapping of Lunar Surface

The surface topographic data are obtained by the high resolution stereo cameras[5] and the laser altimeter[6]. 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 1,600 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 the individual geologic units which would make it possible to identify the origin of the geologic structure. The structure below the surface regolith, such as the dislocation, volcano and lava flow, can be probed by the radar sounder using a 5 MHz transmitter[7]. 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.

4.4 Gravity Field Measurement

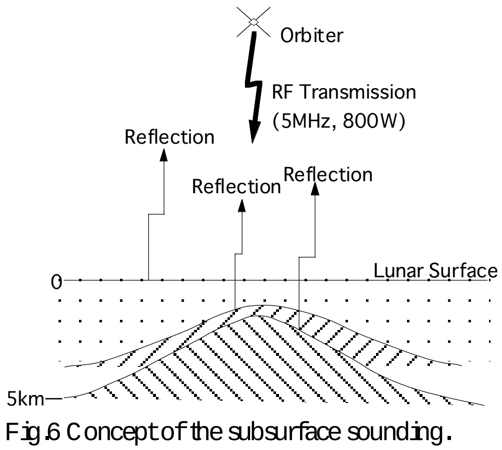

Fig.6 Concept of the subsurface sounding.

The radio sources on the relay satellite and the VRAD satellite are used to conduct differential VLBI observation from the ground[8]. Waves at 4 frequencies in the S and X bands are radiated from each satellite. 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. This will provide accurate information of the low-order gravity field 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[9]. 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.

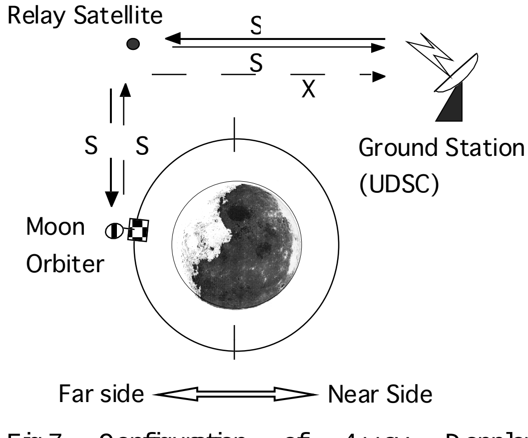

Fig.7 Configuration of 4-way Doppler measurement.

4.5 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[10]. 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[10]. The electron energy analyzer which is capable of detecting the solar wind electrons reflected by the surface 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.

4.6 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 has a valuable scientific aspect. The observation of the energetic particles including heavy cosmic particles will contribute to studying the composition of solar and interstellar matter and their evolution[11]. The plasma analyzer containing ion mass/energy analyzer plus electron energy analyzer and electromagnetic wave receivers will be used to study the solar wind and the geomagnetic tail, as well as the interaction of the solar wind with the Moon[10]. The radio science using coherent X and S band carriers from the orbiter and the relay satellite will make it possible to detect the tenuous lunar ionosphere which was reportedly detected by Luna19 but has not been confirmed yet[12].

4.7 Observation from the Moon

SELENE plans to observe the solar-terrestrial plasma environment from the lunar orbit. The Earth ionosphere is observed by an imaging instrument in the wavelength in extreme ultraviolet (834) and visible radiations (4278, 5577, 5893, 6300 and longer than 7300), which will clarify the global dynamics of the terrestrial plasma environment and auroral activities[13]. The planetary radiations up to 30 MHz from the 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 radiations, the 15 m dipole antennas are shared with the radar sounder experiment.

5. Mission Operation and Analysis Center

A mission operation center for SELENE is to be established at ISAS in Sagamihara. The center will have four major functions as shown in Fig.8; satellite control, acquisition of science data, data analysis, and data distribution. The data are displayed in real time for satellite control and quick evaluation of the observation results. All data are stored and some of them are transmitted to the PI team members outside the center for operation monitor and data analysis. The total data will amount to several tens of terabytes. The center has the capability to generate

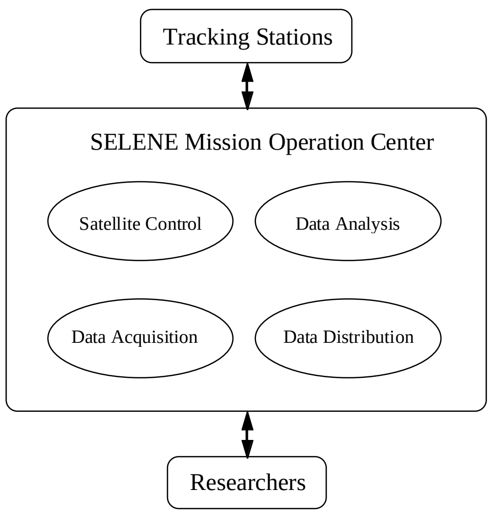

Fig.8 Concept of SELENE Mission Operation Center.

the observation plan based on the requests from the PI team members. The observation plan is up-linked to the main satellite typically twice a week. All scientific data will be open to the public one year after completion of the nominal mission operation (1 year) and are distributed from this center upon request.

6. Summary

Current status of SELENE mission and onboard instruments are described. SELENE will carry 15 mission instruments on the main orbiter, the relay satellite, and the VRAD satellite. It is the largest-scale mission since the Apollo Project. The picture of the Mechanical Test Model is shown in Fig.9 to indicate the size of the spacecraft. The mission will provide systematic data of lunar topography and surface composition, the gravity field, and magnetic field, which will be integrated to study the origin and evolution of the Moon. The variety of the scientific data will provide a data base which could be used for 15 to 20 years after the mission. More detailed information on SELENE science is given in a report[14]. The data will also provide important information to the landing and human activities on the Moon in the future. The fabrication and tests of the flight hardware are now under way for the launch in the beginning of 2006.

Fig.9 SELENE Mechanical Test Model.

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