KAGUYA(SELENE) Science Mission

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The Moon-orbiting KAGUYA (SELENE: Selenological and Engineering Explorer) was successfully launched on Sep. 14, 2007 from JAXA Tanegashima Space Center. It was injected into the lunar orbit on Oct.4, 2007 on schedule. It started science mission in mid-December after checkout of each mission instruments. 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. Totally 14 mission instruments on the main orbiter and two subsatellites (OKINA and OUNA) have been operated. This paper presents the major results of scientific obsevation in the initial mission operation phase.

Key Words: KAGUYA, Lunar Science, Lunar Exploration

1. Introduction

The primary objective of "KAGUYA" 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 conducted for study of gravimetry and geodesy. A magnetometer and electron detectors provide data on the lunar surface magnetic field. Radio sources on the two subsatellites are used to conduct the differential VLBI (Very Long Baseline Interferometer) observation from ground stations.

Measurement of the lunar environment and observation of the solar-terrestrial plasma environment are also conducted 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 operated to observe the Earth and the Moon.

2. Science Instrument and Operation

Table 1 shows the mission instruments that are classified in four categories; science of the Moon, science on the

Table 1. Mission instruments.

Observation	Instrument/method	Characteristics
Element Abundance	X-ray Spectrometer (XRS)	CCD 100 cm^2, Energy range 0.7~10 keV, Resolution<180 eV, 5 μm Be film, Solar x-ray monitor, Calibrator with sample, Global mapping of Al, Si, Mg, Fe distribution, Spatial resolution 20 km
	Gamma-ray Spectrometer (GRS)	High pure 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 (MI)	UV-VIS IR imager, Si-CCD and InGaAs, 9 bands in 0.4-1.6 μm (Si: 415, 750, 900, 950, 1000; InGaAs: 1000, 105, 1250, 1550 nm), Band width 10~50 nm, Spatial resolution 20~60 m
	Spectral Profiler (SP)	Spectrometer, Si pin photo-diode and InGaAs, Band 0.5 to 2.6 μm, Spectrum Sampling 6~8 nm, Spatial resolution 500 m, Calibration by halogen lamp, Observation of standard lunar site
Topography, Geological structure	Terrain Camera (TC)	High resolution stereo camera(±15°), Si-CCD, Spatial Resolution 10 m
	Lunar Radar Sounder (LRS)	Mapping of subsurface structure, Frequency 5 MHz(4~6 MHz swept in 200 μs every 50 ms), four-15 m antennas, 5 km depth with 100 m resolution, Observation of natural waves (10 Hz~30 MHz)
	Laser Altimeter (LALT)	Nd:YAG laser altimeter (1064 nm, 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 (VRAD)	Radio sources on Relay Satellite and VRAD Satellite(3 S-bands, 1 X-band), Several tens of mW, Differential VLBI observation from ground stations (4 domestic and 4 foreign stations assigned)
	Relay Satellite (RSAT)	Far-side gravimetry using 4 way Doppler measurement, S uplink, S spacelink, X downlink, Perilune 100 km and Apolune 2400 km at orbit injection, Doppler accuracy 0.2 mm/s(18 sec)
Magnetic Field	Lunar Magnetometer (LMAG)	3- axis flux gate magnetometer, Accuracy 0.1 nT, 32 Hz sampling, Mast 12 m, Alignment monitor
Lunar Environment	Charged Particle Spectrometer (CPS)	Measurement of high energy particles, Si-detectors, Wide energy range, High energy range, Alpha particle detector 4∽6.5 MeV, 400 cm^2
	Plasma Analyzer (PACE)	Plasma energy and compositon measurement, 5 eV/q∽28 keV/q(ion), 5 eV~15 keV(e)
	Radio Science (RS)	Detection of tenuous lunar ionosphere using S and X band coherent carriers
Earth Ionosphere	Plasma Imager (UPI)	Observation of plasmasphere and aurora, XUV(834 A) and visible(5 bands)
Earth and Moon	High Density TV (HDTV)	Observation of the earth and the lunar surface in a super-high resolution for publicity

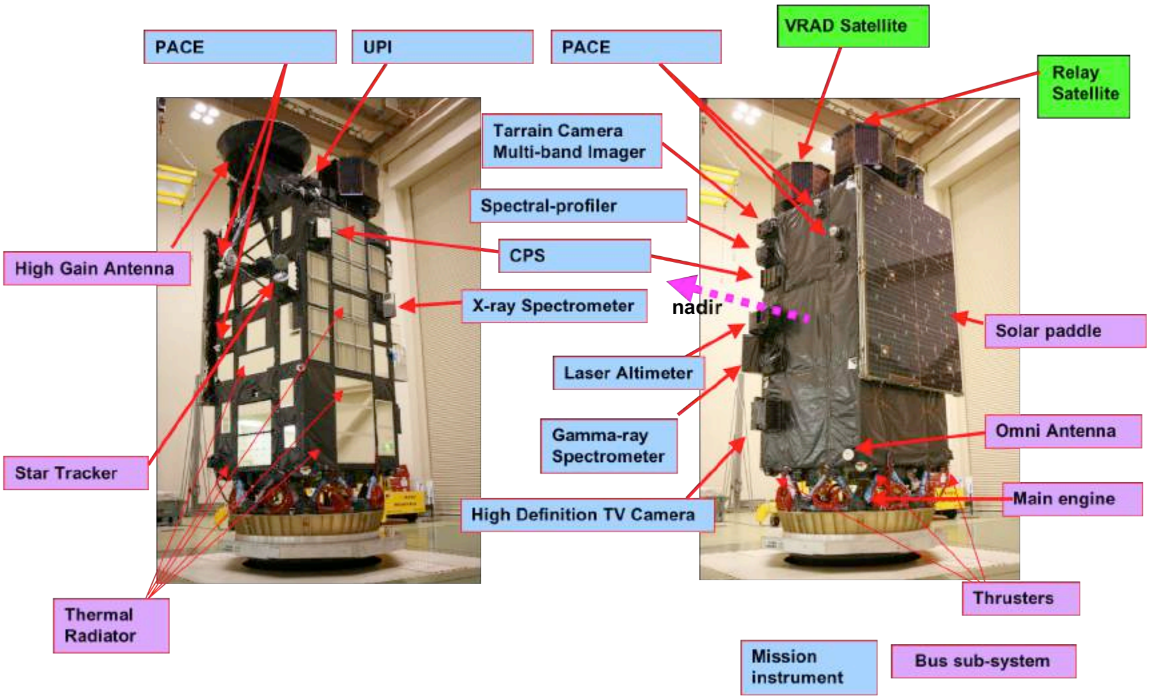

Fig. 1. Configuration of bus subsystem and mission instruments.

Moon, science from the Moon, and publicity. The configuration of the mission instruments on the main orbiter is shown in Fig. 1. Most of the sensors for remote-sensing observation are installed on the nadir-plane which is controlled to face the lunar surface all the time by a three-axis attitude control system. The control accuracy is 0.1°(3 σ). The capabilities for mission data recording and downlink are 100 Gbits and 10 Mbps, respectively.

KAGUYA was injected into the lunar elliptical orbit with apolune at 12,000 km and perilune at 100 km on Oct.4, 2007. The apolune was lowered by orbit transfer maneuver several times and the main orbiter finally reached the circular orbit at about 100 km altitude on Oct.18 2007. During the orbit transition, the relay satellite and the VRAD satellite were released in the elliptical orbit with the apolune at 2,400 km and 800 km, respectively. Upon arriving at the mission orbit, a 12 m mast for the magnetometer (LMAG) and two pairs of 15 m antennas for the radar sounder experiment (LRS) were extended. Then the gimbal for the Upper-Atmosphere and Plasma Imager (UPI) was deployed to the observation position. The checkout of mission instruments was conducted for about two months. In the latter half of the checkout phase, the high-voltage components were carefully tested up to the operational voltage. After completion of the instrument checkout, we started nominal observation on Dec.21 2007. The nominal observation phase will continue by the end of October 2008. The sequence of initial mission operation is summarized in Fig.2.

3. Scientific Results

The typical scientific data obtained in the initial phase are described in this section. These data are already open to public on the homepage (http://www.isas.jaxa.jp/e/).

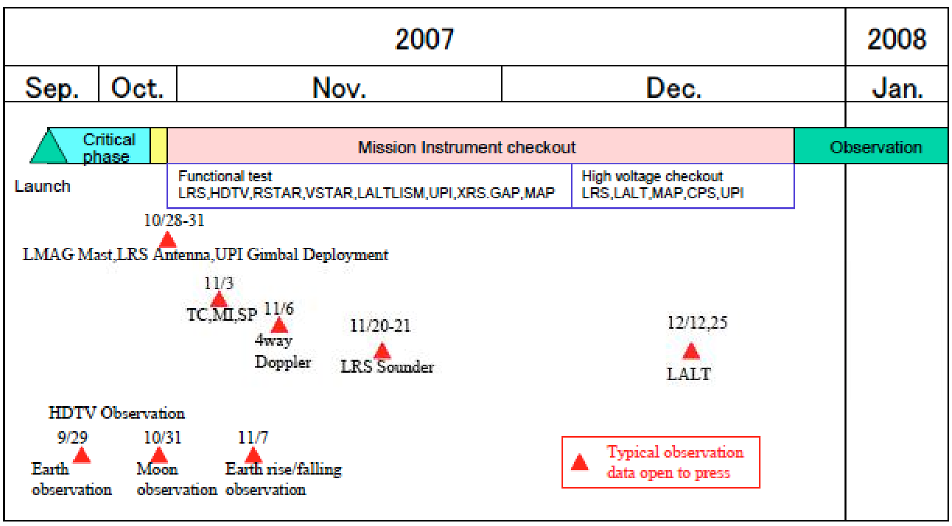

Fig. 2. Sequence of initial mission operation.

3.1. Mineralogical composition

The mineralogical characterization is performed by a multiband imager[1)] with 9 spectral band flters ranging from 0.4 to 1.6 µm at a high spatial resolution typically 20 m. The bandwidth of the optical filters is 10~50 nm. The spatial resolution is nearly 10 times higher than that of the Clementine. Figure 3 shows the first image obtained on Nov.3, 2007. The left panel shows a pseudo-color image at 900, 750, and 415 nm for the spot (37S,240E) at about 1000 km in southwest from the Mare Orientale. The right panel shows an image using the intensity ratio of 750 nm/1000 nm. Ejectors from a crater are clearly shown and the layer structure of the ejectors are identified.

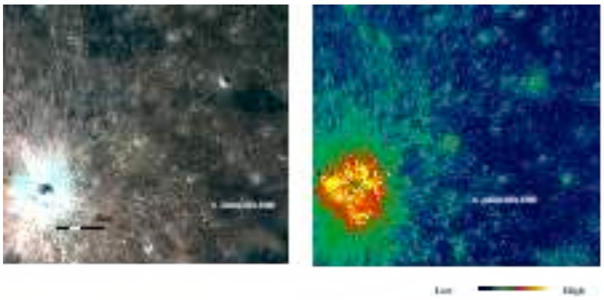

Fig. 3. First image obtained by the multiband imager. Left panel shows a pseudo-color image using three lines at 900, 750, and 415 nm. Right panel shows the ratio of intensity, 750 nm/1000 nm.

The identification of mineralogical composition, such as pyroxene, olivine, and anorthite, is performed by the spectral profiler[2)] with a continuous spectrophotometry from 0.5 to 2.6 µm. The spatial resolution is 500 m. The spectrum is sampled every 6~8 nm. An electric cooler is used for the IR sensor. Figure 4 shows an example of spectrum data obtained along the ground track (120W, longitude) crossing a crater. The spectrum suggests the inside of the crater is relatively fresh as compared with the outside area. The comprehensive data from the multiband imager and the spectral profiler are combined to map the mineralogical composition globally. The data of the spectral profiler are also used to identify the mineralogical composition of the deep crust material which is exposed at the lunar surface, such as the inside of the large-scale impact craters.

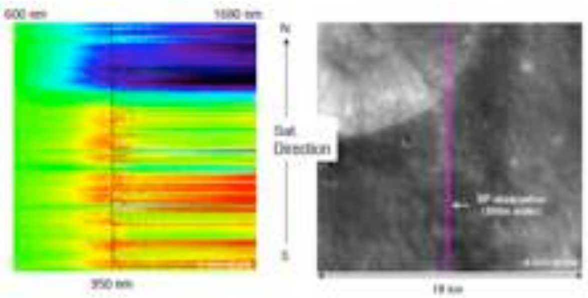

Fig. 4. Left panel is the first data obtained by the spectral profiler. The vertical line in the right panel indicates the ground track of the observation in the view of multiband imager.

3.2. Lunar surface

The surface topographic data are obtained by the high resolution stereo cameras[3)] and the laser altimeter[4)]. 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 left panel in Fig.5 is the first image obtained on Nov.3, 2007. The observation spot is at 30 km from the south pole. It is compared with the digital image obtained by the Clementine high resolution camera for the same spot. The difference of the resolution is very clear.

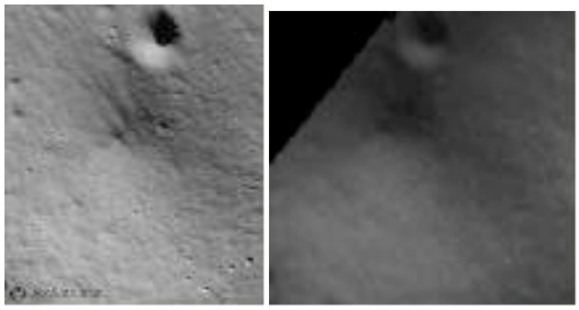

Fig. 5. Comparison of the image obtained by the SELENE terrain camera (left) and Clementine camera (right).

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. Figure 6 shows topographic data near the Orientale (19.4S, 92.8W) which was obtained in December 2007. The data from the laser altimeter are used to produce global topographical maps with a higher accuracy than before. Combining the 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.

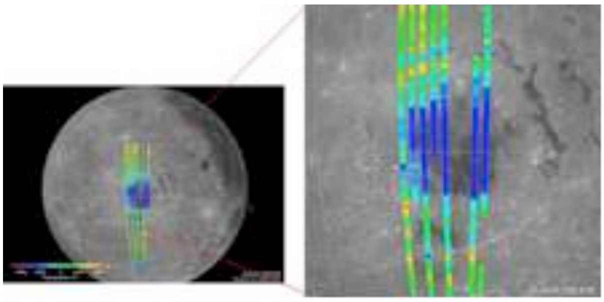

Fig. 6. Topographic data near the Mare Orientale obtained by the laser altimeter.

3.3. Subsurface structure

The structure below the surface regolith, such as the dislocation, volcano and lava flow, can be probed by the radar sounder experiment (LRS) using a 5 MHz transmitter[5)]. The sounder experiment reveals the inside structure up to 5 km below the surface with a vertical resolution of 100 m. Figure 7 shows a typical observation of the subsurface structure which was obtained on Nov.21 2007. The survey will provide important information on the hypothesis of "magma ocean". The observation of the lunar subsurface structure by the radar sounder experiment, as well as the surface structure by the stereo camera and laser altimeter, 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.

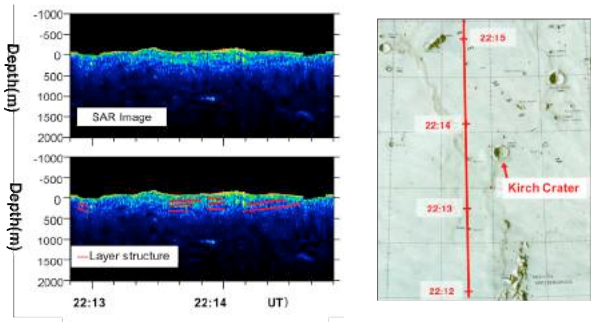

Fig. 7. The synthetic aperture radar (SAR) image for the northeastern part of the Mare Imbrium near the Kirch crater (39.2N, 5.6W, 11 km dia.). Layer-like structure is identified in the left upper panel, which is enhanced by the lines in the left lower panel.

3.4. Gravity field

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[6]. The relay satellite is tracked by the 64 m dish at the Usuda Deep Space Center and the accuracy is 0.2 mm/sec for 18 sec integration time. The gravity anomalies defined as the differences between the observed gravity and the average gravity are determined. The left panel in Fig.8 shows the gravity anomaly at the Apollo crater in the far side which is determined by the Doppler observation. Very clear gravity map is obtained as compared with the previous one (LP165P) in the right panel. The global gravity modeling will provide detailed information on the global crustal asymmetry as well as the internal lunar structure.

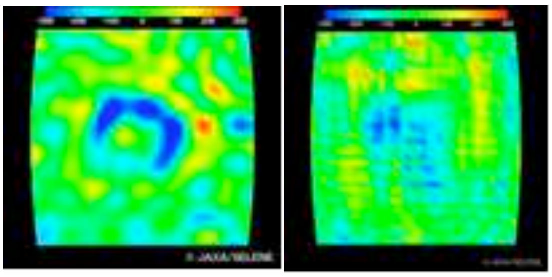

Fig. 8. Gravity anomaly of the Apollo crater (36S, 150W, 500 km diameter) in the far side. Left panel is obtained by KAGUYA. Right panel is the previous model (LP165P).

3.5. Lunar plasma environment

The plasma waves generated by the interaction between the solar winds and the Moon are studied by the high-performance wave receivers up to 30 MHz in the radar sounder experiment system. Figure 9 shows the wave spectrum obtained on Oct.31, 2007. Aurora Kilometric Radiation (AKR) from the earth and the UHR (Upper Hybrid Resonance) waves generated near the Moon were clearly detected. The planetary radiations from the Jupiter and Saturn are also studied under the extremely low noise environment in which the dominant radiations from the Sun and Earth are shielded by the Moon itself. The lunar ionosphere has been probed by radio occultation technique (RS) and preliminary results suggesting an existence of the surface electron layer have been obtained.

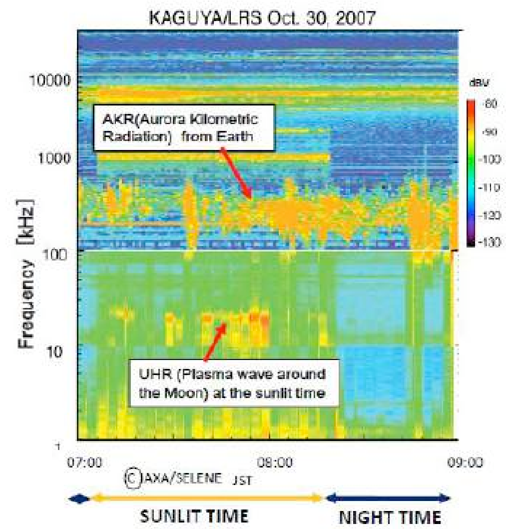

Fig. 9. Wave spectrum observed by LRS wave receivers. Aurora Kilometric R adiation and UHR waves are detected.

4. Summary

Major scientific results obtained in the initial phase of KAGUYA mission are described. Observation will continue

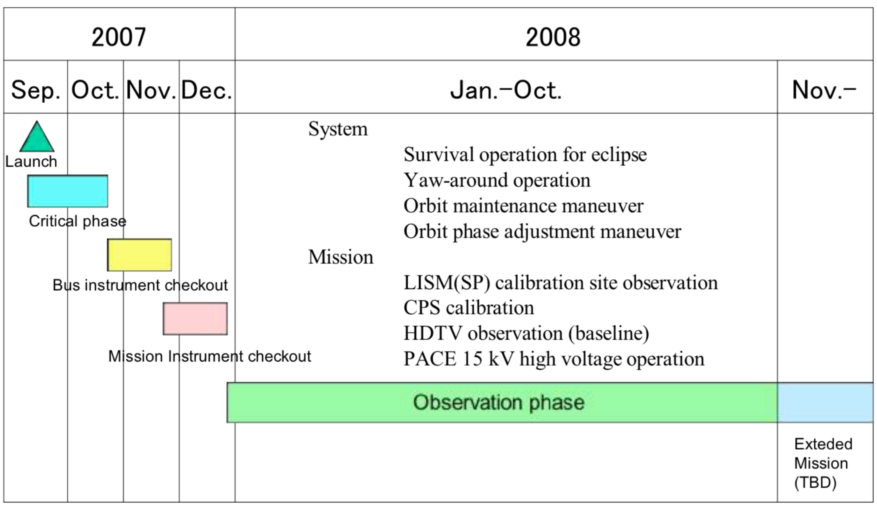

Fig. 10. KAGUYA mission operation plan. Observation for global mapping will be completed by the end of October 2008. Extended mission is now under consideration.

by the end of October 2008 when the global mapping is completed as initially planned. The general operation plan is shown in Fig.10. Considering the amount of the fuel we have at this stage, we will be able to extend the mission for additional scientific research. The operation scenario for the extended mission is now under discussion, but one possible scenario is to lower the altitude of the main orbiter down to 50 km. It will give a good opportunity to measure the lunar magnetic field much more accurately. The data obtained in the nominal observation phase will be open to the researchers all over the country a year after termination of the nominal observation. It will greatly contribute to the lunar science and also to the lunar exploration mission in the future.

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