IAC-09.A3.2A.2

KAGUYA MISSION SUMMARY

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ABSTRACT

The Moon-orbiting KAGUYA (SELENE: Selenological and Engineering Explorer) was launched in September 2007, and reached the lunar mission orbit at about 100 km altitude in October 2007. It kept 100 km circular orbit till the end of December 2008 and made mapping observation for lunar science as planned. From January 2009, it was lowered to observe the lunar surface more precisely for designated areas. The mission was terminated on 11 June 2009 by descending the main orbiter to the surface. This paper summarizes the over-all mission operation from the launch to the final touch-down.

1. INTRODUCTION

KAGUYA was launched on September 14, 2007 [1]. It consists of a main orbiter and two small sub-satellites (OKINA and OUNA). The primary objective of the mission was to study the origin and evolution of the Moon by global mapping observation from the polar orbit at 100 km altitude. It was also intended to measure the lunar environment and to observe the solar-terrestrial plasma environment from the lunar orbit. After the KAGUYA launch, Chinese Chang'E-1(Oct. 2007) [2], India's Chandrayaan-1(Oct. 2008) [3], and American LRO (Lunar Reconnaissance Orbiter) (June 2009) [4] were sequentially launched for the lunar science and exploration. The huge amount of scientific data from a series of recent lunar missions will provide a precious data base for lunar science and future lunar exploration.

Table 1 KAGUYA System characteristics

Main Satellite	
Mass	3 tons approx. at launch including daughter satellites
Dimension	2.1 m x 2.1 m x 4.8 m
Attitude control	3-axis control
Power generation	3.5 kW approx.(max)
Orbit	100 km altitude, inclination 90°
Daughter Satellites	
Mass	50 kg approx.
Dimension	0.99 m x 0.99m x 0.65 m (octagonal column)
Attitude control	Spin stabilized
Power generation	70 W approx.
Orbit	100 km x 2400 km (OKINA) 100 km x 800 km (OUNA)

2. SPACECRAFT DESCRIPTION

The performance of the KAGUYA spacecraft is summarized in Table 1. The configuration of the orbiter in the mission orbit is shown in Fig. 1. 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

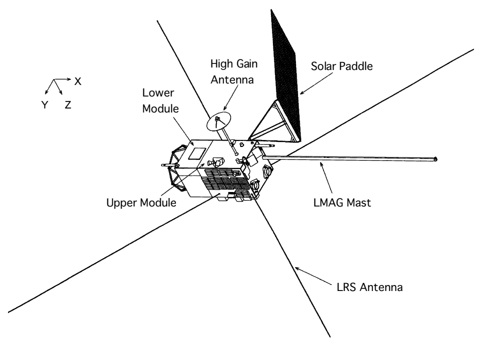

Fig.1 Configuration of the orbiter.

Table 2. 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, 1050, 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 (3 stations or more)
	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 composition 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	High Density TV (HDTV)	Observation of the earth in a super-high resolution for publicity

when the beta angle is 0° and 180°. The z-plane 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). Two pairs of 15 m antenna for radar sounder 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 in the -y direction rotates along the y-axis to track the sun generating 3.5 kW maximum power. The capabilities for mission data recording and downlink are 10 GBytes and 10 Mbps, respectively.

Table 2 summarizes the mission instruments that are classified in four categories; science of the Moon, science on the Moon, science from the Moon, and publicity. The configuration of the onboard instruments on the main orbiter is shown in Fig. 2. Most of the sensors for remote-sensing observation are installed on

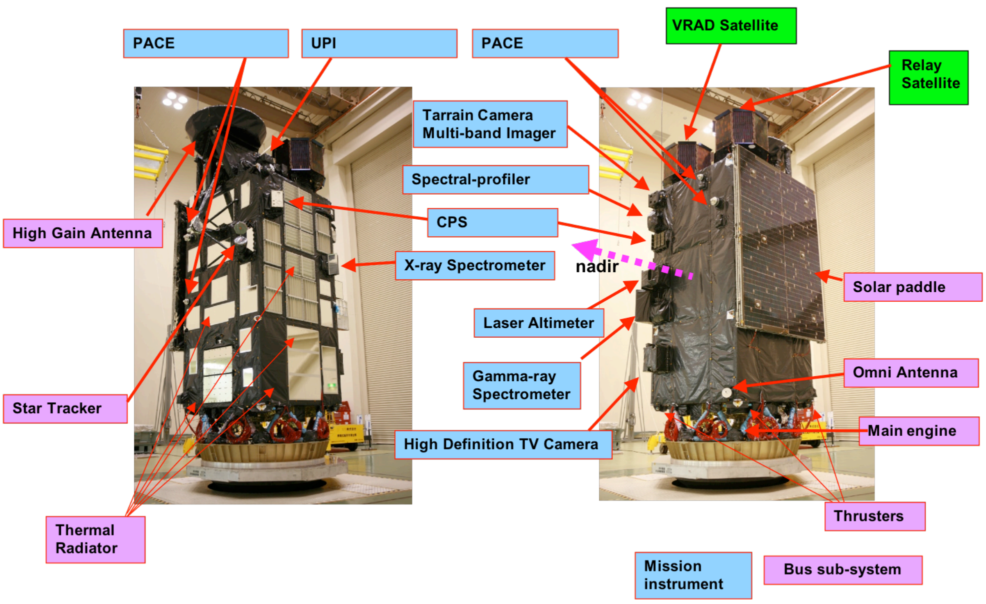

Fig.2 Configuration of onboard instruments.

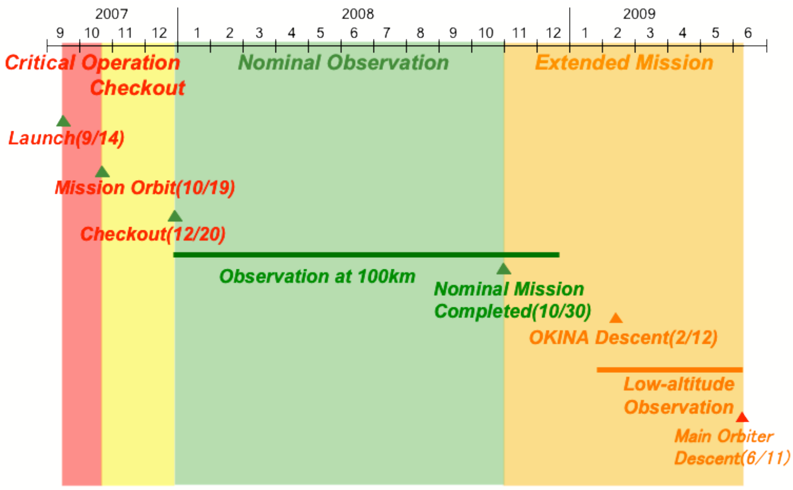

Fig.3 Summary of over-all KAGUYA mission operation.

the nadir-plane (z-plane) facing the lunar surface.

3. MISSION OPERATION

There are three phases in the KAGUYA mission operation; 1) critical operation and checkout phase from launch to completion of observation preparation, 2) nominal observation phase in the following 10 months, and 3) extended mission phase till the fuel exhausted. The major events in the three phases are summarized in Fig.3.

3.1 Critical Operation and Checkout Phase

KAGUYA was launched on Sep. 14 2007. It 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 (OKINA) and the VRAD satellite (OUNA) were released in the elliptical orbit with the apolune at 2,400 km and 800 km, respectively. The initial orbit maneuvering operation is illustrated in Fig.4. 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 themission 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. No anomaly was detected for the high-voltage components. The initial mission operation is summarized in Fig.4. During the checkout phase, initial data were obtained for all scientific instruments. The HDTV cameras were intermittently operated to observe the earth and lunar surface.

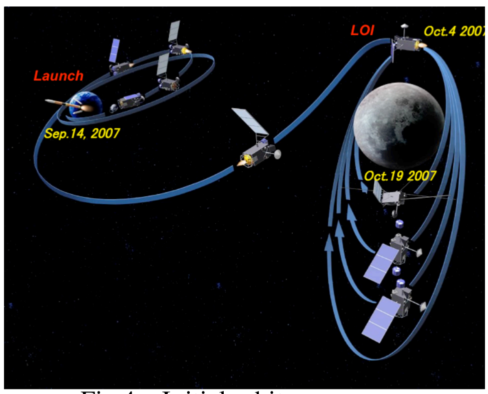

Fig.4 Initial orbit maneuver.

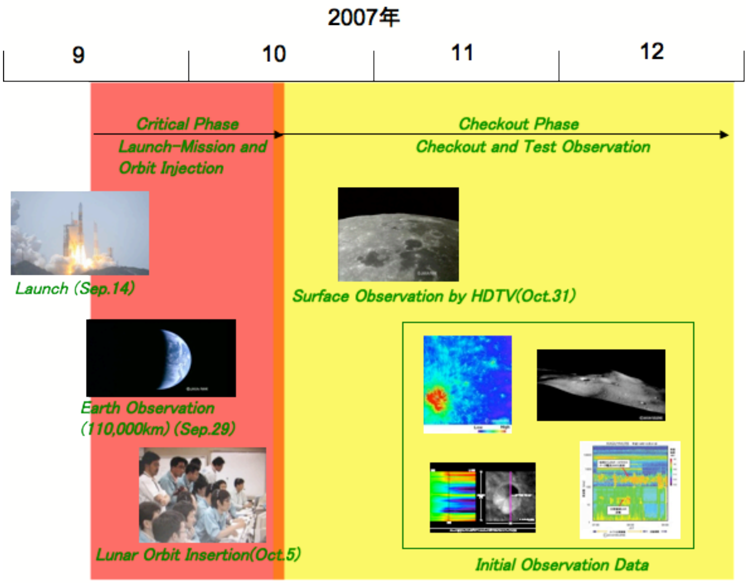

Fig.5 Critical operation and checkout phase.

3.2 Nominal Observation Phase

After completion of the instrument checkout, the nominal observation phase started on Dec.21.2007. The scientific instruments were operated basically according to the predetermined plans. The HDTV camera was operated intermittently to observe the earth and lunar surface. The orbit determination was routinely conducted twice a week. Based on the orbit prediction, observation request for each instrument was generated by the PI team and submitted to the mission operation planning team. The observation requests were integrated and verified, and then up-linked as a timeline to the KAGUYA spacecraft, usually twice a week. The KAGUYA bus system worked quite normally. One of the reaction wheels failed in July 2008, but the attitude was controlled correctly by the 3 remaining reaction wheels. The altitude of the main orbiter was kept at 100 km ±30 km throughout this phase for global mapping observation. The altitude history and typical scientific data obtained in this phase are shown in Fig.6. Although there were several anomalies in the mission instruments, the scientific achievements were obtained as planned.

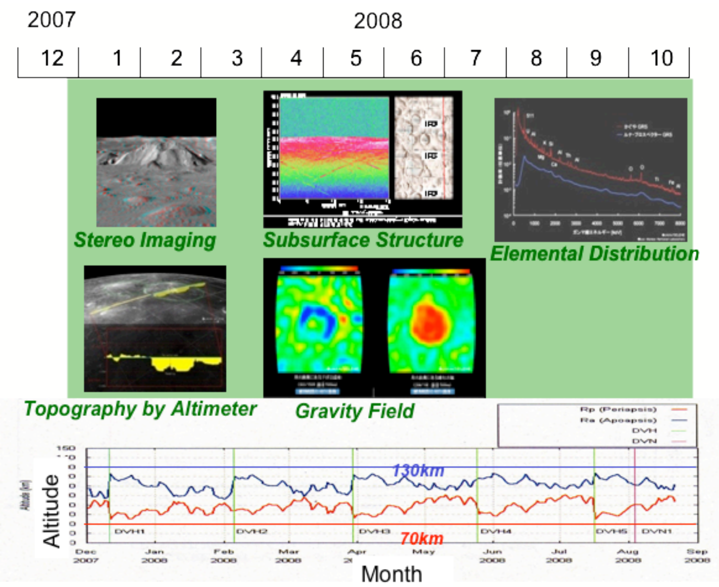

Fig.6 Nominal observation phase.

The element abundances were measured by the gamma-ray spectrometer (GRS). The alpha particle spectrometer (a part of CPS) detected the radiation possibly from the radon gas and polonium. The mineralogical characterization was performed by the multiband-spectrum imager (MI) at a high spatial resolution. The mineralogical composition were identified by the spectral profiler (SP), a continuous spectral analyzer in visible and near infrared bands. The surface topographic data were obtained by the high resolution stereo cameras (TC) and the laser altimeter (LALT). The subsurface structure was probed by the rf radar sounder experiment (LRS). Doppler tracking of the orbiter via the relay satellite (RSAT) when the orbiter was in the far side was conducted for study of gravimetry and geodesy. The magnetometer (LMAG) and electron detectors (a part of PACE) obtained the data on the lunar surface magnetic field. The radio sources (VRAD) on the two sub-satellites were used to conduct the differential VLBI observation from ground stations.

Measurement of the lunar environment and observation of the solar-terrestrial plasma environment were conducted. The study of the lunar environment included the measurement of high energy particles (CPS), electromagnetic field (a part of LRS), and plasma (PACE). The radio wave from the sub-satellite OUNA was also used to detect the tenuous lunar ionosphere using the radio occultation techniques. For the solar-terrestrial plasma observation, the imaging instruments (UPI) observed the earth plasma environment. For publicity and educational purposes, the high-resolution cameras (HDTV) were operated to observe the earth and the lunar surface as long as the high speed data link to the ground station was available.

3.3 Extended Mission Phase

In the extended mission starting on Nov.1 2008, the altitude was kept at 100 ±20km for the first 2 months. In late December, other reaction wheel failed and the attitude was controlled by the thruster system after the failure. We started the low altitude operation at 50 ±30 km from February 2009 to observe the lunar magnetic field and plasma environment. After mid-April, we further lowered the perigee down to 10-20 km to observe the mini-magnetosphere at the designated area. During the extended mission, almost all scientific instruments were operated to get additional data. HDTV camera was intermittently operated, especially for special events such as “ sun eclipse by the earth”. The history of the altitude and

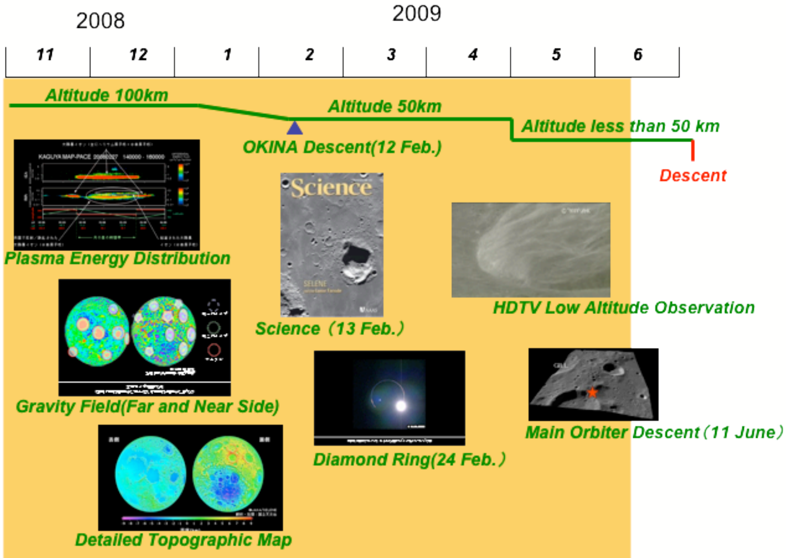

Fig.7 Extended mission phase.

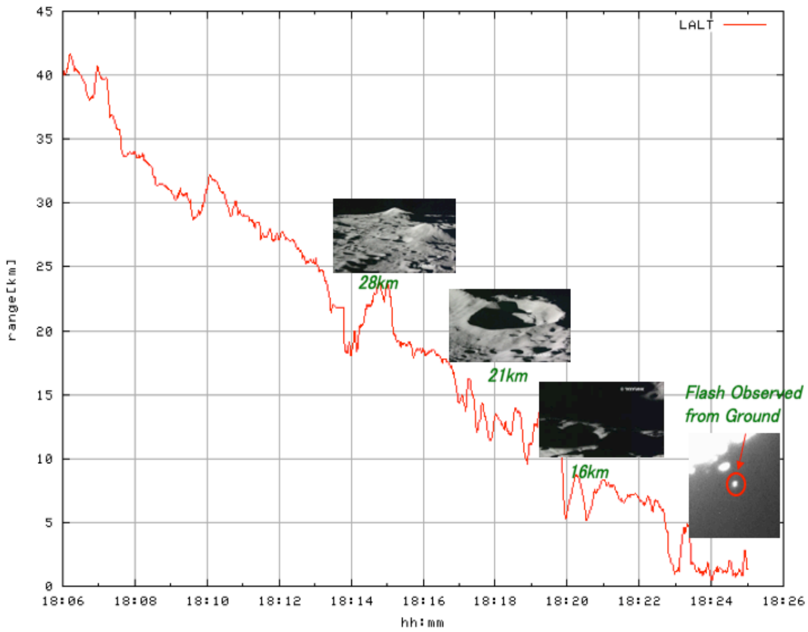

Fig.8 Final trajectory and pictures obtained by the HDTV camera.

major events are summarized in Fig.7.

KAGUYA reached its perigee less than 10 km in the last stage in June. On June 11, final maneuvering operation to decelerate the KAGUYA spacecraft near the apogee was conducted and it descended to the lunar surface near the perigee. The hard landing point was near the Gill crater. The landing time and position were just as predicted. Figure 8 shows the final descent history measured by the laser altimeter, together with the final pictures obtained by the HDTV camera. The flash possibly excited by the collision crash were observed by large telescopes in Australia and India.

4. CONCLUSION

The KAGUYA(SELENE) project was started in 1999 and was successfully completed in 2009 after 2 years' mission operation. It was the largest and most sophisticated lunar mission since the Apollo program. During the two years mission, it collected scientific data on elemental abundance, surface and subsurface structure, gravity fields, magnetic field, and lunar environment for lunar science. It also observed the solar-terrestrial plasma environment from the lunar orbit. The high-quality motion pictures of the earth and the Moon were obtained by the HDTV cameras for publicity and educational purposes. The major part of the scientific data are open to public in November 2009. The huge amount of the data will be used to study the origin and evolution of the Moon, and to investigate the future plan for the lunar exploration and utilization.

References

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