Kaguya (SELENE) Mission

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Definition

The Selenological and Engineering Explorer (SELENE), also known as Kaguya, was the second Japanese lunar orbiter spacecraft, following the Hiten probe. The spacecraft launch in September 2007 and ended in June 2009. Two sub-satellites and a suite of instruments on the Main orbiter mapped across the Moon, exploring several science objectives relating to the geologic history of the lunar surface, including new data pertaining to magnetic anomalies and GRS data with higher spatial resolution were acquired.

Mission Overview

Kaguya was launched successfully on September 14, 2007, from the JAXA Tanegashima Space Center (TKSC) on an H2A rocket. The mission was produced in partnership by the Institute of Space and Astronautical Science (ISAS) and the National Space Development Agency (NASDA). Scientific data was acquired for the primary mission period of 10 months, and an extended mission of 8 months during which reserved fuel was used.

The mission package consisted of three spacecraft: the three-axis-controlled Main Orbiter (Kaguya), and two spin-stabilized sub-satellites (Ouna and Okina) on its roof. Kaguya's dimensions, power, and mass are listed in Table 1. The total wet made at launch was ~3 tons, which included 1.1 tons of fuel, and an estimated 300 kg of total science instrument weight.

On October 3, 2007, Kaguya, after passing through a phasing orbit 2.5 times around the Earth, was inserted into an elliptical orbit with a perilune altitude of 100 km and an apolune altitude of 13000 km (with an inclination of 90 degrees). Ouna and Okina were released halfway to the circular orbit. Okina (the relay satellite) spun on an elliptical orbit of 100 km and 2400 km, which Ouna (the Very Long Baseline Interferometry satellite) was in an elliptical orbit of 100 km and 800 km. On October 19, 2007, Kaguya settled in a nominal circular orbit of 100 km altitude.

The Kaguya mission was completed on June 10, 2009 and was then instructed to impact on the lunar surface near Gill crater (63.9°S, 75.9°E) after a final maneuver of delta V of 2.5 m/s at 45 minutes before impact (Kamikawa et al. 2008; Kato et al. 2010).

Technical Overview

Okina and Ouna support radio science. Okina relayed radio communications between the orbiter and the Earth when the orbiter was on the far side of the Moon. This maneuver also allowed for direct Doppler shift measurements to be taken for the purpose of mapping the gravitational field of the lunar farside. Okina impacted the lunar surface near Mineur D crater (25.9°N, 159.2°W) on February 12, 2009. Ouna used the Very Long Baseline Interferometry (VLBI) as a secondary aspect to map the Moon's gravity field.

Kaguya carried 15 scientific instruments (Figure 1; see Kato et al. 2010), each having their own scientific objectives. The X-ray spectrometer (XRS) and Gamma-ray spectrometer (GRS) are used to determine the lunar elemental abundance (Hasebe et al. 2008); the multi-band imager (MI; resolution NIR 62 m/px and VIS 20 m/px) and the spectral profiler (SP; resolution 562 x 400 m/px) were used to determine the mineral abundance and distribution (Ohtake et al. 2008); the terrain camera (TC; resolution 10 m/px), lunar radar sounder (LRS), and lunar laser altimeter (LALT) were used for topographic measurements and subsurface (Haruyama et al. 2008; Araki et al. 2008); the charged particle spectrometer (CPS), lunar magnetometer (LMAG), and the plasma energy, angle, composition experiment (PACE), radio science (RS), and upper atmosphere plasma imager (UPI) were used to determine the impact of solar wind and/or cosmic radiation on the Moon (Saito et al. 2008; Yoshikawa et al. 2008); and finally the Ouna and Okina radio science instruments to measure the gravity field. In addition, a high-definition 2.2 megapixel CCD television (HDTV) was used for communications and public engagement (Yamazaki et al. 2010).

Discoveries and Research

The instrument suite on Kaguya were grouped with different perspectives and intentions of researching the lunar surface. The science objectives are described below:

(1) Chemical constituents of the Moon

The MI and SP instruments determined the distribution of anorthosite, a plagioclase-rich rock (Figure 2), observing a global distribution of pure anorthosite on the central peak outcrops of large craters (Ohtake et al. 2009). The origin of pure anorthosite is still debatable, mainly due to the returned samples by Apollo (~92% plagioclase and Mg-minerals) was thought to have been formed in chemical equilibrium in an early lunar magma ocean (Warren 1990; Longhi 2003). The SP instrument also provided lithology data about the central peaks in the South Pole – Aitken (SPA) basin, observing orthopyroxene, olivine, and agglutinate (Nakamura et al. 2009).

(2) Interior structure and tectonics

The shallow lunar interior and subsurface were investigated using LRS. Radar soundings using a 5-MHz radio wave discovered the subsurface layer structure, including material discontinuities, up to a depth of 5 km (Oshigami et al. 2009; Pommerol et al. 2010). Discontinuities were found in Mare Imbrium and Oceanus Procellarum, implying connections to magma eruption ages and titanium contents (Pommerol et al. 2010). LRS data also revealed the mare regions spreading in the nearside (Ono et al. 2009). LRS was also able to provide evidence of intermittent magma eruptions and detailed tectonic features in the southern Mare Serenitatis (Ono et al. 2009).

Gravity and topography data were obtained using the Ouna and Okina sub-satellites, and the LALT, to estimate the thickness of the lunar crust (Ishihara et al. 2009). The maximum thickness of luanr crust was found in the Dirichlet-Jackson crater rim, and the minimum thickness under Mare Moscoviense (Morota et al. 2009).

(3) Magma ocean differentiation

Geological studies made by Kaguya clarified the presence of an ancient magma ocean. The distribution of mafic rocks (which coexisted with anorthosite) in the magma ocean must be globally confirmed in the lunar surface. The MI and SP instruments, further investigated by the M^3 (Moon Mineralogy Mapper) instrument onboard the Indian lunar orbiter Chandrayaan-1, provided global coverage of mafic minerals (Pieters et al. 2009; Ohtake et al. 2012).

(4) Nearside and farside dichotomy

Nearside mare and basins show large positive gravitational anomalies, particularly where positive, flat 200 – 500 mGal of free-air anomalies reflect spreading mare basalts, as analyzed by the GRS and Okina sub-satellite. The GRS determined the distribution of radioactive elements (K, U, Th) in the nearside mare regions (Yamashita et al. 2010; Kobayashi et al. 2010).

(5) Lunar magnetic field origins

LMAG aimed at finding weak lunar magnetic remnants (< 0.1 nT) utilizing the three-axis fluxgate magnetometers isolated from the electromagnetic noise of the other Kaguya electronic instruments by using an expandable long mast (Matsushima et al. 2010). Magnetic anomalies were confirmed in the Imbrium, Serenitatis, and Crisium antipodes in the SPA basin, and isolated anomalies such as the Reiner Gamma (Tsunakawa et al. 2015).

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Figures and Tables:

Table 1: Technical aspects of the Main orbiter and sub-satellites of Kaguya. Values given in Kato et al. (2010) and references therein.

Technical Aspect	Main orbiter (Kaguya)	Relay Satellite (Okina)	VLBI Satellite (Ouna)
Mass	2,914 kg	53 kg	53 kg
Size	2.1 x 2.1 x 4.8 m	1.0 x 1.0 x 0.65 m	1.0 x 1.0 x 0.65 m
Attitude Control	3-axis stabilized	Spin-stabilized	Spin-stabilized
Power	3.5 kW (Max.)	70 W	70 W
Inclination	90 degrees	90 degrees	90 degrees

Figure 1: Kaguya instrument suite. Not pictured are the LMAG, LRS, and RS. Image from: https://global.jaxa.jp/projects/sas/selene/

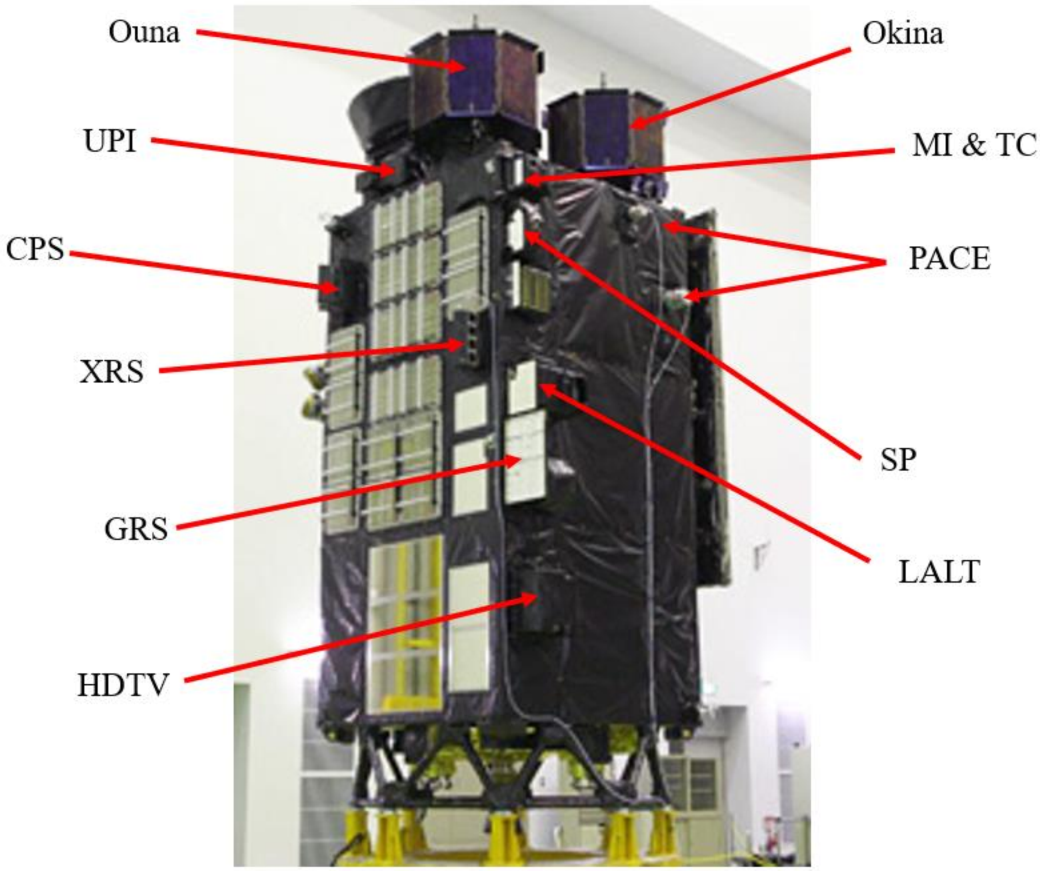

Figure 2: Plagioclase (in wt.%) abundance mosaic map from Kaguya, from -50* to 50* latitude at 512 ppd. Map provided in Lunar Reconnaissance Orbiter (LRO) Quickmap: https://quickmap.lroc.asu.edu/