Lunar Science by Kaguya

Launch, 2007-9-14 T10:31:01 JST
@Tanegashima Space Center
Kaguya’s Sequence of Events

2007,
Sep. 14 launch
Oct. 4 Lunar Orbit Insertion #1
Oct. 9 RSTAR Okina Separation
Oct. 12 VSTAR Ouna Separation
Oct. 19 Lunar Orbit Insertion #6
Nov. 1- Science Instruments Check Out
Dec. 21- Steady Nominal Operation

2008,
Feb. 21 Lunar eclipse
Aug. 16 Lunar eclipse
Nov. 1 Start of Extended Op.

Feb. 12 RSTAR Okina impacted
Apr. 14 10 km altitude op.
June 11 Kaguya impact
June 29 VSTAR Ouna termination
June 30 Mission Completion Review
Nov. 2 Data release of 1st version
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray Spectrometer (XRS)</td>
<td>Global mapping of Al, Si, Mg, Fe distribution using $100 \text{ cm}^2$ CCD, spatial resolution 20 km, Energy range 0.7-8 keV, 5 $\mu$m Be film, Solar X-ray monitor</td>
</tr>
<tr>
<td>Gamma-ray Spectrometer (GRS)</td>
<td>Global mapping of U, Th, K, major elements, distribution using $250 \text{ cm}^3$ large pure Ge crystal, Spatial resolution 160 km, Energy range 0.1-10 MeV</td>
</tr>
<tr>
<td>Multi-band Imager (MI)</td>
<td>UV-VIS-NIR CCD &amp; InGaAs imager, spectral bandwidth from 0.4 to 1.6 microns, 9 bands filters, spectral resolution 20-30 nm, Spatial resolution 20-60 m</td>
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<tr>
<td>Spectral Profiler (SP)</td>
<td>Continuous spectral profile ranging from 0.5 to 2.6 microns, spectral resolution 6-8 nm, Spatial resolution 500 m</td>
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<tr>
<td>Terrain Camera (TC)</td>
<td>High resolution stereo camera, Spatial resolution 10 m</td>
</tr>
<tr>
<td>Lunar Radar Sounder (LRS)</td>
<td>Mapping of subsurface structure using active sounding, frequency 5 MHz, echo observation range 5 km, resolution 75 m, Detection of radio waves (10k-30MHz) from the Sun, the Earth, Jupiter, and other planets</td>
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<tr>
<td>Laser Altimeter (LALT)</td>
<td>Nd:YAG laser altimeter, 100 mJ output power, height resolution 5 m, spatial resolution 1600 m with pulse rate 1 Hz, Beam divergence 3 mrad</td>
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<tr>
<td>Differential VLBI Radio Source (VRAD)</td>
<td>Differential VLBI observation from ground stations, selenodesy and gravitational field, onboard two sub-satellites, 3 S-bands and 1 X-band</td>
</tr>
<tr>
<td>Relay Satellite Transponder (RSAT)</td>
<td>Far-side gravimetry using 4 way range rate measurement from ground station to orbiter via relay satellite, perilune 100 km, apolune 2400 km in altitude, Doppler accuracy 1 mm/s</td>
</tr>
<tr>
<td>Lunar Magnetometer (LMAG)</td>
<td>Magnetic field measurement using flux-gate type magnetometer, accuracy 0.5 nT</td>
</tr>
<tr>
<td>Charged Particle Spectrometer (CPS)</td>
<td>Measurement of high-energy particles, 1-14 MeV(LPD), 2-240 MeV(HID), alpha particle detector, 4-6.5 MeV</td>
</tr>
<tr>
<td>Plasma Analyzer (PACE)</td>
<td>Charged particle energy, angle and composition measurement, 5 eV/q – 28 keV/q</td>
</tr>
<tr>
<td>Radio Science (RS)</td>
<td>Detection of the tenuous lunar ionosphere using S and X-band carriers</td>
</tr>
<tr>
<td>Plasma Imager (UPI)</td>
<td>Observation of terrestrial plasmasphere from lunar orbit, XUV(304A) to VIS</td>
</tr>
<tr>
<td>High Definition TV System</td>
<td>Public Outreach</td>
</tr>
</tbody>
</table>
**Published Kaguya Science 1.**


- **SP**: Discoveries on the lithology of lunar crater central peaks by SELENE Spectral Profiler, Matsunaga et al., *GRL 35* (2008), L23201./ Ultramafic impact melt sheet beneath the South Pole-Aitken basin on the Moon, R. Nakamura, et al., *GRL 36* (2009), L22202./Possible mantle origin of olivine around lunar impact basins detected by SELENE, Yamamoto et al., *Nature Geosci. 3* (2010) 533-536.


- **LRS**: Lunar radar sounder observation and founding of subsurface strata below the nearside lunar maria, Ono et al., *Science 323* (2009), 909-911./ Distribution of the subsurface reflectors of the western nearside maria observed from Kaguya with Lunar Radar Sounder, Oshigami et al., *GRL 36* (2009), L18202./ Detectability of subsurface interfaces in lunar maria by the LRS/SELENE sounding radar: influence of mineralogical composition, Pommerol et al., *GRL 37* (2010), L03201./ The Lunar Radar Sounder (LRS) onboard the Kaguya (SELENE) spacecraft, Ono et al., *Space Sci. Rev. 154* (2010) 145-192./ Electrostatic solitary waves associated with magnetic anomalies and wake boundary of the Moon observed by KAGUYA,
Published Kaguya Science 2.


Published Kaguya Science 3.


Lunar topographic contour map
Gravity Model Version Up, SGM100h

Matsumoto et al., JGR115 (2010)
Max. : 110km in southern rim of Dirichlet – Jackson crater. (199.719E, 6.90625N)
Min.: 0 km beneath Mare Moscivience

Assum., densities of 2800 kg/m³ of crust, 3360 kg/m³ of mantle, and 3200 kg/m³ of mare basalt
Formation age of Giordano Bruno crater

36N/103E, 22 km

Morota et al., *MePS* 44 (2009), 1115-1120
Basalt Thickness of Mare Moscoviense

Morota et al., *GRL* 36 (2009), L21202
History of Mare Volcanism

Morota et al., 2010

PKT, Heisinger et al., 2003

PKT, this work

Outside PKT, this work
Fig. 5. Global map of the model ages of mare basalts on the lunar surface, including Oceanus Procellarum, Mare Imbrium, Nubium, Insularum (This study; Hiesinger et al., 2000, 2003), Mare Orientale (Greeley et al., 1993), Mare Serenitatis, Humorum, Tranquillitatis, Humboldtium, Australe (Hiesinger et al., 2000), Mare Cognitum (Hiesinger et al., 2003), Mare Fecunditatis (Hiesinger et al., 2006), Mare Frigoris and other nearside maria (Hiesinger et al., 2010), Mare Mosoviense (Haruyama et al., 2009; Morota et al., 2009), and those within the South Pole-Aitken basin (Haruyama et al., 2009), the Freundlich-Sharonov basin, the crater Campbell, the crater Kohlschütter (Morota et al., in press), and the crater Tsiolkovsky (Tyrce, 1988).

Morota et al., 2010
Lithology of central peaks of c.p. craters
Multi-band Imager of Jackson Crater

A: 750nm band
B: Close-up
C: Color composite, 950nmR, 1050nmB, and 1250nmG
D: Close-up

Ohtake et al., 2009
Global distribution of rocks of high plagioclase abundance

Ohtake et al., *Nature* 461(2009), 236-241
MI Reflectance 3.

E. Multi-band Spectrum of points a-f in Fig. B

Ohtake et al., 2008
South Pole-Aitken lithology

Nakamura et al., *GRL* 36(2009), L22202

c.p. of Antoniadi crater:
74.1wt%Opx+ 11.1%Ol+14.8%Aggl.
Possible mantle origin of olivine around lunar impact basins detected by SELENE *Nature Geosci.* 3 (2010)

Satoru Yamamoto¹*, Ryosuke Nakamura², Tatsuo Matsunaga¹, Yoshiko Ogawa³, Yoshiaki Ishihara²,
Tomokatsu Morota², Naru Hirata³, Makiko Ohtake², Takahiro Hiroi⁶, Yasuhiro Yokota¹
and Junichi Haruyama²
Subsurface Study of Mare Serenitatis by Lunar Radar Sounder

Subsurface reflector

Ono et al., 2009
Mare Imbrium & Oceanus Procellarum by LRS

Oshigami et al., *GRL 36* (2009), L18202.
Subsurface Interface Detectability with TiO$_2$ content

Pommerol et al., *GRL* 37(2010), L03201
Sputtering surface ions by PACE

Yokota et al., *GRL* 36(2009), L38185
Solar Wind Ion Reflection on the Lunar Surface

Solar Wind reflection Observed by PACE

Saito et al., 2008
SW protons access into Moon wake

SELENE PACE and L MAG  September 24, 2008  09:10-11:10 UT

Type-II entry
scattering
SW + Type-I

sunlit/wake

Type-II entry

scattering

SW  Type-I
Type-I  SW

a  ions (keV/q)
b  Electrons (keV)
c  $B_{GSE}$ (nT)
d  Lat. (deg)
e  SZA (deg)

Time (UT) 09:10 09:30 09:50 10:10 10:30 10:50 11:10

10 100 1000

10^9 10^6 10^3

10^12 10^9 10^6

10^9 10^6

differential energy flux
(cm^2 s^-1 str^-1 keV/keV)

Nishino et al., GRL 36(2009), L12108
Magnetic Anomaly by Kaguya LMAG

LP data (Richmond & Hood, 2008)

Tsunakawa et al., 2010
LMAG@100km vs LMAG@50km (Farside)

Tsunakawa et al., 2009
強い磁場は太陽風の衝突を防ぐ（ミニ磁気圏）

最大 663 nTの月面
太陽風は数nT

ミニ磁気圏が月面を明るく保つ

Tsunakawa et al., 2010
スワール:ライプニッツクレータ
最大 99.6 nT@月面
Uranium & Thorium distribution

Yamashita et al., 2010
Potassium distribution

S. Kobayashi et al., SSR 154
New findings in Kaguya Science

- Farside gravity anomaly --- RSAT
- Farside topography --- LALT
- Crustal thickness-- RSAT/LALT/VRAD
- Pole topography/Illumination rate-- LALT
- Farside volcanic activity-- TC
- Mare formation process-- LRS
- Pure anorthosite identification -- MI/SP
- SPA lithology -- SP/MI
- Olivine distribution in craters’ rim-- SP
- Solar wind interaction -- PACE/LMAG
- Mini magnetosphere -- LMAG/PACE
- K/U/Th Distribution -- GRS