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THE SELENE MISSION AND JAPANESE LUNAR EXPLORATION SCENARIO

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ABSTRACT

We report the current status of Japanese lunar exploration SELENE (SELenological and ENgineering Explorer). As of the end of 2004, scientific instruments onboard the Main Orbiter are under final checkout before they are provided to the proto-flight-model (PFM) integration test. Also, we present the future perspectives of the lunar based instruments and facilities. "In-situ Lunar Orientation Measurement (ILOM)" experiment measures the lunar rotation with high accuracy by tracking stars on the Moon with a small photo-zenith-tube type optical telescope. A basic idea of a radio telescope array of very low frequency range on the lunar far-side is also mentioned.

Key words : Moon — SELENE — selenodesy — lunar exploration — utilization of the lunar environment

I. INTRODUCTION

After the Clementine mission in 1993 and Lunar Prospector mission in 1998-99, many space organization and countries, such as Japan, ESA, NASA, China, and India, are aiming at the exploration of the Moon. Japan's SELENE will be the first full-scale mission to the Moon for Japan. SELENE consists of one satellite called Main Orbiter and two sub-satellites called Rstar and Vstar. All SELENE satellites are launched as one satellite, and Rstar and Vstar are separated from the Main Orbiter when they fly 100×2400 km orbit and 100×800 km orbit around the Moon, respectively. The Main Orbiter flies polar circular orbit of 100 km in altitude so that the global mapping of the lunar surface will be conducted with as much as 14 instruments onboard. These payloads will give the basic data to elucidate lunar origin and evolution. Two sub-satellites are main part of the selenodetic experiments for the determination of the lunar gravity field more precisely than past missions (Iwata et al., 2001). S- and X-band transponders are carried on the Rstar (R stands for "relay") for the purpose of relaying radio waves from the Main Orbiter. Both sub-satellites are equipped with S- and X-band radio sources for differential Very Long Baseline Interferometer (VLBI) measurement (V refers to "VLBI").

The first fitting integration test finished in March 2004, and scientific payloads are refurbished to join the final PFM integration test which will start in February 2005. As of the end of 2004, the launch is scheduled in fiscal year 2006.

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Considering SELENE as the first step for the lunar exploration program in Japan, we discuss the future missions to the Moon with scientific researchers and robotic engineering communities for science and utilization on, of, and from the Moon in a frame of long-term strategy of Japan Aerospace Exploration Agency (JAXA). Two future experiments on the Moon which are still under discussion are also mentioned.

II. THREE SELENODETIC EXPERIMENTS IN SELENE

Geodesy group in Mizusawa Astrogeodynamics Observatory, National Astronomical Observatory of Japan (NAOJ) mainly promotes selenodetic experiments in SELENE with universities and institutes. The laser altimeter (LALT) measures the distance between the Main Orbiter and the lunar surface, while four-way range-rate measurement (RSAT) and different VLBI observation of the two sub-satellites (VRAD) is used for the precise determination of the lunar gravity fields.

(a) LALT for Lunar Topography

Topography is one of the principle measurements of a planetary body. When combined with gravity data, it gives not only the shape of the surface but also the thermal history, and thus these data can provide us of the key for the formation of the Moon.

The transmitter of the LALT consists of neodymium-doped yttrium-aluminum-garnet (Nd:YAG) laser which emits 1064 nm laser with pulse width of 15 nsec. Its beam divergence is 0.3 mrad which gives a surface spot size of 30 m at the nominal orbit. The repetition frequency is nominally 1 Hz which results in an along-track sampling of 1.6 km. Returned laser pulses from the lunar surface are detected by a 20cmϕ Cassegrain telescope with an avalanched photo-diode (APD) in the same LALT telescope unit. The round trip time is counted by 150MHz clock so that the distance is measured. One clock corresponds to almost 1 meter height, and taking internal delay of the instruments and broadening of the return pulse due to the inclination and roughness of the lunar surface into account, the range accuracy becomes less than 5 meters.

The advantage of the LALT to the Clementine lidar (Smith et al., 1997) is the amounts of data points. The total number will be as much as 3×10^7 in the end of nominal mission, which is more than one order of those in Clementine mission. After one-year mission period, the distribution of the data points at the equator is 2.0 km. This amount of data will enable us to determine the offset between center-of-figure and center-of-mass, which is determined from the gravity field missions, within accuracy of 0.5 m. Because the inclination angle of the satellites is almost 90 degrees, the LALT covers both polar areas once per two hours. Thus the amount of data points at the polar regions becomes much larger than the equator area. Polar areas, especially south, are important also in utilization because it is considered that there are eternal light regions which are good sites for instruments on the Moon in terms of thermal environment and power supply.

We finished the first fitting integration test successfully in early 2004, in which the basic performance of scientific instruments such as electronic performance (telemetry and commands) and measurement of electromagnetic compatibility were confirmed. As of early 2005, the LALT is under the final checkout at the manufacturer for the final integration test before it is delivered to JAXA for the next PFM integration test.

(b) RSAT and VRAD for Lunar Gravity Field Measurement

There have been many studies about the determination of the near-side lunar gravity field since the first result by Lorell and Sjogren (1968). Muller and Sjogren (1968) used Doppler data from Lunar Orbiter-V to produce a gravity map of the near side and found positive gravity anomalies within the large circular mare basins called "mascons" (mass concentrations). These mascons give us information of the thermal history of the Moon. Recent progress was realized by the Clementine mission in 1993 and the Lunar Prospector mission in 1998-99. Lunar gravity models of 100th-degree expansion of the spherical harmonics coefficient have been made (Konopliv et al., 2001). Even with these extensive programs, however, the lunar far-side gravity field has been unresolved so far, because these data come from two-way range rate tracking from the ground station so that no direct measurement is possible when spacecraft flies over the far-side. Therefore, actual far-side observation is inevitably needed for the basic research of the physics of the Moon.

The SELENE trio has the same inclination of almost 90 degree to cover all the latitudes of the Moon. Even when the Main Orbiter goes behind of the Moon, the relay sub-satellite will stay visible from the Earth, enabling it to relay the radio waves from the Main Orbiter to measure the far-side gravity field of the Moon by the four-way Doppler tracking (RSAT experiment). Three-dimensional positioning of the sub-satellites will be done by differential VLBI technique by tracking two radio sources onboard both Rstar and Vstar (VRAD experiment). The Doppler measurement is less effective near the limb area, because it measures the acceleration of a satellite in the line-of-sight direction. Thus the VRAD experiment is effective especially at the lunar limb area. While the Main Orbiter requires the attitude control maneuvers as frequent as once per 12 hours, the two sub-satellites keep orbiting after they are separated from the Main Orbiter without maneuvering. The long arc length enables us to determine the low-degree components of the gravity coefficient (Heki et al., 1999). Combined with these data, the lunar "global" gravity field will be measured for the first time, and they contribute to the study of the inner structure of the Moon and navigation of satellites around the Moon (Fig. 1).

In 2003, the compatibility test of RSAT instruments to the ground uplink/downlink station at Usuda Deep Space Center of JAXA. The performance for the two-/four-way range rate measurement and two-way range measurement was tested, and the phase noise of every link was measured and confirmed its compatibility to the ground antenna. After the compatibility test at Usuda, RSAT instruments were refurbished for the integration test. The PFM integration test of two sub-satellites has started in late 2004, ahead of the Main Orbiter. All the components were installed to the sub-satellites and the first electronic checkout and vibration test for Rstar have been already finished. Vibration test for Vstar and thermal vacuum test for Rstar and Vstar are scheduled afterward. The two sub-satellites will join the integration test of the Main Orbiter in the last phase of the integration test before the launch.

III. FUTURE PERSPECTIVE

(a) ILOM: Optical Telescope on the Moon

One possible extension of the SELENE selenodetic experiment is to measure the rotation of the Moon precisely with a small telescope on the Moon. The Lunar Laser Ranging has its long history of 30 years since Apollo and other missions placed optical reflectors on the Moon (Dickey et al., 1994). The LLR contributes not only to the lunar science but also to the geoscience and general relativity theory. The ranging data inevitably include effects of the revolution of the Earth around the Sun, Earth rotation and tidal effects, scintillation by the Earth's atmosphere which regulates the ranging accuracy of $\sim$ 1 cm. If an optical telescope is

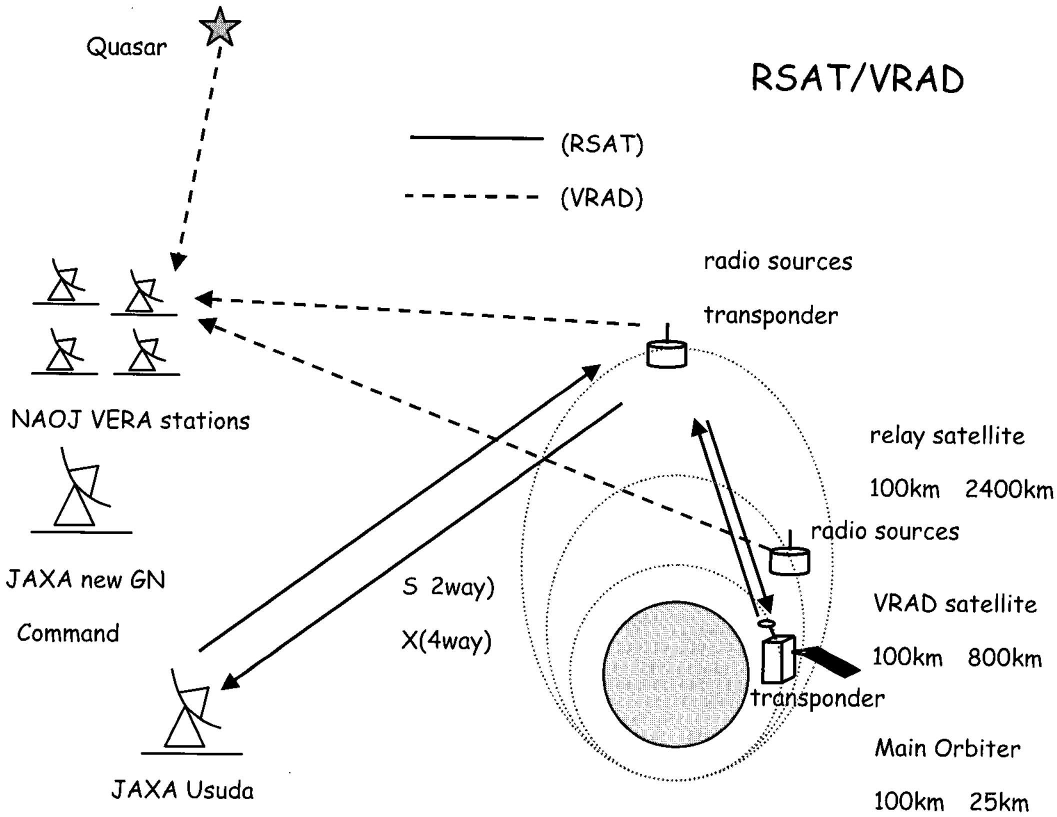

Fig. 1.— The configuration of RSAT and VRAD experiments in SELENE mission.

placed on the Moon and trajectories of stars are observed with high accuracy, with the same principle as the historical latitude observation on the Earth, the lunar rotation called physical librations will be directly detected, and these data will provide us of more information about the lunar interior, e.g., the size, state (solid/liquid) and chemical components of the core (Insitu Lunar Orientation Measurement: ILOM, Hanada et al., 2004).

Because the positions of stars should be measured with reference to the lunar surface, the photo-zenith tube (PZT) type telescope will be adopted to obtain precise vertical direction to the lunar surface. A liquid mercury mirror which is placed at the half of the focal length cancels the inclination of the tube and the ray path is focused on a CCD device installed just below the objective lens. The diameter of the main mirror is 20 cm and the focal length is 2m. The size of a star on the CCD becomes 1 arc second with these parameters, while the center of a star should be decided with accuracy of 1/1000 pixel size to achieve higher accuracy than LLR data by one order. Therefore an algorithm to estimate the center of a star by using star photon-weighted means is in progress, and detection of a star center with accuracy of 1/300 pixel has been achieved thus far (Yano et al., 2004).

Because day and night lasts 14 days continuously, the thermal environment on the Moon is severe for instruments. The surface temperature ranges from below -150°C up to 120°C on the lunar equator (Heiken et al., 1991). Power supply is also a big problem. Also the surface is covered with lunar regolith, fine dusts, which could cause contamination for the optics and electronics. A system which survives and works on this environment should be developed to conduct missions on the lunar surface. Therefore, in terms of engineering, ILOM is also positioned as a proto-type for the future larger telescope facilities or optical interferometers on the Moon.

(b) Very Low Frequency Array on the Moon

Lunar far-side offers us suitable site for the radio astronomy, because this area is free from the artificial radio waves from the Earth based on the human activity as well as radio emission from the Earth's aurora. When the Radio Astronomy Explorer 2 (RAE2) satellite revolved around the Moon in 1974, it is recognized that the noise level of radio waves became very low compared to the level in the near side (Alexander et al., 1975). Therefore another candidate of the utilization of the lunar surface for astronomical purpose is to develop an array of very low frequency radio telescope on the lunar far-side. "Very low frequency", or VLF, is defined here as the frequency range below about 30 MHz.

VLF radio emission, from planets and celestial objects corresponds to low-temperature, low-density, and low magnetic field. This frequency range is still remained untouched mainly because the ionosphere of the Earth prevents us from observing the radio waves (especially below 8 MHz). Around the Earth orbit, the auroral radio emission and artificial noise from the Earth and solar type 2 and 3 bursts prevail. In addition, Jovian kilometric radiation (DAM) masks the faint signals from other sources (Zarka, 1998). If the VLF array is put on the lunar far-side, signals from the Earth can always be avoided, and at night of the Moon the effects of the Sun are completely free. Jovian emissions can be masked during periods of conjunctions so that faint emission from the other outer planets like Saturn, Uranus can be detected. NASA and ESA have already published reports about the feasible study of VLF array on the far-side (Burns et al., 1987, Bély et al., 1997). Discussion of the scenario to deploy such array, including the way to the large facilities from a small prototype antenna for the first step has been done extensively.

IV. CONCLUDING REMARKS

In this report, we showed brief introduction of the selenodetic experiments in SELENE which National Astronomical Observatory of Japan is promoting. The SELENE mission will provide basic and complete lunar data set with 14 instruments and two sub-satellites, which enables us to observe gravity field of the lunar far-side and limb area by RSAT and VRAD experiments. The data set will be used for the future lunar exploration including human activities on the Moon, the step for the further planets like Mars.

Two experiments on the Moon in the future were presented. These plans are still rough ideas and many technical problems should be solved, especially survival at long-lasting nights is important for all missions on the Moon.

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