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Lunar rotation and gravity measurements by SELENE-2 and future landers

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Abstract

Lunar rotation and gravity measurements provide information of the physical state of the lunar interior. Previously only passive LLR (Lunar Laser Ranging) using CCR (corner cube reflectors) has been applied for the detailed study of lunar librations, i.e., rotation variability. As for candidate instruments for SELENE-2 (a lunar landing mission by JAXA) and future lunar missions, we propose VLBI (inverse and differential VLBI) for gravity measurement to constrain tidal Love number, LLR (Lunar Laser Ranging) and ILOM (In-situ Lunar Orientation Measurement) for libration measurements.

1. Introduction

Precise measurements of rotation and gravity of planets are important to obtain the information of their internal structure. The Moon revolves around the Earth once in a month synchronously with its rotation with a small eccentricity. The moon is tidally deformed by the Earth and the deformation excites irregular motion of the lunar rotation with small amplitude, which is called forced librations. Free libration is also excited by impacts, fluid core (if exists), and orbital resonance. Dissipation of the libration terms of lunar rotation may depend on the interior structure of the Moon, especially the state of the core and lower mantle [3,7,8]. Effect of tidal deformation should also appear on gravity. Long-term (> a few months) gravity measurements provide information of the tidal deformation, particularly degree 2 potential Love number k_2, which could constrain the state of the core (solid or liquid) and viscosity of the lower mantle of the Moon [2].

Figure 1 shows degree 2 potential Love number k_2 estimated from LLR and gravity measurements. Also shown are model values from numerical simulation under a priori lunar interior model. There are discrepancies of k_2 values between gravity and LLR measurements. The estimated value form LLR is low and solid core is preferable, simply from k_2 data. On the other hand, gravity measurements prefer liquid core. But as seen in Fig. 1, k_2 depends on the core size. We need to determine the k_2 with errors less than a few per cent and compare it with core size determined by seismic measurements.

SELENE-2 is planed as a follow-on mission of KAGUYA (SELENE). The spacecraft is to be launched in mid 2010's. SELENE-2 also has an orbiter for data transmission. As for candidate instruments for SELENE-2, we propose detailed measurements of lunar rotation by LLR (Lunar Laser Ranging) [1, 7, 8] and gravity measurement by iVLBI (Inverse-VLBI and dVLBI (differential VLBI) [4]. For a future lunar mission, especially for a lander on the polar region, we propose ILOM (In-situ Lunar Orientation Measurement) [3].

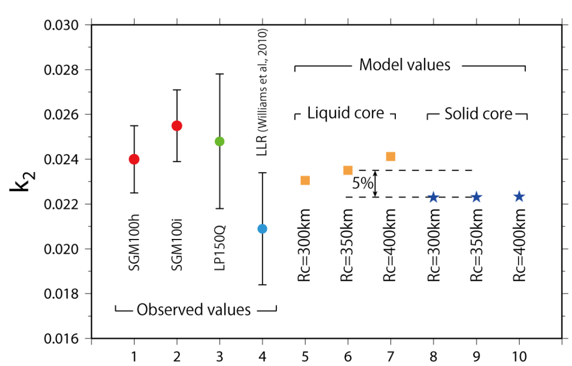

Fig. 1 Values for the degree 2 potential Love number k_2 (left) for various solutions. Errors for k_2 are based on ten times the formal error. The value of SGM100h [5] and SGM100i [2] are obtained by KAGUYA. Model values (right) are calculated assuming the interior structure of the Moon with solid mantle.

2. Inverse and differential VLBI

In SELENE-2 missions, we will have VLBI radio (VRAD) sources both in the lander and the orbiter. Then, using VLBI, we will determine the orbit of the orbiter precisely to have very accurate low degree gravity coefficients. Compare with KAGUYA mission using differential VLBI between high altitude orbiters, differential VLBI between an orbiter and a lander can be done more frequently under the same-beam condition. In the inverse VLBI, radio sources are loaded on the orbiter and the lander. Radio signals transmitted are received at a ground VLBI station [4]. These signals are cross-correlated and the difference of propagation times from the sources to the ground station is measured. A crucial issue for VLBI radio sources is the survival of lunar night. In SELENE-2 mission, the lander radio source is installed within the survival unit of thermal blanket using stored heat in regolith.

3. LLR (Lunar Laser Ranging)

The Lunar Laser Ranging (LLR) is the method to measure the distance between the Earth and the Moon using laser beam from the ground station. For more than 40 years since Apollo and the Lunokhod missions placed retroreflectors on the Moon, LLR has produced data on the lunar rotation as well as the lunar orbital evolution. Williams et al. [8] discussed the dissipation between the solid mantle and a fluid core from LLR data. LLR observation has also provided information of moment of inertia and tidal potential Love number of the Moon.

A new LLR should be on board SELENE-2. Instead of conventional corner cube reflector (CCR) array, we will use a larger single reflector, because a single cube should have smaller distance variation within the reflector on monthly libration of lunar rotation. The new reflector should be somewhere in the southern hemisphere on the nearside Moon. Then in combination with pre-existed reflectors, latitudinal component of lunar libration and its dissipation can be measured precisely.

4. ILOM

The ILOM (In-situ Lunar Orientation Measurement) is an experiment to measure the lunar physical librations in situ on the Moon with a small telescope, which tracks stars [3]. Since ILOM on the Moon does not use the distance between the Earth and the Moon, the effect of orbital motion is clearly separated from the observed data of lunar rotation. This is the advantage of ILOM over the ground-based methods such as LLR and VLBI.

The ILOM will observe the lunar physical and free librations from the lunar surface with an accuracy of 1 millisecond of arc. If ILOM telescope is put on the lunar polar region, it can detect spiral trajectories of the stars. Long-term (> a half year) data will provide information on various components of the physical and free librations.

Thermal and mechanical perturbations during observation should be suppressed. Simulated standard deviation of the parameter estimation becomes nearly 1 milli-arcsecond, which will be comparable with or better than previous LLR observation. The results would constrain the size, density, state of the core (and lower mantle) [6].

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