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Exploration of lunar deep interior state: Tactics of SELENE-2 selenodesy

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Precise measurements of gravity and rotation of planets are important methods to obtain the information of the their internal structure. The Moon with synchronous rotation is tidally deformed by the Earth and irregular motions of the lunar rotation with small amplitude, which is called forced librations, are excited. Moreover free libration would be excited by impacts, fluid core, and orbital resonance. Dissipation of the libration terms of lunar rotation depends on the interior of the Moon, especially the state of the core and lower mantle. Effect of tidal deformation should also appear on gravity. Long-term (longer than a few months) gravity measurements can provide information of the lunar tidal deformation, appearing on lower deree of spherical harmonics function. One important scale of tidal deformation is 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. Liquid core should imply significant amount of sulfur in the core, whereas low-viscosity lower mantle should suggests the presence of water. In effect, the pressure level of lunar lower mantle is compatible with that of terrestrial asthenosphere, where water in silicate greatly reduces the viscosity. Since existence of volatiles would be incompatible with giant impact ? initially hot moon hypothesis, the result of our plan might modify the evolution scenario of the Moon. The Moon should have acquired volatiles by accretion of leftovers within the gravitational well of the Earth into the lunar magma ocean.

In SELENE-2 mission, 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, and then k_2. A preliminary simulation has been conducted under the condition of 2-week arc length, 12-week mission length, 6 hours/day 2-way Doppler observation plus S-band same-beam VLBI observation with the VERA 4 stations. The k_2 uncertainty is evaluated as 10 times the formal error considering the errors in solar radiation pressure modeling and in lander position. Using combined the tracking data of SELENE and other missions the k_2 uncertainty is below 1 % when the orbiter inclination is 90 degree. The Love number k_2 is sensitive to the structure in deep interior. When the size of the core is 350 km in radius, k_2 value changes by about 5 % depending on the state of the core, liquid or solid.

The Lunar Laser Ranging (LLR) is the method to measure the distance between the Earth and the Moon using laser beam from the ground. For more than 40 years, LLR produced data on the lunar rotation as well as orbit. Using LLR data, the state of lunar interior is discussed. The dissipation between the solid mantle and a fluid core was discussed. LLR observation has also provided information of moment of inertia and tidal Love number of the Moon.

Instead of conventional corner cube reflector (CCR) array, we plan to have a larger single reflector in SELENE-2. The new reflector should be somewhere in the southern hemisphere on the nearside Moon. With pre-existed reflectors, latitudinal component of lunar libration and its dissipation can be measured precisely. However, among LLR parameters, k_2 and core oblateness is coupled. Once k_2 is determined by VLBI gravity measurement, we can estimate the core oblateness, which would also constrain the core and lower mantle state.

ILOM (In-situ Lunar Orientation Measurement) is an experiment to measure the lunar physical librations on the Moon by a small star-tracking telescope. 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. ILOM will observe the lunar physical and free librations with an accuracy of 1 mas.

Keywords: the Moon, lower mantle, core, gravity, lunar rotation, volatiles